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GENERAL SENIOR SYLLABUS 2025

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BIOLOGY

FOR QUEENSLAND

UNITS 1&2

NATALIE QUINN
MATTHEW SCHMIDT
JESSICA BRODBECK

FOURTH EDITION

OXFORD

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Introducing *Biology for Queensland Units 1 & 2 (fourth edition)*

Congratulations on choosing *Biology for Queensland Units 1 & 2* as part of your studies this year!

Biology for Queensland Units 1 & 2 has been purpose-written to meet the requirements of the QCAA Biology 2025 General senior syllabus. It includes a range of flexible print and digital products to suit your school and incorporates a wide variety of features designed to make learning fun, purposeful and accessible for all students!

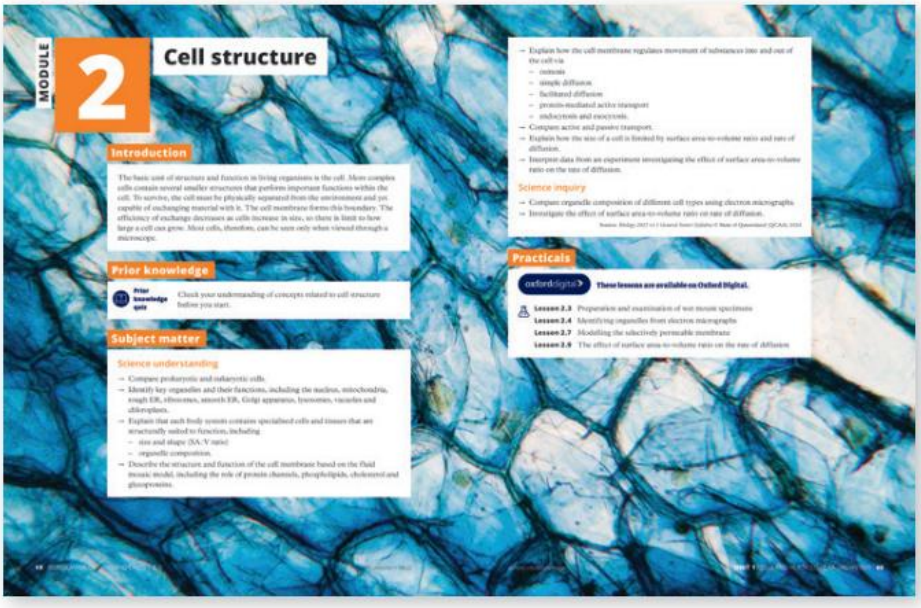
Key features of the Student Books

The Biology toolkit module provides an overview of the syllabus, student-friendly guidance for every science inquiry skill and tips for success on assessment tasks



Each module begins with a module opener that includes:

- QCAA subject matter
- reference to a supporting prior knowledge quiz that assesses and informs student understanding of pre-requisite concepts
- a list of practical lessons that support science inquiry.



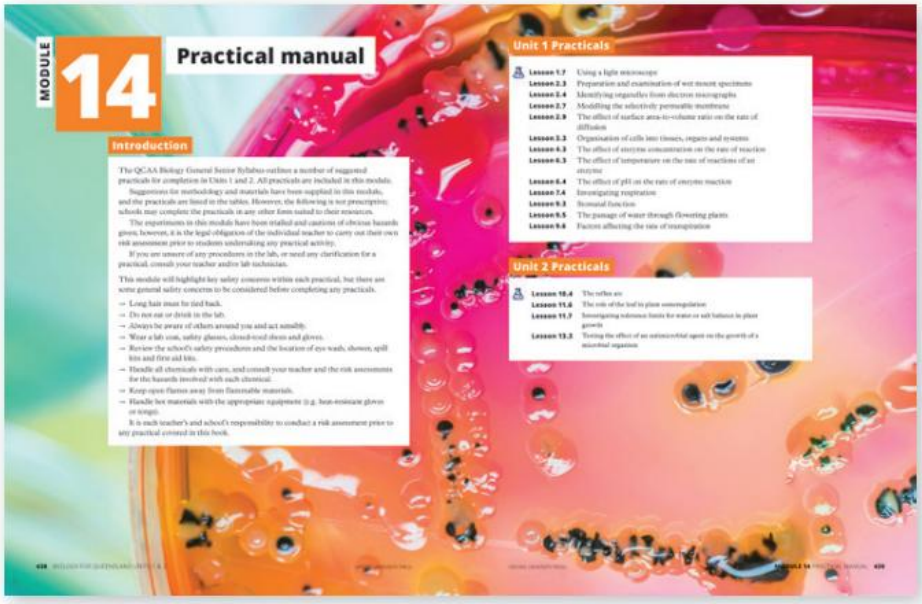
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Lesson 2.1
The cell as the building block of life
Key ideas
Cell structure
Prokaryotic cells

Each lesson includes:

- **learning intentions and success criteria**
- clearly structured content written in clear, concise language
- definitions for all key terms on the page
- engaging, relevant and informative images and illustrations
- a range of tips and features designed to bring course content to life including **study tips**, **worked examples**, **skill drills** and examples of **real-world science applications**
- references to supporting **digital resources**
- **Check your learning** activities organised according to **Marzano and Kendall's taxonomy** and incorporating **cognitive verbs**.


MODULE 14
Practical manual
Introduction
Unit 1 Practicals
Unit 2 Practicals

Each module contains a range of practical activities designed to meet the requirements of science understanding and science inquiry subject matter and develop science inquiry skills.

Find out more

For a complete overview of all the features and benefits of this Student Book, as well as helpful videos showing you how to get the most out of the series:

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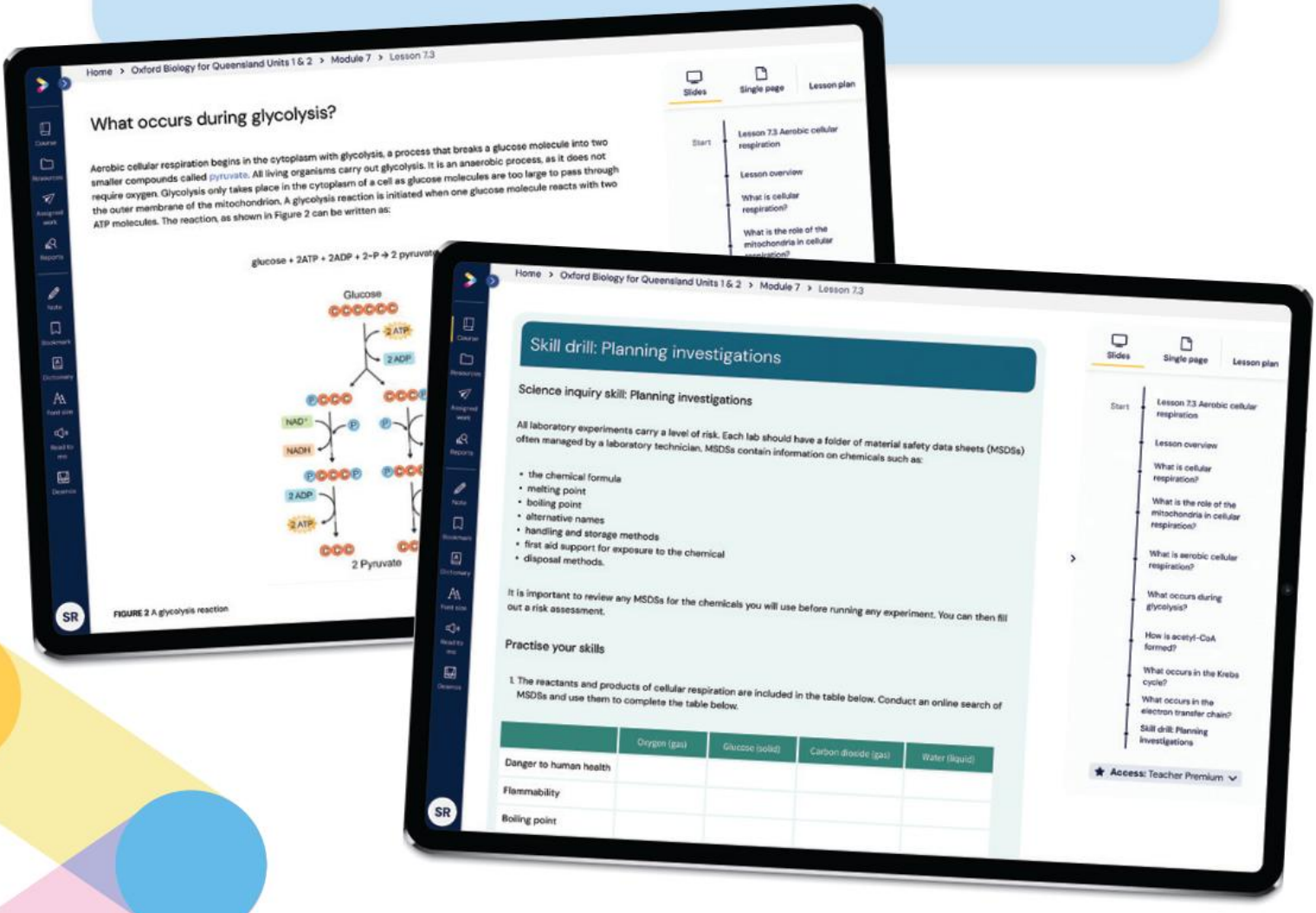
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- use the "Read to me" button to have any part of the course read aloud to you
- **highlight**, **take notes**, **bookmark pages**, or define words with the built-in **Australian Oxford Dictionary**
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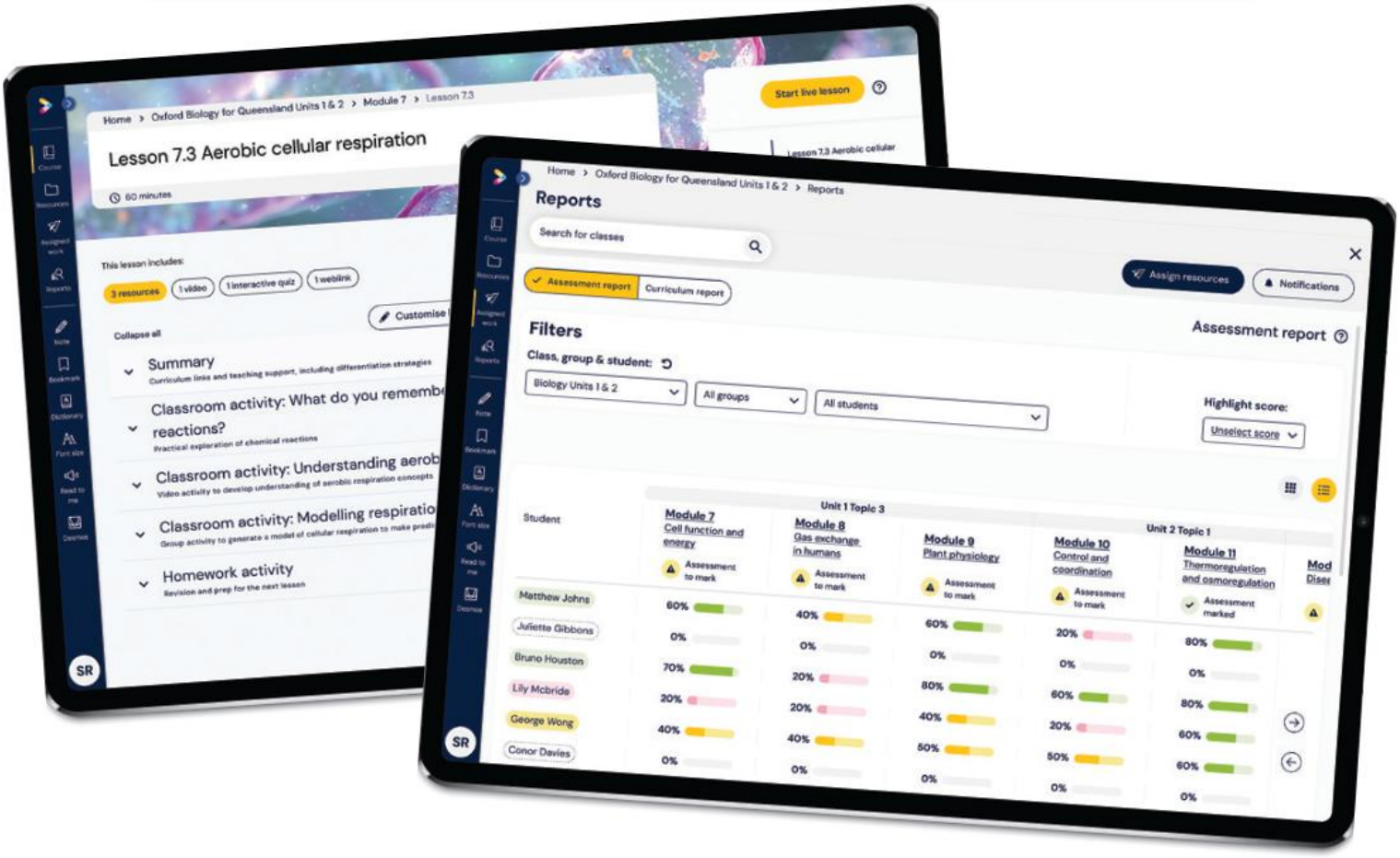
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Meet the authors & reviewers



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Author

Natalie Quinn began her career as a terrestrial ecologist before moving into secondary education and is now a Head of Department (Science) for Education Queensland. She has completed a Master of Education, conducted scientific research, and has 10 years' experience teaching Biology, Chemistry, and Psychology in a variety of state and independent schools across Queensland. Natalie is the author of *Oxford Study Buddy for Biology* and is a QCAA Subject Matter Expert for Biology and Earth and Environmental Sciences.



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Matthew Schmidt has been teaching for 9 years, including teaching senior Biology since 2018. Holding a Bachelor of Marine Studies and a Graduate Diploma of Education, his main areas of interests within biology are ecology and aquatic organisms. A passionate science teacher, Matthew has experience teaching 7–10 Science, Science in Practice and Aquatic Practices as well as senior Biology.



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Author

Jessica Brodbeck has been teaching Senior Biology, Science, and Mathematics since 2018, and has been a Year Coordinator for 5 years. She completed her Bachelor of Science, majoring in Immunology and Parasitology, before completing her Graduate Diploma in Education (Secondary). She implemented the 2019 Senior Syllabus within her school, and has since worked as a QCAA assessor, endorser, and confirmer since its introduction, as well as working as a senior Biology private tutor.

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Tony Fraser

Reviewer

Tony Fraser is an accomplished educator with nearly three decades of experience in teaching, having served in various Catholic and Independent Schools on the Gold Coast and Brisbane. Over the past 15 years, he has held the position of Science Head of Department at three different Catholic colleges. Currently, Tony is the Science Curriculum Leader at Mt Maria College, Mitchelton. He has also contributed to the broader educational community as the Brisbane North Biology District Panel Chair and has been a QCAA assessor since the introduction of the new syllabuses in 2019.



Bernice Zaro

First Nations reviewer

Bernice is a proud Aboriginal and Torres Strait Islander Woman with a strong passion for educational greatness through culturally-inclusive learning. With family cultural heritage connection to the Gubbi Gubbi and Bundjalung of South East Queensland area and Kemer Kemer Meriam Nation and Maluligal Nation of the Torres Strait, she is inspired to share and learn continuously. Bernice and her husband Aicey Zaro, a recognised traditional Artist, have been educating schools and communities through Cultural Awareness art workshops for more than 15 years during their time managing the Zaro Cultural Gallery in the Burdekin region. Bernice has a passion for learning through her ongoing studies in Community Development, Child Wellbeing, Cultural Diversity and also sharing personal experiences through family, community and business, which inspire her to take on new opportunities.

We would also like to acknowledge and thank Lorraine Huxley and Margaret Walter for their contributions.

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MODULE 1

Biology toolkit

Introduction

Biology is the study of all living and once-living organisms on Earth. Biological description, observation and experimentation seek to make sense of the form, function, behaviour and processes of organisms. The great diversity of life on Earth across all kingdoms can be better understood and explained through application of the scientific method in experiments conducted in laboratories and in the field. A deep understanding and knowledge of biological concepts is essential to interpret results and explain interconnected theory and relationships. This module contains a toolkit of strategies and skills that can be used to successfully undertake examination, experimental and research assessment tasks.

Prior knowledge

Prior knowledge quiz Check your understanding of science inquiry skills before you start.

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Online-only lessons

Lesson 1.2 Considering First Nations perspectives in Biology
Lesson 1.11 Preparing for your data test
Lesson 1.12 Conducting your student experiment
Lesson 1.13 Conducting your research investigation
Lesson 1.14 Preparing for your exams

Practicals

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Lesson 1.7 Using a light microscope

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Lesson 1.1
Studying QCE Biology

Key ideas

- → Biology is the study of living organisms.
- → Studying Biology can lead to a diverse range of career pathways.
- → QCE Biology is divided into units and topics.
- → The science inquiry skills and their application are important for success in QCE Biology.

Learning intentions and success criteria

Rationale

Biology aims to develop students':

- sense of wonder and curiosity about life
- respect for all living things and the environment
- understanding of how biological systems interact and are interrelated, the flow of matter and energy through and between these systems, and the processes by which they persist and change
- understanding of major biological concepts, theories and models related to biological systems at all scales, from subcellular processes to ecosystem dynamics
- appreciation of how biological knowledge has developed over time and continues to develop; how scientists use biology in a wide range of applications; and how biological knowledge influences society in local, regional and global contexts
- ability to plan and carry out fieldwork, laboratory and other research investigations, including the collection and analysis of qualitative and quantitative data and the interpretation of evidence
- ability to use sound, evidence-based arguments creatively and analytically when evaluating claims and applying biological knowledge
- ability to communicate biological understanding, findings, arguments and conclusions using appropriate representations, modes and genres.

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024.

What is biology?

biology
the study of all living and once-living organisms on Earth

Biology is the study of living organisms. Biologists are concerned with the types of organisms that exist on Earth and how they operate individually, in interactions with other organisms and with their non-living environment. Biology is such a vast field of study that individual researchers tend to specialise in only a small aspect. Further specialisation occurs within each of these broad branches.

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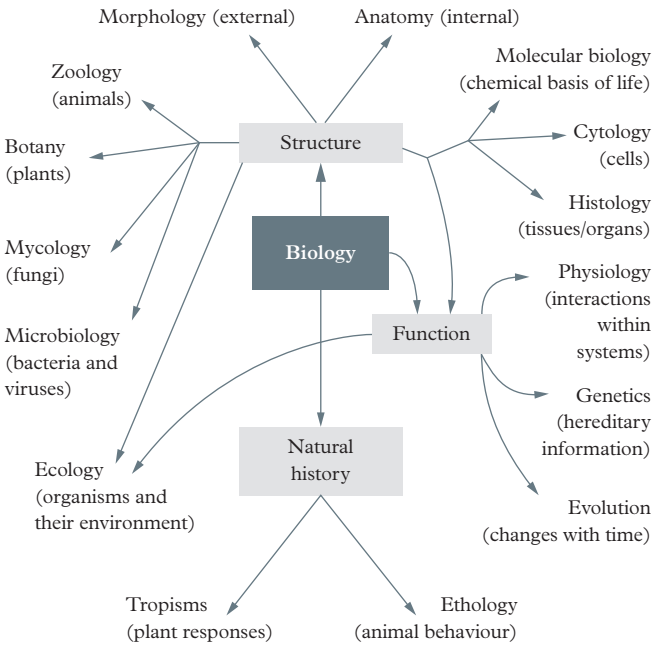


FIGURE 1 Major branches in the study of biology

Studying Biology can lead to a variety of career options in areas such as health sciences, environmental sciences and education. Health sciences cover a wide range of jobs including nursing, dentistry, medicine, pharmacy, physiotherapy, occupational therapy and veterinary science. Opportunities to work in environmental sciences include fields such as marine science, conservation, soil science, water quality, ecology, fisheries and agriculture. Many biologists work in research and education as lecturers, teachers and laboratory scientists.



FIGURE 2 Studying Biology can lead to careers in a range of fields, including (A) medicine, (B) ecology and (C) education.

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Structure of the QCE Biology course

Studying QCE Biology provides you with the opportunity to engage in a range of inquiry tasks and develop science inquiry skills. You will develop an understanding of the structure of cells and multicellular organisms and how they function.

The structure of the QCE Biology course is laid out in the Biology General Senior Syllabus. The course consists of four units. Units 1 and 2 are completed in the first year of the QCE Biology course and Units 3 and 4 in the second year. Each unit is divided into topics and each topic can include science understanding, science as a human endeavour and science inquiry subject matter. You should be familiar with these categories of understanding from your studies in years 7 to 10.

An overview of the QCE Biology units is shown in Figure 3, and Units 1 and 2 are summarised in Table 1.

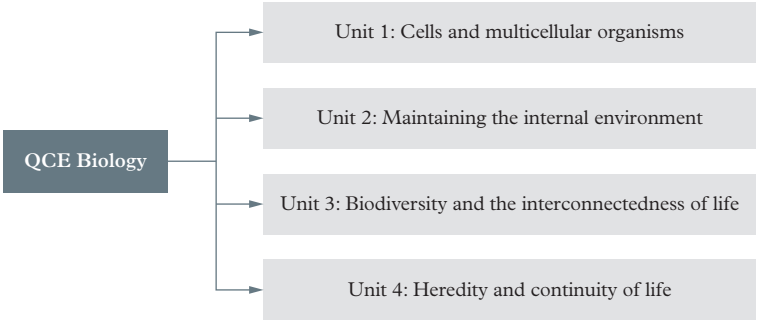
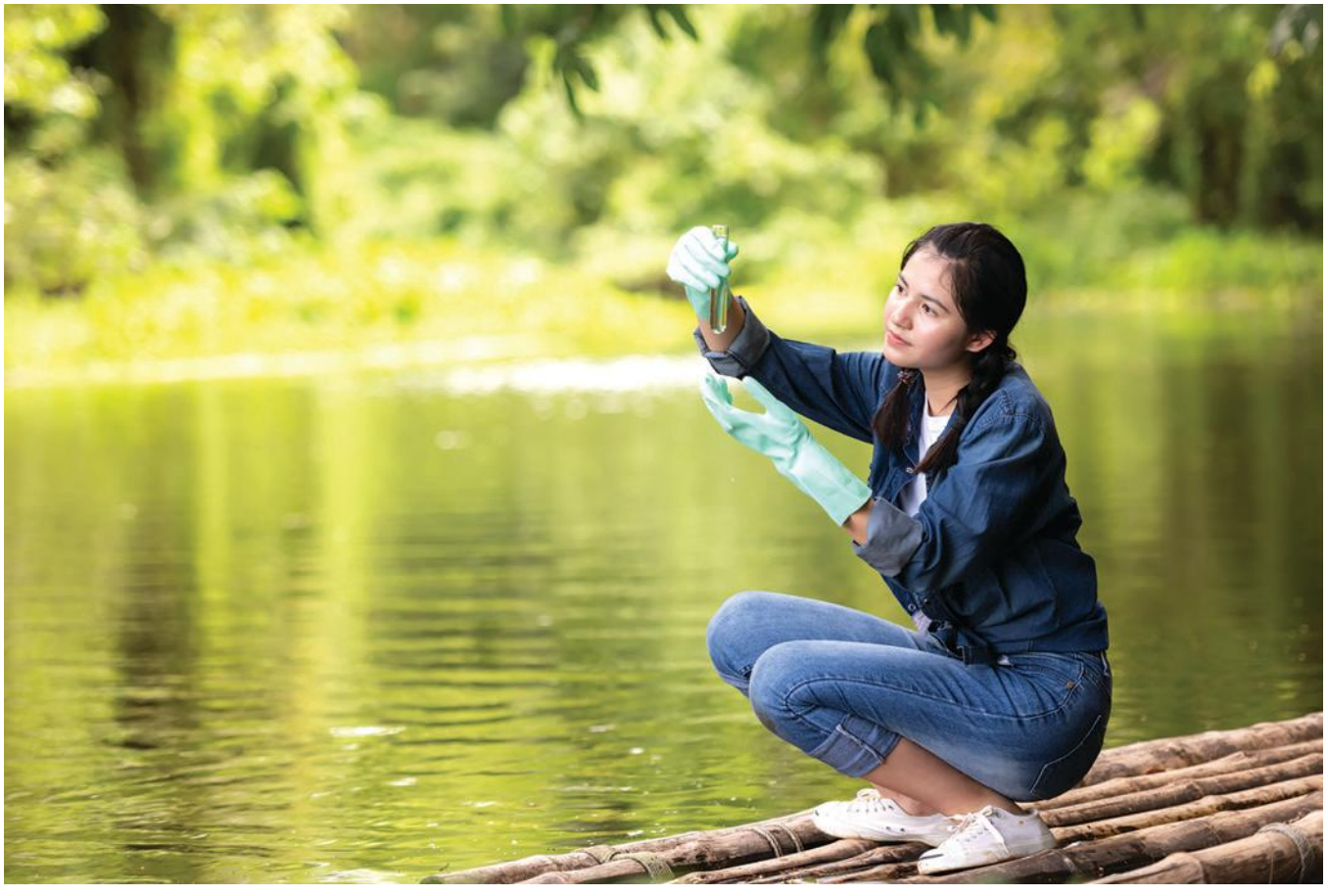


FIGURE 3 The structure of the QCE Biology course



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TABLE 1 Topics in Units 1 and 2 Biology

Unit 1 Cells and multicellular organisms	
Topic	**Description**
1. Cells as the basis of life	In this topic you will learn about: • the structure and function of prokaryotic and eukaryotic cells • the process of cell differentiation • the hierarchical organisation of cells, tissues, organs and systems • surface area-to-volume ratio (SA:V ratio) and organelle composition • the structure and function of the cell membrane • how the cell membrane regulates movement of substances into and out of the cell • active and passive transport • how the size of a cell is limited by SA:V ratio and rate of diffusion.
2. Exchange of nutrients and wastes	In this topic you will learn about: • the structure and function of carbohydrates, proteins and lipids • the role of amylase, protease and lipase in chemical digestion • how structural features of exchange surfaces in the digestive and circulatory systems of mammals (e.g. villi and capillaries) allow for efficient nutrient exchange • how closed circulatory systems facilitate the efficient transport of materials to and from all cells in the body • the parts of a nephron and their functions in the production of urine • how glomerular filtration, selective reabsorption and secretion across nephron membranes contribute to the removal of waste • how metabolic processes, such as digestion, are controlled and regulated by enzymes • the structure and function of enzymes, including the role of the active site • the induced-fit and lock-and-key models of enzyme function.
3. Cellular energy, gas exchange and plant physiology	In this topic you will learn about: • catabolism and anabolism • aerobic and anaerobic respiration • how structural features of exchange surfaces in the respiratory and circulatory systems of mammals allow for efficient gas exchange • using data to predict the direction that materials will be exchanged between alveoli and capillaries and capillaries and muscle tissue • the process of photosynthesis • the structure and function of xylem and phloem tissues • how stomata and guard cells facilitate gas exchange in plants • the effect of light intensity, temperature, wind or humidity on the rate of transpiration.

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Unit 2 Maintaining the internal environment	
Topic	**Description**
1. Homeostasis – thermoregulation and osmoregulation	In this topic you will learn about: • how the nervous and endocrine systems use negative feedback to coordinate responses to internal/external stimuli and maintain homeostasis • the different types of sensory receptors and their stimuli • the structure and function of nerve cells • sensory neurons, interneurons and motor neurons • the passage of a nerve impulse in terms of transmission of an action potential and synaptic transmission • how hormones relay messages to cells • how receptor binding alters cellular activity • feedback-control diagrams • thermoregulatory mechanisms of endotherms • thermoregulation in humans • osmoregulation in humans • how structural and homeostatic mechanisms maintain water balance in plants • how to compare the number and distribution of stomata in plants adapted to different environments.
2. Infectious disease and epidemiology	In this topic you will learn about: • infectious and non-infectious disease • key features of prions, viruses, bacteria, fungi, protists and parasites • how adherence factors, invasion factors, capsules and toxins affect pathogenesis • how host cells recognise self from non-self • the three lines of defence in vertebrates • the inflammatory response • the adaptive immune response • active and passive immunity • how to interpret long-term immune response data • the innate immune responses in plants • the effect of an antimicrobial agent on the growth of a microorganism • modes of disease transmission • factors that affect the spread of disease • measures to control the spread of disease • how data can be analysed to predict outbreaks, determine the source of an outbreak, infer the mode of disease transmission and determine the effectiveness of different strategies in controlling the spread of disease.

Source: Adapted from *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Assessment in QCE Biology

In Units 1 and 2, you can be assessed in several ways across the different topics. The syllabus requires that you:

- complete at least two, but no more than four, assessments
- complete at least one assessment for each unit
- are assessed on each unit objective at least once.

Many schools assess students studying Units 1 and 2 as they would students studying Units 3 and 4. This means that you will likely complete three assessment pieces and an

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end-of-year examination or examinations. One possible structure of your assessment is outlined in Table 2. Keep in mind that your school might choose to conduct the data test, student experiment and research investigation in either of Units 1 or 2.

TABLE 2 Units 1 and 2 assessments

Unit and assessment type	Assessment description	Assessment objectives
Unit 1 Cells and multicellular organisms: Data test	Students respond to items using qualitative data and/or quantitative data derived from practicals, activities or case studies from Unit 1.	• Apply understanding of concepts in Unit 1 to given algebraic, visual or graphical representations of scientific relationships and data to determine unknown scientific quantities or features • Analyse data about concepts in Unit 1 to identify trends, patterns, relationships, limitations or uncertainty in data sets • Interpret evidence about concepts in Unit 1 to draw conclusions based on analysis of data sets
Unit 1 Cells and multicellular organisms: Student experiment	Students modify (i.e. refine, extend or redirect) an experiment relevant to Unit 1 subject matter to address their own related hypothesis or question.	• Describe ideas and experimental findings about subject matter in Unit 1 • Apply understanding of subject matter in Unit 1 to modify experimental methodologies and process data • Analyse experimental data about subject matter in Unit 1 • Interpret experimental evidence about subject matter in Unit 1 • Evaluate experimental processes and conclusions about subject matter in Unit 1 • Investigate phenomena associated with subject matter in Unit 1
Unit 2 Maintaining the internal environment: Research investigation	Students gather evidence related to a research question to evaluate a claim relevant to Unit 2 subject matter. This assessment provides opportunities to assess science inquiry skills and science as a human endeavour (SHE) subject matter.	• Describe ideas and findings about subject matter in Unit 2 • Apply understanding of subject matter in Unit 2 to develop research questions • Analyse research data about subject matter in Unit 2 • Interpret research evidence about subject matter in Unit 2 • Evaluate research processes, claims and conclusions about subject matter in Unit 2 • Investigate phenomena associated with subject matter in Unit 2
Units 1 and 2 examination/s		

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You can use Lesson 1.11 Preparing for your data test, Lesson 1.12 Conducting your student experiment, Lesson 1.13 Conducting your research investigation and Lesson 1.14 Preparing for your exams to guide you through these assessments. Note that Science as a human endeavour content will not be directly assessed in your examinations.

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Science inquiry skills

In addition to developing your science understanding in Biology (which will be covered in Modules 2 to 13), the QCE course requires you to develop and apply a range of science inquiry skills. These skills are specified in the QCE Biology General Senior Syllabus and are listed at the beginning of each lesson in this module. This module will help you develop these skills.

The science inquiry skills are applicable to all areas of study in Units 1 to 4 of the QCE Biology course. They are especially important for preparing and planning for your data test, student experiment and research investigation assessment tasks.

Check your learning 1.1

Check your learning 1.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** the term "biology". (1 mark)
2 **Identify** three careers that are possible after studying Biology. (3 marks)

Analytical processes

3 **Distinguish** between the data test, the student experiment and the research investigation. (3 marks)

Lesson 1.2
Considering First Nations perspectives in Biology

Key ideas

- → First Nations peoples are the traditional custodians of the land we know now as Australia.
- → First Nations peoples have longstanding scientific knowledge.
- → Correctly acknowledging cultural and/or language groups, rejecting deficit discourse, avoiding Eurocentrism and critically evaluating sources of information can help you to respectfully engage with First Nations perspectives in QCE Biology.

Learning intentions and success criteria

Science inquiry skills

This lesson provides support for the following science inquiry skills:

- identify and implement strategies to manage risks, ethics and environmental impact, e.g.
  - cultural guidelines, protocols for working with the knowledges of First Nations peoples.

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oxforddigital **The rest of this lesson is available on Oxford Digital.**

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Lesson 1.3
Understanding the scientific method

Key ideas

→ A hypothesis is a statement that attempts to answer a question raised by observations and can be tested by experimentation.

→ The scientific method is a way of testing a hypothesis through controlled experimentation.

Science inquiry skills

Learning intentions and success criteria

This lesson provides support for the following science inquiry skills:

- identify, research and construct questions for investigation.
- propose hypotheses and/or predict possible outcomes.

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The scientific method

Biology is classified as a natural science. The word "science" is derived from Latin and means *to know*. Therefore the study of biology is an attempt to understand the natural world, of which we are part. All investigations begin with observations, such as:

The leaf is green.

which lead to questions, such as:

Why is the leaf green?

and seeking answers.

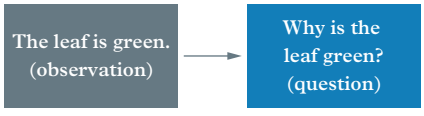


FIGURE 1 Observations lead to questions.

Like other disciplines, such as philosophy and art, science has its own method to verify the answer to the question. This is called the **scientific method**.

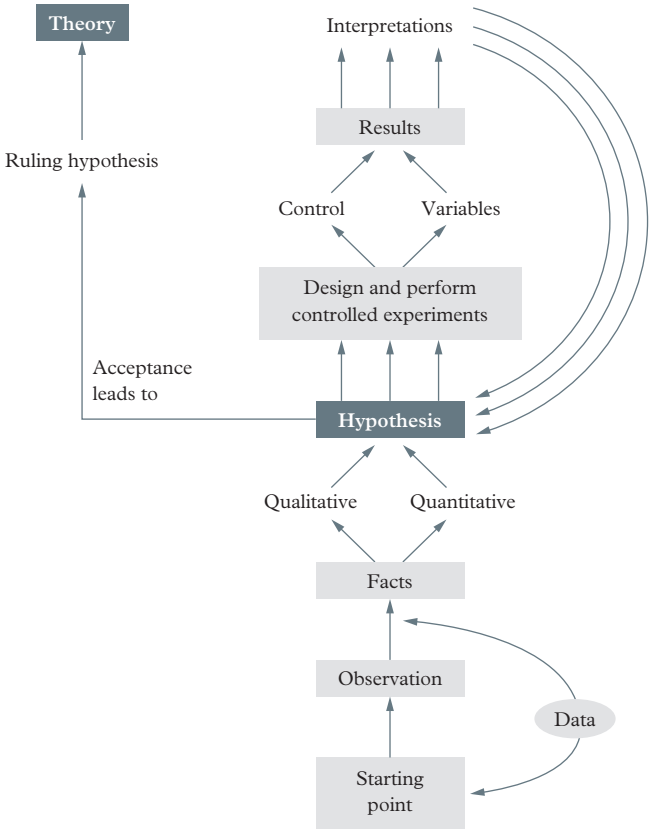


FIGURE 2 Steps in the scientific method

scientific method the testing of hypotheses by controlled experimentation

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The basis of science is accurate observations, which are recorded as data. For example:

> *Dewdrop spiders are found in the webs of golden orb spiders. Orb spiders kill and ingest the body contents of living things trapped in their webs. The silk of golden orb spiders is particularly thick and strong. Golden orb spiders are large. Dewdrop spiders are very small.*

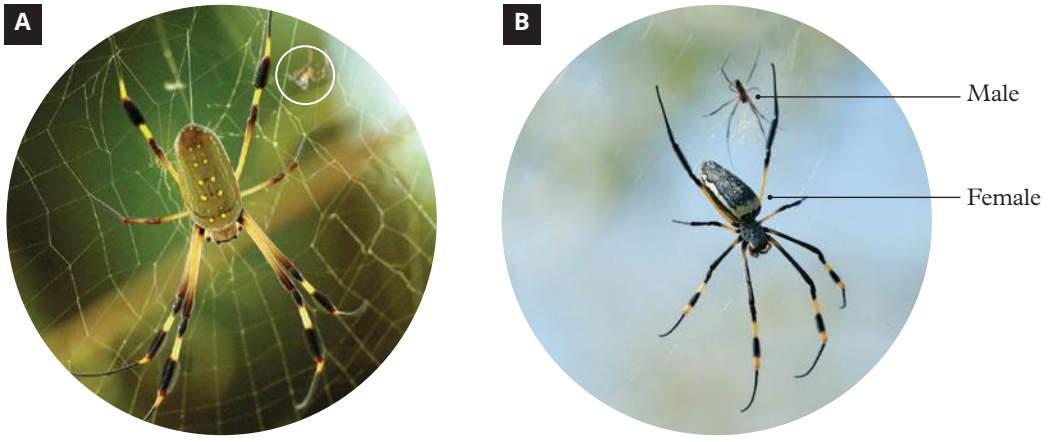


FIGURE 3 (A) The golden orb spider and the dewdrop spider share a web. (B) Male and female golden orb spiders

data
quantitative or qualitative information; facts and statistics

qualitative
descriptive

quantitative
measured

fact
information that has been verified by observation or experimentation

Data may be **qualitative** (descriptive) or **quantitative** (measured and represented by a numerical unit). After repeated observations have been verified, preferably by different people, an observation becomes accepted as **fact**. Observations usually need to be interpreted (logical reasoning), and this leads to question-asking.

TABLE 1 Types of data

Data	Definition	Example
Quantitative	Numerical (measured)	Leaf length
Qualitative	Descriptive (describes a characteristic)	Leaf colour
Objective	Measured according to an identified criterion	Leaf colour using defined special charts, reproducible by others
Subjective	Based on a researcher's opinion	Leaf colour based on researcher's judgement

Questions and hypotheses

Asking the right question is a key step in the scientific method. For example:

> Are dewdrop spiders too small for the golden orb spider to detect? If spiders larger than dewdrop spiders are placed in the webs of golden orb spiders, will they be captured?

The essential requirement about the right question is that it is testable. *Why* and *how* questions cannot be tested; *what if* questions can. Questions lead to hypotheses.

hypothesis
a statement that attempts to answer questions raised by observations and can be tested by experimentation

The **hypothesis** is a statement that attempts to answer the question(s) raised from observation(s). This explanation is then tested by experimentation. For example:

> It is hypothesised that the introduction of spiders slightly larger than the dewdrop spider to golden orb webs in the Brisbane Forest Park, during the spring–summer season of 2025, will result in their being captured and eaten by the golden orb spider.

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This detailed hypothesis:

- sets limits on the problem to be solved, by specifying
  - the particular species under study
  - the area involved
  - the effects to be studied
  - the time period over which the question is to be investigated
- points the way to the solution of the question
- leads to the prediction of new information.

This hypothesis predicts that the independent variable will affect the dependent variable in some way – this type of hypothesis is known as an **alternative hypothesis**. A **null hypothesis** predicts that the independent variable will have no effect on the dependent variable – it contradicts the alternative hypothesis. In this case, the null hypothesis would be:

> It is hypothesised that the introduction of spiders slightly larger than the dewdrop spider to golden orb webs in the Brisbane Forest Park, during the spring–summer season of 2018, will not result in their being captured and eaten by the golden orb spider.

The scientific method is unique in that it tests hypotheses by experimentation. If the experimental evidence for the proposed hypothesis is not supported by the evidence, or if it is inconclusive (there is no clear evidence either for or against), then further hypotheses are suggested. The hypothesis that has the most reproducible evidence is termed the **working hypothesis**.

When an experiment compares the results of two parallel tests that are identical in all but one respect, this is known as a **controlled experiment**. It provides a standard of comparison – a basis for assessing the outcomes of experimental tests. In an **experimental test**, the variation, or **experimental variable**, is altered in a way that is known by the experimenter. Only one variable is changed at a time. Therefore, a different experimental group is set up for each variable to be tested. It is assumed that the changes in the variable factor are the cause of any new effects observed in the experimental test.

Variables

A variable is a quantity or quality that can be different at different times or places. Each experiment has two variables: the **independent variable** (IV) is deliberately changed by the researcher; the **dependent variable** (DV) is the property that is measured in response to the changes in the IV (i.e. the changes observed in the DV *depend* on the deliberately altered condition of the experiment). **Controlled variables** are variables that have been kept consistent to ensure that any change to the DV can be solely attributed to the changes in the IV. For example, if a researcher was testing the effect of a fertiliser on plant growth, the IV would be treatment with fertiliser, the DV would be plant growth measured in cm, and the controlled variables would include plant pot size, soil type, exposure to light, and amount of water given to each plant.

alternative hypothesis
a hypothesis that predicts an effect or relationship between variables

null hypothesis
a hypothesis that predicts no effect or no relationship between variables

working hypothesis
the most successful hypothesis of a particular investigation

controlled experiment
an experiment in which a control group or standard acts as a reference for the experimental group, in which only one variable is different from that in the control group

experimental test
an experiment in which a single variable is compared with that of a control group

experimental variable
the single factor under investigation in a controlled experiment; also known as an independent variable

independent variable
the variable that is changed or controlled in a scientific experiment

dependent variable
a variable whose value is dependent on another variable

controlled variable
a variable that is kept constant by the experimenter to negate any effects it may have on the dependent variable

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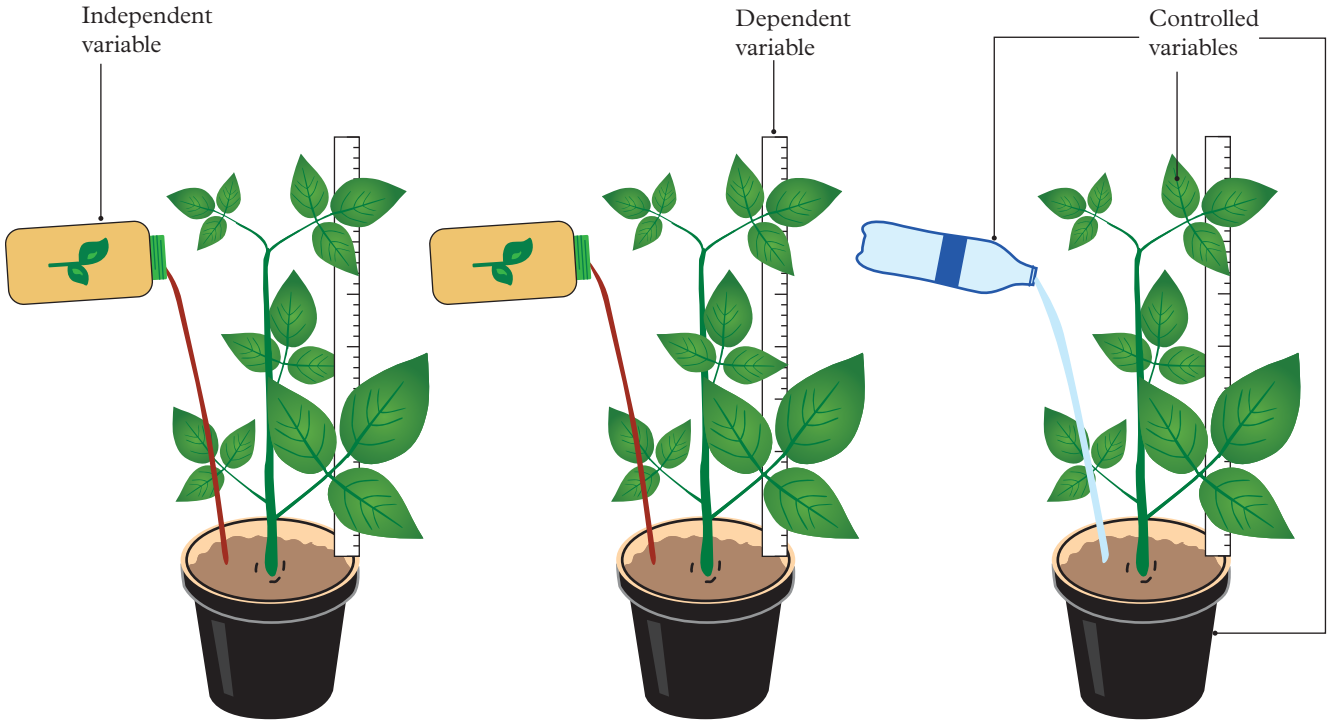


FIGURE 4 When testing the effect of fertiliser on plant growth, the IV would be treatment with fertiliser, the DV would be plant growth, and the controlled variables would include plant pot size, soil type, exposure to light and amount of water given.

Development of theories

Repetition of the sequence (observation – hypothesis – experiment) in a number of situations gradually allows broad generalisations to be made. It is important, therefore, that scientists report the details of their experiments fully, so that others can repeat them and validate their findings. These accumulated generalisations enable a **scientific law** to be developed – this law describes the supported observations that have been made, but it does not explain why or how they occur. The scientific law can be used to make **predictions** (or forecasts) about an *unknown*. A **scientific theory** provides an explanation for the observed, reproducible scientific law. In science, theories are never considered absolute, because further discoveries can lead to more accurate ways of observing, testing or interpreting information.

This account of the steps in the scientific method is not a rigid formula. Other factors can play a role in scientific discoveries. Accident, assumptions, prejudice and emotions all play a part in science and should not be overlooked. The fact remains, however, that science is a logical method of considering problems, following a pattern of reasoning characterised by observation, questions, formation of hypotheses, controlled experiments and prediction.

scientific law
a scientific theory that has been continually upheld by experimentation; a statement based on repeated experimental observations

prediction
forecast of a future event based on similar known events

scientific theory
a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment

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Check your learning 1.3

Check your learning 1.3: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** why scientists prefer not to use the word "prove". (1 mark)
2 **Define** the term "controlled variable". (1 mark)
3 **Define** the terms "hypothesis", "working hypothesis" and "theory". (3 marks)

Analytical processes

4 **Contrast** quantitative and qualitative data. (1 mark)
5 **Distinguish** between a scientific theory and a scientific law. (1 mark)

Knowledge utilisation

6 **Design** a simple concept map that explains the scientific method. (3 marks)
7 **Design** an experiment to test a whether a plant grows best in no sunlight, partial sunlight or direct sunlight. (4 marks)
8 **Generate** an alternative hypothesis and null hypothesis for each of the following scenarios.
   a A researcher is investigating whether a brand of handwash is effective in killing a bacterial species. (2 marks)
   b A researcher is investigating whether an increase in temperature will increase the rate of a reaction. (2 marks)

Lesson 1.4
Planning investigations

Key ideas

→ Primary data is data you collect firsthand; secondary data is data collected by someone else.
→ There are many types of investigations you can run to collect data.

Science inquiry skills

Learning intentions and success criteria

This lesson provides support for the following science inquiry skills:

- design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data required to obtain valid and reliable evidence, e.g.
  - distinguish between different types of investigations: descriptive, comparative, correlational, experimental, case studies
  - consider replicates, sample size, number of data points and quality of sources
  - identify the types of errors, extraneous variables or confounding factors that are likely to influence results and implement strategies to minimise systematic and random error.

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Investigation types

primary data
firsthand data collected from an experiment designed to answer the specific research question

secondary data
secondhand data obtained from other sources

There are many types of investigations that can be used to answer a research question. You might run an investigation that generates **primary data**, which is data you collect firsthand. Or your investigation might use **secondary data**, which is data that has been collected by someone else. Regardless of whether you are working with primary or secondary data, it is important to document all the steps you take in your investigation and all the materials and sources you use to help answer your research question. The procedures and materials you use will vary according to the type of investigation you run.

Certain investigation types are better suited to address specific types of research and research questions. In QCE Biology you can run a range of investigations, including:

- descriptive investigations
- comparative investigations
- correlational investigations
- experimental investigations
- case studies.

Descriptive investigations

descriptive investigation
an investigation that aims to describe the characteristics of a phenomenon

A **descriptive investigation** is one that collects qualitative and/or quantitative information that can be used to help describe a phenomenon. Descriptive investigations do not address research questions that focus on "why" something occurs; rather, they help address questions that focus on "what" something is. For example, "What is the average length of a diamond python?" or "What happens to a dried eucalyptus leaf when it is burnt?" These investigations provide information that can be used to help better understand a variable of interest. A hypothesis is not required for this type of investigation.



FIGURE 1 Descriptive investigations help address questions that focus on "what" something is. For example, "What is the average length of a diamond python?"

Comparative investigations

comparative investigation
an investigation that compares two or more conditions to identify similarities and/or differences

A **comparative investigation** involves collecting data on different factors (e.g. organisms, objects, traits) under different conditions to identify similarities and/or differences. For example, "Which species of birds perform courtship dances?" or "Which bacterial species are able to survive without oxygen?" Comparative investigations are often conducted by collecting data from natural settings; however, in some instances a researcher may need to manipulate conditions to draw comparisons between the variables of interest. A control group is typically not included.

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Correlational investigations

A **correlational investigation** is one that investigates whether a relationship exists between two variables without the researcher manipulating variables. For example, a researcher may be interested to see if there is a relationship between shoe size and height. They collect data on the heights of people and their shoe size, and plot each data point to determine whether a trend exists. You will learn more about how to plot data for correlational investigations in Lesson 1.8. It is it important to note that, even if a relationship is shown between two variables (**correlation**), this does not establish whether one variable is causing the change in the other variable (**causation**).

correlational investigation
an investigation that is run to determine whether a statistical relationship exists between two variables

correlation
the relationship between two variables

causation
a cause–effect relationship in which a change in one variable directly results in change in another variable

Experimental investigations

An **experimental investigation** is one that determines whether a cause-and-effect relationship exists between two variables. There is always at least one independent variable, a dependent variable and a control. For example, consider a researcher investigating the effect of a nitrogen-rich fertiliser (independent variable) on the growth rate (dependent variable) of a tomato plant. Their research question is, "Does nitrogen-rich soil affect the growth rate of tomato plants?" The researcher sets up two conditions of the experiment: one plant that grows in standard potting mix (the control), and one plant that grows in potting mix that has the nitrogen-rich fertiliser added. All variables apart from the independent variable are kept constant and the growth of both plants is measured regularly. Due to the experimental set-up, if the researcher finds that the nitrogen-rich plant grew taller and faster, they can attribute this change to the independent variable alone and thereby establish a causal relationship between the nitrogen fertiliser and plant growth.

experimental investigation
an investigation that involves manipulating one or more variables to determine whether this results in a change in another variable



FIGURE 2 Testing the effect of a nitrogen-rich fertiliser on tomato plant growth is an example of an experimental investigation.

Case studies

A **case study** is an investigation that analyses a specific individual, group or event in detail to explore or better understand a biological concept. This type of investigation often focuses on better understanding "why", "what" or "how" something occurs. It can involve the collection of qualitative and/or quantitative data through observations, interviews or literature review. Data is collected, analysed and interpreted to identify patterns, similarities or mechanisms about the research subject. This often includes comparing data from the case study against the scientific literature or other similar case studies. An example of a case study in biology would be investigating the occurrence of a rare gene mutation in an individual.

case study
a detailed investigation that focuses on a specific individual, group or occurrence to better understand it

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Designing valid and reliable investigations

When designing your investigation, it is important that you take measures to ensure your results are truly representative of what you intended to investigate, and that your results are sound enough to address your research question. Two concepts to consider when designing investigations are validity and reliability.

Validity

validity
a measure of whether an investigation is sound and measures what it is intended to measure

A good experiment is one that has been designed to produce useful information clearly related to the hypothesis and typical of the species under investigation. **Validity** is a measure of how appropriately an investigation has measured what it set out to measure. If the experiment provides data that refers directly to the hypothesis, then it is considered a valid experiment. For example, an experiment that tests whether eating chocolate causes an increased number of pimples would not be valid unless all other food choices, exercise programs and face-cleaning regimens were also controlled.

Reliability

reliability
the extent to which a measurement, test or investigation produces consistent results

repeatability
the extent to which the same results can be produced by a researcher when the experiment is performed again under the same conditions

reproducibility
the degree to which the same results can be generated by other researchers using different equipment and methods in different laboratory settings

An investigation must be repeated many times to ensure that the results are not due to chance. This is particularly important when using living organisms in investigations, because some individuals may respond to the experimental variable on the basis of their individual characteristics rather than those of the species. **Reliability** is the degree to which a measurement, test or investigation produces consistent results over multiple trials. It is based on the concepts of **repeatability** and **reproducibility**. Repeatability refers to the ability of the same scientist to obtain the same results with the same equipment. Reproducibility relates to whether a different scientist would be able to obtain the same results with different equipment.



FIGURE 3 Reliable investigations produce consistent results.

Factors that can influence validity and reliability

Many factors can influence how valid and/or reliable your investigation is. These factors include:

- replicates
- sample size
- number of data points
- quality of sources
- errors
- extraneous variables and confounding factors.

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Number of replicates

A **replicate** is a repeated observation or measurement in an investigation used to improve the consistency and reliability of the results. There are two main types of replicates:

- biological replicates, which involve testing multiple biological samples (e.g. different individuals, bacterial cultures) under identical investigation conditions to make sure that the results generated are not specific to one individual, subject or sample
- technical replicates, which involve performing the same measurement or investigation on the same sample multiple times, to account for variance in measurements or procedures.

replicate
a result obtained from repetition of a measurement using the same methodology, conditions and materials

Increasing the number of replicates helps to ensure that the results generated are not due to random chance. This increases the validity of the investigation, as there is more confidence that the results obtained can be attributed to the phenomenon tested. If an investigation lacks replicates, its results may be skewed due to outliers or random events. Increasing the number of replicates can also increase the reliability of an investigation by providing consistent results across repeated trials.

Sample size

A **sample** is the number of subjects (e.g. individuals, specimens) tested in an investigation. It is a subset of the population you wish to draw conclusions about. Larger sample sizes tend to provide more accurate and generalisable results, as they reduce the influence of random variations between subjects, which would affect the results. This helps to ensure that the results obtained reflect the phenomenon tested and are therefore valid. Large sample sizes also increase the reliability of an investigation's results by reducing the margin of error and generating more consistent results. If a sample size is too small, the investigation may not be valid due to the results not accurately reflecting the population studied, and it may not be reliable due to the higher chance of variability between subjects affecting the results.

sample
a subset of the population of interest in a study

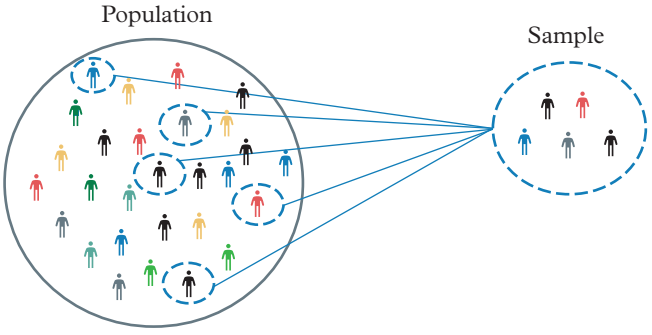


FIGURE 4 A sample is a subset of the population.

Number of data points

The number of data points used in an investigation can also affect the validity and reliability of the results. Using a larger number of data points can generate a clearer picture or representation of the phenomenon being investigated, increasing the validity of the results. For example, if you wanted to investigate the concentration of antibodies produced by an individual over 60 days but only took measurements on five of those 60 days, your graph would not provide as clear a picture as it would have if you had taken measurements each day for 60 days. Including a larger number of data points can also increase an investigation's reliability, because it improves the accuracy of the statistical analysis, reducing the effect of outliers on the results.

Quality of sources

Not all sources of information are equal. The quality of information or data used to inform or complete an investigation can affect the investigation's validity and reliability. High-quality sources will provide accurate, credible and relevant information or data about a phenomenon. Examples of high-quality sources are peer-reviewed scientific literature, textbooks, and information from trusted databases or organisations. Low-quality sources may introduce bias or unjustified claims.

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Using high-quality sources to inform an investigation can improve the investigation's validity by ensuring that the methods used, the interpretations of the results and the conclusions drawn are representative of the phenomenon that has been investigated. Low-quality sources can lead to invalid conclusions being drawn about the phenomenon investigated. High-quality sources are also likely to provide more consistent and trustworthy data, increasing the reliability of the investigation. Low-quality sources may introduce inconsistencies and errors to the data, reducing its reliability.



FIGURE 5 Scientific journals are a credible source of information.

Extraneous variables and confounding factors

extraneous variable
a variable other than the independent variable that may cause changes in the value of the dependent variable

An **extraneous variable** is any variable, other than the independent variable, that may cause a change in the dependent variable. For example, when testing the effects of a fertiliser (IV) on plant growth, the researcher might not have grown all plants in the same temperature conditions. Because plants are sensitive to temperature, the results could be influenced by the varying temperatures in which the plants were grown. If the experimenter has not taken this into account, an incorrect conclusion could be drawn. Care must therefore be taken to work out all possible extraneous variables. An extraneous variable that is controlled for becomes a controlled variable.

If extraneous variables are not controlled, it becomes difficult to determine whether the changes in the dependent variable can be attributed to the independent variable. This can threaten the validity of the investigation. Extraneous variables can also cause variation in the results, making the results less consistent across repeated trials. This means the investigation's results are less reliable, as they might not be able to be reproduced in similar experimental conditions.

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A **confounding factor** is a variable, other than the IV, that has affected the dependent variable. This effect on the dependent variable confounds (confuses) the relationship between the IV and the DV. A confounding factor might be an extraneous variable that has not been controlled for, or it could be a type of variable that cannot be controlled for. Additionally, some confounding factors may affect both the IV and the DV, confusing the relationship between the two variables. Confounding factors reduce the reliability of an investigation by introducing invalid conclusions. The investigation's results are likely to vary due to the presence of the confounding factor, making it difficult to reproduce the results.

confounding factor
an uncontrolled variable that has a systematic effect on the value of the dependent variable; if a confounding variable exists, no valid conclusions about the research can be drawn

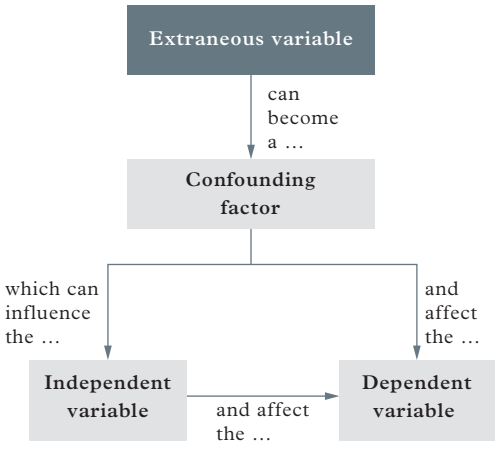


FIGURE 6 Summary of how extraneous variables and confounding factors can affect an investigation's results.

Errors

An error is the difference between a measured value and the **true value** (the value of something if it was measured perfectly) of what is being measured. There are two main types of errors:

- **systematic error**
- **random error**.

true value
the value of a measurement if it were measured perfectly

systematic error
an error that causes readings to deviate from the true value by a consistent amount and in the same direction each time a measurement is made; it is affected by the accuracy of the measurement process

random error
an error due to the limitations (uncertainty) of the measurement equipment, and the uncontrollable effects of the method and the environment on the measurement

A systematic error is an error that is consistent and repeatable. It could be caused by faulty equipment or by using a measuring instrument that has not been calibrated. Systematic errors cause readings to differ from the true value in a consistent way. This means repeating the investigation will not reduce the systematic error. For example, if a weighing scale is not calibrated and measures 0.0 g as 0.02 g each time the scale is used, it will always cause the true value of what is being measured to vary by 0.02 g. Systematic error can be reduced by carefully considering and conducting the investigation method and by calibrating the equipment to be used. Systematic errors reduce the validity of the results, because the results deviate from the true value of what is being measured. Reliability is also reduced, because the deviance in results means the same results are less likely to be generated under similar conditions in another laboratory setting.

Random errors are errors that are unpredictable. They are caused by factors that vary from one measurement to another. For example, consider a researcher observing the number of times an animal exhibits a specific behaviour in a set time period. If the researcher drops their pencil and misses seeing a behaviour while picking up their pencil, this measurement has been affected by random error. Repeating measurements, trials and averaging results can reduce random error.

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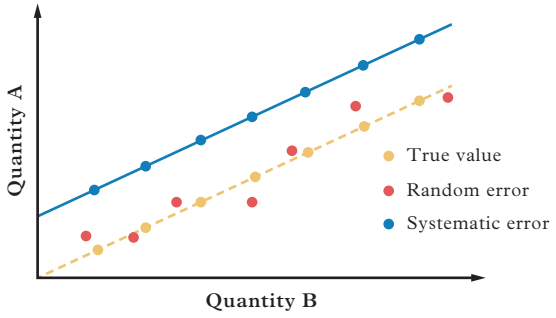


FIGURE 7 Representation of how random error and systematic error can affect results. Systematic error affects the accuracy of results; random error affects precision.

Uncertainty

uncertainty
the degree to which the result of a measurement does not reflect the exact (true) value of what is being measured

Uncertainty describes the degree to which you are unsure of the true value of a measurement. Uncertainty can arise from limitations in the equipment, lack of information or understanding about a phenomenon, or from the variability of different systems. For example, the thermometer shown in Figure 8 has a scale that increases in 1°C increments. The reading on this thermometer sits between 22°C and 21°C, and there are no smaller increments on the scale to discern exactly where the reading falls between these two numbers. Therefore, there is a degree of uncertainty in this measurement. The uncertainty of a measuring instrument is estimated to be plus or minus (±) half the smallest unit that the measuring instrument increases by. A thermometer with units that increase by 1°C would have an uncertainty of (±) 0.5°C. Therefore, the reading on the thermometer in Figure 8 can be recorded as 22°C (±) 0.5°C.



FIGURE 8 Due to the limitations of the thermometer, there is a level of uncertainty with each reading.

Check your learning 1.4

Check your learning 1.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the purpose of the following investigation types:
   - **a** comparative investigation (1 mark)
   - **b** case study (1 mark)
   - **c** descriptive investigation. (1 mark)

2 **Define** the following terms:
   - **a** reliability (1 mark)
   - **b** validity. (1 mark)

3 **Describe** what an extraneous variable is. (1 mark)

4 **Explain** how small sample size can affect the reliability and validity of results. (1 mark)

5 The scale on a ruler increases in 1 mm increments. **Determine** the uncertainty of a reading of 13 mm. (1 mark)

Analytical processes

6 **Compare** correlational investigations and experimental investigations. (2 marks)

7 **Contrast** systematic error and random error. (1 mark)

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Lesson 1.5
Considering safety and ethics

Key ideas

→ Before conducting research, scientists must consider whether the investigation is safe and ethical, and the potential impacts it might have on the environment.

Science inquiry skills



Learning intentions and success criteria

This lesson provides support for the following science inquiry skills:

- identify and implement strategies to manage risks, ethics and environmental impact, e.g.
  - ethical guidelines
  - material safety data sheets
  - workplace health and safety guidelines
  - appropriate disposal methods
  - standard operating procedures
  - acknowledgment of sources and referencing.

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Managing risks, ethics and environmental impact

Before conducting an investigation, scientists must consider whether the investigation is safe and ethical, and the potential impact it might have on the environment. If any safety, ethical or environmental concerns are identified, it is the responsibility of the scientist to modify their investigation to reach a standard that would be accepted by an ethics committee. Strategies used to manage potential safety, ethical and environmental risks include:

- adhering to ethical guidelines
- using material safety data sheets
- following workplace health and safety guidelines
- using appropriate disposal methods
- following standard operating procedures
- correctly acknowledging sources and referencing.

Ethical guidelines

Investigations should not be conducted on vertebrate animals (including humans) without first submitting a full report on the experimental procedure to the bioethics committee in the area for approval. The guidelines for animal experimentation are extremely strict, to ensure the wellbeing of the animals. If humans are participants in an experiment, each participant needs to be given a form outlining the exact procedures to be undertaken, the established means of confidentiality (e.g. no names recorded) and the safety measures in place. Each participant (or their guardian if they are under 18 years old) needs to sign a consent form. No pressure (peer or personal relationship) should be placed on an individual to participate. School students should not undertake experimental investigations using human subjects.

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FIGURE 1 Guidelines for experimentation using animals are extremely strict, to ensure the wellbeing of the animals.

Material safety data sheets

A material safety data sheet (MSDS) is a document that provides detailed information on a specific chemical and its properties. It also includes potential hazards the chemical can cause and safety precautions required when working with or handling the chemical. Material safety data sheets are used to inform risk assessments for investigations. They can be easily accessed on the internet.

Workplace health and safety guidelines

Workplace health and safety guidelines are rules developed by governments to ensure that workers, including scientists, are working in conditions that protect them from injury, illness and accidents. They can include instructions for using equipment, handling various materials, protective personal equipment (PPE) that should be worn and how to manage emergencies to maintain safe working conditions.



FIGURE 2 Workplace health and safety guidelines can include instructions and information on the type of PPE that must be worn when working.

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Appropriate disposal methods

Some materials can be hazardous to different species, particularly if they are not disposed of correctly. Using the appropriate disposal method for a substance can reduce environmental contamination and potential health risks. This includes disposing of hazardous materials, recycling, and following rules for waste management. Table 1 lists safe disposal methods for various materials.

TABLE 1 Safe disposal methods

Material	Examples	Disposal method
Biohazardous waste	Animal cells and tissue	Solids should be collected by your teacher for appropriate disposal. Liquids must be deactivated with bleach before they can be disposed of down the drain.
Grease and oils	Vegetable oil, lubricants	Collect in a bottle and dispose of in general waste. Machinery oils should be disposed of as hazardous chemical waste.
Corrosive liquids	Acids	Weak acids may be able to be poured down the drain. Strong acids must first be neutralised before they can be poured down the drain. Some schools have acid traps.
Solids	Paper towel	Dispose of in general rubbish.
Hydrogen peroxide	> 8%	Dilute before pouring down the drain.

Standard operating procedures

Standard operating procedures (SOP) are a set of instructions that detail all the tasks required to complete an activity or process in a routine way. They are often created by workplaces, schools, government agencies and equipment manufacturers to improve the safety of a process and minimise risks. In addition to information on how to carry out a task, SOPs often also include information on the equipment that should be worn during a procedure, how to handle or store equipment, how to dispose of materials and how to prevent injury.

Acknowledgment of sources and referencing

Acknowledging sources and correctly referencing materials is an important part of scientific research. It ensures that the work of researchers that has provided insights or findings that assist with an investigation is properly credited. You will learn more about referencing conventions in Lesson 1.10. Failing to credit or correctly reference the work of others is unethical, as it wrongfully uses the intellectual property of others. Plagiarising means presenting someone else's original ideas as your own. It is a serious offence that can arise from failing to acknowledge, or incorrectly referencing, the work of others.

Check your learning 1.5

Check your learning 1.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** three things you must do if you want to ethically recruit human participants for a research experiment. (3 marks)
2 **Identify** two pieces of information you might find about a chemical in a material safety data sheet. (2 marks)
3 **Explain** how you would dispose of plasticine you used in a practical activity to model the respiratory system. (1 mark)
4 **Explain** why it is important to correctly acknowledge the work of others. (1 mark)

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Lesson 1.6
Collecting data

Key ideas

- → There are many ways to collect primary and secondary data for an investigation.
- → Sampling is a way to select subjects for an investigation. Common sampling techniques are random sampling, systematic sampling and stratified sampling.
- → Microscopy techniques are important in biological science.
- → Tools such as information and communication technology, scientific texts, databases and online sources can be valuable in generating primary data and/or collating secondary data for an investigation.
- → Data collected for an investigation should be systematically recorded.

Learning intentions and success criteria

Science inquiry skills

This lesson provides support for the following science inquiry skills:

- use appropriate equipment, techniques, procedures and sources to systematically and safely collect primary and secondary data, e.g.
  - microscopy techniques: total magnification and field of view, scientific drawing
  - laboratory and field techniques: measurement, equipment calibration, species identification
  - sampling methods: random, systematic, stratified
  - sampling techniques: quadrats, line transect, belt-transect, capture-recapture
  - models and simulations
  - ICTs, scientific texts, databases, online sources
- use scientific language and representations to systematically record information, observations, data and measurement error, e.g.
  - symbols, units and prefixes
  - scale and magnification
  - indicators of measurement uncertainty
  - tables, graphs and diagrams
  - charts and maps
  - logbooks

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Collecting primary and secondary data

There are many ways to collect primary and secondary data. The way you collect data will vary depending on the type of investigation you are running. In this lesson you will learn about a variety of sampling methods and data collection techniques you can use to either generate your own primary data or collate secondary data.

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Sampling

In research, a **population** is the entire group of individuals or specimens of interest to the researcher. For example, if a researcher was conducting a study on the feeding habits of Southern Cassowaries in the Daintree, the population would include every Southern Cassowary that lives in the Daintree. Because it is extremely difficult (often impossible) to study every individual that makes up a population, researchers select a subset or smaller group of individuals from the population to represent the population in the study. This subset is called a sample. There are three main methods of generating a sample to work with in an investigation: random sampling, systematic sampling and stratified sampling.

population
the group that scientists wish to draw conclusions about

Random sampling

Random sampling is a method of sample selection where every individual in the population has an equal chance of being selected for the sample. For example, if researchers wanted to study the average height of trees in the Daintree, the population would include every tree in the Daintree. To form a random sample of trees to measure, researchers could use a computer to randomly generate a set of coordinates in the Daintree and measure the heights of each tree closest to each coordinate. In this way, each tree has an equal chance of being selected into the sample. Random sampling helps remove selection bias.

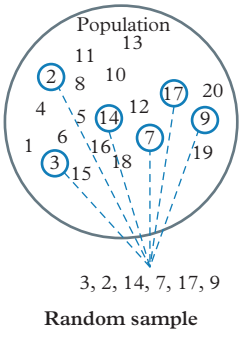


FIGURE 1 Random sampling is a selection process where everyone in the population has an equal chance of being selected for the sample.

random sampling
a sampling procedure in which every member of the population has an equal chance of being selected for the sample

Systematic sampling

Systematic sampling is a method of sample selection that involves selecting members, or sections of a larger population, at consistent intervals. For example, if researchers wanted to study the health of NRL players, they could access an alphabetised list of all NRL players and systematically select every tenth player on the list, to form their sample.

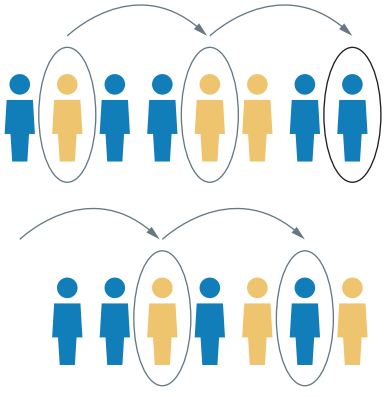


FIGURE 2 Systematic sampling selects members of the population at consistent intervals.

systematic sampling
a sampling procedure in which samples are selected based on a systematic interval from a randomly chosen starting point

Stratified sampling

Stratified sampling involves breaking the population into subgroups (called strata) that share a similar trait and then randomly selecting from each stratum. For example, researchers want to study a species of bird that can be found in three different environments in a region: grasslands, shrublands and coastal saltpans. They divide the bird population into three strata based on the three habitats and randomly sample from each stratum. In this way, the sample is representative of birds from each habitat.

stratified sampling
a sampling procedure in which population is divided into strata and random samples are selected from each stratum

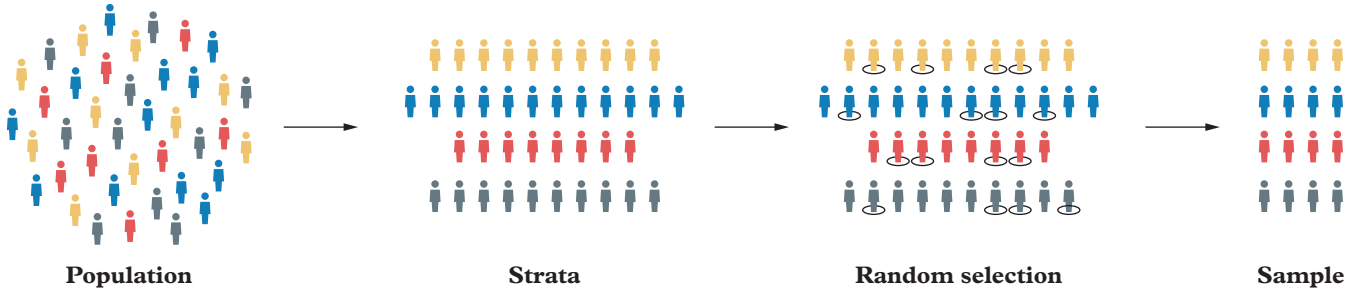


FIGURE 3 Stratified sampling involves breaking the population into strata and randomly sampling from each stratum.

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In addition to sampling methods, there are also many sampling techniques you can use in Biology, particularly when conducting ecological fieldwork. You will learn more about sampling techniques, such as quadrats, line transect, belt-transect and capture-recapture, in Units 3 and 4.

Laboratory and field techniques

When working in a laboratory or in the field, there are techniques you can apply to ensure that you collect data in a systematic and safe way. These techniques include considering measurement, equipment calibration and species identification tools.

Measurement

Research often involves taking measurements of different physical properties such as length, mass, temperature, time, capacity, area and volume. Data collected from measurements should be both accurate and precise. **Accuracy** describes how close a measurement is to its true value (what the measurement would be if it were measured perfectly). For example, if the true value of the length of a shell is 3.63 cm and the reading you get when measuring the shell is 3.62 cm, you can say that this measurement is accurate. If the length you get is 2.8 cm, it is less accurate. **Precision** refers to how close each of the measurements of the same thing are to each other. For example, if you take three readings of the length of the shelf of 3.61 cm, 3.62 cm and 3.61 cm, your measurements are precise, because they are all very close to each other. If the readings you get are 2.8 cm, 3.61 cm and 3.2 cm, these are less precise. A visual representation of precision and accuracy is shown in Figure 4.

accuracy
how close a measurement is to its true value

precision
how close a set of data values are to each other

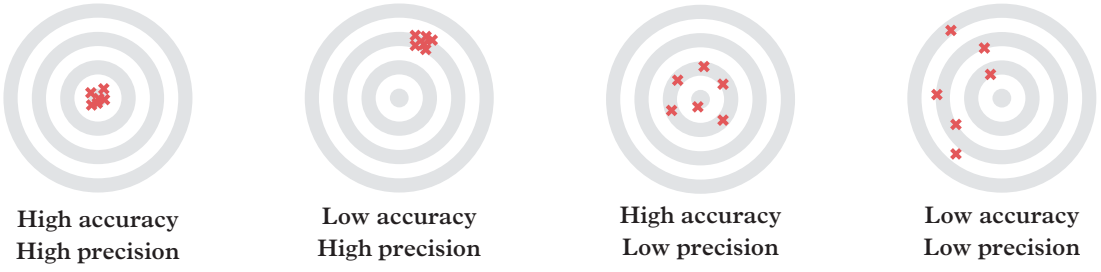


FIGURE 4 Accuracy and precision are different concepts.

It is important to make sure the instruments used to take measurements are reliable and calibrated (if necessary). Your process of measuring should also be consistent. For example, if you are using a ruler to take measurements of leaf length, you would want to ensure that the ruler you use is in good condition, to provide an accurate reading of length. An old wooden ruler with lots of scribbling and dents may lead to less accurate readings than a clean metal ruler. You would also need to ensure that the point you measure from remains consistent for each reading.

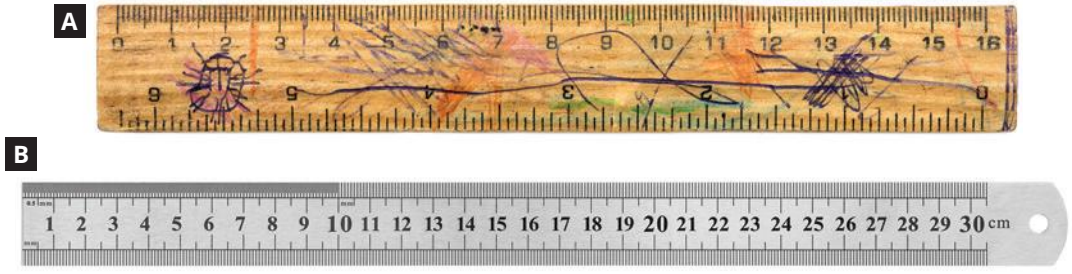


FIGURE 5 (A) An old wooden ruler could give less accurate readings than (B) a clean metal ruler.

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Equipment calibration

Calibration is the process of configuring an instrument or measuring device to ensure it provides accurate readings. When using equipment to record data, it is important to make sure the equipment is calibrated. Common instruments used in research that should be regularly calibrated are listed in Table 1.

TABLE 1 Common laboratory equipment that requires regular calibration

Equipment	How to calibrate
Digital scales	Place a standard or known weight on the scale and adjust the reading until it matches the known weight.
Digital thermometer	Run a controlled temperature bath at a set temperature and place the thermometer in the bath. Let it sit for few minutes, then adjust the reading until it matches the reference temperature.
pH meter	Use standard buffer solutions with known pH values to test the reading given by the meter. Adjust the meter to match the reading of the known solution.
Micropipette	Fill the pipette with water and disperse onto a scale. Weigh the volume of water dispensed to make sure the pipette delivers the correct volume. If there is a difference, adjust the pipette.

Species identification

Being able to identify different species is an important skill in in biological research. Given the large number of species of organisms, biologists often rely on species identification tools to help identify what they are observing. Species identification tools include, but are not limited to, keys, field guides and mobile applications. A key is used to help determine species by first identifying a general characteristic of an organism, then breaking the characteristics into divisions, which a researcher can work through to reach the correct species. For example, Figure 6 shows a plant key. If you knew a particular plant forms seeds and has no true flowers, you could deduce that it is a type of gymnosperm. Other keys may ask a series of questions for the user to work through to eventually arrive at one species.

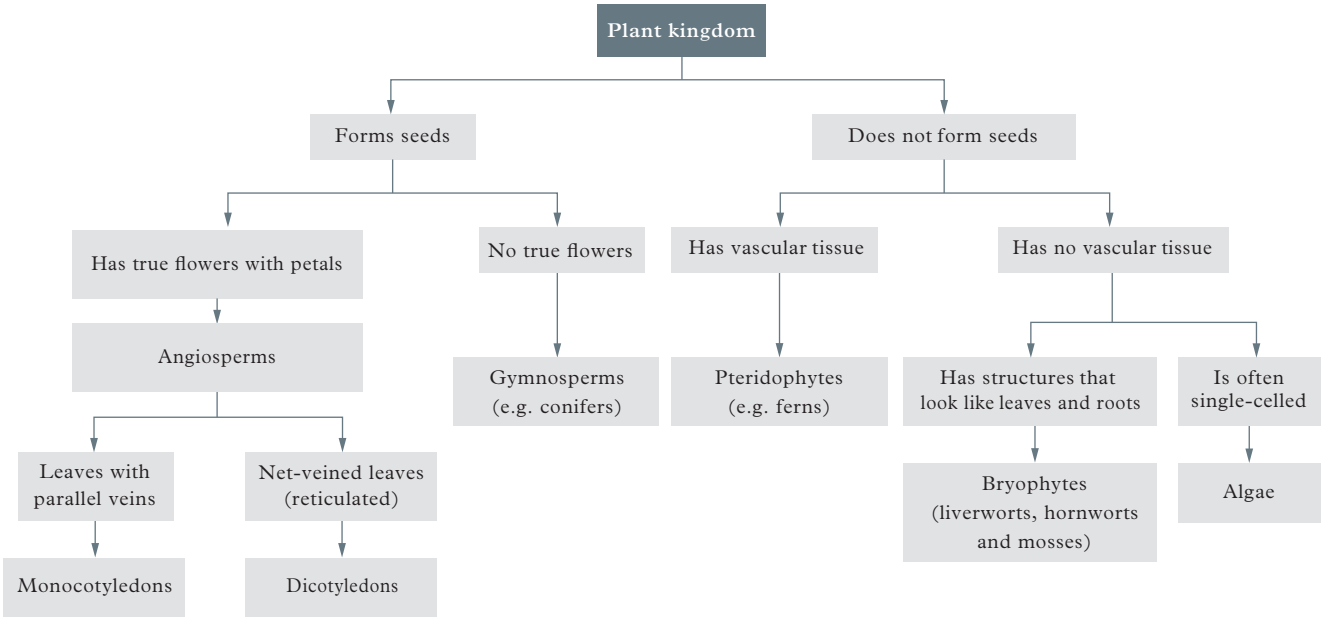


FIGURE 6 A sample plant key

A field guide presents specific information on a variety of species, as well as additional information such as diagrams, photos and distribution data. Depending on the field guide,

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it might include species for one type of animal in a region (e.g. *The Australian Bird Guide*) or multiple animals in a region (e.g. the *Queensland Museum Field Guide to Queensland Fauna*), or it might be very locally specific. In addition to field guides, online apps can also be useful in identifying species. Many apps have a database of species, which you identify by searching through images or by comparing species against photos you've taken.

Microscopy techniques

Microscopy is the use of microscopes to view and observe specimens and structures that cannot be seen or are difficult to see with the naked eye. Two of the main types of microscopes are **light microscopes** and **electron microscopes** (Table 2). Having strong microscope skills is essential in Biology, particularly in Units 1 and 2, where you will need to be able to operate a microscope, examine samples under a microscope and identify the structural features of cells. Lesson 1.7 "Using a light microscope" will allow you develop key microscopy skills, including how to calculate total magnification and field of view.

light microscope
a microscope that uses visible light and lenses to magnify viewed specimens

electron microscope
a microscope that uses a beam of electrons to form an image of the viewed specimen

TABLE 2 Summary of light and electron microscopes

	Light microscope	Electron microscope
How it works	Visible light is shone onto a specimen and the optical lenses magnify the image. Light reflects off the sample and the image can be observed through the eyepiece.	Electrons (which have much shorter wavelengths than visible light) are used instead of light to form an image on a screen.
Magnification	1000× to 2000×	Up to 1,000,000×
Applications	Viewing cells, large organelles, some larger bacteria and live specimens	Viewing smaller specimens and structures (e.g. viruses, macromolecules, small organelles). Not for viewing living specimens

Scientific drawing

After viewing a specimen under a microscope, you might need to draw what you have seen. What is shown in your drawing should match what you see through the eyepiece of the microscope (Figure 7). A scientific drawing of a microscope image should include:

- a title or description of what has been observed
- labels that do not cross over each other
- the total magnification that the specimen was viewed at.

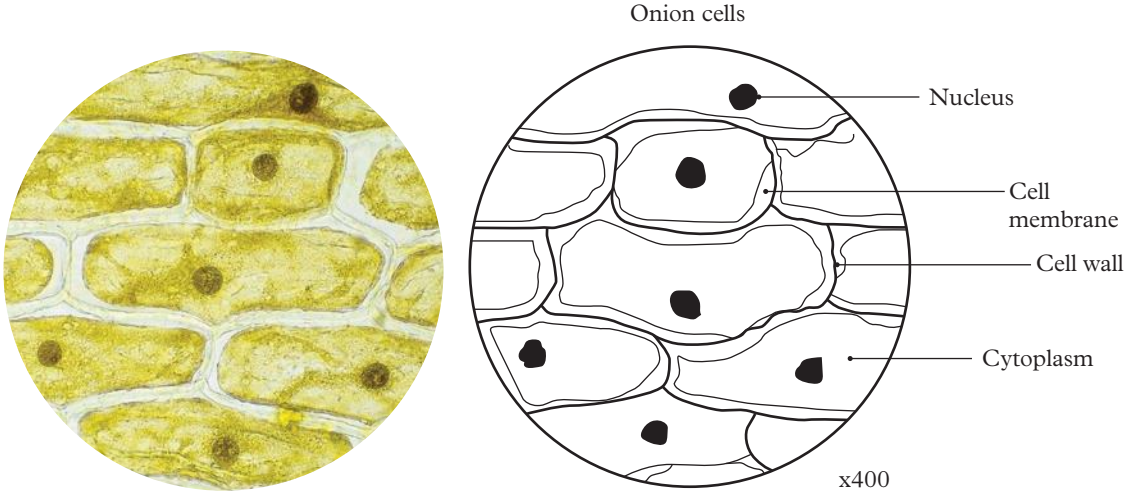


FIGURE 7 Scientific drawing of onion cells compared to the microscope view

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Models and simulations

A model is a representation of a complex system or concept that has been simplified to make it more easily understood or to make predictions. There are many types of models including, but not limited to, physical models (e.g. a model of the human digestive system) and mathematical models (e.g. the SIR model for disease spread). Models can be used to help break down complex ideas and predict how a real-life situation may unfold. Simulations are software programs that mimic or "simulate" the behaviour of a real-life phenomenon. Simulations can be used to test events or occurrences that may be too difficult, time consuming or expensive to test in real life.

Online tools and scientific texts

Other tools, such as **information and communication technologies (ICT)**, scientific texts, databases and online sources, can be valuable in generating primary data and/or collating secondary data for an investigation. Information and communication technologies are computer software and programs that perform a variety of operations. Different ICT can assist the collection of data in various ways. For example, an ICT may assist with processing the information received from a microscope, conduct statistical analysis of data, offer programs that help manage workflow and tasks, or enable quick communication with others you are working on a project with.

information and communication technologies (ICT)
computer and other technologies that process information to perform a range of tasks

A **database** is an organised collection of data, often stored online in an electronic system. Databases can provide access to raw data that researchers can analyse to generate primary data. Data from databases can also be used to collate secondary data for an investigation. Some databases you may find useful for conducting your own biological research are:

database
a large, organised collection of data

- the Australian Bureau of Statistics (ABS), which provides statistics on a variety of economic, social, population and environmental factors
- the WildNet database, which contains information on more than 21,000 wildlife species
- the Australian Burden of Disease Database, which contains disease metrics for over 200 diseases and injuries.

Online sources

Online sources can also be valuable in providing information and data to assist in an investigation. Government websites often include credible information on medical, ecological, geographical and population data. In addition to these online sources, websites such as Google Scholar, JSTOR, ScienceDirect and PubMed contain a wide variety of peer-reviewed journal articles and scientific papers, which can be used to collate data or accessed to better understand a scientific concept being investigated.

Scientific texts

Many scientific texts, such as this textbook, can offer valuable information about conducting research. This includes information on research methods and experimental set-up, as well as background information and context that allows you to better understand the concept you are investigating.

Recording data

In addition to using the correct data-collection techniques, you must also record and organise your data in a way that is consistent and clear. Things that you should consider when recording data include:

- symbols, units and prefixes
- scale and magnification

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- indicators of measurement uncertainty
- tables, graphs and diagrams
- charts and maps
- logbooks.

Symbols, units and prefixes

Biological data often includes symbols, units and prefixes. Examples of symbols you may come across in Biology are:

- μ, the symbol for the unit "micro", meaning 10^{-6}
- Σ, a symbol used in mathematical formulae that means "the sum of"
- Δ, which means "the change in a variable".

Other symbols to become familiar with are the symbols for some chemical elements frequently referred to in Biology (e.g. C for carbon, H for hydrogen, N for nitrogen, O for oxygen). You can revise these chemical symbols using the periodic table at the back of this textbook.

Measurements recorded should include appropriate units. The base units used in the International System of Units (SI) for a range of sciences are listed in Table 3. However, other units, such as grams (g) or milligrams (mg) for mass, or degrees Celsius (°C) for temperature, can be used if these are more appropriate for what you are measuring.

TABLE 3 SI base units

Base quantity		Base unit	
Name	Symbol	Name	Symbol
time	t	second	s
length	l	metre	m
mass	m	kilogram	kg
electric current	I	ampere	A
temperature	T	Kelvin	K
amount of substance	n	mole	mol
luminous intensity	I_v	candela	cd

Prefixes are also commonly used in biological data. Common prefixes are:

- kilo-, meaning 10^3 or 1000
- mega-, meaning 10^6 or 1,000,000
- milli-, meaning 10^{-3} or 0.001
- micro-, meaning 10^{-6} or 0.000001
- nano-, meaning 10^{-9} or 0.000000001

scale
the relationship between the actual size of an object/specimen/area and how it is presented in a depiction

Scale and magnification

Where appropriate, **scale** and magnification should also be included. These details can help readers to understand and interpret the biological data. Scale describes the relationship between the actual size of an object/specimen/area and how it is displayed in a representation (e.g. a photo, diagram, drawing or model). For example, if you draw a map of a large ecosystem, you should include a scale to show how the length of your drawing corresponds to the actual length of the landscape being drawn. To do this, you could include a scale bar that shows that 2 cm (or another length) in your representation is equal to 50 metres in the landscape.

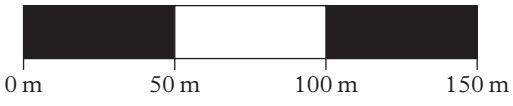


FIGURE 8 A scale bar showing that the length of one segment in the figure equals 50 metres.

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Magnification represents the size of a specimen as seen through an instrument's magnification settings compared to its actual size. Each time you produce a photomicrograph or draw what is seen in a microscope, you must include the magnification at which the specimen was viewed.

Indicators of measurement uncertainty

Indicators of measurement uncertainty are symbols or metrics used to highlight whether uncertainty exists in measurements. These indicators include error bars, standard deviation, standard error and uncertainty calculations. You will learn more about error bars, standard deviation and standard error in Lesson 1.8. Indicators of measurement uncertainty help scientists evaluate the reliability of data that has been collected.

Tables, graphs and diagrams

Raw data (measurements or observations of the dependent variable) can be difficult to interpret, and therefore should be presented in a way that is easy to analyse so conclusions can be drawn.



FIGURE 9 Cross-section of a spinal cord from a mammal, as seen under a light microscope at ×40 magnification

Tables

Tables can be used to present quantitative and qualitative data. The table has a heading, stating what the table is showing, and each column has a heading. Qualitative data may show trends, changes or variations in different conditions or over time, and so it is often useful to present such data in a table before comparing or contrasting the effects in a discussion.

table
a format for presenting data in rows and columns

A table of quantitative data consists of columns displaying the values of related variables. But these might not give an immediate or clear indication of the relationship between the variables. The table is usually the first step in recording the information and forms the basis for selecting the most appropriate graphical presentation. Various mathematical applications can be readily applied once the data is in tabular form. For example, Table 4 shows the times recorded for the heart rates of 10 participants in a medium-fitness group to return to resting rate after exercise.

TABLE 4 Time taken for heart rate to return to resting level after exercise, in participants of medium fitness

Participant	Recovery time (min)
1	6.4
2	5.2
3	1.5
4	2.1
5	4.2
6	7.5
7	2.4
8	2.6
9	2.4
10	3.0

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Graphs

graph
a pictorial representation that displays values and data in an organised way

A **graph** is a two-dimensional plot of two or more measured variables. In its simplest form, a graph consists of two axes:

- the horizontal *x*-axis, which has values called abscissae, which show the magnitude of the independent variable. This is the known quantity and is the variable whose value is chosen by the experimenter.
- the vertical *y*-axis, which carries values called ordinates, which show the magnitude of the dependent variable. This is the unknown quantity and is the variable whose values are not chosen by the experimenter.

Scientific graphs have the following features.

- The information on the graph is easily seen. This includes the heading, axis titles and numbers.
- The title is a descriptive statement that includes the independent variable and the dependent variable.
- The independent variable is on the horizontal axis (*x*-axis) and the dependent variable is on the vertical axis (*y*-axis).
- Each axis starts at zero, and the points on each axis are of equal unit size (scaled).
- Each axis is clearly labelled and includes the unit measurement.
- The data is not plotted beyond the axis.
- A pencilled point or circle is used for plotting each point.
- If there are two sets of data on a single graph, two different symbols or colours are used.

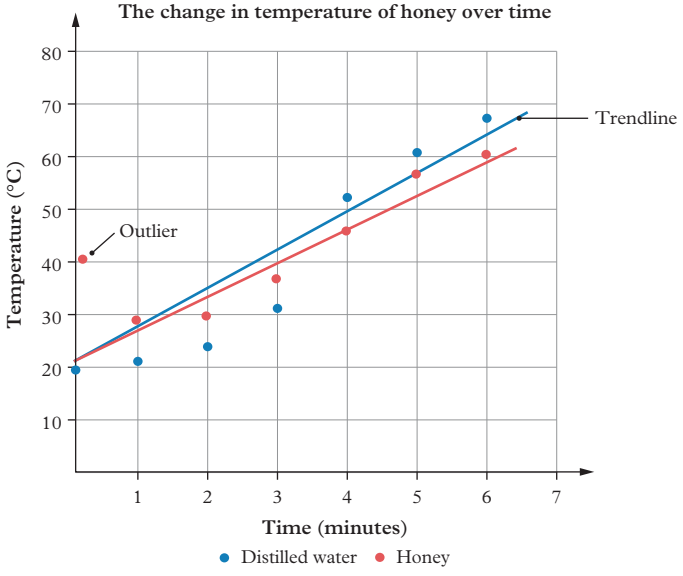


FIGURE 10 This graph shows the key features of a scientific graph.

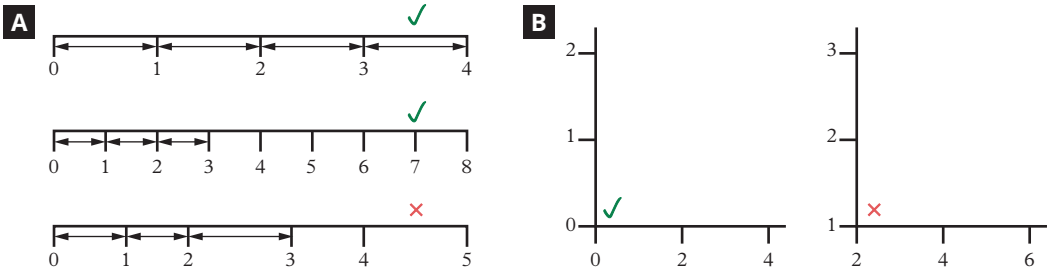


FIGURE 11 When drawing a graph, (A) use the correct scale for each axis, and (B) start each axis at zero.

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You will learn more about specific types of graphs and the forms of data they help display in Lesson 1.8.

Diagrams

A diagram is a visual aid that shows the appearance, structures or set-up of something. Diagrams can be especially useful in Biology for presenting visual data or to show the set-up of an investigation. For example, diagrams of biological systems and cells show important features, their locations, sizes and composition, which allow the viewer to better understand how the system or specimen works. Diagrams should include labels with leader lines that do not overlap, and a title.

Scientific diagrams can be used to show how an experiment was set up. Equipment in these diagrams should be drawn in a simplified way, using two-dimensional figures. When drawing the set-up of an experiment, it is important to:

- keep drawings clear and neat
- use a sharp grey lead pencil
- draw equipment from a side-on view
- avoid shading
- use a ruler for straight lines
- label equipment with leader lines that do not cross over each other.

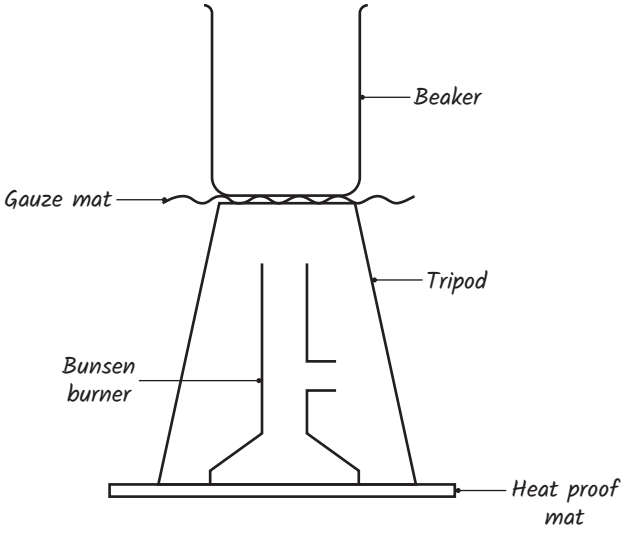


FIGURE 12 Example of a scientific diagram of equipment set-up

Charts and maps

Charts and maps can also be used to collect and present biological data. Some examples of charts are pie charts and bar charts, which help to show the frequency of a variable of interest. You will learn more about how to present data using charts and maps in Lesson 1.8. When reading charts to collect data, pay attention to labels and keys so you can understand what colours, shapes, plots or patterns represent in the chart. Maps can also be used to collect biological data. For example, the map in Figure 13 shows the distribution of sanderlings in Australia. While this map shows distribution data on sanderling species and their habitats, it can be used to generate other types of data. For example, it could be used to help categorise sanderlings as a coastal species of bird.

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FIGURE 13 Map showing the distribution of sanderlings and sanderling habitat in Australia

Logbooks

logbook
an organised record of investigation ideas, events, results and interpretations

A **logbook** is a hard copy or digital record of how you completed an investigation or experiment. Each entry in a logbook must include:

- the date and entries, in chronological order
- acknowledgment of secondary resources, expert advice and teacher assistance when this information is referred to.

Your logbook could also include the following information as you complete your investigation:

- planning notes for experiments
- a description of the activities you have carried out
- the results or data from guided activities or investigations (including outliers and/or risk identification and management)
- personal reflections made during or at the conclusion of demonstrations, activities or investigations
- any links to spreadsheet calculations or other digital records and presentations you might use
- any notes and electronic (or other) images taken on excursions, or any database extracts
- notes of any additional work completed outside class time.

A well-organised logbook that contains all this information will make it easier to complete your student experiment and research investigation.

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Check your learning 1.6

Check your learning 1.6: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** the term "population". (1 mark)
2 **Describe** each of the following sampling techniques:
   a random sampling (1 mark)
   b stratified sampling (1 mark)
   c systematic sampling. (1 mark)
3 **Identify** one advantage of using random sampling. (1 mark)
4 **Explain** why it is important for equipment to be calibrated regularly. (1 mark)
5 **Identify** three features you must include when drawing a specimen viewed under a microscope. (3 marks)
6 **Identify** the SI base units for:
   a time (1 mark)
   b mass (1 mark)
7 **Identify** one advantage of presenting data in a table. (1 mark)

Analytical processes

8 **Distinguish** between accuracy and precision. (1 mark)
9 **Compare** light microscopes and electron microscopes. (2 marks)

Knowledge utilisation

10 **Construct** a graph using the data below, which shows the average growth of a plant species over a period of six weeks. (3 marks)

Week	Average height (cm)
1	3
2	4.5
3	6
4	7.5
5	9
6	10

Lesson 1.7
Using a light microscope

Learning intentions and success criteria

oxforddigital **This practical lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.**

Lesson 1.8
Processing and analysing data

Key ideas

→ Translating information between graphical, numerical and/or algebraic forms is an important skill in Biology.
→ Mathematical techniques can be used to summarise data and help identify relevant trends, patterns, relationships, limitations and uncertainty.
→ Data can be presented and communicated in many formats.

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Learning intentions and success criteria

Science inquiry skills

This lesson provides support for the following science inquiry skills:

- translate information between graphical, numerical and/or algebraic forms, e.g.
  - units and measurement conversions
  - ratios and percentages
  - symbols and notation
  - charts and maps
- use mathematical techniques to summarise data in a way that allows for identification of relevant trends, patterns, relationships, limitations and uncertainty, e.g.
  - comparative investigations: mean, standard deviation, standard error, Student's t-test
  - correlational investigations: regression analysis, Pearson's correlation coefficient, Spearman's rank
- select and construct appropriate representations to present data and communicate findings, e.g.
  - summary tables
  - column graphs (with error bars)
  - scatterplots (with trendline and R2)
  - profile diagrams
  - scientific drawings
  - charts and maps
  - indexes and summary statistics
- analyse data to identify trends, patterns and relationships; recognising error, uncertainty and limitations of evidence

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Translating information

After data has been collected and organised in a systematic way, you can work with your data to understand what it means. Processing your data the right way can help you discover trends, patterns or the significance of the data, to help answer your research question. In this section you will learn about how to:

- translate information
- use mathematical techniques to summarise data
- select and construct appropriate representations to present data and communicate findings
- analyse data to identify trends, patterns and relationships.

Data can often be presented in different forms. In Units 1&2 Biology it is important to be able to translate information between graphical, numerical and/or algebraic forms. This may include unit and measurement conversions, ratios and percentages, symbols and notation, and charts and maps.

Units and measurement conversions

In Biology, the measurements used might need to be converted in order to calculate results, analyse data or make comparisons. Common units used in Biology include units of length, time, mass and capacity, and volume. Figures 1 to 5 summarise how different units can be converted.

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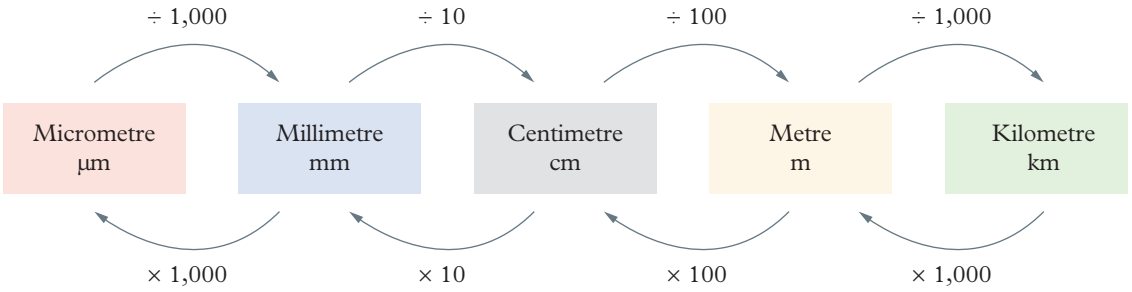


FIGURE 1 Unit conversions for length

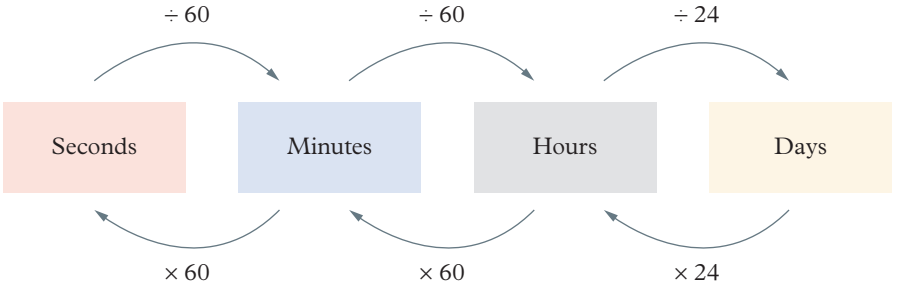


FIGURE 2 Unit conversions for time

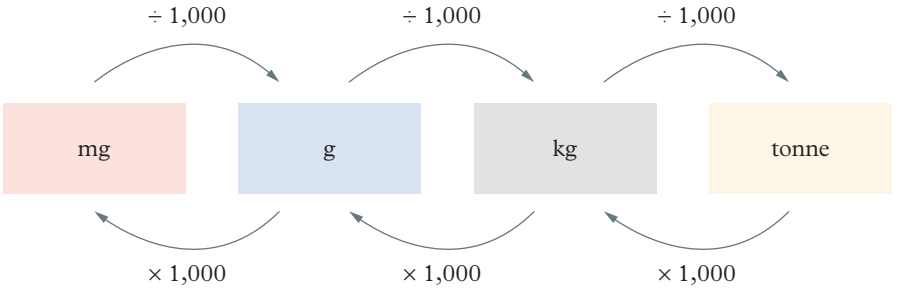


FIGURE 3 Unit conversions for mass

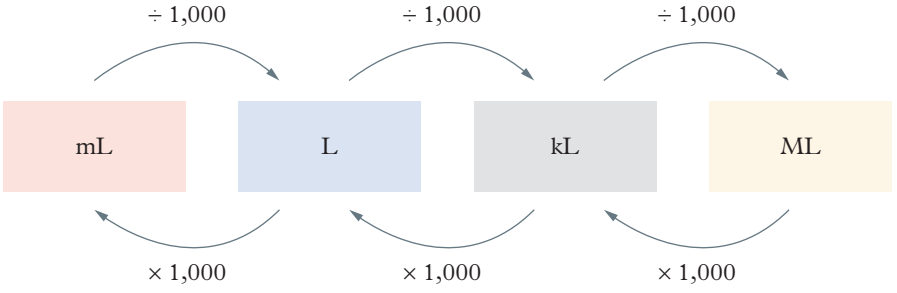


FIGURE 4 Unit conversions for capacity

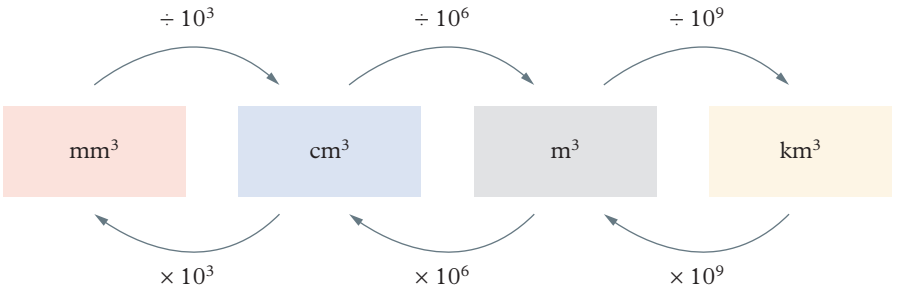


FIGURE 5 Unit conversions for volume

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Ratios and percentages

ratio
a measure that compares the magnitude of two quantities in terms of how many times one value is contained within the other

A **ratio** is a mathematical representation that shows the relationship or a comparison between two numbers. For example, if there are 1200 eucalyptus plants in a population and 200 of them show a particular trait, the ratio of eucalyptuses showing the trait to the total number of eucalyptuses in the population can be written as 200:1200. Ratios can also be simplified as fractions. So for the eucalyptus example, to convert the ratio to a fraction, divide the number of eucalyptuses with the trait by the total population ($\frac{200}{1200}$), which gives ($\frac{1}{6}$). You can use this fraction to simplify the ratio to 1:6. This means that for every six eucalyptuses in the population, there is one that displays the trait.

percentage
a number expressed as a fraction of 100

A **percentage** is the amount of something expressed as a number out of 100. To convert a ratio into a percentage, write the ratio as a fraction and multiply it by 100. For example, to write how many eucalyptuses in the population are affected by the trait as a percentage, use the following calculation:

$$\frac{1}{6} \times 100 = 16.66\%$$

Symbols and notation

In Units 1&2 Biology you may come across symbols used to represent information. For example, chemical equations often use chemical symbols from the periodic table to show which elements are involved and the relative amounts in which they occur in a reaction. Consider the photosynthesis reaction:

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

In this equation, the element symbols C, O and H represent carbon, oxygen and hydrogen. The subscripts indicate how many times the element occurs in each molecule, and the whole numbers in front of molecules indicate how many molecules there are. From this representation you can deduce that photosynthesis begins with 18 oxygen, 6 carbon and 12 hydrogen atoms.

In addition to symbols, scientists often use scientific notation to write very large or very small numbers. In scientific notation, a number between 1 and 10 is written as multiplied by a power of 10. For example, to write the number 4,523,000 using scientific notation:

1. Change the number to a decimal between 1 and 10. So: 4.523000
2. Count the number of places you moved the decimal from the original number, and note the direction you moved it. This allows you to work out the superscript for the power of 10. In this case, the decimal was moved 6 places to the left. The count is a positive value. (If the decimal had moved to 6 places to the right, it would be negative value, −6.)
3. Write the number from Step 1 as a multiplication by 10, with 10 raised to the power of the number from Step 2. So: 4.523000×10^6
4. Remove any insignificant figures (zeros that are not positioned between whole numbers) to get your final notation. So: 4.523×10^6

Charts and maps

Biological information is sometimes communicated through charts (e.g. pie charts, bar charts) and maps. Different visual forms often express different types of data. Pie charts often show a ratio of values, while maps often show distribution data. Being able to translate visual data to numeric data is an important skill. The pie chart shown in Figure 6 shows the percentages of blood types in a population. Because this chart shows blood types as percentages, this information can be translated into a ratio to help people understand the data. The percentage of type B blood is 20% and is therefore a ratio of 20:100 or 1:5. This means one in five people in this population have type B blood.

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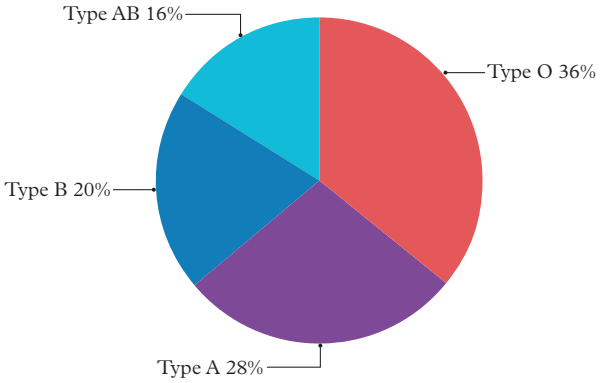


FIGURE 6 Pie chart showing percentages of blood types in a population

Maps are particularly useful in showing distribution data. For example, if you wanted to show the distribution of a species in an area, you could plot the coordinates of sightings to indicate where on a map it is likely to be found. The map in Figure 7 shows the distribution of Eastern Brown snakes in Australia. From the coordinates plotted, it is easy to see that Eastern Brown snakes are more prevalent in Victoria than they are in the Northern Territory.



FIGURE 7 Eastern Brown snake distribution in Australia

Summarising data

Once you have collected your data, you can do calculations and/or tests to process the data, to help you understand what it means. The types of calculations and tests you do will depend on the type of investigation you conducted, specifically whether you conducted a comparative investigation or a correlational investigation.

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Comparative investigations

If the data you collected has come from a comparative investigation, you may be able to use mathematical calculations such as mean, standard deviation, standard error and/or a Student's *t*-test to better understand the data.

Mean

mean
the average of a set of numbers in a data set

measure of central tendency
summary statistic that represents a central point in a data set

The **mean** is the average of all scores in a data set. It is a **measure of central tendency**, a summary statistic that focuses on a central point to represent your data set. To calculate the mean, add (sum) all the scores in the data set, then divide that number by the total number of scores.

$$\text{Mean} = \frac{\text{Sum of all scores}}{\text{Number of scores}}$$

For example, Table 1 shows data on the heights of five tomato plants. To calculate the mean height, add all the heights of the plants together and then divide this by five (the number of plants).

$$\frac{0.7 + 1.2 + 1.4 + 0.9 + 2.1}{5} = 1.26$$

The mean height of the tomato plants is 1.26 metres.

TABLE 1 Heights of five tomato plants

Tomato plant	Height (m)
A	0.7
B	1.2
C	1.4
D	0.9
E	2.1

Standard deviation

measure of variability
summary statistic that describes the spread of data in a data set

variance
a measure of how spread data is from the mean

In addition to measures of central tendency, such as mean, **measures of variability** are also useful in understanding data. Measures of variability are summary statistics that tell you how spread out the data in your data set is. **Variance** indicates how much, on average, each score differs from the mean. Because some scores are higher than the mean (have a positive difference) and some are lower than the mean (have a negative difference), they will cancel out when calculating a "mean difference". A mean variance can be determined by squaring the difference from the mean of each score. (A negative value squared results in a positive value: $-A \times -A = +A^2$). Continuing the tomato plant example, the mean height of the plants is 1.26 metres. To work out the variance of each plant, first calculate each value's difference from the mean, and then square this number.

TABLE 2 Tomato heights with difference from mean and variance

Tomato plant	Height (m)	Difference from the mean	Variance*
A	0.7	−0.56	0.31
B	1.2	−0.06	0.0036
C	1.4	+0.14	0.02
D	0.9	−0.36	0.13
E	2.1	+0.84	0.71

*Variance = the squared difference from the mean.

The mean variance can then be calculated. To do this, divide the sum of all the squared differences from the mean by the number of scores.

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$$\text{Mean variance} = \frac{\text{sum of all squared differences}}{\text{number of scores}}$$
$$= \frac{31 + 0.0036 + 0.02 + 0.13 + 0.71}{5}$$
$$= 0.23$$

The mean variance is therefore 0.23 metres. Mean variance gives an indication of the spread of the data, but because it is a squared value, it is difficult to compare with the mean score. **Standard deviation**, however, determines how different the scores are from the mean. It is calculated from the square root of the mean variance. In our example of the tomato plants, the standard deviation is $\sqrt{0.23} = 0.48$. The closer the standard deviation is to zero, the less the data is spread (variability) and the more reliable it is (i.e. the data is clustered around the mean). As the value of the standard deviation increases away from zero, the data becomes more variable and therefore less reliable.

standard deviation
a measure that describes how far, on average, scores are different from the mean

Standard error

Standard error (SE) is the standard deviation of a sample population. It measures how different the mean of the population is likely to be from the mean of a sample. Standard error can be calculated using the following formula, where SE is standard error, s is the standard deviation of the sample and n is the number of subjects in the sample:

standard error
the standard deviation of the sampling distribution of a statistic

$$\text{SE} = \frac{s}{\sqrt{n}}$$

Student's *t*-test

A **student's *t*-test** is a statistical test to determine whether the difference between the means of two groups is statistically significant (that is, the difference is not due to chance). The student's *t*-test is an unpaired *t*-test, which means it compares the means of two independent or unrelated groups (often the control and the experimental group). Every significance test has two possible hypotheses:

student's *t*-test
a statistical test used to determine whether the difference between the means of two groups is statistically significant

- the null hypothesis – that there is no significant difference between the two groups (e.g. there is no significant difference between mean weight loss before and after treatment)
- the alternative hypothesis – that there is a significant difference between the two groups (e.g. there is a significant difference between mean weight loss before and after treatment)

In a *t*-test, *t* represents the extent to which the means of the two groups are apart. It is calculated using the formula shown below, where:

- x_1 is the mean of sample 1
- s_1 is the standard deviation of sample 1
- n_1 is the sample size of sample 1
- x_2 is the mean of sample 2
- s_2 is the standard deviation of sample 2
- n_2 is the sample size of sample 2

$$t = \frac{(x_1 - x_2)}{\sqrt{\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}}}$$

Once a *t*-value has been calculated, you must determine the degrees of freedom (df) for the test. This is the sum of the sample sizes of each group minus the number of samples compared. For example, if both sample sizes were 10, df would equal 10 + 10 – 2, which gives 18. You then use a *t*-distribution table (Figure 8) to work out the critical *t*-value against the level of statistical significance:

- If your calculated *t*-value is *greater* than the critical *t*-value shown in the table, then you reject the null hypothesis – this means the alternative hypothesis is correct, and there is a significant difference (that is, the difference is not due to chance). In the example in

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Figure 8, a *t*-value higher than 2.101 indicates that there is a significant difference between the two groups (at 0.05 significance, which is the most commonly used significance level).

- If your calculated *t*-value is *lower* than the critical *t*-value shown in the table, then you accept the null hypothesis – this means the alternative hypothesis is incorrect, and there is no significant difference (that is, any difference is due to chance). In the example in Figure 8, a *t*-value less than 2.101 indicates that there is no significant difference between the two groups.

Degrees of freedom (df)	.2	.15	.1	.05	.025	.01
11	1.363	1.548	1.796	2.201	2.593	3.106
12	1.356	1.538	1.782	2.179	2.560	3.055
13	1.350	1.530	1.771	2.160	2.533	3.012
14	1.345	1.523	1.761	2.145	2.510	2.977
15	1.341	1.517	1.753	2.131	2.490	2.947
16	1.337	1.512	1.746	2.120	2.473	2.921
17	1.333	1.508	1.740	2.110	2.458	2.898
18	1.330	1.504	1.734	2.101	2.445	2.878
19	1.328	1.500	1.729	2.093	2.433	2.861
20	1.325	1.497	1.725	2.086	2.423	2.845

FIGURE 8 A *t*-distribution table. The numbers in the row at the top are levels of significance.

Correlational investigations

If data has been collected through a correlational investigation, there are calculations that can be applied or generated to determine the type of relationship that exists between variables. These calculations include regression analysis, Pearson's correlation coefficient and Spearman's rank.

Regression analysis

Regression analysis is a statistical technique used to model the relationship between a dependent variable (*y* on a graph) and the independent variable (*x* on a graph). A main function of regression analysis is to better understand how the dependent variable changes in response to the independent variable. It uses the mathematical formula $y = a + bx$ (where *y* is the dependent variable, *x* is the independent variable, *a* is the intercept and *b* is the slope) to generate a regression line to fit the data plotted on a graph. This regression line or **line of best fit** shows the relationship between the two variables and can be used to make predictions about the data.

line of best fit
a trendline that gives an approximation of the linear relationship between two variables

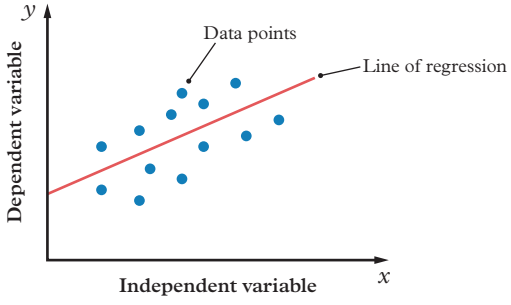


FIGURE 9 Regression analysis uses a mathematical formula to produce a regression line that shows the relationship between the IV and the DV.

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Pearson's correlation coefficient

Pearson's correlation coefficient (*r*) is a measure of the strength and direction of a linear relationship between two variables. It will generate a value that ranges from –1 to +1.

Pearson's correlation coefficient (*r*)
a measure of the strength of the linear relationship between two continuous variables

- An *r* value of +1 indicates a perfect positive correlation (when one variable increases by one unit, the other also increases by one unit).
- An *r* value of –1 indicates a perfect negative correlation (when one variable increases by one unit, the other variable decreases by one unit).
- An *r* value of 0 indicates that no relationship exists between the two variables.

It is important to remember that correlation does not equal causation. This means that if two variables happen to show a statistical relationship (correlation), it does not confirm that a change in one variable truly causes the change in the other variable.

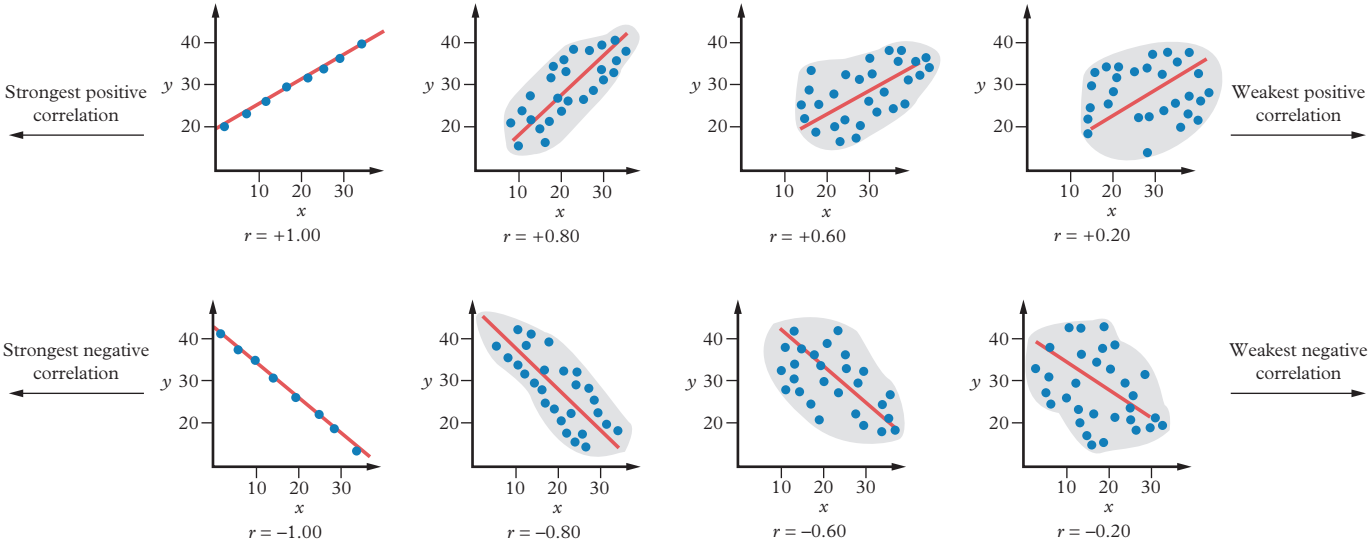


FIGURE 10 Scatterplots showing Pearson's correlation coefficient

Spearman's rank

Spearman's rank (*p*) is a measure of the strength of a relationship between two variables that often have a monotonic relationship (that is, when one variable increases, so does the other; when one variable decreases, so does the other). Like Pearson's correlation coefficient, Spearman's rank provides a value between +1 and –1. However, what is determined to be a strong relationship differs slightly between the two measures. Table 3 provides a summary of positive Spearman's rank values and the strength of the relationship they indicate. Spearman's rank is often used when:

Spearman's rank (*p*)
a measure of the strength and direction of a monotonic relationship between two variables

- the data does not meet the assumptions of the Pearson's correlation coefficient
- the relationship is not linear, meaning it does not show a straight-line relationship but there is still a clear relationship between variables (e.g. Figure 11)
- ordinal data (categorical data that have a set order or scale) is included in the data set
- outliers are present in the data set.

TABLE 3 Spearman's rank values

Spearman's rank (*p*)	Strength of relationship
$p = 0$	No correlation
$0 < p \leq 0.19$	Very weak relationship
$0.20 \leq p \leq 0.39$	Weak relationship
$0.40 \leq p \leq 0.59$	Moderate relationship
$0.60 \leq p \leq 0.79$	Strong relationship
$0.60 \leq p \leq 1.00$	Very strong relationship

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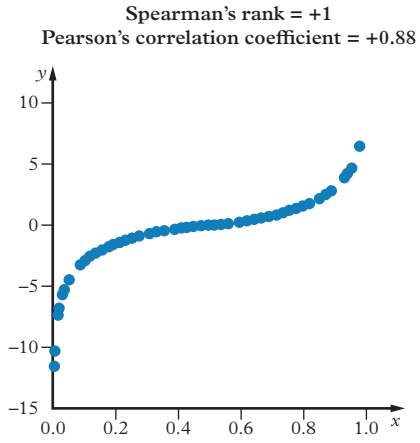


FIGURE 11 Spearman's rank is often used for data that is non-linear. In the graph, $p = +1$ while $r = +0.88$.

Presenting and communicating data

Once your data has been collected and analysed, you need to determine the best method of presenting or communicating that data to others. The best representation to use will depend on the nature of the data you have collected and the message you want to communicate.

Summary tables

Summary tables organise data into columns and rows. This can make it easy to compare and analyse values. Summary tables can also be used to present key findings or statistics you determined when analysing data. For example, if you measured 30 plants from two groups to compare their average leaf length, your raw data is likely to include all the lengths measured from both sets of plants. In your data analysis you would have worked out the average leaf length for the two sets of plants. A summary table can then present these two average values in a concise way (Table 4). The headings of your table should be clear and concise, and any units used in measurements should be included next to the appropriate heading.

TABLE 4 A summary table presenting the average leaf length of two plant species

Plant species	Average leaf length (cm)
Eucalyptus longifolia	16
Eucalyptus macrocarpa	10

Column graphs (with error bars)

Column graphs use vertical bars to present data, where each bar represents a group or category. They are particularly useful for comparing discrete (countable) data from different categories. The height or length of a rectangular column shows the value of one category of data. Column graphs can also include error bars. These are bars that show how variable or uncertain the data is for each column. Error bars may relate to different types of measures of uncertainty, including standard deviation and standard error, or they may relate to range (the difference between the maximum and minimum values in set of data). In Figure 12, from the error bars you can see that there is more uncertainty in the data related to percentage of female toads trapped with lights on than data related to the percentage of female toads trapped with lights off.

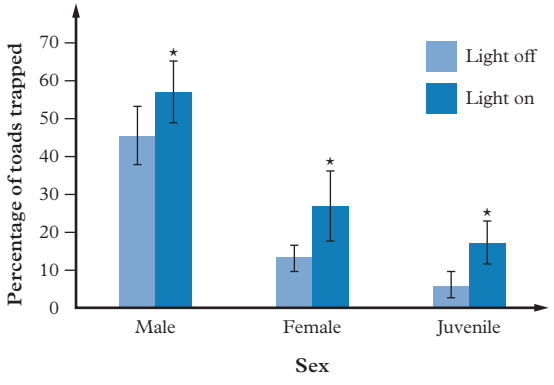


FIGURE 12 A column graph with error bars showing the percentage of male, female and juvenile toads trapped with and without lights.

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Line graphs

A **line graph** is a representation of data in which specific values of a function are plotted as dots on a coordinate plane. The adjacent pairs of dots are connected by straight lines. If the slope of the line is positive (Figure 13A), the conclusion is drawn that as the IV increases, so too does the DV – this is a positive correlation. If the slope of the line is negative (Figure 13B) as the IV increases, the dependent variable decreases – this is a negative correlation.

line graph
a graph of data linking two variables, where one variable is plotted on the *y*-axis and the other on the *x*-axis and the points are connected in a line

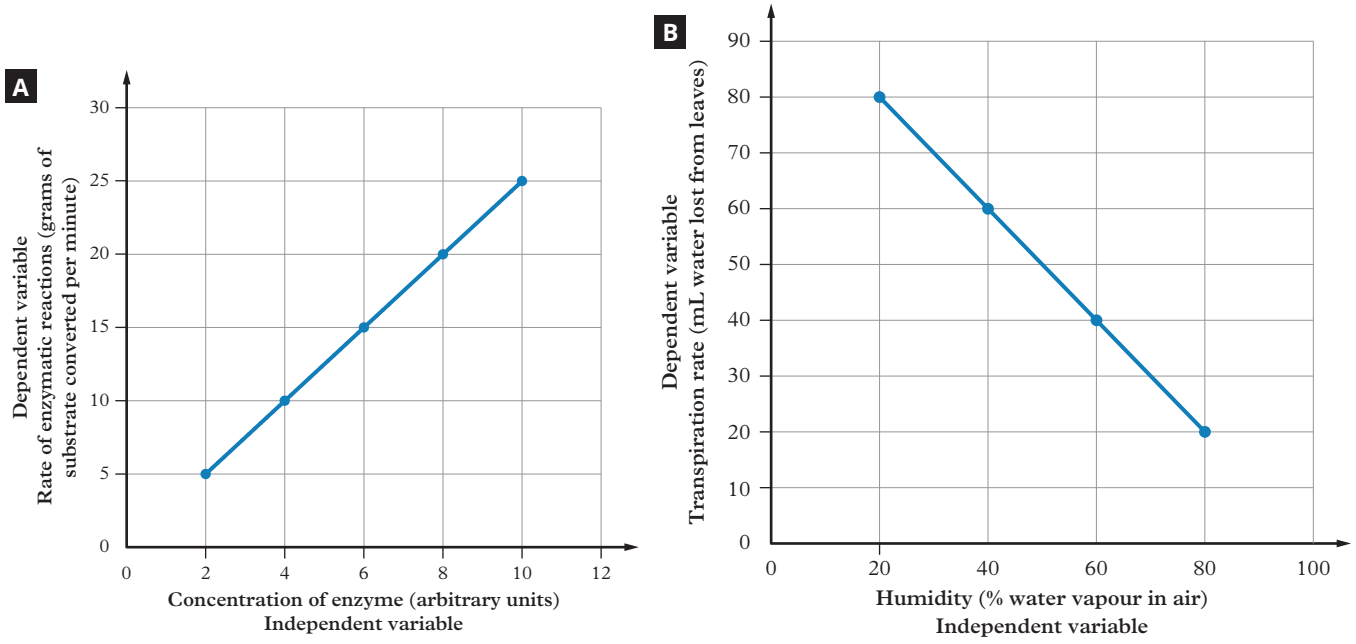


FIGURE 13 (A) The effect of enzyme concentration on the rate of conversion of a substrate: a positive correlation; (B) The effect of humidity on plant transpiration: a negative correlation

With a straight-line graph, the value of the dependent variable can be determined for a value of the independent variable that has not been measured. This can be done by extending the line *outside* the data set, at either end of the graph (**extrapolation**), or by reading between the measured points *within* the data set (**interpolation**). For example, in Figure 13A, at an enzyme concentration of 12 units, the expected reaction rate is 30 g/minute (extrapolation). At an enzyme concentration of 5 units, the reaction rate was 12.5 g/minute (interpolation).

extrapolation
an estimation of a value based on extending a known sequence of values beyond the values that are certainly known

interpolation
an estimation of a value within two known values in a sequence of values

The slope of the graph shows the mean change between the independent and dependent variables. The rate of change is calculated as the change in *y*-axis (dependent variable) values divided by change in *x*-axis (independent variable) values.

$$\text{Rate of change} = \frac{\text{change in } y\text{-axis (dependent variable) values}}{\text{change in } x\text{-axis (independent variable) values}}$$

For example, from the graph in Figure 13A, for every 2 units of enzyme concentration increase there is an increase of 5 g substrate converted per minute.

Scatterplots

Often the points plotted on a graph do not form a straight line but are scattered – this is known as a **scatterplot**. In this situation, a line of best fit (or trendline) can be drawn so that the plotted points are evenly distributed above and below the line.

The amount of scatter from the line of best fit indicates the closeness of the positive or negative relationship (correlation) between the two variables. The closer the points are to the line of best fit, the stronger the correlation between the variables.

scatterplot
a graph in which the values of two variables are plotted along two axes, the pattern of the resulting points revealing whether a relationship (correlation) exists

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When the points are so scattered that a line of best fit cannot be drawn, there is no correlation between the two variables.

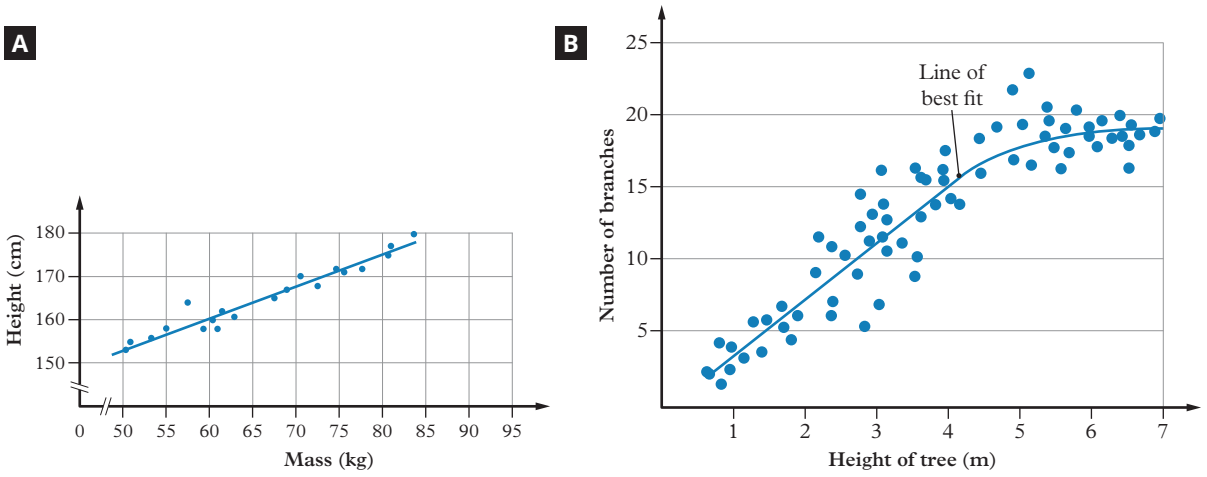


FIGURE 14 Lines of best fit on a scatterplot: (A) mass versus height of 20 sixteen-year-old males; (B) gum tree height versus number of branches over 3 cm in diameter

Indexes and summary statistics

index
a composite measure that summarises and compares multiple variables and presents these factors as a single number

summary statistic
a value that provides a summary of a data set

An **index** is a numeric, composite measure of multiple variables. It combines multiple variables from complex data sets into a single number that can summarise a general trend or state, based on different biological observations, conditions or processes. For example, a biodiversity index measures the variety and abundance of species in a locality. Biodiversity indices can be used to assess the health of ecosystems and compare changes in the overall health of ecosystems at different points in time. A **summary statistic** is a numeric value that summarises the main features of a data set. Examples of summary statistics are measures of central tendency (e.g. mean, median, mode) and measures of dispersion (e.g. range, variance, standard deviation). Presenting the summary statistics of key data can be effective in providing a snapshot of your findings to others.

Other methods of presenting data

Other methods of presenting data include:

- scientific drawings – for example, showing the structure of a cell you have observed under a microscope. Information on how to use scientific drawings can be found in Lesson 1.6.
- charts and maps – for example, using a pie chart to show the percentages of blood groups in a population, or plotting the distribution of disease on a map. For more information on charts and maps, refer to Lesson 1.6.
- profile diagrams – visual representations that show the vertical distribution of different ecological or environmental factors in an area. You will learn more about profile diagrams in Units 3 and 4.

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Analysing data

Once you have collected, processed and presented your data in its most useful representation you can analyse the data to identify trends, patterns and relationships, and recognise error and uncertainty. When analysing data, you may also become aware of limitations in the evidence collected.

Limitations

Limitations are factors that may affect the reliability or validity of findings from research. Limitations generally relate to the investigation methods used or the external environment in which the investigation was conducted (e.g. methods used, limited funding, time constraints, sampling constraints, ethical considerations). Limitations are often outside the control of the researcher. They are not the same as extraneous variables or confounding factors. They may result in an extraneous or confounding factor existing within the study. For example, in a study examining the relationship between exercise and sleep duration, a limitation could be the inability to control for participants' dietary habits, which could introduce an extraneous variable that affects participants' sleep, independent of exercise. If any limitations in an investigation are identified, then recommendations should be suggested to negate the limitation in future. This might include suggesting improvements to the investigation methods or identifying whether further research needs to be conducted.

limitation
a factor or condition that can affect the validity and/or reliability of results

Check your learning 1.8

Check your learning 1.8: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the new measurements for:
   - **a** 360 millimetres converted to metres (1 mark)
   - **b** 3.6 minutes converted to seconds (1 mark)
   - **c** 760 millilitres converted to litres. (1 mark)

2 In a plot of 40 wattle trees, only 8 wattles are flowering.
   - **a** **Determine** the ratio of flowering wattles to non-flowering wattles. (1 mark)
   - **b** **Calculate** the percentage of wattle trees that are flowering. (1 mark)

3 **Identify** one example of data that may be beneficial when presented on a map. (1 mark)

4 The heights of students in a friendship group are: 170 cm, 148 cm, 150 cm, 180 cm and 136 cm.
   - **a** **Calculate** the mean height. (1 mark)
   - **b** **Calculate** the mean variance. (1 mark)
   - **c** **Calculate** the standard deviation. (1 mark)
   - **d** **Calculate** the standard error. (1 mark)

Analytical processes

5 **Contrast** the terms "positive correlation" and "negative correlation". (1 mark)

6 **Compare** Pearson's correlation coefficient with Spearman's rank. (2 marks)

7 **Distinguish** between interpolation and extrapolation. (1 mark)

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Lesson 1.9
Evaluating evidence

Key ideas

- → Data and reasoning can be used to discuss and evaluate the validity and reliability of evidence.
- → Sources of information should be evaluated before being used to support scientific research.
- → If limitations or uncertainty in data have been identified, the researcher should suggest how these can be minimised in future research.
- → Peer review is a process that ensures the work of research scientists is evaluated and of high quality prior to publication.

Learning intentions and success criteria

Science inquiry skills

This lesson provides support for the following science inquiry skills:

- use data and reasoning to discuss and evaluate the validity and reliability of evidence, e.g.
  - discuss ways in which measurement error, instrumental uncertainty, the nature of the procedure, sample size or other factors influence uncertainty and limitations in the data
  - evaluate information sources and compare ideas, information and opinions presented within and between texts, considering aspects such as acceptance, bias, status, appropriateness and reasonableness
  - compare findings to theoretical models or expected values
- suggest improvements and extensions to minimise uncertainty, address limitations and improve the overall quality of evidence
- appreciate the role of peer review in scientific research.

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Evaluating the validity and reliability of evidence

evidence
data, observations or facts obtained from research

Evidence is information or data about a concept that has been systematically collected and can be used to form conclusions. Evaluating evidence is an important science inquiry skill in QCE Biology. Evaluating the evidence that has been used in an investigation should be done before conclusions are draw about the data. In a scientific report, evaluation of the evidence and suggested improvements are typically included in the discussion section. To evaluate evidence, you should consider how measurement error, instrumental uncertainty, the nature of the procedure, the sample size and other factors may influence the level of uncertainty and limitations of the data. Table 1 provides some guidance to help you evaluate evidence based on these factors.

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TABLE 1 Factors to consider and questions to ask when evaluating evidence

Factor to evaluate	Example of questions to ask to evaluate evidence	Impact
Measurement error	Were there random errors in the data?	Random errors reduce the precision of data.
	Were there systematic errors in the data?	Systematic errors reduce the accuracy of data.
Instrument uncertainty	Was the equipment calibrated before being used in the investigation?	Uncalibrated equipment may lead to incorrect readings or may introduce systematic errors into the data set.
Nature of the procedure	Were experimental procedures followed in a systematic way?	Variations in collection methods can result in variability in data.
Sample size	Was the sample size large enough?	A small sample size may not provide an accurate representation of the population of interest, and may also increase the effect of outliers skewing results.

Comparing findings to theoretical models or expected values

Another component of evaluating evidence is to compare the results obtained against biological models, or to compare the results against expected values. If the findings align with what is understood by biological models or with expected values, you can be more confident in the investigation methods and the conclusions drawn. If the findings contradict a theoretical model or deviate from expected values, it could indicate flaws in the investigation design or the hypothesis proposed.



FIGURE 1 To evaluate evidence, take a close look at the results and the investigation methods.

Evaluating information, ideas and opinions

Another important science inquiry skill is the ability to evaluate information sources and compare ideas, information and opinions presented within and between texts, considering aspects such as acceptance, bias, status, appropriateness and reasonableness. An important part of evaluating information from sources is the ability to distinguish between **scientific ideas** and **non-scientific ideas**.

Scientific ideas are ideas that have been acquired, refined or supported by the scientific method (e.g. the theory of evolution, which is based on years of scientific research). Non-scientific ideas are ideas that have been established by techniques that do not follow the scientific method or are not supported by the scientific method (e.g. horoscopes are not supported by scientific evidence). Being able to distinguish between scientific ideas and non-scientific ideas will help you better evaluate information from different types of sources.



FIGURE 2 Predicting the future using tarot cards is a non-scientific idea.

scientific idea
an idea or theory that is based on empirical evidence and has been tested or supported by the scientific method

non-scientific idea
an idea or theory that is not based on empirical evidence and has not been tested or supported by the scientific method

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Sources of information

Many sources of information can be used to help conduct research or understand the findings of research. Understanding the strengths and weaknesses of different sources of scientific information can help you evaluate the credibility of the information, assess claims, make informed decisions and communicate effectively. Table 2 outlines some common sources of information and their strengths and weaknesses.

TABLE 2 Sources of information and their strengths and weaknesses

Source	Description	Example	Strengths	Weaknesses
Journal articles	Scholarly papers published in academic journals that present original research findings, theories or reviews	A paper published in *The Journal of Infectious Diseases* that outlines a treatment for Ebola virus	• Provides detailed information about research methods, results and conclusions • Undergoes peer review by experts in the field	• Can be highly technical and difficult for non-experts to understand • Can take a long time to publish • May not be accessible to the public
Mass media communications	News articles or broadcasts that present information to a wide audience	A news segment on the ABC about a study on the impact of bushfires on wildlife populations	• Reaches a large audience • Can raise awareness of scientific issues	• May oversimplify complex scientific concepts or exaggerate findings for dramatic effect • May not provide sufficient context or detail
Opinions	Personal views or beliefs on topics	A TikTok video by a fitness influencer discussing a diet plan to improve muscle gain	• Can provide different perspectives on scientific issues • Can be accessible to the public	• May not be based on scientific evidence • Can be biased or influenced by personal beliefs or interests
Policy documents	Documents created by governments or organisations that outline plans or guidelines related to an issue	The *Environment Protection and Biodiversity Conservation Act*	• Can influence public policy and decision-making • Can provide a framework for addressing scientific issues	• May not be based on the most up-to-date scientific research • Can be influenced by political or economic interests
Reports in the public domain	Documents created by researchers or organisations that are publicly available and provide information about issues	Suicide Prevention Australia's annual report	• Can provide accessible information about scientific issues to the public • Can highlight areas for further research or action	• May not undergo the same level of scrutiny as peer-reviewed journal articles • May be biased or influenced by the interests of the organisation it was produced by

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FIGURE 3 Mass media communications can reach a large audience.

Factors to consider when evaluating information

Not all information is reliable or written by experts. You need to be careful that you only refer to data and research that is credible. To evaluate the reliability of a source, consider the following factors:

- acceptance – the quality of the research as judged by major science journals. Research papers with high acceptance usually use high-quality methods, descriptive or qualitative analytical methods, and a large sample size, and they disclose any funding sources. Acceptance by a well-respected journal is evidence of reliability.
- bias – the tendency to present unbalanced consideration of a question that encourages one outcome or answer over others. As some degree of bias is nearly always present in a published study, also consider how bias might influence the study's conclusions. Internal bias could come from poor study design, implementation and data analysis that favours one side. External bias happens when the findings are generalised to other groups or populations without justification.
- status – how well a source is regarded by the community. This could range from generally reliable in its areas of expertise, to marginally reliable, generally unreliable, misleading or even blacklisted. Look for sources of high status.
- appropriateness – how well a source is suited to a particular purpose. In our case, appropriate sources would be scholarly, peer-reviewed articles and books. Less appropriate sources would be magazine articles and newspaper articles from well-established companies.
- reasonableness – whether the solutions proposed are based on results, assumptions and observations that make sense. Being able to judge whether an answer is reasonable requires a deeper understanding of biology than just being able to solve a problem mechanically.

Suggesting improvements

Once you have analysed and evaluated the evidence and the investigation methods, you should suggest improvements and extensions to minimise any uncertainty or limitations identified, and/or provide suggestions that can help improve the overall quality of evidence.

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Depending on what you have identified in your evaluation of evidence, you might suggest changes to sample size, equipment used, calibration procedures, sampling techniques used, data analysis methods applied, or to specific steps in the investigation.

The role of peer review in science

peer review
the process in which experts evaluate the quality, relevance and validity of another researcher's work prior to its publication

Peer review is a process in which the work of a researcher or author is evaluated by other experts in that field. Before a scientific article can be published, it must undergo peer review to ensure that the ideas presented in the research and the investigation methods used are valid and reliable. This process helps ensure that only high-quality findings are published and is why journal articles from science publications have high credibility.

Check your learning 1.9

Check your learning 1.9: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** one strength and one weakness of each of the following sources of information:
   - **a** journal articles (2 marks)
   - **b** mass media communications (2 marks)
   - **c** opinions. (2 marks)

2 **Identify** where evaluation of evidence and suggested improvements would be included in a scientific report. (1 mark)

3 **Describe** peer review and explain why it is important in scientific research. (2 marks)

Analytical processes

4 **Distinguish** between scientific and non-scientific ideas. (2 marks)

5 Libby is evaluating a research investigation and notices that the sample used seems much smaller than what is typically used in investigations of that kind. **Evaluate** how a small sample size may affect the reliability and validity of results. (2 marks)

Lesson 1.10
Communicating scientifically

Key ideas

- → Evidence can be used to construct scientific arguments.
- → Scientific arguments and evidence can be used to draw a conclusion, which is a short summary of the findings of an investigation in response to the investigation hypothesis.
- → There are many ways to communicate scientific information.
- → Correctly acknowledging sources using referencing conventions is an important part of scientific communication.

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Science inquiry skills



Learning intentions and success criteria

This lesson provides support for the following science inquiry skills:

- select, synthesise and use evidence to construct scientific arguments and draw conclusions
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes
- acknowledge sources of information and use standard scientific referencing conventions

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA 2024)

Constructing scientific arguments

When you have evaluated evidence and found it to be valid and reliable, you can use it to construct evidence-based, scientific arguments. In doing this, you may address the following broad questions:

- What is the origin of, or who was responsible for, the experimental results, findings, evidence or raw data collected?
- Are the experimental results, findings, evidence or raw data accurate, precise, reliable and/or valid?
- What kinds of errors, inconsistencies and outliers may have affected the experimental results, findings, evidence or raw data collected?
- What kinds of background information (such as biological concepts, scientific understanding or other researched information sources) were used to link or connect the experimental results, findings, evidence or raw data to the investigation question and to the aim?
- What series of steps or procedures could be used to improve the investigation design or methodology for future trials of this scientific investigation?

Argument structure

The structure of the overall argument usually follows a pattern. Its length is determined by the number of supporting arguments addressed. One supporting argument usually corresponds to one paragraph.

Introduction (what is your overall argument/point of view?)

- Position statement (what is your hypothesis or summary of the scientific investigation?)
- List the arguments that you will make.

Explain your supporting arguments

- Supporting argument 1:
  - Point – identify your argument in a topic sentence
  - Explanation – support the argument with evidence, scientific findings, results or data
- Supporting argument 2:
  - Point – identify your argument in a topic sentence
  - Explanation – support the argument with evidence, scientific findings, results or data
- Supporting argument 3:
  - Point – identify your argument in a topic sentence
  - Explanation – support the argument with evidence, scientific findings, results or data

Reinforce your main point – "To sum up …"

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Language features

When writing a scientific argument, using the following language features will enhance your writing:

- connectives to show cause and effect – for example, "As an outcome of ...", "As a result of ...", "because ...", "consequently ..."
- scientific terminology and/or supporting figures
- supporting facts and/or quotes from experts or other researched external sources of information – for example, "A study conducted by XX found that …"
- evaluative statements – for example, "The data shows a clear trend …", "Evidence contradicts the argument that …"
- formal language – avoid personal language (e.g. I, you, he, she, we, they, me, him, her, us, them); for example, use "The hypothesis was supported", not "I proved my hypothesis".

conclusion
a summary of the findings and results obtained from an investigation

support
agree with (in relation to the hypothesis)

refute
contradict or not support (in relation to the hypothesis)

generalisability
the extent to which findings can be applied to other situations or populations

externally valid
in relation to investigation results, applicable to other settings outside the investigation

Drawing conclusions

Once you have evaluated your evidence and used this to construct your arguments, you can then develop an evidence-based **conclusion**. A conclusion is a statement or a few statements that summarise the findings of an investigation in response to the investigation hypothesis. Scientists never say that a hypothesis has been "proved" or "disproved". After all, there may be another hypothesis that explains the relationship even better than the one that was tested. Instead, the conclusion assesses whether findings either **support** or **refute** the hypothesis.

If the results or investigation methods had low validity or reliability, or did not address the research aim, then you should not draw a conclusion. **Generalisability** is the degree to which the findings of research can be applied to other situations. Most conclusions from an investigation only apply to the population of that specific study. Conclusions can only be drawn for wider populations if the investigation is **externally valid**.

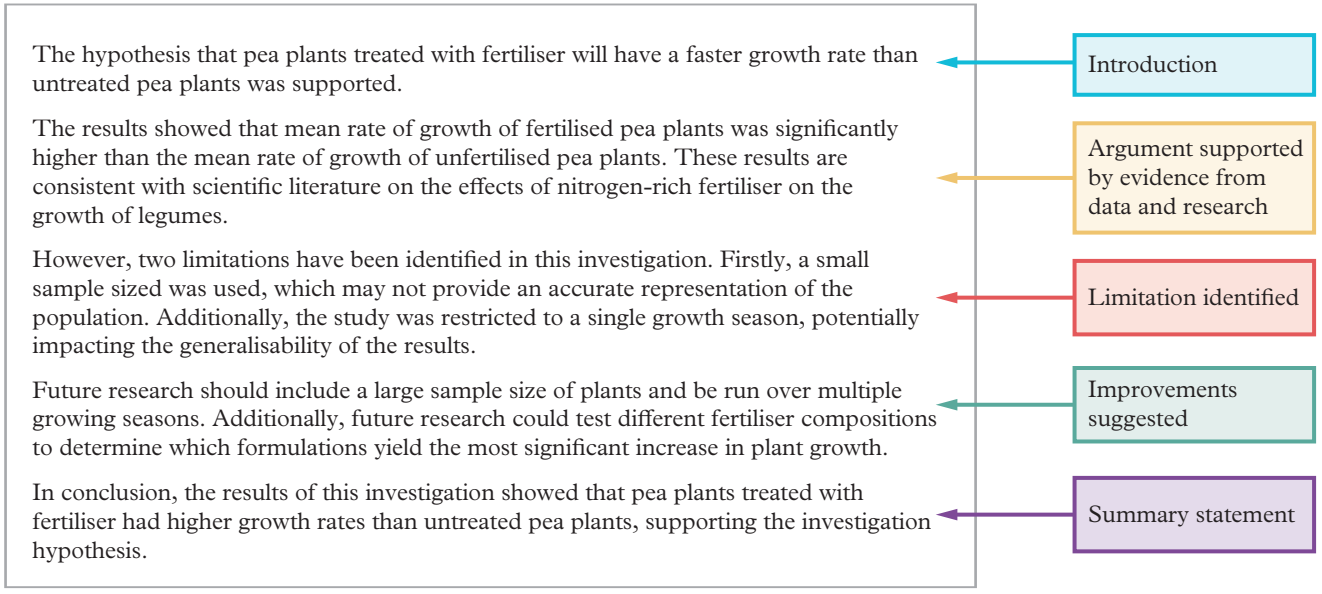


FIGURE 1 Example of using evidence to structure arguments and form a conclusion

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Communicating findings scientifically

Scientific writing has its own requirements and expectations, just as any other type of writing does. It is important to pay attention to those writing conventions.

The findings of experiments can be presented in a number of formats: as a scientific report, scientific poster, conference presentation or a journal article.

When it is time to communicate your findings, you need to plan what is to be written. Time spent in planning will save time overall and result in a better report, which is also easier to write. Think about the different sections in a report in order, and plan each section (Table 1).

TABLE 1 Components of a scientific report

Section	Purpose
Title	Outlines the problem or research question under investigation
Introduction	Indicates what the report is about. It should include: • a rationale for the research question • findings from background research • identification and justification of modifications to the initial methodology • a hypothesis for the experiment that includes the IV and DV
Context	A background paragraph that helps to give the reader the knowledge required to understand the rest of the essay
Equipment list	Lists pieces of equipment or materials needed to carry out the experiment and information about concentration and amount of substances
Risk assessment	Outlines the possible hazards involved in the experiment, as well as the measures taken to control and/or remove these hazards
Method	Lists clearly and concisely all steps involved in conducting the experiment. There should be enough detail to allow another person to conduct the same experiment and collect sufficient data. It may be necessary to include a diagram or photo of the experiment set-up
Results	Displays the collected qualitative and/or quantitative data from the experiment in a format that can be interpreted easily (e.g. table, graph, photo, descriptions, or any equations necessary)
Discussion	Includes: • an analysis of the data in relation to the research question and an identification of trends, patterns and/or relationships • an evaluation of the validity of the experiment through the identification of uncertainty and limitations of the evidence collected • suggestions for improvements to the experimental design. Do *not* re-state the results in the discussion unless it is to analyse or interpret them in a meaningful way
Conclusion	States the findings in relation to the research question; acknowledges whether the hypothesis was supported or refuted
Bibliography	Lists all the references used in the research; may be presented in alphabetical order, using a consistent style for each entry

It is important to proofread what you have written. Look for spelling and grammatical errors. Be alert for unnecessary repetition and sentences that are too long. Strategies include proofreading from the bottom of the page and reading up one sentence at a time, or reading the report aloud. The first draft should never be the last draft.

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Tips for writing scientifically

The following tips will help you write scientifically.

- Use shorter sentences and words where possible. This will make your meaning clearer and your argument easier to follow. When there are many subordinate clauses, each winding around a meaning lost somewhere in a muddle of obscurantism and verbosity, included to make the author seem more clever and important, this often instead results in the reader becoming lost, in a maze of impenetrable text, when the sentence really needs to be split up into shorter, more digestible sentences in order to facilitate comprehension of the written text. How hard was the preceding sentence to read? Instead, keep it short, keep it simple. For example, "The aim of the present study by the author was to provide insight into …" is too wordy. It could be better written as: "The aim of the experiment was to …".
- Scientific writing avoids the first person. So don't use "I" or "We", or if you must use it, do so sparingly.
- If you are reporting the results of an experiment, use the past tense because it is a report of work that you have already carried out. Often, instructions are given in the present tense, but a lab report reports what was done. For example, "The liquid was heated to 78°C, and the temperature was measured using a thermometer".
- When discussing analysis of data, use the present tense. For example, "The mean of the results in Table 2 is 6.4 cm, which overestimates the actual length of the stem by 15%".
- It is never possible to prove a fact definitively. For this reason, biologists talk about evidence being *consistent with* a hypothesis, rather than *proving* the hypothesis. It is possible that the results may show that a particular hypothesis should be rejected. If so, it is fine to say that.
- In referring to work done by others, some verbs that are commonly used are "claimed", "suggested" and "demonstrated" – these are in order of increasing confidence by the writer in what has been written.
- When using a key term or an unusual abbreviation for the first time, provide a definition. Some common abbreviations do not require an explanation – examples are e.g., i.e., et al., ca. and etc. Use these abbreviations correctly.
- Don't be vague. For example, do not use "structure" when you mean "organelle". If there is a specific biological or scientific term to describe what you are referring to, then you should use it.
- Always report numbers with their associated units. Consider using either scientific notation for very small or very large numbers, or a unit with an appropriate prefix. For example, 0.000045 grams is better written as 4.5×10^{-5} g or 45 µg.
- Pictures, graphs, equations, biological structures and reactions can all play an important part in communicating meaning in a scientific essay. These should be referred to in the main part of the text by a figure number. For example, "Reaction rate levelled off after 1 minute, as shown in Figure 1".
- In an essay or a report, where you are relying on the work of others, use references to indicate this. Your teacher will advise you on the precise format to use. One method is to put the surname of the author(s) and the year of the publication in brackets; for example (Smith and Jones, 2019). Another method is to insert a superscript number at the end of the relevant sentence or phrase. The full details of the source are provided in a references section (or bibliography) at the end of the essay or report. These details should include the authors' names and enough details for readers to find them for

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themselves. There are various free online and downloadable tools to help you keep track of references and to create a properly formatted bibliography (e.g. Zotero, Citation Machine). However, even though these tools will do much of the work, you still need to check the end result and proofread it, particularly when it comes to consistency in references.

Referencing

An important part of communicating in science is acknowledging the sources of information you have used to obtain and make sense of your findings. Correct acknowledgement of where you have sourced or collected data from is very important. When acknowledgement is not given, it can appear as if you are trying to pass off the work of other people as your own. This is called plagiarism.

There are many referencing styles that can be used to acknowledge sources. You should always check your assessment details to see whether a particular style of referencing is required. If not, two common referencing styles used in science are:

- Harvard style referencing
- APA (American Psychological Association) referencing.

Whichever style you select, make sure you stick to it and only use one style consistently – do not mix and match different referencing styles.

in-text references references that appear in the flow of body text; also known as citations

bibliography a list of all references used

In-text references are used each time you write about, refer to or quote the work of others in the body text of your response. These references are placed next to, or within, the flow of text or information in your response that has come from an external source. A final reference list or **bibliography** should be included at the end of every scientific report. This is the full list of sources you have used to conduct your research. Each referencing style has specific conventions for the way in which in-text references and references lists are presented. Different sources of information (e.g. a website versus a book) can have slightly different conventions in one referencing style. Many universities have online referencing guides that explain the conventions used in different reference styles. An example of APA style for an in-text reference and the corresponding entry in the references list is shown in Figures 2 and 3.

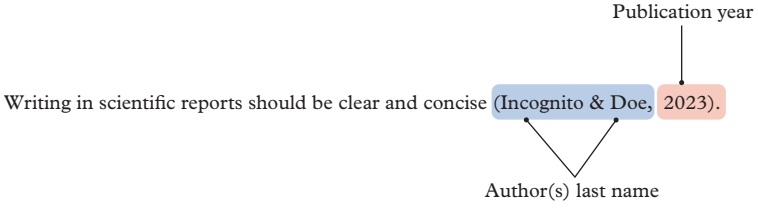


FIGURE 2 Example of an in-text reference from a journal article using APA 7 style

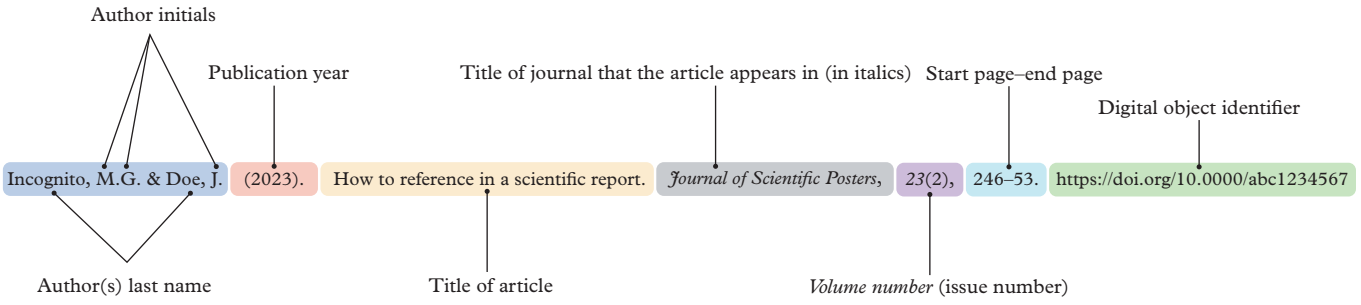


FIGURE 3 How to list the referenced journal article from Figure 2 in a references list using APA 7 style

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Check your learning 1.10

Check your learning 1.10: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** which section of a scientific report features the following:
   - **a** the hypothesis (1 mark)
   - **b** interpretation of results (1 mark)
   - **c** suggested improvements that could be made to the investigation (1 mark)
   - **d** a statement explaining whether the hypothesis was supported or refuted. (1 mark)

2 **Describe** how scientific writing differs in style from other kinds of writing. (1 mark)

3 **Explain** the purpose of a list of references at the end of a scientific report or essay. (1 mark)

Analytical processes

4 For each of the following statements, **identify** how the statement has not adhered to scientific writing conventions and **propose** how the statement could be rewritten to be scientific.
   - **a** "We hypothesised that tomato plants treated with fertiliser would have a faster rate of growth compared to untreated tomato plants." (2 marks)
   - **b** "The results of the experiment proved the hypothesis." (2 marks)

Lesson 1.11
Preparing for your data test

Key ideas

→ The data test is an assessment that gets you to apply understanding, analyse data and interpret evidence.

→ You can prepare for your data test by completing practical work, skill drills and data drills.

Learning intentions and success criteria

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Lesson 1.12
Conducting your student experiment

Key ideas

→ Your student experiment requires you to modify an experiment and address your own related hypothesis or question.

→ You will research and plan your experiment, analyse, interpret and evaluate your evidence, and communicate your findings.



Learning intentions and success criteria



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Lesson 1.13
Conducting your research investigation

Key ideas

→ There are two parts to the research investigation: obtaining secondary evidence for your research question through scientifically credible sources and then, based on the research you have conducted, reaching a justified conclusion about whether your findings support the claim.



Learning intentions and success criteria



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Lesson 1.14
Preparing for your exams

Key ideas

→ There are a range of habits you can practise to maximise your success in exams.

→ Cognitive verbs tell you what information you need to provide in your answer to a question.



Learning intentions and success criteria



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MODULE 1

Lesson 1.15
Review: Biology toolkit

Summary

1.1
- Biology is the study of living organisms.
- Studying Biology can lead to a diverse range of career pathways.
- QCE Biology is divided into units and topics.
- The science inquiry skills and their application are important for success in QCE Biology.

1.2
- First Nations peoples are the traditional custodians of the land we know now as Australia.
- First Nations peoples have longstanding scientific knowledge.
- Correctly acknowledging cultural and/or language groups, rejecting deficit discourse, avoiding Eurocentrism and critically evaluating sources of information can help you to respectfully engage with First Nations perspectives in QCE Biology.

1.3
- A hypothesis is a statement that attempts to answer a question raised by observations and can be tested by experimentation.
- The scientific method is a way of testing a hypothesis through controlled experimentation.

1.4
- Primary data is data you collect firsthand; secondary data is data collected by someone else.
- There are many different types of investigations you can run to collect data.

1.5
- Before conducting research, scientists must consider whether the investigation is safe and ethical, and the potential impacts it might have on the environment.

1.6
- There are many ways to collect primary and secondary data for an investigation.
- Sampling is way to select subjects for an investigation. Common sampling techniques are random sampling, systematic sampling and stratified sampling.
- Microscopy techniques are important in biological science.
- Tools such as information and communication technology, scientific texts, databases and online sources can be valuable in generating primary and/or collating secondary data for an investigation.
- Data collected for an investigation should be systematically recorded.

1.7
- Practical lesson: Using a light microscope

1.8
- Translating information between graphical, numerical and/or algebraic forms is an important skill in Biology.
- Mathematical techniques can be used to summarise data and help identify relevant trends, patterns, relationships, limitations and uncertainty.
- Data can be presented and communicated in many formats.

1.9
- Data and reasoning can be used to discuss and evaluate the validity and reliability of evidence.
- Sources of information should be evaluated before being used to support scientific research.
- If limitations or uncertainty in data have been identified, the researcher should suggest how these can be minimised in future research.
- Peer review is a process that ensures the work of research scientists is evaluated and of high quality prior to publication.

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1.10
- Evidence can be used to construct scientific arguments.
- Scientific arguments and evidence can be used to a draw conclusion, which is a short summary of the findings of an investigation in response to the investigation hypothesis.
- There are many ways to communicate scientific information.
- Correctly acknowledging sources using referencing conventions is an important part of scientific communication.

1.11
- The data test is an assessment that gets you to apply understanding, analyse data and interpret evidence.
- You can prepare for your data test by completing practical work, skill drills and data drills.

1.12
- Your student experiment requires you to modify an experiment you have conducted in Units 1 and 2 to address your own related hypothesis or question.
- You will research and plan your experiment, analyse, interpret and evaluate your evidence, and communicate your findings.

1.13
- There are two parts to the research investigation: obtaining secondary evidence for your research question through scientifically credible sources and then, based on the research you have conducted, reaching a justified conclusion about the whether your findings support the claim.

1.14
- There are a range of habits you can practise to maximise your success in exams.
- Cognitive verbs tell you what information you need to provide in your answer to a question.

Review questions 1.15A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 "Koalas are adapted to their environment." This statement communicates that:

A due to features that they possess, koalas are able to survive in most environments.

B due to features that they possess, koalas are well suited to the environment in which they are naturally found.

C koalas developed special features that they needed in order to survive in their environment.

D koalas are able to develop features that make them better suited to the environment should the need arise.

2 Which of the following statements best describes the relationship between a hypothesis and an experiment?

A The results of an experiment may support a hypothesis.

B An experiment is designed to show whether a hypothesis is supported or not.

C The results of an experiment are needed for a hypothesis to be formed.

D A hypothesis cannot be formed unless experimental evidence is available.

Use the following information to answer questions 3 and 4.

A biologist is interested in a certain chemical compound (compound X) that might be used to promote the growth of plants.

To test the effect of compound X on plant growth, the biologist planted three groups of plants of the same species (50 plants in each group) and watered each plant with the same weighted quantity of rainwater or solution of rainwater and compound X. The table summarises the results of the investigation.

Group	Watered with	No. dead plants	No. surviving plants	Average weight of surviving plants (g)
I	Rainwater	3	47	310
II	1% compound X in rainwater	12	38	420
III	2% compound X in rainwater	26	24	410

3 Which of the following could explain the difference in average weight of the surviving plants in groups I and II?

A Compound X stimulated the growth of some plants.

B Compound X caused the death of some plants, which may have been the smaller ones.

C Compound X caused the death of some plants, which left more room for the rest to grow.

D All of the above could explain it.

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4 In considering the causes of death of the plants in all groups, which of the following seems the most reasonable interpretation?

A Compound X can kill plants but the lethal concentration (that required to kill) varies with individual plants.

B The deaths could not have been due to compound X because some group I plants died.

C Compound X caused the death of plants in groups II and III, but the amount applied to different plants must have varied.

D Twice as many plants died in group III as in group II because they were given twice as much compound X.

5 A researcher is recording the length of gum leaves on a eucalyptus branch. The lengths of the leaves are as follows: 10.3 cm, 9.8 cm, 10.4 cm, 7.8 cm, 9.3 cm and 7.6 cm. What is the mean length of gum leaves on the branch?

A 9.2 cm **B** 9.6 cm

C 9.2 mm **D** 9.6 mm

6 Which of the following r values indicates the strongest correlation?

A +0.8 **B** +0.7 **C** −0.9 **D** −0.6

7 Which of the following investigation types involves a researcher manipulating variables to determine whether a cause–effect relationship exists?

A case study

B descriptive investigation

C experimental investigation

D correlational investigation

8 Which of the following statements is correct?

A Random errors reduce the precision of data, while systematic errors reduce the accuracy of data.

B Random errors increase the precision of data, while systematic errors reduce the accuracy of data.

C Random errors increase the accuracy of data, while systematic errors reduce the precision of data.

D Random errors reduce the precision of data, while systematic errors increase the accuracy of data.

9 In which section of a scientific report are limitations identified and suggested improvements recommended?

A Introduction **B** Conclusion

C Method **D** Discussion

10 Which of the following summary statistics relates to the spread of data around the mean?

A range **B** variance

C mean **D** standard deviation

Review questions 1.15B Short answer

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

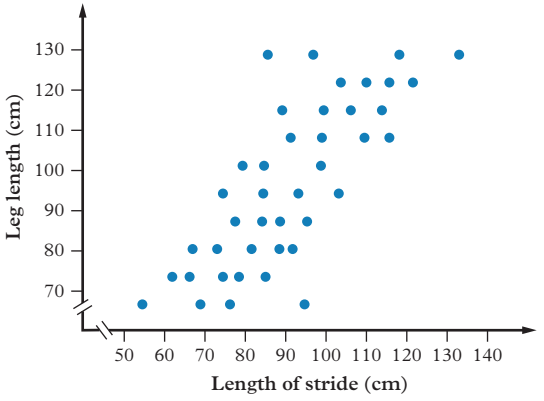
11 **Describe** the scientific method in three steps. (3 marks)

12 **Explain** the importance of a logbook during a student experiment. (1 mark)

13 **Define** validity. (1 mark)

Analytical processes

14 A student noticed that there seemed to be a direct relationship (correlation) between the length of a person's leg (measured in centimetres from the hip joint to the base of the ankle) and the length of their stride. To check the accuracy of this observation, the student measured the leg length and stride of several people. A sand area with a base board was set up. The subjects aligned the tips of their toes with this board and stepped into the sand. Length of stride was measured as the distance from the base board to the back of the heel marking in the sand. The results were plotted as shown below.



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a **Deduce** what hypothesis the student was testing. (1 mark)

b **Identify** the IV and DV in the experiment. (2 marks)

c **Explain** whether this was a controlled experiment. (1 mark)

d **Determine** what scientists call the measurements shown on the graph. (1 mark)

e **Explain** why the results were presented graphically. (1 mark)

f **Determine** the range of lengths of stride recorded for people with legs 90 cm long. (1 mark)

g Divide the graph into four equal boxes to give four categories: short leg, short stride; short leg, long stride; long leg, short stride; and long leg, long stride. Count the number of people in each category. **Determine** which boxes most people fit into. (1 mark)

h **Reflect on** the hypothesis. Was it supported? (1 mark)

i **Identify** a possible extraneous variable in this experiment. (1 mark)

j **Describe** two ways this experiment could be improved to give a more accurate interpretation. (2 marks)

Knowledge utilisation

15 A student germinated 50 oat seeds. Once germinated, the height of each seedling was measured every 2 days for 26 days. The mean height of the seedlings was calculated for each set of measurements. The results are shown in the table.

Time (days)	Mean height (mm)
1	1
2	2
4	4
6	11
8	24
10	43
12	73
14	92
16	105
18	112
20	117
22	122
24	124
26	126

a **Deduce** how the student determined the mean height for each set of individual heights. (1 mark)

b **Construct** this data as a graph. (3 marks)

c **Determine** the rate of growth on:

i day 3 (1 mark)

ii day 15 (1 mark)

iii day 22. (1 mark)

d **Interpret** the data to draw a conclusion about the growth of oat seedlings over this period. (1 mark)

e **Judge** the reliability of the data. **Explain** your answer. (2 marks)

f **Predict** the mean height of the oat plants on day 28 from this data. **Explain** your answer. (2 marks)

16 When either grapes or sugar are mixed with yeast and water, fermentation can occur. This produces carbon dioxide gas and alcohol. Some yeast is naturally present on the skin of grapes.

a **Design** an experiment to find the role of grapes, sugar and yeast in the process of fermentation. (4 marks)

b Draw any equipment used and **explain** what and how outcomes will be measured to achieve consistent results. (4 marks)

A qualitative measure of the amount of carbon dioxide gas formed can be obtained by bubbling any gases emitted from the solution through limewater. Limewater turns milky in the presence of carbon dioxide – the greater the amount of carbon dioxide, the milkier the solution. If the boiling point of the final solution is measured, a quantitative measure of the % volume of alcohol can be obtained. The greater the percentage of alcohol present, the lower the boiling point. (Tables of boiling point versus % volume of alcohol are available on the internet.)

c **Predict** one extraneous variable in your design and devise a way to eliminate it. (2 marks)



Module 1 checklist: Biology toolkit



Quizlet: Revise key terms online to test your understanding

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UNIT 1

Cells and multicellular organisms

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Unit 1 overview

In Unit 1, students explore the ways biology is used to describe and explain how the structure and function of cells and their components are related to the need to exchange matter and energy with their immediate environment. An understanding of the structure and function of cells is essential to appreciate the processes vital for survival. Students investigate the structure and function of cells and multicellular organisms. They examine the structure and function of plant and animal systems at cell and tissue levels in order to analyse how they facilitate the efficient provision or removal of materials.

Unit 1 objectives

1. Describe ideas and findings about cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.
2. Apply understanding of cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.
3. Analyse data about cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.
4. Interpret evidence about cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.
5. Evaluate processes, claims and conclusions about cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.
6. Investigate phenomena associated with cells as the basis of life; exchange of nutrients and wastes; and cellular energy, gas exchange and plant physiology.

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Unit 1 Topics

Topic	Module	
Topic 1 Cells as the basis of life	**Module 2**	Cell structure
	Module 3	From cell to multicellular organism
Topic 2 Exchange of nutrients and wastes	**Module 4**	The chemicals of life
	Module 5	Transport of materials in animals
	Module 6	Exchange of nutrients and waste in animals
Topic 3 Cellular energy, gas exchange and plant physiology	**Module 7**	Cell function and energy
	Module 8	Gas exchange in humans
	Module 9	Plant physiology

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MODULE 2

Cell structure

Introduction

The basic unit of structure and function in living organisms is the cell. More complex cells contain several smaller structures that perform important functions within the cell. To survive, the cell must be physically separated from the environment and yet capable of exchanging material with it. The cell membrane forms this boundary. The efficiency of exchange decreases as cells increase in size, so there is limit to how large a cell can grow. Most cells, therefore, can be seen only when viewed through a microscope.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to cell structure before you start.

Subject matter

Science understanding

- → Compare prokaryotic and eukaryotic cells.
- → Identify key organelles and their functions, including the nucleus, mitochondria, rough ER, ribosomes, smooth ER, Golgi apparatus, lysosomes, vacuoles and chloroplasts.
- → Explain that each body system contains specialised cells and tissues that are structurally suited to function, including
  - size and shape (SA:V ratio)
  - organelle composition.
- → Describe the structure and function of the cell membrane based on the fluid mosaic model, including the role of protein channels, phospholipids, cholesterol and glycoproteins.

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- → Explain how the cell membrane regulates movement of substances into and out of the cell via
  - osmosis
  - simple diffusion
  - facilitated diffusion
  - protein-mediated active transport
  - endocytosis and exocytosis.
- → Compare active and passive transport.
- → Explain how the size of a cell is limited by surface area-to-volume ratio and rate of diffusion.
- → Interpret data from an experiment investigating the effect of surface area-to-volume ratio on the rate of diffusion.

Science inquiry

- → Compare organelle composition of different cell types using electron micrographs.
- → Investigate the effect of surface area-to-volume ratio on rate of diffusion.

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Practicals

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Lesson 2.3 Preparation and examination of wet mount specimens
Lesson 2.4 Identifying organelles from electron micrographs
Lesson 2.7 Modelling the selectively permeable membrane
Lesson 2.9 The effect of surface area-to-volume ratio on the rate of diffusion

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Lesson 2.1
The cell as the building block of life

Key ideas

- → All living things are composed of cells, the building blocks of life.
- → Unicellular organisms consist of one cell, while multicellular organisms consist of many cells.
- → Prokaryotes are unicellular organisms that do not have membrane-bound organelles.
- → Eukaryotes are organisms whose cells have membrane-bound organelles.

Learning intentions and success criteria

organism
a living thing

cell
the basic unit of life, able to perform all fundamental processes of life

unicellular
composed of a single cell

microscopic
so small that it can only be seen with a microscope

multicellular
composed of many cells

colonial
composed of many unicellular organisms joined into a cluster, where each individual cell can carry out all the functions necessary for life

cell membrane
a selectively permeable barrier that controls the movement of substances into and out of the cell

cytoplasm
cell contents not including the nucleus

Study tip

Most cells are very small in size, but there are a few notable exceptions. For example, an unfertilised emu's egg is made up of a single cell 13 cm long.

Cell structure

Every **organism** (living thing) is made up of **cells**, the basic unit of life. Cells are membrane-bound structures that perform all the processes required to sustain life. They tend to be very small (0.5–10 μ, or micrometres, in diameter, where $1\mu = 10^{-6}$ m = 1 millionth of a metre). The smallest organisms, which consist of only one cell, are called **unicellular** organisms ("uni" = one). Almost all unicellular organisms are **microscopic**. Larger organisms, which can consist of anything from two to trillions of cells working together, are called **multicellular** organisms. In multicellular organisms, different cells perform different jobs to keep the organism alive. Each cell works with, and relies on, other cells to survive.

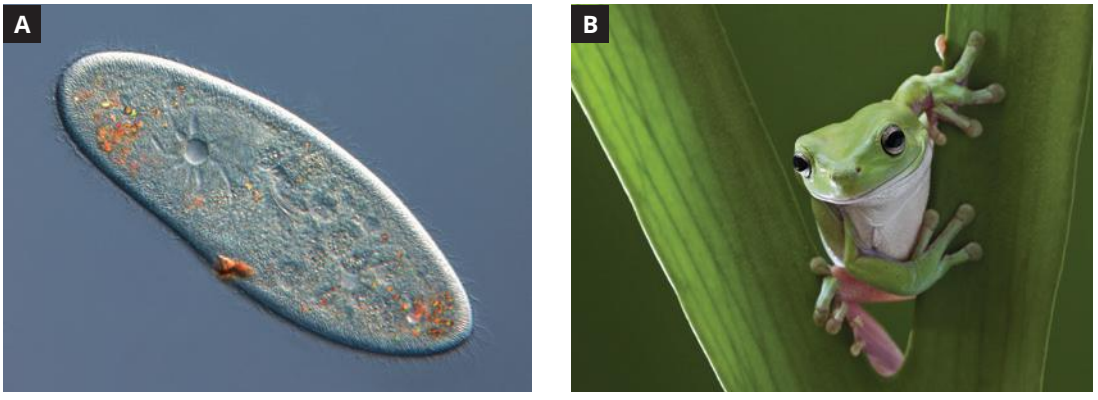


FIGURE 1 (A) A paramecium is a unicellular organism. (B) A green tree frog is a multicellular organism.

Occasionally, cells in a group can be closely associated with each other but not directly connected. These groups of cells are described as **colonial**. Colonial cells work together and divide their functions, but each cell is technically able to live independently. An example of this is the bluebottle jellyfish, which is not a single animal but, rather, a colony of four kinds of highly modified individuals (zooids) that work together to survive.



FIGURE 2 The bluebottle or Pacific man-of-war is not a single animal but a colony of four kinds of highly modified individuals (zooids).

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All the chemical reactions required for a cell to stay alive occur in the internal environment of the cell. To maintain this internal environment, the cell must be physically separated from the environment but still able to acquire nutrients and remove wastes. To enable this, all cells have the following features:

- a **cell membrane** that encases the cell and forms a boundary between the chemical reactions occurring inside the cell and the external environment that surrounds the cell
- **cytoplasm**, a liquid medium that fills the cell and holds other cellular components
- **deoxyribonucleic acid (DNA)**, a type of nucleic acid that contains all the genetic information and instructions needed for the cell to survive
- **ribosomes**, small intracellular structures that are used to create proteins.

While all cells have these structural features in common, cells are divided into two categories: **prokaryotic cells** and **eukaryotic cells**.

Prokaryotic cells

It is believed that the first life forms arose in unique environmental conditions about four billion years ago, in a process called **abiogenesis**. These first organisms were **prokaryotes**, single-celled organisms that lacked smaller membrane-bound components. These early cells consisted of a cell membrane that contained a watery mixture of organic chemicals and a nucleic acid strand. It is highly likely that there were many types of nucleic acid, each coding for slightly different proteins, and so the earliest cells would have been slightly different from each other right from the beginning. All the chemical processes required to sustain life occurred in these single cells.

Prokaryotes include all bacteria and archaea. It is theorised that they mutated and changed over billions of years into diverse types with different physical and chemical characteristics. However, all prokaryotes have the following general features:

- consist of a single cell
- small size
- contained within a semi-rigid **cell wall**
- do not contain membrane-bound **organelles**.

The DNA or genetic material of prokaryotes is usually located in an area of the cell called the **nucleoid region** in the form of a single circular **chromosome** (Figure 3). Prokaryotes do not have compartmentalisation of cell contents for specific functions; however, they do contain ribosomes scattered throughout the cytoplasm of the cell.

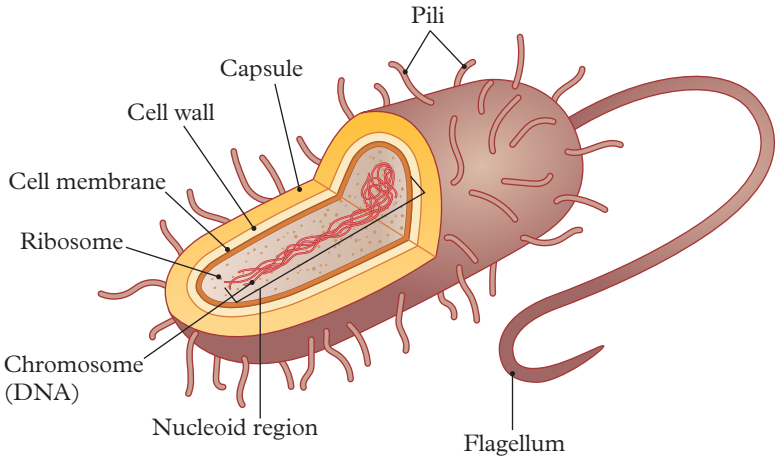


FIGURE 3 A prokaryotic cell

deoxyribonucleic acid (DNA)
a molecule found in nearly all living cells which contains the genetic information responsible for the development and function of an organism

ribosome
a complex molecular structure found in all cells which creates proteins in a process called protein synthesis

prokaryotic cell
a cell that does not contain a membrane-bound nucleus or membrane-bound organelles

eukaryotic cell
a cell that contains membrane-bound organelles

abiogenesis
the theory that living organisms formed from non-living matter

prokaryote
an organism without a membrane-bound nucleus or membrane-bound organelles

cell wall
a rigid structure surrounding plant, fungal and prokaryotic cells; provides protection and support for the cell; made up of murein (prokaryotic cells), cellulose (plant cells) or chitin (fungal cells)

organelle
a subcellular structure that has at least one specific function

nucleoid region
in prokaryotic cells, the region within the cell in which genetic material is located; not bounded by a membrane

chromosome
a thread-shaped body consisting of nucleic acid (usually DNA) and protein (except in bacteria)

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Some prokaryotes have evolved specialised features to help them survive, such as:

- a **capsule** – a sticky outer layer that protects the cell and helps it adhere to substances
- a **flagellum** – a hair-like appendage that helps the cell to move around or swim in an aqueous or liquid environment
- **pili** – small hair-like structures on the cell's surface that help the cell attach to other surfaces.

capsule
the outermost layer of a prokaryotic cell, made of polysaccharides; plays a role in adhering to surfaces, substances and other bacteria

flagellum
a whip-like extension of the cell, used in locomotion by some bacteria, protozoa and spermatozoa; plural "flagella"

pili
in many prokaryotes, small hair-like projections that are used for adhesion to surfaces, other bacteria and host cells

In addition to having different structural features, prokaryotes have also evolved to survive in specific environments. Some prokaryotes will die in the presence of oxygen, while others cannot survive without it. Some are heterotrophs (feed on other organisms), some use inorganic molecules to provide for their energy needs (chemosynthesis) and others rely on photosynthesis.

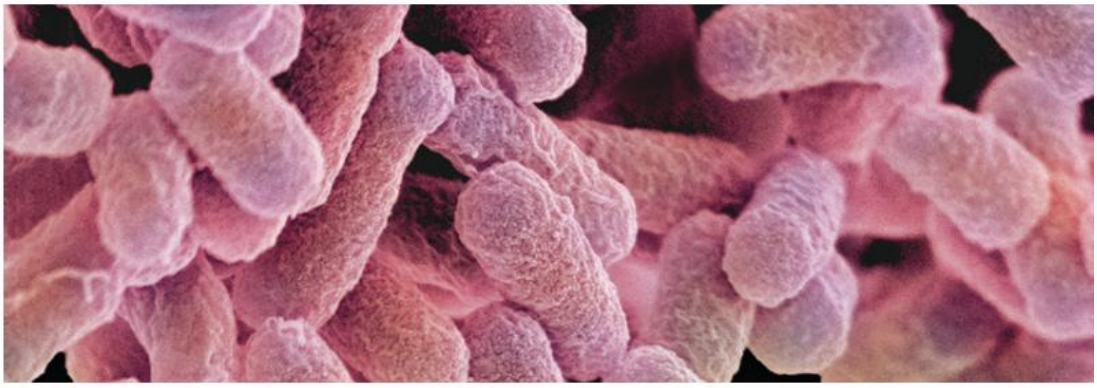


FIGURE 4 All bacterial species, such as *Escherichia coli*, pictured above, are prokaryotes.

Eukaryotic cells

For larger cells, it is more difficult and inefficient for nutrients to get to all parts of the cell, and for waste products to leave the cell. Eukaryotic cells, which are larger than prokaryotes, contain membrane-bound organelles. The DNA of eukaryotes is enclosed by a double-layered membrane, forming a **nucleus**. The cytoplasm contains membrane-bound organelles that have different functions and work together to help the cell survive. Having membrane-bound organelles has enabled eukaryotic cells to be larger in size than a typical prokaryotic cell. You will learn more about eukaryotic cell organelles in Lesson 2.2. Organisms made up of eukaryotic cells are known as **eukaryotes**. Animals, plants, protists and fungi are all examples of eukaryotes.

nucleus
control centre of the eukaryotic cell

eukaryote
an organism whose cells contain membrane-bound organelles

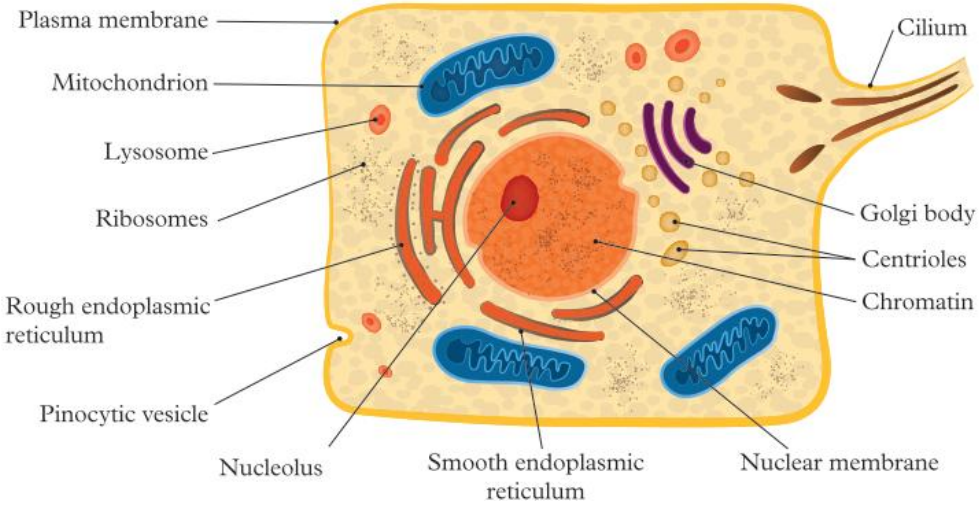


FIGURE 5 A eukaryotic animal cell

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Evolution of eukaryotic cells

One theory of the evolution of eukaryotic cells is the endosymbiotic hypothesis, in which small prokaryotic cells survived within a larger prokaryotic cell in a symbiotic relationship, later becoming the organelles of a now eukaryotic cell. Further mutations in these cells resulted in different types of single-celled eukaryotic organisms. The development of the eukaryotic cell paved the way for the evolution of the multicellular organism. Different cells could become specialised for specific functions because of the numbers and types of organelles they possessed.

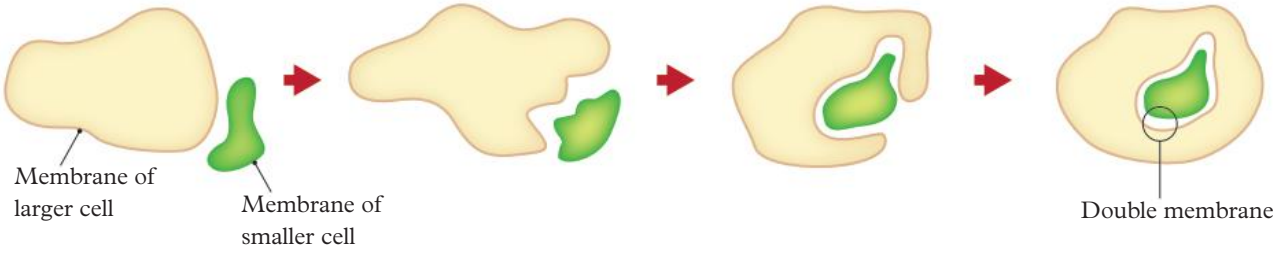


FIGURE 6 Endosymbiosis is thought to have led to the evolution of cells with organelles.

Comparing prokaryotic and eukaryotic cells

Prokaryotes are the most ancient cells. They are smaller than eukaryotic cells and have a simpler structure (Figure 7). Like plant cells, prokaryotes have a semi-rigid cell wall surrounding the cell membrane; however, in prokaryotes the cell wall is made of **murein** (a protein–carbohydrate complex). Prokaryotes also lack distinct membrane-bound organelles and a cytoskeleton. The genetic material is bound into a single circular DNA molecule floating within the cytoplasm. Smaller circular molecules of DNA, called plasmids, are not part of the prokaryote's chromosome, but can carry **antibiotic resistance** and other genetic advantages. Although many ribosomes are present in prokaryotes, they are not attached to any other structure and differ chemically from those of eukaryotes. Some bacteria have flagella. However, the flagellum is outside the cell membrane and is different in structure from those of animals.

murein
a glycoprotein (protein–carbohydrate complex) that forms the cell wall in bacteria

antibiotic resistance
the ability of bacteria to resist the effects of an antibiotic to which they were once sensitive

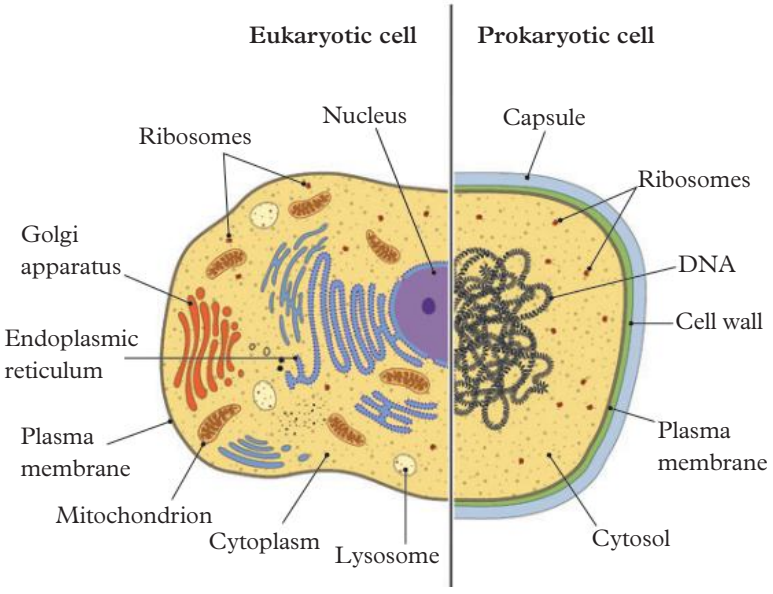


FIGURE 7 Eukaryotic and prokaryotic cell structure

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Table 1 provides a comparison of the structures in prokaryotic and eukaryotic cells.

TABLE 1 Comparison of eukaryotic and prokaryotic cells

Structure	Eukaryotic cells	Prokaryotic cells
Cell wall	Absent in animal cells, present in plant cells (cellulose) and fungal cells (chitin)	Present (murein)
Cell membrane	Present	Present
Nucleus	Surrounded by membrane	Not surrounded by membrane
Chromosomes	Multiple, composed of nucleic acid (linear DNA) and proteins	Singular, composed only of nucleic acid (circular DNA)
Ribosomes	Present	Present but are different chemically
Chloroplasts Endoplasmic reticulum Golgi apparatus Lysosomes Membrane-bound organelles Mitochondria Vacuoles	Present (chloroplasts only in plants)	Absent
Flagella	Complex, with microtubules	Simple, with no microtubules (extracellular, i.e. not enclosed by the cell membrane)

Check your learning 2.1

Check your learning 2.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** the following terms:
   - **a** cell (1 mark)
   - **b** unicellular (1 mark)
   - **c** multicellular. (1 mark)

2 **Identify** two structural features that could be used to determine whether a cell is prokaryotic or eukaryotic. (2 marks)

3 **Identify** two differences between animal cells and plant cells. (2 marks)

4 **Explain** why eukaryotic cells require specialised organelles. (1 mark)

Analytical processes

5 **Differentiate** between a prokaryote and a eukaryote. (1 mark)

Knowledge utilisation

6 **Determine** whether the following cells are prokaryotic or eukaryotic based on the descriptions given.
   - **a** The cell appears to have no membrane-bound nucleus. (1 mark)
   - **b** The cell has numerous organelles. (1 mark)
   - **c** The sample is a specialised human skin cell. (1 mark)

Lesson 2.2
Eukaryotic cell organelles

Learning intentions and success criteria

Key ideas

→ Organelles have different structures and functions.

→ Animal cells and plant cells are organised differently.

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Eukaryotic organelles

The cells of eukaryotic organisms contain membrane-bound organelles. Most of these structures are not normally visible under the light microscope but can be viewed with an electron microscope. Organelles are not scattered randomly throughout the cytoplasm. In most cells, the nucleus has a central position in the cell and the other organelles are located around the nucleus in a way that facilitates a range of cellular functions. In this lesson you will learn about the functions of organelles in eukaryotic organisms. Many organelles are found in both animal and plant cells – these include the nucleus, mitochondria, rough ER, ribosomes, smooth ER, Golgi apparatus, lysosomes and vacuoles.

Nucleus

The nucleus is the control centre of a cell. It controls cell activity through DNA, the genetic material that controls protein production and cell division. In a non-dividing cell, DNA and protein form a diffuse network of threads called **chromatin**. During cell division, chromatin condenses into chromosomes. The nucleus is surrounded by a double membrane, called the **nuclear envelope**, which has pores that allow specific molecules into and out of the nucleus. The nucleus contains the **nucleolus**, which is composed of proteins, DNA and RNA, and produces ribosomes. The **nucleoplasm** is the total contents of the nucleus.

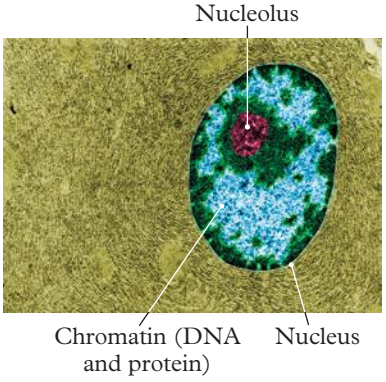


FIGURE 1 Electron micrograph of a nucleus

Mitochondria

Mitochondria (singular "mitochondrion") are the site of chemical reactions that release energy in a usable form. They are often referred to as the "powerhouse" of the cell. They are cigar-shaped organelles that are bound by a double membrane. The inner membrane is folded into cristae, which increase the surface area for attachment of enzymes and their metabolic reactions (Figure 2). The membranes enclose a fluid matrix. Mitochondria contain special mitochondrial DNA and ribosomes that control their enzyme production, and allow them to replicate. Mitochondria are crucial for the process of **cellular respiration**.

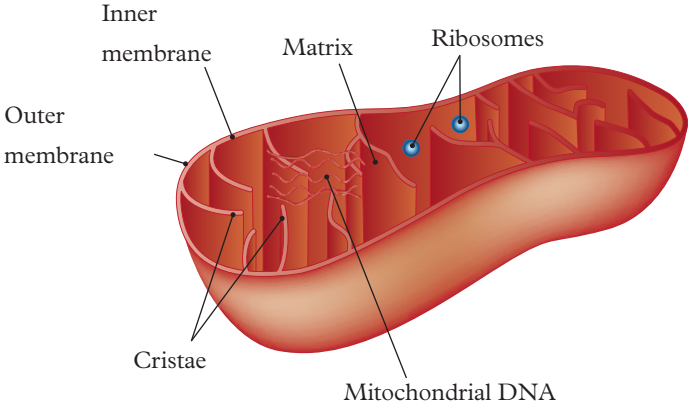


FIGURE 2 The structure of a mitochondrion

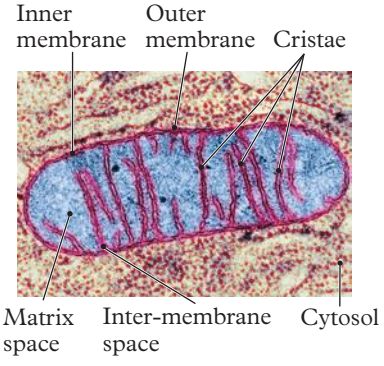


FIGURE 3 Electron micrograph of a mitochondrion

chromatin
the nucleoprotein (complex of DNA bound around proteins) of chromosomes seen as fine, dispersed threads of genetic material and found in eukaryotic cells

nuclear envelope
the membrane that encloses the nucleus and is structurally similar to the cell membrane; allows the transport of specific molecules into and out of the nucleus; must be broken down for cell division to occur

nucleolus
a spherical area within the nucleus that is the site of ribosome production; contains RNA and proteins

nucleoplasm
a protoplasm within the nuclear membrane; contains DNA, RNA and proteins; involved in control of cell activities through protein production and cell division

mitochondrion
a membrane-bound cellular organelle; has enzymes for cellular respiration on inner folded membrane (cristae), and a fluid matrix; plural "mitochondria"

cellular respiration
the breaking down of glucose in cells to release energy; may occur with oxygen (aerobic) or without oxygen (anaerobic)

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Endoplasmic reticulum

The endoplasmic reticulum is a network of flattened, membrane-bound sacs called cisternae. It is located relatively close to the nucleus of the cell, because it is primarily involved in synthesising and transporting molecules around the cell. There are two types of endoplasmic reticulum:

- **smooth endoplasmic reticulum** – responsible for the synthesis and transport of lipids and steroids
- **rough endoplasmic reticulum** – studded with ribosomes on the membrane surface to facilitate the synthesis of proteins. The transport of proteins occurs in the cisternae.

The extensive network of the endoplasmic reticulum provides a large surface area for enzyme-mediated metabolic reactions to occur.

smooth endoplasmic reticulum (smooth ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cell; lipids and steroids are produced here

rough endoplasmic reticulum (rough ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cell; proteins are synthesised on ribosomes

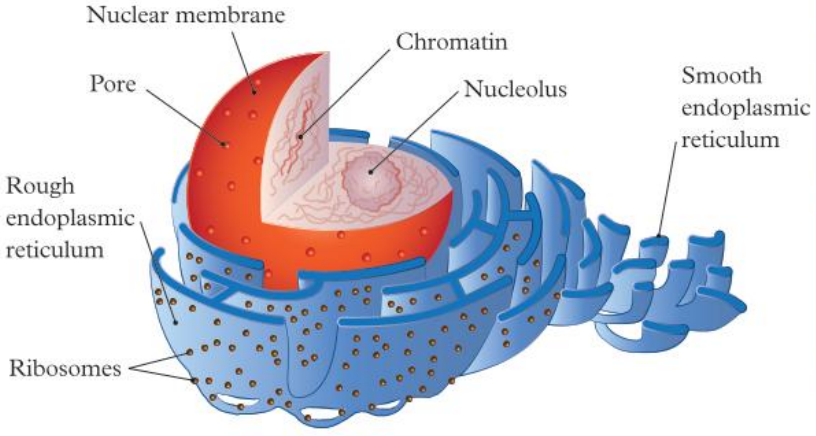


FIGURE 4 Smooth and rough endoplasmic reticulum surround the nucleus.

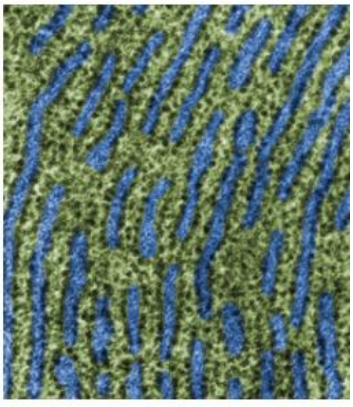


FIGURE 5 Electron micrograph of rough ER – ribosomes are the small dots on the surface

Golgi apparatus

Golgi apparatus
a membranous stack of cisternae involved in the packaging and secretion of cell products

The **Golgi apparatus** is a stack of flattened membranous sacs (cisternae), which are continually being formed at one end and budding off as vesicles at the other. They are closely associated with the endoplasmic reticulum and receive enzymes, proteins, lipids, glycoproteins and polysaccharides that are synthesised there. Once these substances are received, the Golgi apparatus encloses them in membranes and releases them either into the cytoplasm or outside the cell. They then serve as collecting, sorting, processing and distribution centres for these molecules, much like a "post office" for the cell.

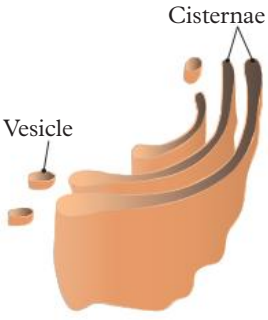


FIGURE 6 The structure of Golgi apparatus

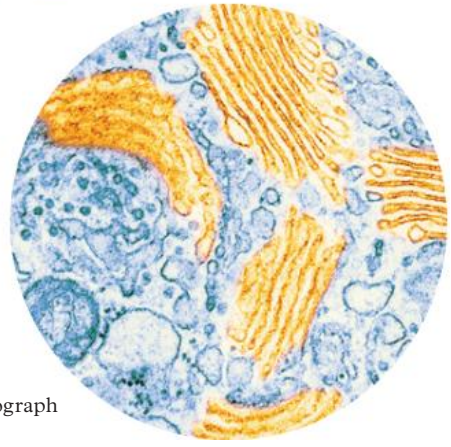


FIGURE 7 Electron micrograph of Golgi apparatus

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Vacuoles

A **vacuole** is a membranous sac that stores different molecules. In animal cells, vacuoles are small and are typically used for food storage and digestion. Plant cells tend to have one large central vacuole that contains cell sap and is used for storage of substances and control of water levels in the cell (osmotic balance).

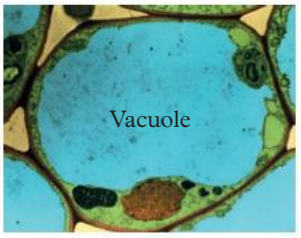


FIGURE 8 An electron micrograph of a vacuole in a plant cell

vacuole
a cellular inclusion or space within a cell; small in animal cells (food storage or digestion), large in plant cells (storage and osmotic control)

Lysosomes

A **lysosome** is a simple spherical sac containing digestive enzymes. Lysosomes can fuse with vesicles or food vacuoles to digest their contents. Unwanted cellular products and wastes are broken down (autophagy) by lysosomes. Lysosomes can also break down damaged cells (autolysis) and destroy invading bacteria.

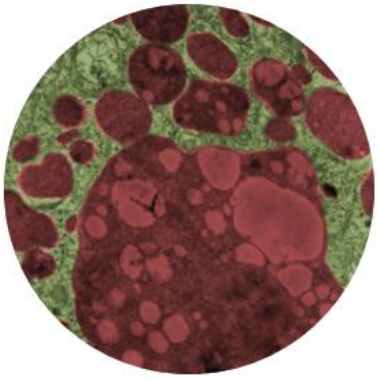


FIGURE 9 Electron micrograph showing lysosomes (red)

lysosome
an organelle that contains digestive enzymes involved in intracellular digestion

Plant-specific organelles

Plant and animal cells have many organelles in common; however, plants contain some organelles that are not found in animals. These organelles, including chloroplasts and cell wall, have evolved in plant cells to optimise the plants' chances of survival.

Chloroplasts

Chloroplasts are large, consisting of a fluid matrix or stroma and stacks of flattened membranous discs called **grana** (single stack = "granum"). A single disc is called a thylakoid. Chloroplasts contain chlorophyll, and their function is photosynthesis. Like mitochondria, they also contain DNA and ribosomes, and can replicate.

Chloroplasts are an important site of photosynthesis. Photosynthesis is a process that occurs in plant cells, in which light energy is converted into the chemical energy of glucose through a series of reactions. These reactions require chlorophyll, sunlight, water and carbon dioxide.

chloroplast
a plastid (small membrane-bound organelle containing pigment) in the cells of green plants; contains chlorophyll on membranous grana and enzymes in the liquid stroma; a photosynthetic organelle

grana
stacks of thylakoids within chloroplasts; surrounded by the stroma; a single stack is a "granum"

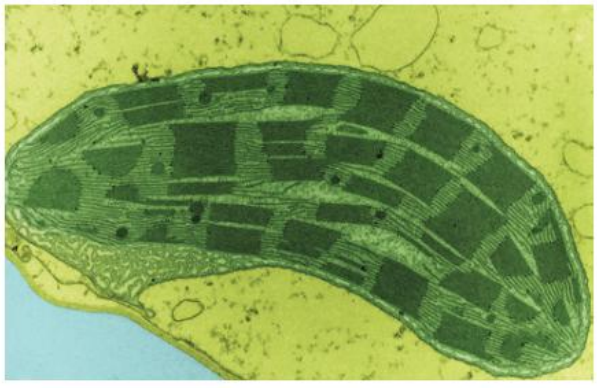


FIGURE 10 Electron micrograph of a chloroplast

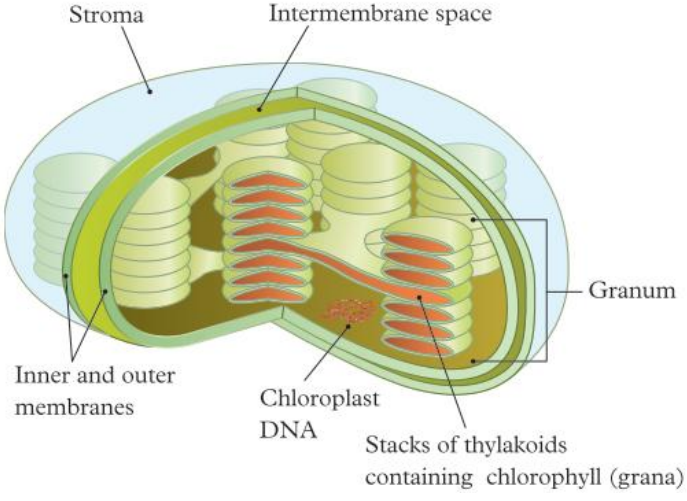
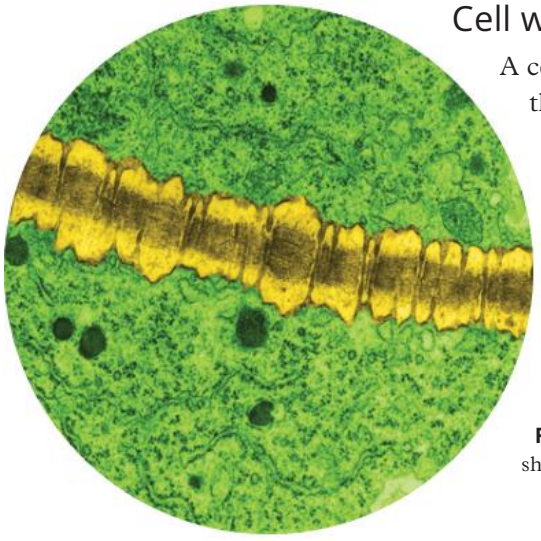


FIGURE 11 The structure of a chloroplast

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Cell wall

A cell wall is a non-living structure composed of cellulose that encases the cell membrane. It may be secondarily thickened with the chemical lignin. The cell wall provides mechanical support and protection of the cell. It prevents the cell from rupturing when large amounts of water diffuse into the cell (turgor pressure). A middle lamella between the walls of adjacent cells cements neighbouring cells together. Gaps in the cell wall can allow two plant cells to connect to each other. These links are called plasmodesmata. They allow rapid movement of materials from cell to cell.

FIGURE 12 Electron micrograph showing a cell wall between two cells

Cell specialisation

The number of specific organelles in a cell can vary, depending on the cell's function. For example, human heart muscle cells contain much higher concentrations of mitochondria than other human cells, because the heart requires large amounts of energy to function.

In a similar way, the presence or lack of certain organelles in a cell is also determined by the cell's function. For example, plant root cells do not have chloroplasts, because they are not exposed to sunlight and do not need to use sunlight to make glucose. Leaf cells, which are directly exposed to light, contain many chloroplasts. The chloroplasts in leaf cells are packed close to the surface, and are positioned with their grana facing the light source.

Comparing animal and plant cells

While animal and plant cells have many common organelles, their general organisation differs. Figures 13 and 14 show the general structure of animal cells and plant cells.

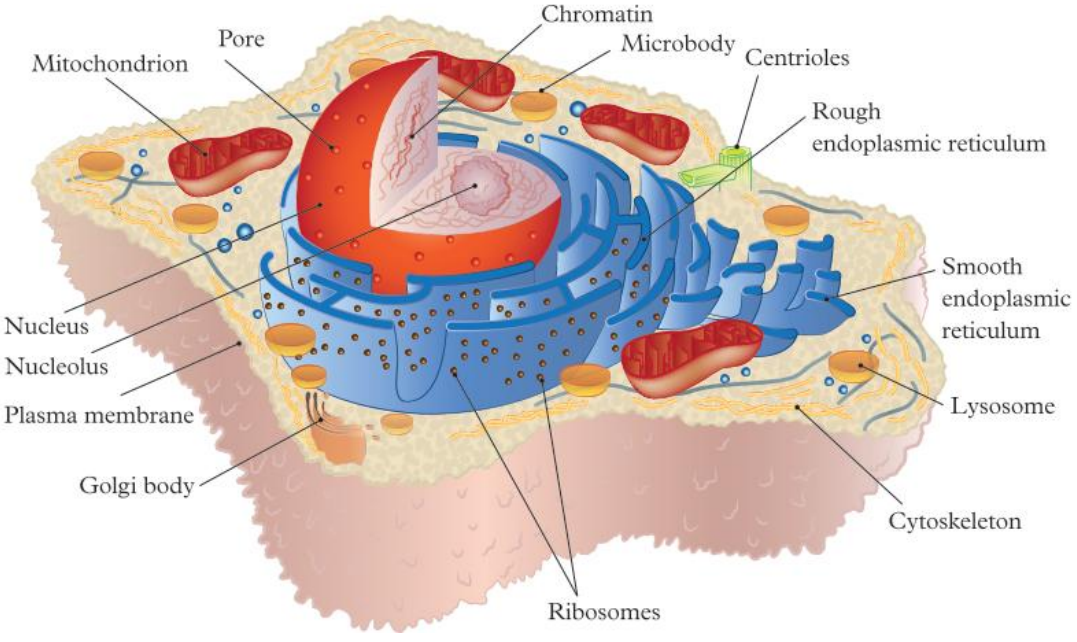


FIGURE 13 The structure of an animal cell

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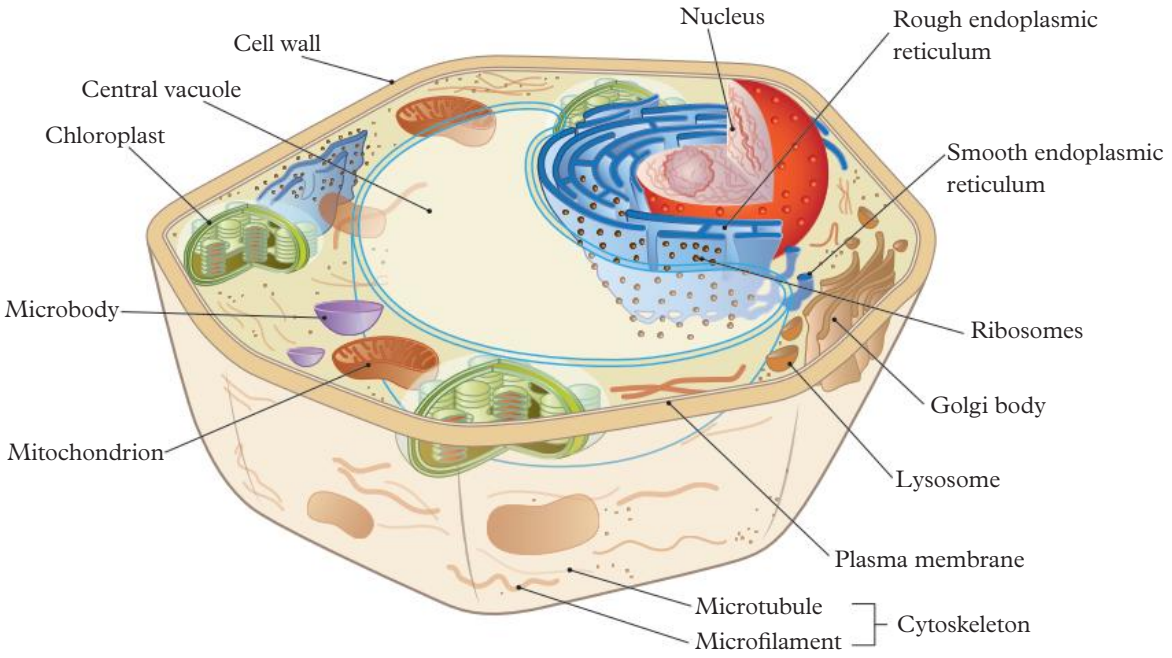


FIGURE 14 The structure of a plant cell

Real-world biology

Making sense of the complexity of life

The relationship between science and technology is clearly demonstrated in the development of the cell theory. This is the theory that all organisms are made up of cells and their products, and that growth and reproduction are fundamentally due to the division of cells. Anatomy and the study of body organs can be traced back to at least 1600 BC. However, prior to 1665, there was no knowledge of cells because they were too small to be seen by the naked eye. Before this time, living things were believed to have generated spontaneously. For example, it was believed that maggots sprouted directly from rotting meat. It was only after the invention of the microscope that scientists discovered the previously unseen world of cells. Following the discovery of cells in the seventeenth century, advances in our understanding of cells slowed. Two scientists (Matthias Schleiden and Theodor Schwann) are credited with having developed the cell theory in the nineteenth century. According to the cell theory:

- all known living things are made up of one or more cells
- all living cells arise from pre-existing cells by division.

This more complex understanding of the existence and function of cells developed as scientists discovered previously unknown organisms, such as protists and bacteria, that were too small to be seen without a microscope. They were also able to observe the structural differences between various types of cells, such as red blood cells and sperm cells.

Later developments in technology allowed scientists to investigate these smaller structures, including the different organelles within cells. Lysosomes and peroxisomes, for example, were only discovered in the mid-twentieth century. Today, scientists continue to "zoom in" on the smaller components of cells, to discover the chemical composition and functions of organelles and other features, such as the role of DNA in cell activities.

Apply your understanding

1 **Describe** the cell theory. (1 mark)

2 **Explain** why scientists were limited in their understanding of cells until the 1600s despite the human body having been studied since at least 1600 BC. (2 marks)

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Check your learning 2.2

Check your learning 2.2: Complete these questions online or in your workbook.

Retrieval and comprehension

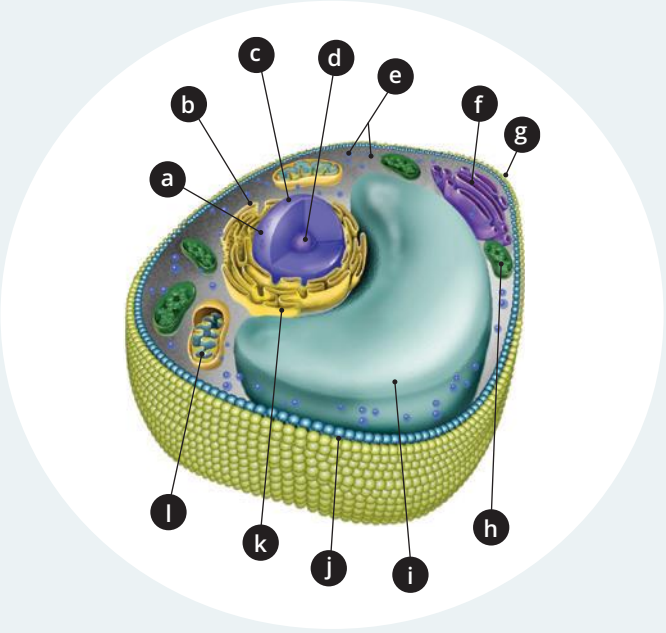
1 **Describe** the main functions of the following cell parts. Indicate the type(s) of cells in which they are usually found.
   - **a** Cell wall (1 mark)
   - **b** Chloroplast (1 mark)
   - **c** Endoplasmic reticulum (1 mark)
   - **d** Golgi apparatus (1 mark)
   - **e** Lysosome (1 mark)
   - **f** Mitochondrion (1 mark)
   - **g** Nucleus (1 mark)
   - **h** Ribosome (1 mark)
   - **i** Vacuole (1 mark)

2 Using the letters in the diagram, **identify** each of the organelles in this plant cell. (12 marks)

Analytical processes

3 **Compare** rough and smooth endoplasmic reticulum. (2 marks)

4 **Compare** the structures and functions of a chloroplast and a mitochondrion. (4 marks)



Practical

Lesson 2.3

Preparation and examination of wet mount specimens

Learning intentions and success criteria

oxforddigital **This practical lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.**

Lesson 2.4

Identifying organelles from electron micrographs

Learning intentions and success criteria

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Lesson 2.5
The cell membrane

Key ideas

- → The cell membrane is a selectively permeable barrier.
- → The fluid mosaic model describes the chemical structure of the cell membrane.
- → Protein channels, phospholipids, cholesterol and glycoproteins all have specific roles in the cell membrane.

Learning intentions and success criteria

Chemical structure of the cell membrane

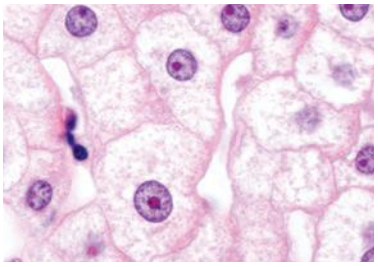


FIGURE 1 Light microscope image of liver cells (hepatocytes). Each cell is encased in a cell membrane.

The cell membrane is a selectively permeable barrier that controls the movement of substances into and out of the cell. It is described as "selectively permeable" because some small molecules (such as water) can diffuse through easily, while larger molecules (such as proteins) are prevented from moving through the membrane. A permeable membrane allows the free movement of all molecules in both directions. A selectively permeable membrane allows particular molecules that fit the selective criteria to move through.

The structure of the cell membrane allows it to carry out the following functions:

- aids in the transport of materials into and out of the cell
- provides mechanical support to the cell, so the cell can maintain its shape
- acts as a receptor for chemical materials (e.g. hormones) and maintains the specificity of a particular cell type.

The cell membrane is very thin – about 7.5 nm (nanometres) (1 nm = 10^{-9} m). The basic structure of the membrane is known as a **phospholipid bilayer**. This is because it consists of two thin sheets of polar **phospholipids**. A phospholipid is a molecule that has a negatively charged phosphate "head" and two fatty acid "tails". The phosphate end of the molecule can mix well with water and is therefore described as hydrophilic (water-loving). The fatty acid tails do not mix with water and are described as hydrophobic (water-hating). The hydrophobic nature of the fatty acid tails means that only small, uncharged, relatively hydrophobic molecules can easily pass across the phospholipid bilayer.

phospholipid bilayer
the main structure of the cell membrane, consisting of two layers of phospholipids arranged with the hydrophilic heads facing the internal and external fluid environments

phospholipid
the major unit of the phospholipid bilayer, composed of a hydrophilic phosphate head and two hydrophobic fatty acid tails; provides structure for the cell and helps separate the cytoplasm from the external environment

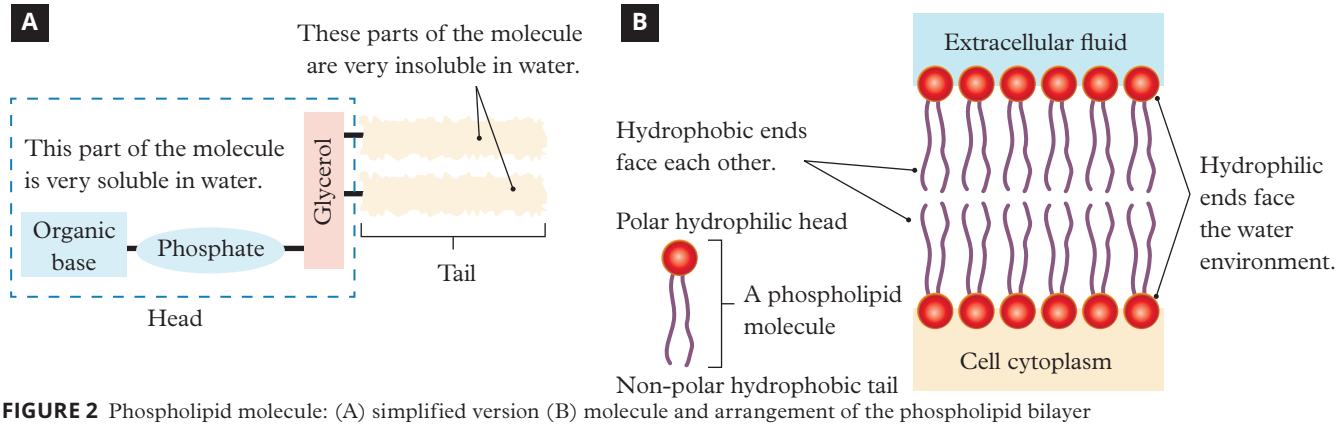


FIGURE 2 Phospholipid molecule: (A) simplified version (B) molecule and arrangement of the phospholipid bilayer

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The cell membrane must be arranged as a double layer because it is surrounded on both sides by a water-based mixture (the extracellular fluid and the cytoplasm). This also dictates the orientation of the individual phospholipid molecules. The hydrophobic tails repulse water, so the phospholipid molecules automatically arrange themselves so that the hydrophobic tails are sandwiched between the hydrophilic phosphate heads. This arrangement of these molecules is termed a bilayer.

As with all molecules, the phospholipid molecules move about. However, their polarity restricts their movement mainly to the lateral plane. A lot of energy is required to move a phospholipid molecule from one layer to the other, because the hydrophilic head must pass through the hydrophobic tail region. The tails must come into contact with water in this action. As a result, "flip-flop" movement is very rare.

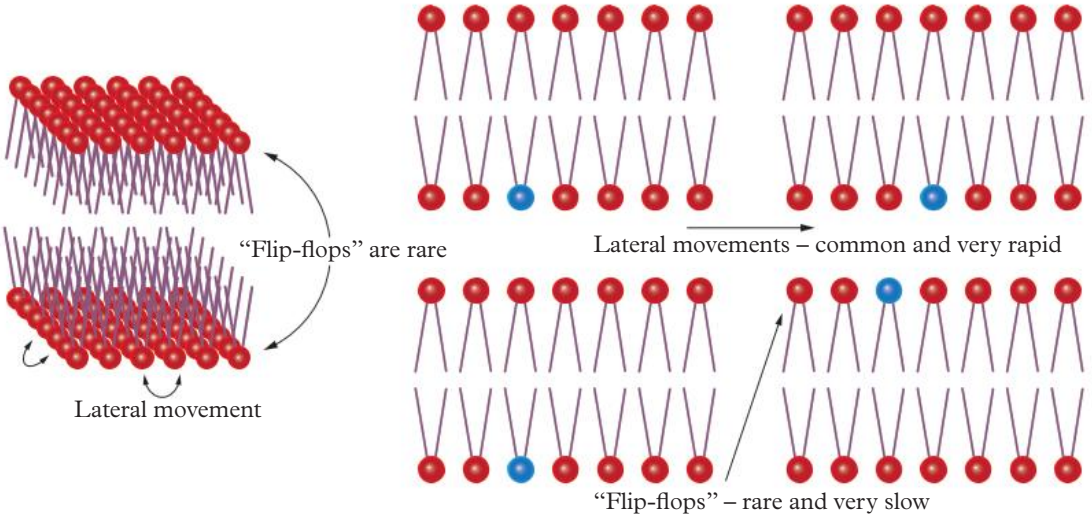


FIGURE 3 Movement of phospholipids within the membrane

The fluid mosaic model

fluid mosaic model
a description of how molecules are arranged in the cell membrane; "mosaic" refers to the many types of molecules (including phospholipids) that make up the structure of the membrane; "fluid" refers to the constant movement of the phospholipids and other molecules that make up the membrane

The cell membrane is not just made up of phospholipids. According to the **fluid mosaic model**, the cell membrane is a dynamic structure that is embedded with a range of molecules, such as protein channels, cholesterol and glycoproteins. Some of these molecules are able to move about freely, while others are fixed in position by microfilaments running into the cytoplasm.

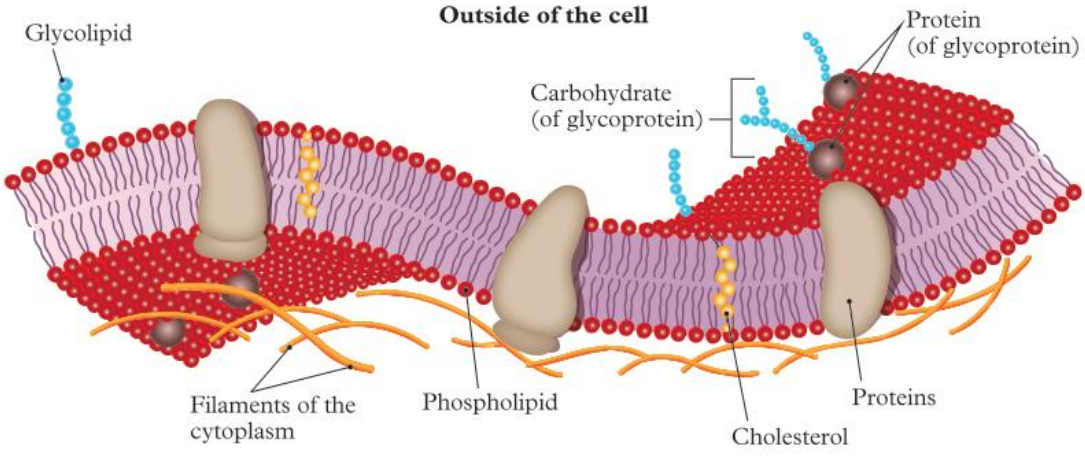


FIGURE 4 The fluid mosaic model of the cell membrane suggests that the phospholipid bilayer contains other molecules such as proteins, cholesterol and glycoproteins.

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Protein channels

Some proteins, known as **integral proteins**, penetrate either part of the way into the cell membrane (monotopic) or all the way through it (transmembrane). The middle parts of these proteins are hydrophobic and can therefore mix freely with the hydrocarbon tails of the membrane lipids. The parts of the protein in contact with extracellular or intracellular fluid are hydrophilic. **Peripheral proteins** are proteins that are situated outside the cell membrane or attached to the outer surfaces of integral proteins. These peripheral proteins are weakly bound to the membrane or other proteins.

integral protein
a protein within the structure of the cell membrane

peripheral protein
a protein attached to, or partially embedded in, the cell membrane

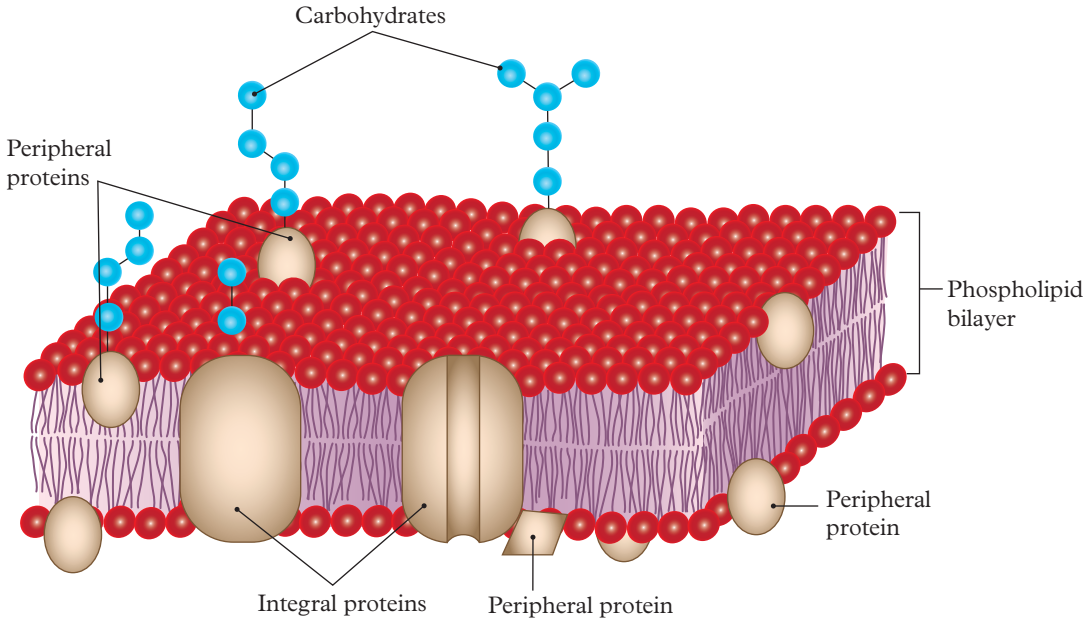


FIGURE 5 The cell membrane consists of integral proteins, which penetrate either partially or fully through the membrane, and peripheral proteins, which are situated along the surface of the membrane.

Integral proteins usually have a hydrophobic portion that interacts with the phospholipids, and a hydrophilic portion facing the water-based surroundings. Some of the proteins (of which thousands may occur in membranes) may be purely structural in function. Others act as carrier molecules in transporting specific substances through the membrane. It is thought that hydrophilic channels called **protein channels** occur within integral proteins or between adjacent protein molecules. These channels allow the passage of large molecules, and some water-soluble molecules (such as glucose and amino acids) that otherwise would be excluded by the phospholipid molecules. Other membrane proteins may act as recognition markers or receptor molecules that bind to chemical messengers that may be in the fluid outside the cell.

protein channel
a channel that passes through the centre of a protein; its lining is hydrophilic and it is the site of facilitated diffusion of large or highly polarised molecules

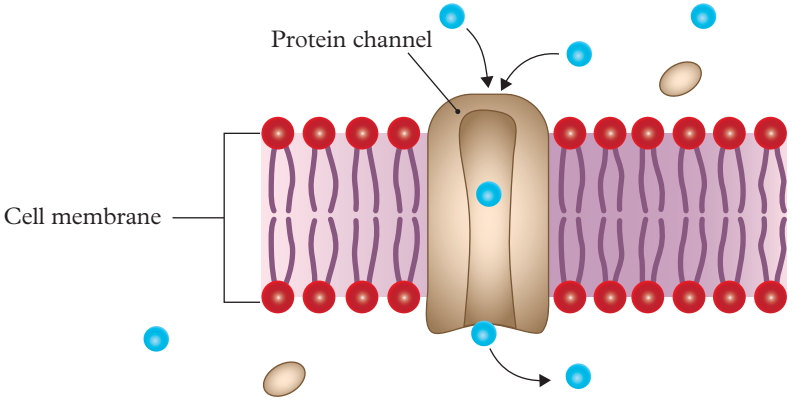


FIGURE 6 Protein channels allow large molecules, and some water-soluble molecules, to pass through the cell membrane.

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Glycoproteins

glycoprotein
a protein with attached polysaccharides, used in signalling, cell-to-cell communication and tissue formation

Glycoproteins are peripheral or integral proteins in the cell membrane. They have branching carbohydrate portions on their free surfaces. These antennae-like carbohydrate chains are made up of several sugar molecules and have a range of precisely defined patterns. Glycoproteins are important recognition features that:

- facilitate cell-to-cell binding when the sugar recognition site on one glycoprotein adheres to the surface of another cell (this triggers cells to orientate themselves a certain way and aids with tissue formation)
- act as specific markers when the body is trying to defend itself (for example, **antigens** in the immune response)
- facilitate cell-to-cell communication and targeted response (for example, hormones and other chemicals have recognition sites that enable them to be taken up specifically by cells that have the complementary sites).

antigen
a protein on the surface of matter that is foreign to the body

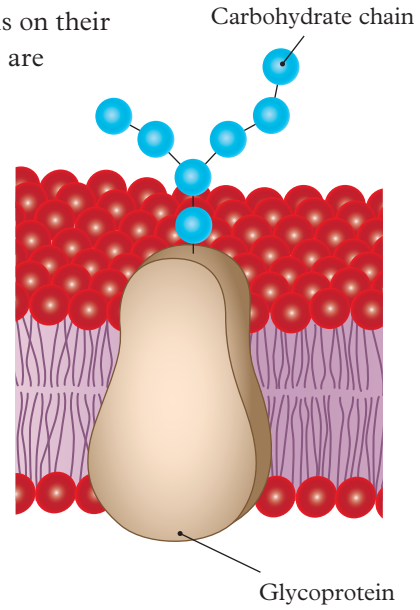


FIGURE 7 Glycoproteins are proteins that have an attached carbohydrate chain that extends out from the surface of the cell membrane.

Cholesterol

cholesterol
a steroid in animals; an important component of cell membranes and a precursor molecule for other steroids

Cholesterol is located between the phospholipid molecules in the bilipid layer. It also has hydrophobic and hydrophilic portions. Cholesterol regulates the fluidity of the membrane so that it is neither too rigid nor too fluid for the functioning of the cell. The fluidity of the cell membrane is temperature dependent: as temperature increases, membrane fluidity increases. Therefore, the role of cholesterol is also temperature dependent. At high temperatures, cholesterol stabilises the cell membrane, decreasing the fluidity and keeping the cell from rupturing. At low temperatures, the cholesterol tail helps to separate the phospholipid tails, maintaining fluidity within the cell membrane. Cholesterol also plays a role in regulating "flip-flopping" of phospholipids and proteins, and causes integral proteins to change their conformation or distribution throughout the cell membrane.

Variations in membrane properties

Different types of phospholipids in the membrane affect its properties, such as fluidity and permeability. In turn, these properties affect the ease with which membranes fuse with each other, and the activity of the protein channels and glycoproteins. The variations in membrane properties of different cells can be attributed to differences in:

- lipid composition – this affects the membrane's fluidity
- integral proteins – this affects the size and specificity of the protein channels
- peripheral and integral proteins – this affects the:
  - recognition sites
  - carrier molecules
  - enzymes attached.

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Check your learning 2.5

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Retrieval and comprehension

1 **Summarise** two functions of proteins in the cell membrane. (2 marks)
2 **Identify** three factors that determine whether a particle will pass through a cell membrane's phospholipid bilayer. (3 marks)
3 **Describe** the three functions of the cell membrane. (3 marks)
4 **Describe** the role of cholesterol in the cell membrane. (1 mark)

Analytical processes

5 **Deduce** why recognition sites on the outside of cell membranes are significant for living things. (3 marks)

Lesson 2.6
Transport across the cell membrane

Key ideas

→ Passive transport is a way of moving molecules across the cell membrane that does not require energy.
→ Simple diffusion, facilitated diffusion and osmosis are forms of passive transport.
→ Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient.
→ Protein-mediated active transport, exocytosis and endocytosis are forms of active transport.

Movement of chemicals into and out of cells

Learning intentions and success criteria

The cell membrane is a major barrier that is impermeable to many water-soluble substances, such as ions, glucose and amino acids. Lipid-soluble substances such as oxygen, nitrogen and alcohols can dissolve into phospholipids and diffuse rapidly through the cell membrane as if it were not there. Even though water is highly insoluble in the membrane phospholipids, it is readily able to penetrate the phospholipid layer. The reason for this is not certain. It is theorised that water molecules are small enough in size and have enough kinetic energy to penetrate the lipid portion before the hydrophobic "tails" can stop them. Water is also able to pass through protein channels.

The very fluid nature of the cell membrane ensures that it is in constant motion, so small molecules can pass between the lipid molecules. At any time, there are "pores" in the membrane that allow small molecules such as water, or water-soluble molecules such as urea, to pass through.

The phospholipid bilayer is impermeable to ions because of their electrical charge, and to glucose and amino acids because of their larger size. These molecules must enter the cell through the channels in the integral proteins.

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solvent
the liquid in which other substances (solutes) are dissolved to form a solution

solute
the substance that is dissolved in a solution

passive transport
the movement of materials into and out of a cell without the expenditure of energy

active transport
the movement of materials into and out of a cell, usually against a concentration or ionic gradient, requiring cellular energy (ATP)

Various materials must move into and out of cells so that biological activities can take place in the cell. The cell membrane allows some solute molecules or ions, but not others, to move freely through it – it is selectively permeable. A permeable membrane allows the free movement of all molecules in both directions. Often, a selectively permeable membrane allows **solvent** molecules and excludes **solute** molecules.

Materials move into and out of cells via **passive transport** or **active transport**.

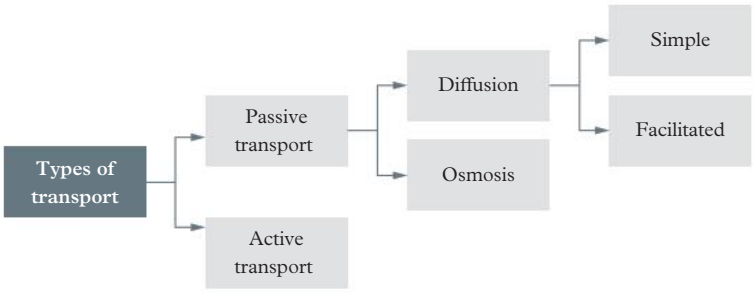


FIGURE 1 The basic mechanisms of transport across a membrane

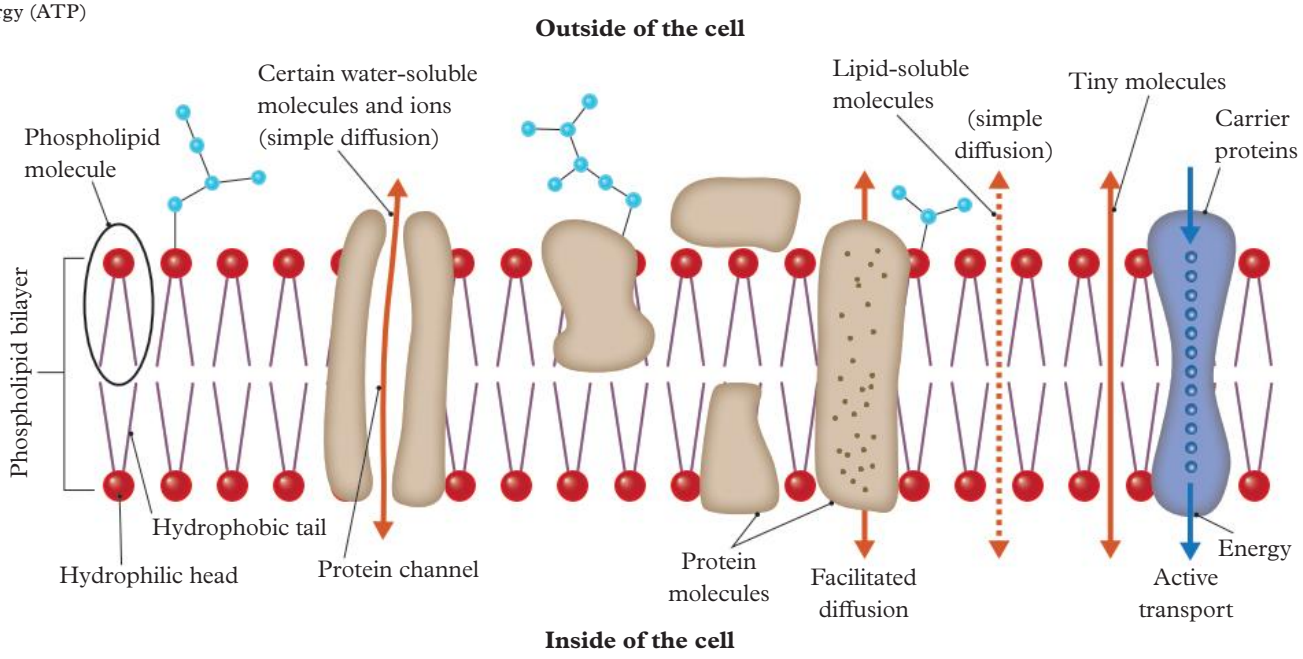


FIGURE 2 Transport pathways through the cell membrane

Passive transport

Passive transport is a way of moving molecules across the cell membrane that does not require energy. Many molecules do not need extra energy to move across a membrane. Passive transport can be further broken into categories as shown in Figure 1.

diffusion
the movement of molecules from an area of greater concentration to an area of lower concentration

Diffusion is the process by which molecules, or ions of liquids or gases, tend to spread out from regions of higher concentration to regions of lower concentration. This results from their random movement (Brownian motion). Eventually, the molecules become evenly distributed throughout the space they occupy. For example, a sugar cube (solute) placed in water (solvent) will dissolve and slowly spread throughout the solution.

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Three main factors affect the rate of diffusion.

- Temperature – molecules move faster at higher temperatures, so diffusion is faster at high temperatures.
- Particle size – small molecules require less energy to move, so smaller particles diffuse faster than larger particles.
- Concentration – the greater the difference in concentration between the two locations (the **concentration gradient**), the more quickly diffusion occurs.

Diffusion through the cell membrane consists of two processes: **simple diffusion** and **facilitated diffusion**.

concentration gradient
a difference in the concentration of a solution at two different points, e.g. across a barrier such as a cell membrane

simple diffusion
the unaided movement of molecules or ions across a differentially permeable membrane from an area of high solute concentration to an area of low solute concentration

facilitated diffusion
the passive movement of molecules loosely bound to carrier molecules through the cell membrane from an area of high solute concentration to an area of low solute concentration

Simple diffusion

Simple diffusion is the free and unaided movement of molecules or ions through the cell membrane from an area of high solute concentration to an area of low solute concentration. Certain molecules, such as those that are soluble in both water and lipids, can pass freely through the cell membrane. If the concentration of such a molecule outside a cell is higher than that inside the cell, a concentration gradient exists. Initially, the number of molecules entering the cell is greater than the number exiting the cell, and so there is a net flow into the cell. Once inside the cell, some molecules continue to move and are used in cellular processes. As the concentrations on both sides of the membrane become equal, the number of molecules passing from each direction becomes the same. This point is called **dynamic equilibrium** – when the number of molecules entering the system is equal to the number of molecules leaving.

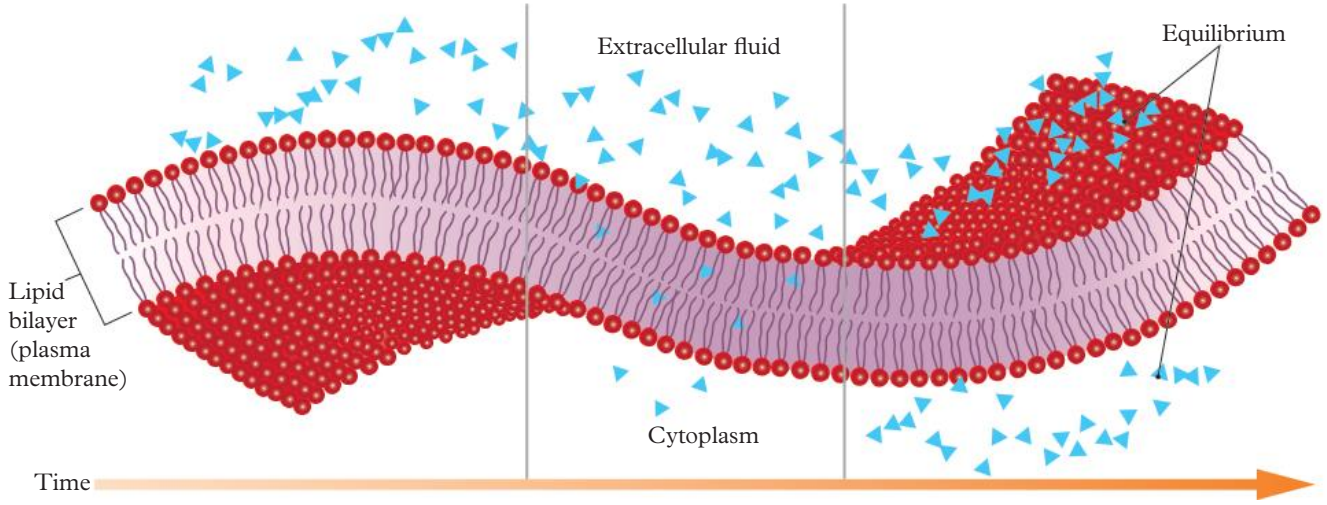


FIGURE 3 Simple diffusion occurs when molecules move freely from an area of high concentration to an area of low concentration until equilibrium is reached.

dynamic equilibrium
a state of balance that exists when the amount of a particular substance entering a cell is the same as the amount leaving it

Facilitated diffusion

Sometimes, specific proteins in the cell membrane provide a pathway for particular molecules that cannot pass freely through the membrane. This passive movement through a membrane with the help of a protein, from an area of high solute concentration to an area of low solute concentration, is called facilitated diffusion. For example, glucose molecules are insoluble in the phospholipid bilayer of the cell membrane and are too large to pass through. However, the glucose plus its protein carrier is soluble in lipids and can diffuse across. It is thought that no overall energy is expended in this process.

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Two types of proteins make facilitated diffusion possible.

- Channel proteins are typically used to transport ions into and out of the cell. Open channel proteins act as an open pore in the membrane that allows particles to flow into and out of the cell. Gated channel proteins are specific – they will open and shut in response to certain molecules or triggers.
- **Carrier proteins** change shape to allow a molecule to pass through the membrane after the molecule binds to a specific receptor on the surface of the protein.

carrier protein
a protein in the cell membrane that transports a molecule across the phospholipid bilayer through an enzyme-like structural change

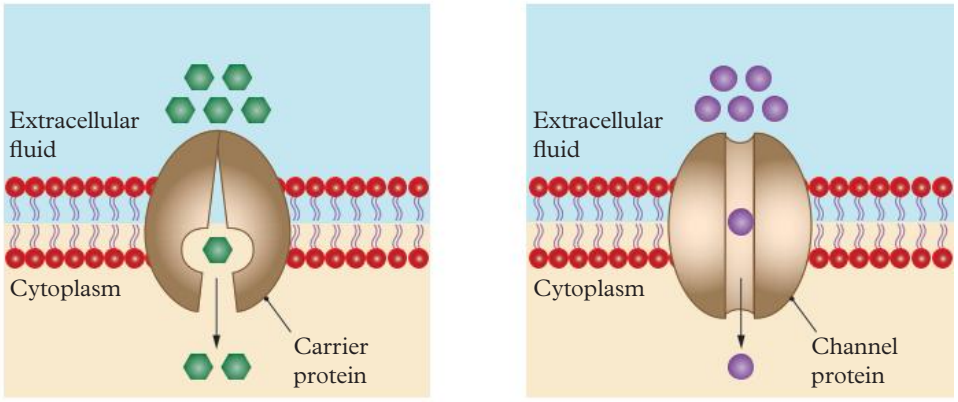


FIGURE 4 Channel proteins and carrier proteins are involved in facilitated diffusion.

Osmosis

Osmosis is the passive movement of water molecules across a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration. Osmosis occurs when there is a concentration gradient of solute (dissolved molecules) across a membrane that is impermeable to the solute. Because the high solute concentration traps many of the water molecules around the hydrophilic solute, the water molecules are not free to move back across the membrane. For example, when a cell is placed in a strong sugar solution, the sugar cannot diffuse through the cell membrane. There is a net flow of water out of the cell to a region of high solute concentration, until the concentration on both sides of the cell is equal.

osmosis
the movement of water through a selectively permeable membrane, from a region of low solute concentration to a region of high solute concentration, to counteract the difference in solute concentration

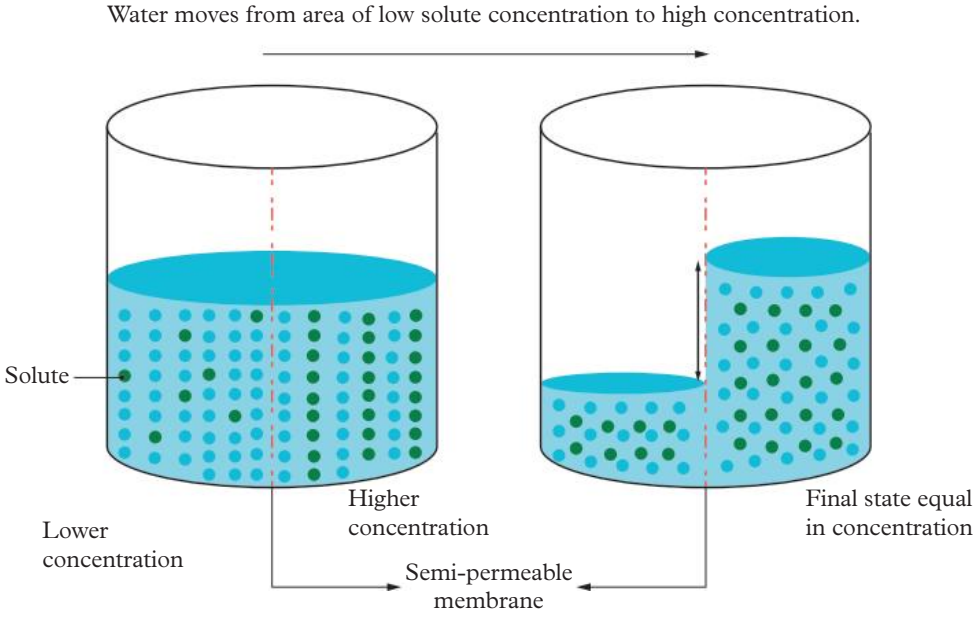


FIGURE 5 Osmosis is the movement of water molecules across a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration.

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Osmotic potential is the capacity of a solution to lose water molecules through a selectively permeable membrane. If the osmotic potential of a cell is low, there will be a net flow of water *into* the cell by osmosis. If the osmotic potential is high, there will be a net flow of water *out of* the cell by osmosis. In an isotonic solution, the same amount of water leaves the cell as enters.

Osmotic potential is determined by the concentration of the solute in the solution (e.g. the cytoplasm of a cell), compared with the concentration on the other side of the membrane (e.g. extracellular fluid). If the solute concentration in the extracellular fluid is higher than the solute concentration in the cytoplasm, the surrounding extracellular solution is said to be **hypertonic**, and its osmotic potential is low. Water will move out of the cell. If the solute concentration of the surrounding extracellular fluid is lower than the solute concentration of the cytoplasm in the cell, the solution of the extracellular fluid is **hypotonic**, and its osmotic potential is high. Water will move into the cell. When the solute concentration of the extracellular fluid is the same as that inside the cell, the solutions are said to be **isotonic** (Table 1).

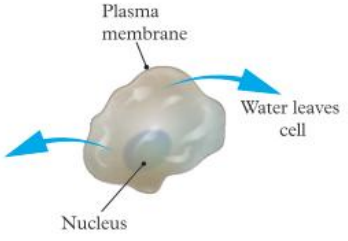
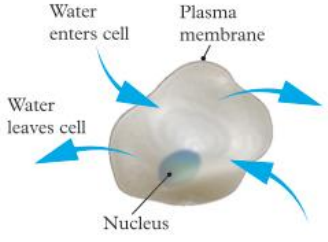
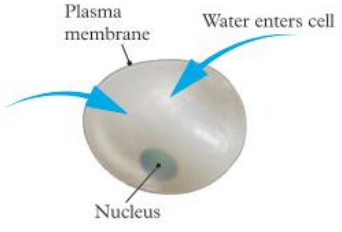
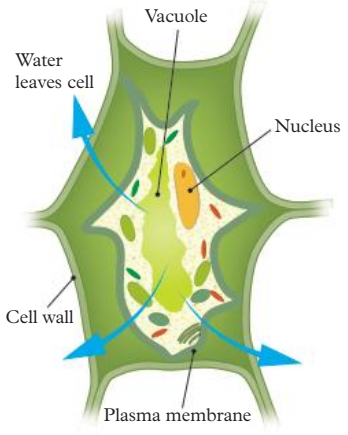
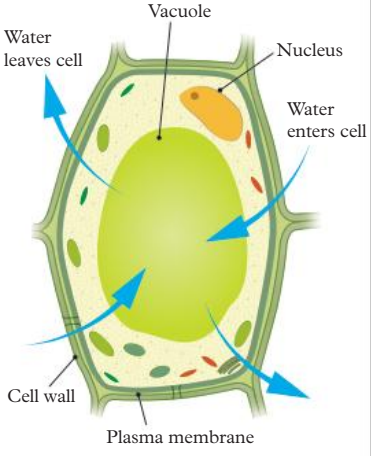
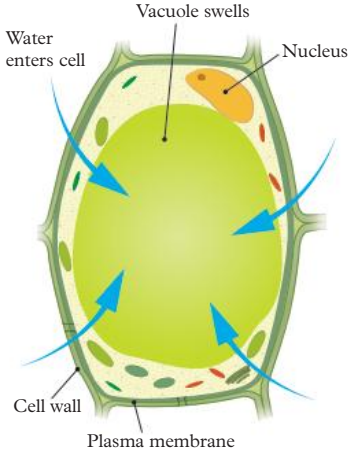
osmotic potential
the potential for water to move through a permeable membrane from an area of low solute concentration to an area of high solute concentration

hypertonic
a solution with a higher solute concentration than its surroundings

hypotonic
a solution with a lower solute concentration than its surroundings

isotonic
a solution with an equal solute concentration to its surroundings

TABLE 1 Relationship between solute concentration and osmotic potential between extracellular fluid and the cytoplasm in cells

	Hypertonic solution	Isotonic solution	Hypotonic solution
Extracellular solute concentration	High	Equal to cytoplasm	Low
Cytoplasm solute concentration	Low	Equal to extracellular fluid	High
Osmotic potential of extracellular fluid and direction of water movement	Low – water moves out of the cell	Nil – water moves into and out of the cell at an even rate	High – water moves into the cell
Example in animal cell			
Example in plant cell	 Plasmolysis		 Turgidity

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Plant cells have large vacuoles that are involved in maintaining the water balance of the cell. In doing so, they are important in the support structure of non-woody plants. When plant cells are placed in a hypertonic solution, the cell wall remains rigid but the protoplasm loses water through osmosis and the membrane shrinks away from it, because the fluid of the vacuole is reduced in volume by osmosis. Shrinkage of the cytoplasmic membrane away from the cell wall is known as **plasmolysis**. If these cells are then placed in distilled water or a hypotonic solution, water enters the cytoplasm and the vacuole, and restores the cell to its normal state. The cell is now deplasmolysed.

plasmolysis
the shrinkage of the cytoplasm of a plant cell away from the cell wall as a result of loss of water from the cell by osmosis

When plant cells are placed in a hypotonic solution, water enters the cell by osmosis. The volume of the total cell contents increases and exerts **turgor pressure** against the rigid cell wall. When this is at a maximum, no net movement of water into the cell can occur. The cell is fully turgid. The cell wall prevents further uptake and so protects the cell membrane from rupturing.

turgor pressure
the pressure exerted by fluid within a plant cell as it presses the plasma membrane against the cell walll

A similar phenomenon occurs in animal cells. However, because animal cells do not have a cell wall, in a hypertonic solution the entire cell shrinks and shrivels (crenation). In a hypotonic solution the cell expands, stretching the cell membrane, which may burst (lysis).

Study tip
"Where salt goes, water flows." This suggests that there is a net water movement towards the higher solute concentration.

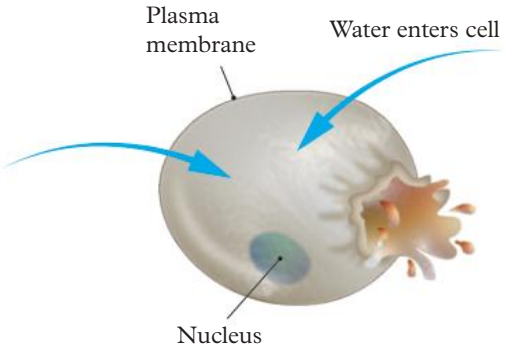


FIGURE 6 If an animal cell is placed in a hypotonic solution and swells too much, it may burst. This is known as lysis.

Active transport

Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient. Energy is required because the substance must be moved against its natural tendency to diffuse in the opposite direction. Movement is unidirectional. In contrast, diffusion is reversible, depending on the direction of the concentration gradient. Three types of active transport are:

- protein-mediated active transport
- endocytosis
- exocytosis.

Protein-mediated active transport

protein-mediated active transport
the transport of molecules or ions against a concentration gradient via specific proteins; requires energy (ATP) and is therefore considered "active"

In **protein-mediated active transport**, integral proteins require energy to act as pumps or channels to move specific molecules or ions against a concentration gradient. This energy comes from the common chemical energy molecule, adenosine triphosphate (ATP), which gets broken down by the protein. This breaking down of ATP releases a form of energy that can be used to transport the molecule across the cell membrane. One example of protein-mediated active transport is the sodium–potassium pump. This pump uses energy from ATP to transport sodium ions out of the cell and import potassium ions. This transport of ions is particularly important for nerve cells to respond to stimuli and transmit impulses.

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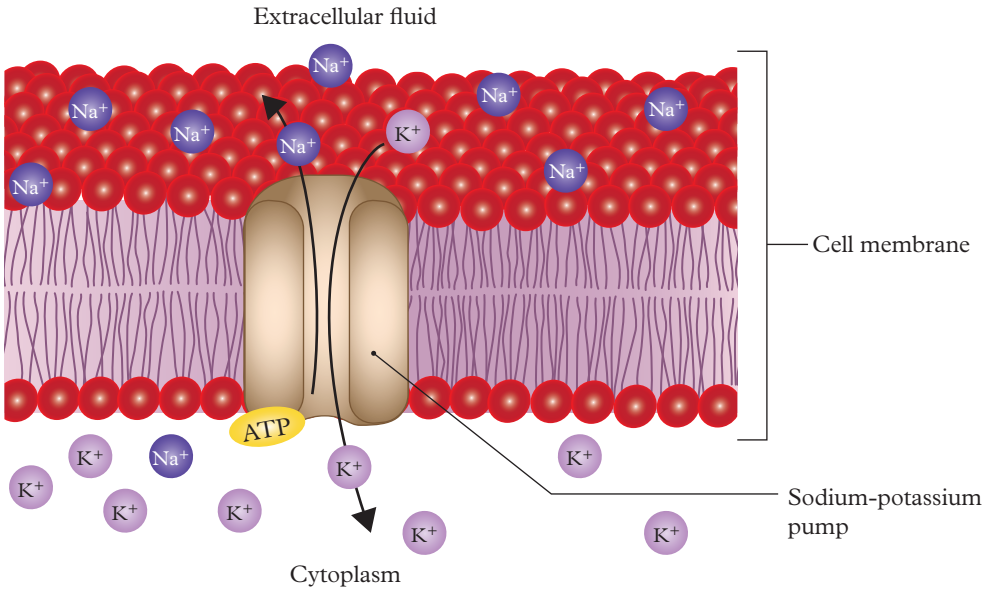


FIGURE 7 The sodium–potassium pump is an example of protein-mediated active transport.

endocytosis
the movement of materials into the cell

phagocytosis
"cell eating": engulfing of a solid material by a cell through extension of the cell membrane over the particle, and formation of a food vacuole

pinocytosis
"cell drinking": formation of channels in the cell membrane that take in fluid at their base

Endocytosis

Endocytosis is a type of active transport that allows substances to enter the cell. In endocytosis, the cell membrane engulfs a particle by folding inward and encasing the target particle in its own vesicle. Energy is used to fold the plasma membrane inwards. The vesicle carrying the substance then moves through the cytoplasm and is delivered to the relevant organelle. There are two types of endocytosis:

- **phagocytosis** ("cell eating"), in which solid particles are engulfed
- **pinocytosis** ("cell drinking"), in which liquid particles are engulfed.

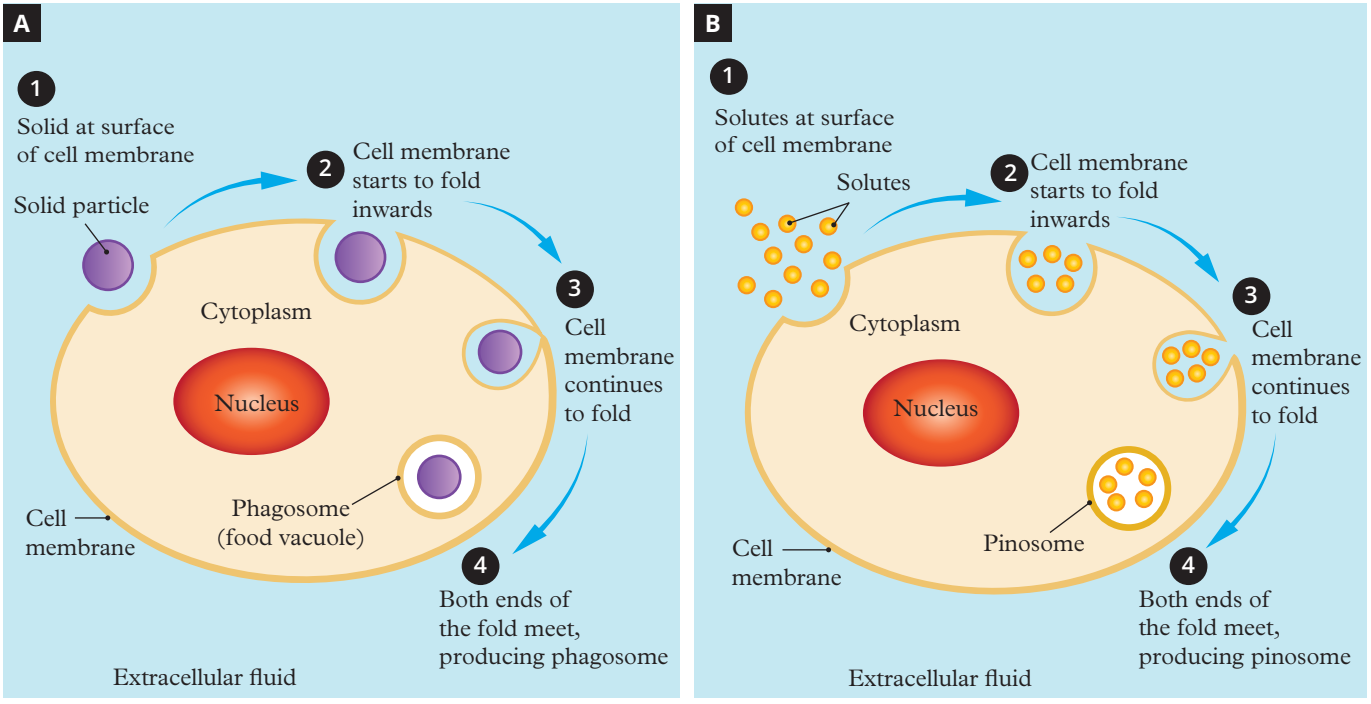


FIGURE 8 The process of (A) phagocytosis (B) pinocytosis

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Phagocytosis involves part of the cell membrane extending out and surrounding a solid particle outside the cell. The cell membrane fuses around the particle and, in doing so, forms a vesicle called a **phagosome**, which becomes incorporated into the cytoplasm. The term "vacuole" is used when large particles are taken up. Lysosomes fuse with this food vacuole, releasing enzymes. The resulting digested molecules diffuse into the cytoplasm.

phagosome
a small food vacuole that encapsulates a phagocytosed particle for digestion

Pinocytosis occurs by infolding of the cell membrane to form a channel. The liquid material enclosed in the channel is pinched off in a vesicle, called a **pinosome**, as the membrane fuses at the surface. The molecules are digested and released by the lysosome in the same manner as in phagocytosis.

pinosome
a vesicle filled with extracellular fluid, brought into the cytoplasm through pinocytosis

Phagocytosis and pinocytosis do not occur in plant cells, because of the relatively inflexible cell wall. In many single-celled animals (Protozoa), phagocytosis is an important feeding mechanism. In multicellular animals, it is one means of destroying invading bacteria and viruses.

Exocytosis

exocytosis
the movement of materials out of the cell

Exocytosis is a type of active transport that allows substances to exit the cell. In exocytosis, substances held in vacuoles and vesicles inside the cell move towards the plasma membrane. When the vesicle reaches the cell membrane, it fuses with the membrane, which opens the contents of the vesicle and expels it into the external environment. Energy is used to allow the vesicles to fuse with the cell membrane and release their contents. White blood cells use exocytosis to expel the digested remains of bacterial cells. Nerve cells (neurones) use exocytosis to pass chemical messenger molecules to other cells.

Study tip

The Latin prefix "phago-" means "eating", and "pino-" means "drinking". This is why phagocytosis describes a cell engulfing solid particles and pinocytosis describes a cell engulfing liquids.

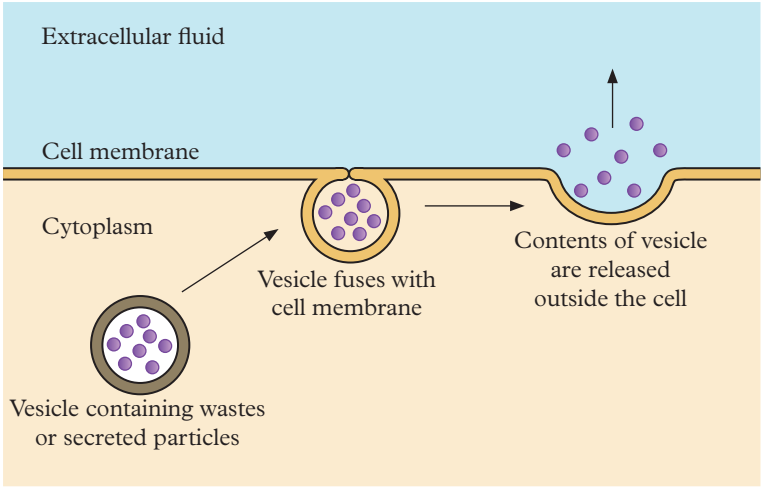


FIGURE 9 The process of exocytosis

Study tip

When explaining the method of transport through a cell membrane, always name the mode of transport, describe whether it is active or passive, and specify the direction of motion (e.g. simple diffusion, passive movement from an area of high solute concentration to an area of low solute concentration).

TABLE 2 Comparison of passive and active transport

Feature	Passive transport	Active transport
Movement of substance	Down concentration gradient	Against concentration gradient
Site of transport	Phospholipid bilayer or protein channels	Carrier proteins or protein pumps
Energy requirement	No energy required	Uses energy, usually provided by ATP
Characteristics of substance	Small, lipid-soluble	Charged, large or lipid-insoluble
Selectivity	Partially selective	Highly selective
Example	Water moves through the cell membrane by osmosis.	Glucose molecules are actively transported into body cells from the blood.

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Check your learning 2.6

Check your learning 2.6: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** what is meant by the terms "passive transport" and "active transport". (2 marks)

2 **Describe** the difference between a permeable membrane and a selectively permeable membrane. (2 marks)

3 **Explain** what is meant by dynamic equilibrium between two solutions separated by a selectively permeable membrane. (1 mark)

4 **Identify** how simple diffusion differs from facilitated diffusion. (2 marks)

5 **Describe** the different methods of active transport used by cells. (3 marks)

Analytical processes

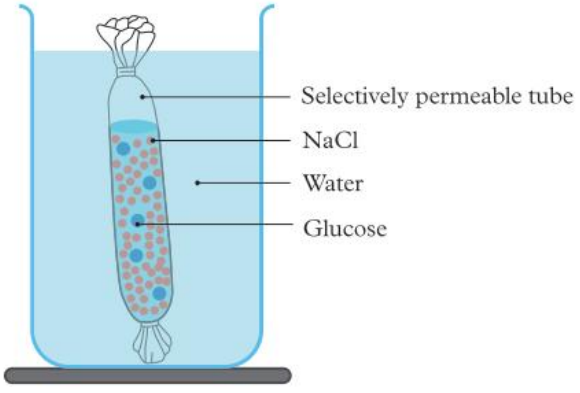
6 **Compare** diffusion and osmosis. (2 marks)

7 Animal cells placed in a hypotonic solution swell and burst. Plant cells placed in a hypotonic solution swell only to a certain point and do not rupture.

- **a** **Classify** the process involved in the swelling. (1 mark)
- **b** **Consider** why animal cells rupture but plant cells do not. (2 marks)
- **c** **Deduce** the name given to this action in plant cells. (1 mark)

8 A protozoan is a single-celled eukaryotic organism. Many freshwater protozoans contain contractile vacuoles that can change their volume. Analysis shows that these vacuoles contain a lower concentration of dissolved substances than the same substances in the rest of the organism. **Determine** the method of transport used. Provide a justified reason for your answer. (3 marks)

9 The image below shows a tube containing an aqueous solution of glucose and NaCl in a beaker of water. If the tube is permeable to NaCl and water, but not to glucose, **predict** the movement of substances and any other changes that would be observed in this experiment. (3 marks)



Practical

Lesson 2.7

Modelling the selectively permeable membrane

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Learning intentions and success criteria

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Lesson 2.8
Cell size

Key ideas

- → Cell size is limited by the ability to diffuse substances.
- → The rate of diffusion is affected by the surface area-to-volume ratio of a cell.
- → Cells have specific shapes and structures to increase their surface area-to-volume ratio.
- → The effect of surface area-to-volume ratio on the rate of diffusion can be observed experimentally.

Learning intentions and success criteria

SA : V and rate of diffusion

Cells come in many shapes and sizes (Figure 1), which can make them difficult to compare. As a cell grows in size, both the surface area and the volume of the cell increase. However, the cell's volume increases at a faster rate than its surface area. In fact, as a cell grows (assuming it stays the same shape), the surface area increases exponentially by the power of 2, whereas the volume increases exponentially by the power of 3. For this reason, biologists use the **surface area-to-volume ratio (SA : V)** of cells to compare cell size. Large cells tend to have a small SA : V, while small cells tend to have a large SA : V. In this lesson you will learn about how SA : V and rate of diffusion limit cell size.

surface area-to-volume ratio (SA : V)
the ratio of a cell's surface area compared to its volume, a critical factor in the survival of cells; cells with greater surface area in proportion to their volume are able to transport nutrients and wastes of metabolic processes more efficiently

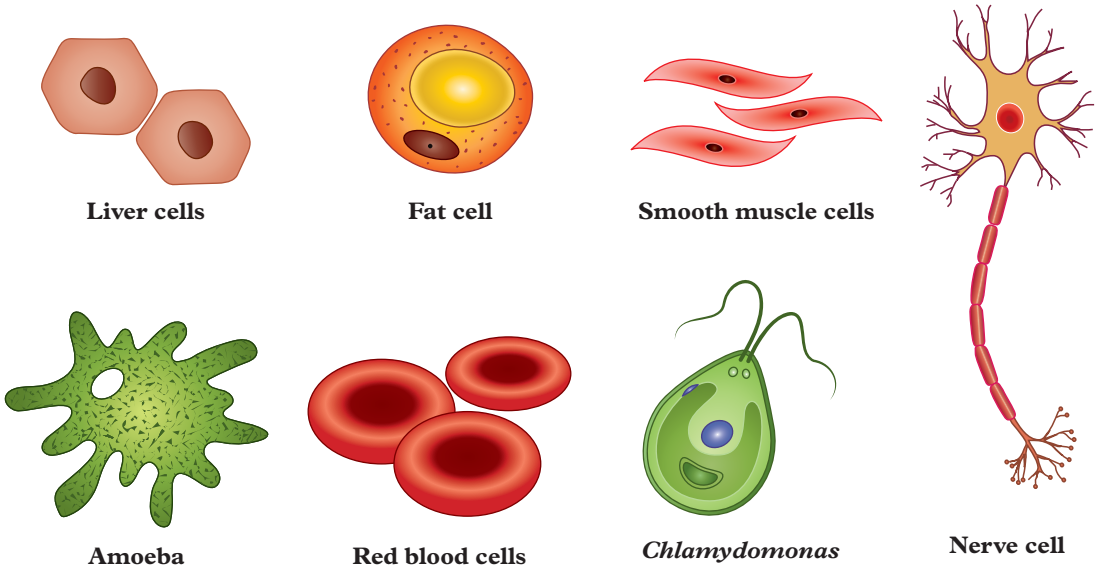


FIGURE 1 Cells come in all shapes and sizes.

Chemical reactions necessary for survival occur throughout the cell. Cells need to be small so that the substances that fuel these reactions can move easily into the centre of the cell and wastes from these reactions can move easily out of the cell. The speed at which substances diffuse into or out of a cell is known as the **rate of diffusion**. Cells with a small SA : V are not as efficient at moving molecules into and out the cell. This is because when surface area is less than volume, the cell is less efficient at collecting the nutrients needed to fuel the cell.

rate of diffusion
the speed at which various substances diffuse into or out of a cell

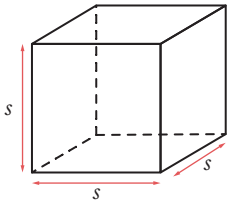
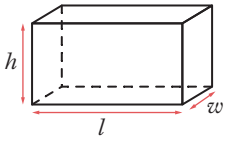
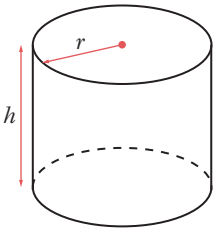
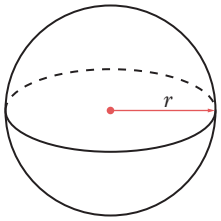
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If volume exceeds surface area, the distance that nutrients and wastes need to travel increases along with the time taken to move them. In other words, the smaller the SA:V the slower the rate of diffusion. If nutrients take too long to be imported and/or wastes are not removed quickly enough, the cell will struggle to survive. Therefore, cells are limited by SA:V, because they must have an SA:V that allows materials to diffuse at a rate that can sustain the cell.

The formulae for calculating SA and V in different shapes is summarised in Table 1.

TABLE 1 Formulae for calculating surface area and volume of a range of shapes

Shape	Cube	Rectangular prism	Cylinder	Sphere
				
Surface area (SA)	SA = $6s^2$	SA = $2(lw + lh + wh)$	SA = $2\pi r^2 + 2\pi rh$	SA = $4\pi r^2$
Volume (V)	V = s^3	V = $l \times w \times h$	V = $\pi r^2 h$	V = πr^3

When SA and V have been calculated, you can work out SA:V by dividing SA over V to determine the ratio of SA to V. For example, if a cube has a side length of 5 mm, the SA of the cube is 6×5^2 or 150 mm^2. The volume of the cube is 5^3 or 125 mm^3. $\frac{150}{125}$ is 1.2, so the SA:V ratio is 1.2:1 (the surface area is 1.2 times the volume).

Maximising SA:V

Cells overcome the constraints of being large by forming into shapes that increase their surface area or by developing projections. A flattened or lengthened shape, or numerous fine projections of the cell membrane (**microvilli**), can increase a cell's SA:V.

microvillus
a projection from the surface of cells; forms a brush border that increases the surface area of the cell membrane; plural "microvilli"

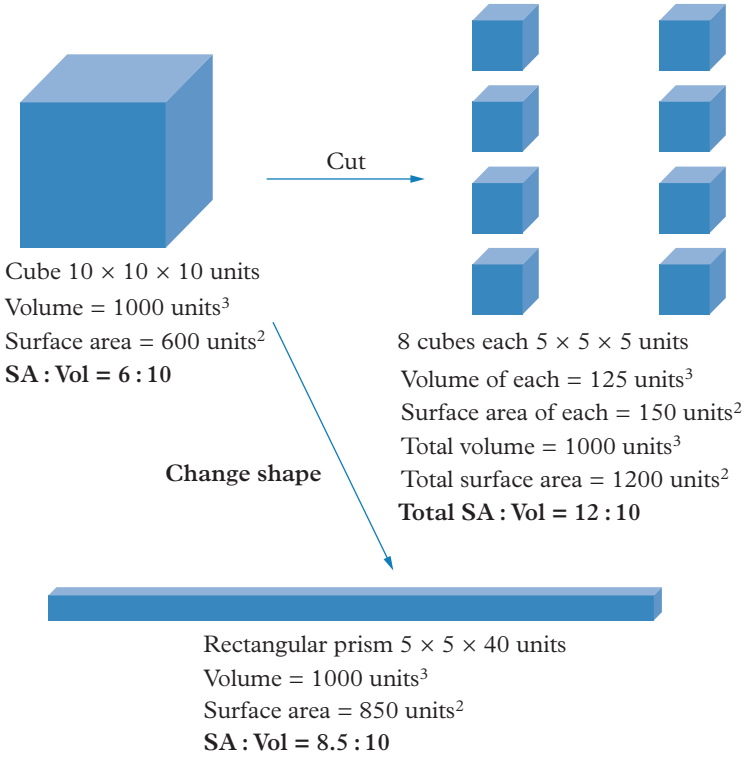
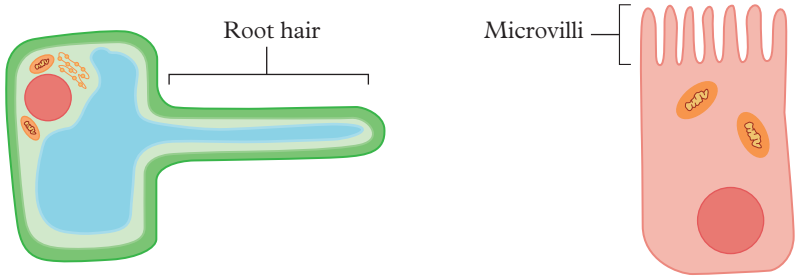


FIGURE 2 SA:V changes with size and shape. If the large cube is cut into eight equal-sized cubes, its SA:V increases from 6:10 to 12:10 – its surface area doubles, even though the volume is the same. If the cube is changed to a rectangular prism, the SA:V increases from 6:10 to 8.5:10 – the flatter the "cell", the greater the SA:V for the same volume.

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Root hair protrusion increases SA : V and aids with water uptake.

Highly folded membrane (microvilli) increases SA : V and aids with nutrient uptake.

FIGURE 3 Root hair cells in plants and epithelial cells in animals are shaped in a way that maximises their SA : V and ability to acquire nutrients.

One of the largest plant cells known is that of the green alga *Valonia*, at approximately 1 cm in diameter (the average diameter of plant cells is 30–50 µm). This alga lives in the warm waters of the Great Barrier Reef. Tidal movement ensures the rapid supply of nutrients and removal of wastes. The longest animal cell is the nerve cell of the giant squid (*Architeuthis*), at 2 m long (and width of less than 1 mm). An increase in the internal membranes of the eukaryotic cell can also improve exchange with its environment. However, cells tend to be small and large organisms tend to be multicellular. The cells of multicellular organisms are also arranged in a way that increases the SA : V of various organs – an example is the folding of human intestinal tissue.

Increasing the surface area for metabolic reactions within the cell

Eukaryotic cells contain membrane-bound organelles in which specific metabolic reactions occur. In some of these organelles, the membrane is highly folded – examples are the inner membrane of the mitochondria and the endoplasmic reticulum. This increases the surface area for attachment of enzymes involved in enzyme-controlled reactions. The more enzymes available, the greater the reaction rate for the available substrate.

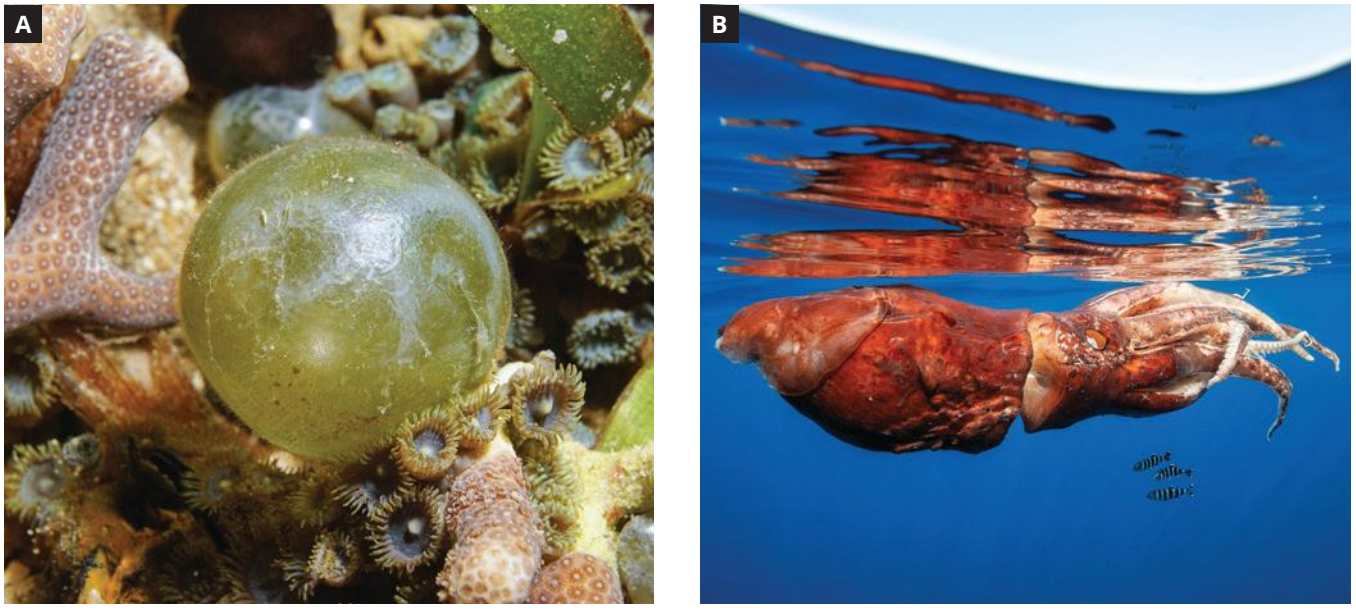


FIGURE 4 (A) *Valonia* is a unicellular organism approximately 1 cm wide. (B) The largest animal cells are in the giant squid, at 2 m long and 1 mm wide.

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Challenge

Supersized single cells

Caulerpa taxifolia (Figure 5) is the largest unicellular organism in the world. It is a marine alga that can grow up to 12 inches long. It looks similar to a fern you might see on land, but it consists of only one cell. This single cell has multiple nuclei, and when a section of the cell is broken off, it becomes a separate individual cell that will grow independently.

1 **Use** your understanding of SA : V ratio to **explain** how *Caulerpa taxifolia* can grow to such lengths. (3 marks)



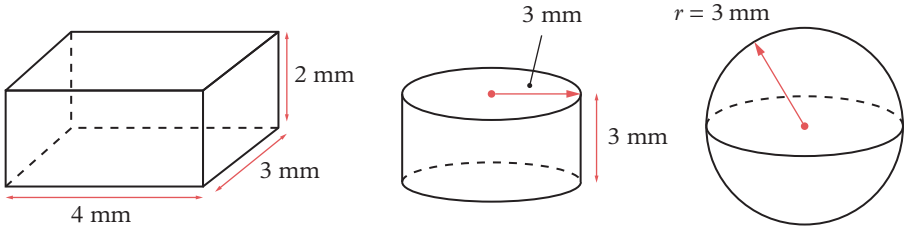
FIGURE 5 *Caulerpa taxifolia*

Skill drill

Calculating surface area-to-volume ratio

Science inquiry skill: Processing and analysing data (Lesson 1.8)

A student wants to determine which of the following cell shapes has the highest SA : V.



Practise your skills

1 **Calculate** the surface area, volume and SA : V of the following cells. (9 marks)

Cell	Surface area	Volume	SA : V
Rectangular prism			
Cylinder			
Sphere			

2 **Determine** which cell shape is likely to result in the greatest rate of diffusion. (1 mark)

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Check your learning 2.8

Check your learning 2.8: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** rate of diffusion. (1 mark)

2 **Explain**, in terms of the cell's nutrients and wastes, why cells generally need to have a large surface area-to-volume ratio. (2 marks)

3 **Explain** how membrane folds or projections out from the body of a cell help to increase the rate of diffusion. (2 marks)

Analytical processes

4 A large, mature cell reproduces by splitting in half through mitosis.

Apply your understanding of surface area-to-volume ratio to **deduce** what will happen to the cell's rate of diffusion. (2 marks)

Knowledge utilisation

5 A student used modelling clay to make models of 'cells' that were a sphere, a rectangular prism, a cylinder and a flat sheet. All had the same volume.

Predict which shape(s) would have:

a the largest surface area-to-volume ratio (1 mark)

b the smallest surface area-to-volume ratio. (1 mark)

Practical

Lesson 2.9

The effect of surface area-to-volume ratio on the rate of diffusion

Learning intentions and success criteria

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MODULE 2

Lesson 2.10
Review: Cell structure

Summary

2.1
- All living things are composed of cells, the building blocks of life.
- Unicellular organisms consist of one cell, while multicellular organisms consist of many cells.
- Prokaryotes are unicellular organisms that do not have membrane-bound organelles.
- Eukaryotes are organisms whose cells have membrane-bound organelles.

2.2
- Organelles have different structures and functions.
- Animal cells and plant cells are organised differently.

2.3
- Practical: Preparation and examination of wet mount specimens

2.4
- Practical: Identifying organelles from electron micrographs

2.5
- The cell membrane is a selectively permeable barrier.
- The fluid mosaic model describes the chemical structure of the cell membrane.
- Protein channels, phospholipids, cholesterol and glycoproteins all have specific roles in the cell membrane.

2.6
- Passive transport is a way of moving molecules across the cell membrane that does not require energy.
- Simple diffusion, facilitated diffusion and osmosis are forms of passive transport.
- Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient.
- Protein-mediated active transport, exocytosis and endocytosis are forms of active transport.

2.7
- Practical: Modelling the selectively permeable membrane

2.8
- Cell size is limited by the ability to diffuse substances.
- The rate of diffusion is affected by the surface area-to-volume ratio of a cell.
- Cells have specific shapes and structures to increase their surface area-to-volume ratio.
- The effect of surface area-to-volume ratio on the rate of diffusion can be observed experimentally.

2.9
- Practical: The effect of surface area-to-volume ratio on the rate of diffusion

Review questions 2.10A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Plant cells can usually be distinguished from animal cells because only plant cells possess

A cell walls and mitochondria.

B Golgi apparatus and central vacuoles.

C cell walls and central vacuoles.

D chromosomes and mitochondria.

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2 In a multicellular organism, the growth rate of a cell decreases as the cell gets larger. Which of the following is the most probable reason for this?
   A The materials needed for growth are in short supply in the surroundings.
   B As the cell gets larger it approaches maturity and assumes a very specialised role, depending on its position in the organism.
   C Most of the energy available for growth of the cell has already been used.
   D Small cells can more readily obtain nutrients and release wastes than large cells in the same environment.

3 A plant cell is in a turgid condition when
   A it is put in an isotonic solution.
   B it is haemolysed.
   C water enters it and causes the vacuole to press the cytoplasm against the cell wall.
   D it is put in a hypertonic solution.

4 Which of the following do all living cells have?
   A mitochondria
   B a cell wall
   C DNA
   D chloroplasts

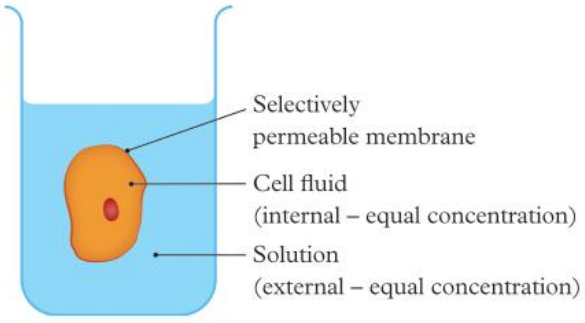
5 Which of the following is not found in animal cells?
   A chloroplasts
   B ribosomes
   C cell membrane
   D vacuole

6 Identify the term used for the transport of water across a membrane.
   A facilitated diffusion
   B osmosis
   C active transport
   D phagocytosis

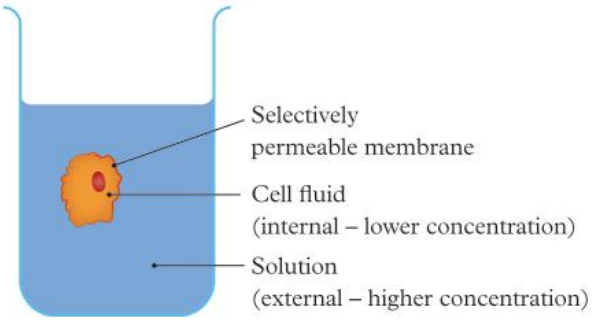
7 Which of the following is a form of active transport?
   A simple diffusion
   B facilitated diffusion
   C osmosis
   D endocytosis

8 Which of the following diagrams of the movement of water in different solutions is incorrect?

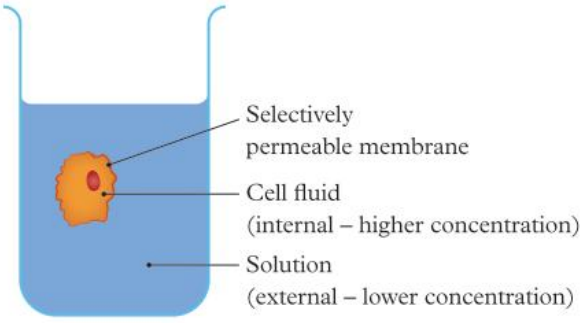
A Isotonic solution



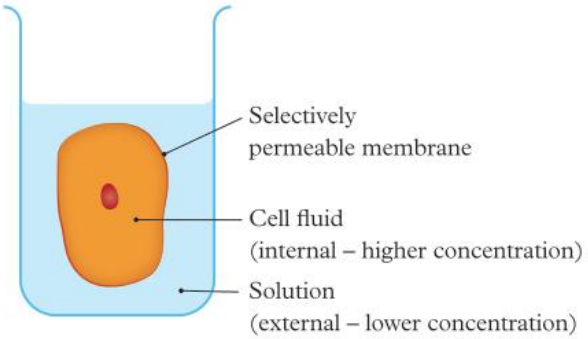
B Hypertonic solution



C Hypertonic solution



D Hypotonic solution



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Review questions 2.10B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

9 **Explain** the meaning of the terms "diffusion" and "concentration gradient". (2 marks)

10 **Describe** a simple experiment to demonstrate diffusion in water. (2 marks)

11 **Explain** how diffusion and osmosis are necessary for cells to exist. (2 marks)

12 **Identify** the function of the Golgi apparatus. (1 mark)

13 **Identify** the function of lysosomes. (1 mark)

Analytical processes

14 The surface area of a cube = $6 \times s^2$, where s is the length of one side.
The volume of a cube = s^3.
The surface area of a cylinder (both ends included) = $(2\pi r \times h) + 2r^2$, where r is the radius, $\pi = 3.14$ and h is the height.
The volume of a cylinder = $\pi r^2 \times h$.
Showing your working for all calculations, **calculate** surface area, volume and SA:V:

a of a cube where s is:

i 1 µm (3 marks)

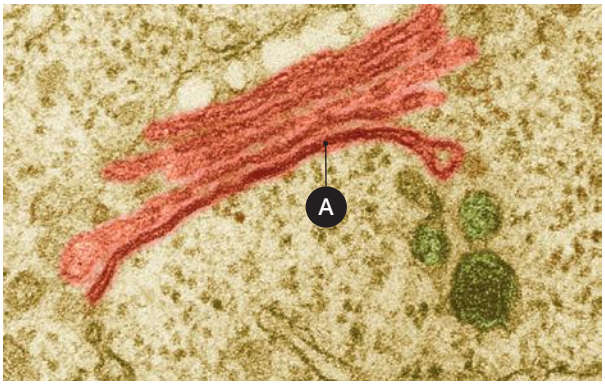
ii 3 µm. (3 marks)

b of a cylinder where $r = 0.5$ µm and $h = 1$ µm. (3 marks)

c Referring to the calculations above, **infer** the most efficient size and shape for a cell. (1 mark)

15 **Compare** prokaryotic and eukaryotic cells. (2 marks)

16 The electron micrograph in the image shows a cell organelle, labelled A.



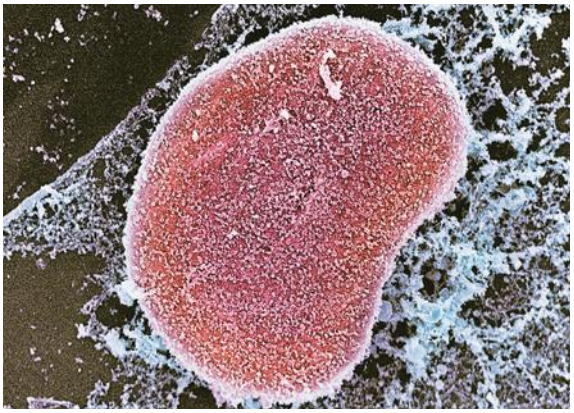
a **Identify** this organelle. Give one reason to support your answer. (2 marks)

b **Judge** whether this organelle is found in plant cells, animal cells or both. (1 mark)

c **Identify** the function of this organelle. (1 mark)

17 Examine the three electron micrographs of cell organelles shown in i, ii and iii.

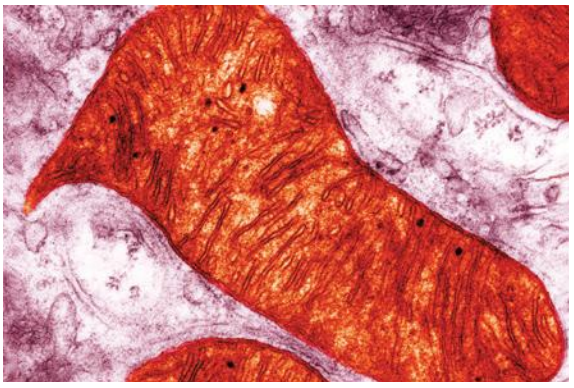
i



ii



iii



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a **Identify** each organelle, giving one reason to support each of your choices. (6 marks)

b **Judge** whether you would expect to find all three organelles in the same cell type. (1 mark)

18 The green alga *Valonia* has the largest known plant cells. This alga lives in tropical oceans with high water movement. The cells are spherical and contain a large, highly folded central vacuole. Apply your understanding of surface area-to-volume ratio and transport of nutrients and waste to **explain** how the *Valonia* cells can be so large. (2 marks)

Knowledge utilisation

19 A group of students on an excursion to a beach collected 50 sandworms of approximately equal size. They organised the worms into five groups of 10. Each group was weighed. Each group of worms was then placed in a separate jar. The students poured into each of the first four jars a different concentration of saline (salt) solution. The fifth jar was filled with normal sea water. The worms were left in the solutions for one hour and then reweighed. (Sandworms can tolerate extremes of salt concentration for several hours.) The weight change for each group of worms was recorded and is shown in the table below.

Jar	Saline concentration (M)	Weight change (g)
1	0.1	+10.0
2	1.0	+5.0
3	1.5	0.0
4	2.0	–10.0
5	Normal sea water	0.0

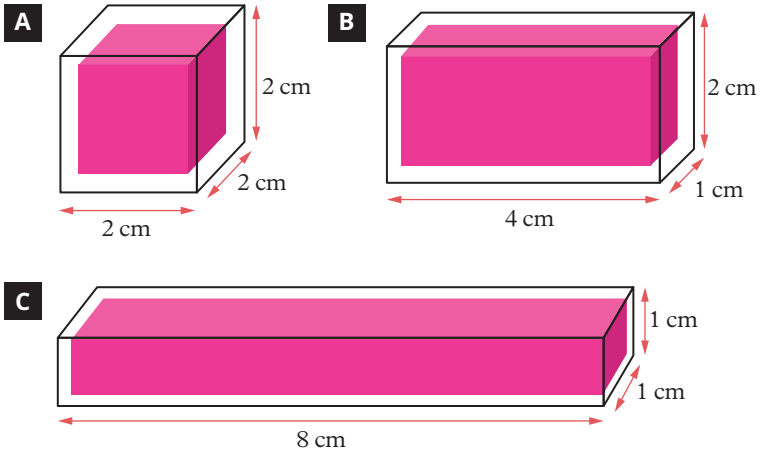
Analyse the relationship between the weight of the worms and the solution in which they were placed, suggesting reasons for any variation in weight. (3 marks)

20 A 5% glucose solution is often given intravenously to patients who have undergone surgery. **Predict** whether the 5% glucose solution will be hypertonic, hypotonic or approximately isotonic. **Justify** your answer. (2 marks)

Data drill

Surface area-to-volume ratio and rate of diffusion

A student is investigating the effect of surface area-to-volume ratio on the rate of diffusion for cells with the same volume. The student created three different-shaped model cells using agar gel infused with the base sodium hydroxide (NaOH) and the pH indicator phenolphthalein, which appears pink in the presence of a base, or colourless in a neutral or acidic environment. She placed the three model cells into a solution of hydrochloric acid (HCl) for 5 minutes. The results of the experiment are shown in the diagram.



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Apply your understanding

1 Examine the qualitative results in Figure 1 to **identify** which cell appears to have the highest rate of diffusion. (1 mark)

2 Complete the table by calculating the results for cell C. (6 marks)

	Cell		
	A	B	C
Dimensions (cm)	$2 \times 2 \times 2$	$4 \times 2 \times 1$	$8 \times 1 \times 1$
Volume (cm^3)	$2^3 = 8$	$4 \times 2 \times 1 = 8$	
Surface area (cm^2)	$6(2^3) = 24$	$2(4 \times 2 + 4 \times 1 + 2 \times 1) = 28$	
Surface area-to-volume ratio	3 : 1	3.5 : 1	
Diffusion distance (cm)	0.3	0.3	0.3
Undiffused volume (cm^3)	$1.7^3 = 4.913$	$3.7 \times 1.7 \times 0.7 = 4.403$	
Diffused volume (cm^3)	$8 - 4.913 = 3.087$	$8 - 4.403 = 3.597$	
Percentage diffusion	$\frac{3.087}{8} \times 100 = 38.6\%$	$\frac{3.597}{8} \times 100 = 45\%$	

Analyse evidence

3 **Identify** which cell had the greatest rate of diffusion (as measured by percentage diffusion) after 5 minutes. (1 mark)

Interpret evidence

4 **Interpret** the relationship between surface area-to-volume ratio and percentage diffusion in this experiment. (1 mark)



Module 2 checklist: Cell structure



Quizlet: Revise key terms online to test your understanding

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MODULE 3

From cell to multicellular organism

Introduction

A multicellular organism originates from a single stem cell. Stem cells can replicate as the same type of cell or become a different type of cell. The processes involved in the development of a multicellular organism include cell proliferation (mitosis), cell specialisation (from stem cells), and cellular interactions and movements, leading to the formation of tissues, organs and systems. These systems improve the efficiency of obtaining nutrients, gas exchange and waste removal in multicellular organisms.

Prior knowledge



Prior knowledge quiz

Check your understanding of concepts related to multicellular organisms before you start.

Subject matter

Science understanding

- → Describe how stem cells originate through the process of mitosis and differentiate into specialised cells to form tissues.
- → Distinguish between unipotent, multipotent, pluripotent and totipotent stem cells.
- → Describe how the hierarchical organisation of cells, tissues, organs and systems allow multicellular organisms to
  - obtain nutrients, e.g. digestive and circulatory systems
  - exchange gases, e.g. respiratory and circulatory systems
  - remove wastes, e.g. respiratory, circulatory and excretory systems.
- → Explain that each body system contains specialised cells and tissues that are structurally suited to function, including
  - size and shape (SA:V ratio)
  - organelle composition.

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Science as a human endeavour

→ Appreciate that
  – pluripotent stem cells have the potential to be grown into specialised cells that can be used to repair or replace ailing organs and tissues. Advances in technology have allowed scientists to reprogram cells to become pluripotent.

Science inquiry

→ Use a light microscope or photographs to
  – view tissues from the respiratory, circulatory, excretory, digestive and/or plant systems
  – compare epithelial, connective, muscle and nervous tissues
  – calculate total magnification and field of view.
→ Explore the safety, ethics and efficacy of stem cell technologies.

Science inquiry skills

→ Use scientific language and representations to systematically record information, observations, data and measurement error, e.g.
  – tables, graphs and diagrams.
→ Use appropriate equipment, techniques, procedures and sources to systematically and safely collect primary and secondary data, e.g.
  – microscopy techniques: total magnification and field of view, scientific drawing.

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Practicals

This lesson is available on Oxford Digital.

Lesson 3.3 Organisation of cells into tissues, organs and systems

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Lesson 3.1
Formation of the multicellular organism

Key ideas

→ The size of a cell is limited by its ability to exchange materials with its environment.

→ Large organisms are composed of many cells organised into tissues, organs and systems, each of which has its own function. These cells communicate with each other for the overall functioning of the organism.

Learning intentions and success criteria

Formation of an organism

All organisms have the same life functions.

- They require nutrients and gases from their environment to carry out metabolic reactions.
- They remove the waste products of metabolic reactions.
- They reproduce.

For a unicellular organism to carry out these functions, there must be chemical communication between the different parts of the cell that allow it to coordinate its activities. Because the exchange of nutrients and waste across the cell membrane needs materials to be in solution, unicellular eukaryotic organisms are often restricted to environments that are rich in moisture or fully aquatic.

As you learnt in Module 2, to operate efficiently, cells cannot grow too large. As a cell grows, its surface area-to-volume ratio (SA:V) decreases, limiting the rate of diffusion of nutrients into a cell and the removal of wastes out of the cell. It is very difficult for a unicellular organism to grow into a large organism. The way in which a eukaryotic organism can grow larger and overcome this limitation is to divide into many small cells. This ensures that each cell has an appropriate SA:V to maximise its functionality. These cells need to be able to hold together, communicate with each other and allow materials to be exchanged and transported to other cells.

daughter cell
a cell produced by the division of a parent (mother) cell

All multicellular organisms start life as a single cell. In sexually reproducing organisms this cell has a combination of the genetic material of both parents, with each parent contributing half its genetic material to the offspring. In asexually reproducing organisms, the cell is a **daughter cell**, a genetically identical copy of the parent's cells. In both cases, the first cell that makes up a multicellular organism contains all the genetic instructions needed

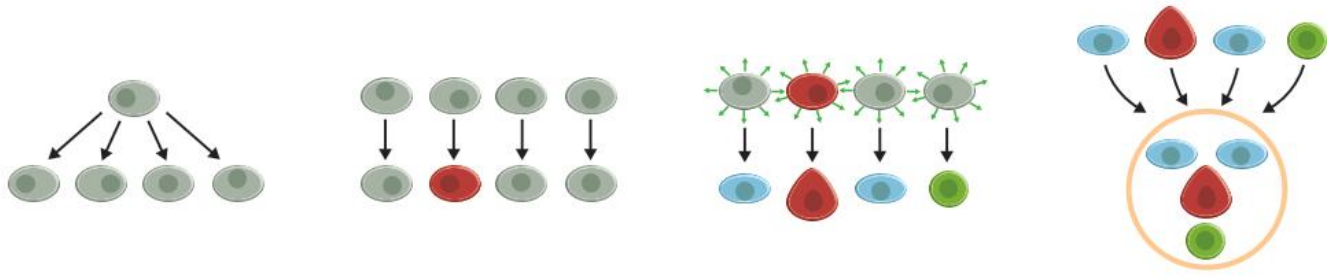


FIGURE 1 Stages in the development of the multicellular organism

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to produce every type of cell in the multicellular organism. This first cell must undergo a series of stages to produce the final organism.

1 **Cell proliferation** – the cell produces many more daughter cells with the same genetic code. Every cell in an individual organism will contain the same genetic code as this first cell.
2 **Cell specialisation** – daughter cells have a specialised structure and function. For example, in humans, red blood cells are specialised to carry oxygen around the body, while immune cells attack pathogens.
3 **Cell interaction** – cells communicate with each other in a coordinated manner. For example, a muscle cell that needs extra nutrients such as glucose or oxygen must be able to communicate to the rest of the multicellular organism that more glucose or oxygen should be supplied.
4 **Cell movement** – cells start forming the multicellular organism by moving to their correct positions. This ensures that each cell is surrounded by other cells that provide essential requirements. In this way, specialised **tissues** form.

cell proliferation
the formation of new cells via cell division

cell specialisation
the process in which a generic cell develops the structures needed to function as a specific type of cell

cell interaction
any form of communication or exchange between cells

cell movement
the migration of cells from one location to another

tissue
a group of cells of the same cell type, performing a function

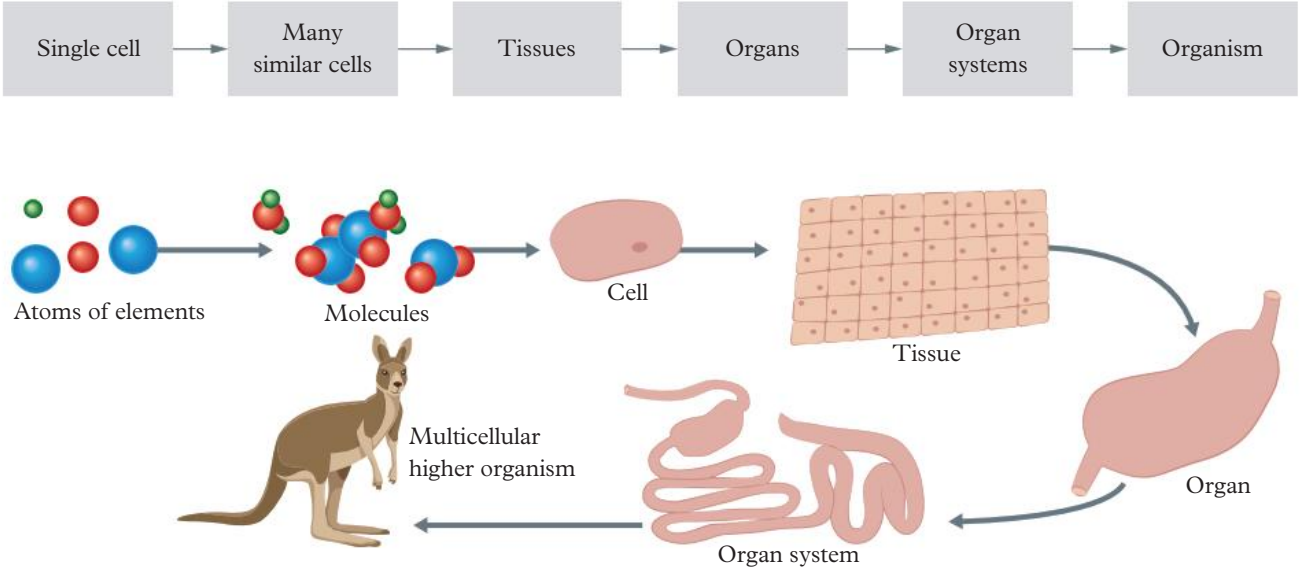


FIGURE 2 Multicellular organisms all share the same basic structural hierarchy.

Check your learning 3.1

Check your learning 3.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the factor that limits the size of unicellular organisms. (1 mark)
2 **Define** "daughter cell". (1 mark)
3 **Describe** the four processes involved in the formation of a multicellular organism from a single cell. (4 marks)

Analytical processes

4 **Deduce** why unicellular eukaryotic organisms are found only in moist environments. (1 mark)

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Lesson 3.2
Organisation of cells in multicellular organisms

Key ideas

- → Tissues are composed of cells of one type that are differentiated for a particular function (e.g. cardiac muscle).
- → Organs are functional and structural units made up of more than one type of tissue (e.g. the heart).
- → A system comprises different organs working together for one main function (e.g. the respiratory system).
- → Plants have tissues arranged into organs (e.g. the leaf) and two systems (root and shoot).

Learning intentions and success criteria

Specialised cells

As multicellular organisms become more complex, the number of specialised cell types they have increases. To ensure that specific cells can function to support the survival of an organism, complex multicellular organisms are organised in a hierarchy:

cells → tissues → organs → systems

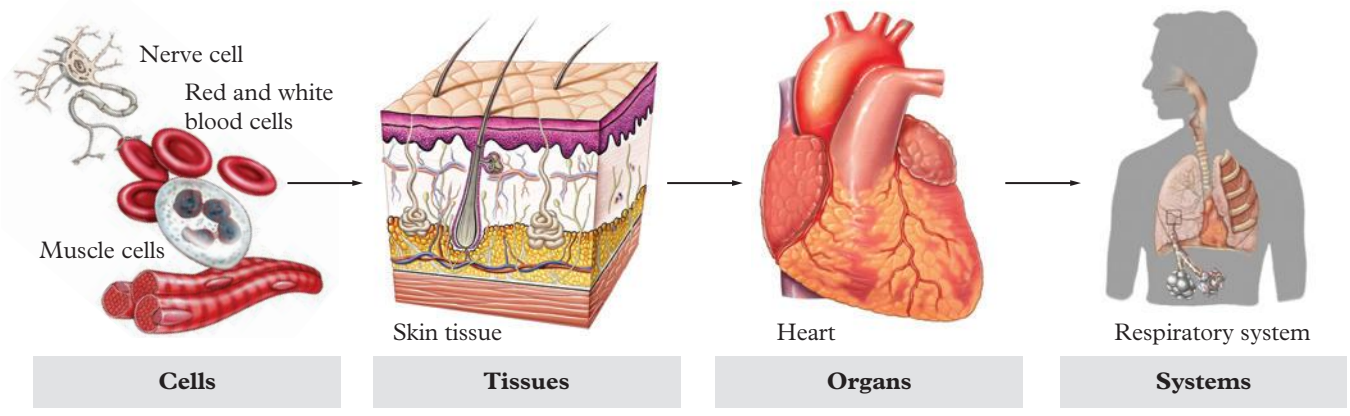


FIGURE 1 Levels of organisation in complex multicellular organisms

In Lesson 3.1 you learnt that cells specialise into different cell types, each type developing specific structures that suit their function(s). Because different genes are activated during cell specialisation, each cell type produces different proteins. This difference in protein production dictates the cell's structure and function. Cell types commonly found in mammals include red blood cells, nerve cells, muscle cells, epithelial cells, immune cells, sex cells, bone cells and fat cells. Each of these cell types has a different function and is made up of a selection of organelles that allows it to perform its role. For example, mature red blood cells, which carry oxygen around the body, lack a nucleus to increase their carrying capacity. Muscle cells, which contract to facilitate movement, contain higher concentrations of mitochondria because they use up more energy to contract.

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Other complex organisms such as plants also have specialised cell types. For example, the function of root hair cells is to absorb water, while guard cells control gas exchange.

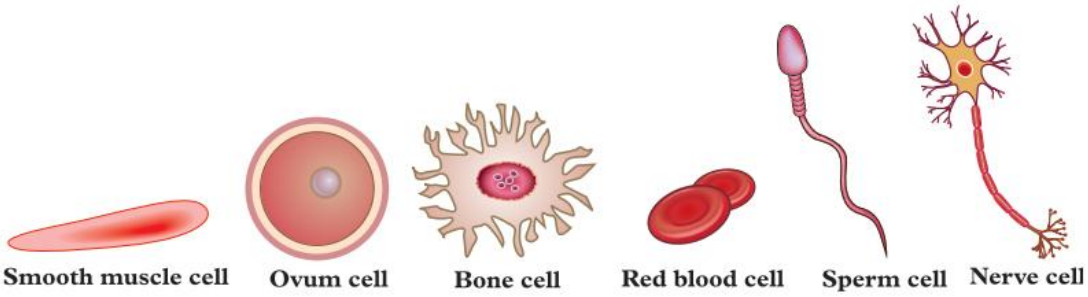


FIGURE 2 Specialised cells perform different functions.

Tissues

In most multicellular organisms, the cells are arranged into tissues. A tissue is a group of the same type of cells specialised to perform a specific function. The cells in a tissue are bathed in **extracellular fluid**. Exchanges of chemicals occur between the cell and its surrounding fluid in a similar way to those between unicellular organisms and their aquatic environment. The cells within a tissue are held together by integral proteins along the cell membrane that attach to cells of the same type. Common tissue types in mammals are:

- epithelial tissue – made up of epithelial cells that coat or line the surface of organs. Provides protection and support, and secretes and absorbs nutrients
- connective tissue – connects, supports and separates other tissue types (e.g. blood, bone, cartilage, lymph)
- muscle tissue – made up of muscle cells that can contract and allow the body to move
- nervous tissue – made up of nerve cells that allow the body to send and receive neural messages.

extracellular fluid
body fluid outside the cells of any multicellular organism; enables the transport of materials between cells and maintains a constant environment for cellular processes

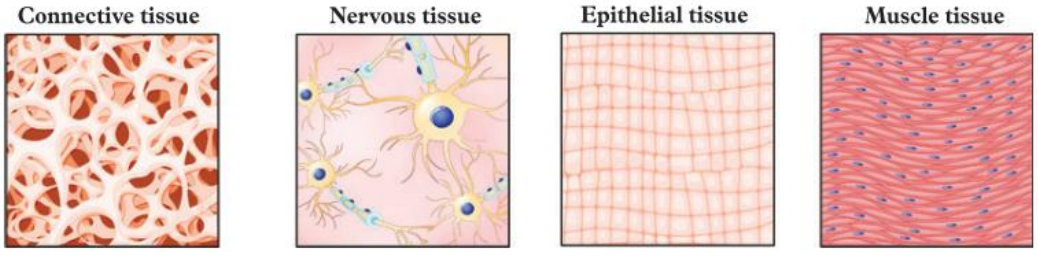


FIGURE 3 Tissue types in mammals

Sometimes specialisation for a function results in a change to the shape of cells. For example, epithelial tissue that lines parts of an animal is called **epithelium**. Cells on the outside of the organism tend to be flat; this type of tissue is called squamous epithelium. This shape provides stability and binding, so the underlying tissues are protected. The cells of other epithelial tissues may be column or cube shaped. Tissue formation also involves structural changes to the individual cells of each tissue type. Some cells that make up epithelial tissue have **cilia** or microvilli on their surface, to increase their surface area for absorption of nutrients.

epithelium
body tissue that forms the lining of all internal and external surfaces in the body

cilia
microscopic hairlike projections from the cell membrane that pulse, causing currents in the surrounding fluid

Like mammals, plants also consist of more than one type of plant tissue. These tissues include vascular tissue, which controls the flow of water and nutrients around the plant, epidermal tissue, which covers the external parts of the plant, and parenchyma tissue (the location of photosynthesis).

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Organs

organ
a group of different tissues bound together to perform a particular function

An **organ** is a structural and functional unit composed of more than one type of tissue and multiple cell types. For example, the human heart is made up of muscular, epithelial, connective and nervous tissue. Other examples of organs in mammals are the brain, lungs, liver, kidneys and stomach. Plants also have organs, such as roots, stems and leaves.

Systems

system
different organs working together to perform a specific function

A **system** is composed of different organs working together to perform one main function. For example, the excretory system includes the kidneys, ureter, bladder and urethra working together to remove wastes and excess fluid from the body. Systems are coordinated to facilitate the supply of nutrients to, and production/removal of materials from, all cells of the organism.

Mammalian systems

Most vertebrates have similar body systems. However, each system's precise structure and function vary according to the environment in which the organism lives. While some systems are regarded as more important than others, almost every body system is needed for survival. If one organ within a system is damaged or malfunctions, this can have major consequences for other systems, which could result in the death of the organism. A summary of the major mammalian body systems is given in Table 1. You will learn more about each of these systems throughout Units 1&2 Biology.

TABLE 1 Summary of major mammalian systems

System	Function(s)	Components
Nervous	• Sends and receives messages around the body	Brain, spinal cord and nerves
Circulatory	• Circulation of blood, loaded with nutrients and oxygen, throughout the body • Removal of waste products of metabolism to excretory systems • Exchange of gases • Body temperature control • Transport of hormones	Heart, blood vessels (arteries, veins and capillaries) and blood
Respiratory	• Absorbs oxygen through breathing actions • Releases carbon dioxide from the body • Removal of wastes	Lungs, bronchi, diaphragm, pharynx and larynx
Digestive	• Breaks down food (complex molecules to monomers) into nutrients to be absorbed by the blood and taken to different parts of the body • Elimination of undigested food	Mouth, salivary glands, oesophagus, stomach, intestines (and associated organs – liver, pancreas, gall bladder)
Excretory	• Extracts nitrogenous and other wastes from the blood and removes them from the body	Kidneys, ureters, urinary bladder, urethra
Endocrine	• Releases hormones into the body • Helps the body maintain homeostasis (internal balance)	Pancreas, hypothalamus, glands (e.g. pituitary, thyroid, parathyroid, thymus, adrenal)

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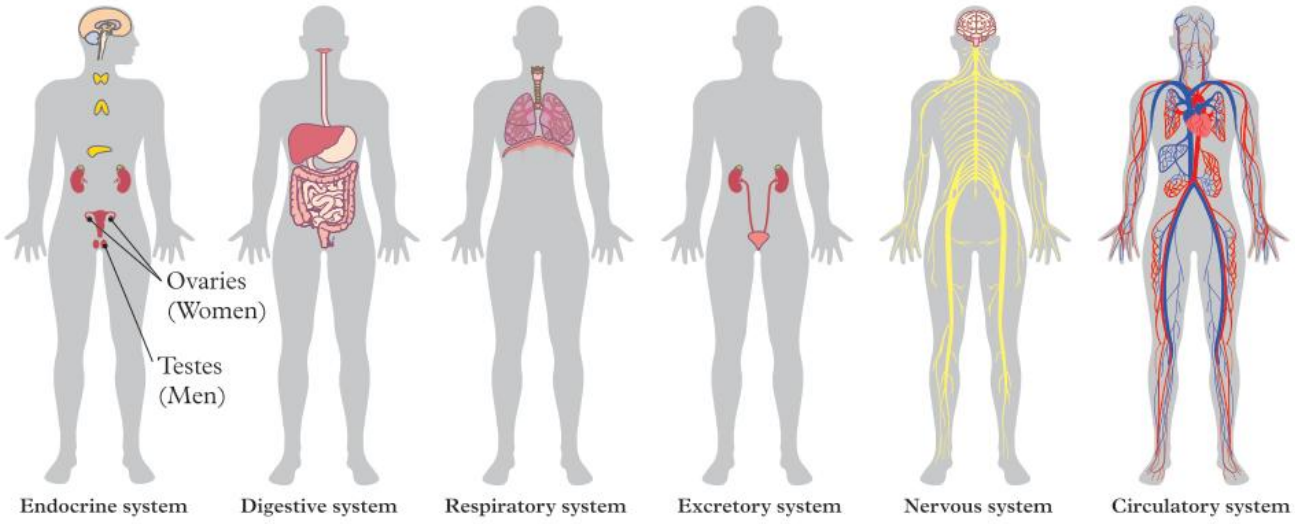


FIGURE 4 Major mammalian systems

Plant systems

There are two plant systems. The shoot system is composed of all the tissues above the ground, and the root system controls the function of tissues below the ground. The shoot system consists of organs, including the leaf, shoots and reproductive organs (e.g. flowers). The root system consists of the roots, tubers (storage organs) and rhizomes (underground stems).

Communication between cells

For an organism to survive, its cells, tissues, organs and systems must coordinate with each other. Communication among the cells of tissues, between organs and therefore between systems, is achieved by chemical signals, in a similar way to how messages are sent within a cell. Substances transported out of a cell travel to another cell, causing a change in the recipient (target) cell. In animals, cells coordinate in two ways: slowly, through the transmission of chemical hormones; or quickly, via electrical impulses in the nervous system.

Check your learning 3.2

Check your learning 3.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the following:
   - **a** a cell (1 mark)
   - **b** a tissue (1 mark)
   - **c** an organ (1 mark)
   - **d** a system. (1 mark)

2 **Explain** why a particular type of cell might have a higher energy requirement than another type of cell. (1 mark)

3 **Identify** the role of extracellular fluid in multicellular organisms. (1 mark)

4 **Explain** how coordination between tissues, organs and systems occurs in animals. (2 marks)

Knowledge utilisation

5 For each of the scenarios below, **determine** the system that is most likely to be affected and **propose** one negative side effect that may result based on that system's function.
   - **a** Ayesha is in a car accident, in which her kidney is punctured. (2 marks)
   - **b** After years of smoking, Reuben develops chronic bronchitis (long-term inflammation of the bronchi). (2 marks)

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Practical

Lesson 3.3
Organisation of cells into tissues, organs and systems

Learning intentions and success criteria

oxforddigital **This practical lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.**

Lesson 3.4
Mitosis

Key ideas

- → There are three stages of the cell cycle: interphase, mitosis and cytokinesis.
- → During interphase, the cell grows and prepares for cell division.
- → During mitosis, the nucleus of the cell is replicated.
- → During cytokinesis, the cytoplasm of the cell divides, forming two identical daughter cells.

Learning intentions and success criteria

The cell cycle

cell cycle
the continuous cycle of growth and division in cells

interphase
stage in the cell cycle in which the cell grows, stores energy and replicates chromosomes

mitosis
nuclear division resulting in daughter cells with the same number and types of chromosomes as in the parent cell

cytokinesis
division of cells after mitosis

The **cell cycle** is an organised series of events that involves the growth of a cell and its division into two genetically identical daughter cells. There are three stages of the cell cycle:

- **interphase** – the longest stage, when the cell undergoes normal growth and prepares for cell division
- **mitosis** – the nucleus of the cell divides
- **cytokinesis** – after mitosis, the cytoplasm of the cell divides, forming two identical daughter cells.



FIGURE 1 Onion cells undergoing cell division

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In this lesson you will learn about each of these stages and the processes involved when a cell replicates.

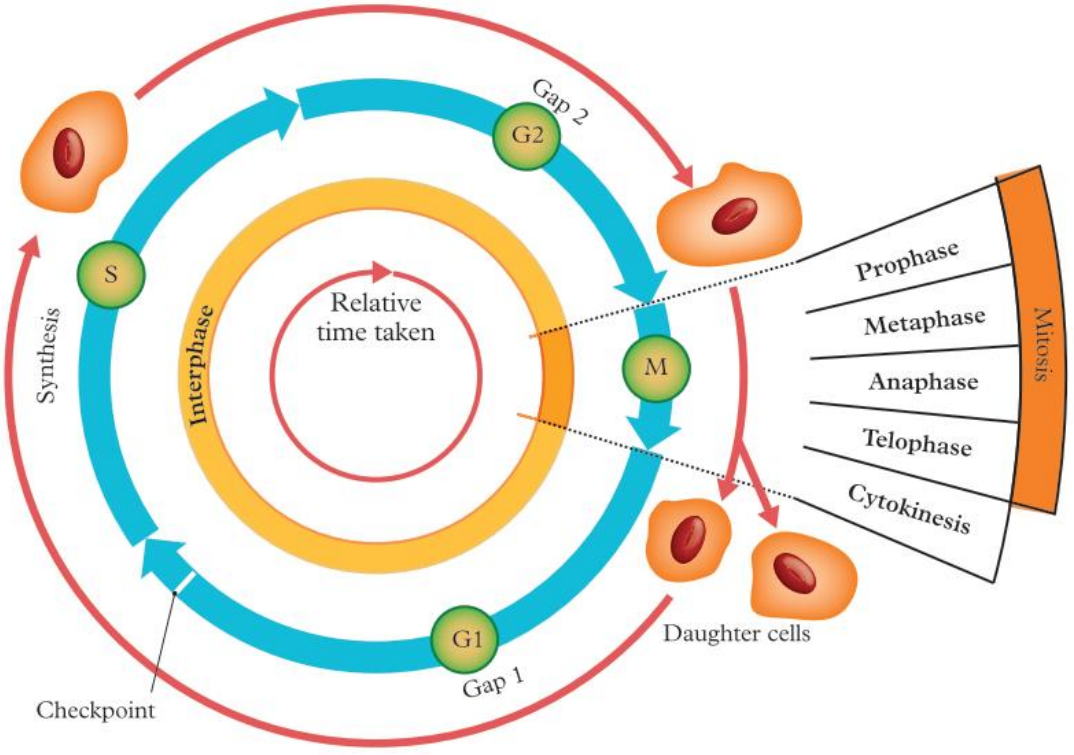


FIGURE 2 The cell cycle

Interphase

During interphase, a cell actively undergoes the many chemical reactions needed for it to stay alive. This includes reactions necessary to prepare the cell for division. There are three phases of interphase:

- gap 1 (G1)
- synthesis (S)
- gap 2 (G2).

G1 phase

In multicellular organisms, the cells spend most of their time undergoing the everyday metabolic activities of the first stage of interphase, the G1 phase. During this phase, a cell grows to its maximum size for efficient nutrient and waste exchange across the membrane. When the cell has reached this point it will either maintain its function level (e.g. adult brain cells) or prepare to undergo cellular division.

Before a cell can undergo mitosis, it must first check that all the genetic material (DNA) is intact and that all its organelles and enzymes are functioning correctly. Chemical messengers inside the cell check the health of the cell at the G1 checkpoint. If this check suggests that something is wrong, the cell will undergo a process of organised cell death, called **apoptosis**.

apoptosis
programmed cell death

If the chemical messengers inside the cell indicate that cellular functioning is occurring correctly, the cell will pass into the second part of interphase, the S phase.

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S phase

chromatin
a complex structure made up of DNA wrapped around proteins called histones; condenses to form a chromosome

Deoxyribonucleic acid (DNA) is strung out in long threads, called **chromatin**. Before a cell can replicate, it must make a copy of each DNA molecule in the cell. The second stage of interphase, S phase, is when DNA is replicated. During S phase, the cell's DNA unwinds and separates into two single strands (Figure 3).

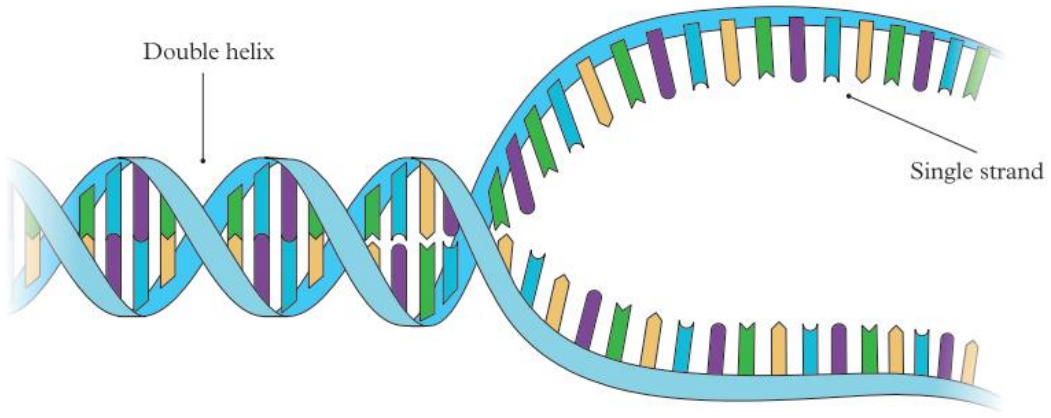


FIGURE 3 DNA unwinding into two single strands

chromatid
a replicated chromosome, still attached to the original at the centromere

centromere
the point of attachment of two chromatids

Each strand then synthesises a new complementary strand of DNA, which results in two molecules of identical DNA, called **chromatids** (Figure 4). Chromatids remain attached at a central point called the **centromere**. After the DNA has been replicated and the chromatids are attached to the centromere, the cell can enter the G2 phase.

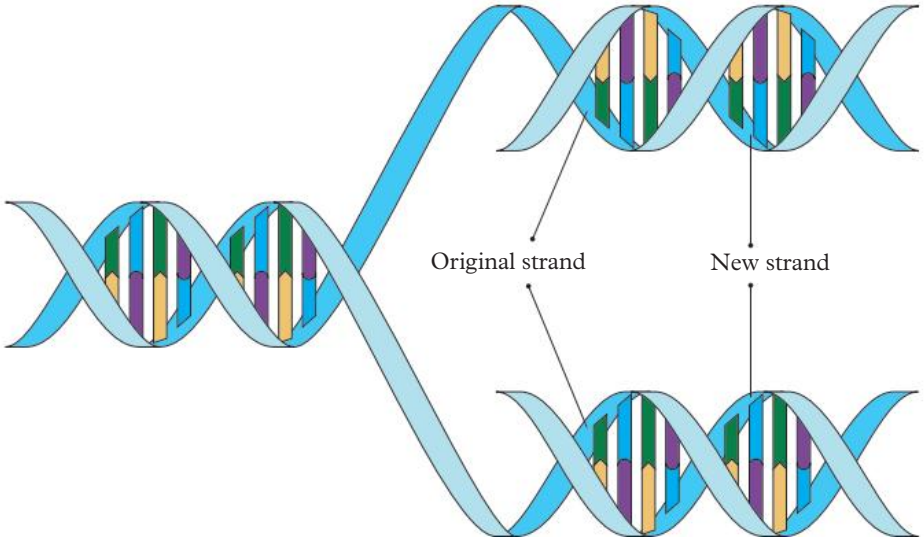


FIGURE 4 DNA replication results in two identical molecules of DNA, called chromatids. Each chromatid is made up of one original strand of DNA and one newly synthesised strand of DNA.

G2 phase

centriole
an organelle that produces spindle fibres, which separate the chromosomes during mitosis

The third and final stage of interphase is G2. This stage requires energy and nutrients. During G2, the cell synthesises an extra copy of each organelle and protein to prepare the cell for division. In animal cells, the **centrioles** replicate. Strands of protein that will form the spindle fibres start to develop. By the end of the G2 phase, the cell will have accumulated the chemical resources and energy necessary to make a whole new copy of the nucleus (mitosis).

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Mitosis

Mitosis or "nuclear division" is the second stage of the cell cycle, when the cell's nucleus replicates. It has four stages: prophase, metaphase, anaphase and telophase.

Prophase

During **prophase**, the cell's chromatin condenses into a form of DNA called a **chromosome**. Each chromosome consists of two "sister" chromatids, which lie parallel to each other and are joined at the centromere (Figure 5).

Each chromatid contains one side of the original DNA and a new complementary, replicated side. While the chromosomes are condensing, a series of protein threads form a structure, called a spindle, that extends the full length of the cell. The two ends of the spindle are called the poles and the middle region is the equator. In animal cells, the spindle-producing centrioles separate and migrate to opposite poles of the spindle. The nucleolus of the nucleus breaks down, as does the nuclear membrane.

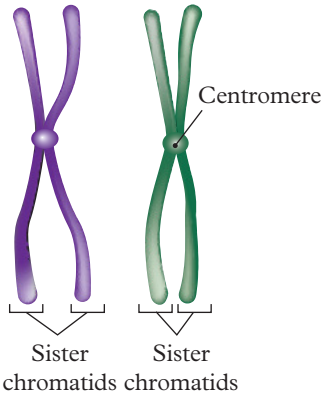


FIGURE 5 A chromosome consists of two sister chromatids attached at the centromere.

prophase
the first stage of cell division, in which the chromosomes condense, sister chromatids join together and the nucleolus and nuclear membrane dissolve

Metaphase

Metaphase follows the breaking down of the nuclear membrane. The chromosomes migrate to the centre (equator) of the cell and each attaches its centromere to an individual spindle fibre. The arrangement of the chromosomes on the spindle fibres is apparently random and may change from division to division.

Anaphase

During **anaphase**, the sister chromatids of each chromosome separate, and are no longer attached by their centromeres. The identical sister chromatids are each pulled by the spindle to opposite poles of the cell. The exact mechanism is not known, but congregation of mitochondria around the spindle suggests that large amounts of energy are required. It is thought that the spindle fibres, with the input of energy, contract and separate at the equator and, as they pull towards opposite poles, the centromeres separate to release the sister chromatids.

Telophase

During **telophase**, chromosomes congregate tightly together when they reach the polar ends of the spindle. The spindle then breaks down and a nuclear membrane forms around each bundle of chromosomes. The nucleolus starts producing nucleotides and the chromosomes uncoil and revert to chromatin threads.

Cytokinesis

Cytokinesis is when the entire cell divides, so each new daughter cell has a complete set of chromosomes as well as cytoplasm and organelles. While telophase is occurring, division of the cytoplasm between the new groups of chromosomes commences. In animal cells, the cell membrane constricts across the centre (equator) of the cell, forming two new cells. In plants, a cell plate formed from vesicles of the Golgi apparatus grows across the middle of the cell. The new membrane joins with the existing cell membrane to form two cells. New cell walls are produced between the membranes of the plate prior to separation. Each new cell formed from cytokinesis then enters interphase and the cycle repeats.

Although cytokinesis normally follows the formation of the new nuclei (mitosis), there are exceptions. The formation of skeletal muscle fibres in vertebrate animals, for example, results from mitosis without cytokinesis. These cells often have multiple nuclei in a single cell.

chromosome
highly condensed chromatin fibres that form for the process of cell division

metaphase
the second stage of cell division, in which the chromosomes align in the middle of the cell and spindle fibres attach to the centromeres

anaphase
the third stage of cell division, in which sister chromatids separate and are pulled to opposite poles of the cell

telophase
the fourth stage of cell division, in which sister chromatids reach the ends of the cell and unravel back to chromatin, and the nuclear membrane and nucleolus re-form

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Study tip

In **M**etaphase, the chromosomes line up along the **M**iddle of the cell.
In **A**naphase, the chromosomes move **A**way from each other.

Some cell types go through the cell cycle – growth, mitosis and cytokinesis – continuously throughout the life of the organism. Because the red blood cells of vertebrates do not have a nucleus and live only for about 120 days, special stem cells in the bone marrow constantly divide to maintain enough red blood cells in the body. Other cell types (e.g. some brain cells) do not undergo further division once the organism is mature. A third category of cells divide only at a sufficient rate to produce the number of cells required for growth and replacement. Human liver cells, for example, do not normally divide after the liver has reached a certain size. If some of the liver is surgically removed, the existing cells are triggered into division mode until the liver has regained its original size. Cell division then stops.

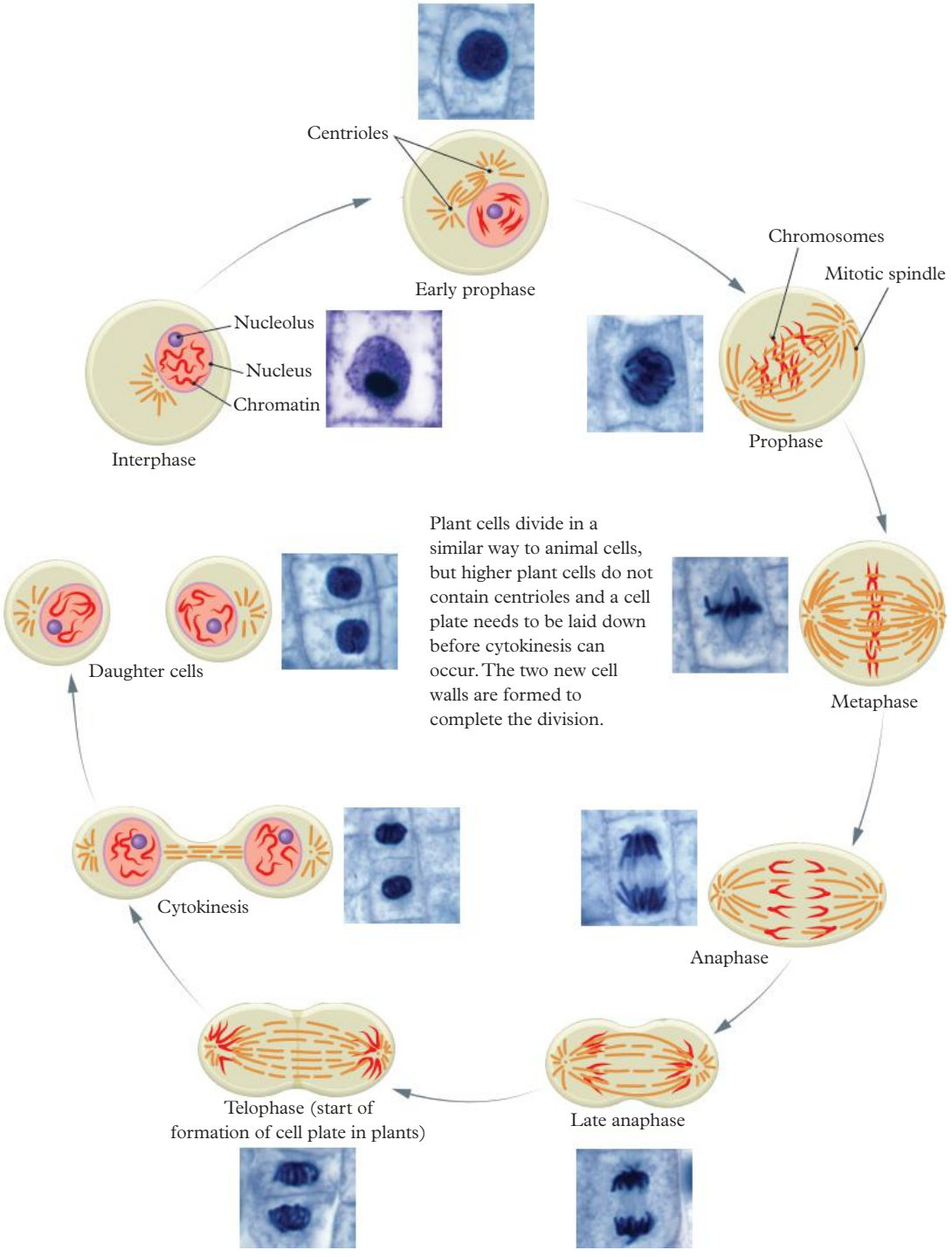


FIGURE 6 Stages of mitosis and cytokinesis in a diploid cell (a cell that has two of each type of chromosome). An animal cell is shown in the drawings and a plant cell in the photographs.

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Summarising the cell cycle

The cell cycle is a complex process with many events. The key events of the cell cycle can be summarised as follows:

- Just prior to division, the DNA replicates. Each chromosome now consists of two identical chromatids.
- Each chromosome attaches to a separate spindle fibre.
- The chromatids of each chromosome separate and move to opposite poles of the spindle. This ensures that each pole contains the same number and types of new chromosomes.
- The daughter cells will therefore have an identical set of chromosomes to the original cell.
- At each division, two daughter cells are produced.
- The time between divisions (interphase) is needed for the cell to grow, store energy, and replicate its DNA and organelles.

The nature of the control system or systems that regulate the cell cycle is still not fully understood. Certain hormones (e.g. growth hormones) and other chemicals have been shown to stimulate cell division. Other chemicals, or cell overcrowding, can inhibit division. The control of cell division is of particular interest to researchers, because cancers result from uncontrolled cell division in multicellular organisms.

Real-world biology

Cancer – uncontrolled cell division

Within each cell of multicellular organisms is a series of genes that program for cell death, or apoptosis. Other genes suppress these death genes. It appears that the balance of activity between the two sets of genes determines whether a cell lives or dies. In many cases studied, damage to the cell's DNA triggers the activity of the death genes and suppresses that of the survival genes. These sets of genes help prevent a cell from growing uncontrollably. For a cell to mutate and become a cancer-causing cell, up to six changes to the operation of its DNA have to occur.

1. The cell becomes self-sufficient. Most cells need signals from other cells before they can undergo mitosis. Cancerous cells can signal themselves to divide.
2. The cell blocks the signal that stops mitosis. All cells have genes that suppress mitosis and prevent the cell from growing uncontrollably. A mutation in these genes allows a cell to divide at any time.
3. The cell avoids apoptosis. This is caused by a mutation in the genes that would normally make the cell apoptose.
4. The cell is able to undergo limitless cell cycles. Cancerous cells can divide an unlimited number of times.
5. The cell has access to nutrients through a good blood supply. Most cancerous cells can encourage blood vessels to grow around them.
6. The cell is able to migrate (metastasise) around the body. This enables it to spread to new sources of nutrition.

Cancer cells kill the surrounding cells, either by strangling them or by being more competitive in using the

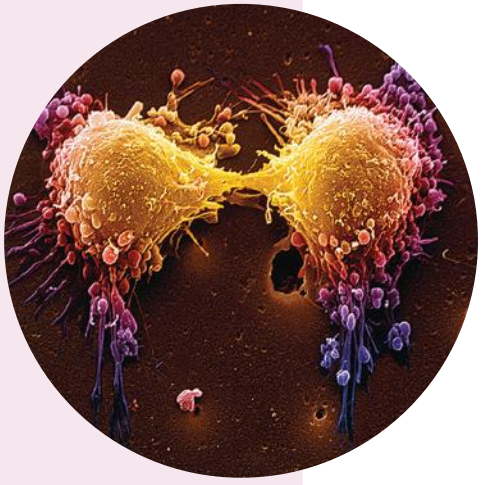


FIGURE 7 Cancer cells in the final stage of cell division (cytokinesis)

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limited resources available. Vital functions of the body are therefore disrupted and this can affect the survival of the multicellular organism.

The causes of cancer are numerous. All cancer cells result from changes in the DNA of body cells. Some cancers result from constant injury or aggravation of tissue (e.g. when a benign mole becomes cancerous), mutagens (radiation and chemicals that cause DNA changes or mutations) or viruses.

Apply your understanding

1 **Explain** the importance of "death genes" and "survival genes" in a normal cell. (2 marks)

2 **Identify** why it is important for scientists to learn about the control process of cell division. (1 mark)

3 According to the Skin Cancer Foundation, a person's risk for melanoma doubles if they have had more than five sunburns.

a Hypothesise why multiple burns are stated. (1 mark)

b Pose a research question to address an aspect of this claim. (1 mark)

Check your learning 3.4

Check your learning 3.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Select** the correct order for the following events of the cell cycle. (7 marks)

- DNA replicates.
- Chromosomes line up at the equator of the spindle.
- Spindle forms.
- Nuclear membranes form.
- Chromatids separate.
- Nuclear membrane disintegrates.
- Chromosomes move to opposite ends of the spindle.

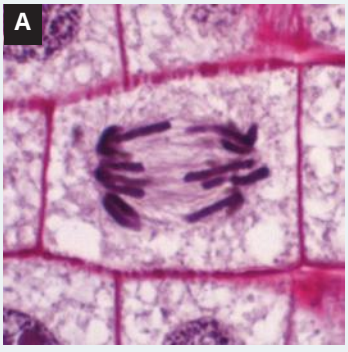
2 **Identify** the longest stage in the cell cycle for most cells. (1 mark)

3 **Describe** the structure that is unique to plant cell division. (1 mark)

4 **Describe** the importance of DNA replicating before mitosis takes place. (1 mark)

Analytical processes

5 **Identify** the stages of mitosis shown in the images. **Justify** your decision. (4 marks)





Knowledge utilisation

6 A student is reading an old biology textbook and comes across a description of interphase as a "resting phase". **Apply** your knowledge to **argue** why this term is inappropriate. (3 marks)

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Lesson 3.5
Stem cells

Key ideas

- → A stem cell is a cell that can replicate or differentiate into one or more cell types.
- → There are two types of stem cells: embryonic stem cells and adult stem cells.
- → Stem stells can be classified as totipotent, pluripotent, multipotent or unipotent.

Learning intentions and success criteria

Stem cells

Multicellular organisms begin life as a fertilised egg cell (**zygote**), which has the potential to form an entire organism. The first few cycles of cell division via mitosis produce identical, unspecialised cells, called **stem cells**. After several cycles, these cells begin to specialise, preparing to form the different organs and tissues of the body. Even when the organism is fully formed, the cells need remnant sets of unspecialised cells.

zygote
a fertilised egg cell that has the potential to form all the cells of an organism

stem cell
a cell that is capable of forming different cell types

When an organism is damaged or a cell "wears out", the cell may need to be replaced. If the cell is specialised, it must be replaced by another cell with the same specialisation. Because the body cannot afford to store extra specialised cell types to replace damaged cells, stem cells are maintained throughout the body. When required, these stem cells will undergo mitosis to produce specialised replacement cells.

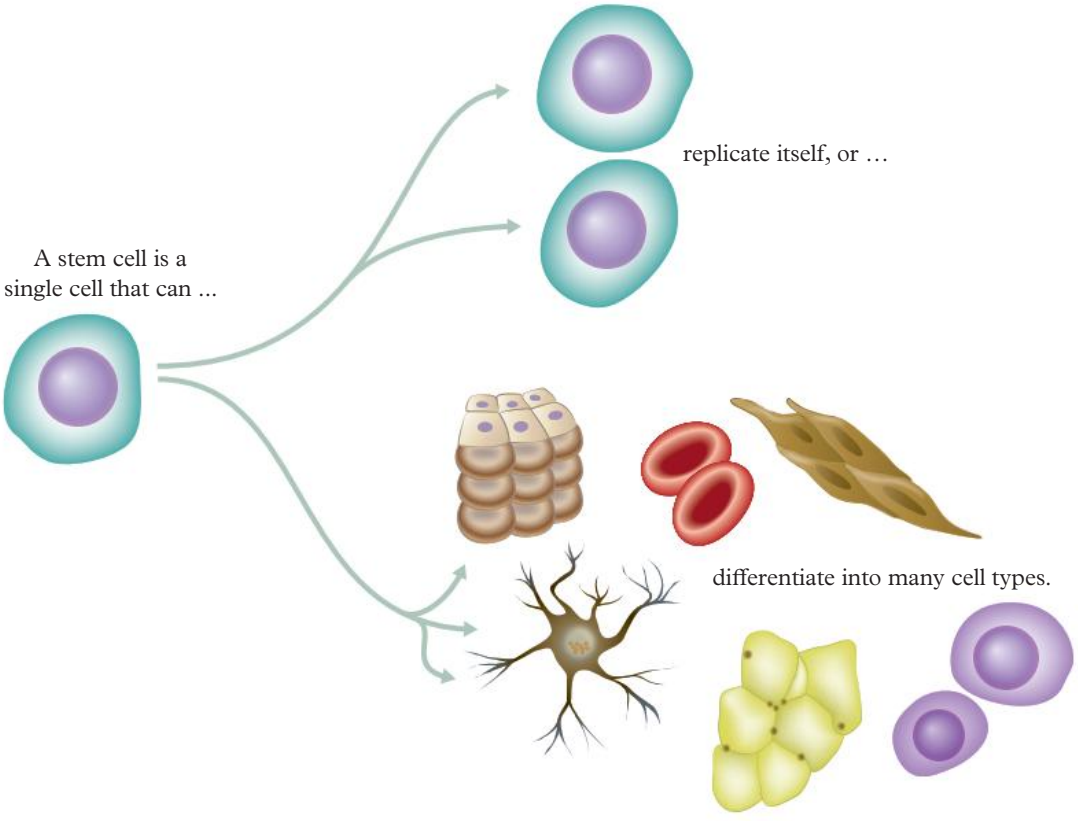


FIGURE 1 A stem cell can either replicate or differentiate into different cell types.

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Stem cells are unspecialised cells that have the capacity to develop into different cell types under special conditions. Some of these cells can activate any part of their genetic material if it is needed.

All stem cells have two main properties:

self-renewal
the ability to divide to produce more stem cells

potency
the ability to differentiate into other cell types

- **self-renewal** – the ability to go through several cell cycles without further differentiation. Stem cells are unique in this, as they can continually self-renew throughout the life of the organism.
- **potency** – the ability to differentiate (change) into specialised cell types. Different types of stem cells have varying degrees of potency.

Stem cells in animals

blastula
a hollow ball of cells resulting from division in an animal zygote

gastrula
the early embryonic stage in animals, formed from the ingrowth of cells at one end of the blastula to produce a double layer of cells from which future tissues and organs develop

embryonic stem cell
an undifferentiated, totipotent or pluripotent cell in the early embryo

adult stem cell
a partially differentiated animal cell, responsible for repair and maintenance of the adult body

totipotent stem cell
an undifferentiated cell that can later differentiate into any type of cell

pluripotent stem cell
a stem cell that can differentiate into any cell type within a broad group

multipotent stem cell
a stem cell that can only differentiate into a limited number of closely related cell types

Cell potency is the capacity of a cell to differentiate into different cell types. Cells with high potency can differentiate into many different types of cells, while cells with low potency are limited in the number of cell types they can differentiate into. A stem cell's potency is determined by the stage in which the stem cell developed.

In animals, the first mass of cells formed in the embryo develops as a hollow ball with a single layer of outer cells, called the **blastula**. As further division occurs, in all animals except sponges, one end of the mass begins to push into the cavity of the embryo to form a double layer, called the **gastrula**. This triggers the first stage of cell differentiation. Depending on where the cell is in the gastrula, it will receive a chemical message to switch the DNA of specific genes on or off.

Embryonic stem cells, which are those that formed in the embryo during the early stages of an organism's life, can differentiate into many cell types – they have high cell potency. **Adult stem cells**, which are those that formed outside of the embryo, are more restricted in their ability to differentiate into different cell types. Different levels of potency include totipotent, pluripotent, multipotent and unipotent.

Totipotent cells

Totipotent stem cells are the first cells that form during cell proliferation in a multicellular organism – all their genetic material is expressed in the daughter cells formed. Totipotent stem cells are embryonic stem cells and can differentiate into any cell type in an organism. They are only produced in the early stages of embryo development.

Pluripotent cells

Pluripotent stem cells are also embryonic stem cells and can differentiate into almost any cell type in an organism. Unlike totipotent cells, pluripotent cells are unable to differentiate into placental cells. This is because they are formed inside the blastocyst at a later stage of embryo development than totipotent cells, after the first stage of cell differentiation. With further development, pluripotent cells become more and more specialised. Once an infant is born, cells become so specialised that they can only differentiate into a limited number of cell types.

Multipotent cells

Multipotent stem cells are adult stem cells and can only specialise into a single, closely related "family" of cells. For example, cells in the bone marrow are multipotent as they can become any of the cells found in the blood (red blood cells, white blood cells or platelets) but cannot produce any other cell types.

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Unipotent cells

Unipotent stem cells are adult stem cells that can produce only their own cell type. For example, stem cells within the ovaries are only able to differentiate into oocytes (egg cells) and no other types. Unipotent and multipotent stem cells are often responsible for repair and maintenance of the adult body.

unipotent stem cell
a stem cell that can only form one cell type on division

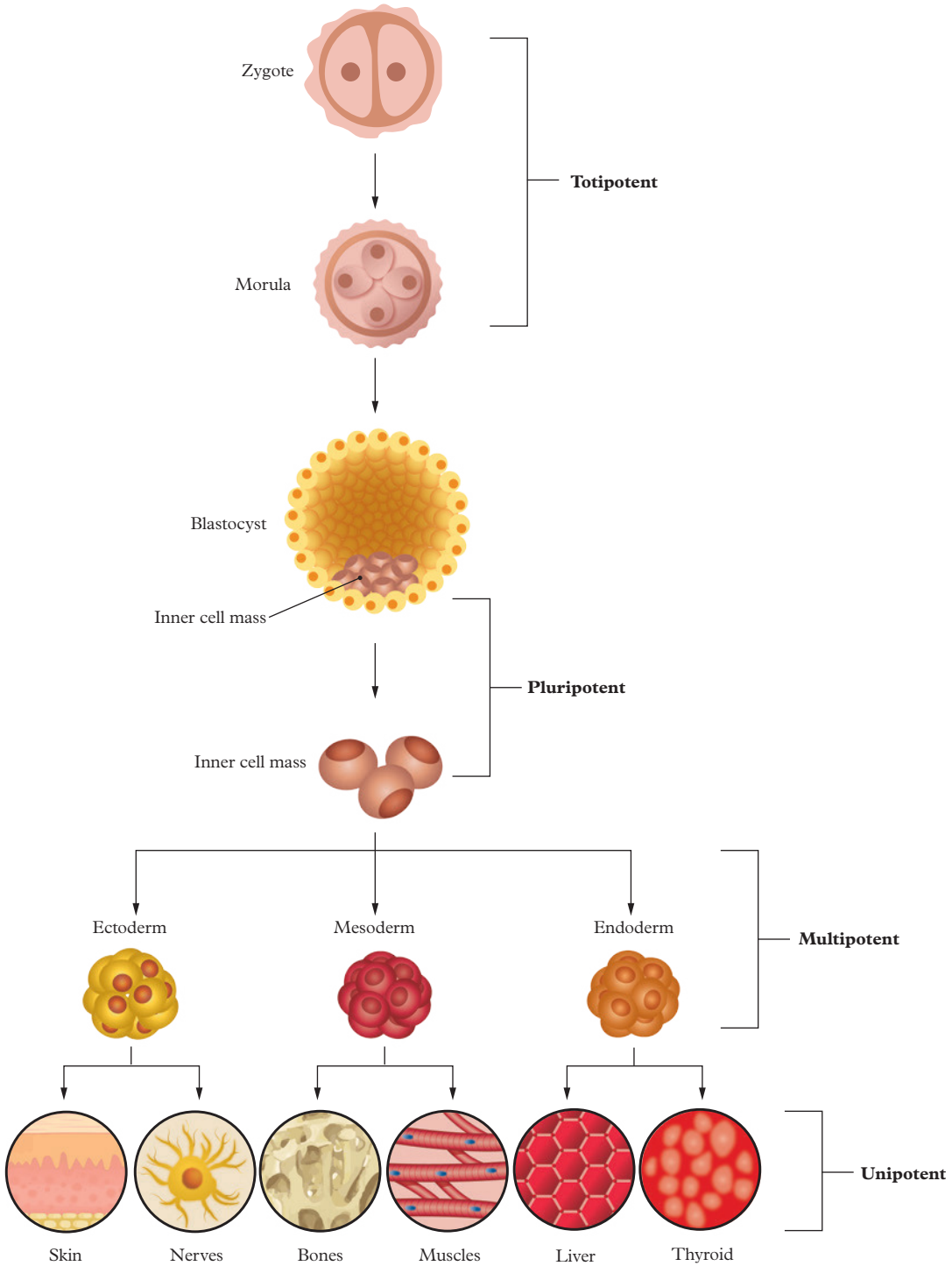


FIGURE 2 The process of forming cells that are more specialised with each step

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Real-world biology

Amazing axolotls

Axolotls are a type of salamander that may hold the key to regrowing human limbs. There are more than 1 million limb amputations every year, as a result of accidents and medical conditions such as diabetes. Until now, the only answer for amputees has been prosthetic limbs, but the axolotl's ability to regrow amputated limbs is being studied in the hope of one day enabling regeneration of limbs in humans.

In axolotls, regeneration of a lost limb begins with the formation of a wound epidermis, as a layer of cells quickly cover the amputation. These cells and the cells below the epidermis rapidly divide, forming a cone-shaped structure called a blastema. The blastema is a mass of stem cells, as well as other cells that de-differentiate to return to a multipotent state. These cells within the blastema then differentiate again to form a structure that resembles the lost limb, including nerves, blood vessels and connective tissues.

Scientists have found that various tissues work together to detect the loss of a limb and coordinate the regrowth, including the cells of the immune system and the nerve cells. Their removal interferes with the regeneration and creates scar tissue, although their roles are still undetermined. Scientists have also found that genes used in the formation of the structure during embryonic development are reactivated to regenerate the limb. Researchers are now comparing the mechanisms governing regeneration in axolotls and mice. Perhaps one day, with further research into the process, drugs can be manufactured to modulate these genes in order to help regenerate a human limb.



FIGURE 3 An axolotl

Apply your understanding

1 **Identify** the three factors that have been recognised as playing a role in axolotl limb regeneration. (3 marks)

2 **Explain** why it is important for research to compare axolotl and mice regeneration. (1 mark)

3 "Perhaps one day, with further research into the process, drugs can be manufactured to modulate these genes in order to help regenerate a human limb." Pose a research question that addresses an aspect of this claim. (1 mark)

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Stem cells in plants

In plants, the embryo, and later the adult plant, grows outwards by forming an extra layer at its outer edges. These groups of cells are called **apical meristems**, and they contain pluripotent stem cells. When each pluripotent cell divides, it creates a daughter cell that enlarges and differentiates to build roots, shoots and leaves. The other cell from this division becomes the new mother stem cell.

Some cells outside the apical meristems are multipotent stem cells. In this way the trunk and roots of trees and other perennial plants can increase in girth over time or sprout new shoots from dormant cells if the plant is damaged. The cells responsible for this are in the **cambium**, a zone of tissues between the water-conducting (xylem) and food-conducting (phloem) vessels.

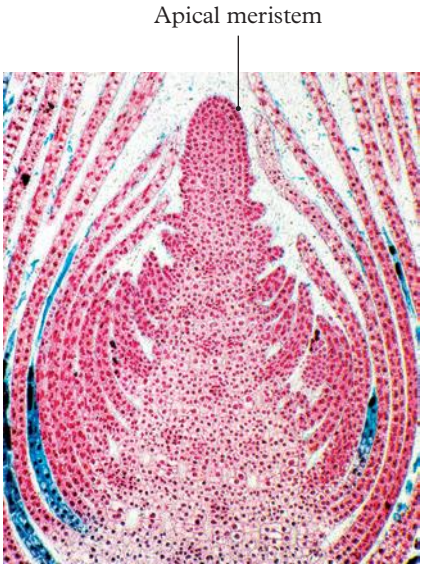


FIGURE 4 Magnified section of a huckleberry shoot. The pale pink cells are stem cells that are undergoing elongation and vacuolisation. The smaller and darker pink cells towards the top are undergoing mitosis. Surrounding the apical meristem and stem cells are young leaves.

apical meristem
the growing point of the tip of the root and stem in vascular plants

cambium
a layer of actively dividing plant cells

Check your learning 3.5

Check your learning 3.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** stem cell. (1 mark)
2 **Explain** the meanings of "self-renewal" and "potency" with respect to stem cells. (2 marks)
3 **Explain** the importance of self-renewal of stem cells. (1 mark)

Analytical processes

4 **Contrast** the blastula and gastrula. (1 mark)
5 **Distinguish** between totipotent, pluripotent, multipotent and unipotent stem cells. (4 marks)

Knowledge utilisation

6 Stem cells provide opportunities to generate healthy cells to replace cells affected by disease. **Apply** your knowledge to **determine** why embryonic stem cells provide more opportunities for research in this field than do adult stem cells. (2 marks)
7 **Propose** why it is beneficial that adult stem cells are multipotent or unipotent, rather than pluripotent. (2 marks)

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Lesson 3.6
Cell specialisation

Key ideas

- → Specialisation of cells into different cell types leads to groups of cells that have different structures and functions.
- → Cell specialisation is controlled by internal factors. Chemical cell-to-cell contact and mechanical forces play a role in determining cell specialisation.
- → Transcription factors turn specific genes on or off, determining cell specialisation and function.
- → There are both advantages and concerns associated with embryonic stem cell research.

Learning intentions and success criteria

Factors influencing cell specialisation

Multicellular organisms are too large for all cells in the body to be able to exchange materials directly with the external environment. Cells must therefore undergo specialisation to perform particular functions within the organism. Cell specialisation involves a succession of changes in a cell line, in cell morphology and metabolic activity, which leads to the development of cells with a specific role within the organism. This specialisation can lead to the new cells increasing the presence of some structures needed for their function, while decreasing or losing other structures that are not required.



FIGURE 1 Stem cells produce specialised cell types to replace dead or damaged cells, such as skin cells that have been badly damaged by sunburn.

During mitosis of a stem cell, the parent cell produces two daughter cells. Scientists have found that, in humans, the two daughter cells produced may be either two stem cells, to maintain the pool of stem cells, or two specialised cells, to replace dead or damaged cells.

The processes involved in cell specialisation are not fully understood, but scientists have identified several factors. The signals that influence stem cell specialisation can be

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categorised as either internal or external. External signals include the presence of certain chemicals secreted by the surrounding tissue, physical contact between cells, transmembrane molecules used for signalling, and mechanical forces causing changes in cell shape. Internal signals include specific molecules called **transcription factors**, which are a group of proteins that regulate the expression of certain **genes**, switching them on or off. These transcription factors can also be influenced by external signals, such as the presence of vitamin A, which has been found to play a role in the differentiation of neurons.

transcription factors
proteins that switch particular genes on or off

gene
a segment of DNA that codes for a specific protein and provides the instructions for the formation of a cell

Specialised cells may have some parts of their DNA switched off permanently. For example, a skin cell does not need many of the molecules that are used by kidney cells. Therefore, in the skin cell, the parts of DNA (genes) that contain instructions to produce kidney cell molecules are switched off. The skin cell is now described as specialised or differentiated.

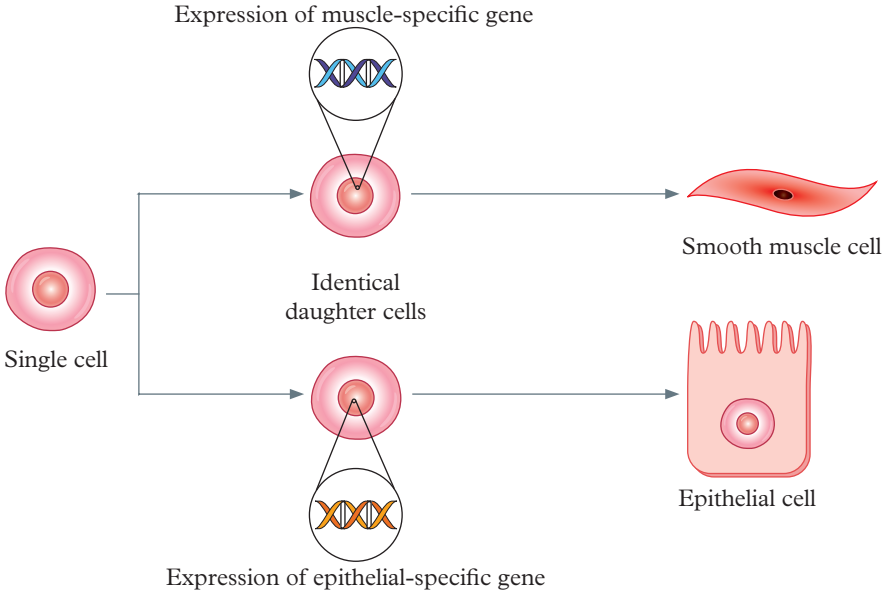


FIGURE 2 For a cell to specialise, certain genes are expressed and others are switched off.

Stem cell ethical concerns

Scientists study the process of specialisation in different cell types, in order to study the effect of diseases or reactions to various drugs or environmental factors. Although human trials using embryonic stem cells for research in spinal cord injuries were conducted in 2010, the research was stopped because of two major concerns about the use of embryonic stem cells.

- Because cell specialisation is controlled by several factors, including chemical signalling, embryonic stem cells injected into the body may form many different cell types, leading to the formation of cysts.
- Because the embryonic stem cells are not from the patient's body, their immune system will recognise the cells as "foreign" (in the same way that it would for an infection) and so the implanted cells may be rejected.



FIGURE 3 Maintaining a stem cell line in the laboratory

In many countries, further research has not been permitted for ethical reasons, as the harvesting of embryonic stem cells requires the destruction of an embryo. For this reason, recent research has focused on techniques aiming to revert adult stem cells to a pluripotent state.

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Real-world biology

Induced pluripotent cells

Stem cells have the potential to be one of the most important breakthroughs in modern medicine. In 1962, John Gurdon cloned frogs by inserting adult somatic cells into an egg cell, showing that specialised cells could revert to pluripotency. In 1987, another study found that it was possible to reprogram specialised cells to become completely different cell types. In 2006, Shinya Yamanaka and Kazutoshi Takahashi reprogrammed an adult stem cell to revert back to a pluripotent cell. These cells were called induced pluripotent stem cells (iPSCs). This breakthrough has led to research into the possibility of using iPSCs to repair or replace ailing organs and tissues, and even the potential to reverse ageing.

Induced pluripotent stem cells are more effective than adult stem cells, because they are able to differentiate into any type of cell in the body and avoid the use of embryos in stem cell therapy. Because they can be made by reprogramming the patient's own cells, iPSCs also pose no risk of immune rejection, which is a concern for other stem cell therapies and organ transplants.

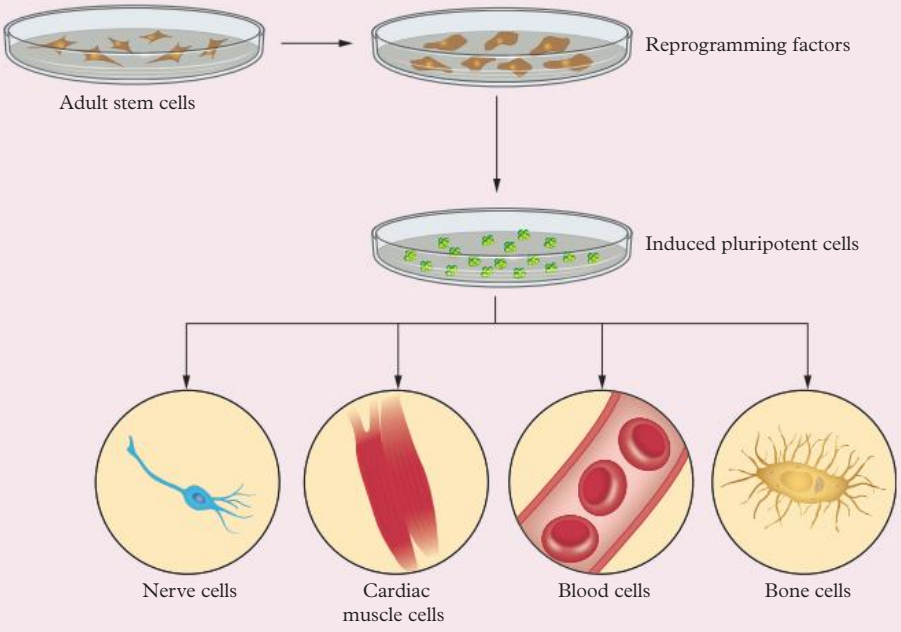


FIGURE 4 Adult stem cells can be reprogrammed to create induced pluripotent cells.

Many serious medical conditions could potentially be treated using stem cells. Clinical trials are currently underway for patients with type 1 diabetes, where stem cells have been induced to form insulin-producing cells. Neural stem cell therapy has the potential to treat spinal cord injuries and stop neurodegenerative diseases such as Parkinson's disease and Alzheimer's disease. Because iPSCs are pluripotent, in time, any ailing organs may be able to be replaced. Stem cells may even be used to reverse the effects of ageing.

Apply your understanding

1 **Explain** why the discoveries made in 1962 and 1987 were critical to the development of iPSCs. (2 marks)

2 **State** the importance of the development of iPSCs for medical research, with consideration of embryonic stem cells. (1 mark)

3 "Stem cells may even be used to reverse the effects of ageing." Pose a research question that addresses an aspect of this claim. (1 mark)

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Skill drill

Stem cell therapy treatment

Science inquiry skill: Processing and analysing data (Lesson 1.8)

A group of researchers monitored 30 patients who had received stem cell therapy to treat hip injuries, for four years. They wanted to determine whether the average functionality of the hip had improved four years after receiving stem cell therapy.

Their results are provided in the table.

Time	Hip function* (%)
Just before procedure	46
1 month after	56
3 months after	60
6 months after	62
1 year after	65
1.5 years after	70
2 years after	75
3 years after	80
4 years after procedure	85

*100% = fully functioning hip

Practise your skills

1 **Present** the results from the table as a graph. (3 marks)
2 **Determine** the average percentage of improved hip function after four years following stem cell therapy. (1 mark)

Challenge

Embryonic stem cell research

Some areas of research, such as embryonic stem cell research, are strictly regulated and must adhere to certain guidelines. The aim of these regulations and guidelines is to provide the opportunity for scientific advancement in the field of stem cell research while also considering the ethical issues involved. Research the policies that regulate embryonic stem cell research in Australia, and **evaluate** whether you believe it meets ethical standards. (4 marks)

Check your learning 3.6

Check your learning 3.6: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the four external signals involved in cell specialisation. (4 marks)
2 **Describe** the role of transcription factors in cell specialisation. (1 mark)
3 **State** the importance of specialised cells in multicellular organisms. (2 marks)

Analytical processes

4 **Identify** two advantages and two disadvantages of using embryonic stem cells. (4 marks)

Knowledge utilisation

5 **Discuss** why the concerns that arose with the use of embryonic stem cells would not apply to the use of the induced pluripotent stem cells described in Real-world Biology. (2 marks)

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MODULE 3

Lesson 3.7
Review: From cell to multicellular organism

Summary

3.1
- The size of a cell is limited by its ability to exchange materials with its environment.
- Large organisms are composed of many cells organised into tissues, organs and systems, each of which has its own function. These cells communicate with each other for the overall functioning of the organism.

3.2
- Tissues are composed of cells of one type that are differentiated for a particular function (e.g. cardiac muscle).
- Organs are functional and structural units made up of more than one type of tissue (e.g. the heart).
- A system comprises different organs working together for one main function (e.g. the respiratory system).
- Plants have tissues arranged in organs (e.g. the leaf), and two systems (root and shoot).

3.3
- Practical: Organisation of cells into tissues, organs and systems

3.4
- There are three stages of the cell cycle: interphase, mitosis and cytokinesis.
- During interphase, a cell grows and prepares for cell division.
- During mitosis, the nucleus of a cell is replicated.
- During cytokinesis, the cytoplasm of the cell divides, forming two identical daughter cells.

3.5
- A stem cell is a cell that can replicate or differentiate into one or more cell types.
- There are two types of stem cells: embryonic stem cells and adult stem cells.
- Stem stells can be classified as totipotent, pluripotent, multipotent or unipotent.

3.6
- Specialisation of cells into different cell types leads to groups of cells that have different structures and functions.
- Cell specialisation is controlled by internal factors. Chemical cell-to-cell contact and mechanical forces play a role in determining cell specialisation.
- Transcription factors turn specific genes on or off, determining cell specialisation and function.
- There are both advantages and concerns associated with embryonic stem cell research.

Review questions 3.7A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 The table below shows the results recorded for cells of a tissue during a cell cycle.

Stage of cell cycle	Prophase	Metaphase	Anaphase	Telophase	Interphase
Time taken (min)	6	7	4	9	14

Which of the following statements is correct?

A The spindle would be visible for more than 26 minutes.

B Separation of the chromatids would take approximately 4 minutes.

C One cell cycle would be completed every 26 minutes.

D The cytoplasm would start dividing after 13 minutes.

2 If you were observing a cell undergoing mitosis, which of the following would be evidence that it was a plant cell rather than an animal cell?

A absence of a spindle

B development of a cell plate in the middle of the cell

C replication of chromosomes

D disappearance of the nuclear membrane

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3 Two cells that are the product of mitosis each have
- **A** double the number of chromosomes of the "parent" cell.
- **B** half the number of chromosomes of the "parent" cell.
- **C** the same number of chromosomes as the "parent" cell.
- **D** a mixture of chromosomes from each "parent" cell.

4 In order, the stages of the cell cycle are
- **A** prophase, anaphase, interphase, metaphase, telophase, cytokinesis.
- **B** interphase, prophase, metaphase, anaphase, telophase, cytokinesis.
- **C** interphase, cytokinesis, prophase, telophase, metaphase, anaphase.
- **D** prophase, interphase, cytokinesis, anaphase, metaphase, telophase.

5 Totipotent stem cells
- **A** have many genes permanently switched off.
- **B** can only differentiate into a single cell type.
- **C** can differentiate into a limited number of cell types.
- **D** can turn on any gene in their genetic material.

6 The potency of a stem cell refers to its ability to
- **A** go through several cell cycles in a short period of time.
- **B** maintain its integrity even with long delays between cell divisions.
- **C** remain unspecialised.
- **D** differentiate into specialised cell types.

7 In plants, pluripotent stem cells are found in the
- **A** apical meristems.
- **B** leaf stalks.
- **C** leaf blades.
- **D** main stem.

8 An embryonic animal system develops in the following sequence:
- **A** organs → cells → tissues.
- **B** tissue → cells → organs.
- **C** cells → organs → tissues.
- **D** cells → tissues → organs.

9 A stem cell is
- **A** a specialised cell in the brain, responsible for transmitting electrical impulses.
- **B** a cell with a specific shape and function.
- **C** an unspecialised cell, capable of replicating and differentiating.
- **D** an unspecialised cell, capable of producing one type of cell.

10 Cell specialisation can be defined as
- **A** the process of cell replication by division.
- **B** the ability of cells to change shape.
- **C** the coordination of cells during development to form tissues.
- **D** the development of cells with a specific shape and function, from a stem cell.

11 A stem cell that can differentiate into a few, related cell types would be described as
- **A** totipotent.
- **B** multipotent.
- **C** pluripotent.
- **D** unipotent.

12 Lung epithelial cells are specialised to enable the rapid movement of gases into or out of the body. The structural specialisation that is most important for this function is
- **A** a thin, flattened shape.
- **B** a high concentration of mitochondria.
- **C** cilia.
- **D** a high concentration of lysosomes.

Review questions 3.7B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

13 **Describe** one ethical issue involved in embryonic stem cell research for medical therapies. (1 mark)

14 **Describe** the role of mitosis of stem cells in the development of an organism. (1 mark)

15 Cells are invariably very small in size and can usually only be seen under a microscope. As organisms become larger, their cells remain the same size but increase in number. **Explain** the importance of this phenomenon for body systems. (2 marks)

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16 **Describe** how stem cells differentiate into specialised cells. (2 marks)

17 **Explain** how cells coordinate to form tissues and organ systems. (2 marks)

Analytical processes

18 **Differentiate** between totipotent, pluripotent, multipotent and unipotent stem cells in terms of life cycle stage and potency. (8 marks)

19 **Distinguish** between an embryonic stem cell and an adult stem cell. (1 mark)

Knowledge utilisation

20 In the United States there are "banks" of stem cell samples. In one such stem cell bank in North Carolina, there are over 100,000 samples of stem cells that have been collected from the amniotic fluid surrounding embryos within wombs. This form of collection does not harm the embryo. **Evaluate** three advantages of such a bank of stem cells for producing a compatible bioartificial organ for a recipient. (3 marks)

Data drill

Calculating total magnification and field of view

While observing samples under a microscope, it is important to determine the total magnification and field of view of the image. The magnification of a microscope is determined by multiplying the magnification of the optical lens by the magnification of the objective lens. The field of view is calculated by dividing the field number (the aperture of the objective lens) by the total magnification.

Total magnification = optical magnification × objective magnification

Field of view (FOV) = field number ÷ total magnification

Apply understanding

1 **Calculate** the total magnification and field of view to complete the two tables. (10 marks)

Calculation of total magnification

Optical magnification	10×	10×	10×
Objective magnification	4×	10×	40×
Total magnification	= 10 × 4 = 40×		

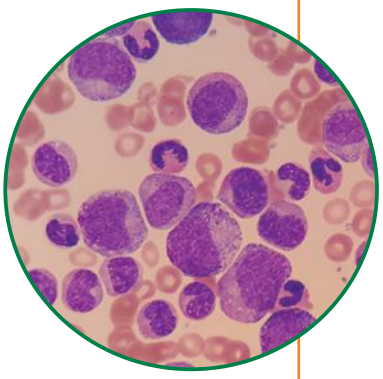


FIGURE 1 Human blood smear

Calculation of field of view

Field number	Field of view (mm)		
	Total magnification 10×	Total magnification 20×	Total magnification 60×
0.10	0.10 / 10 = 0.01 mm		
0.15			
0.65			

2 Figure 1 shows a human blood smear containing a large number of leukaemia cells (indicated) at 100× magnification, using an objective lens with a field number of 20.

a **Calculate** the field of view of the image. (1 mark)

b **Determine** the approximate diameter of the leukaemia cells in microns (1 mm = 1000 microns). (1 mark)

Interpret evidence

3 **Infer** the relationship between magnification and field of view. (1 mark)

4 **Infer** the relationship between field number and field of view. (1 mark)

Module 3 checklist: From cell to multicellular organism

Quizlet: Revise key terms online to test your understanding

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UNIT 1

Topic 1 Review

Multiple choice

(1 mark each)

1 Prokaryotic organisms have the following characteristics:
- **A** cell cytoplasm, nucleus and are unicellular.
- **B** cell wall, organelles and are multicellular.
- **C** cell wall, unicellular and have a nucleoid region.
- **D** nucleus, ribosomes and are unicellular.

2 Ribosomes produce proteins from monomers called
- **A** amino acids.
- **B** lipids.
- **C** phosphates.
- **D** sugars.

3 The cell membrane is
- **A** hydrophobic.
- **B** impermeable to water.
- **C** present in animal cells but not in plant cells.
- **D** semi-permeable.

4 Molecules that make up the cell membrane are called
- **A** fatty acid tails.
- **B** fluid mosaic membranes.
- **C** hydrophilic phosphate heads.
- **D** phospholipids.

5 The purpose of extracellular fluid is to
- **A** allow transport of materials between cells.
- **B** secrete enzymes to aid digestion.
- **C** suspend organelles within the cell membrane.
- **D** transport hormones.

6 Which of the following statements about organelles is correct?
- **A** Amino acids are produced by ribosomes.
- **B** Mitochondria are the powerhouse of the nucleus.
- **C** Ribosomes are found only on the smooth endoplasmic reticulum.
- **D** The endoplasmic reticulum and the Golgi apparatus are both made of cisternae.

7 Glycoproteins are best described as
- **A** integral or peripheral proteins.
- **B** monomers.
- **C** nutrients.
- **D** organelles.

8 The body system responsible for breaking complex molecules into monomers to allow nutrients to be absorbed is called the
- **A** circulatory system.
- **B** digestive system.
- **C** endocrine system.
- **D** excretory system.

9 Simple diffusion
- **A** occurs across the cell membrane only.
- **B** allows molecules to be moved against a concentration gradient.
- **C** is a form of passive transport.
- **D** requires energy in the form of ATP.

10 The component of the cell membrane that prevents it being too rigid or too fluid is called
- **A** a glycoprotein.
- **B** cholesterol.
- **C** dynamic equilibrium.
- **D** integral proteins.

11 Which of the following statements about eukaryotic and prokaryotic organisms is correct?
- **A** Eukaryotic organisms are unicellular and prokaryotic organisms are multicellular.
- **B** Eukaryotic organisms are animals and prokaryotic organisms are plants.
- **C** Eukaryotic organisms evolved from prokaryotic organisms.
- **D** Prokaryotic organisms evolved from eukaryotic organisms.

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12 The figure shows a cell in which phase of mitosis?

A anaphase
B cytokinesis
C metaphase
D prophase



13 "Cristae" is a term used to describe the

A folds of the internal membrane in mitochondria.
B stacks of thylakoids in chloroplasts.
C organelles that produce proteins from amino acids.
D tail-like extension of some cells used for locomotion.

14 Apoptosis in cells can be described as a

A phase of mitosis.
B process that allows DNA to replicate before mitosis.
C process of organised cell death.
D structure that produces spindle fibres to pull chromosomes to the poles of a cell.

15 Cells grow during a phase of the cell cycle called

A anaphase.
B interphase.
C metaphase.
D telophase.

Short response

16 The surface area and volume measurements of different cells and organelles are given in the table. The surface area-to-volume ratio (SA : V) of the sperm cell is provided.

	Surface area (SA)	Volume (V)	SA : V
Sperm cell	106 μm²	22 μm³	4.8 : 1
Mitochondrion	40 μm²	10 μm³	
Red blood cell	134 μm²	82 μm³	
Egg cell	45,239 μm²	900,000 μm³	

a **Calculate** the SA : V of the mitochondrion, red blood cell and egg cell to 1 decimal place. (3 marks)
b **Sequence** each cell/organelle from highest SA : V to lowest SA : V. (1 mark)
c **Contrast** the SA : V of the sperm and egg cells. (1 mark)

17 **Describe** the function of chloroplasts in plant cells. (1 mark)

18 Bubble tea is a popular drink made with syrup and water. Sometimes small spheres of gelatine containing concentrated syrup, called popping pearls, are added.



Some students drinking bubble tea noticed that when they left their drinks for an hour, the popping pearls increased in size and burst. The students decided to conduct an experiment. They prepared three drinks at different concentrations of syrup and water, as shown in the table. They then added popping pearls to each of the three teas. Each popping pearl contains 1 mL of water and 1 mL of syrup.

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Bubble tea preparation	Water (mL)	Syrup (mL)
Bubble tea 1	150	50
Bubble tea 2	100	50
Bubble tea 3	50	200

a **Determine** the direction of water movement between the bubble tea and the popping pearls for each of the three drinks. (3 marks)

b **Infer** what may happen to the popping pearls when they are put into the most concentrated bubble tea drink. (2 marks)

c **Suggest** two improvements the students could make to their experiment to improve the reliability of their results. (2 marks)

19 **Explain** the role of the cell membrane in controlling the internal environment of the cell. (3 marks)

20 **Explain** why cells cannot grow to a very large size. (4 marks)

21 **Compare** endocytosis and exocytosis. (2 marks)

22 While house sitting for a friend, you watered one of their house plants with water left over from cooking pasta. The water had cooled but it had salt in it from seasoning the pasta. Using your knowledge of diffusion and osmosis, **explain** why the plant died despite being given enough water. (4 marks)



23 **Explain** the importance of cell specialisation in eukaryotic organisms. (3 marks)

24 **Describe** the process of facilitated diffusion across a cell membrane. (3 marks)

25 **Describe** the structure and function of the endocrine system. (3 marks)

TOTAL MARKS

/50 marks

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MODULE 4

The chemicals of life

Introduction

All living organisms require an energy source and matter to survive. Organic matter is composed of carbohydrates, proteins, lipids and other compounds. The gases carbon dioxide and oxygen, water and mineral ions from the surroundings are prerequisite to the formation of these organic compounds. The energy required for cellular activities is released from organic compounds under the influence of enzymes, which are proteins that regulate the rate of chemical reactions in living organisms.

Prior knowledge

Prior knowledge quiz

Check your understanding of concepts related to the chemicals of life before you start.

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Subject matter

Science understanding

→ Describe the structure and function of carbohydrates, proteins and lipids.
→ Describe the structure and function of enzymes, including the role of the active site.
→ Compare the induced-fit and lock-and-key models of enzyme function.
→ Explain how enzyme activity is affected by factors such as temperature, pH, presence of inhibitors and substrate concentration.

Science inquiry

→ Investigate the effect of temperature/pH/substrate concentration on the reaction rate of different enzymes.
→ Explore how understanding enzymes, and their roles in metabolism, can be used to diagnose and treat metabolic disease.

Science inquiry skills

→ Translate information between graphical, numerical and/or algebraic forms, e.g.
  – units and measurement conversions
  – ratios and percentages
  – symbols and notation
  – charts and maps.

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Practicals

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Lesson 4.3 The effect of enzyme concentration on the rate of reaction

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Lesson 4.1
Organic compounds in living things

Learning intentions and success criteria

Key ideas

- → Matter can be divided into two categories: inorganic compounds (non-living substances) and organic compounds (living substances).
- → The three main types of organic compounds are carbohydrates, proteins and lipids.
- → Carbohydrates, proteins and lipids are large "macromolecules" that are made up of smaller subunits.

inorganic compound
a chemical compound that does not contain carbon (except for carbonates and cyanides) or carbon–hydrogen bonds

organic compound
a complex carbon compound formed by living things; usually a macromolecule

macromolecule
a large, complex molecule or polymer consisting of repeated smaller subunits (monomers)

carbohydrate
a molecule of carbon hydrated with water; the general formula for monosaccharides is $(CH_2O)n$ (C:H:O = 1:2:1) and for polysaccharides is $(C_6H_{10}O_5)n$ (less hydrogen and oxygen because of glycosidic bonds)

monomer
a molecule that can bond to other identical molecules to form a large molecule (polymer)

saccharide
a sugar compound

monosaccharide
a monomer of carbohydrates

disaccharide
a molecule composed of two chemically bound monosaccharides (e.g. sucrose)

glycosidic bond
a bond formed by condensation between two monosaccharides

Types of organic compounds

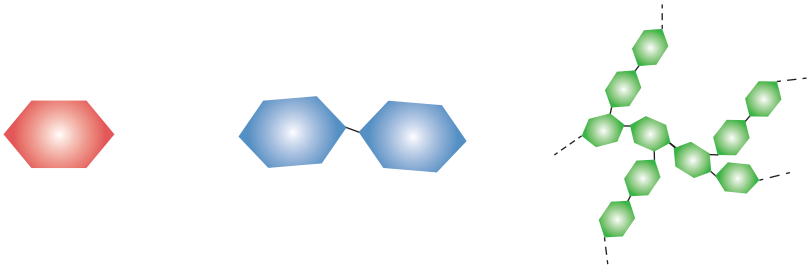
Matter can be divided into two categories.

- **Inorganic compounds** are non-living substances such as water, oxygen, carbon dioxide, nitrates and phosphates.
- **Organic compounds** are living substances made from carbon, hydrogen and other elements arranged into large, complex structures (called macromolecules).

Macromolecules are large organic molecules that play many important roles in biological processes. In this lesson we will look at the three main types of macromolecules – carbohydrates, proteins and lipids – including how they are formed and their functions in living organisms.

Carbohydrates

A **carbohydrate** is a macromolecule that consists of the elements carbon, hydrogen and oxygen. Carbohydrates are "hydrated carbons", as they generally form in a set ratio where, for each carbon in a carbohydrate, there is one water molecule. The **monomers** (subunits) that make up carbohydrates are simple sugars, called **saccharides**. A **monosaccharide** ("mono" means one) is a single sugar molecule. Glucose, maltose and fructose are all examples of monosaccharides and have the same general formula, $C_6H_{12}O_6$. Two monosaccharides can be linked together through a condensation reaction to form a **disaccharide** ("di" means two). Disaccharides have the general formula $C_{12}H_{22}O_{11}$, with the condensation reaction releasing a water molecule. The specific bond that links saccharides together is called a **glycosidic bond**. **Polysaccharides** ("poly" means many) are long-chained carbohydrates that consist of multiple saccharides bonded together.



Monosaccharide Disaccharide Polysaccharide

FIGURE 1 Monosaccharides, disaccharides and polysaccharides are types of carbohydrates.

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Carbohydrates are an important energy source. They can be stored in the form of the polysaccharide **starch** in plants or **glycogen** in fungi and animals. Some polysaccharides also help provide structural integrity to living things (e.g. cellulose in plant cell walls, chitin in fungi and the exoskeletons of invertebrates). Polysaccharides are good storage molecules because:

- their large size makes them practically insoluble in water, so they do not affect the water balance of the cell
- they can fold into compact shapes
- they can readily be converted to sugars when energy is needed.

polysaccharide
a complex carbohydrate composed of many monosaccharides bonded together

starch
a complex carbohydrate made up of many glucose units joined by glycosidic bonds

glycogen
a branched carbohydrate made from many glucose units, which animals use as an energy reserve

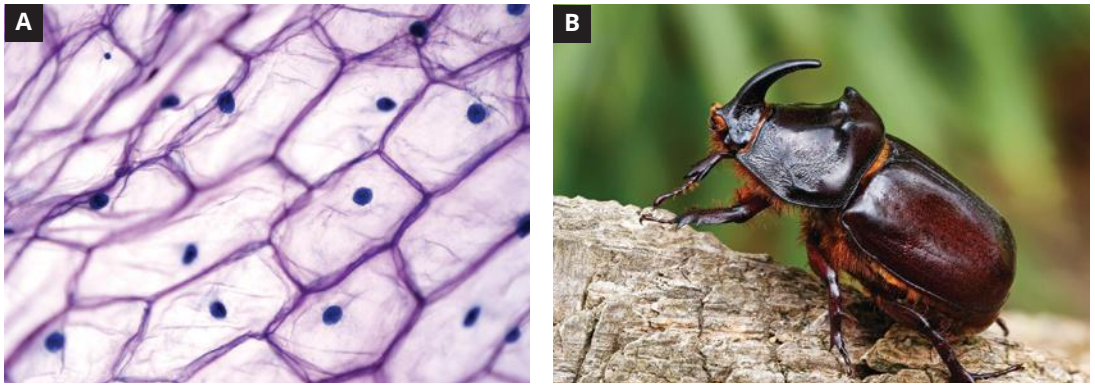


FIGURE 2 Some carbohydrates help improve the structural integrity of living things. (A) Cellulose is a component of plant cell walls. (B) Chitin forms the exoskeletons of invertebrates.

Proteins

Proteins are chained macromolecules that contain the elements C (carbon), H (hydrogen), O (oxygen) and N (nitrogen). The monomers of proteins are called **amino acids**.

protein
a macromolecule consisting of one or more polypeptide chains; may be folded, branched and/or cross-linked at intervals

amino acid
a building block of protein; consists of an amino group (NH_2), a carboxyl (acid) group (COOH), a variable (R) group and a hydrogen atom attached to a carbon atom

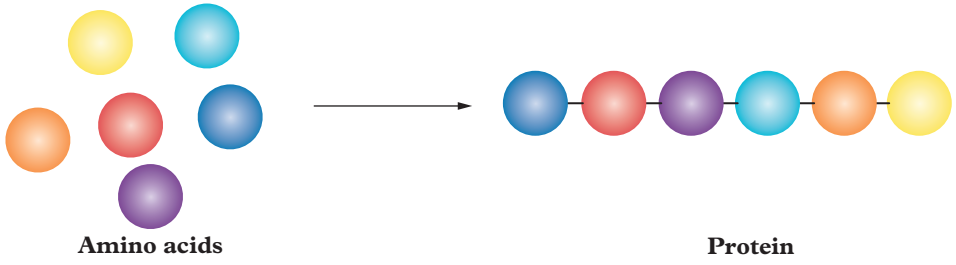


FIGURE 3 A protein molecule is a chain of amino acids.

Each amino acid has the same basic structure except for one group of atoms, which varies and is given the general letter 'R' (Figure 4). There are 20 types of amino acid in the human body, each differing only in the composition of the R group, which can vary from a single atom to a large molecule. Although there are only 20 types of amino acid, the differing order of the amino acids results in an enormous number of potential unique amino acid sequences. For example, there are more than 19,000 types of proteins in humans, each with a specific function determined by its unique amino acid sequence. A small change in the amino acid sequence of a protein can potentially destroy that protein or change the way it functions.

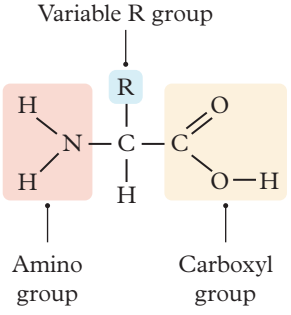


FIGURE 4 General structure of an amino acid

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peptide bond
a bond formed from condensation between two amino acids, where hydrogen (H) is lost from the amino group and a hydroxyl group (OH) from the carboxyl group

dipeptide
a molecule formed by the bonding of two amino acids

polypeptide
a macromolecule formed by the union of many amino acids

primary structure
the first level of structure of protein molecules; a chained linear sequence of amino acids

secondary structure
the second level of structure of protein molecules; the local arrangement of a protein backbone that has been stabilised by intramolecular hydrogen bonding

The bond that links amino acids is called a **peptide bond**. A **dipeptide** is formed when two amino acids bond together, and a **polypeptide** is formed when multiple amino acids bond together. Every protein consists of one or more polypeptide chains. These chains may be folded, branched and/or cross-linked at intervals, depending on their structure.

Protein structure

Proteins have four levels of structural configuration: primary, secondary, tertiary and quaternary. The **primary structure** of a protein is its linear polypeptide chain, which consists of 50 to 1000 linked amino acids (Figure 5). As a polypeptide chain is assembled, interactions between the amino acids along the chain and hydrogen bonding cause the chain to fold. This folding is the **secondary structure**, and it forms one of two shapes: α-helix or β-pleated sheet (Figure 6). Fibrous proteins are proteins whose structure is mainly secondary, forming either sheets or long strands. They often have a structural or mechanical function (e.g. spider webs consist of fibroin, which contains many β-pleated sheets).

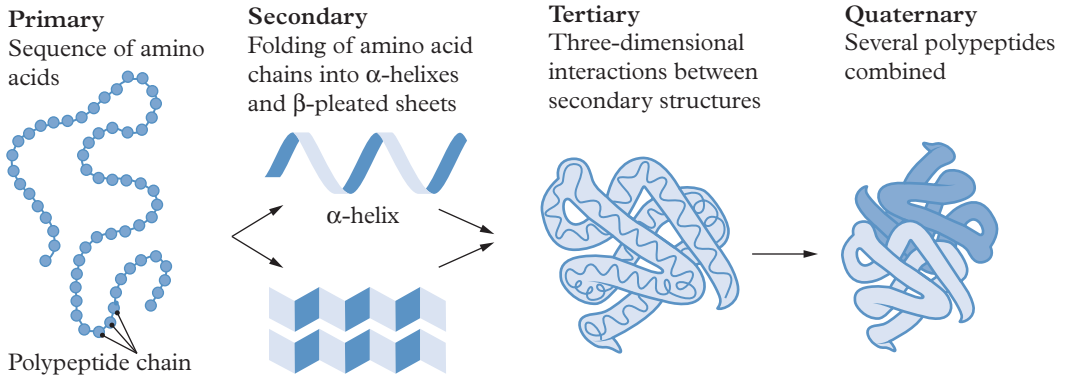


FIGURE 5 Summary of the four levels of protein structure

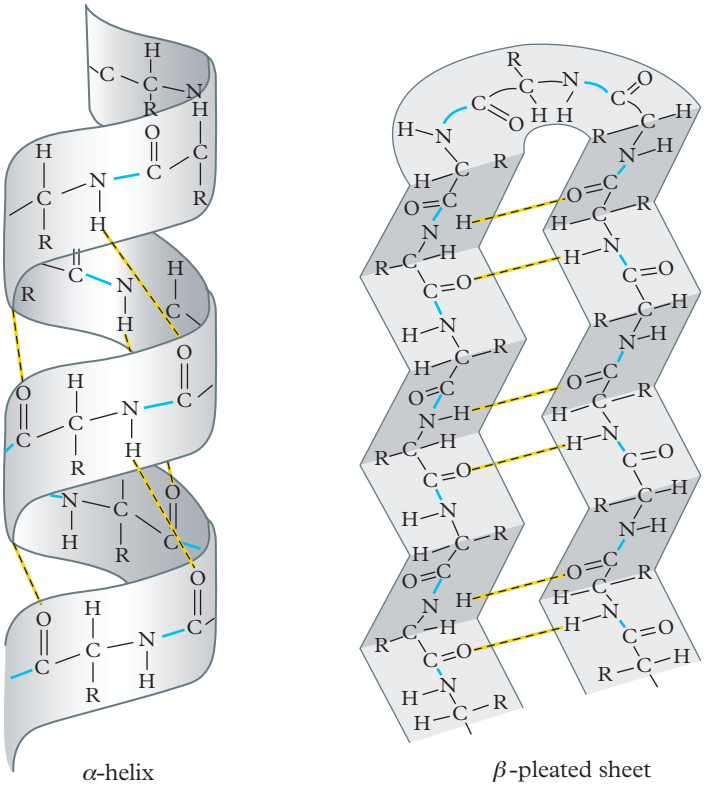


FIGURE 6 Secondary protein structures: α-helix and β-pleated sheet

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Proteins with a **tertiary structure** are polypeptide chains that have folded into a three-dimensional, globular shape. This occurs when the R groups of amino acids along a polypeptide chain interact with each other. Proteins with a **quaternary structure** consist of two or more polypeptide chains that have folded in together to form a three-dimensional structure.

Proteins are not indestructible. They can undergo **denaturation** (the breaking down and loss of their shape and therefore functionality) when exposed to high heat, strong acids or bases, organic solvents or heavy metals. The types of proteins and their functions in living organisms are summarised in Table 1.

tertiary structure the third level of structure of a protein molecule; exists when a polypeptide chain is folded into a three-dimensional molecule

quaternary structure the fourth level of structure of a protein molecule; exists when more than one polypeptide chain is folded into a three-dimensional molecule

denaturation the process in which the weak links or bonds in a biological molecule (i.e. proteins, carbohydrates) break down

TABLE 1 Types of proteins and their functions in living organisms

Category	Example	Type	Occurrence/function
Structural	Keratin	Fibrous	Skin, feathers, nails, hair, horn, silk
	Sclerotin	Fibrous	Exoskeleton of insects
Mechanical	Collagen	Fibrous	Tendons, cartilage, bones – resists stretching
	Elastin	Fibrous	Ligaments
Enzyme	Amylase	Globular	Catalyses hydrolysis of starch to maltose
	Trypsin	Globular	Catalyses hydrolysis of protein
Hormone	Insulin	Globular	Involved in glucose metabolism
Transport	Haemoglobin	Globular + iron group	Transports oxygen in vertebrates' blood
Protective	Antibodies	Globular	Form complexes with foreign proteins to neutralise them
Contractile	Myosin	Fibrous	Moving filaments involved in muscle contraction
	Actin	Fibrous	Stationary filaments involved in muscle contraction
Storage	Egg albumin	Globular + non-protein group	Egg white protein
	Casein	Globular + non-protein group	Milk protein
Toxins	Snake venom (enzymes)	Globular	Paralyse/kill prey

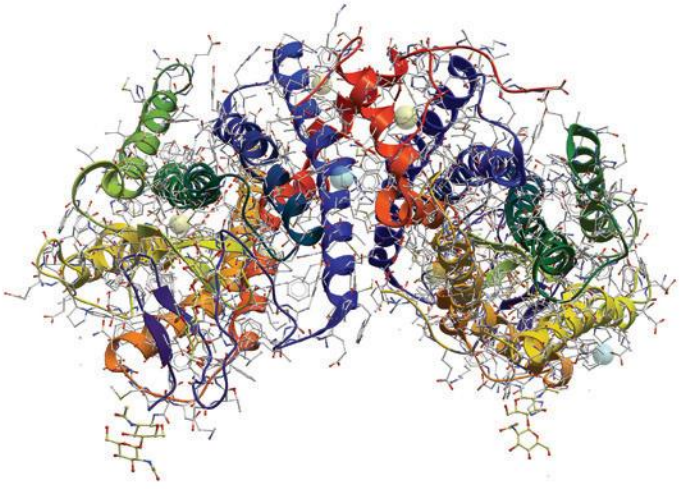


FIGURE 7 Rhodopsin is a protein with a complex 3D structure. It is important in your ability to process visual information.

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Real-world biology

Errors in the amino acid sequence

Haemoglobin is a pigment carried in red blood cells. It has the special property of being able to combine loosely with oxygen, picking it up from areas where oxygen levels are high (e.g. the lungs) and depositing it in areas where it is low (e.g. active cells).

The haemoglobin molecule consists of two pairs of polypeptide chains, each of which is combined with an iron-containing group. Each type of chain contains about 150 amino acids. The entire haemoglobin molecule consists of 600 amino acids and four iron groups.

In the hereditary disease sickle-cell anaemia, one amino acid (glutamic acid) in each chain of one of the pairs is replaced by a molecule of a different amino acid, valine. The two substituted valines create two "sticky" areas on the surface of the haemoglobin molecule. These areas are attracted to each other and distort the shape of the entire molecule into a stiffened rod.

Red blood cells containing large proportions of these altered molecules become stiff and deformed, taking on a characteristic sickle shape. These cells are much more fragile than normal red blood cells and rupture easily. Because of their shape, they tend to clog small blood vessels, creating blood clots that prevent a full supply of blood to vital organs. This results in pain, intermittent illness and often a shortened life span.

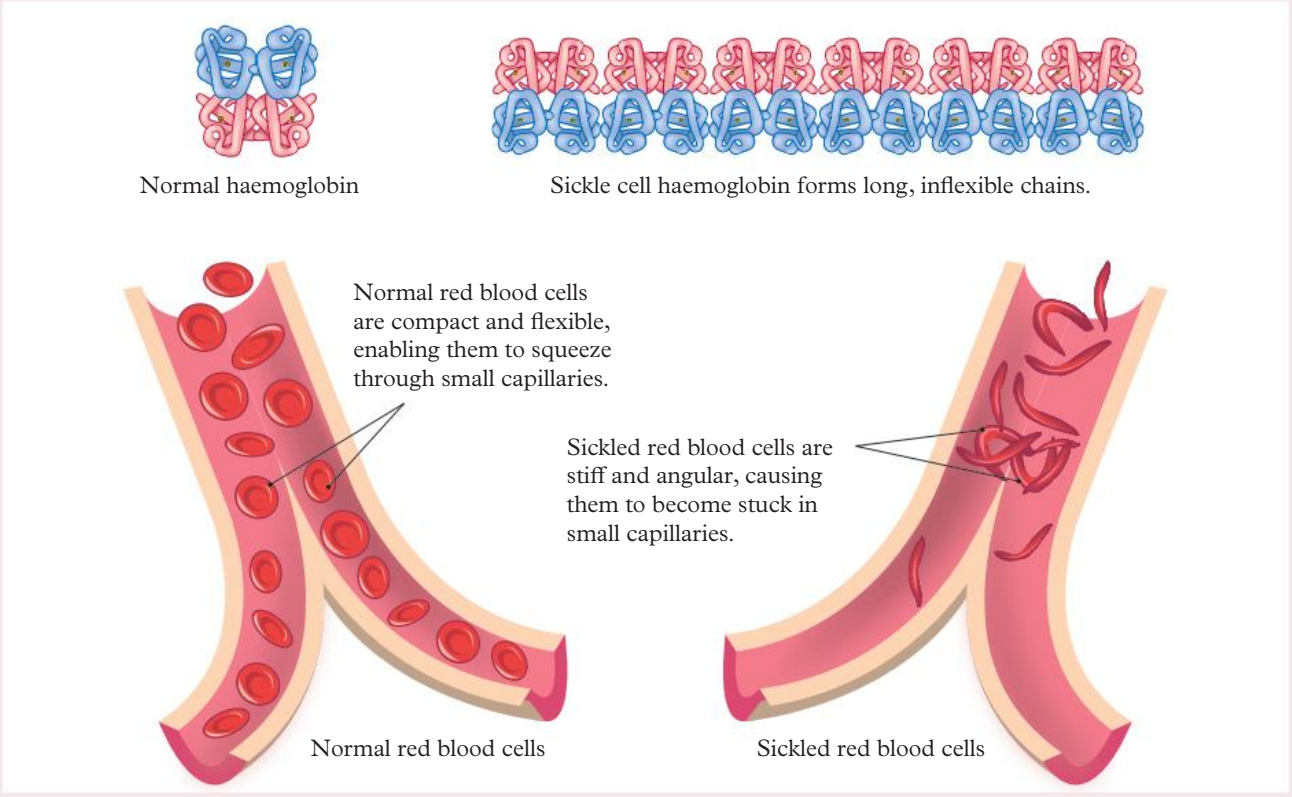


FIGURE 8 Comparison of normal haemoglobin (and red blood cells) and sickle cell haemoglobin (and abnormal sickled red blood cells)

Apply your understanding

1 **Contrast** normal haemoglobin structure with the altered haemoglobin structure in sickle-cell anaemia. (1 mark)

2 **Describe** how the altered structure of sickle cell haemoglobin affects its function. (1 mark)

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Lipids

Lipids are fats, oils and waxes. Fats and waxes are solid, whereas oils are liquid at room temperature. Lipids contain carbon, hydrogen and oxygen but, unlike carbohydrates, there is no set ratio of these elements. Lipids are composed of two basic monomers: **fatty acids** and **glycerol**.

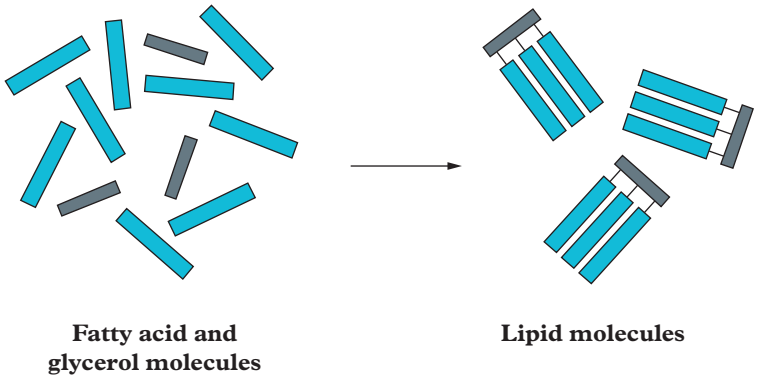


FIGURE 9 Lipids are made from fatty acids (blue) and glycerol (grey).

Fatty acids have the general formula RCOOH, where R is a variable group consisting of a hydrocarbon chain (Figure 10). This chain or "tail" is non-polar (does not carry an electric charge) and **hydrophobic** (water repellent). The carboxyl (acid) group (–COOH) is polar and **hydrophilic** (water loving). Lipids are formed when fatty acids and glycerol bond together. This bond, known as an **ester bond**, removes a –OH from the fatty acid and a –H from the glycerol and forms water as a byproduct.

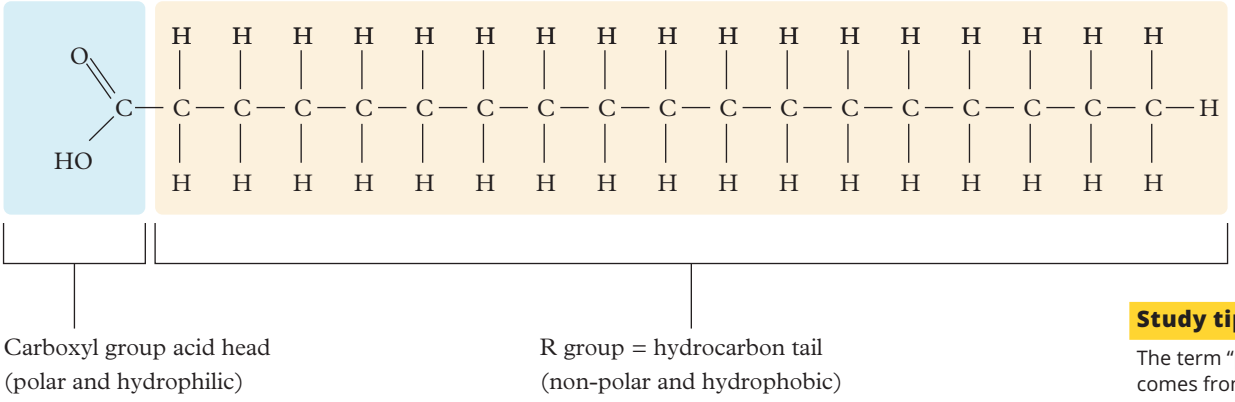


FIGURE 10 Basic structure of a fatty acid

Triglycerides

The most common lipids are **triglycerides**, which are formed when three fatty acids bond with a single glycerol molecule (Figure 10). The three fatty acids that bond to glycerol may be all the same or a combination of different fatty acids.

lipid
a macromolecule made up of fatty acids and glycerol

fatty acid
a compound (RCOOH) formed between a carboxyl (COOH) group and a chain of hydrocarbons of variable length (R)

glycerol
a structural component of lipids

hydrophobic
describes substances that are insoluble in water

hydrophilic
describes substances that dissolve readily in water

ester bond
a bond formed by condensation between a fatty acid (removal of OH) and glycerol (removal of H)

Study tip

The term "phobic" comes from the Latin for "fear" and the term "philic" comes from the Latin for "love". You can use this to help remember that hydrophobic means "water fearing" and hydrophilic means "water loving".

triglyceride
a lipid formed from one molecule of glycerol and three molecules of one or more types of fatty acids

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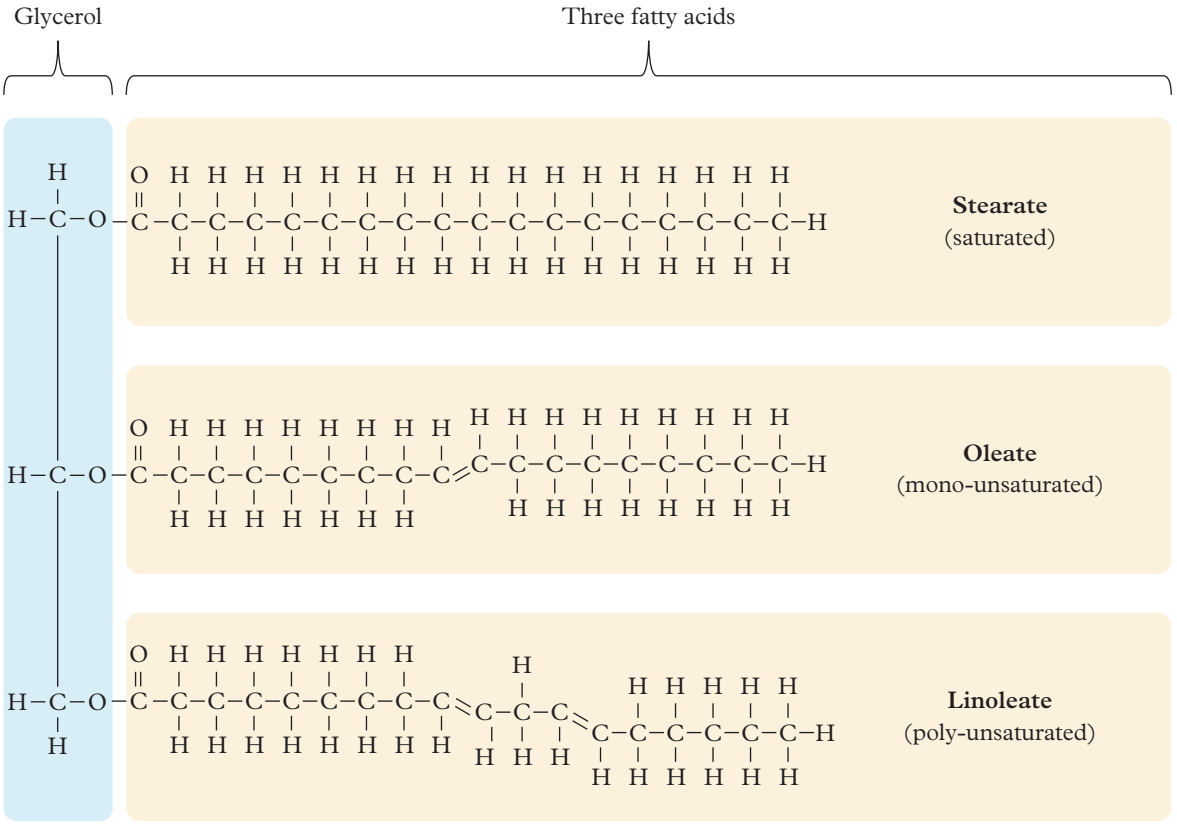


FIGURE 11 A triglyceride molecule

saturated
describes a lipid in which the carbon atoms are linked by single bonds only (C–C)

unsaturated
describes a lipid in which the carbon atoms are linked by one or more double bonds (C=C)

The physical nature of a lipid is determined by the length of the carbon chains in the fatty acids, and whether these chains are **saturated** (consist of only single bonds between carbon atoms) or **unsaturated** (consist of one or more double bonds between the carbon atoms). Lipids formed from saturated fatty acids are more compact, and therefore form solid fats and waxes (e.g. butter and lard). Lipids with one or more unsaturated fatty acid chain do not pack as closely together and therefore tend to form liquid oils (e.g. olive oil, eucalyptus oil).

Lipids are non-polar, so they are relatively insoluble in water. They play an important role in the control of water balance in the organism, and are therefore an important component of the membranes surrounding cells. Waxes form protective waterproof coatings on the external surface of the exoskeleton of insects, the feathers of birds and the hair of mammals. Many plant surfaces, such as leaves and fruit skins, are coated with a lipid cuticle that reduces evaporative water loss.

phospholipid
the major unit of the phospholipid bilayer, composed of a hydrophilic phosphate head and hydrophobic fatty acid tails; provides structure for the cell and helps separate the cytoplasm from the external environment

In terms of energy content, lipids can store up to twice the amount of energy that a carbohydrate of the same mass can store. This makes lipids an important energy reserve in living organisms. In animals, fat is stored in special cells, which in vertebrates are commonly found under the skin. These fat layers can be especially important to animals that live in cold environments. In seals and whales, "blubber" acts as an insulator and contributes to buoyancy. Hibernating animals, such as bears, build up large fat reserves during summer, to provide them with energy over the cold winter months. Fat also surrounds and protects vital organs such as heart and kidneys. Plants store oils rather than fats. Plant oils can help provide energy for germination and can play a role in plant defence mechanisms.

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Phospholipids

Phospholipids are similar to triglycerides, except that rather than containing three fatty acids, one fatty acid is replaced by a phosphate group plus an organic base (Figure 12). Phospholipids are an important component of cell membranes. In Module 2 you learnt that the cell membrane of eukaryotic cells is made from a phospholipid bilayer.

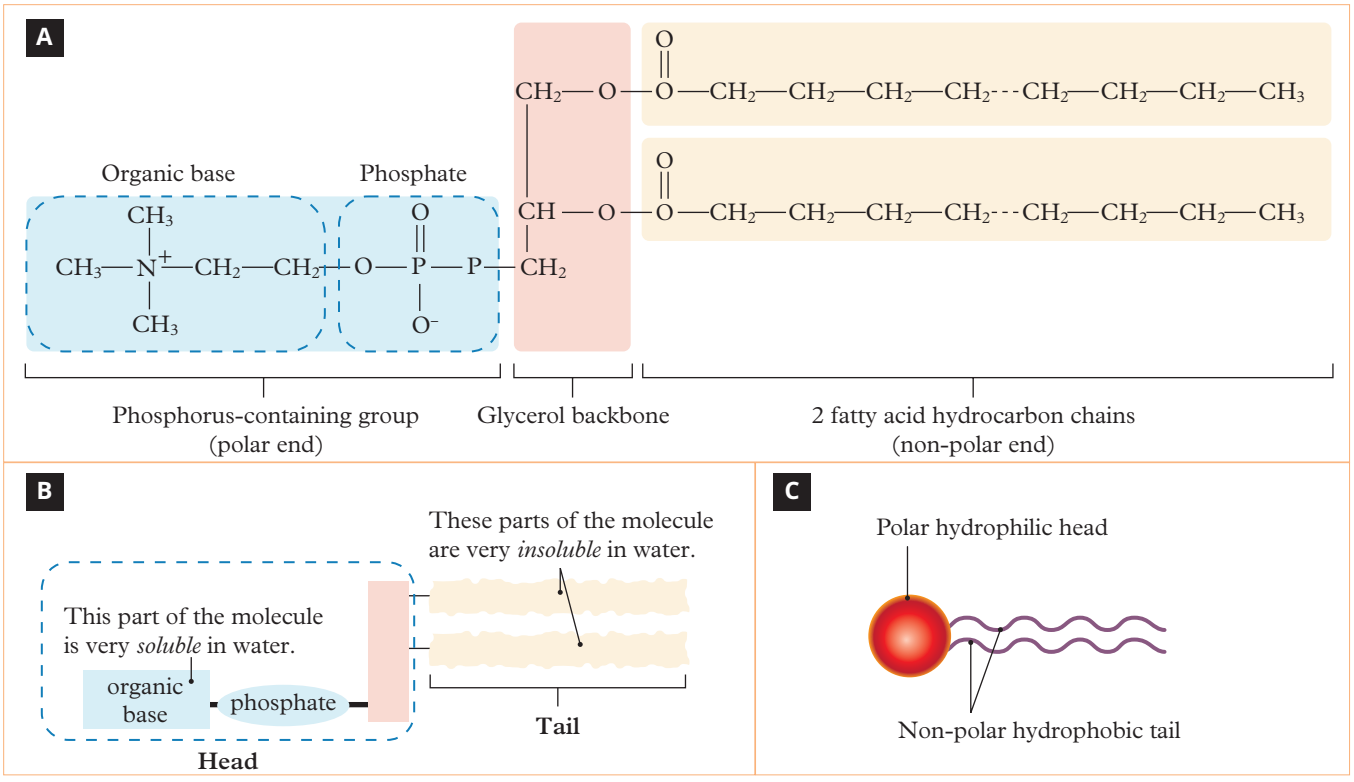


FIGURE 12 Structure of a phospholipid, shown in three ways: (A) molecular, (B) solubility and (C) 3D structure

Steroids

Steroids have a ring-like chemical structure that differs from all other lipids. However, they are still classified as lipids, because they are insoluble in water and soluble in fat solvents. Steroids include sex hormones, adrenal cortex hormones and cholesterol. They are abundant in both plants and animals, where they have many important biochemical and physiological roles. Cholesterol is a steroid found throughout the human body. It is an important component of cell membranes and a constituent of bile, which emulsifies fats.

steroids
a class of lipid molecules that have a distinct chemical structure that contains four fused carbon rings

TABLE 2 Summary of the structure and function of carbohydrates, proteins and lipids

Macromolecule	Elements	Smaller molecules (monomers, building blocks)	Macromolecules (polymers)	Type of bonding
Carbohydrate (e.g. glycogen, starch)	C, H, O	Monosaccharides – single simple sugar (e.g. glucose) Dissacharides – 2 simple sugars bonded together (e.g. sucrose)	Polysaccharides	Glycosidic
Protein (e.g. enzymes)	C, H, O, N	Amino acids – 20 common types; all may be present in one molecule	Polypeptides, proteins	Peptide
Lipid (e.g. fats, oils, waxes)	C, H, O (+ P in phospholipids)	Fatty acids and glycerol – may also contain phosphate	Lipids (e.g. phospholipids, triglycerides, waxes and steroids)	Ester

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Check your learning 4.1

Check your learning 4.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the monomers for:
   - **a** carbohydrates (1 mark)
   - **b** proteins (1 mark)
   - **c** lipids. (1 mark)

2 **Define** a macromolecule. (1 mark)

3 **Describe** the general structure of carbohydrates. (3 marks)

4 **Explain** why polysaccharides make good storage molecules. (3 marks)

5 **Describe** the formation of a polypeptide chain, including the type of bond. (1 mark)

6 **Identify** the structural components of a phospholipid molecule. (1 mark)

7 **Describe** three functions of lipids in living organisms. (3 marks)

8 **Describe** the secondary structure of a protein. (2 marks)

Analytical processes

9 **Compare** triglycerides and phospholipids. (2 marks)

10 **Distinguish** between tertiary and quaternary protein structure. (1 mark)

Knowledge utilisation

11 **Determine** whether the triglyceride shown in Figure 10 would be solid or liquid at room temperature. **Justify** your answer. (2 marks)

Lesson 4.2
Enzymes

Key ideas

- → All metabolic reactions require activation energy, a specific initial input of energy, to proceed.
- → Enzymes are biological catalysts that lower the activation energy needed for a chemical reaction to occur.
- → There are two models for understanding how enzyme action works: the lock-and-key model and the induced-fit model.
- → Temperature, pH, substrate concentration and inhibitors are all factors that can influence enzyme activity.

Learning intentions and success criteria

chemical energy the energy stored within molecular bonds that is released during a chemical reaction

metabolism chemical reactions occurring within a cell

activation energy the energy needed to start a chemical reaction

Chemical reactions within the cell

Energy is the ability to do work. All living cells require energy so they can grow, reproduce and perform tasks that help them stay alive. Cells primarily use **chemical energy** (energy that is stored within chemical bonds between the atoms of molecules) to store energy for later use and to release energy to power cellular processes. You will learn more about how cells use energy in Module 7. Cellular **metabolism** is the complete set of chemical reactions that occur for a cell to function. All reactions, including those needed to form and break down molecules, require a specific amount of energy to "jump-start" the reaction – this is known as **activation energy**.

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Activation energy

All cellular reactions require activation energy, which is the initial input of energy required to start a reaction, before they can proceed. Activation energy helps prevent reactions from occurring spontaneously, at unwanted times or in an uncontrolled manner. For example, the breaking down of the sugar molecule glucose is an important metabolic reaction that yields energy for the cell. Glucose contains potential energy, which can only be released when glucose is broken down into smaller molecules after an oxidation reaction.

Mixing glucose and oxygen does not automatically ensure that the oxidation process will proceed. The reaction must be activated. For this to occur, activation energy is needed. An example is the burning of wood. Wood will not just burn spontaneously. It requires the addition of heat from fire for the bonds between the cellulose molecules in the wood to be broken. Once the added energy reaches the activation energy required, the wood will burn and release the large amount of energy stored in its bonds. Regardless of whether a reaction gives off or absorbs energy, some energy is required initially to start the reaction.



FIGURE 1 The carbon in wood requires activation energy from heat to react with oxygen and create carbon dioxide.

Reaction rate

The molecules of **reactants** in any chemical reaction are in continual random motion. These molecules can only react after they have successfully collided with each other. Therefore, any factor that increases the frequency of successful collisions will also increase the rate at which the reaction occurs. Two factors that can influence the frequency of successful collisions are:

1. the concentration of reactants – the greater the concentration of reactants (i.e. the more densely they are packed), the more likely they are to collide and react
2. temperature – raising the temperature speeds up the random motion of the molecules, thereby increasing the probability of their colliding.

While these two factors can be used to increase reaction rate, their use is sometimes limited in cells. For example, a cell might not always have the resources needed to increase the concentration of reactants. Additionally, while many biological reactions can be made to occur more quickly by heating, cells cannot tolerate too much heat, because biological compounds can decompose at high temperatures. Because of this, sometimes cells need to rely on other mechanisms to increase the rate of a reaction.

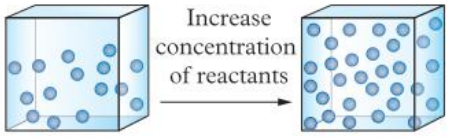


FIGURE 2 The rate of a reaction can be increased by increasing the concentration of reactants.

reactant
a substance that is present at the start of a reaction and changes as the reaction proceeds

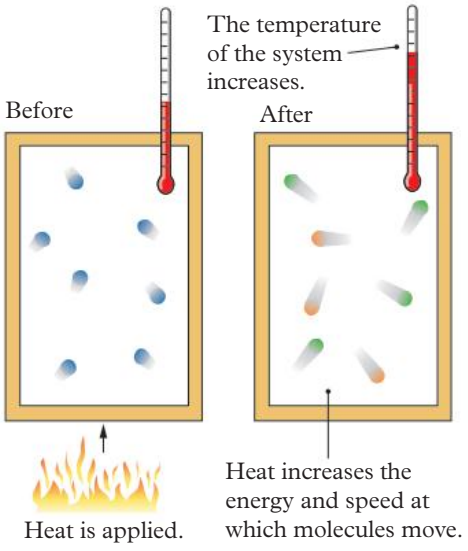


FIGURE 3 The rate of a reaction can be increased by increasing the temperature.

Enzymes

Catalysts are molecules that lower the activation energy of a reaction, so the reaction can reach completion more quickly. When a catalyst is present, each reactant is drawn to the surface of the catalyst where, once they are in close enough proximity, they can react. The new product then detaches from the catalyst, which remains unchanged by the process and can be used again. Biological catalysts that speed up the rate of a reaction without being consumed in the reaction are called **enzymes**. Enzymes are tertiary proteins that regulate the

catalyst
a substance that increases reaction rate without being consumed or changed by the reaction

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enzyme
a biological catalyst, produced by living cells, that changes the rate of chemical reactions in living organisms

intracellular
located within the cell

extracellular
located outside the cell

substrate
the molecule(s) that an enzyme reacts with to form an enzyme–substrate complex

active site
the portion of an enzyme in contact with the substrate; at this stage it has a specific shape that corresponds to the shape of at least a portion of the substrate molecule

rate of metabolic processes inside and outside cells. Enzymes can be classified into two main groups: **intracellular** and **extracellular**. Intracellular enzymes occur within the cell, where they control metabolism. Extracellular enzymes are catalytic proteins produced by cells, but they work outside the cell. Normally an enzyme is named by adding the suffix "-ase" to the name of the substrate on which it acts. So, for example, maltase acts on maltose and lipase acts on lipids.

A cell can contain thousands of types of enzymes, each interacting only with a specific molecule or set of molecules, called a **substrate(s)**. Enzymes bind with their substrate(s) at a region on the enzyme known as the **active site** (Figure 4). Some enzymes orientate the reacting particles to increase the chance of successful collisions. Other enzymes can form enzyme–substrate complexes that requires less energy for the reaction to proceed. The enzyme–substrate complex can bend the substrate molecule in a way that helps to break the chemical bonds to reach the transition state. Regardless of how an enzyme acts, they produce the same product that the uncatalysed reaction would have, but at a lower net activation energy. Because the enzyme does not react and is left relatively unchanged, it can be reused.

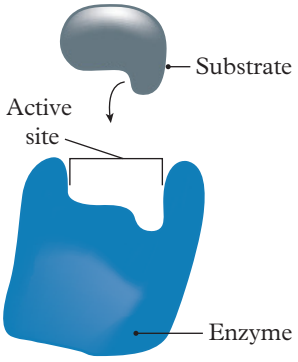


FIGURE 4 Substrates bind to the active site of an enzyme.

Each enzyme controls only one (or one type of) reaction. This enzyme specificity occurs because the active site of any particular enzyme can accommodate only a certain shape of substrate molecule. Therefore, many different enzymes may be required in a multi-step reaction (e.g. respiration, photosynthesis, synthesis or hydrolysis of organic molecules).

While enzymes may differ in function, they share the following properties.

- Their structure is tertiary and globular in shape.
- They increase the rate of reaction without being used up.
- Their presence does not alter the nature of the end products of the reaction.
- A small amount of enzyme catalyses a large quantity of substrate.
- They are specific in action, generally catalysing one specific reaction or part of a reaction.

Study tip

Enzymes are proteins, but not all proteins are enzymes.

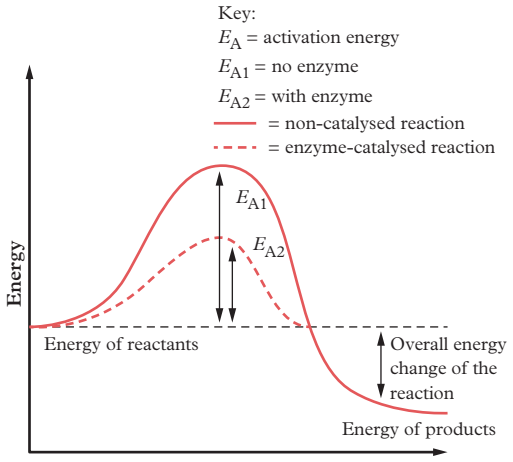


FIGURE 5 This energy diagram shows that the presence of an enzyme lowers the activation energy of a reaction.

Enzyme action

Various models have been proposed to explain how enzymes lower the activation energy of a reaction. Different reactions may use one or more of the following methods.

- When bound to the substrate, the enzyme may change shape. This may place stress on some substrate bonds, making them more easily broken.
- Substrates may form weak bonds with their specific enzymes, resulting in the redistribution of electrons within the substrate molecule, making it more reactive.
- The binding of the substrate to the enzyme may orientate the substrate molecules in a way that maximises reactivity.

Two models that can explain the overall action of enzymes are the **lock-and-key model** and the **induced-fit model**.

lock-and-key model
a model that suggests that the substrate and active site of an enzyme are complementary in shape and fit together like a lock and key

induced-fit model
a model that suggests that the active site of an enzyme, after initially attracting a specific substrate, changes to suit the substrate's shape, which in turn also affects the shape of the substrate

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The lock-and-key model

The lock-and-key model proposes that an enzyme's function depends on its shape. According to the lock-and-key hypothesis, a substrate will attach to the active site of an enzyme in much the same way as a key fits into a lock. The shape of the enzyme's active site is complementary to the shape of the substrate. Because of this, the substrate molecule fits almost perfectly into the enzyme. The portion of the enzyme that is in contact with the substrate (active site) is very small compared with the total size of the enzyme molecule.

When the substrate binds to the active site, it forms an enzyme–substrate complex, which triggers the formation of products. Once formed, the product molecules no longer fit into the active site and escape into the surrounding medium, leaving the active site free to interact with other substrate molecules.

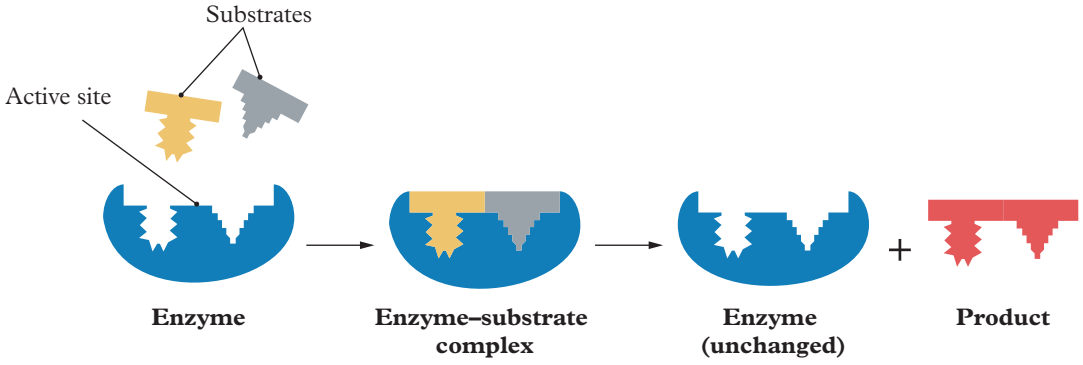


FIGURE 6 The lock-and-key model

The induced-fit model

Sometimes a substrate does not have a complementary shape that fits precisely into the active site of the enzyme. The induced-fit model proposes that the shapes of both the enzyme and the substrate change after they make contact, to induce a better fit between the substrate and the active site. The substrate and active site change in conformation (arrangement) until the substrate is fully bound to the enzyme, forming the enzyme–substrate complex. Once bound, strong bonds form between the substrate and the enzyme that lower the activation energy of the reaction. The product(s) then detach from the enzyme and the enzyme can be reused.

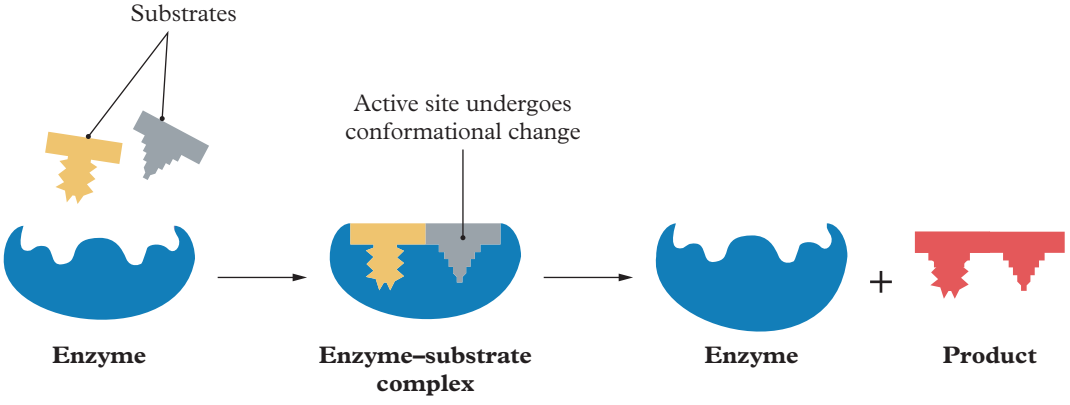


FIGURE 7 The induced-fit model

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Real-world biology

A metabolic pathway – phenylalanine

The metabolism of chemical compounds in the cell usually involves several separate reactions, each mediated by a specific enzyme. If an enzyme in a metabolic pathway is absent or faulty, the correct sequence of chemical reactions might not occur. Different products would form, and some of these could be dangerous to the health of the cell.

When excess proteins are taken into the body, they are not stored but are broken down in a series of steps. Each step requires an energy input, but energy is also released as a product. In the normal course of events, a protein will undergo a series of hydrolysis reactions to release the component amino acids, one of which is phenylalanine. The liver produces the enzyme phenylalanine hydrogenase, which brings about the conversion of phenylalanine to another amino acid, called tyrosine. If this enzyme is faulty, phenylpyruvic acid is formed instead of tyrosine. This can lead to a disease called phenylketonuria (PKU) which, when untreated, can result in symptoms including intellectual disability, musty body odour and seizures.

Tyrosine can be used in two other series of reactions – one that results in the formation of the growth hormone thyroxin and the other in the production of the skin pigment melanin. Each set of reactions has its own series of enzymes. The absence of any of these enzymes can produce chemicals that may have adverse effects on the body. The figure illustrates the products that can result from enzyme failure at various points along the catabolic pathway of phenylalanine.

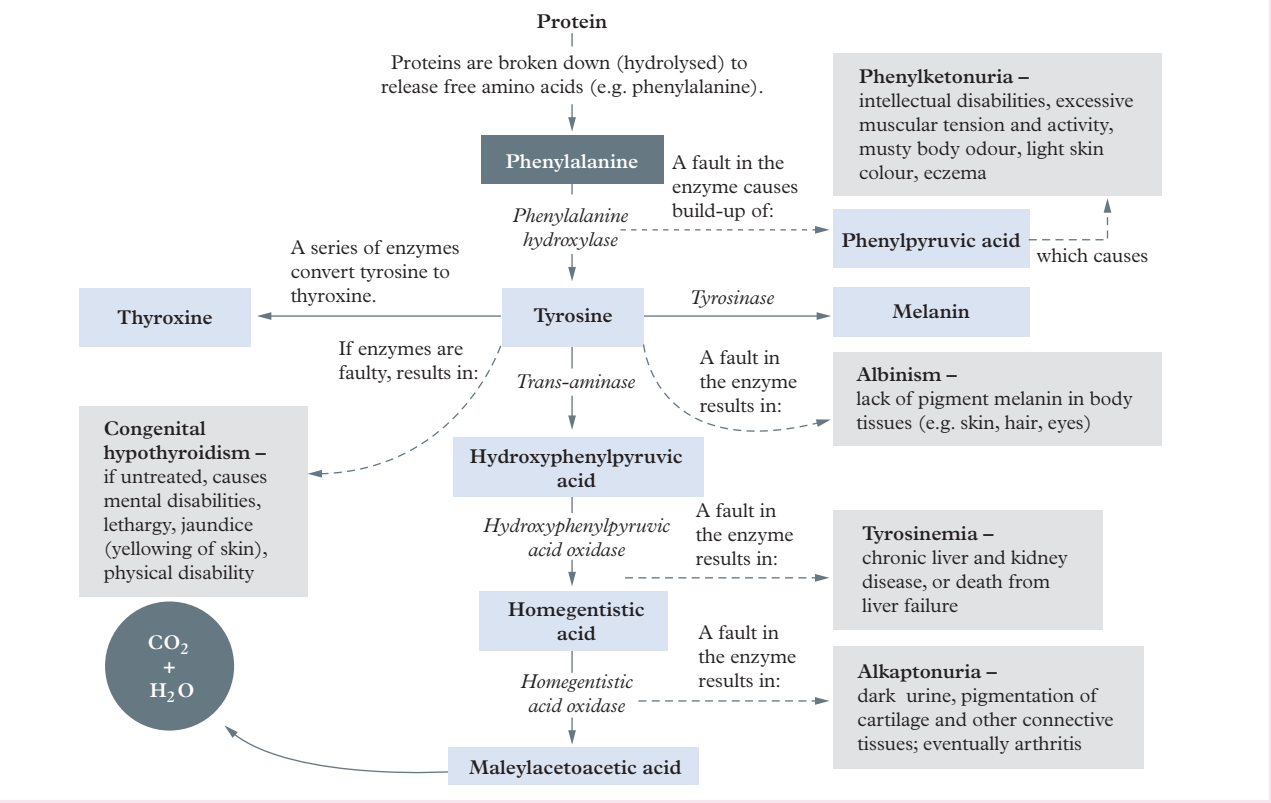


FIGURE 8 The metabolism of phenylalanine

Apply your understanding

1 **Identify** which enzyme is required for the appropriate breaking down of phenylalanine. (1 mark)

2 **Describe** the process of breaking down phenylalanine in a person with phenylketonuria (PKU). (1 mark)

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Factors that influence enzyme activity

Enzyme activity can be influenced by several factors, including temperature, pH, substrate concentration and the presence of inhibitors.

Temperature

Enzymes are heat-sensitive – that is, each enzyme has an optimum temperature at which it functions best (approximately 30°C in plants and 37°C in humans). Enzymes may still function outside their optimal temperature (or tolerance range), at reduced efficiency. If the temperature is far above what enzymes can tolerate (e.g. 50°C in humans), they are destroyed by denaturation, which involves a change in the shape of the enzyme protein. Although the action of enzymes may be inhibited at low temperatures (e.g. freezing), their protein structure remains unaltered.

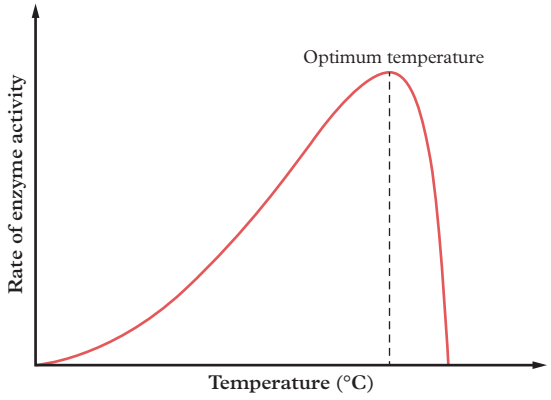


FIGURE 9 The effect of temperature on rate of enzyme activity

pH

Enzymes are pH sensitive. This means each enzyme has a specific optimum pH and will only work within a narrow range of its optimum pH (Figure 10). If the pH surrounding an enzyme is higher or lower than the enzyme's pH tolerance range, the bonds within the enzyme can break down. This can cause the enzyme to lose its shape and function.

Substrate concentration

Enzymes are influenced by the concentration of substrates. As the concentration of substrate increases, the rate of enzyme action increases to a maximum value, known as the limiting value, and then plateaus (Figure 11). This maximum rate is reached when the enzyme is being used at maximum efficiency. Any substrate added after this point will not increase the reaction rate, because the enzyme is already working as efficiently as possible.

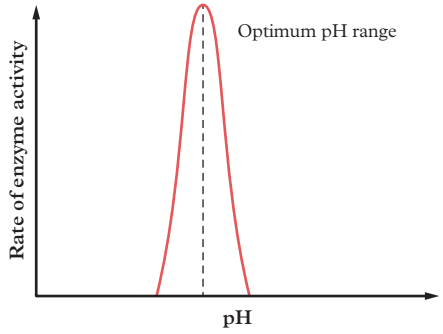


FIGURE 10 The effect of pH on rate of enzyme activity

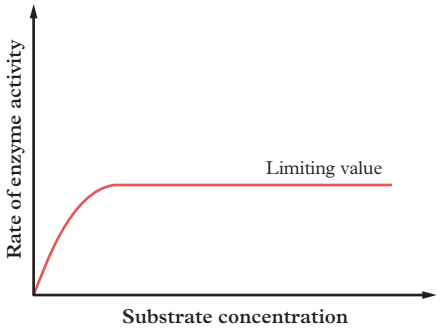


FIGURE 11 The effect of substrate concentration on rate of enzyme activity

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Inhibitors

enzyme inhibitor
a molecule that binds to an enzyme and blocks its activity

competitive inhibitor
a substance that occupies the active site of an enzyme and prevents the normal substrate from binding

non-competitive inhibitor
a substance that binds to the allosteric site of an enzyme and permanently reduces or blocks an enzyme's activity

allosteric site
a region on an enzyme, separate from the active site, where a molecule may bind, altering the shape of the active site

Enzyme inhibitors are molecules that bind to an enzyme to reduce or prevent its activity. There are two main types of inhibitors.

- **Competitive inhibitors** compete with the normal substrate molecules for the active site.
- **Non-competitive inhibitors** bind to a different site on the enzyme, called the **allosteric site**, causing a change in the enzyme that reduces or completely blocks its activity.

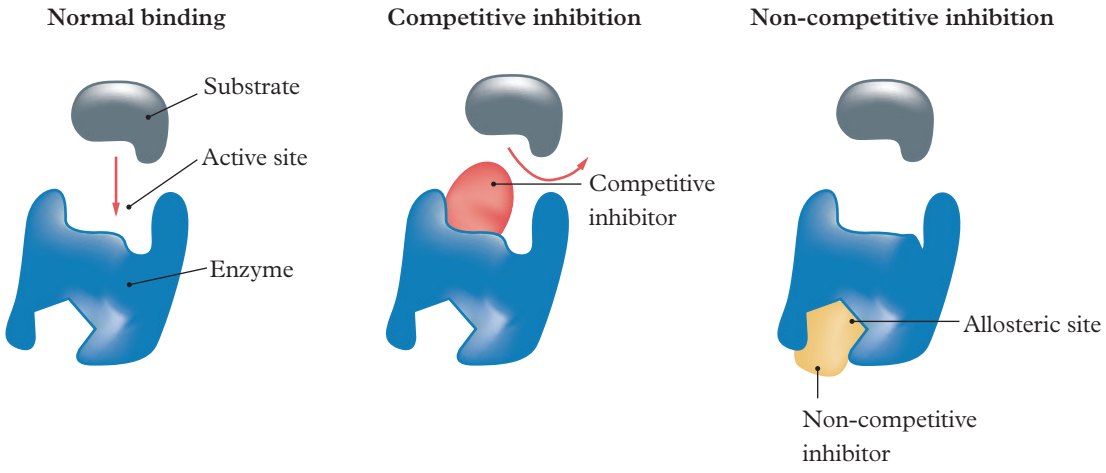


FIGURE 12 How competitive and non-competitive inhibitors bind to enzymes

Competitive and non-competitive inhibitors both decrease enzyme activity and therefore the rate at which a reaction occurs. A competitive inhibitor will initially lower the rate of reaction, but the rate of reaction can return to that of a normal enzyme with increasing substrate concentration. A non-competitive inhibitor decreases the rate of reaction even with increasing substrate concentration, because it alters the way in which the enzyme functions.

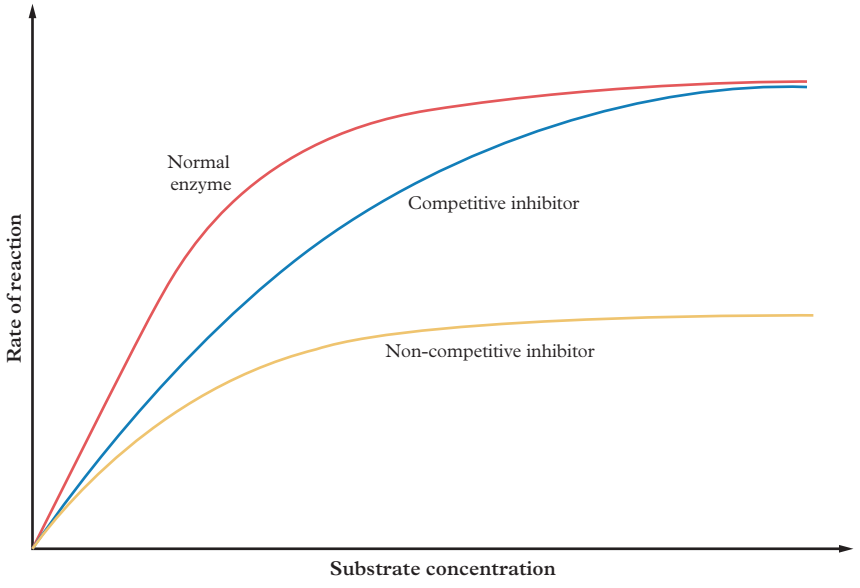


FIGURE 13 The effect of inhibitors on reaction rate

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Challenge

Predicting enzyme experiment results

A student wants to investigate how enzyme concentration influences the rate of a reaction. They run two conditions of an experiment.

- In condition A they track the progress of an enzyme-catalysed reaction by monitoring reaction rate in response to a steady increase of both substrate concentration and enzyme concentration.
- In condition B they track the progress of an enzyme-catalysed reaction by monitoring reaction rate in response to a steady increase of enzyme concentration and a constant substrate concentration.

1 **Predict** the impact on reaction rate you would expect the student to see in experiment A. **Justify** your prediction. (2 marks)

2 **Predict** the impact on reaction rate you would expect the student to see in experiment B. **Justify** your prediction. (2 marks)

Skill drill

Reading and calculating data

Science inquiry skill: Processing and analysing data (Lesson 1.8)

The pancreas produces enzymes that are used in the digestion of proteins, lipids and carbohydrates (proteases, lipases and amylases). For people suffering from cystic fibrosis, pancreatitis and other conditions of the pancreas, pancreatic enzymes are available in tablet form and are taken orally. However, the tablet dosage must be increased gradually from the lowest dose. The dosage instructions are as follows:

- 500 lipase units/kg of body weight/meal for 2 months, then
- 1000 lipase units/kg of body weight/meal for 2 months, then
- 1500 lipase units/kg of body weight/meal for 2 months, then
- 2000 lipase units/kg of body weight/meal for 2 months, then
- 2500 lipase units/kg of body weight/meal until a 1 year review appointment.

Tablets are colour coded and available in 5000 (red), 10,000 (green), 15,000 (blue) and 20,000 (yellow) lipase units.

Practise your skills

1 **Determine** for a 110 kg patient:
   a the starting dose (1 mark)
   b the combination of coloured tablets for the starting dose. (1 mark)

2 A 60 kg elderly patient with pancreatitis requires pancreatic enzymes. **Use** the colour code of the tablets to **structure** a set of instructions for the patient and their carer, from the start of treatment until the 1 year review. Try to keep the same colour for each dose. Remember, the doses are per meal, not per day. Use the least number of tablets possible. (4 marks)

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Check your learning 4.2

Check your learning 4.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** activation energy. (1 mark)

2 **Describe** the function of enzymes, with reference to activation energy. (1 mark)

3 **Describe** the role of the active site in enzyme function. (1 mark)

4 **Explain** how each of the factors below influences the rate of enzyme activity.

- **a** temperature (1 mark)
- **b** substrate concentration (1 mark)
- **c** inhibitors (1 mark)
- **d** pH (1 mark)

Analytical processes

5 **Compare** the lock-and-key and induced-fit models of enzyme function. (2 marks)

6 **Distinguish** between a competitive inhibitor and a non-competitive inhibitor. (1 mark)

Knowledge utilisation

7 A student monitoring an enzyme-catalysed reaction collected the data shown in the table.

Substrate concentration (μM)	Reaction rate (M/min)
4	0
5	0.5
10	2
15	3
20	3.5
25	4
30	4
35	4
40	4
45	4
50	4

- **a** **Graph** the data in the table. (3 marks)
- **b** **Identify** the substrate concentration at which the reaction reached its limiting value. (1 mark)
- **c** **Deduce** why the reaction rate plateaued (rather than increasing) after reaching the limiting value. (1 mark)

Practical

Lesson 4.3

The effect of enzyme concentration on the rate of reaction

Learning intentions and success criteria

This practical lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.

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MODULE 4

Lesson 4.4
Review: The chemicals of life

Summary

4.1
- Matter can be divided into two categories: inorganic compounds (non-living substances) and organic compounds (living substances).
- The three main types of organic compounds are carbohydrates, proteins and lipids.
- Carbohydrates, proteins and lipids are large "macromolecules" that are made up of smaller subunits.

4.2
- All metabolic reactions require activation energy, a specific initial input of energy, to proceed.
- Enzymes are biological catalysts that lower the activation energy needed for a chemical reaction to occur.
- Two models for understanding how enzyme action works are the lock-and-key model and the induced-fit model.
- Temperature, pH, substrate concentration and inhibitors are all factors that can influence enzyme activity.

4.3
- Practical: The effect of enzyme concentration on the rate of reaction

Review questions 4.4A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 A protein that consists of two polypeptide chains folded together into a three-dimensional shape would be considered as having
- **A** primary structure.
- **B** secondary structure.
- **C** tertiary structure.
- **D** quaternary structure.

2 Simple proteins are composed of
- **A** fatty acids.
- **B** monosaccharides.
- **C** glycerol.
- **D** amino acids.

3 Phospholipids are an important structural macromolecule in
- **A** cell walls.
- **B** collagen.
- **C** cell membranes.
- **D** oils.

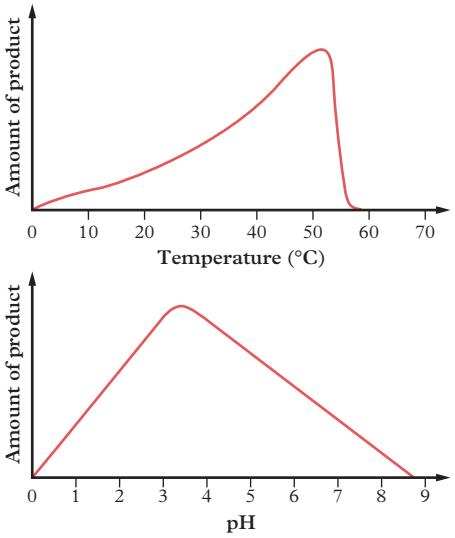
4 Enzymes are essential for biochemical reactions because they
- **A** regulate the rate of reaction.
- **B** work best at temperatures over 50°C.
- **C** are not sensitive to pH changes.
- **D** are used up in chemical reactions.

5 Saccharides are the monomers of
- **A** proteins.
- **B** carbohydrates.
- **C** lipids.
- **D** phospholipids.

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Use the following information to answer questions 6 to 8.
Scientists studied an enzyme called enzymase. They tested the amount of product formed at different temperatures and pH levels, and their results are shown in the graphs.



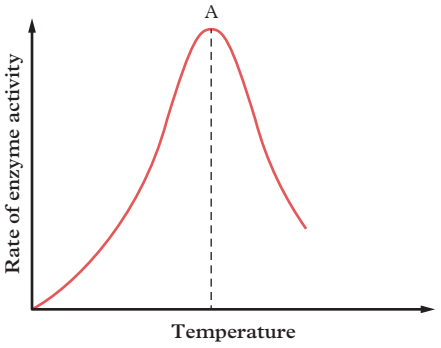
6 The enzyme functions best at which of the following temperature ranges (in °C)?
- **A** 10 to 20
- **B** 20 to 30
- **C** 30 to 40
- **D** 40 to 50

7 At what pH does the enzyme function best?
- **A** acidic
- **B** basic
- **C** neutral
- **D** The pH does not affect the reaction.

8 The enzyme probably does not function at 70°C because
- **A** the enzyme denatures at that temperature.
- **B** there is too little substrate at that temperature.
- **C** the amount of product increases at a higher temperature.
- **D** the pH is not favourable.

9 Which of the following best summarises the lock-and-key model?
- **A** The enzyme and substrate are modified to fit together.
- **B** The enzyme is used up during the reaction.
- **C** The enzyme and substrate fit together almost perfectly with no modifications.
- **D** The activity of an enzyme increases with temperature.

10 The dotted vertical line (A) in the graph represents
- **A** the optimal substrate level for enzyme function.
- **B** the optimal temperature for enzyme function.
- **C** the tolerance temperature for enzyme function.
- **D** the tolerance substrate level for enzyme function.



Review questions 4.4B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

11 **Identify** and **describe** the monomer of carbohydrates. (2 marks)

12 **Define** activation energy. (1 mark)

13 **Describe** the structure and function of lipid macromolecules. (2 marks)

14 **Describe** the induced-fit model of enzyme function. (1 mark)

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15 Phosphatase is an enzyme that will release phosphate groups from certain substrates.

When phenylphosphate is acted on by phosphatase, phenol is formed and its presence can be detected by a colour reaction. A student used this test to look for the presence of phosphatase in a variety of substances. Reactions included the following:

Material	Whole	Ground	Boiled
Liver	+	++	–
Milk	++	NT	–
Bacterium A	+	++	–
Bacterium B	–	–	NT

++ strong reaction; + weak reaction; – no reaction; NT not tested

No reaction occurred with any of the substances after the material had been boiled. The student concluded that this is due to the phosphatase denaturing. **Explain** this conclusion, with reference to optimal temperature. (3 marks)

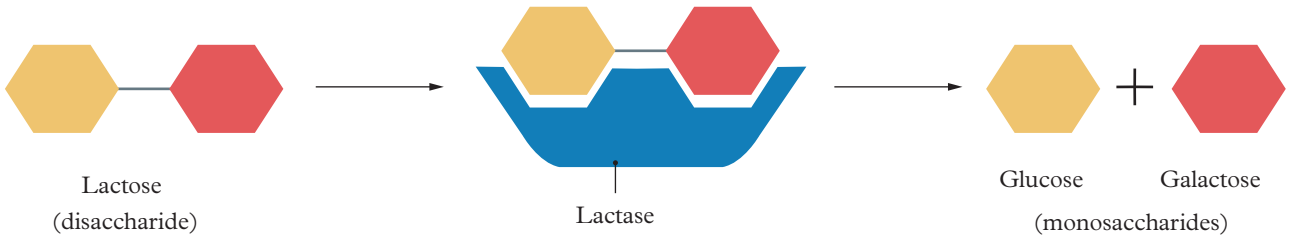
Knowledge utilisation

16 Folate synthesis in cells relies on the activity of two enzymes: dihydrofolate reductase (DHFR) and dihydrofolate synthase (DHFS). Because cancer cells require large amounts of folate to support their prolific growth, inhibiting the action of DHFR can reduce folate synthesis, resulting in the death of the cancerous cells. Methotrexate is an enzyme inhibitor that does this, by competing with DHFR's substrate and binding to the active site of DHFR, reducing folate synthesis. Because of this, methotrexate is often used as a chemotherapy drug in cancer treatments.

a **Identify** which type of inhibitor methotrexate is an example of. **Justify** your answer. (2 marks)

b Folate synthesis is also important for the growth of other cells in the body (not just cancerous cells). **Predict** one negative side-effect that could result from treatment with methotrexate. (1 mark)

17 The figure shows the biochemical process of the breaking down of lactose, the sugar in cow's milk products.



a **Identify** the enzyme that regulates the breaking down of lactose in cow's milk products. (1 mark)

b **Describe** the structure and role of the active site of an enzyme. (2 marks)

c Lactose-intolerant individuals are not able to digest lactose in dairy products. **Propose** what may cause lactose intolerance. (1 mark)

18 Fatty acids are saturated or unsaturated.

Unsaturated fatty acids (e.g. oleic acid, the chief constituent of olive oil) contain one or more double carbon bonds (C=C), allowing each carbon to react with another element or group of elements. These fatty acids melt at much lower temperatures (approximately 13°C) than saturated fatty acids (approximately 63°C).

In saturated fatty acids there are only single bonds between the carbons (e.g. stearic acid in lamb and beef fat).

Cells of ectothermic animals (animals that use behavioural means to partially control their body temperature, which varies with that of the environment) have a higher proportion of unsaturated fatty acids than endothermic animals (which control their body temperature by physiological means). **Propose** a reason for this and **justify** your response. (2 marks)

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Data drill

Enzymes in milk

Rennin is an enzyme that curdles milk and is found in the stomachs of mammals.

An experiment is conducted in which rennin is added to milk at different temperatures. The results are shown in the table.

Temperature of milk (°C)	Weight of curdled product (g)				Standard error
	Trial 1	Trial 2	Trial 3	Average	
4	0.2	0.4	0.5	Question 1	0.09
37	7.0	5.5	9.6	7.37	1.20
80	0.0	0.0	0.0	0.0	0.0

Apply understanding

1 **Calculate** the average weight of curdled product at 4°C. (1 mark)

Analyse data

2 **Identify** the optimal temperature for the enzyme rennin to function, giving evidence to support your response. (2 marks)

3 **Comment** on the accuracy of the collected data. (1 mark)

Interpret evidence

4 A statistical test for the difference in mean weight of curdled product at 4°C and 37°C gave a p value of $p = 0.03$. **Use** this information to **draw a conclusion** about the effect of temperature on the reaction rate of rennin, giving reasons for your response. (2 marks)

Module 4 checklist: The chemicals of life

Quizlet: Revise key terms online to test your understanding

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MODULE 5

Transport of materials in animals

Introduction

The cells of multicellular organisms extract nutrients from their environment, exchange respiratory gases and eliminate wastes. In multicellular organisms, the larger the organism, the further their internal cells are from the surface where this exchange takes place. Therefore, specialised systems are needed to transport materials to and from cells. In mammals, the main transport system is the closed circulatory system, which includes the heart, blood vessels and blood.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to transport of materials in animals before you start.

Subject matter

Science understanding

→ Explain how structural features of exchange surfaces in the digestive and circulatory systems of mammals (e.g. villi and capillaries) allow for efficient nutrient exchange.

→ Describe how closed circulatory systems facilitate the efficient transport of materials to and from all cells in the body.

Science as a human endeavour

→ Appreciate how understanding the anatomy and physiology of different body systems allows medical professionals to predict, diagnose, monitor and treat disease.

Science inquiry skills

→ Identify research and construct questions for investigation.

→ Design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data required to obtain valid and reliable evidence.

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Lesson 5.1
Transport in animals

Key ideas

- → Large animals, such as humans, require a specialised transport system to deliver needed nutrients, facilitate gas exchange and remove wastes.
- → In mammals, three fluids are involved in transport systems: tissue fluid, lymph and blood.
- → The structure of red blood cells (erythrocytes) is highly specialised to facilitate their function of transporting oxygen around the body.

Learning intentions and success criteria

Transport systems

All multicellular organisms have the same basic requirements. They need to take in nutrients, exchange gases and remove wastes. While all organisms share these essential needs, the way in which each organism carries out these functions varies due to differences in their mode of nutrition, level of mobility, structure and physiology. Most animals have evolved specialised **transport systems** to meet these basic needs. In some small animals (e.g. flatworms), the transport of materials involves diffusion only. Larger animals (e.g. humans) have a dedicated transport system to move materials around the body. In mammals, materials are transported throughout the body in a liquid medium. Three fluids are involved: **tissue fluid** (or extracellular fluid), **lymph** and **blood**.

transport system
a system of vessels responsible for the movement of materials throughout an organism

tissue fluid (extracellular fluid)
fluid formed from plasma that has been pushed out through the walls of capillaries under arterial pressure; surrounds the cells, providing a medium for exchange between blood and the cells

lymph
tissue fluid that has been taken up by lymphatic vessels to be returned to the blood (vascular system); contains a high volume of white blood cells

blood
the transporting medium in animal bodies; in mammals, it is composed of plasma, platelets, and red and white blood cells

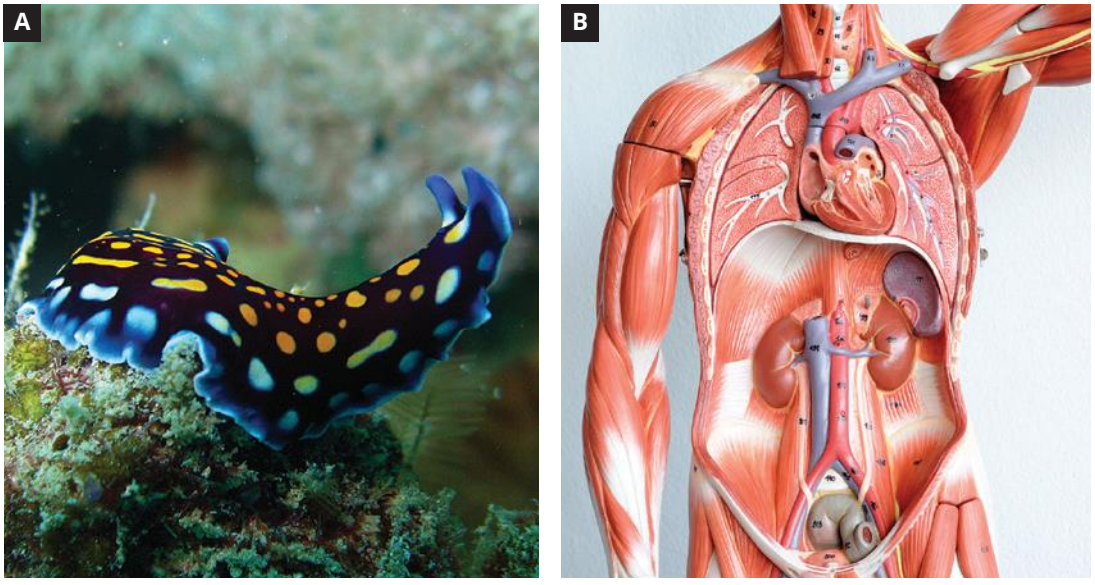


FIGURE 1 (A) In flatworms, materials are transported by diffusion only. (B) In humans, dedicated transport systems exchange nutrients and wastes.

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Tissue fluid

Tissue fluid is the liquid medium that surrounds individual cells. It is the main source of nutrients and gases from the blood, and it carries wastes from a cell to the blood or lymph. A cell's plasma membrane controls the passage of molecules into and out of the cell through diffusion, facilitated diffusion or active transport.

Lymph

Lymph is a clear liquid that consists of lipids and white blood cells (leucocytes). Lymph is carried in **lymphatic vessels**. It picks up tissue fluid and particles and returns these to the blood system. Lymph plays an important role in the body's immune response. You will learn more about the immune response in Module 12.

lymphatic vessel
a tubular structure that carries lymph from tissues to the blood circulatory system

Blood

Human blood is composed of red blood cells (**erythrocytes**), white blood cells (**leucocytes**), plasma proteins and platelets suspended in a straw-coloured fluid called **plasma**. Plasma carries many important substances, including:

- proteins (e.g. enzymes, hormones and enzyme-coated lipids)
- specific plasma proteins involved in water balance, immunity and blood clotting
- carbon dioxide and nitrogenous wastes
- ions (salts)
- vitamins
- nutrients from digestion.

A comparison of the composition and function of transporting fluids in mammals is given in Table 1.

erythrocyte
a red blood cell

leucocyte
a white blood cell

plasma
the liquid component of blood; contains water, salts, hormones and waste materials such as carbon dioxide

TABLE 1 Composition and function of transporting fluids in mammals

Fluid	Composition	Functions
Plasma (55% of blood)	92% water 7% proteins Serum and fibrinogen	Transport of nutrients, waste products, hormones and heat
Tissue fluid (bathes living cells)	Similar to plasma but has less protein	Cell homeostasis Transport
Lymph (inside lymph vessels)	No protein Rich in lipids Contains lymphocytes	Transport to veins Phagocytosis of bacteria

Blood moves through a series of tubular vessels. These vessels, including **arteries**, **veins** and **capillaries**, vary in size, structure and function (Figure 2). The pumping action of the muscular heart moves blood through the vessels.

artery
a thick-walled blood vessel that carries blood away from the heart; the main artery leaving the heart is the aorta; the smallest arteries are arterioles, which lead to capillaries

vein
a thin-walled blood vessel that carries blood towards the heart; the smallest veins begin at the capillaries; the largest vein in animals is the vena cava, which enters the heart

capillary
a fine blood vessel with walls only one cell thick; capillaries permeate the body tissues and pressure causes plasma to pass out into the tissue fluid

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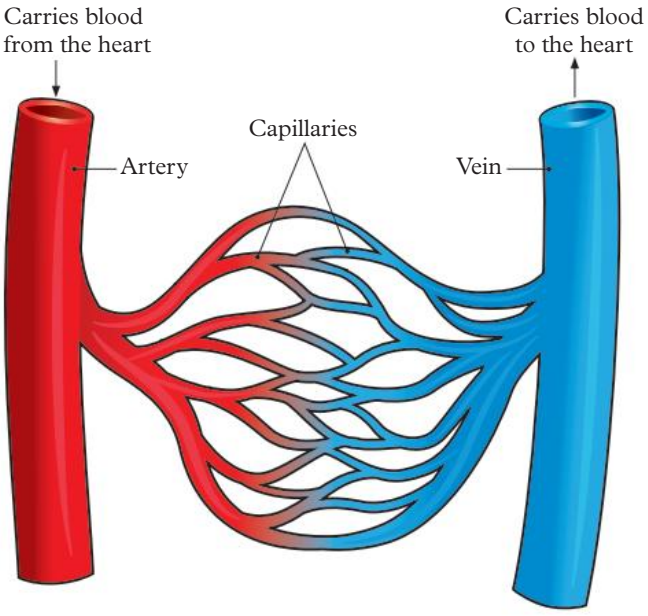


FIGURE 2 Arteries, veins and capillaries are vessels that transport materials in the human body.

Study tip

"erythr-" is derived from Ancient Greek and means red. "leuco-" means white.

The structure and function of blood

The main function of red blood cells is to transport oxygen from the respiratory surfaces to the tissues. Mature red blood cells have no nucleus and therefore cannot replicate, so they must be constantly produced in the bone marrow. This occurs at a rate of about 1.5 million per second. Their biconcave shape (concave on both sides) ensures a maximum ratio of surface area to volume for the uptake and release of respiratory gases (oxygen). The shape also ensures smooth flow through the smallest blood vessels, as the diameter of a red blood cell is about the same as that of the finest capillaries.

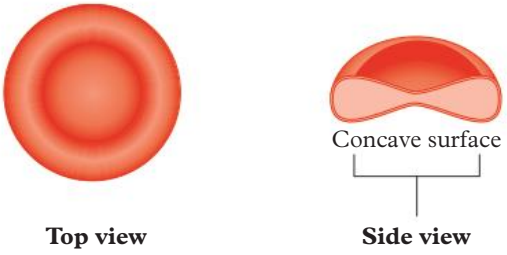


FIGURE 3 Red blood cells have a biconcave shape.

haemoglobin
an iron-containing protein in red blood cells; binds to oxygen for transport around the body

A red blood cell is packed with the red pigment **haemoglobin**. A haemoglobin molecule consists of two pairs of polypeptide chains, and each chain is combined with an iron-containing (haem) group. Each haem group can carry one oxygen molecule. Because the cell has no nucleus, it can carry more haemoglobin (and therefore more oxygen). A single red blood cell can carry 1000 million oxygen molecules.

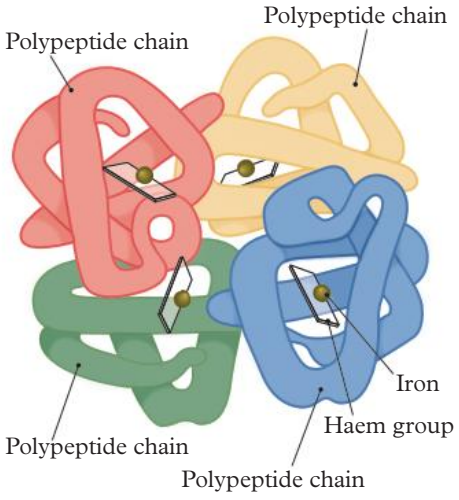


FIGURE 4 The structure of haemoglobin. Each folded polypeptide chain is a protein molecule, globin.

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One of the most common plasma proteins is albumin, which is involved in regulating the water content of cells and tissues through osmosis.

Plasma also contains globulin proteins. Two important groups of globulins are:

- gamma globulins, which are rich in antibodies and are produced by white blood cells. They play a significant role in the immune response (covered in Module 12).
- fibrinogens, which are essential in blood clotting. These and all other plasma proteins are formed in the liver.

Blood clotting

Elaborate mechanisms have evolved to prevent the accidental loss of blood when a vessel is damaged. One of these mechanisms is to form a solid clot to plug the broken vessel. Clotting involves the conversion of soluble fibrinogen to insoluble fibrin. When a tissue is damaged, it releases a specific protein called thromboplastin. This protein sets off a series of complex chemical reactions that allow fibrinogen to be converted into fibrin. Because fibrin is insoluble, it forms a complex web that can bind platelets together and seal the damaged site of a transport vessel.

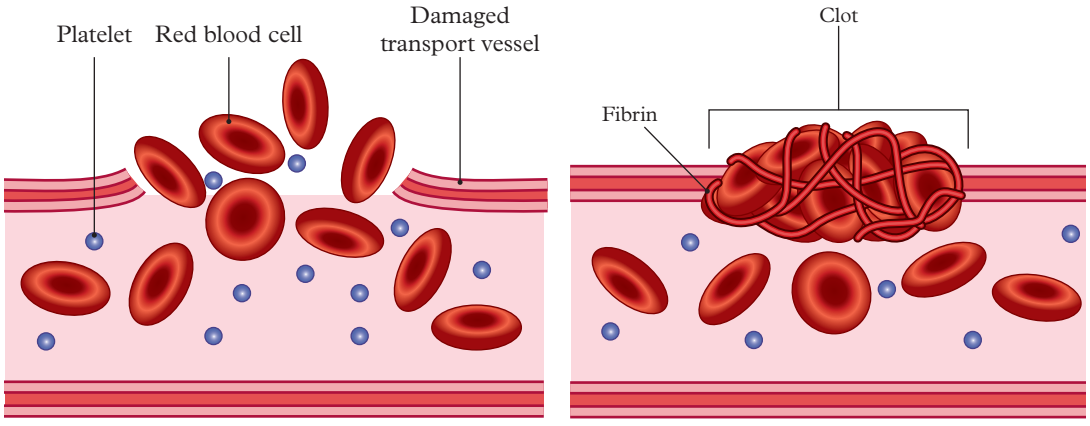


FIGURE 5 Damage to a transport vessel triggers the conversion of fibrinogen to fibrin, which can bind platelets together to cover the damaged site.

Challenge

Heparin and blood clotting

Heparin is an anticoagulant (sometimes called a blood thinner) produced in the liver and lung cells that decreases the clotting ability of blood. **Explain** what would happen if too much, or too little, heparin was produced in the human body. (4 marks)

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Real-world biology

Blood tests for disease diagnosis

Phlebotomy is the collection of a blood sample from a vein using a needle. Taking a sample allows a doctor to examine the blood for causes of disease. Blood tests can be used to give information about a wide range of health indicators, including cell counts, enzyme and hormone levels, blood glucose levels and cholesterol levels. Understanding the anatomy and components of blood allows medical professionals to diagnose diseases, infections and deficiencies, depending on the results of a blood test. This allows the monitoring and potential treatment of illnesses.



FIGURE 6 Phlebotomist taking a blood sample for disease diagnosis

Apply your understanding

1 A patient presenting with fatigue (low energy levels) returns a blood test indicating low iron levels. **Explain** why low iron in the blood may cause fatigue for the patient, with reference to red blood cell function. (2 marks)

Check your learning 5.1

Check your learning 5.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the role of tissue fluid, blood and lymph in the transportation of materials around the human body. (2 marks)

2 **Identify** the constituents of blood. For each, **describe** its function. (4 marks)

3 **Describe** the structure of a red blood cell (erythrocyte) and how its structure aids its function. (3 marks)

Lesson 5.2
The mammalian circulatory system

Learning intentions and success criteria

Key ideas

- → The circulatory system facilitates movement of materials around the body. It varies in structure between different organisms.
- → Mammals have a closed double circulatory system, with blood travelling around the body within blood vessels and passing through the heart twice to complete a full circuit.
- → Blood vessels have specialised structures to assist with their function of transporting blood around the body. There are three types of blood vessels: arteries, veins and capillaries.

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Circulatory systems

The **circulatory system** is network of organs that includes the heart, blood vessels and blood. In multicellular organisms, the circulatory system facilitates the movement of nutrients, gases and waste materials throughout the body via blood. Circulatory systems vary between different organisms. Some organisms, such as jellyfish and coral, do not have a "true" circulatory system. They do not have a pump organ or transport vessels to carry fluids. Instead, they exchange nutrients, gases and wastes with the water that surrounds them, via diffusion.

More complex organisms, such as mammals, have a true circulatory system, which has three key features:

- a muscular pump (e.g. the heart) to propel circulatory fluid through the system
- circulatory fluid (e.g. blood) that acts as the medium for transporting materials to the cells in the organism
- pipes or vessels (e.g. veins, arteries, capillaries) to carry the circulatory fluid.



FIGURE 1 Some organisms, such as jellyfish, do not have a circulatory system. Instead, they rely on diffusion for transport of materials.

Open and closed circulatory systems

Most invertebrates have an **open circulatory system**. In an open circulatory system, the circulatory fluid (**haemolymph**) is not always contained in vessels. Instead, the fluid is pumped by the heart into vessels that are open at one end, with the fluid passing into an open cavity in the body, where exchange of nutrients and wastes takes place. In this open cavity, cells are bathed with haemolymph before the haemolymph is taken back, via vessels, to the heart to be pumped again.

All vertebrates (such as mammals, fish, reptiles, birds, amphibians) and some invertebrates (such as octopi), have a **closed circulatory system** to facilitate the transport of nutrients and wastes within the body. In a closed circulatory system, circulatory fluid (blood) is always contained within vessels during circulation. Circulation in a closed system is in one direction, with blood being pumped from the heart, through blood vessels, and back to the heart in a cycle. This enables a much larger volume of circulatory fluid to move through the body and makes closed circulatory systems more efficient at exchanging nutrients and wastes than open systems. The efficiency of the closed circulatory system is one of the contributing factors that allows organisms with closed systems to be more metabolically active.

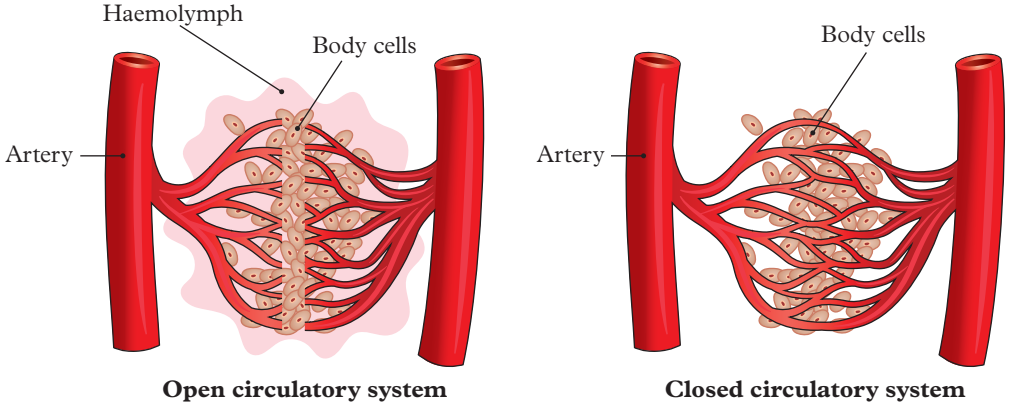


FIGURE 2 Open and closed circulatory systems

circulatory system
the body system, including the heart and blood vessels, that is involved in transporting circulatory fluid, such as blood, around the body

open circulatory system
a circulatory system where the circulatory fluid is not entirely contained within vessels but is pumped into a body cavity

haemolymph
the circulatory fluid in organisms that have an open circulatory system; is a mixture of blood and extracellular fluid

closed circulatory system
a circulatory system where blood is always contained within blood vessels and the heart

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The mammalian circulatory system

The mammalian circulatory system is made up of a series of vessels through which blood is pumped around the body by the rhythmic contractions of the heart. The mammalian circulatory system is known as a **double circulatory system**, because blood passes through the heart twice during one complete circuit.

Pulmonary circulation is the first passage of blood through the heart: when deoxygenated blood returns from the body to the heart, it is pumped by the right **ventricle** in the heart to the lungs. Gas exchange takes place on the surfaces of the alveoli in the lungs, and the oxygenated blood is then pumped back to the heart. **Systemic circulation** is the second passage of blood through the heart: when the oxygenated blood returns from the lungs to the heart, it is pumped by the left ventricle in the heart to the body tissues. The cells of the body tissues use the oxygen from this blood for aerobic cellular respiration, and then the deoxygenated blood is pumped back to the heart.

double circulatory system
a system of blood vessels where the blood passes through the heart twice in a single circuit around the body

pulmonary circulation
the circulation of deoxygenated blood from the right side of the heart to the lungs, and the return of oxygenated blood from the lungs to the left side of the heart

ventricle
one of two muscular chambers of the heart that pump blood out of the heart into the arteries

systemic circulation
the circulation of oxygenated blood from the left side of the heart to the body cells, and the return of deoxygenated blood from the body cells to the right side of the heart

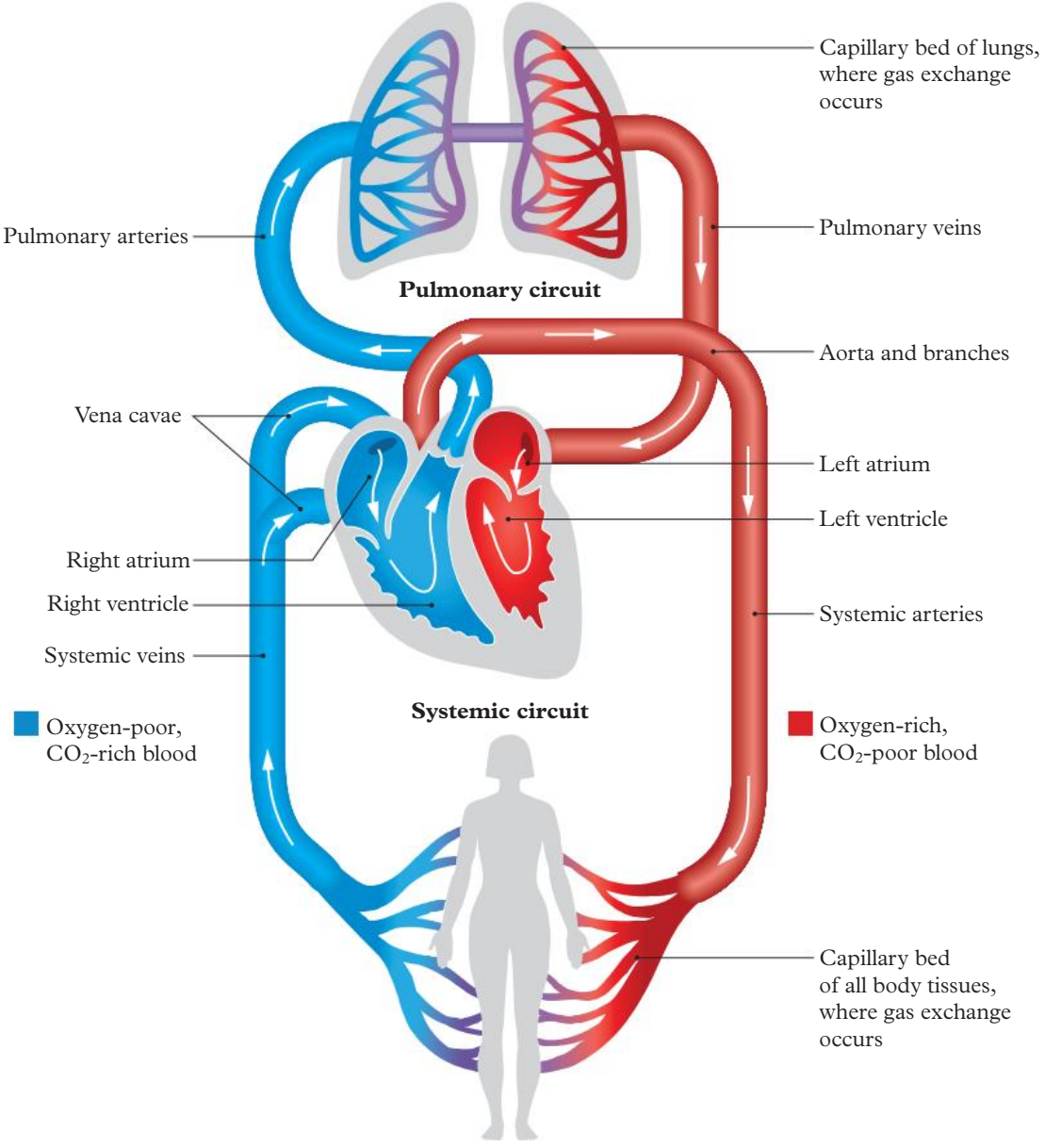


FIGURE 3 The mammalian circulatory system

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Vessels of the circulatory system

In Lesson 5.1, you learnt that blood is transported through three types of vessels: the arteries, veins and capillaries.

Arteries

Arteries are blood vessels that carry blood away from the pumping heart. Large arteries that are close to the heart are subject to blood flowing at high pressure and so they have thick muscular walls, to prevent the vessel from bursting. Exchange of material cannot occur between the arteries (or veins) and tissues due to the thickness of their walls, which consist of several layers of tissue.

The middle layers of the arteries are composed mainly of elastic fibres that enable them to dilate (expand) during ventricular contraction. When the ventricles of the heart relax, the muscles in the artery walls contract. This produces an even flow of blood along the length of the arteries.

As blood flows through the vessels, it loses energy due to friction between the plasma and the artery walls, and so pressure reduces. Further away from the heart, where blood pressure is lower, the artery walls contain more smooth muscle fibres that are served by nerves. Nervous stimulation controls the diameter (or size) of these vessels and therefore blood flow. As the diameter decreases, blood pressure increases.

Blood passes from the arteries into smaller branches called **arterioles**, which become finer and finer, eventually leading into capillaries. Capillaries form a vast network of capillary beds pervading all parts of the body.

arteriole
a small branch of an artery that breaks up into capillaries

Capillaries

Capillaries are the smallest blood vessels in the body. No cell in the body is more than 0.5 mm away from a capillary. The diameter of a capillary is approximately that of a red blood cell. Capillary walls are composed of a single layer of thin flat cells (with a large surface area-to-volume ratio) that are permeable to all blood components except red blood cells and plasma proteins. This structure enables the efficient delivery of gases, nutrients and wastes between the blood in the capillaries and the surrounding body cells and tissues.

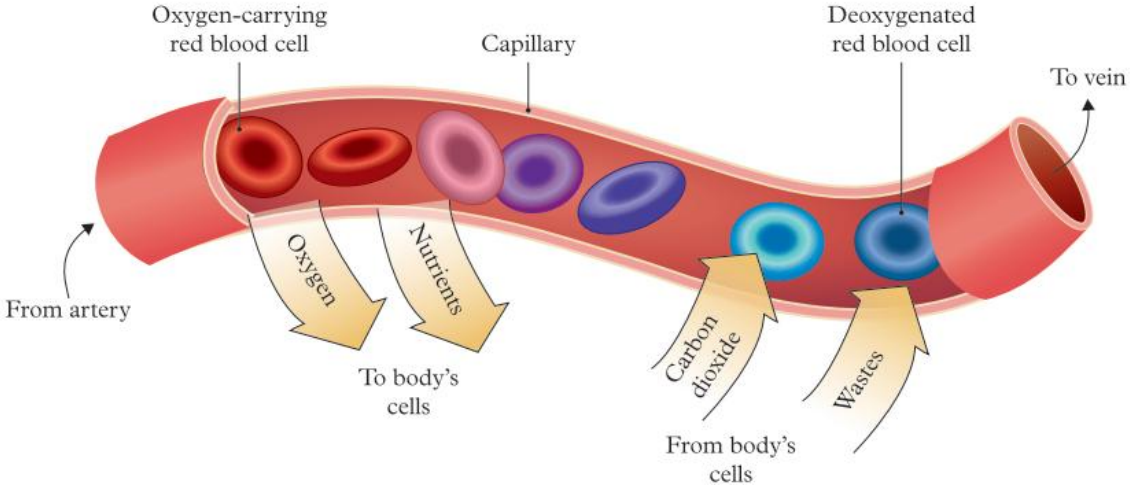


FIGURE 4 A capillary with red blood cells flowing through it

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Blood from the arteries enters the capillaries. Blood pressure forces the fluid, ions, gases and nutrients (other than red blood cells and plasma proteins) through the minute spaces between the cells of the capillary wall. These forced-out substances form the tissue fluid that surrounds cells. It is in this tissue fluid that materials are exchanged between the cells and blood. Eventually the concentration of large proteins left behind in the capillaries at the venous end becomes large enough to form an osmotic gradient, encouraging the movement of water back into the capillary. This fluid has negligible pressure. Excess tissue fluid not returned to the capillary vessels is taken up by the lymphatic vessels, while blood in the capillaries flows through to the veins.

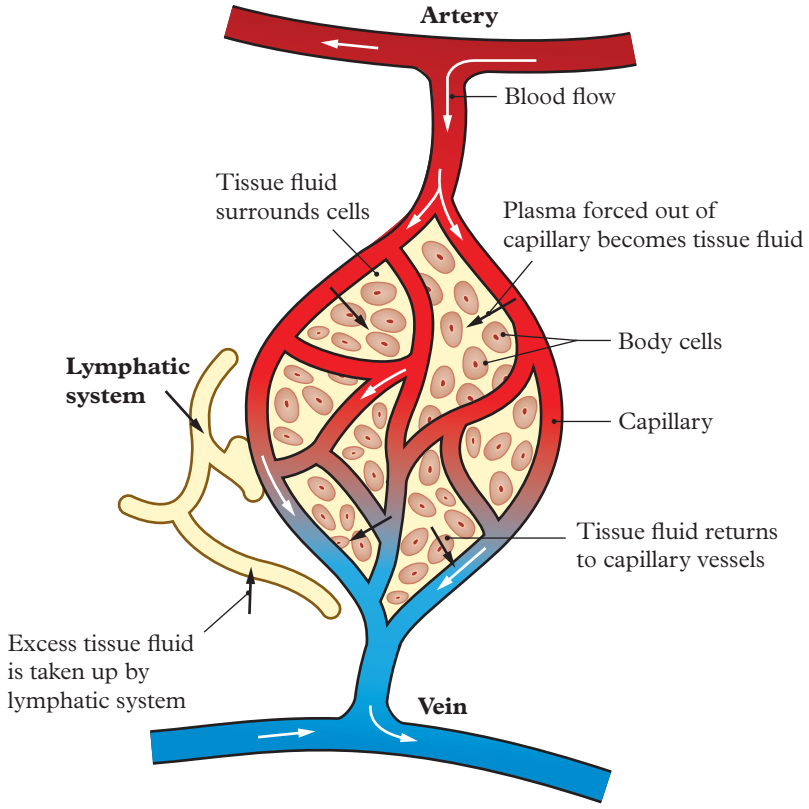


FIGURE 5 A capillary bed, where materials are exchanged between blood and body cells

Study tip

Arteries carry blood **A**way from the heart.
Capillaries **C**onnect the arteries and the veins.
Veins have **V**alves and carry blood back to the heart.

Veins

venule
a thin-walled vessel that directly connects capillaries to veins

Capillaries unite to form fine **venules** that increase in size to form veins. Veins have thinner walls than arteries and are surrounded by skeletal muscle. Blood is returned to the heart due to the muscular contractions of the skeletal muscles surrounding the veins. Valves along the length of the veins prevent backflow of blood when these muscles relax. If a person is sitting still on an aeroplane or in front of a computer for a long time, their leg muscles are not contracting, and the blood is not being pushed through the veins. This causes the fluid to accumulate in the tissue, increasing the number of blood cells bumping against each other in the veins. As a result, blood clots can form, in a process called deep vein thrombosis. If parts of this blood clot travel to the heart, lungs or brain, it can result in death.

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TABLE 1 Comparison of the structure and function of arteries, veins and capillaries

Arteries	Capillaries	Veins
Transport blood away from the heart	Link arteries to veins	Transport blood towards the heart
Thick muscular walls	Walls one cell thick, no muscle	Thinner, less muscular walls
Elastic tissue	No elastic tissue	Less elastic tissue than arteries
Can contract	Cannot contract	Cannot contract
No valves	No valves	Valves present
Circular cross-section	Circular cross-section	Oval cross-section
Not permeable	Permeable to tissue fluid and white blood cells	Not permeable
High blood pressure	Intermediate blood pressure	Low blood pressure
Rapid flow	Slow flow	Slow flow
Pulse	No pulse	No pulse

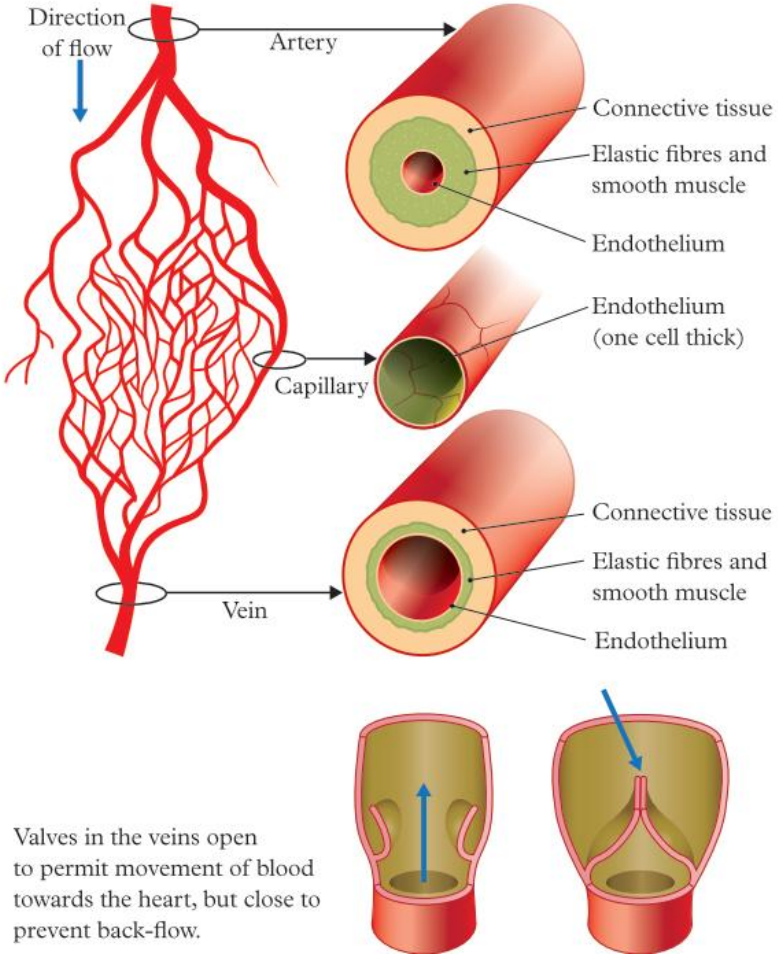


FIGURE 6 The structure of arteries, veins and capillaries

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Check your learning 5.2

Check your learning 5.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the main structural components of all true circulatory systems. (3 marks)
2 **Describe** the structure of a closed circulatory system. (1 mark)
3 **Describe** the movement of blood through a closed double circulatory system, starting at the heart. (5 marks)
4 **Explain** how the structural features of capillaries enable efficient exchange of nutrients, gases and wastes. (4 marks)

Analytical processes

5 **Compare** the structure of arteries, veins and capillaries. (4 marks)
6 **Contrast** blood pressure in the arteries and the veins. **Explain** what causes the differences in blood pressure for each structure. (3 marks)

Skill drill

Anabolic steroids and atherosclerosis

Science inquiry skill: Understanding the scientific method (Lesson 1.3) and Planning investigations (Lesson 1.4)

Anabolic steroids are a group of synthetic (human-made) drugs that imitate testosterone, the male sex hormone that is important in the production of muscle mass. The use of anabolic steroids is banned in many sporting competitions, due to the advantage they may give competitors. There are several side-effects associated with their use, including the potential for increased risk of heart diseases, such as atherosclerosis. Atherosclerosis is the narrowing of the arteries, the blood vessels responsible for carrying blood away from the heart under high pressure, due to a build-up of plaque (fats, cholesterol and other substances) on the inner walls of the arteries.

Practise your skills

1 **Design** a research question to investigate the link between anabolic steroid use and atherosclerosis. (1 mark)
2 **Identify** the independent and dependent variables in the research question. (2 marks)
3 **Suggest** the types of evidence that could be researched for the investigation, and justify your choice(s). (2 marks)
4 **Identify** limitations of evidence that may affect the ability to draw a confident conclusion about a link between anabolic steroid use and increased risk of atherosclerosis. (2 marks)

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MODULE 5

Lesson 5.3
Review: Transport of materials in animals

Summary

5.1
- Large animals, such as humans, require a specialised transport system to deliver needed nutrients, facilitate gas exchange and remove wastes.
- In mammals, three fluids are involved in transport systems: tissue fluid, lymph and blood.
- The structure of red blood cells (erythrocytes) is highly specialised to facilitate their function of transporting oxygen around the body.

5.2
- The circulatory system facilitates movement of materials around the body. It varies in structure between different organisms.
- Mammals have a closed double circulatory system, with blood travelling around the body within blood vessels and passing through the heart twice to complete a full circuit.
- Blood vessels have specialised structures to assist with their function of transporting blood around the body. There are three types of blood vessels: arteries, veins and capillaries.

Review questions 5.3A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 The human red blood cell is structurally suited to its function because it
- **A** contains haemoglobin, which can reversibly form a complex with oxygen.
- **B** is disc-shaped to increase surface area.
- **C** contains enzymes to digest foreign bodies that enter the blood.
- **D** contains a nucleus to ensure a long and active life.

2 Capillaries of the body are
- **A** thin-walled blood vessels.
- **B** tiny veins leading towards the heart.
- **C** vessels that carry deoxygenated blood.
- **D** tiny structures in the heart that help to operate the valves directing blood flow.

3 Valves, which prevent backflow of blood, are found in
- **A** arteries.
- **B** capillaries.
- **C** veins.
- **D** all blood vessels.

4 The flow of blood to the lungs and back to the heart is called
- **A** arterial circulation.
- **B** pulmonary circulation.
- **C** systemic circulation.
- **D** lung circulation.

5 The clotting of blood occurs when insoluble fibrin forms a web to bind together
- **A** platelets.
- **B** red blood cells.
- **C** white blood cells.
- **D** plasma.

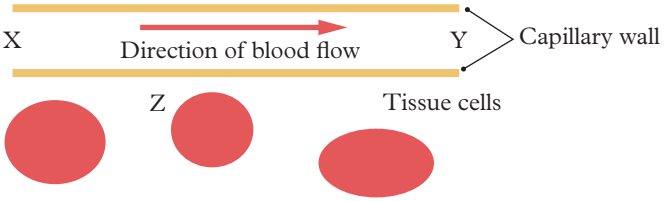
6 The percentage of blood made up of plasma in humans is
- **A** 20%.
- **B** 45%.
- **C** 55%.
- **D** 85%.

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7 Simple organisms such as jellyfish exchange nutrients and wastes with their surroundings via
A their circulatory system.
B active transport.
C interstitial fluid.
D diffusion.

Use the following information to answer questions 8 to 10.



8 X is connected to
A an artery.
B a venule.
C an arteriole.
D a vein.

9 The fluid filling the space labelled Z is the
A plasma.
B tissue (extracellular) fluid.
C blood.
D intracellular fluid.

10 The process in which materials are exchanged through Z is
A diffusion.
B osmosis.
C hydrolysis.
D haemolysis.

Review questions 5.3B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

11 **Identify** the features of a capillary that allow it to exchange materials with the extracellular fluid. (2 marks)

12 **Describe** the movement of materials between the capillaries and extracellular fluid. (1 mark)

13 For blood vessels that are not capillaries, **explain** why exchange of matter cannot occur between the blood vessel and the extracellular fluid. (2 marks)

14 **Describe** a closed circulatory system. (1 mark)

15 Humans have a double circulatory system. **Describe** the movement of blood through this system. (2 marks)

16 **Identify** five components of human blood, and the function of each. (5 marks)

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Data drill

Microscopy: red blood cells

The figure shows the field of view of human erythrocytes (red blood cells) seen through a light microscope with an eyepiece magnification of ×10 and using the ×40 objective lens.

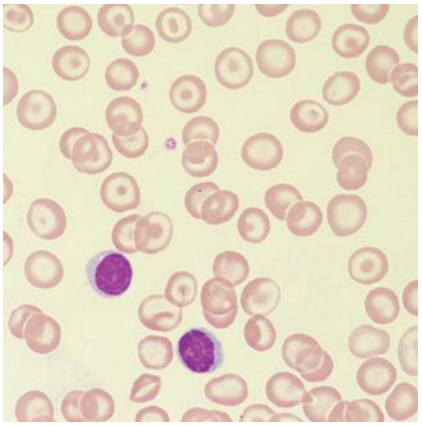


Table 1 provides a summary of the magnifications and field of view (mm) of the light microscope.

TABLE 1 Magnifications and field of view (mm) of the light microscope

Eyepiece	Objective lens	Total magnification	Field of view (mm)
× 10	× 4	× 40	4
× 10	× 10	× 100	1.6
× 10	× 40	**Question 1**	**Question 2**
× 10	× 100	× 1000	0.16

Table 2 provides the average diameter of some of the different types of blood cells in the human body.

TABLE 2 Average diameter of some types of human blood cells

Red blood cells (erythrocytes) (μm)	Lymphocytes (μm)	Monocytes (μm)	Neutrophils (μm)
6.2 to 8.2	14 to 20	16 to 22	12 to 15

Apply understanding

1 **Calculate** the total magnification used to view the cells. (1 mark)

2 **Calculate** the field of view at the ×40 objective lens magnification. (1 mark)

3 **Calculate** the approximate diameter of the red blood cells (in μm) shown in the figure. (1 mark)

Analyse data

4 **Identify** which type of blood cell has smallest diameter, based on the values in Table 2. (1 mark)

Interpret evidence

5 **Infer** why the type of blood cell you identified in Question 4 is smaller than other types of blood cells in the human body. (2 marks)

Module 5 checklist: Transport of materials in animals

Quizlet: Revise key terms online to test your understanding

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MODULE 6

Exchange of nutrients and waste in animals

Introduction

Animals are heterotrophs, organisms that are not able to synthesise their own food. Instead, they take in nutrients in organic form. Large macromolecules are chemically digested by enzymes into monomers, which can pass across exchange surfaces into the bloodstream and into cells. In the cell, these monomers are reconfigured, providing the cell with energy and nutrients. Waste materials resulting from cellular activities are removed from bodily fluids via the excretory system.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to exchange of nutrients and waste in animals before you start.

Subject matter

Science understanding

- → Describe the role of amylase, protease and lipase in chemical digestion.
- → Explain how metabolic processes, such as digestion, are controlled and regulated by enzymes.
- → Explain how structural features of exchange surfaces in the digestive and circulatory systems of mammals (e.g. villi and capillaries) allow for efficient nutrient exchange.
- → Identify the parts of a nephron and their functions in the production of urine, i.e. glomerulus, Bowman's capsule, proximal tubules, Loop of Henle, distal tubules and collecting duct.
- → Explain how glomerular filtration, selective reabsorption and secretion across nephron membranes contribute to the removal of waste.

Science as a human endeavour

- → Appreciate how understanding the anatomy and physiology of different body systems allows medical professionals to predict, diagnose, monitor and treat disease.

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Science inquiry

→ Investigate the effect of temperature/pH/substrate concentration on the reaction rate of different enzymes.

→ Explore how understanding enzymes, and their roles in metabolism, can be used to diagnose and treat metabolic disease.

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Practicals

oxforddigital **These lessons are available on Oxford Digital.**

Lesson 6.3 The effect of temperature on the rate of reactions of an enzyme

Lesson 6.4 The effect of pH on the rate of enzyme reaction

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Lesson 6.1
Digestion

Learning intentions and success criteria

nutrient
any substance used as food by an organism

non-essential nutrient
a nutrient that can be synthesised by an organism

essential nutrient
a nutrient that must be ingested and absorbed because it cannot be synthesised by the organism

heterotroph
literally, "other-feeder"; an organism that derives its energy by consuming other living organisms

digestion
the process of physically and chemically breaking down food into smaller, usable substances that can be absorbed into the bloodstream

alimentary canal
a continuous tubular pathway of the digestive system by which food enters the body via the mouth and unused materials are expelled through the anus

mouth
the opening of the anterior region of the alimentary canal, through which food is ingested

anus
the end of the alimentary canal, through which faeces (undigested food) are egested

ingestion
consumption of materials by an organism

Key ideas

- → A nutrient is a substance that an organism uses for maintenance, growth or repair.
- → Heterotrophs acquire nutrients by ingesting food and digesting the nutrients from food.
- → Physical digestion is the breaking down of food into smaller units by the crushing or cutting action of the mouth and other body parts.
- → Chemical digestion is the process in which food is broken down by digestive enzymes.

Digestion

A **nutrient** is any substance used by an organism for maintenance, growth, repair or reproduction. There are two broad categories of nutrients.

- **Non-essential nutrients** can be synthesised by the organism from basic materials.
- **Essential nutrients** cannot be synthesised by the organism and therefore must come from an outside source.

All animals are **heterotrophs**, meaning they are unable to synthesise organic compounds from inorganic matter and must obtain nutrients by consuming other organisms as food. The process in which this food is broken down into nutrients that an organism can use is called **digestion**.



FIGURE 1 Lysine is an essential amino acid that is not produced in the human body. Humans obtain lysine by eating foods rich in lysine, such as meats, nuts, soy, eggs, beans and lentils.

The digestive tract

Most animals have an **alimentary canal**, a muscular tube that runs through the centre of the animal and has two openings to the outside. Food enters by one opening, the **mouth**, and is processed as it passes through the canal. Nutrients released by digestive actions are transported from the alimentary canal to body cells via the circulatory system. Any material that is not processed is expelled out of the organism through the other opening, the **anus**. Matter in the alimentary canal flows in one direction. Once food has entered via the mouth (**ingestion**), it flows through to the anus, where it can be removed (**egestion**). Absorption of nutrients from food that enters the body is made possible by two processes: physical digestion and chemical digestion.

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Physical digestion

Physical digestion is the breaking down of food into smaller units by the crushing or cutting actions of the mouth and other body parts. Organisms that digest large pieces of food must have a means of breaking down the food into molecules small enough to pass across cell membranes. A variety of structures that aid in obtaining food and breaking it down have evolved for this purpose. For example, teeth, tentacles, claws and other appendages have evolved to aid in collecting food to enter via the mouth. Special structures, such as the rasp-like tongue of the snail and the teeth and tongues of vertebrates, help to physically break down food in the mouth into smaller pieces.

Once food has been ingested, muscular contractions move the food mass through the system as well as physically breaking and churning it. Most animals have a body cavity, which separates the alimentary canal from the body wall. The body can be thought of as consisting of two tubes, one inside the other. The outer tube, which is in contact with the external environment, protects the inner organs and provides a framework for support and movement. The outer tube is connected to the inner tube only at the two openings to the external environment: the mouth and the anus. For the rest of its length, the outer tube is separated from the inner tube by a space in which many organs lie, such as the heart, liver, lungs and kidneys. The inner tube, the alimentary canal, can act independently of the outer tube because it has its own muscular system. This arrangement is shown in Figure 3.

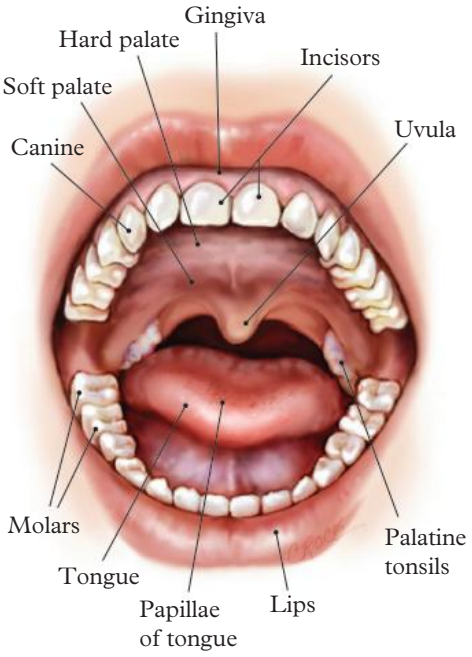


FIGURE 2 The teeth and mouth aid in physically breaking down food during ingestion.

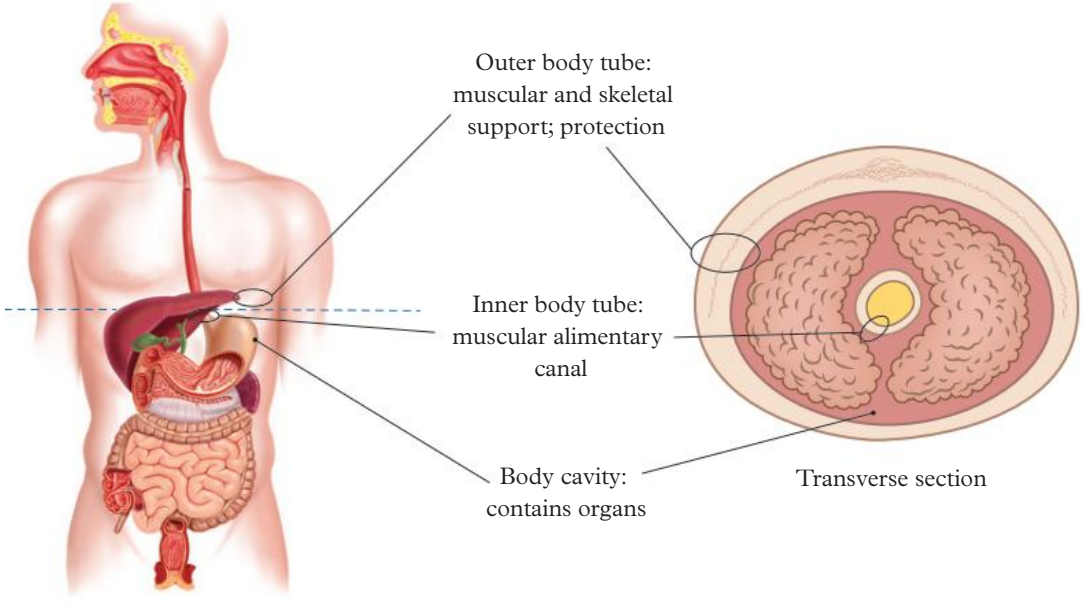


FIGURE 3 In animals with a true body cavity, the body can be thought of as comprising two tubes, one inside the other.

egestion
the removal of undigested food (faeces) from the alimentary canal

physical digestion
the breaking down of food into small units by the crushing or cutting actions of mouthparts (in invertebrates), teeth, muscles and so on

The movement of the muscles of the alimentary canal play a major role in physical digestion. Two muscle layers line the alimentary canal. One layer, the circular muscle, travels in rings around the circumference. When these muscles contract, the internal diameter of the tube becomes smaller. The second layer, the longitudinal muscle, is oriented along the entire length of the tube. When this muscle layer contracts, the tube becomes shorter.

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peristalsis
waves of contraction and relaxation in the muscular walls of the alimentary canal, aiding in mechanical digestion and moving food along its length

Waves of contraction and relaxation of these muscle layers move the food through the canal in a process called **peristalsis**. The muscles just in front of the food relax, providing an enlarged area into which the food can pass. The muscles just behind the food contract and push the food forward. As the food moves, the muscles behind it then contract, so a region of contraction follows the food and constantly pushes it forward (Figure 4).

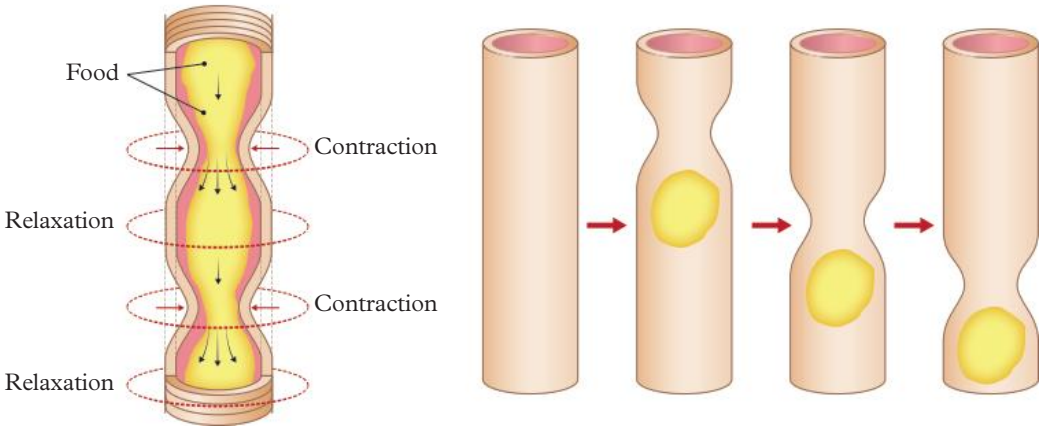


FIGURE 4 Peristalsis moves food along the alimentary canal.

The separation of the alimentary canal from the body wall has allowed the development of specialisation of parts of this canal for different functions. Some parts of the gut have developed into storage areas, others relate to digestion, absorption and elimination. Bile, a substance made in the liver and released from the gall bladder, is an emulsifier (a mixture of chemical substances that act like a detergent) that physically breaks down large fat particles in the small intestine into small droplets. Within the alimentary canal, solid food is subjected to a variety of actions that convert it into smaller, soluble compounds. As the pieces of food become smaller, their ratio of surface area to volume increases. This gives a greater surface area for the enzymes to attach to during chemical digestion of the food. Physically breaking up the food makes digestion more efficient.

Chemical digestion

chemical digestion
the hydrolysis of complex organic molecules into smaller units that are small enough to pass through cell membranes; mediated by enzymes specific to each chemical

amylase
an enzyme that stimulates the conversion of polysaccharides to disaccharides

protease
the general term for an enzyme involved in the hydrolysis of proteins

lipase
the general term for an enzyme involved in the hydrolysis of lipids

Chemical digestion is the process in which food is broken down by digestive enzymes. These enzymes facilitate the decomposition of large organic molecules, by speeding up hydrolysis reactions that help break down the chemical bonds holding molecules together. Chemical digestion breaks down complex carbohydrates into saccharides (such as glucose), proteins into amino acids, and lipids into fatty acids and glycerol.

Digestive enzymes

As enzymes are highly specific to the substrates they can bind, different enzymes mediate the chemical digestion of different macromolecules. Three types of digestive enzyme play an important role in chemical digestion.

- **Amylase** breaks down complex carbohydrates such as starch (in foods such as pasta and potato) into simpler sugar molecules, such as disaccharides. Amylase is secreted by salivary glands and the pancreas, and is present in saliva and pancreatic juice.
- **Protease** breaks down proteins into smaller molecules, such as peptides or their amino acid monomers. Proteases are secreted by the pancreas and are in pancreatic juice.
- **Lipase** breaks down lipids by catalysing the hydrolysis of larger fat molecules into their smaller fatty acid and glycerol monomers. Lipases are secreted by the pancreas and are in pancreatic juice.

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Enzyme activity can be regulated by factors such as pH, and therefore certain enzymes are found in different parts of the digestive system. For example, the enzyme pepsin, a type of protease, thrives in the acidic conditions of the stomach because its optimal pH is 1 to 2, whereas salivary amylase functions better in the more neutral pH within the mouth. After food molecules have been chemically digested into usable nutrients, they are ready to be absorbed by the body.

Absorption

Most nutrient molecules produced by digestion are small enough to pass through cell membranes by simple diffusion. Other molecules, such as glucose, require facilitated diffusion. Active transport is used if a substance must be absorbed against a concentration gradient. In larger animals, these nutrient molecules generally pass from the alimentary canal to a circulatory system, which transports them to the appropriate cells.

Assimilation

Once in the cells, digested nutrients are assimilated. The monomers are built up into complex compounds required by the body, converted into other forms as storage products for later use, or broken down for energy release during cellular respiration.

Elimination

Egestion is the process of removing food that was never part of the organism. Any undigested food is eliminated from the gut as **faeces** in the process of egestion. This is different from **excretion**, which is the removal of the waste products of the chemical reactions in a cell.







FIGURE 5 (A) Amylase breaks down starch in foods such as pasta. (B) Protease breaks down proteins in foods such as salmon. (C) Lipase breaks down fats in foods such as avocado.

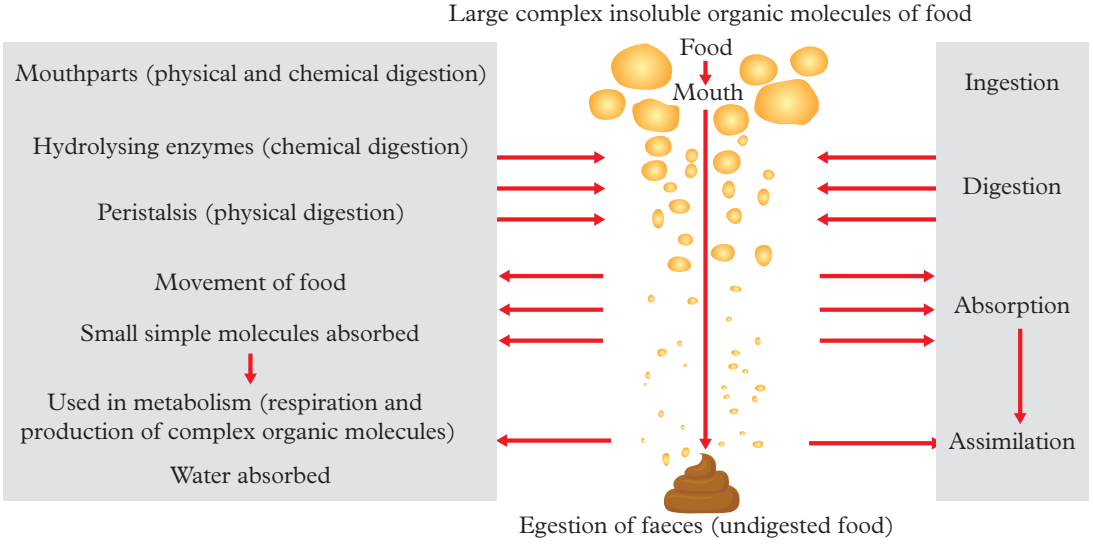


FIGURE 6 Stages in acquiring nutrients

Study tip

If the name of a molecule has "-ase" at the end, it is probably an enzyme. The rest of the name is often a hint of its function. For example, proteases digest protein, and lipases digest lipids.

faeces
a compacted, undigested food mass that is voided from an animal

excretion
the removal of metabolic wastes from the body

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Check your learning 6.1

Check your learning 6.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** one physical structure in humans that aids physical digestion. (1 mark)
2 **Describe** the role of each of the following in chemical digestion:
   a amylase (1 mark)
   b protease (1 mark)
   c lipase. (1 mark)
3 **Describe** the role of physical digestion in the digestive system, providing examples of the organs or structures involved. (4 marks)
4 **Describe** the concept of enzyme specificity, using an example to support your response. (2 marks)
5 **Summarise** the movement of food through the alimentary canal, from ingestion to egestion. (5 marks)

Lesson 6.2
The human digestive system

Key ideas

→ The human digestive system is made up of an alimentary canal and associated organs that help to break food down physically and chemically.
→ The human digestive system functions so that the body can obtain nutrients and remove waste.

Learning intentions and success criteria

chunk feeder
an animal that ingests large pieces of food

digestive system
the body system involved in physically and chemically breaking down food into smaller molecules able to pass into the bloodstream

Structure of the human digestive system

Humans feed on large chunks of solid organic material derived from plant and animal organisms. Like other **chunk feeders**, they must be able to:

- obtain and ingest food
- physically and chemically digest the food
- absorb the digested molecules and transport them to the cells for assimilation
- egest undigested food.

These tasks are facilitated by the human **digestive system**.

The human digestive system consists of an alimentary canal and associated organs. Throughout the length of the alimentary canal, each part is modified for a specific function. Other organs, such as the liver and pancreas, are linked for its support and function. The overall structure of the digestive system (Figure 1), and the functions performed at each specialised part, are summarised here.

- Mouth, tongue and teeth – in the mouth, food is digested physically and chemically. Biting, chewing and grinding by teeth increase the surface area of the food for the action of digestive enzymes. The tongue mixes food with saliva and forms it into a ball, called a bolus.

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- Palate – this structure separates the mouth and nose, which allows a person to eat and breath at the same time.
- Salivary glands – secrete saliva into the mouth. Saliva contains amylase, which breaks down complex carbohydrates into smaller disaccharides.
- Oesophagus – food passes along this muscular tube to the stomach.
- Stomach – a J-shaped sac in which some of the proteins in food are chemically digested by proteases activated by hydrochloric acid. Food is also broken down into fine particles by contractions of the muscles of the stomach walls. This increases the surface area of the food for contact with digestive enzymes in the intestine.
- Liver – makes bile, which is used to digest fat and neutralise stomach acid.
- Gall bladder – stores bile until the food reaches the small intestine, then releases the bile into the small intestine via a small tube called the bile duct.
- Pancreas – produces pancreatic juice, which contains a mixture of digestive enzymes (e.g. proteases and amylase) and can help neutralise stomach acid.
- Small intestine – absorbs nutrients from food that has flowed on from the stomach. It consists of the **duodenum** (the first part of the small intestine) and receives secretions from the gall bladder and pancreas. The small intestine also produces its own digestive enzymes from the glands in the walls of the intestine. As food passes through the small intestine, it breaks down into molecules small enough to pass through the intestinal walls into the blood.
- **Ileum** – the coiled long section of the small intestine. It follows on from the duodenum. Digested food molecules are absorbed across the walls into blood capillaries. The walls of the ileum have projections, called villi, which increases the surface area available to absorb food.

duodenum
first section of the small intestine; receives partially digested materials from the stomach

ileum
the last and largest section of the small intestine

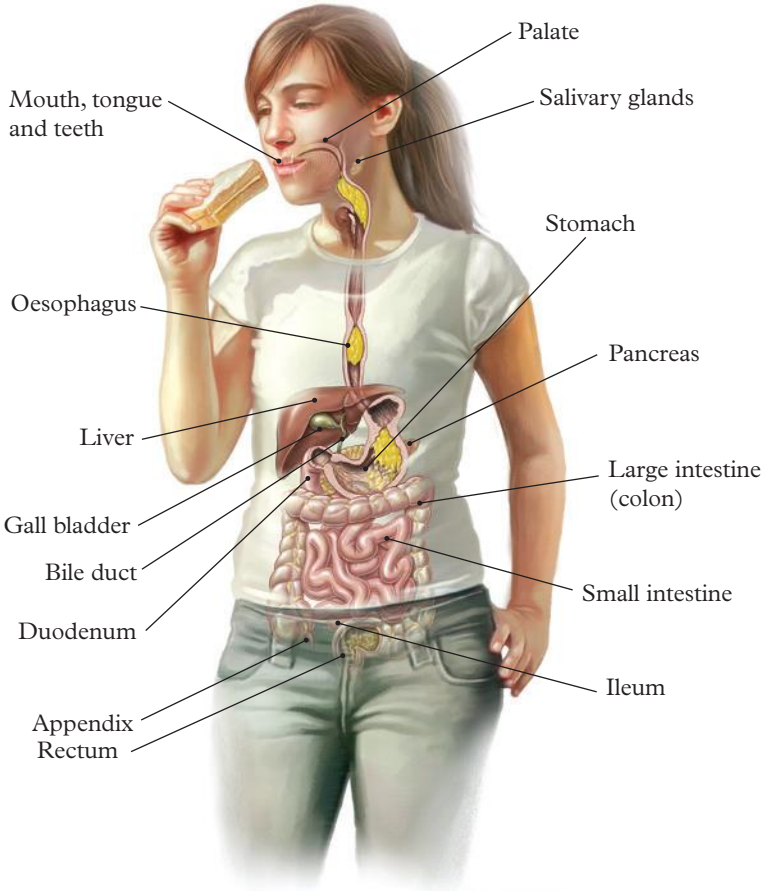


FIGURE 1 The human digestive system

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- Large intestine – also known as the colon; absorbs water from undigested food that passes from the small intestine. Most of the undigested food is fibre, which consists mostly of cellulose from plant cell walls. Fibre in the diet is necessary as it helps waste products to retain some water and move through the large intestine faster.
- Rectum and anus – the rectum stores waste products of digestion (faeces), which are passed out through the anus.

In the abdominal region, there are thin membranes with blood and lymph vessels running through them, connecting the alimentary canal to the body wall. The mesentery membranes also hold the loops of the alimentary canal in the correct position.

The inner layer of the human alimentary tract differs along its length, reflecting its function at any point. However, the general structure is the same and consists of four basic layers.

- The outer layer is connective tissue and is continuous with the thin supporting membrane (mesentery).
- Inside the connective tissue is an external muscle layer, usually consisting of an outer layer of longitudinally oriented cells and an inner circular layer. These are smooth (involuntary) muscle cells. The muscles are not consciously controlled and are responsible for peristalsis.
- The third layer contains the major blood and lymphatic vessels, nerves and stretch receptors, connected by strong fibres of connective tissue.
- The innermost layer consists of more smooth muscle fibres and loose connective tissue that supports the lining or epithelium. All glands of the alimentary tract are derived from this epithelium.

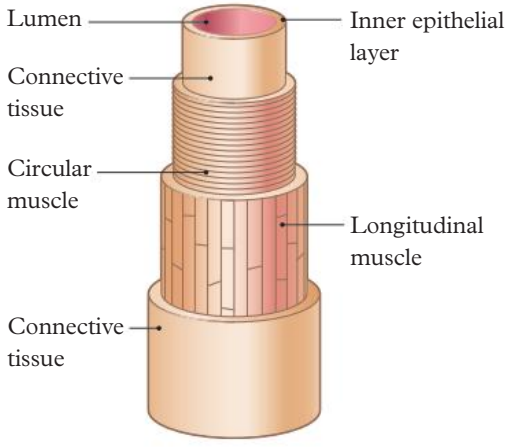


FIGURE 2 General structure of the walls of the alimentary canal

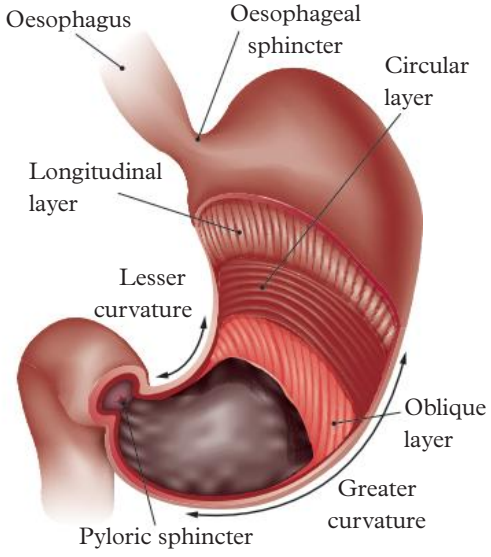


FIGURE 3 The structure of the stomach

Chemical digestion in humans

The chemical digestion of each food type is controlled by specific enzymes, each of which works at an optimal pH. If the acid levels surrounding the enzyme are too high or too low, the enzyme becomes deformed and unable to catalyse the digestion reaction. Different parts of the alimentary canal therefore have closely controlled pH levels.

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Chemical digestion of complex carbohydrates begins in the mouth, where the pH is about 7.5 (slightly basic/alkaline). The salivary glands secrete a juice containing mucus and the enzyme salivary amylase. The mucus moistens the food, and the salivary amylase starts the digestion of starch to a disaccharide (maltose).

When the food reaches the stomach, gastric juice is secreted by glands in the stomach wall. This very acidic solution (pH 2) immediately stops the action of salivary amylase. Gastric juice contains the protein-digesting enzyme called pepsin (a protease), which breaks complex proteins into smaller polypeptide chains and dipeptides. Pepsin is produced by the stomach gland cells in an inactive form; it only becomes active when mixed with the stomach contents. Other proteases are also released. Some glands in the lining secrete mucus, which protects the stomach wall from being digested. If this protective mucus is not produced in sufficient amounts, the stomach walls may become damaged by the acid and ulcers may form.

In the first part of the small intestine (the duodenum), secretions from the liver (via the gall bladder) and the pancreas are introduced through the bile and pancreatic ducts to the acidic food mass that leaves the stomach. Bile (pH 7 to 8) contains waste materials from metabolism and the breaking down of old red blood cells by the liver. One of these products (bile salts) physically breaks up (**emulsifies**) lipids into small droplets. This increases the surface area available for lipases to act on during chemical digestion. Pancreatic juice (pH 7 to 8.8) contains amylases, proteases and lipases, which chemically digest complex carbohydrates, proteins and lipids, respectively. The pH of both secretions neutralises the stomach acid to provide optimal pH for the pancreatic enzymes to act.

emulsify
break up large lipid particles into small droplets

Other secretions from glands in the walls of the small intestine (intestinal juice, pH 7.5 to 8.5) provide further proteases and lipases to complete the chemical digestion of polymers into monomers that can be absorbed. Mucus is also secreted, to protect the cells lining the small intestine.

Skill drill

Researching claims: Metabolic diseases

Science inquiry skill: Evaluating evidence (Lesson 1.9)

Enzymes are proteins that act as catalysts in biochemical reactions, speeding up the conversion of substrates into products. Metabolism involves a complex network of enzymatic reactions that regulate the synthesis and breaking down of molecules essential for the proper functioning of cells and organisms. Deficiencies in specific enzymes can result in metabolic diseases. In cases where a metabolic disease is caused by a deficiency of a specific enzyme, enzyme replacement therapy (ERT) can be employed. Enzyme replacement therapy involves administering the missing or defective enzyme, to restore normal metabolic function. It is used in therapy for Gaucher disease, a rare disease where an enzyme that assists in breaking down lipids is missing.

Practise your skills

1 "Enzyme replacement therapy (ERT) has the potential to significantly enhance the quality of life of individuals with metabolic disorders." Research the above claim to **determine**:
   - **a** the cause of Gaucher disease in affected individuals (1 mark)
   - **b** a current ERT used in the treatment of Gaucher disease (1 mark)
   - **c** how ERT improves outcomes for patients with Gaucher disease. (2 marks)

2 **Propose** a possible research question to investigate the claim in Question 1. (1 mark)

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Absorption of nutrients in humans

Absorption of nutrients involves osmosis, diffusion and active transport. Diffusion of the nutrients depends on a concentration gradient and the length of the diffusion pathway. For this reason, there is a large capillary network immediately below the lining cells of the intestinal cavity, to remove the diffused nutrients. This maintains the steep concentration gradient necessary for effective diffusion.

Small intestine

Some absorption of water and glucose occurs across the lining of the stomach wall into the underlying capillaries. Most absorption of the small molecules resulting from chemical digestion occurs in the very long, coiled, second part of the small intestine, the ileum. The inner surface of the ileum has folds from which small finger-like **villi** project. These folds help to slow down the passage of food, and the villi increase the surface area for digestion and absorption. By contraction and swaying, the villi also circulate the contents.

villus
a finger-like projection of the lining of the small intestine; increases the surface area available for absorption; plural "villi"

The surface area is further increased in this area by hair-like extensions of the epithelial cells of the villi, called **microvilli**. As absorption proceeds, there is a rapid build-up of nutrients in epithelial cells. Monosaccharides, nucleotides and amino acids are removed from these cells into the bloodstream by the capillaries of the villi. Transport away from the cells is not always rapid enough and a concentration barrier may build up. It is only by active transport across the cell membranes that this can be overcome.

microvillus
a projection from the surface of cells; forms a brush border that increases the surface area of the cell membrane; plural "microvilli"

Glucose and galactose are absorbed more rapidly than the other monosaccharides. This is possibly because they undergo a chemical conversion when they first enter the epithelial cells, ensuring the maintenance of a steep concentration gradient. These sugars then pass by diffusion into the capillaries that drain into the **hepatic portal vein**. This blood vessel acts as a short circuit, carrying the absorbed food molecules directly to the liver.

hepatic portal vein
the vein that transports absorbed food molecules directly from the small intestine to the liver

Small droplets of lipids, and their subunits, glycerol and fatty acids, are absorbed into the epithelial cells of the villi. There they are assembled into fat-storage molecules (triglycerides), phospholipids and cholesterol (part of cell membranes) and packaged in a protein coat by the cells' Golgi bodies into structures called **chylomicrons**. They are released into the tissue fluid and taken up by lacteals (of the lymphatic system) in the villi. The lacteals lead to lymphatic vessels, which enter the blood supply just before its return to the heart. Small amounts of fatty acids and glycerol may also enter the capillaries of the villi.

chylomicron
small droplets of lipids, glycerol and fatty acids enclosed in a protein coat; involved in the absorption of products of fat digestion in the alimentary canal directly into the lymphatic system

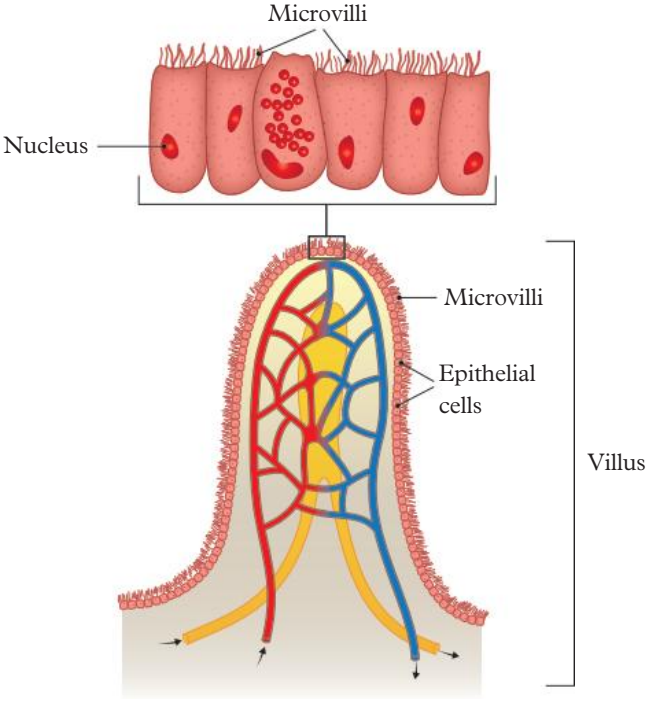


FIGURE 4 The structure of a villus

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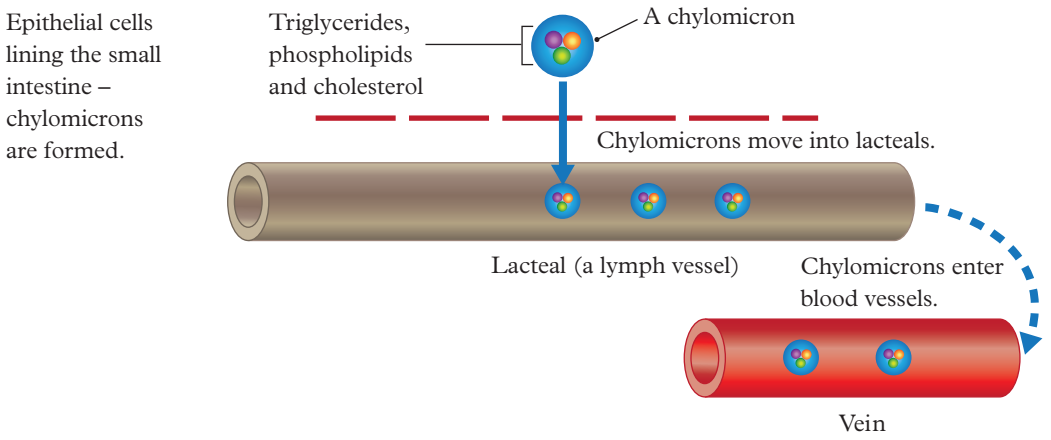


FIGURE 5 Transport of fat storage molecules via chylomicrons

Absorption of vitamins, inorganic salts and water also occurs in the small intestine. Water absorption takes place by osmosis, as the gut contents develop a lower solute concentration (i.e. become hypotonic) compared to the blood.

Study tip

The term "lipids" includes all fats and oils. At room temperature, fats are solid and oils are liquid.

Large intestine

The main function of the large intestine is the absorption of water. About seven litres of water enters the alimentary canal each day as a solvent for the digestive juices. Although most of this is reclaimed by absorption in the small intestine, the remainder must be removed in the colon, the largest part of the large intestine. This results in the compaction of solid, insoluble undigested material, known as faeces. If the lining of the colon is irritated – for example, by an infection – the undigested material moves too quickly, less water than normal is reabsorbed, and diarrhoea results. If the material passes through the colon too slowly, an excess of water is removed. The result is a faecal blockage, called constipation.

In addition to the waste materials secreted in the bile from the liver, excess mineral salts may be secreted into the colon of the large intestine from blood vessels in its walls.

Normally there is a large bacterial community in the large intestine. These bacteria obtain their nourishment from undigested food. In return for this continual supply of nutrients, they release byproducts of their metabolism, vitamin K and several of the B group vitamins. These vitamins are absorbed through the large intestinal epithelium. This is virtually the body's only source of vitamin K, which is essential in blood-clotting reactions in humans. Therefore, there is a mutualistic relationship (where both organisms benefit) between these bacteria and the human organism harbouring them.

Assimilation in humans

Assimilation is the incorporation of nutrients into the body. These chemicals are carried from the intestine to the liver by the hepatic portal vein. In the liver they are stored, changed or redirected to other organs.

assimilation
the incorporation of simple organic molecules, or products of digestion, into complex constituents of the organism

Amino acids are needed for growth, maintenance, repair and secretion, but they cannot be stored within cells. Excess amino acids taken into the body must be changed in one of three ways:

- conversion to urea for removal by the kidneys
- transfer of amino groups to carbohydrates to produce glycoproteins, which are needed by the body
- conversion to glucose and other carbohydrates.

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Real-world biology

Alcoholic beverages

Ethyl alcohol ("ethanol"), the active component of alcoholic beverages, is a small molecule that is readily absorbed by the stomach and small intestine. The rate at which this molecule is absorbed is increased if there is no food present, particularly fats and proteins. Absorption is also increased if the alcohol is mixed with carbonated fluid. Carbon dioxide stimulates movement of alcohol through the stomach, passing it rapidly to the intestine, where the absorption rate is higher. In this way alcohol is rapidly absorbed into the bloodstream. The blood distributes the alcohol to the body tissues, where it is slowly absorbed. Alcohol may therefore be present in the blood up to 18 hours after it was ingested.

As alcohol concentration in the blood rises to between 0.05% and 0.1%, areas of the brain that control judgment, self-criticism and learnt inhibitions do not operate effectively. Between 0.1% and 0.3%, depression of brain activity causes the person to be less alert, have a hazy awareness of their surroundings, lose coordination and become sleepy. At blood alcohol levels greater than 0.3%, brain function becomes significantly impaired. This may lead to respiratory failure and/or shock associated with low blood pressure. At blood alcohol levels of approximately 0.5%, coma and death usually result.

For alcoholics (people who have an addiction to alcohol), alcohol assumes the characteristics of food. The body cells become so adapted to alcohol that they operate poorly in its absence. Continued excessive drinking causes inflammation of the stomach lining and poor digestion of food. Nausea makes food unpalatable. These factors result in loss of essential nutrients. Nerves, particularly in the legs, begin to degenerate and the excessive drinker experiences pain and weakness. Liver degeneration, caused by a number of changes to the cells, collectively termed cirrhosis, usually results in death.



FIGURE 6 Alcohol can have a wide range of effects on the body.

Apply your understanding

1 **Identify** how alcoholism affects the body's cells and their adaptation to alcohol. (1 mark)

2 **Describe** the impact of continued excessive drinking on the stomach lining and digestion of food. (1 mark)

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Check your learning 6.2

Check your learning 6.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** why protein-digesting enzymes are produced and secreted in an inactive form in the stomach. (3 marks)

2 **Describe** features of the small intestine that make it an efficient organ for the absorption of digested food. (4 marks)

3 **Describe** the digestion and absorption of fats in humans. (2 marks)

4 **Explain** how the structural features of villi assist in the absorption of nutrients into the bloodstream. (2 marks)

Analytical processes

5 Read the following passage carefully and apply your knowledge to answer the questions.

Peristaltic contractions of the stomach keep the partly digested food moving towards the duodenum, the first loop of the small intestine. The duodenum is the main site of digestion in the gut. The agents of digestion come from three sources: the liver, the pancreas and the wall of the intestine. The liver produces bile, a mixture of substances. Not all of these substances are involved in digestion. The digestive components are bile salts, which emulsify fats. Bile salts are not enzymes. Bile is also rich in sodium bicarbonate, which neutralises acid from the stomach. The pH of the small intestine is therefore distinctly basic (alkaline), which favours the action of the various enzymes. Some of these enzymes are constituents of the pancreatic juice that flows into the duodenum from the pancreas via the pancreatic duct. The main enzymes flowing into the small intestine are amylases, proteases and lipases.

a **Describe** peristaltic contractions and what causes them. (2 marks)

b **Define** the term "emulsify". (1 mark)

c **Explain** why bile salts are not classed as enzymes. (1 mark)

d **Deduce** why the stomach contents are acidic. (1 mark)

e **Determine** the function of each of the enzymes in the small intestine. (3 marks)

Practical

Lesson 6.3

The effect of temperature on the rate of reactions of an enzyme

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Learning intentions and success criteria

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Practical

Lesson 6.4
The effect of pH on the rate of enzyme reaction

Learning intentions and success criteria

oxforddigital **This practical lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.**

Lesson 6.5
Excretion

Learning intentions and success criteria

Key ideas

- → The excretory system removes wastes from the body.
- → Major organs involved in the excretory system are the kidneys, ureters, bladder and urethra.

The excretory system

All organisms produce wastes. Because a build-up of wastes in an organism can be toxic, organisms need to have processes or systems in place to remove wastes from the body. In mammals, wastes are removed from the body by excretion. The main function of the excretory system is to allow the body to remove wastes in the form of urine (waste materials dissolved in water) and sweat. It is also important in facilitating **osmoregulation** (maintaining a balance of water and salt in the body), which you will learn more about in Module 11.

osmoregulation the physiological regulation of water and salt concentrations in the body



FIGURE 1 Mammals expel urine via the excretory system to remove wastes from the body.

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The main organs in the excretory system are:

- kidneys – filter blood and produce urine
- **ureters** – a pair of ducts that move urine from the kidneys to the bladder
- **bladder** – a membranous sac that stores **urine**
- **urethra** – a duct the transports urine from the bladder to outside the body.

urine
the excretory fluid produced in the kidney; contains metabolic wastes (urea, salts) in a watery solution

urethra
a tube running from the bladder to the body's exterior; in human females, it eliminates urine; in human males, it is joined by the vas deferens, so it eliminates semen as well as urine

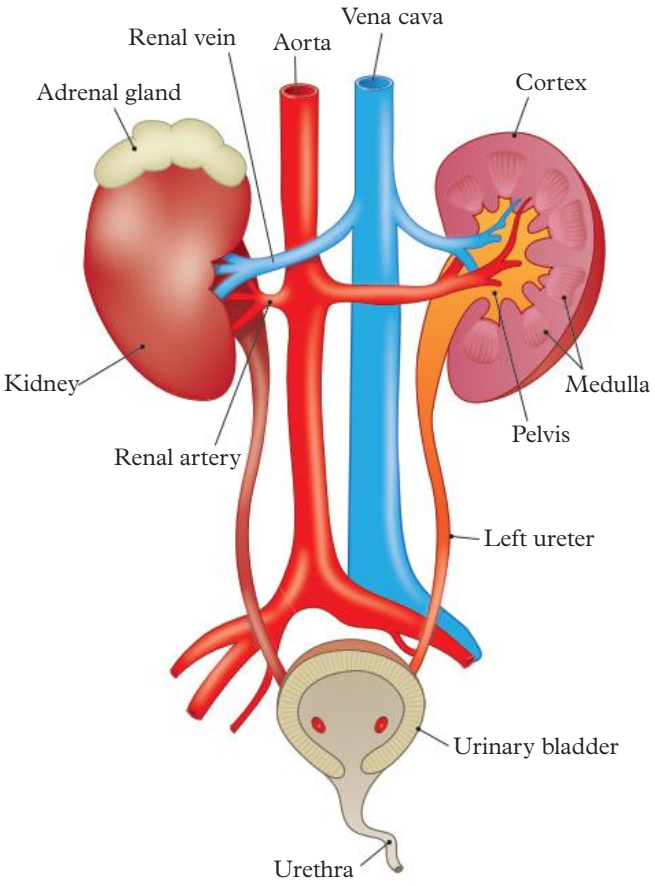


FIGURE 2 The human excretory system

In humans, proteins are broken down into a nitrogenous compound called **ammonia** in nearly all tissues of the body. Ammonia is then transported in the blood to the liver. Because ammonia is toxic, the liver converts ammonia to **urea**, a less harmful compound. Because urea is less toxic than ammonia, it can be retained in the body for a limited period before being removed as a waste substance via the excretory system. In the mammalian excretory system, the separation of excretory substances from blood and the conservation of water occur in a pair of kidneys. Urine passes from the kidneys through the ureters to be stored in the bladder. The urine eventually passes to the external environment through the urethra.

ammonia
an inorganic nitrogen compound; in animals, a toxic product of the breaking down of excess amino acids

urea
a water-soluble nitrogenous excretory product of protein breakdown

Structure of the kidney

The kidney is the main organ of the excretory system. A kidney is located on each side of the vertebral column in the abdominal cavity, between the lowest rib and the top of the hip bone. The kidneys remove excretory products from the blood plasma and produce urine. As shown in Figure 3, each kidney is bean-shaped. It is enclosed by a capsule of connective tissue and composed of two layers of tissue: an outer, darker-coloured **cortex** and an inner, lighter-coloured **medulla**, surrounding a central cavity.

cortex
the outer part of a vertebrate kidney; contains the Bowman's capsule, glomerulus and convoluted tubules of the nephron

medulla
the inner layer of a vertebrate kidney; contains loops of Henle and collecting tubules

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Study tip

The kidney medulla is in the middle of the kidney. The cortex is just under the capsule of the kidney.

The kidneys are connected to the circulatory system via the **renal arteries**, which carry blood to the kidneys, and the **renal veins**, which return the "cleaned blood" to the heart and to the bladder via the ureters. Within the central cavity of the kidney, the top of the ureter expands to form the **renal pelvis**. The inner medulla of the kidney is divided into lobes of approximately conical shape, called **pyramids**. The renal artery forms branches between the pyramids that deliver blood to the outer cortical region containing **nephrons**. These are drained by branches of the renal vein.

renal artery
the blood vessel entering the kidney

renal vein
the blood vessel leaving the kidney

renal pelvis
a funnel-shaped expanded area where the ureter leaves the kidney

pyramid
the bundle of collecting ducts in the mammalian kidney

nephron
the functional unit of the vertebrate kidney

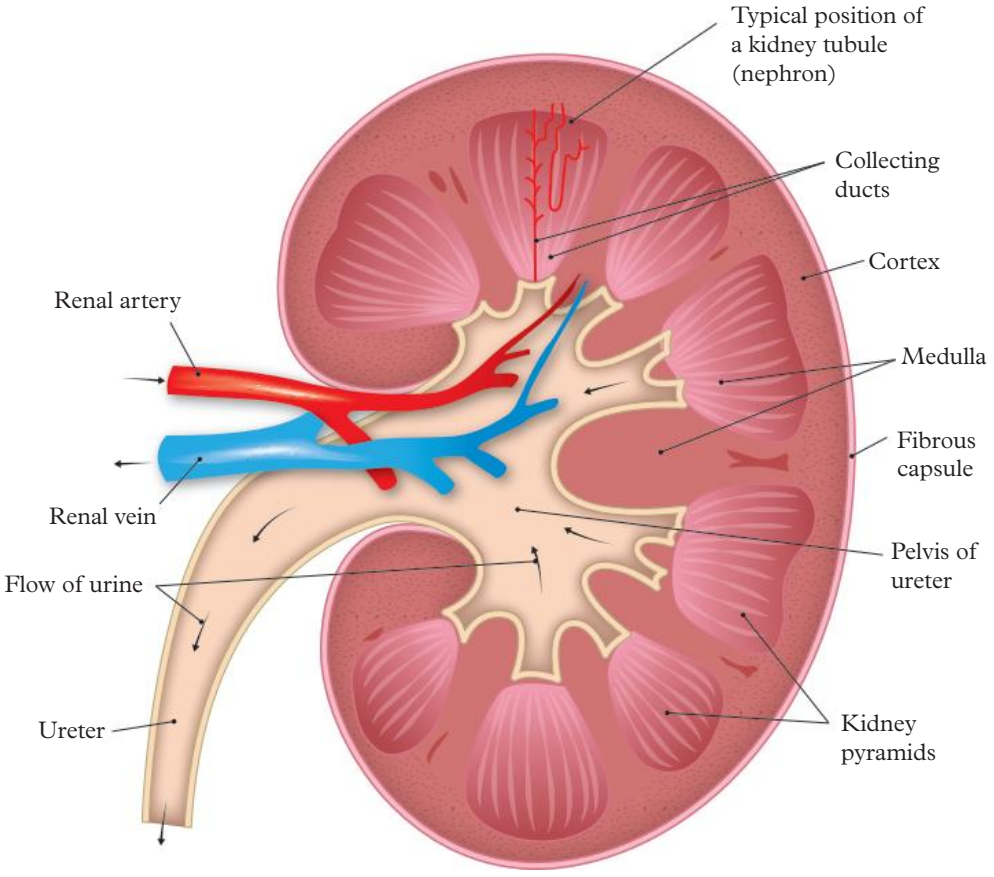


FIGURE 3 The structure of a kidney

The nephron

The nephron is the functional unit of the kidney. Each kidney contains approximately one to two million nephrons embedded in loose connective tissue that is richly supplied with blood. Each nephron consists of an elongated tubule with many distinct sections. Figure 4 shows the key sections of the nephron, which include the:

- **glomerulus** – a network of capillaries
- **Bowman's capsule** – a cup-shaped section that wraps around the glomerulus
- proximal convoluted tubule – a highly coiled section of tubule next to the Bowman's capsule
- loop of Henle – a U-shaped stretch of tubule
- distal convoluted tubule – a section of coiled tubule that runs on from the loop of Henle
- **collecting duct** – an extension of the tubule that drains urine into the pelvis so it can be removed via the ureter.

Only the loop of Henle and the collecting duct are located in the medulla. The rest of the nephron is contained within the cortex of the kidney.

glomerulus
a capillary knot in the Bowman's capsule through which ultrafiltration of blood (plasma minus protein) into the nephron of the mammalian kidney occurs

Bowman's capsule
the area of the mammalian kidney nephron in which ultrafiltration of the blood occurs

collecting duct
a duct into which waste materials from each nephron in the kidney drain

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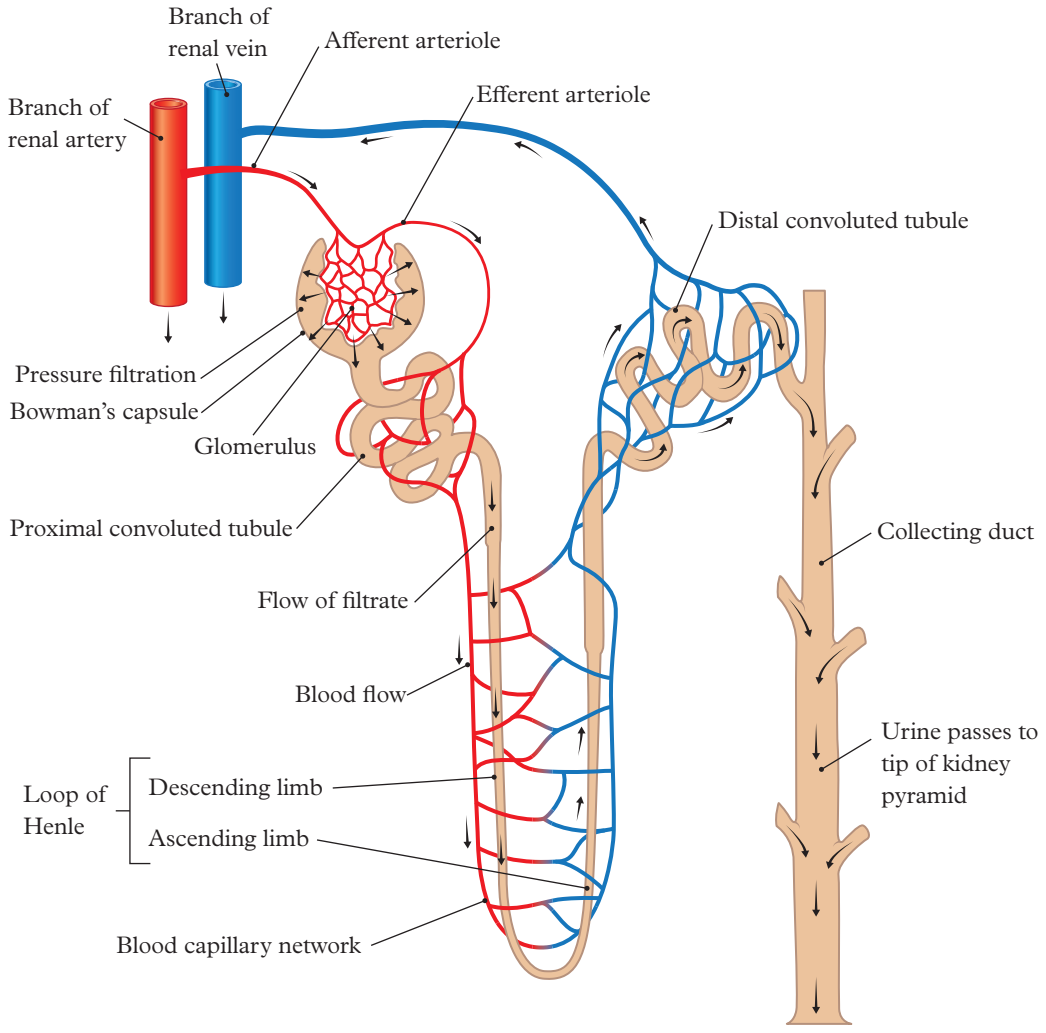


FIGURE 4 Diagram of a nephron

Processes involved in waste removal

In the nephron and its structures, three main processes help form urine and allow wastes to be removed from the body: glomerular filtration, selective reabsorption and secretion.

Glomerular filtration

The first step in urine production is glomerular filtration. Blood enters the capillaries of the glomerulus under high pressure from the **afferent arteriole**, a branch of the renal artery. Water, ions and small molecules such as glucose, amino acids and urea are forced through the capillary walls into the Bowman's capsule. This filtered fluid in the Bowman's capsule is called **filtrate** and is similar to plasma in composition but without the larger protein molecules. Blood cells normally do not leave the blood vessels because they are too large to cross the cell wall.

Selective reabsorption

The second step in the formation of urine for removal of wastes is selective reabsorption. As filtrate leaves the Bowman's capsule, it passes into the **proximal convoluted tubule**, where many useful substances are reabsorbed into the surrounding capillaries. The proximal convoluted tubule is the site where most water reabsorption in the nephron takes place. The cells lining the inside of the tubule have microvilli to increase surface area for absorption and

afferent arteriole
the arteriole leading into a structure, e.g. the glomerulus of the kidney

filtrate
the fluid that is left after water, ions and small molecules have been filtered out of the blood into the glomerulus of the kidney

proximal convoluted tubule
the tubule of the kidney nephron arising from the Bowman's capsule and leading to the loop of Henle; responsible for the reabsorption of glucose, sodium chloride and water

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are heavily loaded with mitochondria for energy production. Glucose and amino acids are absorbed via active transport into the cells that line the proximal convoluted tubule. Sodium ions are also absorbed via active transport in the proximal tubule. This creates an osmotic gradient that results in the passive diffusion of the negative chloride ions.

loop of Henle
an area between the proximal and distal convoluted tubules of the nephron in the mammalian kidney; a counter-current multiplier whereby high salt concentration in the tissue fluid is maintained, resulting in diffusion of water from the filtrate to the surrounding blood capillaries

Filtrate continues to move through to the **loop of Henle**, where reabsorption of water and salts takes place. In the loop of Henle, the walls lining the descending limb are permeable to water but impermeable to sodium chloride and urea. As filtrate passes through the descending limb, water diffuses out of the loop and the concentration of salt and urea in the filtrate increases towards the base of the loop. The lining of the ascending limb is impermeable to water and urea but permeable to sodium ions. This means that, as filtrate moves up the ascending limb, the body reabsorbs any useful salts into the surrounding tissue fluid in the medulla.

At any given level of the loop, the concentration of sodium in the descending limb is slightly above that in the ascending limb. Because the salt concentration in the descending limb is always just below that of the fluid surrounding it, it facilitates the passive removal of water. This also maintains a large concentration gradient along the whole depth of the loop. This concentrating effect is multiplied along the length of the loop from top to bottom, so that the longer the loop, the greater the concentration that can be reached, enabling mammals to reabsorb very large quantities of water from the filtrate and resulting in urine that is hypertonic to blood.

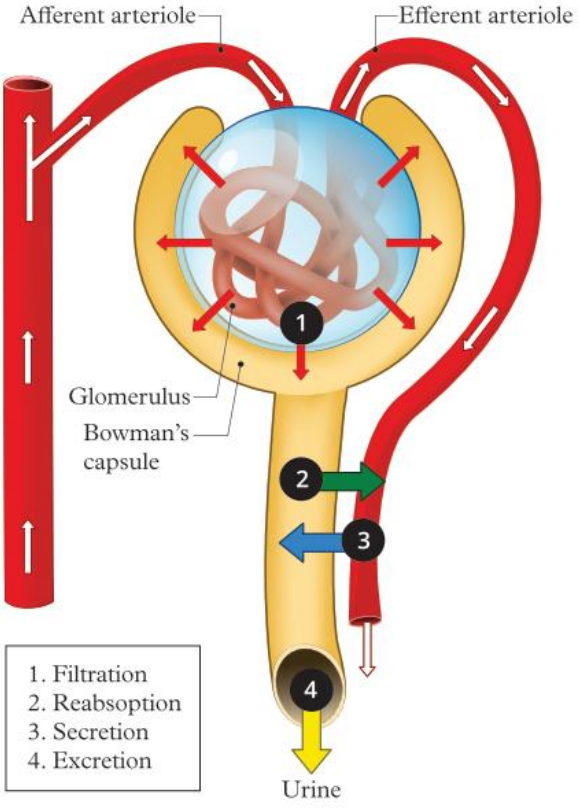


FIGURE 5 Urine formation involves filtration, reabsorption and secretion.

Secretion

Secretion is the movement of waste products from cells of the tubule walls into the filtrate. It occurs when substances such as ammonium, potassium, hydrogen ions, dyes and drugs get secreted into the convoluted tubule during reabsorption. As these substances are added to the filtrate, the filtrate continues to become more concentrated. Eventually the filtrate is moved to the collecting duct, so it can be either stored or passed as urine.

distal convoluted tubule
the part of the nephron that joins the loop of Henle to the collecting duct; responsible for the reabsorption of sodium, potassium, phosphate and calcium ions under the control of hormones

Challenge

Thirsty for ADH

Antidiuretic hormone (ADH) is a chemical that, when released, influences the kidney's ability to reabsorb water. Specifically, when released, ADH acts on a nephron's **distal convoluted tubule** and collecting duct to make both sections of tubule more permeable to water. Use your understanding of the nephron and the effect that ADH has on sections of the nephron to **explain** whether ADH would be released during times of dehydration or when the body is overhydrated. (1 mark)

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Real-world biology

Effect of diabetes on kidney function

Diabetes is a medical condition that can occur in two forms: diabetes mellitus and diabetes insipidus. Diabetes mellitus results from an inability to control blood sugar levels. Normally the pancreas secretes the hormone insulin, which converts excess blood glucose to glycogen for storage. A person's pancreas may not be able to produce enough insulin (Type 1 diabetes) or their cells may develop insulin resistance (Type 2 diabetes). In both cases, there is an excess of glucose in the blood. The proximal convoluted tubule of the nephron can remove only a limited amount of glucose from the glomerular filtrate. When this threshold is reached, the glucose is excreted in the urine. This affects the ability of the nephron to reabsorb water.

Diabetes insipidus is another form of diabetes. It results from either an inability to produce ADH or the kidneys being unable to respond to ADH. This results in the body releasing large amounts of dilute urine.

Both diabetes mellitus and diabetes insipidus result in symptoms including excessive urination, dehydration of the body and extreme thirst. Diabetic nephropathy is a complication of diabetes that affects the kidneys. It is a progressive kidney disease that develops over time because of prolonged high blood sugar levels, a common feature of diabetes. Diabetic nephropathy can affect people with Type 1 or Type 2 diabetes mellitus and is a leading cause of chronic kidney disease and end-stage renal disease, ultimately requiring dialysis or kidney transplantation.

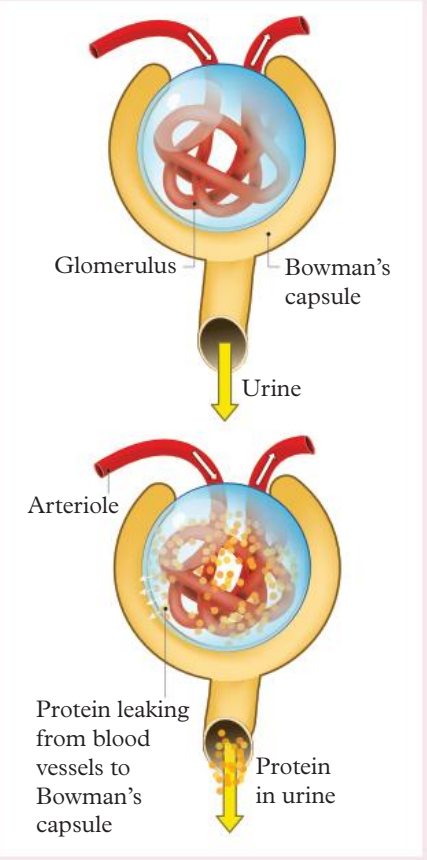


FIGURE 6 Diabetic nephropathy

Apply your understanding

1 **Differentiate** between diabetes mellitus (Type 1) and diabetes mellitus (Type 2). (1 mark)
2 **Identify** the common symptoms shared by diabetes mellitus and diabetes insipidus, including the relationship between excessive urination, dehydration and extreme thirst. (2 marks)
3 **Describe** how diabetic nephropathy affects people with diabetes. (1 mark)

Check your learning 6.5

Check your learning 6.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the role of the excretory system in animals. (1 mark)
2 **Identify** and **describe** the organs of the human excretory system. (4 marks)
3 For each of the following parts of the nephron, **identify** its function in the production of urine.
   a glomerulus (1 mark)
   b Bowman's capsule (1 mark)
   c proximal convoluted tubule (1 mark)
   d loop of Henle (1 mark)
   e distal convoluted tubule (1 mark)
   f collecting duct (1 mark)
4 **Summarise** the movement of glomerular filtrate through the nephron. (5 marks)
5 **Explain** how selective reabsorption and secretion across nephron membranes assists removal of wastes in urine. In your answer, provide examples of substances secreted in this process. (6 marks)
6 **Explain** how the urinary system works in coordination with the circulatory system to regulate waste elimination. (4 marks)

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MODULE 6

Lesson 6.6
Review: Exchange of nutrients and waste in animals

Summary

6.1
- A nutrient is a substance that an organism uses for maintenance, growth or repair.
- Heterotrophs acquire nutrients by ingesting food and digesting the nutrients from food.
- Physical digestion is the breaking down of food into smaller units by the crushing or cutting actions of the mouth and other body parts.
- Chemical digestion is the process in which food is broken down by digestive enzymes.

6.2
- The human digestive system is made up of an alimentary canal and associated organs that help to break food down physically and chemically.
- The human digestive system functions so that the body can obtain nutrients and remove waste.

6.3
- Practical: The effect of temperature on the rate of reactions of an enzyme

6.4
- Practical: The effect of pH on the rate of enzyme reaction

6.5
- The excretory system removes wastes from the body.
- Major organs of the excretory system are the kidneys, ureters, bladder and urethra.

Review questions 6.6A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 In mammals, the structure that takes urine from the bladder to the exterior is the
A urethra. **B** ureter.
C uriniferous tubule. **D** anus.

2 The Bowman's capsule is located in the region of the kidney called the
A pelvis. **B** pyramid.
C cortex. **D** medulla.

3 Which is the best description of digestion?
A Digestion is the action of enzymes on food in the digestive tract.
B Digestion is the breaking down of complex organic molecules into small molecules that can be used by the body.
C Digestion is the dissolving of food and its absorption into the blood.
D Digestion is the breaking up of food into soluble molecules that can diffuse through cell membranes.

4 Most of the nutrient absorption that takes place in the digestive system occurs in the
A stomach. **B** oesophagus
C small intestine. **D** large intestine.

5 Which one of the following does NOT aid the transfer of certain substances from the bloodstream to the tubules of the mammalian kidney?
A the large surface area of the capillaries of the glomerulus
B the relatively small sizes of the molecules (or ions) of these substances
C the larger diameter of the arteriole leaving Bowman's capsule compared with the diameter of the arteriole entering the capsule
D the relatively great length of each of the tubules

6 Which of the following types of enzyme is responsible for breaking down proteins in the stomach?
A amylase **B** lipase
C protease **D** lactase

7 The primary waste product excreted by the kidneys is
A urea. **B** carbon dioxide.
C ammonia. **D** lactic acid.

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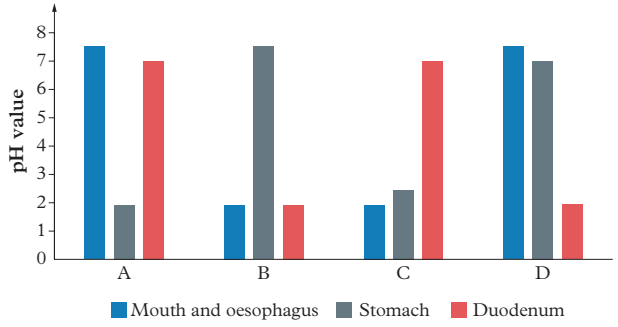
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8 In which system does peristalsis occur?
A digestive system **B** nervous system
C circulatory system **D** respiratory system

9 The role of amylase in the body is to catalyse the breaking down of
A protein. **B** carbohydrates.
C lipids. **D** nucleic acids.

10 Which is the correct order of travel through the alimentary canal?
A mouth → oesophagus → stomach → caecum → ileum → duodenum → large intestine → rectum
B mouth → oesophagus → stomach → ileum → duodenum → large intestine → caecum → rectum
C mouth → oesophagus → stomach → duodenum → ileum → large intestine → caecum → rectum
D mouth → oesophagus → stomach → duodenum → ileum → caecum → large intestine → rectum

11 Identify the graph that correctly represents the changes in pH as food travels from the mouth to the duodenum.



A graph A **B** graph B
C graph C **D** graph D

12 In the nephron, most water reabsorption occurs in the
A glomerulus.
B Bowman's capsule.
C loop of Henle.
D proximal convoluted tubule.

13 The primary function of the glomerulus is
A reabsorption of water.
B filtration of blood.
C secretion of waste products.
D concentration of urine.

14 The primary function of microvilli is to
A increase surface area.
B increase removal of waste.
C protect internal capillaries.
D decrease nutrient absorption.

15 Which is the correct order of travel of glomerular filtrate, starting from the Bowman's capsule?
A proximal convoluted tubule → descending limb → ascending limb → distal convoluted tubule → collecting duct
B proximal convoluted tubule → ascending limp → descending limb → distal convoluted tubule → collecting duct
C distal convoluted tubule → descending limb → ascending limb → proximal convoluted tubule → collecting duct
D distal convoluted tubule → ascending limb → descending limb → proximal convoluted tubule → collecting duct

Review questions 6.6B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

16 **Describe** the process of nutrient absorption in the small intestine, including the role of villi. (3 marks)

17 **Describe** how the structure of villi assists with efficient nutrient absorption. (1 mark)

18 **Describe** the function of the loop of Henle in the nephron and its contribution to urine concentration. (2 marks)

19 **Describe** the role of lipase in chemical digestion. (1 mark)

20 **Explain** how nephron structure contributes to the removal of waste, with reference to glomerular filtration, selective reabsorption and secretion. (4 marks)

21 **Describe** the role of the convoluted tubules in the nephron, focusing on their role in selective reabsorption. (2 marks)

22 **Identify** which factors contribute to the movement of substances out of the blood at the glomerulus and into the Bowman's capsule. (2 marks)

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Analytical processes

23 **Compare** chemical digestion and physical digestion. (2 marks)

24 **Differentiate** between the functions of the small intestine and the large intestine in the digestive system. (1 mark)

Knowledge utilisation

25 Orlistat is a prescription medication that acts as a lipase inhibitor and is marketed as a weight-loss treatment. **Evaluate** whether you believe a medicine like Orlistat could assist patients with weight loss. (2 marks)

26 The table gives information about substances filtered from blood in normal human kidneys and excreted as urine.

Substance	Approximate daily quantity (g)	
	Filtered through glomerulus	Excreted in urine
Water	180×10^3	1.5×10^3
Sodium (as Na^+ ions)	550.0	2.5
Glucose	187.0	0.0
Amino acids	8.5	0.1
Urea	51.0	30.0

Of the filtered water, 80% is reabsorbed in the proximal convoluted tubule and in the descending loop of Henle. Using this information, **propose** a reason for the differences in quantities for each of these substances. (2 marks)

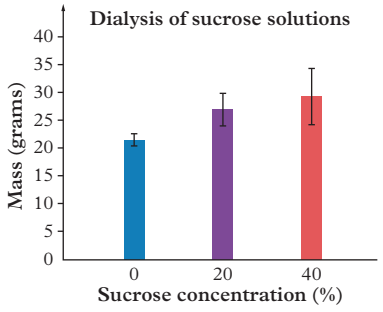
Data drill

Dialysis of sucrose solutions

Dialysis tubing is a semi-permeable membrane used during the process of kidney dialysis. An experiment was conducted using the tubing to investigate the movement of molecules across the tubing by placing dialysis tubing filled with sucrose solutions of increasing concentrations into distilled water. The table shows the change in mass of the dialysis tubing over time for the varying concentrations of sucrose.

Solution concentration	Mass of tubing (g)		
	0 min	30 min	60 min
0% sucrose (distilled water)	21.5	21.4	21.5
20% sucrose	23.2	25.1	26.8
40% sucrose	24.9	26.5	29.2

The figure depicts the mass of the tubing at varying sucrose concentrations after being in distilled water for 60 minutes.



Apply understanding

1 **Calculate** the percentage change in mass over 60 minutes for the 40% sucrose concentration. (1 mark)

Analyse data

2 **Contrast** the change in mass between the 0% and 20% sucrose solution tests. (1 mark)

3 An unpaired Student's *t*-test was conducted to compare results between the 20% and 40% sucrose solutions, and a *p*-value of 0.6 was returned. **Comment** on the statistical significance of the comparative data. (1 mark)

Interpret evidence

4 **Draw a conclusion** about how sucrose concentration affects the diffusion of water into the dialysis tube. (1 mark)

5 **Draw a conclusion** about the statistical accuracy of the data. (1 mark)

Module 6 checklist: Exchange of nutrients and waste in animals

Quizlet: Revise key terms online to test your understanding

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UNIT 1

Topic 2 Review

Multiple choice

(1 mark each)

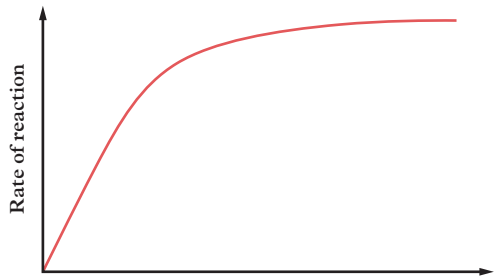
1 The monomers of proteins are called
- **A** amino acids.
- **B** carbon.
- **C** monosaccharides.
- **D** tertiary structures.

2 A change in the physical structure of an enzyme preventing its active site binding with substrates is called
- **A** activation energy.
- **B** competitive inhibition.
- **C** denaturation.
- **D** melting.

3 Enzyme rate of reaction is increased by
- **A** decreasing the temperature.
- **B** decreasing the volume of the enzyme.
- **C** increasing the volume of both the enzyme and the substrate.
- **D** increasing the volume of the substrate.

4 The induced-fit model describes binding between an enzyme and the substrate, where
- **A** a different molecule binds to the enzyme's active site, preventing the enzyme from binding with the substrate.
- **B** a different molecule binds to a non-active part of the enzyme, which changes the shape of the active site, preventing the enzyme from binding with the substrate.
- **C** the active site of the enzyme and the substrate both change shape to fit together.
- **D** the active site of the enzyme fits perfectly with the substrate.

5 The graph shows the rate of reaction of an enzyme as an unknown independent variable is increased.



The most likely independent variable is
- **A** pH.
- **B** substrate concentration.
- **C** temperature.
- **D** volume of solution.

6 The term "hydrophilic" means
- **A** attracted to hydrogen.
- **B** attracted to water.
- **C** hydrogen repelling.
- **D** water repelling.

7 Lymph is a liquid carried in lymphatic vessels and is made up of
- **A** erythrocytes and platelets.
- **B** erythrocytes and leucocytes.
- **C** lipids and leucocytes.
- **D** lipids and plasma.

8 Haemoglobin carries oxygen and is found in
- **A** erythrocytes.
- **B** lipids.
- **C** plasma.
- **D** platelets.

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9 What is the role of enzymes in digestion?

A They chemically break macromolecules into smaller components.

B They direct macromolecules to be absorbed through the stomach wall.

C They physically break monomers into polymers.

D They physically break food into smaller components.

10 The enzyme responsible for breaking down fats is called

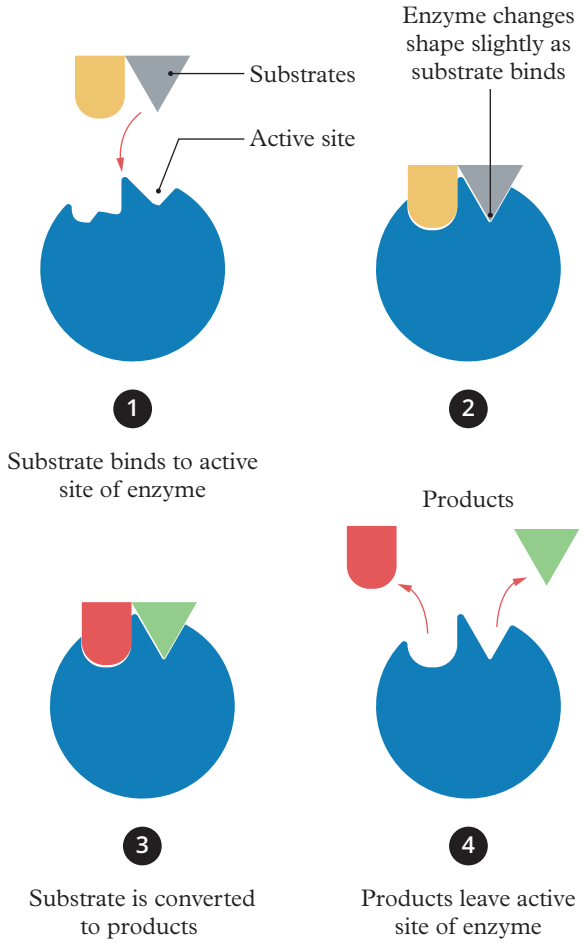
A amylase.

B catalase.

C lipase.

D pepsin.

11 Enzyme function is shown in the figure.



Step 2 is showing

A competitive inhibition.

B denaturation.

C the enzyme/substrate complex.

D the lock-and-key model.

12 Veins are vessels in the circulatory system that

A carry blood away from the heart.

B contain valves.

C contract to move blood through the body.

D have walls that are one cell thick.

13 Temperature increases enzyme rate of reaction by

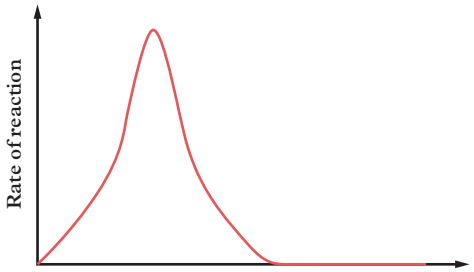
A denaturing enzymes.

B improving enzyme active site/substrate fit.

C increasing collision rate.

D lowering activation energy.

14 The graph shows the rate of reaction of an enzyme as an unknown independent variable is increased.



The most likely independent variable is

A enzyme concentration.

B pH.

C substrate concentration.

D temperature.

15 Nutrients and gases diffuse between the bloodstream and the cells at the juncture between cells and

A arteries.

B capillaries.

C valves.

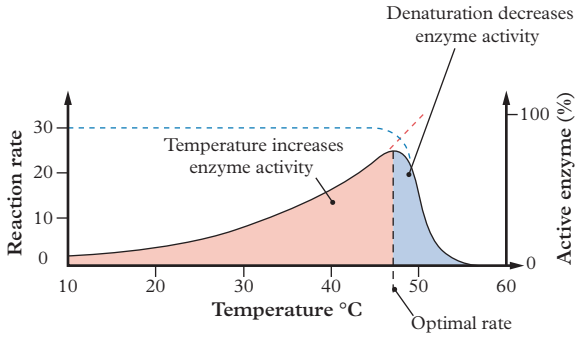
D veins.

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Short response

16 The graph shows the relationship between temperature and rate of reaction of an enzyme.



a **Identify** the optimal temperature of this enzyme. (1 mark)

b **Explain** why the rate of reaction increases slowly before reaching the optimal rate and decreases quickly after reaching the optimal rate. (2 marks)

c **Predict** the rate of reaction if the experiment was extended to 70°C. (1 mark)

17 **Contrast** essential and non-essential nutrients, and **identify** an example of each. (3 marks)

18 **Identify** three components of blood plasma. (3 marks)

19 **Describe** the advantages of a closed circulatory system over an open circulatory system. (3 marks)

20 **Describe** the molecular structure of fatty acids and their interactions with water molecules. (4 marks)

21 **Explain** the importance of valves in veins. (3 marks)

22 **Compare** the pulmonary and systemic circuits in the circulatory system. (2 marks)

23 **Describe** the elements and monomers that make up proteins. (4 marks)

24 **Contrast** arteries and veins with respect to their structure and function. (2 marks)

25 **Explain** the importance of red blood cells' small size. (1 mark)

26 **Describe** the progression of a protein through primary, secondary, tertiary and quaternary structures. (4 marks)

27 **Explain** the process of peristalsis, including the structures involved (2 marks).

28 The image shows an experiment on enzyme rate of reaction.



a **Suggest** a possible independent variable that would result in different rates of reaction in each beaker. (1 mark)

b **Identify** one controlled variable that is apparent in the two beakers. (1 mark)

c If the liquid contains the enzyme amylase, **infer** the substrate contained in the solid component. (1 mark)

TOTAL MARKS
/47 marks

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MODULE 7

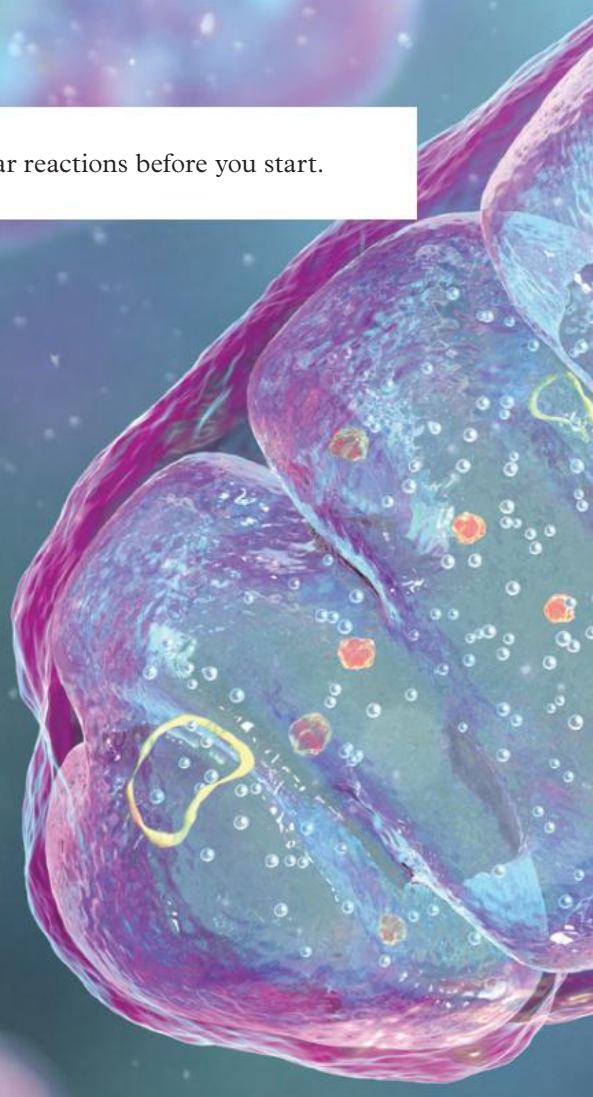
Cell function and energy

Introduction

All organisms require energy to drive the chemical reactions necessary for their survival. Metabolism is the total sum of chemical reactions that occur inside cells, to help the cells survive. There are two types of metabolic reactions: catabolic reactions, which produce energy, and anabolic reactions, which require energy. Cellular respiration is a key catabolic reaction that occurs in all living things. In cellular respiration, glucose is broken down, producing chemical energy in the form of ATP. This process is more efficient when it occurs in the presence of oxygen. When it occurs in the absence of oxygen, unwanted chemicals are produced.

Prior knowledge

Prior knowledge quiz Check your understanding of cellular reactions before you start.



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Subject matter

Science understanding

→ Distinguish between catabolism and anabolism.
→ Explain how ATP allows energy from catabolic reactions to be used in anabolic reactions.
→ Describe the process of aerobic respiration, identifying the location in the cell and net inputs and outputs of
  – glycolysis
  – Krebs cycle and electron transport chain
  – the overall reaction ($C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36–38\,ATP$).
→ Compare aerobic and anaerobic respiration.

Science as a human endeavour

→ Appreciate how scientists use their understanding of natural systems to develop new technologies.

Science inquiry skills

→ Identify and implement strategies to manage risks, ethics and environmental impact.

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Practicals

oxforddigital **This lesson is available on Oxford Digital.**

Lesson 7.4 Investigating respiration

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Lesson 7.1
Cellular energy

Key ideas

- → Energy is the ability to do work or to cause a change.
- → Metabolism is all the chemical reactions that take place inside a cell or an organism.
- → There are two types of metabolic reactions. In anabolic reactions, new larger molecules are synthesised and energy is consumed. In catabolic reactions, large molecules are broken down, releasing energy.

Learning intentions and success criteria

Energy conversion

energy
the capacity to do work

Energy is the ability to do work or to cause a change. Energy is required for all the chemical reactions that occur within cells. All cells need a constant supply of energy to grow, reproduce and stay alive. Cells mostly use chemical energy, and many organisms obtain chemical energy from their food. For some types of cells, light is an important source of energy. There are two main types of energy: **kinetic energy** (the energy of motion) and **potential energy** (energy that is stored).

kinetic energy
the energy of motion

potential energy
stored energy

The compounds that make up living cells are highly complex. Some are composed of thousands of atoms bonded together. Many of these bonds, particularly carbon-to-hydrogen or "C–H" bonds, have relatively large amounts of chemical energy stored within them. This means that each living organism has a "storehouse" of potential chemical energy that can be harnessed when necessary to do work. Each time this stored energy is converted to other forms for use, less energy remains in reserve. Therefore, each organism needs an external source of energy that can be used to replenish its supply of chemical-bond energy. For organisms that cannot create their own food (heterotrophs), this outside energy source is other organisms. For organisms that can produce their own food (autotrophs), the source may be inorganic molecules (**chemosynthesis**) or sunlight (**photosynthesis**).

chemosynthesis
the process in which reactions of inorganic substances are used to provide energy for the synthesis of organic compounds

photosynthesis
the process in which light energy is converted to the chemical energy of glucose; requires chlorophyll, carbon dioxide, water and a suitable temperature; occurs in green plants, algae and some bacteria

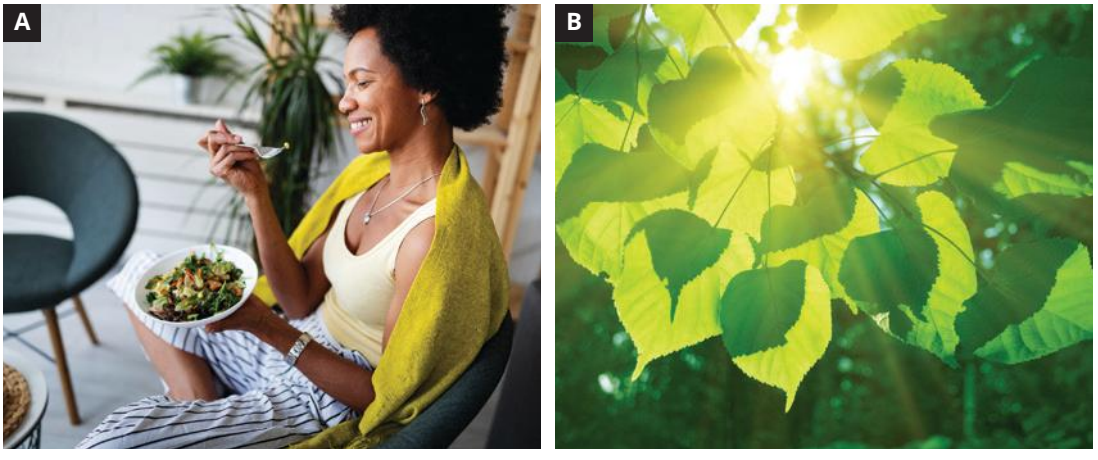


FIGURE 1 All organisms require a source of energy from their external environment to ensure they can replenish their chemical-bond energy. (A) Humans are heterotrophs – they eat other organic substances as an external energy source. (B) Plants are autotrophs – they use sunlight as an external energy source.

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Metabolism

Metabolism is all the chemical reactions that take place inside a cell or an organism. Metabolic processes proceed in small steps, the sum of which is called a metabolic pathway. There are two types of metabolic reactions.

- **Anabolism** describes the reactions that synthesise new larger molecules. Anabolic reactions tend to absorb energy (**endergonic**), as energy is used to form new bonds.
- **Catabolism** describes the reactions that break down large molecules into smaller ones. Catabolic reactions tend to release energy (**exergonic**), as bonds are broken between atoms.

All the catabolic and anabolic reactions occurring at any time in a cell constitute its metabolism.

anabolism + catabolism = metabolism

The energy released in catabolic reactions is used to drive anabolic reactions, for work (e.g. muscular contractions) and for maintenance. Some energy is lost as heat energy.

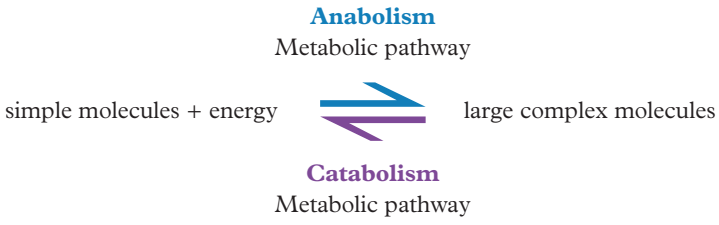


FIGURE 2 Anabolic and catabolic reaction pathways

One of the most important metabolic pathways yielding energy is the breaking down of sugar. This is an oxidation process. As sugar is broken down, energy is released and carbon dioxide and water are formed. The process, called cellular respiration, can be shown in simplified form by the following:

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

The sugar molecule, $C_6H_{12}O_6$ or glucose, contains potential energy, which is freed only when the bonds holding the atoms in the molecule together are broken and new, lower-energy molecules are formed.

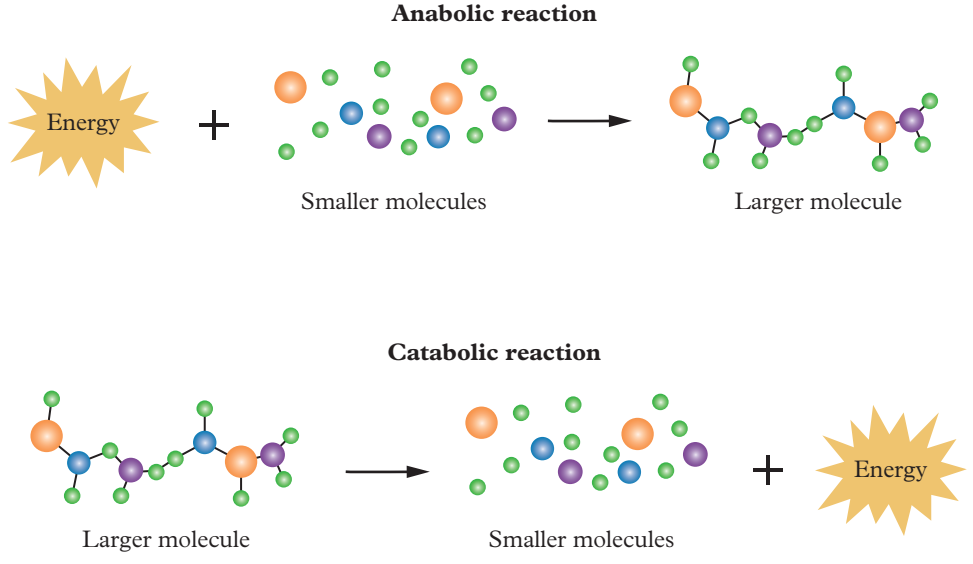


FIGURE 3 Visual summary of anabolic and catabolic reactions

Study tip

To remember the difference between anabolism and catabolism, think of "ABCD": **a**nabolism **b**uilds, **c**atabolism **d**estroys.

metabolism
all the chemical reactions occurring within a cell

anabolism
chemical reactions in which large molecules are built up, usually with a net input of energy

endergonic
describes a chemical reaction involving the absorption of energy

catabolism
chemical reactions in which large molecules are broken down into smaller ones, usually with the release of energy

exergonic
describes a chemical reaction in which energy is released

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Check your learning 7.1

Check your learning 7.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** metabolism. (1 mark)

2 **Explain** why cells require a constant input of energy. (1 mark)

3 **Explain** what happens to energy when a chemical bond is broken and when a chemical bond is formed. (2 marks)

Analytical processes

4 **Distinguish** between anabolism and catabolism. (1 mark)

5 **Classify** each of following reactions as anabolic or catabolic. **Justify** your answer.

a $6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$ (2 marks)

b $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$ (2 marks)

Lesson 7.2
Biological energy transformations

Key ideas

- Adenosine triphosphate (ATP) is an important molecule in living organisms. In ATP, energy is stored in a readily available form and can be transported from one site to another.
- An ATP molecule consists of the nitrogen base adenine, a ribose sugar and three phosphate groups arranged in sequence.
- When ATP loses a phosphate, it becomes adenosine diphosphate (ADP). Energy is released by the breaking of the high-energy bond.

Learning intentions and success criteria

adenosine triphosphate (ATP)
an organic chemical able to store and release large amounts of energy; consists of the nitrogen base adenine bound to three phosphate groups

ATP and ADP

Energy released at one site of a cell is often required at another site. This is important in all metabolic reactions. In biological systems, some molecules are used to transport energy molecules from place to place, or simply to store energy in a readily accessible form. **Adenosine triphosphate (ATP)** is the major molecule involved in this process. ATP is in all living things.

An ATP molecule is composed of an adenine unit, a ribose (five-carbon sugar) and three phosphate groups in sequence (Figure 1).

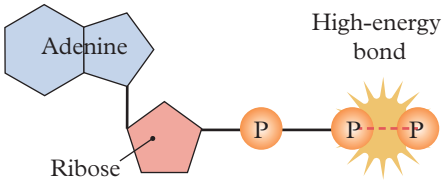


FIGURE 1 An ATP molecule consists of an adenine base (blue), a ribose sugar (pink) and a chain of three phosphate groups.

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The bonds between the phosphate groups are high-energy bonds, often represented by the symbol " ~ ". These high-energy phosphate bonds are weak and unstable, and therefore can be readily broken. Usually, it is the phosphate bond furthest from the adenine that is broken to provide energy for metabolic reactions. The breaking of this phosphate bond produces a lower-energy, more stable compound called **adenosine diphosphate (ADP)**. ADP consists of an adenine base, a ribose sugar and only two phosphate groups. The conversion of ATP to ADP releases a phosphate group and energy (Figure 2).

adenosine diphosphate (ADP) the nitrogen base adenine bound to two phosphate groups, each bond requiring an input of energy

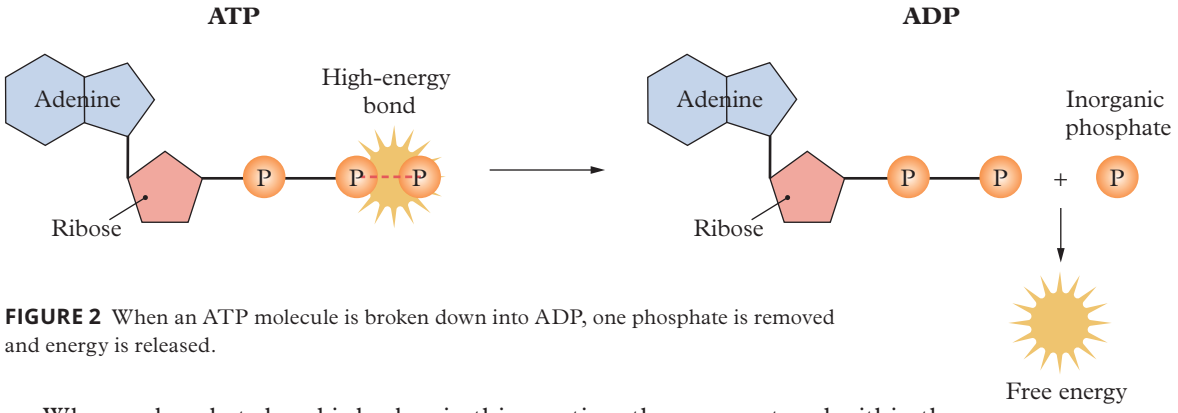


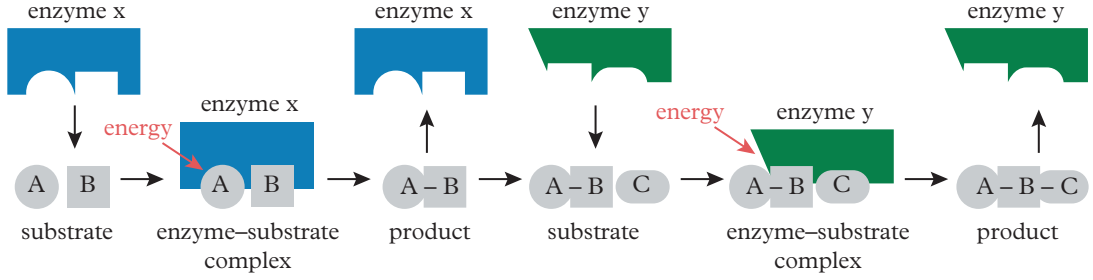
FIGURE 2 When an ATP molecule is broken down into ADP, one phosphate is removed and energy is released.

When a phosphate bond is broken in this reaction, the energy stored within the bond is released. This energy can then be used to fuel other metabolic reactions. The detached phosphate molecule will often attach to other molecules in a reaction called **phosphorylation**. New ATP can be synthesised from ADP and a phosphate if there is enough energy available to bind a third phosphate group to the ADP.

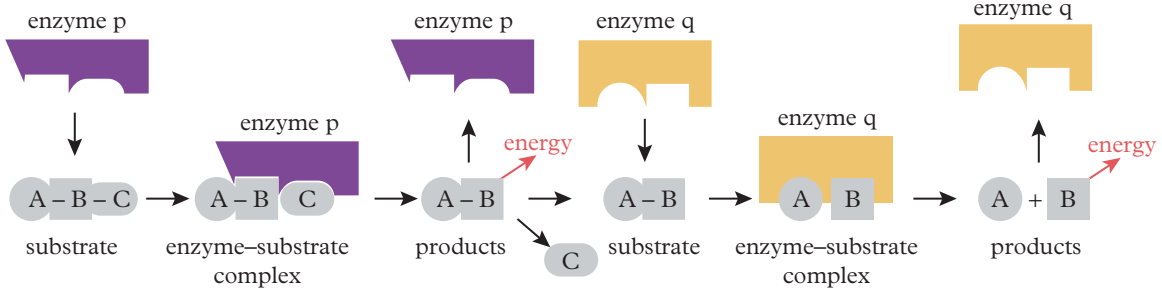
phosphorylation the addition of a phosphate group to a molecule; can be non-cyclic (e.g. formation of ATP) or cyclic (e.g. the cyclic flow of electrons along the electron transport chain from chlorophyll, the released energy being used in the formation of ATP)

The phosphate-bond energy of ATP is used to do cellular work. Metabolism therefore involves enzymes and the transport of energy. Figure 3 summarises these reactions.

Anabolic reactions in cells build complex molecules from simpler molecules.
These reactions usually involve specific enzymes and use energy.



Catabolic reactions in cells break down complex molecules into simpler molecules.
These reactions usually involve specific enzymes and release energy.



A substrate is a substance acted upon by enzymes.
Products are substances produced in chemical reactions.

FIGURE 3 The relationship between metabolism, enzymes and energy. These diagrams represent very simple metabolic pathways.

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Carrier molecules

Other organic carrier molecules are also important in energy transport in metabolic pathways.

- NAD^+ (nicotinamide adenine dinucleotide) receives electrons from other molecules and reacts with hydrogen ions to form NADH, which donates electrons for other reactions.
- FAD (flavin adenine dinucleotide) reacts with electrons and hydrogen ions in a similar way, to form $FADH_2$.

It takes energy for the hydrogen ions and electrons to bond with the carrier molecules. Therefore, when the hydrogen ions are released from the carrier molecule, energy is also released. The NADH and $FADH_2$ molecules are important in the carriage of hydrogen in metabolic pathways.

Check your learning 7.2

Check your learning 7.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the features of the ATP molecule that enable it to function as an energy carrier in biological systems. (2 marks)

2 **Explain** how ATP provides energy for metabolic reactions. (2 marks)

Analytical processes

3 **Compare** ATP and ADP. (2 marks)

Lesson 7.3
Aerobic respiration

Learning intentions and success criteria

Key ideas

- → Cellular respiration is a process in which glucose is changed into a usable form of energy. It can be summarised by the reaction: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36–38$ ATP.
- → Aerobic cellular respiration takes place in the presence of oxygen. It has three stages: glycolysis, the Krebs cycle and the electron transport chain.
- → Glycolysis occurs in the cytoplasm. All other stages of aerobic respiration take place in the mitochondria.

Cellular respiration

cellular respiration the breaking down of glucose in cells to release energy; may occur with oxygen (aerobic) or without oxygen (anaerobic)

Some autotrophs, such as plants and some bacteria, convert light energy into chemical energy in the form of glucose, through photosynthesis. Heterotrophs, such as humans and other animals, need to consume other organisms to acquire chemical energy in the form of glucose. All cells, whether heterotrophic or autotrophic, must convert glucose ($C_6H_{12}O_6$) into the energy 'currency' molecule, ATP.

Cellular respiration is the process in which glucose is converted into a usable form of energy. All cells, including the cells of autotrophs, must carry out cellular respiration to survive.

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The process generally involves the oxidation of sugar in a series of small steps, each controlled by an enzyme. The energy released is stored in the ATP molecule for further use by the cell and can be transported to other cells or other sections of the cell within an organism.

Some steps in cellular respiration are endergonic (energy consuming), but most are exergonic (energy releasing). The overall reaction is exergonic and leads to the production of ATP. Each step in cellular respiration is controlled by a specific enzyme. Cellular respiration can occur two ways: **aerobically** (in the presence of oxygen) or **anaerobically** (in the absence of oxygen). In this lesson you will learn about **aerobic respiration**.

Mitochondria in aerobic cellular respiration

Cellular respiration begins with the breaking down of glucose into two molecules of pyruvate. Pyruvate and oxygen then enter the mitochondrion, where the pyruvate is broken down to release carbon dioxide, water and ATP molecules in the Krebs cycle and the electron transport chain. Oxygen is needed to remove hydrogen released in the Krebs cycle, so that this cycle can continue.

The mitochondrion (plural "mitochondria") is a double-membraned cell organelle. Its inner membrane is deeply folded, forming a series of cristae (shelves), which increase the surface area of this membrane. The whole structure is either spherical (e.g. in liver cells) or cigar-shaped, providing a high surface area-to-volume ratio for the efficient uptake and release of materials.

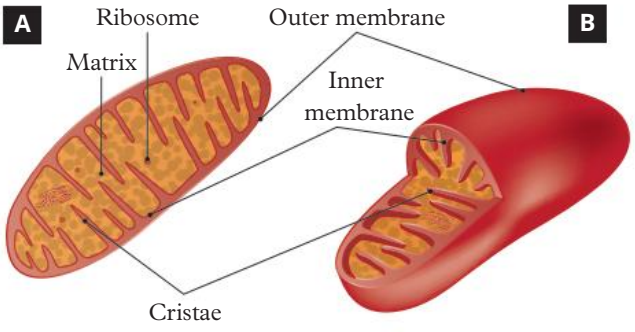


FIGURE 1 The structure of a mitochondrion: (A) longitudinal section (B) cut-away view

The outer membrane controls the passage of materials into and out of the mitochondrion. The inner membrane contains the enzymes responsible for ATP production.

The matrix within the mitochondrion contains ribosomes, circular DNA molecules and the enzymes required for many of the steps in aerobic cellular respiration.

Aerobic cellular respiration

Aerobic cellular respiration has three stages:

1. **glycolysis**, followed by **acetyl-CoA** formation
2. the **Krebs cycle**
3. the **electron transport chain**.

Glycolysis

Aerobic cellular respiration begins in the cytoplasm with glycolysis, a process in which a glucose molecule is broken down into two smaller molecules of a compound called **pyruvate**. Glycolysis occurs in all living organisms. It is an anaerobic process – it does not require oxygen.

aerobically
occurring in the presence of oxygen

anaerobically
occurring in the absence of oxygen

aerobic respiration
the complete conversion of glucose to carbon dioxide and water in the mitochondria of cells with oxygen present, resulting in the release of a large amount of energy (net gain of 36 ATP)

glycolysis
the first stage in cellular respiration; occurs in the cytoplasm and results in the gain of 2 ATP and 2 pyruvate molecules; does not require oxygen

acetyl-CoA
a biomolecule involved in metabolism; the substrate that enters the Krebs cycle

Krebs cycle
a cyclic series of chemical reactions in the mitochondria of cells: two acetyl-CoA molecules are converted to citric acid; with the addition of six water molecules, the citric acid releases six carbon dioxide molecules as waste and 16 hydrogen atoms; the hydrogen atoms are transferred to carrier molecules; two ATP are formed

electron transport chain
a series of coenzymes along which high-energy electrons pass, releasing energy to form ATP at each step in the chain; the final stage in aerobic cellular respiration in which most ATP molecules are formed

pyruvate
the product of glycolysis; used to synthesise many metabolic pathways

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It takes place in the cytoplasm of the cell, not the mitochondrion, because glucose molecules are too large to pass through the outer membrane of the mitochondrion. The glycolysis reaction is initiated when one glucose molecule reacts with two ATP molecules. The reaction (Figure 2) can be written as:

$$\text{glucose} + 2\text{ATP} + 2\text{ADP} + 2\sim\text{P} \rightarrow 2\,\text{pyruvate} + 4\text{ATP}$$

The glycolysis reaction results in:

- conversion of a six-carbon glucose molecule to two three-carbon pyruvate molecules
- formation of four ATP molecules, resulting in a net gain of two ATP molecules (four ATP molecules are produced, but two are initially needed as activation energy)
- formation of two hydrogen carriers (NADH).

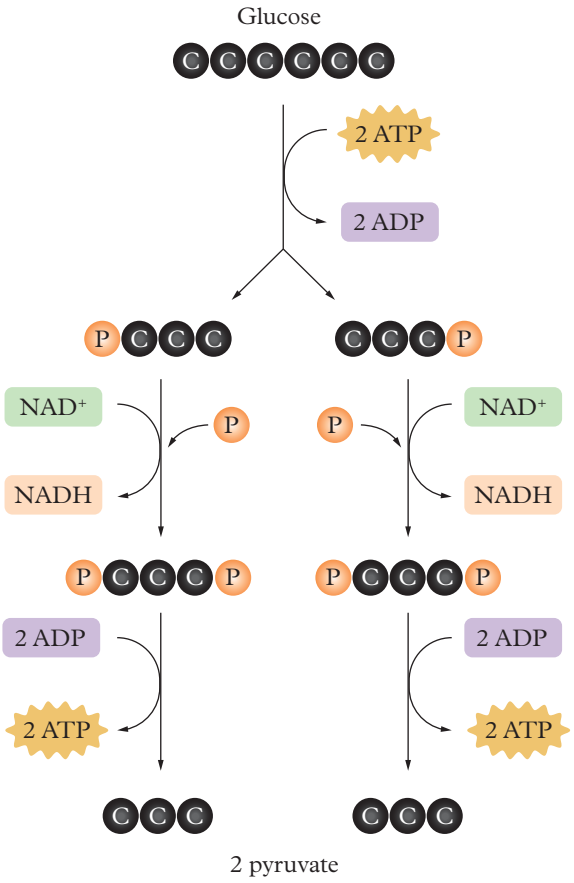


FIGURE 2 The glycolysis reaction

TABLE 1 Summary of the location, inputs and outputs of glycolysis

Process	Location	Inputs	Outputs
Glycolysis	Cytoplasm	2 ATP	2 pyruvate
		Glucose ($C_6H_{12}O_6$)	4 ATP (net gain of 2 ATP)
		2 ADP	2 NADH
		2 NAD^+	

Acetyl-CoA formation

coenzyme A
a coenzyme in biochemical reactions; reacts with pyruvate to form acetyl-CoA

If oxygen is present (aerobic respiration), the pyruvate molecules formed by glycolysis leave the cytoplasm and enter the mitochondrion by passing through the mitochondrion's outer and inner membranes. Then, in the mitochondrial matrix, each pyruvate molecule reacts in the presence of a carrier molecule called **coenzyme A**. Pyruvate must be converted into acetyl-CoA before it can enter the Krebs cycle.

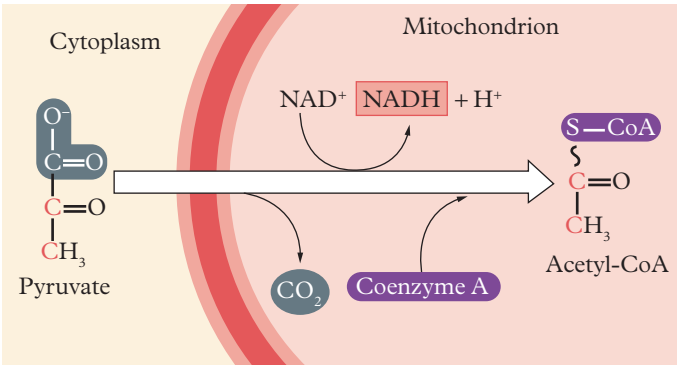


FIGURE 3 Formation of acetyl-CoA from pyruvate

In this reaction (Figure 3), for each pyruvate molecule:

- a carbon dioxide molecule is released from the pyruvate as a waste product
- the two-carbon molecule that is left from the first step attaches to a coenzyme A molecule, forming acetyl-CoA and a hydrogen ion
- NAD^+ gains two electrons and a hydrogen ion to form the hydrogen carrier NADH.

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TABLE 2 Summary of the location, inputs and outputs of acetyl-CoA formation

Process	Location	Inputs	Outputs
Acetyl-CoA formation	Mitochondrial matrix	2 pyruvate 2 coenzyme A 2 NAD^+	2 acetyl-CoA 2 CO_2 2 NADH

Krebs cycle

The Krebs cycle is a series of chemical reactions in the mitochondrial matrix that start and finish with the same four-carbon molecules. Two acetyl-CoA molecules enter the cycle separately by combining with these four-carbon compounds to form two molecules of citric acid. Each step in the cycle is enzyme driven. For the cycle to proceed, it requires an input of six water molecules for each citric acid molecule, which releases:

- 16 hydrogen ions and electrons that are passed to hydrogen carriers (6 NADH and 2 $FADH_2$)
- another two ATP molecules
- four carbon dioxide molecules as a waste product
- a molecule that reacts with water to re-form the original four-carbon molecule.

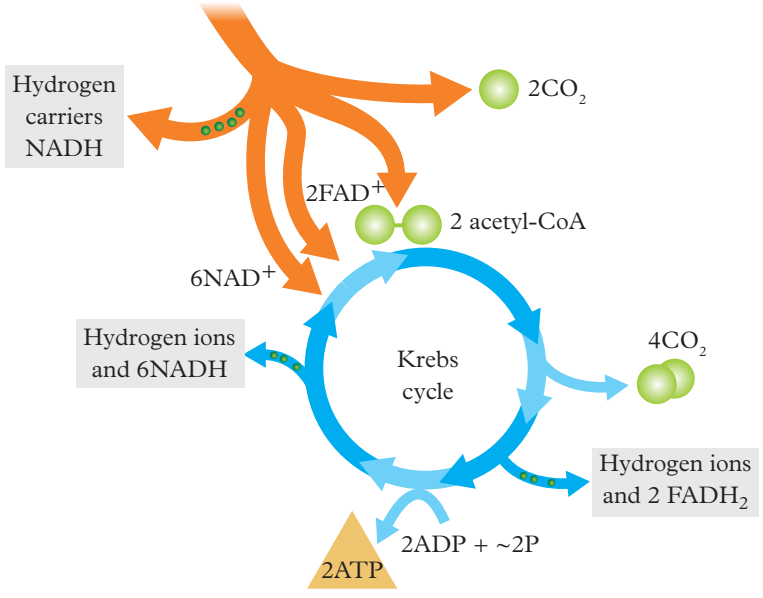


FIGURE 4 Glycolysis produces two three-carbon pyruvate molecules. If oxygen is present, the pyruvate moves into the mitochondria. Each pyruvate loses carbon dioxide and becomes acetyl-CoA. The acetyl-CoA then enters the Krebs cycle, resulting in the formation of carbon dioxide, ATP, and hydrogen ions and electrons on their hydrogen carriers.

TABLE 3 Summary of the location, inputs and outputs of the Krebs cycle

Process	Location	Inputs	Outputs
Krebs cycle	Mitochondrial matrix	2 acetyl-CoA 6 NAD^+ 2 FAD^+ 2 ADP	2 coenzyme A 4 CO_2 6 NADH 2 $FADH_2$ 2 ATP

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Electron transport chain

The inner membrane of the mitochondrion has many deep folds, known as cristae, to increase its surface area for the chemical reactions. A series of specialised enzymes associated with these reactions are embedded in this inner membrane. Hydrogen ions formed in the previous steps are released from their carriers to the electron transport chain, along with high-energy electrons. At each step in the chain, energy is released from the electrons and used in the formation of ATP. At the end of the chain, the low-energy electrons combine with the hydrogen ions and, with an input of six oxygen molecules, form water. Overall, this step produces:

- 32 to 34 ATP molecules
- 12 water molecules, so there is a net of 6 molecules as a waste product.

The overall equation for aerobic cellular respiration is often written as:

glucose + 6 oxygen + 6 water + ADP + ~P → 6 carbon dioxide + 12 water + energy (ATP)

$C_6H_{12}O_6 + 6O_2 + 6H_2O + 36–38\,ADP + 36–38{\sim}P \rightarrow 6CO_2 + 12H_2O + 36–38\,ATP$

It can be summarised as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36–38\,ATP$$

Depending on certain conditions, either 32 or 34 ATP molecules are produced during electron transport chain reactions. There is a net gain of either 36 or 38 ATP molecules for every glucose molecule aerobically respired. For each glucose molecule, $6\,CO_2$ and $6\,H_2O$ are released (as waste), and 36 ATP molecules are released (as a chemical energy transfer molecule).

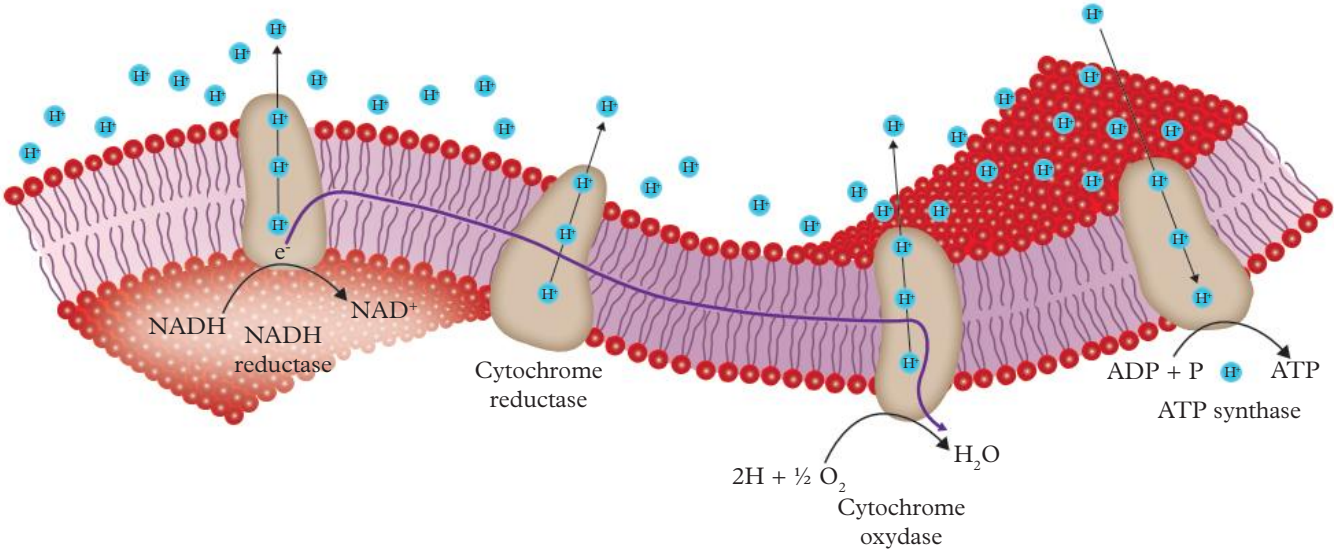


FIGURE 5 Enzymes embedded in the inner membrane of the mitochondrion carry electrons to the final electron acceptor, which produces ATP molecules.

TABLE 4 Summary of the location, inputs and outputs of the electron transport chain

Process	Location	Inputs	Outputs
Electron transport chain	Inner membrane of mitochondria (cristae)	$6\,O_2$ 10 NADH $2\,FADH_2$ 32 or 34 ADP	$6\,H_2O$ $10\,NAD^+$ $2\,FAD^+$ 32 or 34 ATP

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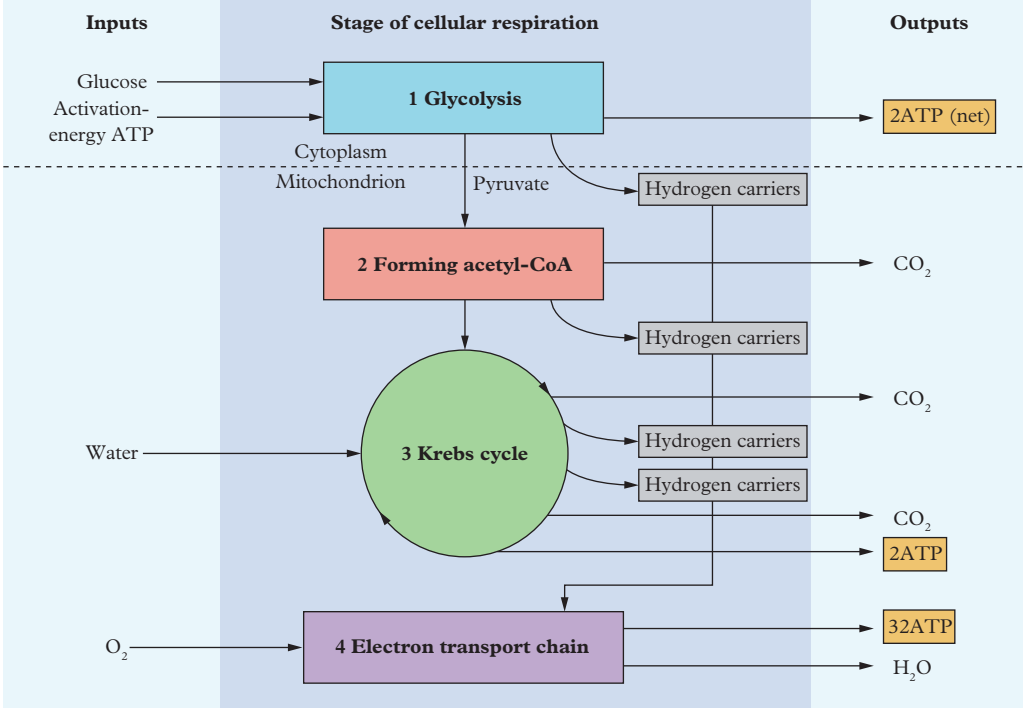


FIGURE 6 Simplified flow chart of aerobic cellular respiration

Skill drill

Risk assessments

Science inquiry skill: Considering safety and ethics (Lesson 1.5)

All laboratory experiments carry a level of risk. Each lab should have a folder of material safety data sheets (MSDS), which are often managed by a laboratory technician. Each MSDS contains information on a particular chemical, such as:

- chemical formula
- melting point
- boiling point
- alternative names
- handling and storage methods
- first aid support in case of exposure to the chemical
- disposal methods.

Before running any experiment, it is important to review the MSDS for the chemicals you will be using. You can then fill out a risk assessment.

Practise your skills

1 The reactants and products of cellular respiration are listed in the table. **Conduct** an online search of MSDS and **use** the information in them to complete the table. (4 marks)

	Oxygen (gas)	Glucose (solid)	Carbon dioxide (gas)	Water (liquid)
Danger to human health				
Flammability				
Boiling point				
Melting point				

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Check your learning 7.3

Check your learning 7.3: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Construct** a worded equation and a balanced chemical equation to describe aerobic cellular respiration. (2 marks)

2 **Summarise** aerobic cellular respiration by copying and completing the table. (4 marks)

3 **Explain** why the folded inner membrane (cristae) of a mitochondrion is important for aerobic cellular respiration. (1 mark)

Analytical processes

4 Use the information in Question 2 to **deduce** which part of aerobic cellular respiration would be most affected by a lack of oxygen. (1 mark)

	Glycolysis	Acetyl-CoA formation	Krebs cycle	Electron transport chain
Location				
Input(s)				
Output(s)				
Number of ATP formed				

Practical

Lesson 7.4
Investigating respiration

Learning intentions and success criteria

oxforddigital **This practical lesson is provided on Oxford Digital. It is also provided as part of a printable resource that can be used in class.**

Lesson 7.5
Anaerobic respiration

Learning intentions and success criteria

Key ideas

- → Anaerobic respiration occurs in the absence of oxygen.
- → There are two types of anaerobes: complete anaerobes, which respire using anaerobic respiration only, and partial anaerobes, which can switch between aerobic and anaerobic respiration depending on oxygen availability.
- → Anaerobic respiration in animals is facilitated through lactic acid fermentation.
- → Anaerobic respiration in plants, fungi and bacteria is facilitated through ethanol fermentation.

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Anaerobes

In all chemical pathways driven by enzymes, many factors can affect the rate of cellular respiration. The absence of oxygen is one such factor. Oxygen is required in the electron transport chain; if oxygen is limited, this series of reactions cannot occur. This means that in the absence of oxygen, a cell will not be able to produce as much ATP. In such conditions, organisms produce ATP through **anaerobic respiration**.

In all organisms that respire, glycolysis occurs outside the mitochondria to break down glucose molecules into pyruvate and produce a net of two ATP molecules. If oxygen is present, respiration proceeds with the electron transport chain to produce more ATP. However, oxygen is not always freely available. When this is the case, organisms generate additional ATP through anaerobic respiration. Some organisms can generate enough energy from anaerobic respiration alone. These organisms are known as anaerobes. In general, there are two types of anaerobes: **complete anaerobes** and **partial anaerobes**.

Complete anaerobes live permanently in oxygen-deficient conditions and therefore only carry out anaerobic respiration. Some of these anaerobes (including certain bacteria and some parasites) may be poisoned by even low concentrations of oxygen.

anaerobic respiration
cellular respiration in the absence of oxygen, resulting in a net gain of 2 ATP and lactic acid (in animals), or ethyl alcohol and carbon dioxide (in plants, fungi and bacteria)

complete anaerobe
an organism that does not need oxygen for cellular respiration

partial anaerobe
an organism that can undergo a period of anaerobic cellular respiration when oxygen is at low levels or in short supply

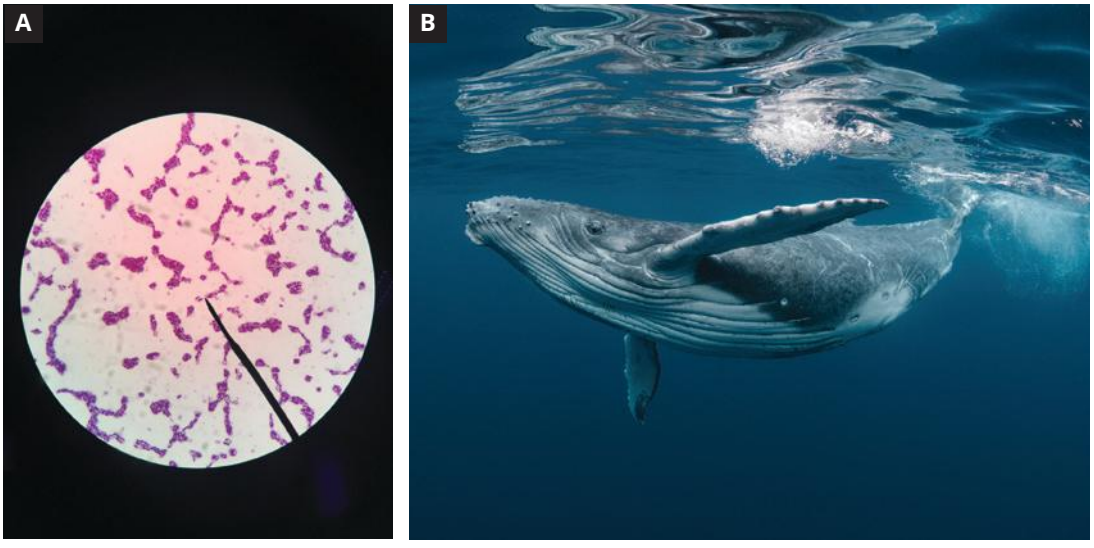


FIGURE 1 (A) The soil-dwelling bacterium *Clostridium botulinum* is a complete anaerobe. (B) Whales are partial anaerobes.

Partial anaerobes thrive in the presence of oxygen but will resort to anaerobic respiration if oxygen is absent or in short supply. Examples of partial anaerobes are worms living in the mud at the bottom of stagnant pools or oceans and diving mammals such as whales that can stay under water for long periods. The length of time an organism can survive without oxygen varies. Humans can survive without oxygen for only minutes, whereas some simpler organisms and plants can respire anaerobically for much longer periods.

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Fermentation

fermentation
the anaerobic breaking down of sugar by bacteria and yeasts to form ethyl alcohol, carbon dioxide and two ATP

lactic acid fermentation
a biological process in which glucose is converted into cellular energy, with lactate as a byproduct

ethanol fermentation
a biological process in which glucose is converted into cellular energy, with ethanol and carbon dioxide as byproducts

Fermentation is an anaerobic process in which glucose is broken down in the absence of oxygen. After pyruvate is formed by glycolysis, it enters one of two fermentation pathways, depending on the type of organism. In animals, **lactic acid fermentation** occurs, while in plants, fungi and bacteria, **ethanol fermentation** occurs.

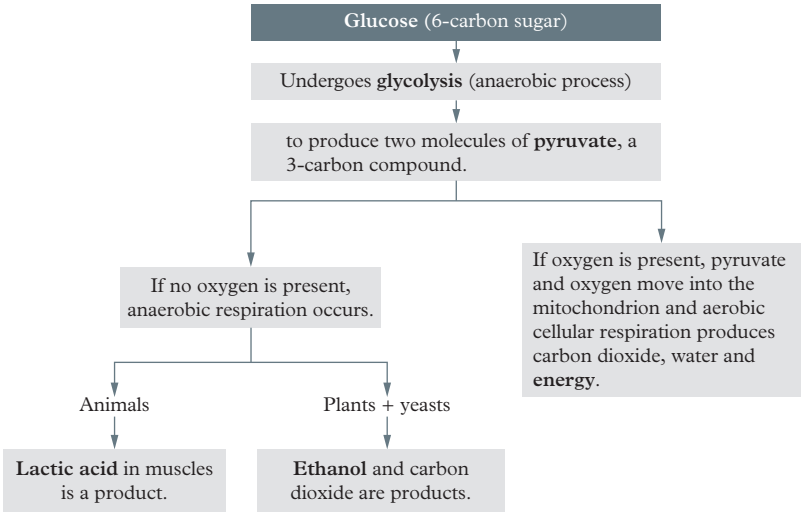


FIGURE 2 Summary of anaerobic and aerobic respiration

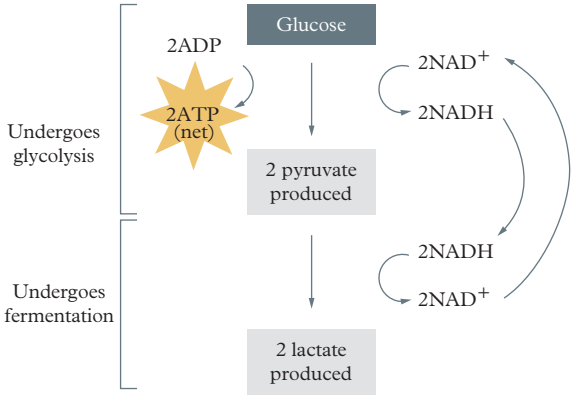


FIGURE 3 Summary of anaerobic respiration in animals

Fermentation in animals

Anaerobic respiration in animals occurs through lactic acid fermentation. This can be represented by the following equation:

$$\text{glucose } (C_6H_{12}O_6) \rightarrow 2\,\text{lactic acid} + 2\text{ATP}$$

As you learnt in Lesson 7.3, the glycolysis reaction produces two pyruvate molecules, two NADH and a net of two ATP molecules. When oxygen is not present, the two pyruvate molecules produced by glycolysis do not move into the mitochondria. Instead, they are converted into two lactate molecules in the cytoplasm of the cell.

When a person exercises vigorously, their body requires more energy than can be supplied aerobically. This is because their respiratory and circulatory systems cannot operate fast enough to sustain an adequate supply of oxygen. When oxygen levels in the blood begin to run low, oxygen is released from **myoglobin**, an oxygen-storing molecule in muscles. The levels of oxygen attached to the myoglobin are limited and eventually they become too low to sustain aerobic cellular respiration. The muscle fibres then provide energy anaerobically, producing lactate (which can become **lactic acid**). Like all acids, lactic acid is a metabolic poison and can cause damage if too much accumulates in the body. To prevent this, it is often rapidly transported to the liver, where it can be converted back into pyruvate and then glucose. Lactate that has been converted back to pyruvate can then re-enter the aerobic cellular respiration pathway if oxygen becomes available. The amount of oxygen needed to get rid of the lactic acid is called the **oxygen debt**. 'Stiffness' of muscles occurs when lactic acid accumulates and causes muscle fibre damage before it is broken down.

myoglobin
a protein in the muscles that can bind to oxygen

lactic acid
an organic acid with the formula $C_3H_6O_3$ formed by the breaking down of glucose during anaerobic cellular respiration in animals

oxygen debt
the amount of oxygen required to convert the lactic acid produced during anaerobic respiration to pyruvate

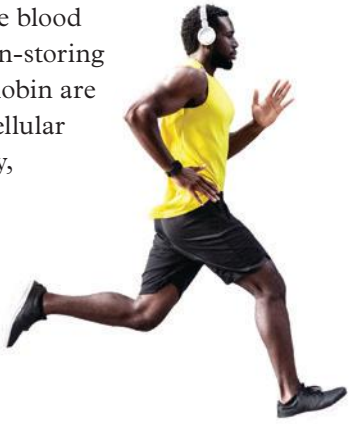


FIGURE 4 During vigorous exercise, lactic acid can build up in the muscles.

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Fermentation in plants, fungi and bacteria

Anaerobic respiration in plants, fungi and bacteria occurs through **ethanol** fermentation. This can be represented by the equation:

$$\text{glucose } (C_6H_{12}O_6) \rightarrow 2\,\text{ethanol } (C_2H_5OH) + 2CO_2 + 2ATP$$

This process begins after glycolysis has occurred in the cytoplasm of the plant, fungal or bacterial cell that lacks oxygen. When oxygen is not present, the two pyruvate molecules produced stay in the cytoplasm and are converted into two **acetaldehyde** molecules and two carbon dioxide molecules. The acetaldehyde molecules are then converted into two ethanol molecules via NADH.

Because ethanol cannot be broken down by plants, a build-up of too much ethanol can be toxic to the organism. This means that, while plants can resort to anaerobic respiration for a short period (e.g. germinating seeds or roots in waterlogged soil), they must revert to aerobic respiration before ethanol levels reach toxic levels and cause death. Natural fermentation of yeasts (single-celled fungi) and bacteria has been used by humans for thousands of years.

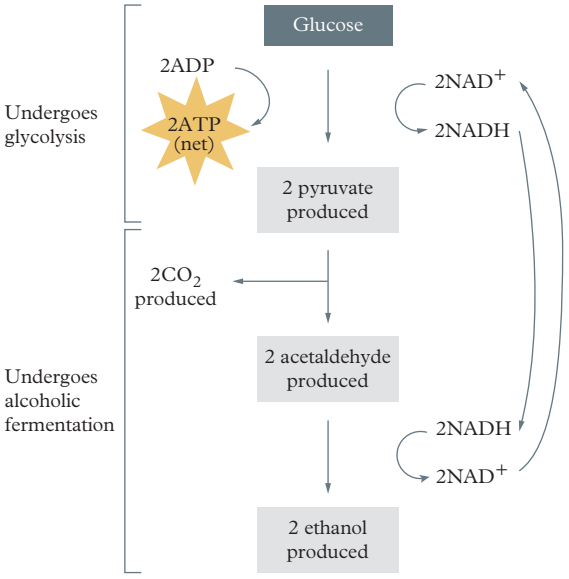


FIGURE 5 Summary of anaerobic respiration in plants, fungi and bacteria

Challenge

The things you do for love

During the breeding season of the "spring peeper" frog, *Hyla crucifer*, males let out a loud mating call to attract a female mate. Researchers studying male spring peepers have found that vocalising this call consumes large amounts of energy. When male spring peepers call, their concentration of lactic acid doubles compared to when they are in a resting state.



FIGURE 6 A spring peeper

1 **Explain** why a higher concentration of lactic acid builds up in spring peepers during a mating call. (1 mark)

Real-world biology

Mimicking respiration to develop batteries

Researchers have been developing biomolecules that enhance the performance and prolong the life of metal–air batteries, basing their design on cellular respiration. Metal–air batteries are still in development, but they have the potential to effectively replace petroleum-based fuel, instead using oxygen gas and metals such as sodium or zinc. Just as cells use oxygen to generate energy through metabolic pathways, metal–air batteries "breathe in" oxygen to generate electrochemical energy.

ethanol
an alcohol with the formula C_2H_5OH formed from the breaking down of glucose in plants, yeasts and bacteria

acetaldehyde
an organic compound that forms as an intermediate compound between pyruvate and ethanol during alcoholic fermentation

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Metal–air batteries are still currently limited in their rechargeability, due to inefficient reactions. To overcome this, scientists have created synthetic molecules that mimic catalysts and other chemicals in mitochondria, to enable the metal to react more efficiently with oxygen during discharge. The metal oxides produced during discharge then decompose during the charging phase, "exhaling" oxygen gas. These batteries use graphene sheets, which provide a large surface area, enabling reactions to occur faster, just like the cristae within mitochondria. This research holds promise for the development of high-capacity, reversible, efficient and eco-friendly batteries. Understanding the links between the structure and function of biomolecules involved in cellular respiration will enable scientists to manufacture advanced energy-storage devices for the future.



FIGURE 7 Metal–air batteries have the potential to replace petroleum-based fuels.

Apply your understanding

1 **Identify** two similarities between cellular respiration and metal–air batteries. (2 marks)
2 **Explain** the importance of developing synthetic molecules that mimic mitochondrial catalysts. (1 mark)
3 **Propose** a research question that could address an aspect of the following claim: "Understanding the links between the structure and function of biomolecules involved in cellular respiration will enable scientists to develop advanced energy-storage devices for our future." (1 mark)

Check your learning 7.5

Check your learning 7.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the site where anaerobic cellular respiration occurs. (1 mark)
2 **Identify** the type of fermentation in which the following substances are the end products.
   a carbon dioxide (1 mark)
   b ethanol (1 mark)
   c lactate (lactic acid) (1 mark)
3 Red blood cells do not contain mitochondria. **Explain** why these cells can only obtain energy through anaerobic respiration. (1 mark)
4 **Construct** a word equation for each of the following types of cellular respiration.
   a aerobic respiration (1 mark)
   b lactic acid fermentation (1 mark)
   c ethanol fermentation (1 mark)

Analytical processes

5 **Distinguish** between a complete anaerobe and a partial anaerobe. (1 mark)
6 **Compare** aerobic and anaerobic cellular respiration. (2 marks)

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MODULE 7

Lesson 7.6
Review: Cell function and energy

Summary

7.1
- Energy is the ability to do work or to cause a change.
- Metabolism is all the chemical reactions that take place inside a cell or an organism.
- There are two types of metabolic reactions. In anabolic reactions, new larger molecules are synthesised and energy is consumed. In catabolic reactions, large molecules are broken down, releasing energy.

7.2
- Adenosine triphosphate (ATP) is an important molecule in living organisms. In ATP, energy is stored in a readily available form and can be transported from one site to another.
- An ATP molecule consists of the nitrogen base adenine, a ribose sugar and three phosphate groups arranged in sequence.
- When ATP loses a phosphate, it becomes adenosine diphosphate (ADP). Energy is released by the breaking of a high-energy bond.

7.3
- Cellular respiration is a process in which glucose is changed into a usable form of energy. It can be summarised by the reaction: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36–38\,ATP$.
- Aerobic cellular respiration takes place in the presence of oxygen. It has three stages: glycolysis, the Krebs cycle and the electron transport chain.
- Glycolysis occurs in the cytoplasm. All other stages of aerobic respiration take place in the mitochondria.

7.4
- Practical: Investigating respiration

7.5
- Anaerobic respiration occurs in the absence of oxygen.
- There are two types of anaerobes: complete anaerobes, which respire using anaerobic respiration only, and partial anaerobes, which can switch between aerobic and anaerobic respiration depending on oxygen availability.
- Anaerobic respiration in animals is facilitated through lactic acid fermentation.
- Anaerobic respiration in plants, fungi and bacteria is facilitated through ethanol fermentation.

Review questions 7.6A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 A catabolic reaction is
- **A** the process of building up complex molecules from simpler ones.
- **B** the breaking down of complex molecules into simpler ones.
- **C** the synthesis of ATP from ADP and a phosphate group.
- **D** the sum of all chemical reactions in the body.

2 Protein synthesis is the process of creating a large protein chain from many smaller amino acids. This is an example of
- **A** a catabolic reaction.
- **B** phosphorylation.
- **C** cellular respiration.
- **B** an anabolic reaction.

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3 Adenosine triphosphate is a high-energy molecule composed of
- **A** an adenine molecule and two phosphate groups, joined by a high-energy bond.
- **B** a guanine molecule and three phosphate groups.
- **C** an adenine molecule and three phosphate groups, joined by low-energy bonds.
- **D** an adenine moclecule and three phosphate groups, joined by high-energy bonds.

4 The conversion of ADP into ATP is an example of
- **A** a catabolic, exergonic reaction.
- **B** a catabolic, endergonic reaction.
- **C** an anabolic, exergonic reaction.
- **D** an anabolic, endergonic reaction.

5 How many ATP molecules are produced during aerobic cellular respiration?
- **A** 2
- **B** 36 to 38
- **C** 4
- **D** 30 to 32

6 Which molecule is formed as the product of glycolysis?
- **A** pyruvate
- **B** acetyl-CoA
- **C** lactic acid
- **D** carbon dioxide

7 In which phase of aerobic cellular respiration is oxygen required?
- **A** the Krebs cycle
- **B** glycolysis
- **C** the electron transport chain
- **D** acetyl-CoA formation

8 Anaerobic cellular respiration is a chemical reaction that
- **A** occurs in the mitochondria of cells.
- **B** forms lactate (lactic acid) and a large amount of ATP in plants and yeasts.
- **C** occurs in the cytoplasm and releases small amounts of ATP.
- **D** forms ethyl alcohol and a small amount of ATP in animals.

9 Which phase of cellular respiration can occur in the absence of oxygen?
- **A** glycolysis
- **B** the Krebs cycle
- **C** the electron transport chain
- **D** all three of the above phases

10 Fermentation occurs in plant cells in a low-oxygen environment. The products of fermentation in plants are
- **A** lactate and 2 ATP.
- **B** lactate, CO_2 and 2 ATP.
- **C** ethyl alcohol and 2 ATP.
- **D** ethyl alcohol, CO_2 and 2 ATP.

Review questions 7.6B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

11 **Describe** the role of ATP in metabolism. (1 mark)

12 **Recall** the balanced chemical equation for aerobic cellular respiration. (1 mark)

13 **Summarise** the phases of aerobic respiration by creating a table that outlines the location, reactants, products and net ATP produced in glycolysis, the Krebs cycle and the electron transport chain. (3 marks)

14 **Explain** the different number of ATP molecules that may be formed through aerobic cellular respiration. (1 mark)

15 ADP and ATP are often referred to as a chemical energy shuttle. Using the last phase of aerobic respiration as an example, **explain** how this shuttle analogy is appropriate. (2 marks)

16 **Explain** the advantages to the cell of having a cyclical metabolic system, such as the Krebs cycle. (2 marks)

Analytical processes

17 **Distinguish** between catabolic and anabolic reactions and **explain** the relationship between these reactions within a cell. (2 marks)

18 Several jars of strawberry jam were made and stored in a cupboard. When opened several months later, they were frothy and smelled of alcohol.
- **a** **Deduce** what has happened. (2 marks)
- **b** **Explain** how this could have been prevented. (1 mark)

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Knowledge utilisation

19 The table shows the energy contribution of anaerobic and aerobic respiration in an athlete doing high-intensity exercise.

Duration of exercise (s)	% aerobic	% anaerobic
0–10	94	6
0–20	82	18
0–30	73	27
0–60	55	45

a **Use** the data in the table to **discuss** the importance of anaerobic respiration for a person doing high-intensity exercise. (3 marks)

b **Explain** the trend seen in the contribution of aerobic respiration as the duration of the high-intensity exercise increases. (1 mark)

20 When the body runs out of readily available glucose molecules, it will turn to stored glycogen, then fats and finally proteins as an energy source. Glycogen is the molecule formed when glucose is stored, particularly in the muscles and liver. Fat is stored in fat tissues and is used for energy storage and protection. Proteins are important for the growth and repair of muscles.

a **Determine** the stage of cellular respiration in which the products from the following molecules would enter:

i glycogen → glucose (1 mark)

ii fat → acetyl-CoA (1 mark)

iii protein → pyruvate. (1 mark)

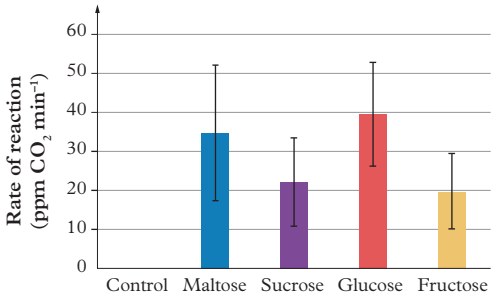
b **Discuss** the implications of this process for an individual whose energy demand is greater than their intake of simple carbohydrates such as glucose. (3 marks)

c A camel stores fat in its hump primarily as a water source rather than an energy source. **Evaluate** which metabolic process would make water available from fat. (3 marks)

Data drill

Investigating the fermentation rate of sugars

To investigate the rate of fermentation of sugars, activated *Saccharomyces cerevisiae* yeast was placed into a test tube containing 100 mL of a 10% sugar solution. Five solutions were tested: two monosaccharides (glucose and fructose), two disaccharides (sucrose and maltose) and one control, which did not contain sugar. The experiment was carried out in a hot bath set to 40°C. The amount of CO_2 produced per minute for total of 10 minutes was used as an indicator of reaction rate.



Apply understanding

1 **Determine** the mean rate of fermentation of glucose. (1 mark)

Analyse data

2 **Identify** which sugar is least efficiently fermented by *S. cerevisiae*. (1 mark)

Interpret evidence

3 **Deduce** why some sugars were more efficiently fermented by *S. cerevisiae* than others. (2 marks)

Module 7 checklist: Cell function and energy

Quizlet: Revise key terms online to test your understanding

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MODULE 8

Gas exchange in humans

Introduction

In multicellular organisms, nutrients are transported from the external environment to the organism's cells for metabolic processes. These metabolic processes produce waste, which must be transported to the external environment for removal. In larger organisms, the cells of the organism's internal organs are further from the surface of the body where this exchange occurs. Specialised transport systems have evolved to enable the movement of nutrients and waste into and out of large multicellular organisms. One such system is the respiratory system, which enables the exchange of gases such as oxygen and carbon dioxide.

Prior knowledge

Prior knowledge quiz

Check your understanding of concepts related to gas exchange in humans before you start.

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Subject matter

Science understanding

→ Explain how structural features of exchange surfaces in the respiratory and circulatory systems of mammals (alveoli and capillaries) allow for efficient gas exchange.

→ Analyse data to predict the direction that materials will be exchanged between
- alveoli and capillaries
- capillaries and muscle tissue.

Science inquiry

→ Investigate
- adaptations that allow for efficient nutrient and/or gas exchange in plants or animals.

Science inquiry skills

→ Design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data required to obtain valid and reliable evidence.

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Lesson 8.1
Gas exchange in humans

Key ideas

- → The main organs of the mammalian gas exchange system are the nose, mouth, pharynx, trachea, bronchi and lungs.
- → Inhalation and exhalation of air into and out of the lungs is controlled by movement of the diaphragm.
- → Alveoli allow the passage of gases between the bloodstream and inhaled air because alveoli are thin and moist, and have a large surface area.

The respiratory system

Learning intentions and success criteria

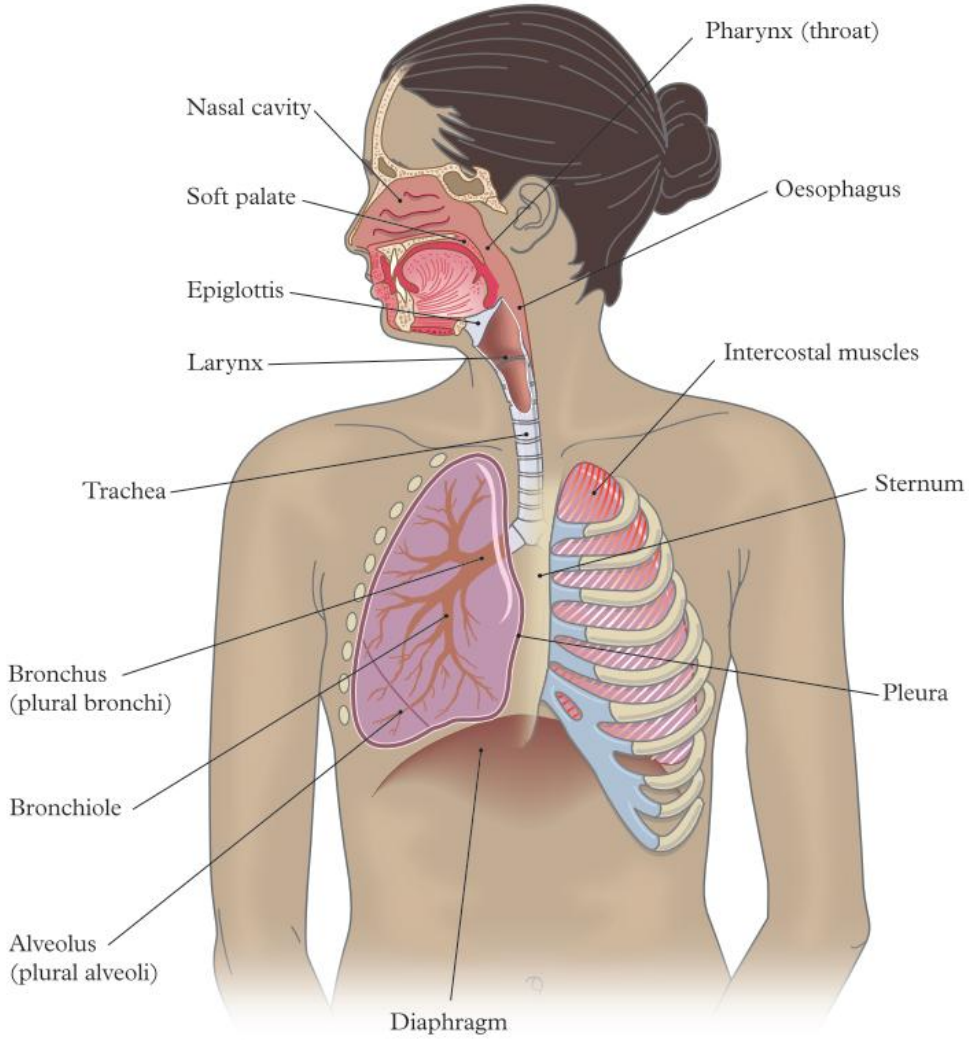


FIGURE 1 Structures of the human respiratory system

respiratory system
the body system that delivers oxygen to the body and expels gaseous wastes such as carbon dioxide

lungs
a pair of organs in the body that enable gas exchange, to supply the body with oxygen and remove carbon dioxide

Most mammals live on land, where gas is exchanged through the air. To protect their delicate gas exchange surfaces from drying out, mammals have developed an internal **respiratory system** containing **lungs**. Aquatic mammals also use lungs for gas exchange but have

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adaptations to protect them from drowning. In mammalian respiratory systems, the lungs are located within the chest cavity and are connected to the air in the external environment by specialised tube-like structures. The location of the heart directly between the lungs allows these organs to work together to exchange gas efficiently – the heart pumps deoxygenated blood (carrying carbon dioxide waste) to the lungs, and also pumps freshly oxygenated blood to the body. The thoracic cavity, which contains the lungs and heart, is separated from the abdomen by a sheet-like muscle called the **diaphragm**.

The primary functions of the respiratory system are to:

- transport oxygen from the lungs to the cells of the body for cellular respiration
- transport waste products of cellular respiration (e.g. carbon dioxide) from the cells to the lungs so they can be removed through exhalation.

When we breathe in, the air moves from our mouth and nose through the **trachea** into the two **bronchi** of the lungs. The bronchi branch into smaller **bronchioles**, which continue to branch into increasingly smaller tubes until the air reaches the **alveoli**, the site of gas exchange with the bloodstream.

Alveoli have features that allow rapid exchange of large volumes of gas, to maintain homeostasis in the body.

- The lining of alveoli is only one cell thick, so diffusion of oxygen into the bloodstream and carbon dioxide out of the bloodstream can occur across this membrane.
- The alveoli secrete a moist substance that allows gases to dissolve and move between capillaries and the air in the alveoli.
- The alveoli of human lungs have an extremely large surface area, which enables more gas to diffuse simultaneously. The volume of the lungs of an adult human is approximately four litres, and the surface area is around 100 square metres, about the size of two classrooms or a small Australian house. In mammals, the very high surface area-to-volume ratio of the lungs allows enough gas exchange to occur to support the growth of a large body.

diaphragm
a sheet-like structure of muscle and connective tissue located between the lungs and the abdomen

trachea
a tube that moves air from the mouth and nose to the lungs; also known as the windpipe

bronchi
the branches of the trachea that direct air to each lung; singular "bronchus"

bronchioles
the branches of tube between the bronchi and alveoli in the lungs

alveoli
small, thin-walled air sacs in the lungs that allow inhaled oxygen to enter the bloodstream and carbon dioxide to leave the bloodstream; singular "alveolus"

inhalation
the movement of air into the lungs, caused by contraction of the diaphragm

Ventilation

An **inhalation** of air is caused by the contraction and flattening of the muscle of the diaphragm, which increases the volume of the ribcage. The increase in volume reduces the pressure within the lungs compared to the external air pressure, which causes air to flow into the lungs. Air in the inhaled breath brings oxygen to the alveoli for diffusion into the bloodstream.

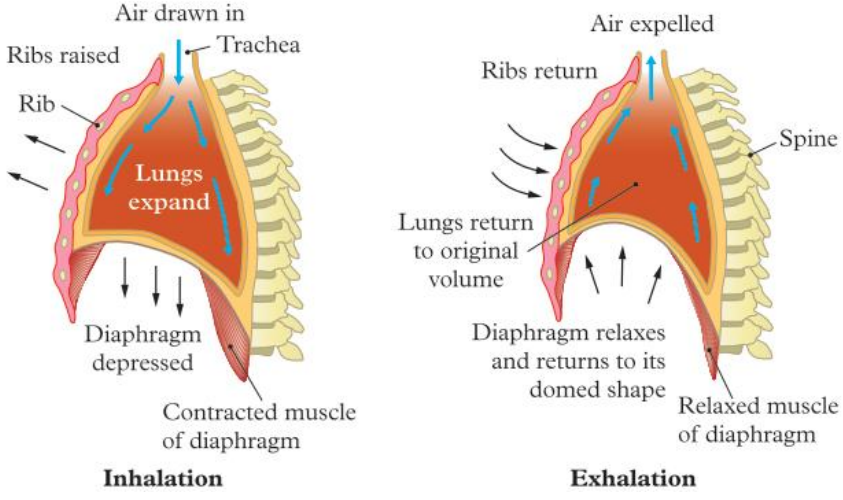


FIGURE 2 Ventilation of the lungs is controlled by contraction and relaxation of the diaphragm, which changes lung volume and pressure.

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exhalation
the movement of air out of the lungs, caused by relaxation of the diaphragm

An **exhalation** occurs when the muscles of the diaphragm relax, causing it to return to its resting dome-shaped position, which reduces the volume of the ribcage, forcing air out of the lungs. Carbon dioxide in the blood diffuses from the capillaries surrounding the alveoli into the lungs and is removed from the body with the exhaled air.

Real-world biology

Free-diving

Most people can hold their breath for around 15 seconds before feeling a strong urge to take a breath. This urge is the brain's response to rising carbon dioxide levels in the bloodstream, which, if allowed to build up, would cause the blood to become dangerously acidic. Interestingly, after 15 seconds, there is still sufficient oxygen in the bloodstream to supply the cells of the body, and carbon dioxide concentrations have not yet reached a dangerous level. To hold their breath for long periods, free-divers practise ignoring the urge to take a breath. They spend many months increasing their tolerance of the discomfort of this urge, until they are able to hold their breath for up to several minutes. The current record for the longest time under water after taking only one breath is 24 minutes and 37 seconds. Extended breath holding and free-diving are extreme sports, with participants risking side-effects such as collapsed lungs and blackouts under water, which can cause death by drowning.



FIGURE 3 A free-diver returning to the water's surface after holding their breath for several minutes

Apply your understanding

1 **Describe** the process that causes a decrease in oxygen and an increase in carbon dioxide concentrations in the bloodstream of a free-diver. (1 mark)
2 **Predict** the changes in gas concentration gradients between the alveoli and the bloodstream in the lungs during a free-dive. (2 marks)

Check your learning 8.1

Check your learning 8.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the two main functions of the respiratory system. (2 marks)
2 **Describe** three characteristics of the alveoli that allow efficient gas exchange. (3 marks)
3 **Explain** how the diaphragm controls inhalation and exhalation of air by the lungs. (4 marks)
4 **Explain** how the position of the heart between the lungs improves the efficiency of gas exchange. (2 marks)

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Lesson 8.2
Carriage of respiratory gases in the blood

Key ideas

- → Oxygen is transported from the lungs to the body's cells for aerobic respiration, primarily by binding to haemoglobin in red blood cells.
- → The concentration gradient of oxygen between oxygenated blood and respiring cells that are using oxygen causes the oxygen to be released from the haemoglobin and used by the cell.
- → Aerobic and anaerobic respiration in cells produce carbon dioxide as waste. The carbon dioxide is transported to the lungs in the bloodstream, dissolved in water and in plasma, and bound to haemoglobin.
- → The concentration gradient of carbon dioxide between deoxygenated blood and the alveoli in the lungs causes the carbon dioxide to diffuse across the thin membrane for removal from the body.

Transport of oxygen in the bloodstream

Cells require oxygen and glucose to produce energy in the form of ATP through aerobic respiration. When oxygen is limited, cells revert to anaerobic respiration, which is a much less efficient means of producing ATP.

Oxygen diffuses from the alveoli into capillaries, where it binds with **haemoglobin** proteins in red blood cells. Haemoglobin has a high **affinity** for oxygen, binding more readily to oxygen in higher concentrations and then releasing the bond when surrounding oxygen concentrations are low. This allows haemoglobin to transport oxygen from the lungs where oxygen concentration is high, to respiring cells where oxygen concentrations are low. Haemoglobin in red blood cells effectively "picks up" oxygen in the lungs, where it is plentiful, and "drops it off" to cells that are rapidly using oxygen for aerobic respiration.

Transport of carbon dioxide in the bloodstream

Carbon dioxide is a waste product of aerobic and anaerobic respiration in cells. If carbon dioxide builds up in the body, it creates an acidic environment that disrupts **homeostasis** and normal metabolic function. Therefore, it is essential that carbon dioxide waste is efficiently transported to the lungs and removed via exhalation. Carbon dioxide is transported in the bloodstream primarily dissolved in water as **carbonic acid**, with small amounts transported in plasma and bound to haemoglobin. When deoxygenated blood with high levels of carbon dioxide reaches the lungs, the carbon dioxide diffuses from the bloodstream into the alveoli, and haemoglobin becomes available for binding to oxygen. Increases in carbon dioxide concentration in the blood are detected by the **medulla oblongata** in the brain, which then triggers the diaphragm to contract, causing an inhalation so that gas exchange can continue and maintain homeostasis.

Learning intentions and success criteria

haemoglobin
an iron-containing protein in red blood cells; binds to oxygen for transport around the body

affinity
the extent to which a substance tends to bind or attach to another

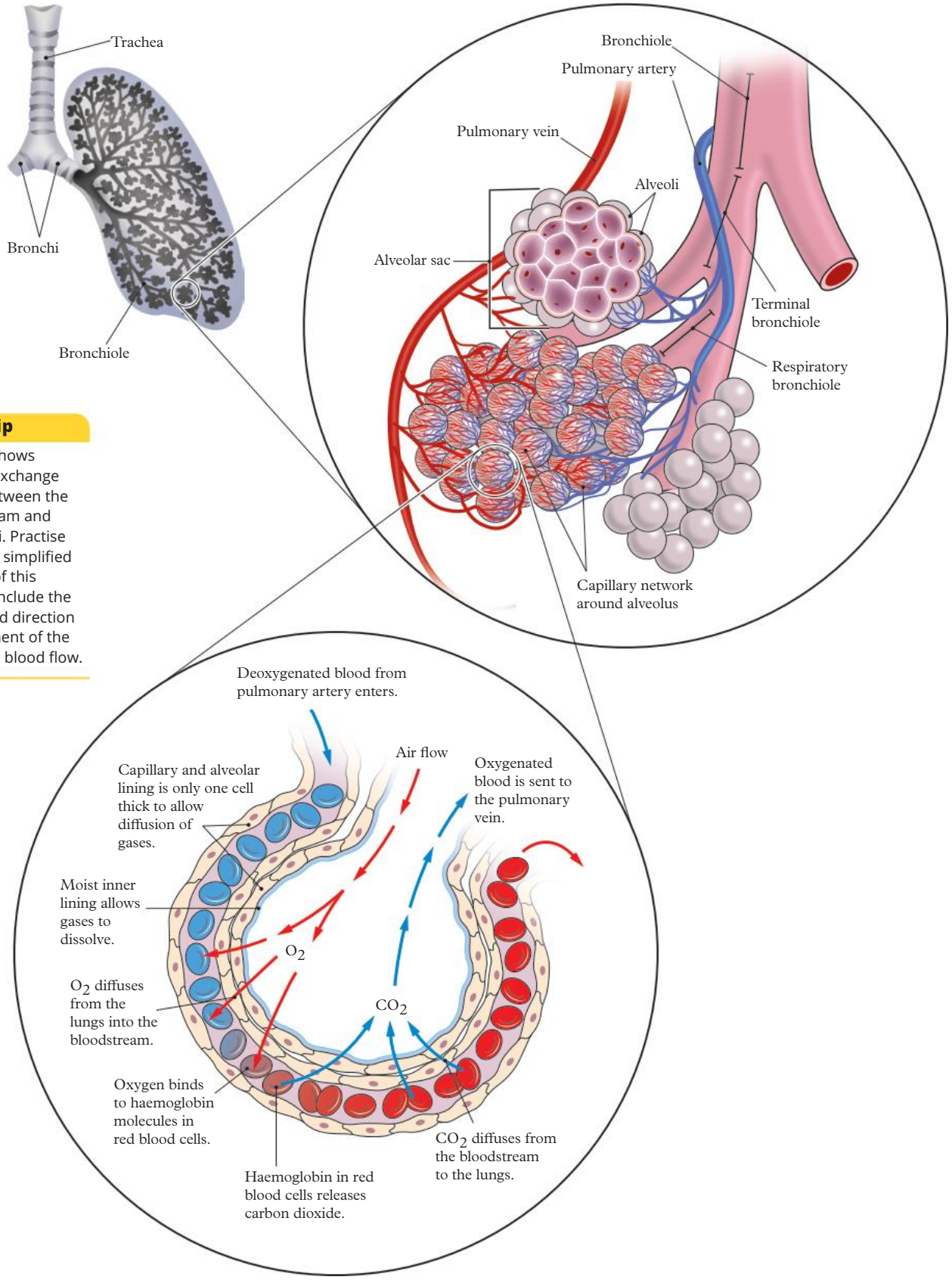
homeostasis
the process by which living organisms maintain an internally stable environment

carbonic acid
a type of acid produced when carbon dioxide is dissolved in a solution; lowers the pH of the blood

medulla oblongata
the part of the brain that coordinates aspects of respiration

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Study tip

Figure 1 shows how gas exchange occurs between the bloodstream and the alveoli. Practise drawing a simplified diagram of this process. Include the names and direction of movement of the gases and blood flow.

FIGURE 1 Gas exchange occurs in the alveoli, between air in the lungs and the bloodstream.

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Skill drill

Identifying extraneous variables

Science inquiry skill: Planning investigations (Lesson 1.4)

A medical scientist is measuring the lung capacity of several patients from a local doctor's clinic. Some are heavy smokers, and some have never smoked. Two measurements are taken: the forced vital capacity (FVC) and the forced expiratory volume over 1 second (FEV1).

- FVC is the amount of air that can be forcibly exhaled from the lungs after a deep breath. This is close to the capacity of the lungs.
- FEV1 is the volume of air that can be forcibly blown out in the first 1 second, after a deep breath. The results are shown in the table.

Patient	FVC (L)	FEV1 (L)	Comments
#1 non-smoker	5.25	4.50	Male, 36 yo
#2 smoker	3.25	2.76	Female, 20 yo
#3 smoker	2.51	2.10	Female, 65 yo
#4 smoker	4.00	3.28	Male, 61 yo
#5 non-smoker	5.50	4.53	Male, 24 yo
#6 non-smoker	5.20	4.24	Male, 41 yo
#7 non-smoker	3.75	3.25	Female, 19 yo
#8 smoker	3.50	2.95	Female, 35 yo

Practise your skills

1 The medical scientist is surprised to find that some non-smoking patients' FVC and FEV1 measurements are lower than those of the smoking patients. **Describe** two extraneous variables that are likely to have affected the validity of the results in this study. (2 marks)

2 Based on your answer to Question 1, **suggest** one thing the doctor should specify to improve the experimental design when recruiting patients to join the study. (1 mark)

3 **Suggest** what steps could be taken during the analysis of the data to clarify any trends for smokers/non-smokers. (2 marks)

Real-world biology

Foetal haemoglobin

Babies use their lungs for the first time after taking their first breath. Before this, all the oxygen required by a baby's cells for rapid growth and development must come from their mother. The placenta is the structure where the blood vessels of the mother and the developing foetus meet and exchange nutrients and gases, including oxygen and carbon dioxide, by diffusion. Foetal red blood cells have a special type of haemoglobin, called foetal haemoglobin, that is only produced during development in utero. Foetal haemoglobin has an even higher affinity for oxygen than the haemoglobin of the mother, allowing it to "pull" oxygen away from the mother's bloodstream to that of the foetus.

Apply your understanding

1 Muscle cells also contain slightly different haemoglobin, called myoglobin. Myoglobin has a higher affinity for oxygen. Using your knowledge of the function of foetal haemoglobin, **infer** why muscle cells produce this type of haemoglobin. (1 mark)

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2 **Predict** the changes that would occur in the body of a pregnant female to support the increased demand for production of oxygen and elimination of carbon dioxide waste during pregnancy. (2 marks)



FIGURE 2 During pregnancy, the haemoglobin of the foetus has a higher affinity for oxygen than the haemoglobin of the mother.

Challenge

Ain't no mountain high enough

Humans are adapted to survive above sea level, where oxygen in the air is just over 20%. However, in high-altitude areas like the Andes Mountains in South America or the Plateau of Tibet in Asia, the oxygen concentration in the air is as low as 13%. Mountaineers from lowland areas venturing into these terrains often experience the effects of hypoxia (oxygen deprivation). Amazingly, Andean and Tibetan highlanders have adapted to live and thrive in these conditions. For example, Andean highlanders have, on average, much higher concentrations of haemoglobin in their blood. Additionally, Tibetan highlanders and some Andeans possess the *EPAS1* gene, which improves the efficiency of haemoglobin use in the body.



FIGURE 3 Cerro Chaltén, a mountain in Patagonia, in the Andes mountain range

1 **Use** your understanding of the respiratory system to **explain** how adaptations in Andean and Tibetan highlanders have enabled them to avoid hypoxia in high-altitude conditions. (2 marks)

Check your learning 8.2

Check your learning 8.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** how each of the following is carried in red blood cells:
   - **a** oxygen (2 marks)
   - **b** carbon dioxide. (2 marks)

2 **Identify** the factors contributing to the following:
   - **a** loss of carbon dioxide and uptake of oxygen at the capillary beds of the lungs (2 marks)
   - **b** release of oxygen from haemoglobin at the tissues. (2 marks)

3 **Explain** why it is important for oxygen to be transported around the body. (4 marks)

4 **Explain** why the average person cannot hold their breath under water for more than 2 minutes. (3 marks)

Knowledge utilisation

5 **Discuss** why it is essential that foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin. (3 marks)

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MODULE 8

Lesson 8.3
Review: Gas exchange in humans

Summary

8.1
- The main organs of the mammalian gas exchange system are the nose, mouth, pharynx, trachea, bronchi and lungs.
- Inhalation and exhalation of air into and out of the lungs is controlled by movement of the diaphragm.
- Alveoli allow passage of gases between the bloodstream and inhaled air because alveoli are thin and moist, and have a large surface area.

8.2
- Oxygen is transported from the lungs to the body's cells for aerobic respiration primarily by binding to haemoglobin in red blood cells.
- The concentration gradient of oxygen between oxygenated blood and respiring cells that are using oxygen causes the oxygen to be released from the haemoglobin and used by the cell.
- Aerobic and anaerobic respiration in cells produces carbon dioxide as waste. The carbon dioxide is transported to the lungs in the bloodstream dissolved in water and in plasma, and bound to haemoglobin.
- The concentration gradient of carbon dioxide between deoxygenated blood and the alveoli in the lungs causes the carbon dioxide to diffuse across the thin membrane for removal from the body.

Review questions 8.3A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Alveoli exchange gas efficiently because they have
- **A** a large surface area, thin walls and high oxygen levels.
- **B** a small surface area, thin walls and high oxygen levels.
- **C** a small surface area, moist lining and high oxygen levels.
- **D** a large surface area, thin walls and a moist lining.

2 The structure responsible for changing the pressure in the lungs, allowing ventilation, is the
- **A** diaphragm.
- **B** lungs.
- **C** trachea.
- **D** alveoli.

3 The structure that allows passage of inhaled air into the lungs is the
- **A** diaphragm.
- **B** bronchi.
- **C** trachea.
- **D** alveoli.

4 Anaerobic respiration
- **A** is more efficient than aerobic respiration.
- **B** is less efficient than aerobic respiration.
- **C** occurs only in plants.
- **D** produces oxygen as a waste product.

5 Select the correct pathway of air from the external environment to the lungs.
- **A** mouth/nose → pharynx → larynx → trachea → bronchioles → bronchus → alveoli
- **B** mouth/nose → larynx → pharynx → trachea → bronchus → bronchioles → alveoli
- **C** mouth/nose → pharynx → larynx → trachea → bronchus → bronchioles → alveoli
- **D** mouth/nose → trachea → pharynx → larynx → bronchus → bronchioles → alveoli

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Review questions 8.3B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

6 **Explain** how oxygen is transported from the alveoli to respiring cells. (4 marks)

7 **Explain** how carbon dioxide is transported from respiring cells to the alveoli. (4 marks)

Analytical processes

8 Babies growing in the womb have a different type of haemoglobin, called foetal hemoglobin, which has a higher affinity for oxygen than the haemoglobin of the mother. **Infer** why babies might need this different type of haemoglobin before they are born. (3 marks)

Data drill

Predicting direction and speed of gas exchange

Tables 1 and 2 show concentrations of gases in different locations within the body, with partial pressure (mmHg) as the unit of measurement. Using this information, it is possible to determine the concentration gradient of each gas and therefore predict its direction of movement. Remember: movement of gas occurs from an area of high concentration to an area of low concentration until equilibrium is reached.

Apply understanding

1 **Identify** whether the information in Table 2 represents gas exchange at an aerobically respiring cell or in the lungs. **Use** the data to support your response. (2 marks)

TABLE 1 Gas pressures in respiring cells and capillaries

Gas	Partial pressure (mmHg)		Direction of movement
	Respiring cell	Capillary	
Oxygen	32	67	Question 3
Carbon dioxide	116	22	Question 3

Analyse data

2 **Identify** the relative rates of oxygen and carbon dioxide diffusion in Table 1. (2 marks)

Interpret evidence

3 **Use** the data in Table 1 to **predict** the direction of movement of oxygen and carbon dioxide between the respiring cell and the capillary. (1 mark)

4 **Use** your knowledge of gas exchange within the body to **infer** which parts of the body are represented by Site A and Site B in Table 2. (2 marks)

TABLE 2 Gas pressures at Sites A and B

Gas	Partial pressure (mmHg)		Direction of movement
	Site A	Site B	
Oxygen	100	43	Site A ← Site B
Carbon dioxide	37	46	Site B ← Site A

Module 8 checklist: Gas exchange in humans

Quizlet: Revise key terms online to test your understanding

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MODULE 9

Plant physiology

Introduction

Plants are the most abundant life forms on Earth, making up 80% of all biomass. All other multicellular organisms rely on plants directly or indirectly as a source of energy and oxygen. Through photosynthesis, plants use carbon dioxide and water to produce energy stored in the bonds of glucose, and oxygen gas as waste. Because plants are largely immobile, they must adapt to the conditions of their environment to obtain sufficient water and nutrients to photosynthesise, grow and reproduce. The transport systems of plants include xylem to transport water from roots to leaves, and phloem to transport organic molecules such as glucose around the plant. Plants have specialised leaf structures, called stomata, that allow exchange of gases and movement of water into the surrounding air.

Prior knowledge

Prior knowledge quiz

Check your understanding of concepts related to plant physiology before you start.

Subject matter

Science understanding

- Describe the process of photosynthesis, identifying the location in the cell and net inputs and outputs of
  - light-dependent reactions
  - light-independent reactions
  - the overall reaction ($6CO_2 + 6H_2O$ + light energy $\rightarrow C_6H_{12}O_6 + 6O_2$).
- Compare the structure and function of xylem and phloem tissues.
- Explain how stomata and guard cells facilitate gas exchange in plants.
- Interpret and explain data from an experiment investigating the effect of light intensity, temperature, wind or humidity on the rate of transpiration.

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Science inquiry

→ Investigate
- factors affecting the rate of transpiration in different plants.
- adaptations that allow for efficient nutrient and/or gas exchange in plants or animals.

Science inquiry skills

→ Select and construct appropriate representations to present data and communicate findings.

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Practicals

oxforddigital **These lessons are available on Oxford Digital.**

Lesson 9.3 Stomatal function
Lesson 9.5 The passage of water through flowering plants
Lesson 9.6 Factors affecting the rate of transpiration

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Lesson 9.1
Photosynthesis

Key ideas

- → Photosynthesis can be simply expressed in a chemical equation, with carbon dioxide and water as reactants and glucose and oxygen as products.
- → Chloroplasts are organelles in which photosynthesis occurs, allowing energy from sunlight to be stored in the bonds of glucose.
- → Photosynthesis has two stages: a light-dependent stage and a light-independent stage.
- → The rate of photosynthesis is affected by the availability of reactants and the intensity of sunlight.

Learning intentions and success criteria

photosynthesis
the series of reactions that converts light energy into chemical energy in the form of glucose; summarised as $6CO_2 + 6H_2O +$ light energy $\rightarrow C_6H_{12}O_6 + 6O_2$

producer
an organism that produces its own energy by absorbing light energy and converting it into a usable form; also known as an autotroph

consumer
an organism that must consume other living organisms for energy; also known as a heterotroph

decomposer
an organism that breaks down dead and decaying matter for energy

stroma
the colourless fluid contained within a chloroplast that surrounds the grana and contains enzymes used in the light-dependent reaction of photosynthesis

grana
a stack of thylakoids found within chloroplasts; surrounded by the stroma; a single stack is a "granum"

thylakoid
membrane-bound, disc-shaped structures found in chloroplasts; the site of the light-dependent reactions of photosynthesis

The process of photosynthesis

Photosynthesis is a series of enzyme-mediated chemical reactions that plants, algae and some bacteria use to produce glucose. Photosynthetic organisms are autotrophs because they make their own food, whereas heterotrophs obtain their food by consuming other organisms. Photosynthesis occurs in specialised organelles called chloroplasts, which use carbon dioxide and water to produce glucose for respiration, and release oxygen gas as a waste product. Photosynthesis occurs in a series of separate reactions, but the overall reaction showing reactants and products can be given as a balanced chemical equation:

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

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

Through photosynthesis, the inorganic compounds of carbon dioxide and water are used to make glucose, the organic molecule required for cellular respiration.

During photosynthesis, light energy is converted to chemical energy (glucose molecules) by **producers**. Other metabolic processes convert these simple carbohydrates to all the other organic compounds required by living organisms. These organic compounds are then passed on to **consumers** and **decomposers** through the food web.



FIGURE 1 Plants and other autotrophs convert light energy into chemical energy stored in the bonds of glucose, through the process of photosynthesis.

Photosynthetic cell structures and molecules

Chloroplasts are membrane-bound organelles in photosynthetic cells. Within each chloroplast, a liquid solution called the **stroma** encloses stacks of flattened, coin-shaped discs called **grana** (singular "granum"). An individual disc is called a **thylakoid**. Chloroplasts also

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chlorophyll
a pigment molecule that allows plants to convert radiation in sunlight to glucose as an energy source

contain **chlorophyll**, a pigment necessary for the energy transformations of photosynthesis, although it is not used up in the process. Organisms that have chlorophyll in their cells include green plants, algae, cyanobacteria and some bacteria. In plants, most photosynthesis occurs in leaf cells that are exposed to light. Depending on the environment in which the plant lives, different adaptations of leaf structure and their arrangement on stems have evolved to maximise their ability to "capture" light.

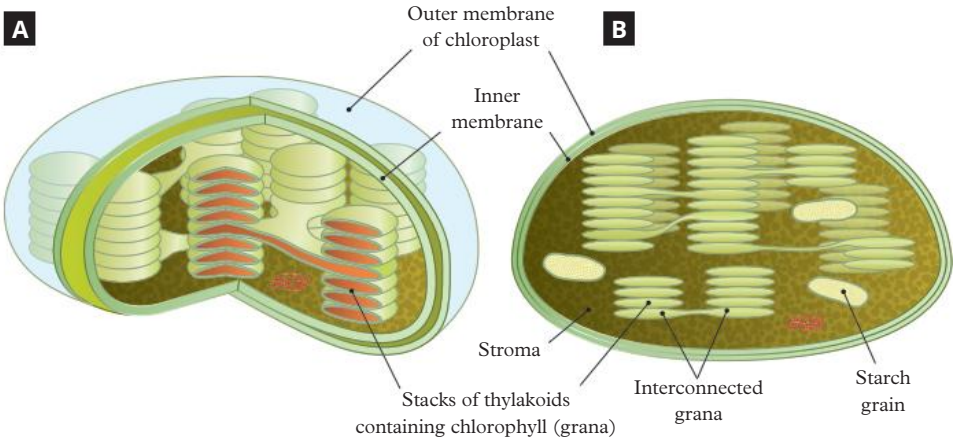


FIGURE 2 The structure of a chloroplast: (A) cut-away view (B) transverse section

photosystem I
a structure made of proteins containing chlorophyll; located in the thylakoid membrane in chloroplasts; facilitates production of NADPH from NADP+

photosystem II
a structure made of proteins containing chlorophyll; located in the thylakoid membrane in chloroplasts; facilitates photolysis of water to produce oxygen gas and hydrogen ions

Certain sites within the chloroplast also contain integral membrane protein complexes, such as **photosystem I** and **photosystem II**. These protein complexes play specific roles in facilitating parts of the overall photosynthesis reaction. Photosystem I is located on the outer surface of the thylakoid membrane, and photosystem II on the inner surface of the membrane. Photosystems I and II contain chlorophyll molecules, which allow energy from sunlight to be accessed and used in reactions. The grana are connected by structures called stromal lamellae, which ensure that the stacks of thylakoids do not clump together, maximising the rate of photosynthesis. Glucose produced by photosynthesis is stored as starch in the stroma of the chloroplasts.

Stages of photosynthesis

light-dependent reactions
the first stage of photosynthesis, in which light energy is converted into ATP and NADPH

light-independent reactions
the second stage of photosynthesis, in which ATP and NADPH are used to convert CO_2 into glucose

Because the reactions of photosynthesis are enzyme-mediated, the rate of these reactions is influenced by temperature. Carbon dioxide is readily available in most terrestrial and aquatic environments on Earth, and so carbon dioxide concentration does not usually limit the rate of photosynthesis. The most important factor affecting the rate of photosynthesis in most environments is light intensity and availability. Photosynthesis consists of two stages: the **light-dependent reactions** and the **light-independent reactions**.

Light-dependent reactions

photon
a packet of energy in sunlight that can excite electrons

photolysis
the process of light energy breaking the bonds between atoms in molecules

The light-dependent reactions are the first stage of photosynthesis. They can only occur in the presence of sunlight, and they take place in the thylakoid. They are triggered when ultraviolet radiation in the form of sunlight penetrates the plant's cells and interacts with chlorophyll-containing proteins in the thylakoid membrane. This sets off a series of reactions, which can be summarised as follows:

1 **Photons** from sunlight excite electrons in the chlorophyll molecules of photosystem II.
2 These excited electrons have enough energy to split water molecules into molecules of oxygen (O_2) and hydrogen ions (H^+), in a process called **photolysis**.
3 The oxygen molecules produced are either used in aerobic respiration or released through stomata into the environment as waste.

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4 Photons from sunlight excite electrons in the chlorophyll molecules of photosystem I.
5 Some of these excited electrons allow $NADP^+$ to bond with hydrogen ions to form NADPH for use in the light-independent reaction, while some move into the thylakoid membrane.
6 Hydrogen ions that move into the thylakoid membrane build up to form a concentration gradient, which allows ATP to be produced from ADP.

TABLE 1 Summary of light-dependent reactions

Stage of photosynthesis	Site	Inputs	Outputs
Light-dependent reactions	Thylakoid membranes of chloroplast	UV light $12H_2O$ 18ADP $24NADP^+$	$6O_2$ 18ATP 24NADPH

Light-independent reactions

After the light-dependent reactions have occurred, their products, ATP and NADPH, are used as inputs to trigger a series of light-independent reactions. Light-independent reactions enable the breaking down of carbon dioxide molecules, which are then used to construct glucose molecules. These reactions, also known as the Calvin cycle, occur in chloroplasts in the stroma surrounding the thylakoids. They do not require light as an input. They can be summarised as follows:

1 ATP and NADPH molecules produced by the light-dependent reaction are released from the thylakoid membrane into the stroma of the chloroplast.
2 Enzymes floating in the stroma, such as **RuBisCO**, break carbon dioxide into carbon and oxygen and reassemble the carbon atoms in several stages to produce glucose.
3 The enzymes that construct glucose from carbon, hydrogen and oxygen use energy from ATP and NADPH, allowing them to occur without energy from sunlight.

RuBisCO
an essential enzyme in photosynthesis; catalyses carbon fixation and oxygenation

TABLE 2 Summary of light-independent reactions

Stage of photosynthesis	Site	Inputs	Outputs
Light-independent reactions	Stroma of chloroplast	$6CO_2$ >18ATP 24NADPH	Glucose ($C_6H_{12}O_6$) $6O_2$ $24NADP^+$ 18ADP

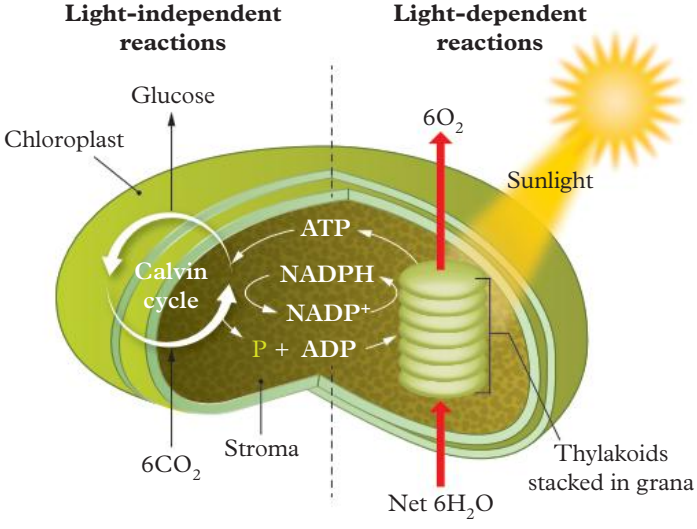


FIGURE 3 Summary of reactions in photosynthesis

Study tip

The reactants in the chemical reaction of photosynthesis are carbon dioxide and water; the products are glucose and oxygen. Chlorophyll and sunlight are often represented in the word equation; however, they are not reactants or products. Sunlight is the source of energy for the reaction, and chlorophylls are pigments that facilitate the reaction but are not used up in the process.

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Factors affecting the rate of photosynthesis

abiotic factors
non-living environmental factors, such as sunlight, temperature and water availability

Photosynthesis requires a variety of reactants and **abiotic factors**. Reactants, carbon dioxide gas and liquid water, must be present. The carbon dioxide concentration of Earth's atmosphere is more than sufficient for photosynthesis, and therefore it is not considered a factor that affects the rate of photosynthesis. Meanwhile, the availability of water varies over time and in different areas on Earth.

Water availability

Photosynthetic organisms that live in dry environments are adapted to low water availability and have specialised structures that allow them to produce glucose through photosynthesis with limited water. Species that are not adapted to dry conditions struggle to produce sufficient glucose for their metabolic needs during times of drought, resulting in slow growth, reduced reproduction, or death of the organism.

xylem
vessels that transport water and dissolved minerals from the roots of a plant to the leaves, allowing the passage of water upwards through the plant in the transpiration stream

transpiration stream
the stream of water that enters the plant from the soil into the roots and travels through the xylem before evaporating through the stomata

stomata
openings created by guard cells in the leaf of a plant; allow gas exchange and water evaporation from the transpiration stream; singular "stoma"

Temperature

The temperature of air, water and soil influences the rate of photosynthesis in a variety of ways. In plants, water to be transported in the **xylem** must be in a liquid state. This means that temperatures below freezing or above boiling will prevent photosynthesis. Water at the top of the **transpiration stream** evaporates through the **stomata**, and this exerts a transpirational pull. Water evaporates faster at higher temperatures, so the volume of water moving through the xylem increases. This increases the availability of water to chloroplasts for photolysis and increases the rate of photosynthesis. Because photosynthesis is a series of enzyme-mediated reactions, temperatures that exceed the maximum tolerance of the enzymes will cause the rate of photosynthesis to slow and eventually stop, if the enzymes denature.

Light intensity

Energy in the form of photons allows the light-dependent reactions to occur. Therefore, when light intensity is low, the rate of the light-dependent reactions is lower. When light intensity is high, the rate of the light-dependent reactions is higher. In low-light environments, such as the deep ocean and the rainforest floor, photosynthetic organisms have adapted by developing more chloroplasts in their cells. This allows them to produce sufficient glucose for their metabolic needs where energy from the Sun's radiation is limited.

Challenge

Chlorophyll pigments

Chlorophylls are pigment molecules that allow plants to transform radiation in sunlight to energy stored in the bonds of glucose. There are several types of chlorophyll. Each type absorbs and reflects different wavelengths of light, which determines the colour that the leaves of plants appear to the human eye. The wavelengths absorbed by the chlorophyll pigments chlorophyll a, chlorophyll b, beta-carotene and xanthophyll are shown in Figure 4. Wavelengths absorbed by the pigments show a higher absorption, while wavelengths reflected by the pigments show low absorption.

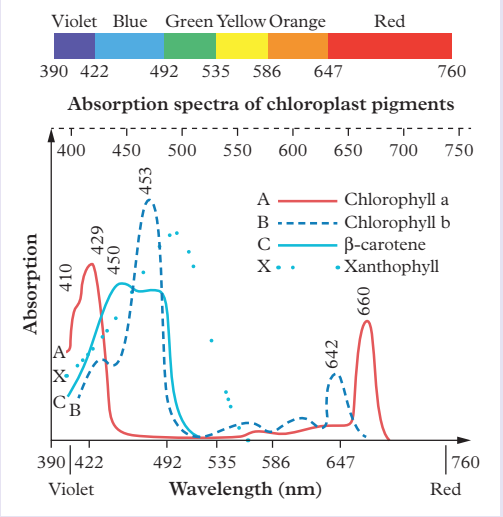


FIGURE 4 Absorption spectra of chloroplast pigments

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1 **Determine** which pigment would appear most red in colour. (1 mark)
2 **Predict** which pigment would appear darkest green in colour. **Justify** your prediction, using wavelength absorption. (2 marks)
3 The leaves of plants come in many shades of green. **Use** your knowledge of chlorophyll pigments to **suggest** why there is so much variation in leaf colour between plants. (2 marks)

Real-world biology

Blue plants use green light

Most chlorophyll molecules absorb red and blue wavelengths of light and reflect green wavelengths, giving plants their green appearance. On the rainforest floor, not only is there little light available but light wavelengths are predominantly green, having been filtered through many layers of the rainforest already. Some plants have evolved with a solution that allows them to photosynthesise enough glucose to grow and reproduce. Some begonias living in extreme shade on the floor of rainforests have modified thylakoids that maximise light absorption and are able to absorb green wavelengths. This structural adaptation also gives the leaves a beautiful iridescent blue colour.



FIGURE 5 An iridescent blue begonia leaf

Apply your understanding

1 **Infer** why plants with blue leaves do not grow in arid environments. (1 mark)
2 **Predict** what would happen to a begonia with blue leaves if it was moved from the rainforest floor to a suburban Australian backyard. (1 mark)

Check your learning 9.1

Check your learning 9.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the light-independent reaction of photosynthesis, including detail on the structures involved and their locations within the chloroplast. (4 marks)
2 **Identify** the site, inputs and outputs of light-independent reactions. (3 marks)
3 **Identify** three abiotic factors that affect the rate of photosynthesis. **Explain** one way each factor slows or accelerates photosynthesis. (6 marks)

Analytical processes

4 Roberto is revising for a biology test and has written the equation below to summarise the process of photosynthesis. **Identify** the errors in Roberto's equation and write the correct equation for photosynthesis. (2 marks)

$$6CO_2 + 12HO \xrightarrow[\text{chlorophyll}]{\text{sunlight}} 2C_6H_{12}O_6 + 6H_2O$$

Knowledge utilisation

5 **Predict** what would happen to a plant that floats on the surface of water, such as a lily, if it had stomata on the underside of its leaves. (2 marks)

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Lesson 9.2
Gas exchange in plants

Key ideas

- → Plants take in carbon dioxide and release oxygen through the stomata in their leaves.
- → Guard cells respond to environmental conditions to control the opening and closing of stomata.
- → Adaptations for improving the efficiency of gas exchange and minimising water loss allow plants to thrive in a variety of extreme environmental conditions.

Learning intentions and success criteria

Stomata and guard cells

Plants produce energy for cellular growth and maintenance through cellular respiration. Like animals, plants yield more ATP through aerobic respiration than anaerobic respiration. Because oxygen is a product of photosynthesis, plants have a ready supply of oxygen available for aerobic respiration. The volume of gas exchange by plants during respiration is much smaller than that exchanged by animals. Because the volume of gas to be exchanged is smaller, plants can meet their respiration needs through direct diffusion with the surrounding air, avoiding the need for a specialised respiratory system like that of animals. The site of gas exchange in plants is the leaves, specifically in structures called stomata.

guard cells
a pair of specialised cells in the epidermis of leaves that control gas exchange in plants by opening and closing stomata

abscisic acid
a plant hormone that regulates numerous aspects of plant growth, development and stress responses

Stomata (singular "stoma") are openings in the epidermal layers of leaves. They are created by specialised cells, called **guard cells**, which work together to open and close the stomata. When stomata are open, gases can diffuse freely between the environment and the inside of the leaf. Open stomata also allow water to evaporate from the plant, which continues the transpiration stream and promotes the movement of water through the xylem. When stomata are closed, water is retained in the plant but carbon dioxide can no longer move in and oxygen can no longer move out. In this way, the opening and closing of stomata allows the plant to respond to environmental pressures such as low water availability.



FIGURE 1 The lower epidermis of a french lavender leaf (*Lavendula dentata*) showing open and closed stomata surrounded by guard cells

Opening of stomata

Guard cells differ from the surrounding leaf epidermal cells because they contain a high number of chloroplasts. This allows them to rapidly photosynthesise and produce large amounts of glucose. Guard cells require a high concentration of chloroplasts to facilitate the opening and closing of stomata in response to water availability. When the sun rises, chloroplasts start producing glucose via photosynthesis. The guard cells then become concentrated in glucose, which triggers responses by enzymes and molecules, such as **abscisic acid**, to open and close ion channels that mediate the balance between carbon dioxide intake and water loss. When water flows into guard cells, they inflate and bend, which causes the stomata to open.

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When stomata are open, carbon dioxide can diffuse into chloroplasts and sunlight can power the light-dependent reactions of photosynthesis. As sunlight intensity decreases in the afternoon, the rate of photosynthesis slows, until it stops at sunset. While photosynthesis stops overnight, cellular respiration must continue, to allow the cells of the plant to survive. Therefore, the net products of gas exchange are reversed at night: the plant continues to take in oxygen for cellular respiration and release carbon dioxide as waste through the stomata. It does not produce oxygen, because photosynthesis is not occurring. Because plants are mostly stationary, they do not require energy to move, in the way that animals do. Therefore, their demands for gas exchange are lower and can be met solely through stomatal diffusion.

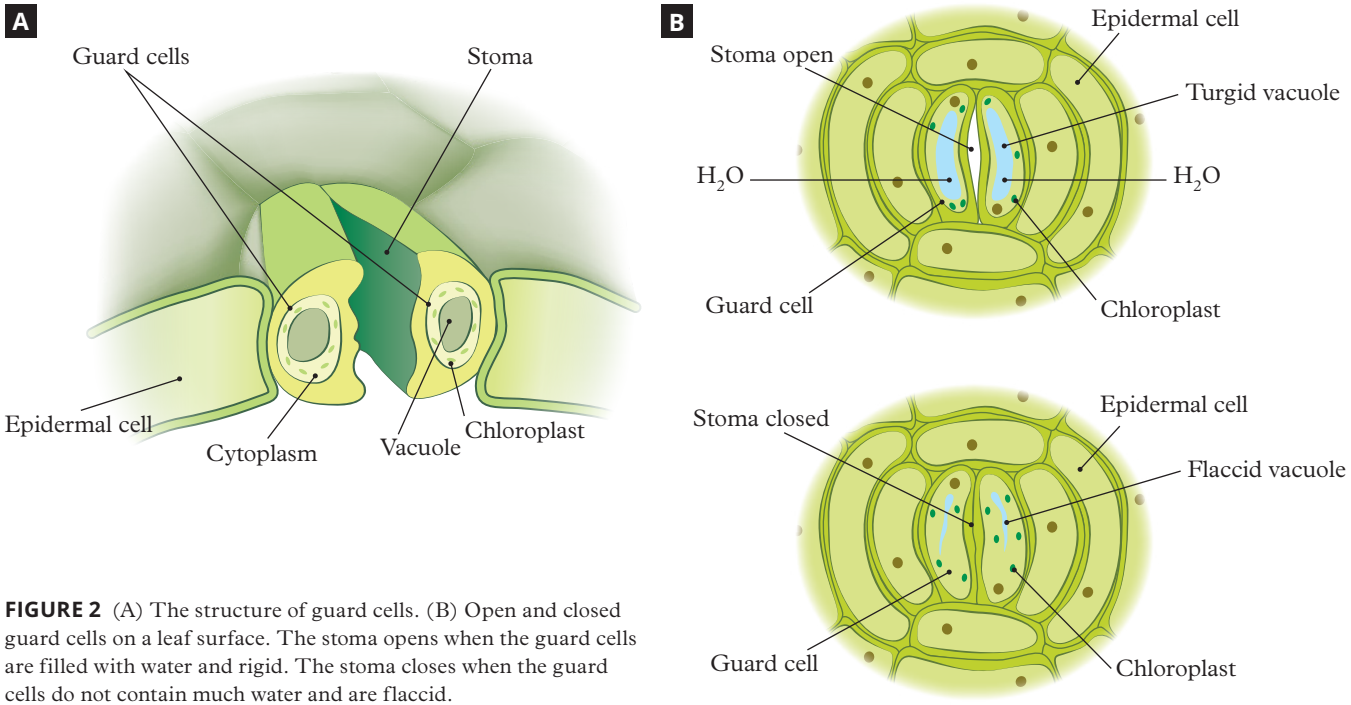


FIGURE 2 (A) The structure of guard cells. (B) Open and closed guard cells on a leaf surface. The stoma opens when the guard cells are filled with water and rigid. The stoma closes when the guard cells do not contain much water and are flaccid.

Closing of stomata

Stomata are sensitive to water availability. They open when there is enough water available for the guard cells to be turgid (swollen) and close when the guard cells lose water and become flaccid (soft and limp). This means that when outside temperatures are high and cause water in the external environment and on the surface of a plant's leaves to evaporate, the guard cells lose water and the stomata close. This opening and closing mechanism ensures that when water availability is low (e.g. during high temperatures or dry conditions), the closing of the stomata prevents water loss.

Plant adaptations for efficient gas exchange

All plants need reliable gas exchange for growth, maintenance and reproduction. However, the gas exchange structures of plants can vary greatly between species. This is because plants have developed adaptations to survive the environmental conditions of their specific habitats. For example, plants that float on the surface of water, such as water lilies, have a constant supply of water but all their stomata must be located on the upper surface of their leaves to allow gaseous carbon dioxide to enter the leaf.

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Arid environments are sparsely vegetated, allowing sunlight to bring an unlimited source of energy to plants for photosynthesis. The heat accompanying the sunlight increases the rate of transpiration in plants, leading to water loss. Because arid plants are not limited by light availability or intensity, they have smaller leaves with fewer stomata, to reduce water loss.

Rainforest ecosystems have abundant water and carbon dioxide but light intensity is limited in the shady understorey, so the plants need adaptations that will enable them to capture light to power photosynthesis. Plants living in low-light conditions have large leaves to increase the sunlight absorbed, to facilitate photosynthesis.



FIGURE 3 Environmental conditions vary greatly in Australia and plants have adapted to survive these conditions. (A) Stomata in the gigantic water lily are only on the upper surface of leaves. (B) Sturt's desert pea has smaller leaves with fewer stomata, so the plant can survive in arid environments. (C) The spoon lily has large leaves, to capture light in rainforests.

xerophyte
a plant with adaptations that allow it to function with little water

Challenge

Don't pick pineapples at night!

Cacti, pineapples and other **xerophytes** have adapted their photosynthetic cycles using a process called crassulacean acid metabolism (CAM). CAM plants live in extreme environmental conditions that place them under water stress. To minimise water loss, CAM plants have several interesting mechanisms. While the opening of stomata is essential for carbon dioxide intake, it also allows water to evaporate from the transpiration stream. CAM plants overcome this problem by fixing carbon dioxide from the environment at night, when the stomata are open and cooler conditions reduce water loss. The carbon dioxide is dissolved in water and stored within the leaves until morning, when sunlight can facilitate the rest of the light-dependent reaction.

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As a result of this delayed cycle, CAM plants are often smaller and grow more slowly than plants that do not delay any stage of photosynthesis. The fruit of CAM plants, such as pineapples, tastes more acidic at night due to the storage of carbon dioxide, and sweeter during the day when more glucose is produced.

1 **Infer** which organelle in a plant cell would be suitable for carbon dioxide storage overnight in CAM plants. (1 mark)
2 **Explain** the challenges for a cactus that is used as an indoor plant in a northern European climate. **Suggest** how humans could change the environment of the cactus to overcome these challenges. (3 marks)



FIGURE 4 A pineapple picked at night will taste sourer than one picked during the day.

Check your learning 9.2

Check your learning 9.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** which gases are exchanged by plants. **Describe** the direction of movement of each type of gas through the stomata of plants. (2 marks)
2 **Describe** the processes that cause the opening and closing of stomata. (2 marks)
3 **Explain** how plants can survive without complex respiratory structures like lungs for gas exchange. (4 marks)

Knowledge utilisation

4 **Construct** a labelled diagram of an open and closed stoma. (4 marks)
5 The mulga tree (*Acacia aneura*) is common in the hot, dry Australian outback. Its stomata sit slightly lower than the surrounding epidermal cells on its leaves. **Infer** why sunken stomata allow *Acacia aneura* to thrive in these harsh conditions. (1 mark)

Practical

Lesson 9.3
Stomatal function

This lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.

Learning intentions and success criteria

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Lesson 9.4
Movement of water in the xylem

Learning intentions and success criteria

Key ideas

- → Water is transported through plants in one direction, from the roots to the leaves, in a process called transpiration.
- → Transpiration occurs in the xylem vessels, due to root pressure, cohesive forces, adhesive forces and transpiration pull; no ATP energy is required.

vessel element
pitted, narrow tube for transporting small amounts of water within the xylem; reinforced with lignin to provide strength

tracheid
the thinnest tube of xylem for transporting very small amounts of water; unperforated and lignified

lignin
a polymer produced by plant cells to provide strength to xylem cells

xylem fibre
non-living xylem cells that provide strength and support to water-carrying xylem vessels and tracheids; do not transport water themselves

xylem parenchyma
the only living cells of the xylem tissue in plants; transport water and nutrients and store carbohydrates, oils and tannins

Xylem structure and function

Most vascular plants obtain water from the soil and transport it from the roots to other parts of the plant. As most plant structures are located above ground, the plants must work against gravity to transport water to where it is needed – in the leaves and reproductive structures. The transpiration stream is the stream of water and solutes taken up from the roots to the leaves of a plant, where the water will evaporate. The structures that plants use to transport water from their roots to other locations are made up of xylem cells.

A combination of living and dead xylem cells form straw-like tubular structures that allow water to move upwards from the roots to different parts of the plant. This combination of cell types makes the structures robust, which contributes to the structural integrity of the plant as well as acting as a passage for the transport of water.

The hollow tube-like shape of xylem is formed from two cell types: **vessel elements** and **tracheids**. Vessel elements are elongated, pipe-shaped cells that stack together to form a tube through which water can flow. The cell walls of vessel elements contain a complex polymer called **lignin** that improves the structural integrity of the cell. Tracheids are thin, hollow cells that have more lignified cell walls than vessel elements. Tracheids provide sturdiness to a plant's overall structure and aid in the transport of water and inorganic salts. Vessel elements and tracheids have pitted walls that allow water to diffuse into adjacent cells. Vessel elements are wider than tracheids, and can therefore move more water when it is abundant. Tracheids can move small amounts of water during times of drought. Both cell types, vessel element and tracheid, are dead cells.

Other cell types that make up the xylem are **xylem fibres** and **xylem parenchyma**. Xylem fibres are long, lignified fibres found between tracheids and vessel elements. They are made up of dead sclerenchyma cells (cells that provide a plant with stiffness and strength). Xylem fibres provide support and protection to tracheids and vessel elements, and can transport some water. Xylem parenchyma are the only living cells that make up the xylem. These cells contain a nucleus and cytoplasm, and have thin cell walls so substances can quickly diffuse in and out of cells. Xylem parenchyma store water and nutrients such as carbohydrates, proteins and oils. They are also able to regenerate in the event of damage to the xylem. Table 1 provides a summary of the cell types that make up the xylem.

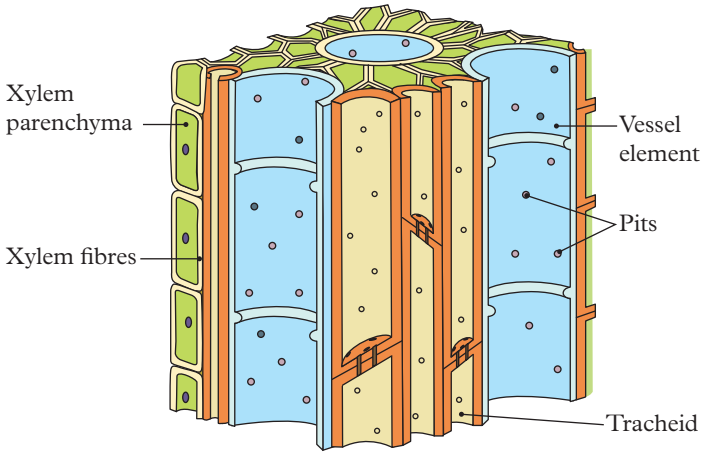
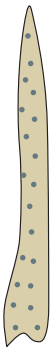
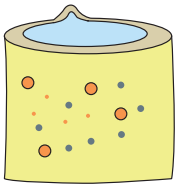
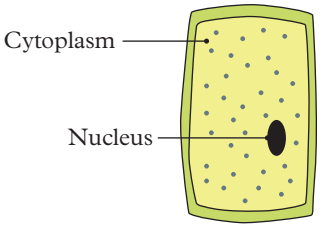


FIGURE 1 Components of xylem

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TABLE 1 The characteristics and functions of cell types in xylem

Cell name	Living/dead	Characteristics	Function	Diagram
Tracheid	Dead	Lignified, hollow cells with pointed ends	Transport small amounts of water	
Vessel element	Dead	Hollow, cylindrical lignified cells stacked on top of each other	Transport large amounts of water when available	
Xylem fibre	Dead	Long narrow cells located between tracheids and xylem vessels	Provide structure and support; transport some water	
Xylem parenchyma	Living	Contains a nucleus and cytoplasm; has a thin cell wall to facilitate diffusion	Storage of nutrients and water; can replicate to repair damage to xylem	

Transpiration

In the xylem, water molecules are attracted to each other through **cohesive forces** (forces that attract molecules of the same type together). This cohesion between molecules ensures that, when water is pushed by root pressure or pulled by the transpiration stream, the water molecules will pull each other to move in the same direction. Water molecules are also attracted to the walls of xylem through **adhesive forces** (forces that attract molecules of different types together). The adhesive forces between water molecules and the xylem vessels work to resist the downward pull of gravity and support the continuous upward movement of water in the xylem. Cell types that make up the walls of the xylem (such as vessel elements and tracheids) are elongated and have a large surface area to maximise contact with water. This helps increase the adhesion of water to the xylem walls. Tracheids in particular are very narrow in diameter and allow cohesive and adhesive forces to facilitate transpiration in low water conditions.

When water molecules reach the stomatal pores at the top of the transpiration stream, the water evaporates out due to energy from the sun and the diffusion gradient with the outside

cohesive forces
the attractive force between molecules allowing them to clump together; in this context the attractive forces between water molecules

adhesive forces
the attractive force between molecules that are different to each other; in this context the attractive forces between water molecules and the xylem cell walls

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air. As the water molecules evaporate and detach from each other, cohesive forces between them exert a pull on the transpiration stream, contributing to the upward movement of water through the xylem.

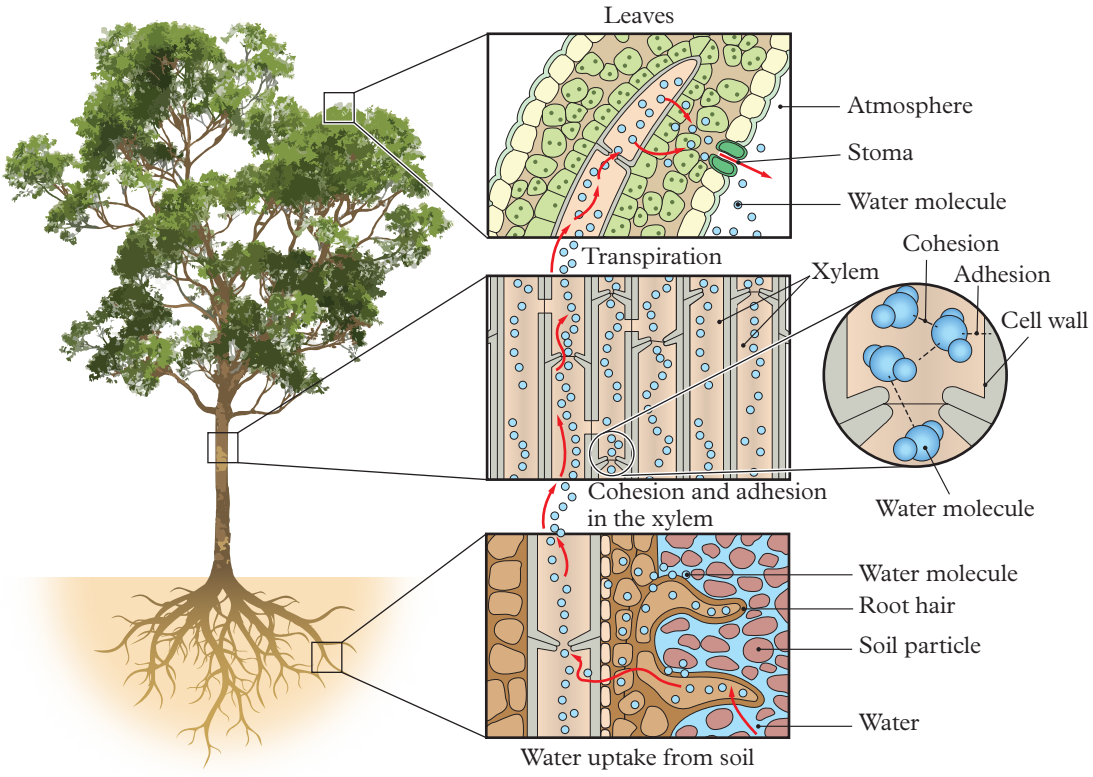


FIGURE 2 Transpiration stream of water in a tree: water moves from the soil into the roots, through the xylem and out through the stomata in the leaves.

In summary, water movement through the xylem is driven by:

- root pressure – pressure from water in the roots prevents the downward movement of water due to gravity
- adhesive forces – adhesion between water molecules and the surfaces of the xylem vessels assists in the upward pull of water against gravity
- cohesive forces – water molecules are attracted to each other, creating a continuous upward stream through the xylem
- stomatal evaporation – at the top of the transpiration stream, water molecules evaporate from liquid water to water vapour in the surrounding air.

Movement of water through the transpiration stream occurs by passive transport, requiring no ATP energy. Water molecules absorb energy from the sun, which causes evaporation. This in combination with cohesive forces, adhesive forces and root pressure allows the water molecules to move through the plant in a constant stream against gravity.

Factors affecting the rate of transpiration

The rate of transpiration, or how quickly water molecules move through the transpiration stream and evaporate from the stomata to the environment, is affected by the level of light, temperature, humidity, wind, and the water content of the soil.

Light

Radiation from sunlight triggers the opening of stomata in most plants, allowing evaporation of water from the top of the transpiration stream.

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Temperature

As temperature increases, the energy of water molecules increases, accelerating evaporation from the top of the transpiration stream.

Humidity

The diffusion gradient between the water within the intracellular spaces of a leaf and the outside humidity determines the speed of evaporation. Low humidity increases the rate at which water evaporates, while high humidity decreases the diffusion gradient and therefore the rate of evaporation.

Wind

Wind increases transpiration by blowing away water vapor from the stomata. This maintains drier air around the stomata, creating a diffusion gradient where water moves from high water concentration in the transpiration stream to the low water concentration of the air in the stomata.

Soil water

The higher the diffusion gradient between the water in the soil and the roots of a plant, the faster water diffuses across the root membrane. When soil water is low, diffusion to the root slows. Water may even diffuse from the roots to the soil in times of drought. Low soil water reduces root pressure and slows the movement of water through the transpiration stream.

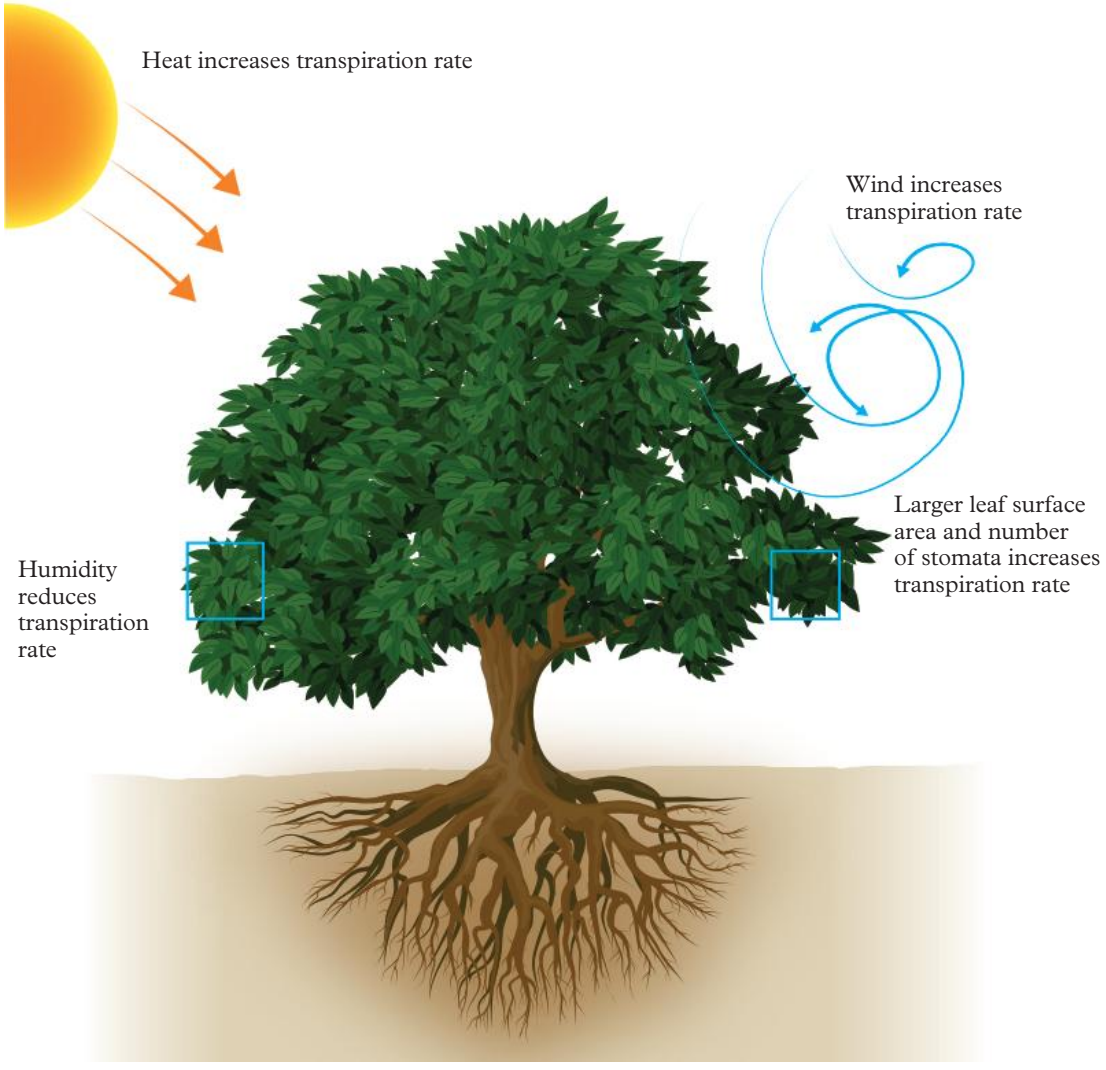


FIGURE 3 Many factors affect the rate of transpiration.

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Skill drill

Graphing transpiration data

Science inquiry skill: Processing and analysing data (Lesson 1.8)

A researcher wants to determine which of two species of plants has a rate higher of transpiration. They measure the amount of water lost in 100 g of plant tissue from each species each minute for 10 minutes. Their results are given in Table 1.

TABLE 1 Water loss over time for two plant species

Time (min)	Total water loss (mL H_2O/100 g of plant tissue)	
	Species A	Species B
0	0	0
1	0.3	0.1
2	0.4	0.2
3	0.8	0.3
4	1	0.3
5	1.2	0.4
6	1.4	0.6
7	1.6	0.7
8	1.8	0.8
9	2.2	1
10	2.4	1.2

Practise your skills

1 **Use** data from the results table to **graph** the rate of transpiration of Species A and Species B. (3 marks)

2 **Determine** which species of plant had a higher rate of transpiration. (1 mark)

3 One of the plant species had a larger number of stomata on its leaves than the other. **Infer** which plant species this would be and why. (2 marks)

Check your learning 9.4

Check your learning 9.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the factors that affect transpiration of water through xylem vessels. (3 marks)

2 **Identify** two abiotic factors that affect the rate of photosynthesis. **Explain** the way each factor slows or accelerates the rate of photosynthesis. (4 marks)

Analytical processes

3 **Compare** adhesive forces and cohesive forces. (2 marks)

Practical

Lesson 9.5

The passage of water through flowering plants

Learning intentions and success criteria

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Practical

Lesson 9.6
Factors affecting the rate of transpiration



This lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.



Learning intentions and success criteria

Lesson 9.7
Movement of organic molecules in the phloem



Learning intentions and success criteria

Key ideas

- → Phloem is made up of different cell types, each with a specialised structure and function, that all work together.
- → Translocation is the movement of organic substances around a plant according to the needs of each of the plant's structures.
- → Translocation is a form of active transport, as organic substances can move in any direction including against gravity and concentration gradients.

phloem
vessels within a plant that transport sugar produced by photosynthesis to other parts of the plant; phloem vessels may carry dissolved sugars in any direction within the plant, by active transport (ATP energy)

sieve tube
a transport vessel made up of a long chain of sieve elements attached end-to-end at the sieve plate; allows passage of cytoplasm carrying dissolved organic molecules around the plant

phloem fibre
a long, thin cell that gives strength and flexibility to phloem

companion cell
a phloem cell that contains mitochondria to produce ATP energy to supply phloem vessels with energy

Structure and function of phloem

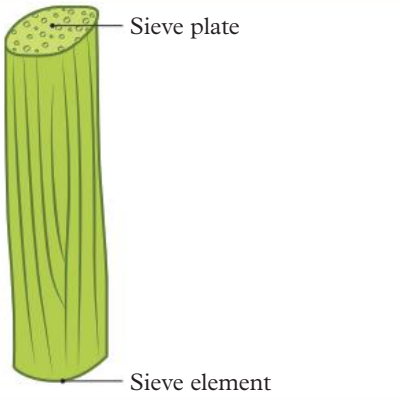
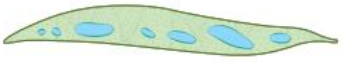
Phloem is the transport system for organic molecules including glucose, amino acids and hormones around a plant. Phloem vessels are made up of different specialised cells: **sieve elements**, **phloem fibres** and **companion cells**. These cells have different functions but work together to move organic molecules from the area of production or storage in a plant to the structure that requires them.

Sieve element cells attach to each other end-to-end, forming a long tube that transports cytoplasm containing dissolved organic molecules around the plant. At maturity, sieve elements lose their nucleus and some organelles, but retain their mitochondria, endoplasmic reticulum and starch-storing plastids. This provides space for the flow of large volumes of cytoplasm through the sieve tubes. Phloem fibre cells provide structure and strength to phloem vessels. Their thick cell walls and long, narrow structure allow them to align vertically alongside sieve elements to prevent collapse or damage to the phloem vessel. Companion cells have a high concentration of mitochondria and ribosomes to supplement the sieve elements with ATP energy and proteins required.

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TABLE 1 Summary of cell types in phloem and their functions

Cell name	Living/dead	Characteristics	Function	Diagram
Sieve elements	Living but without nucleus	Perforated plate at top and bottom; join together to form sieve tube	Transport organic molecules (e.g. sugars) around plant	
Phloem fibres	Dead	Long, narrow cells with thick cell walls	Provide structural strength	
Companion cells	Living	Large number of mitochondria and ribosomes	Supply sieve elements with ATP energy and proteins	

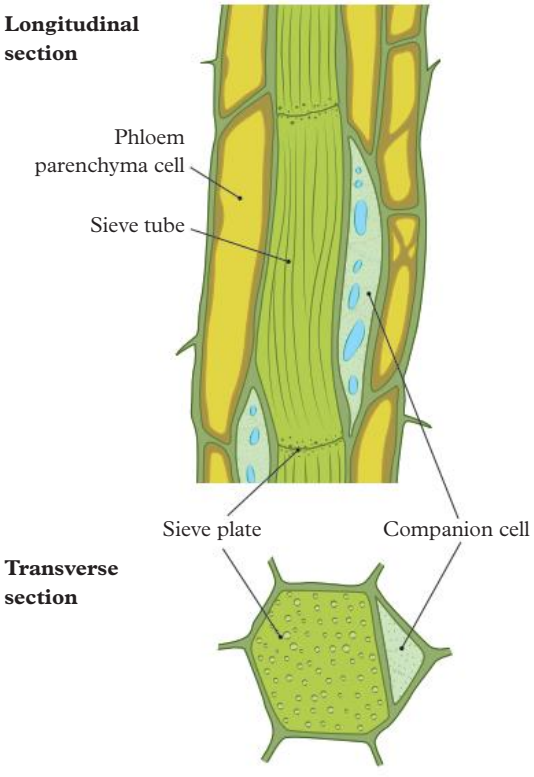


FIGURE 1 Components of phloem

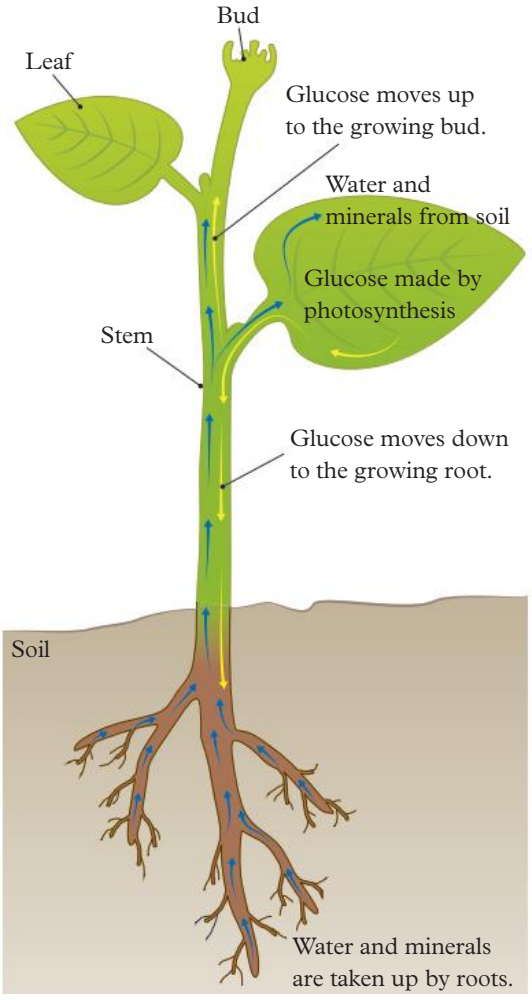


FIGURE 2 In the xylem, water moves in one direction, from the roots to the leaves. In the phloem, organic molecules (e.g. glucose) can move in any direction.

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Translocation

translocation
the movement of organic materials around a plant in phloem vessels by active transport

Translocation is the movement of organic molecules such as glucose, amino acids and hormones through a plant's phloem vessels. Unlike the unidirectional movement of water through the xylem, organic molecules in the phloem must be transported in all directions, and this requires ATP energy. Glucose must sometimes be moved against the concentration gradient from where it is produced in the leaves, into phloem vessels that already contain a high concentration of glucose. This movement of molecules from an area of low concentration to an area of high concentration against the concentration gradient requires active transport, and therefore uses ATP energy.

Once the glucose has moved into the phloem, water moves along the concentration gradient from the xylem to the phloem, creating pressure to allow the flow of dissolved sugars through the phloem to areas of need. Because the leaves of most plants are the primary location of photosynthesis and are at the top of the plant, glucose produced in the leaves must be transported to non-photosynthetic plant structures. Cells in the roots, leaf tips and reproductive structures grow quickly and have a constant demand for the products of photosynthesis delivered through the phloem. Plants also store glucose as starch for future demands, when resources may be limited. For example, potato plants store starch in tubers attached to roots below the ground (Figure 3).



FIGURE 3 A potato plant stores starch in tubers below the soil.

Check your learning 9.7

Check your learning 9.7: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the structure and function of the three different phloem cell types. (3 marks)

2 **Explain** why translocation requires active transport using ATP. (1 mark)

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MODULE 9

Lesson 9.8
Review: Plant physiology

Summary

9.1
- Photosynthesis can be simply expressed in a chemical equation, with carbon dioxide and water as reactants and glucose and oxygen as products.
- Chloroplasts allow energy from sunlight to be stored in the bonds of glucose via photosynthesis.
- Photosynthesis occurs in two stages: a light-dependent stage and light-independent stage.
- The rate of photosynthesis is affected by the availability of reactants and the intensity of sunlight.

9.2
- Plants take in carbon dioxide and release oxygen through the stomata in their leaves.
- Guard cells respond to environmental conditions to control the opening and closing of stomata.
- Adaptations for improving efficiency of gas exchange and minimising water loss allow plants to thrive in a variety of extreme environmental conditions.

9.3
- Practical: Stomatal function

9.4
- Water is transported through plants in one direction, from the roots to the leaves, in a process called transpiration.
- Transpiration occurs in the xylem vessels, due to root pressure, cohesive forces, adhesive forces and transpiration pull; no ATP energy is required.

9.5
- Practical: The passage of water through flowering plants

9.6
- Practical: Factors affecting the rate of transpiration

9.7
- Phloem is made up of different cell types, each with a specialised structure and function, that all work together.
- Translocation is the movement of organic substances around a plant according to the needs of each of the plant's structures.
- Translocation is a form of active transport, as organic substances can move in any direction including against gravity and concentration gradients.

Review questions 9.8A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Autotrophs are
- **A** able to produce their own food.
- **B** always plants.
- **C** consumers.
- **D** the food source for all living things.

2 Photosynthesis occurs in two parts, called
- **A** aerobic and anaerobic reactions.
- **B** light-dependent and light-independent reactions.
- **C** transpiration and translocation.
- **D** xylem and phloem.

3 The reactants of photosynthesis are
- **A** glucose and oxygen.
- **B** carbon dioxide and chlorophyll.
- **C** carbon dioxide and water.
- **D** carbon, oxygen and hydrogen.

4 Guard cells in plants
- **A** join together to form phloem.
- **B** support phloem vessels by providing ATP energy.
- **C** swell and shrink to open and close stomata.
- **D** transport water from the roots to the leaves.

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5 Xylem vessels transport
- **A** carbon dioxide out of the plant.
- **B** glucose.
- **C** oxygen out of the plant.
- **D** water.

6 The movement of glucose from the leaves of a plant to the roots for storage is called
- **A** active transport.
- **B** translocation.
- **C** transpiration.
- **D** photosynthesis.

7 Sieve tubes are
- **A** a type of phloem cell.
- **B** a type of xylem cell.
- **C** found in the leaves of plants.
- **D** found in both plants and animals.

8 The rate of transpiration is reduced by
- **A** high humidity.
- **B** low humidity.
- **C** phloem size.
- **D** rate of photosynthesis.

9 Liquid in the xylem vessels can move
- **A** from leaves to the roots only.
- **B** from roots to leaves only.
- **C** in any direction.
- **D** only in the presence of sunlight.

10 Active transport can be used to
- **A** close stomata.
- **B** increase cohesive forces between water molecules.
- **C** increase the rate of transpiration.
- **D** move molecules against a concentration gradient.

11 Xylem cells are able to transport water because
- **A** some xylem cells create the stomatal opening.
- **B** some xylem cells have small hairs.
- **C** some xylem cells are dead and hollow.
- **D** some xylem cells have a high number of mitochondria to produce energy.

Review questions 9.8B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

12 **Describe** the movement of water through the transpiration stream from the soil to evaporation from the leaves. (6 marks)

13 **Explain** how adhesive and cohesive forces contribute to movement of water through plants. (4 marks)

14 **Explain** how translocation allows plants to store glucose for long periods of time. (2 marks)

15 **Explain** why stomata usually close at night. (2 marks)

Analytical processes

16 **Contrast** xylem and phloem. (1 mark)

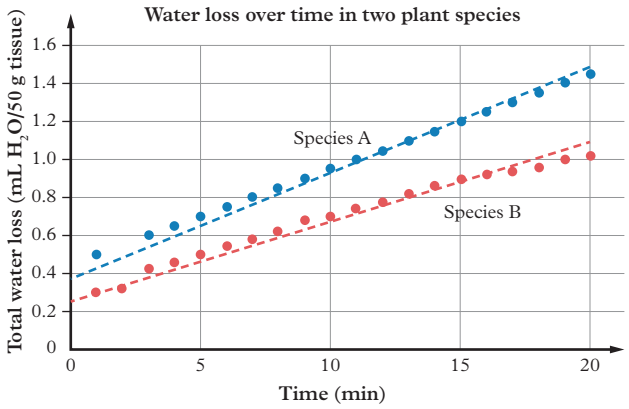
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Data drill

Transpiration rate

A researcher conducts a transpiration experiment to compare the rate of transpiration in two plant species. The results of the experiment are shown in the graph.



Apply understanding

1 **Calculate** the rate of transpiration for each plant species. Rate of transpiration can be calculated using the formula:

rate of transpiration (mL H_2O/50 g/min) = $\frac{\text{volume of water lost (mL)}}{\text{time taken (min)}}$ (2 marks)

Analyse data

2 **Identify** which plant species had the greater rate of transpiration. (1 mark)

Interpret evidence

3 **Infer** which plant species is likely to have a greater concentration of stomata. (1 mark)

Module 9 checklist: Plant physiology

Quizlet: Revise key terms online to test your understanding

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UNIT 1

Topic 3 Review

Multiple choice

(1 mark each)

1 Reactions in which energy is absorbed, new bonds are formed and larger molecules are synthesised can be described as
- **A** anabolic.
- **B** catabolic.
- **C** metabolic.
- **D** photosynthetic.

2 Glycolysis is a stage of cellular respiration that occurs in the
- **A** bloodstream.
- **B** cell cytoplasm.
- **C** Krebs cycle.
- **D** mitochondria.

3 Blood vessels that are permeable to white blood cells and tissue fluid are known as
- **A** arteries.
- **B** capillaries.
- **C** valves.
- **D** veins.

4 Diffusion of gas between the alveoli and the bloodstream relies on
- **A** blood pressure.
- **B** a concentration gradient of gases.
- **C** heart rate.
- **D** red blood cells.

5 The liquid solution inside chloroplasts is known as
- **A** chlorophyll.
- **B** grana.
- **C** stroma.
- **D** thylakoids.

6 The chemical responsible for triggering the closing of stomata is called
- **A** abscisic acid.
- **B** adenosine triphosphate.
- **C** chlorophyll.
- **D** RuBisCO.

7 The only living cell type in the xylem of plants is called a
- **A** tracheid.
- **B** vessel element.
- **C** xylem fibre.
- **D** xylem parenchyma.

8 The cells that provide ATP energy and proteins to other phloem cells are called
- **A** companion cells.
- **B** phloem fibres.
- **C** sieve elements.
- **D** sieve plates.

9 During inhalation, air moves into the lungs while
- **A** the diaphragm contracts and the ribs lower.
- **B** the diaphragm contracts and the ribs raise.
- **C** the diaphragm relaxes and the ribs lower.
- **D** the diaphragm relaxes and the ribs raise.

10 Which combination of processes demonstrates gas exchange in the lungs?
- **A** Carbon dioxide and oxygen diffuse from the alveoli to the bloodstream.
- **B** Carbon dioxide and oxygen diffuse from the bloodstream to the alveoli.
- **C** Carbon dioxide diffuses from the alveoli to the bloodstream, and oxygen diffuses from the bloodstream to the alveoli.
- **D** Carbon dioxide diffuses from the bloodstream to the alveoli, and oxygen diffuses from the alveoli to the bloodstream.

11 Phosphorylation, the addition of a phosphate group to a molecule, occurs during
- **A** glycolysis.
- **B** photosynthesis.
- **C** the conversion of ADP to ATP.
- **D** the conversion of ATP to ADP.

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12 The stage of aerobic respiration that produces the highest yield of ATP is called
- **A** the electron transport chain.
- **B** lactic acid fermentation.
- **C** glycolysis.
- **D** the Krebs cycle.

13 Which combination of reactants and products represents photosynthesis?

	Reactants	Products
A	carbon dioxide + glucose	oxygen + water
B	carbon dioxide + water	oxygen + glucose
C	oxygen + water	carbon dioxide + glucose
D	oxygen + carbon dioxide	glucose + water

14 Photosynthesis is a series of reactions that can best be described as
- **A** anabolic and endothermic.
- **B** anabolic and exothermic.
- **C** catabolic and endothermic.
- **D** catabolic and exothermic.

15 Which of the following is an example of an organelle?
- **A** autotroph
- **B** chloroplast
- **C** photosystem II
- **D** thylakoid

Short response

16 The table shows the stages involved in aerobic and anaerobic respiration, and their net ATP production.

	Glycolysis 2 ATP	Krebs cycle 2 ATP	Electron transport chain 34 ATP
Aerobic respiration	Yes	Yes	Yes
Anaerobic respiration	Yes	No	No

- **a** **Calculate** the net output of ATP in aerobic respiration. Show your working. (2 marks)
- **b** **Contrast** the net output of anaerobic and aerobic respiration. (1 mark)
- **c** **Explain** what is meant by "net output of ATP" and what happens to the ATP produced that is not included in this amount. (2 marks)

17 **Identify** the reactants and products of photosynthesis. (2 marks)

18 **Describe** how the internal membrane of mitochondria is suited to its function. (3 marks)

19 **Explain** how adenosine triphosphate transforms into another molecule to produce energy for cells to use. (3 marks)

20 **Describe** how haemoglobin's affinity for oxygen allows it to transfer oxygen from one area of the body to another. (4 marks)

21 **Contrast** endothermic and exothermic reactions. (1 mark)

22 **Explain** the transformation of energy through photosynthesis. (4 marks)

23 **Describe** the process of fermentation. (4 marks)

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24 **Compare** aerobic respiration and anaerobic respiration, with reference to the type and location of reactions, and their inputs and outputs. (2 marks)

25 **Explain** the process of human ventilation, with reference to the main organs involved. (5 marks)

26 **Contrast** anabolic and catabolic reactions in living organisms, using glucose as an example. (2 marks)

27 **Explain** the role of abscisic acid in plants. (4 marks)

28 **Describe** the role of thylakoids in photosynthesis. (1 mark)

TOTAL MARKS
/55 marks

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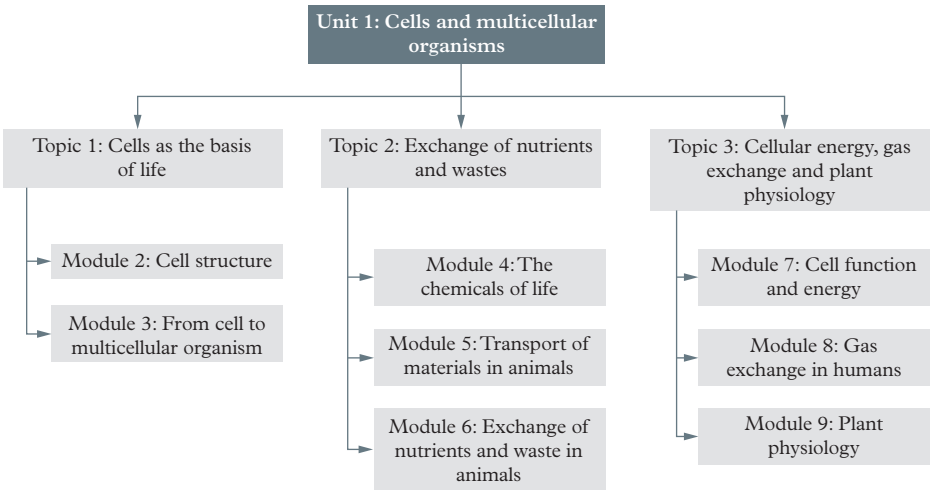
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UNIT 1

Review

Part A – Revisit and revise

Part A of the Unit review asks you to reflect on your learning and identify areas in which you need more work.



Part B – Exam essentials

Now that you've completed your revision for Unit 1, it's time to learn and practise some of the skills you'll need to answer exam questions like a pro! To help you, our expert authors have created the following advice and tips to help you maximise your results on the end-of-year examination.

Exam tip 1: Use the mark allocation as a guide

All exam questions have a mark allocation, which can be useful for determining how much detail you need to provide in your responses. This is particularly helpful for "explain" and "describe" questions. Typically, one mark is awarded for each new piece of information that addresses the question. Therefore, an explain question worth 3 marks will require three pieces of information, while an explain question worth 2 marks will only require two pieces of information.

See it in action

Read the exam question and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

QUESTION 1 (3 marks)

Mitochondria are organelles that produce energy in the form of ATP using glucose and oxygen through a process called cellular respiration. The inner membrane of the mitochondria is called the cristae and is highly folded. Explain how this feature increases the efficiency of the mitochondria in producing ATP.

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Complete response

1 mark awarded for describing how the folded nature of cristae increases surface area available for movement of reactions.

The folded membrane of the cristae increases the surface area available for movement of reactants across the membrane. The more reactants (oxygen and glucose) that can move into the cristae, the more reactions can occur, increasing the efficiency of the mitochondria in producing ATP for energy.

1 mark awarded for explaining that more reactions can occur if an increased number of reactants enter the cristae.

1 mark for linking explanation of how it increases the efficiency of the mitochondria in producing ATP.

3 pieces of information have been provided to appropriately address the detail indicated by the mark allocation.

Incomplete response

1 mark awarded for describing how the folded nature of cristae increases surface area available for movement of reactants.

Cristae are highly folded, which increases the surface area available for movement of reactants across the membrane.

Only 1 mark awarded as only one piece of information is provided. Information about how increased reactants allow for more reactions and how this improves efficiency is missing.

Think like an assessor

To maximise your marks on an exam, it can help to think like a QCAA assessor. Consider how many marks each question is worth and what information the assessor is looking for.

A student has given the following response in a practice exam. Imagine you are a QCAA assessor and use the marking guide to mark the response.

QUESTION 2 (3 marks)

Some animals adapted to life in arid environments have a longer than usual loop of Henle in the kidney. Explain how this allows them to minimise water loss while still excreting waste through urine.

The loop of Henle is the location of water reabsorption from filtrate into the bloodstream. By increasing the distance travelled through the loop of Henle, more water can be reabsorbed from the filtrate into the bloodstream.

Marking guide

Question 2

- Identifies reabsorption of water from the loop of Henle to the bloodstream (1 mark]
- Explains that increased distance travelled by filtrate through the loop of Henle allows for more reabsorption of water into the bloodstream [1 mark]
- Explains how water loss is minimised through retention of water [1 mark]

Fix the response

Consider where you did and did not award marks in the above response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

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Exam tip 2: Understand the difference between compare and contrast

The terms "compare" and "contrast" are often used synonymously in everyday language. However, in QCAA exams and assessments, each of these cognitive verbs requires different tasks. Compare questions require you to identify both similarities and differences, while contrast questions require just differences. A response to a compare question that does not identify similarities will lose one mark.

See it in action

Read the exam question and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

QUESTION 3 (2 marks)

Compare prokaryotic and eukaryotic cells.

Complete response

1 mark for identifying a similarity.

Both prokaryotic and eukaryotic cells contain ribosomes, genetic material, cytoplasm and plasma membrane.
However, eukaryotic cells have membrane-bound organelles, which prokaryotic cells lack.

1 mark for identifying a difference.

Incomplete response

Response is not awarded full marks, as a similarity has not been identified.

1 mark for identifying a difference.

Eukaryotic cells have membrane-bound organelles while prokaryotic cells do not.

Think like an assessor

To maximise your marks on an exam, it can help to think like a QCAA assessor. Consider how many marks each question is worth and what information the assessor is looking for.

A student has given the following response in a practice exam. Imagine you are a QCAA assessor and use the marking guide to mark the response.

QUESTION 4 (2 marks)

Compare aerobic and anaerobic respiration.

Aerobic respiration occurs in the presence of oxygen while anaerobic respiration occurs in the absence of oxygen.

Marking guide

Question 4	• Identifies a similarity [1 mark] • Identifies a difference [1 mark]

Fix the response

Consider where you did and did not award marks in the response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

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Exam tip 3: Make connections between concepts

Students often write responses that contain the correct information and use the right scientific terminology, but they don't connect concepts together to provide an explanation. If an "explain" question is followed by the word "why" or "how", your response will need to include a statement that details the specific way in which the thing you are describing results in an outcome or event.

See it in action

Read the exam question below and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

QUESTION 5 (3 marks)

Explain how temperature influences enzyme rate of reaction.

Complete response

1 mark for stating that an increase in temperature increases movement of molecules.

As temperature increases, molecules have more kinetic energy, allowing them to move faster. Faster movement increases the collision rate between enzyme active sites and substrates, allowing for more reactions to occur and increasing the rate of reaction.

1 mark for making connection between increased movement and collision rate of active site and substrate.

1 mark for stating that increased connections between active site and substrate increases rate of reaction.

Incomplete response

1 mark for stating that an increase in temperature increases movement of molecules.

As temperature increases, molecules have more kinetic energy, allowing them to move faster, which increases the rate of the reaction.

Answer not awarded full marks as it does not connect how the faster movement of molecules leads to an increased frequency of collisions between enzyme and substrate and how this results in more reactions taking place, increasing the overall rate of reaction.

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Think like an assessor

To maximise your marks on an exam, it can help to think like a QCAA assessor. Consider how many marks each question is worth and what information the assessor is looking for.

A student has given the following response in a practice exam. Imagine you are a QCAA assessor and use the marking guide to mark the response.

QUESTION 6 (3 marks)

A researcher was investigating if the presence of oxygen affects the metabolism of glucose in red blood cells at 37°C. Their results are shown in the table below.

Oxygen	Glucose consumed (nmoles/10^7 cells/hour)	Lactic acid produced (nmoles/10^7 cells/hour)
Absent	1.5	3.3
Present	1.5	3.3

Explain why the results are the same in both conditions (oxygen present and oxygen absent).

Red blood cells can only undergo anaerobic respiration. This means that both conditions will use anaerobic respiration and covert glucose/pyruvate to lactate at the same rate, producing the same result.

Marking guide

Question 6

- Identifies that red blood cells lack mitochondria [1 mark]
- Explains that due to their lack of mitochondria, which is the site of aerobic respiration, red blood cells only use anaerobic respiration [1 mark]
- Explains that both conditions will convert glucose to lactic acid at the same rate, due to red blood cells using anaerobic respiration [1 mark]

Fix the response

Consider where you did and did not award marks in the response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

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Part C – Practice exam questions

Now it's time to put the tips and advice you've learned into practice while you complete these exam-style questions!

Multiple-choice

1 What do all living cells have in common?

A All cells have mitochondria.

B All cells have a cell wall.

C All cells have DNA.

D All cells have chloroplasts.

2 A cube-shaped bacterial cell with sides that are 2 μm long would have a simplified surface area-to-volume ratio of

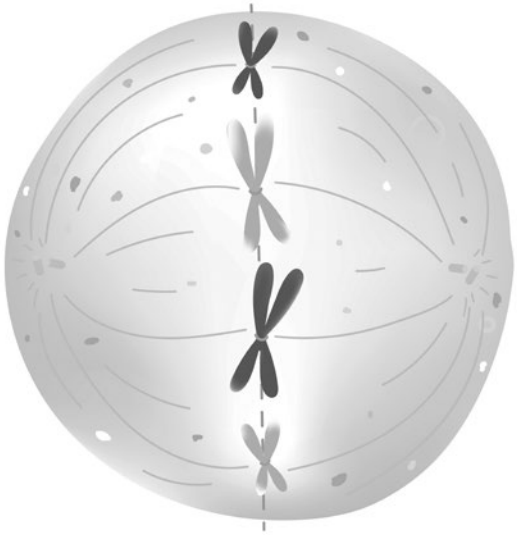
A 3:1.

B 1:3.

C 24:8.

D 3%.

3 What stage of mitosis is shown in the figure?



A anaphase

B metaphase

C prophase

D telophase

4 Water can be lost from a plant via the stomata on its leaves. To combat loss of water, the guard cells

A fill with water, which cause the stomata to close.

B lose water, which cause the stomata to open.

C fill with water, which cause the stomata to open.

D lose water, which cause the stomata to close.

5 What is the role of amylase in the body?

A to catalyse the breakdown of proteins

B to catalyse the breakdown of carbohydrates

C to catalyse the breakdown of lipids

D to catalyse to breakdown of nucleic acids

6 What is the correct order of processes that take place during aerobic respiration?

A Krebs cycle → glycolysis → electron transport chain

B glycolysis → electron transport chain → Krebs cycle

C glycolysis → Krebs cycle → electron transport chain

D electron transport chain → glycolysis → Krebs cycle

7 What is the product of anaerobic respiration in yeasts and plants?

A ethanol

B carbon dioxide

C ATP

D glucose

8 Identify how the size of a cell typically affects its surface area-to-volume ratio (SA:V).

A The larger the cell, the smaller the SA:V ratio.

B The smaller the cell, the smaller the SA:V ratio.

C The SA:V ratio is not affected by the size of the cell.

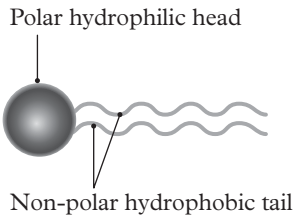
D The SA:V ratio is only relevant to prokaryotic cells.

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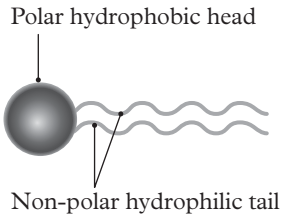
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9 Identify the correct structure of a phospholipid molecule.

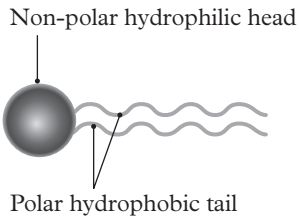
A



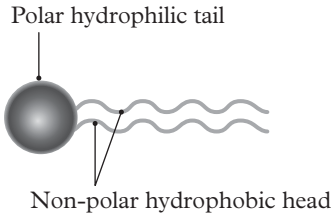
B



C



D



10 Choose the correct terms to complete this statement: "Water and minerals travel through the _____ of a plant, while glucose travels through the _____."

A phloem, xylem
B stoma, xylem
C xylem, phloem
D sieve tube, support cells

11 Which of the following best describes the lock-and-key model?

A The enzyme and substrate are modified to fit together.
B The enzyme is used up during the reaction.
C The enzyme and substrate fit together almost perfectly with no modifications.
D The activity of an enzyme increases with temperature.

12 Identify the term used for the transport of water across a membrane.

A facilitated diffusion
B osmosis
C active transport
D phagocytosis

13 Tissue culture is a laboratory technique in which cells from living things are grown artificially in a nutrient medium (a solution containing all the nutrients cells need to survive). In plant tissue culture, stem tissue from a plant can be placed into a nutrient medium and grows into a new plant, with the cells of the plant multiplying and differentiating into the various tissue types. Identify the term used to describe this form of development.

A totipotent
B pluripotent
C unipotent
D embryonic

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14 Which one of the following statements is true?
- **A** Arteries have valves to prevent blood flowing backwards.
- **B** Veins are highly muscular.
- **C** Arteries and veins are both permeable to tissue fluids and white blood cells.
- **D** Blood in arteries is under very high pressure, having just left the heart.

15 Determine the correct pathway of air from the external environment to the lungs.
- **A** mouth/nose → pharynx → larynx → trachea → bronchioles → bronchus → alveoli
- **B** mouth/nose → larynx → pharynx → trachea → bronchus → bronchioles → alveoli
- **C** mouth/nose → pharynx → larynx → trachea → bronchus → bronchioles → alveoli
- **D** mouth/nose → trachea → pharynx → larynx → bronchus → bronchioles → alveoli

16 The enzyme amylase is produced by salivary glands and breaks down
- **A** glucose.
- **B** lipids.
- **C** protein.
- **D** starch.

17 Proteins are polypeptides made from chains of
- **A** amino acids.
- **B** glucose.
- **C** lipids.
- **D** sugars.

18 Animal and plant cells share many common features. However, only plant cells have a
- **A** cell membrane.
- **B** cell wall.
- **C** golgi apparatus.
- **D** vacuole.

19 Peripheral proteins are
- **A** attached to or partially embedded in the cell membrane.
- **B** found within the structure of the cell membrane.
- **C** steroids found in animals.
- **D** the major unit of the phospholipid bilayer.

20 The fluid mosaic model describes the
- **A** arrangement of phospholipids in the cell membrane, where hydrophilic heads are attracted to the water and hydrophobic tails repel the water.
- **B** dynamic structure of the cell membrane, which is embedded with a range of molecules.
- **C** movement of molecules down a concentration gradient from high to low concentration.
- **D** surface area-to-volume ratio that allows organelles to maximise movement of molecules across the membrane.

Short response

21 Photosynthesis occurs in two major sets of reactions. **Identify** these two stages and **state** specifically where each occurs in a plant cell. (4 marks)

22 The plasma membrane of each cell surrounds the cytoplasm, protecting and separating it from the extracellular fluid. The plasma membrane is semi-permeable, with the structure and composition being described by the fluid mosaic model. **Define** the following terms with respect to the plasma membrane:
- **a** semi-permeable (1 mark)
- **b** fluid. (1 mark)

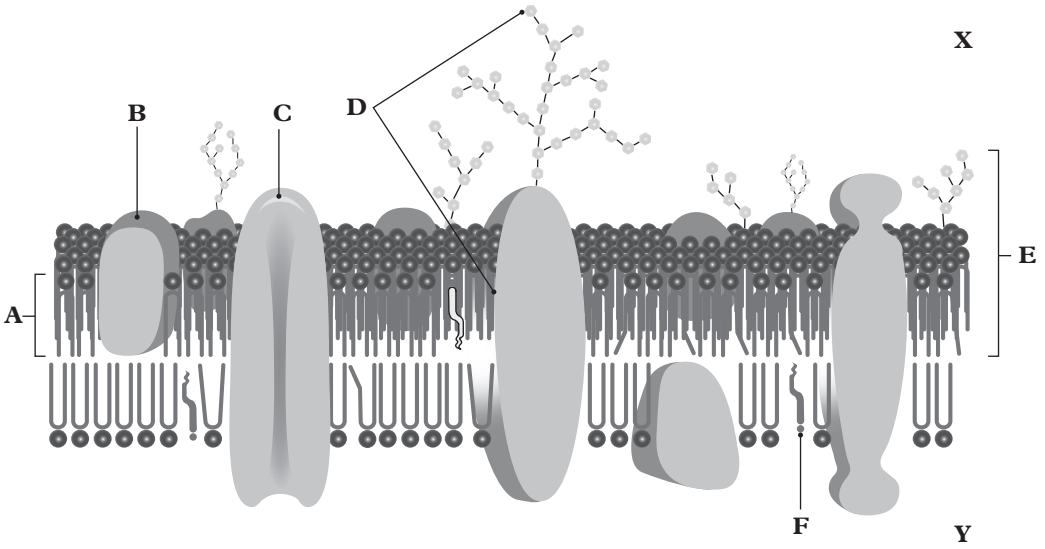
23 **Compare** endocytosis with exocytosis. (2 marks)

24 **Explain** why animals need to "eat" food while plants do not. (2 marks)

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25 The diagram shows the fluid mosaic model of cell membrane structure.

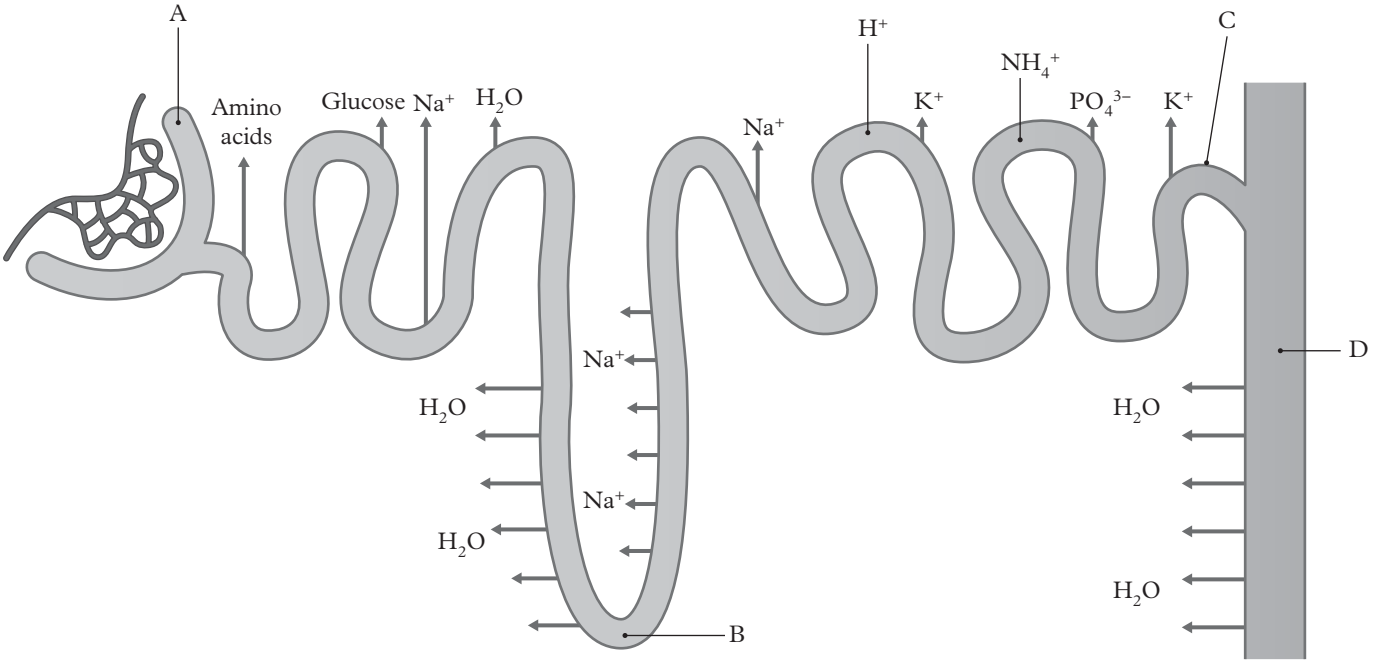


a **Identify** the molecules labelled A and B. (2 marks)

b **Explain** why A is present as a double layer. (2 marks)

c **Deduce** whether the cytoplasm would be on side X or side Y. Justify your answer using evidence from the diagram. (2 marks)

26 The figure shows a diagram of the nephron.



a **Identify** each of the structures labelled A, B, C and D. (4 marks)

b The excretion of urine from the collecting duct can be summarised by the following equation:

Urinary excretion rate = filtration rate – reabsorption rate + secretion rate

If the filtration rate remained constant, **describe** how the reabsorption rate and secretion rate may change to cause the following outcomes:

i high urinary output (1 mark)

ii low urinary output. (1 mark)

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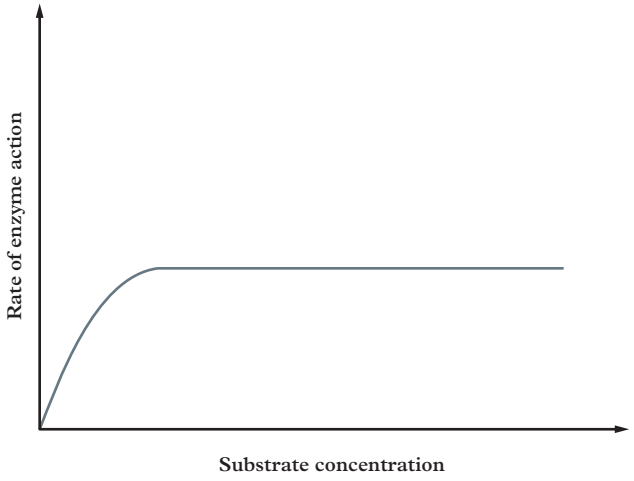
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27 **Compare** anabolism and catabolism. (2 marks)

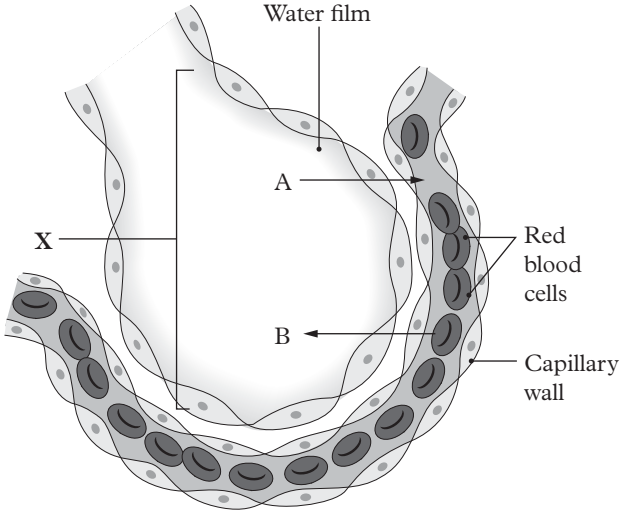
28 **Explain** how the presence of wind affects the rate of transpiration. (2 marks)

29 **Compare** villi and capillaries with respect to their roles in nutrient exchange in biological systems. (2 marks)

30 The graph shows the rate of enzyme action against increasing substrate concentration. Use your understanding of enzymes to **explain** why the graph first increases before plateauing. (2 marks)



31 The diagram shows the structures involved in gaseous exchange in humans.



a **Identify** the structure labelled X. (1 mark)

b **Identify** the process by which gases cross the exchange surface. (1 mark)

c Using the labelling on the diagram, **describe** gas exchange between the capillary and X. (4 marks)

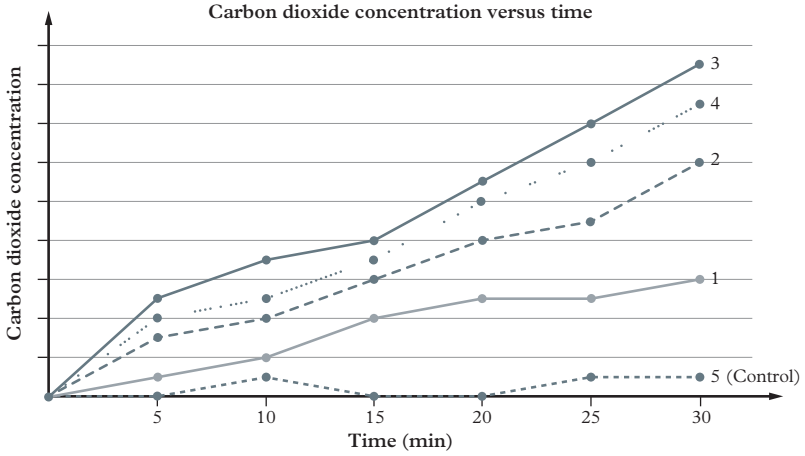
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32 Seeds use cellular respiration to germinate. Germination occurs in the presence of water, and carbon dioxide is produced as a by-product. This process can be affected by temperature, which is why some seeds stay in the ground over winter (regardless of the amount of soil moisture) and begin growing when the soil warms up. An experiment was conducted using germinating peas, which were placed in sealed flasks under the conditions shown in the table.

At 5-minute intervals, the amount of carbon dioxide in each flask was measured to indicate the effectiveness of cellular respiration. The results were plotted and are shown in the graph.

Trial	Moisture	Temperature (°C)
1	+	5
2	+	10
3	+	15
4	+	20
5 (control)	Dry (non-germinating)	15

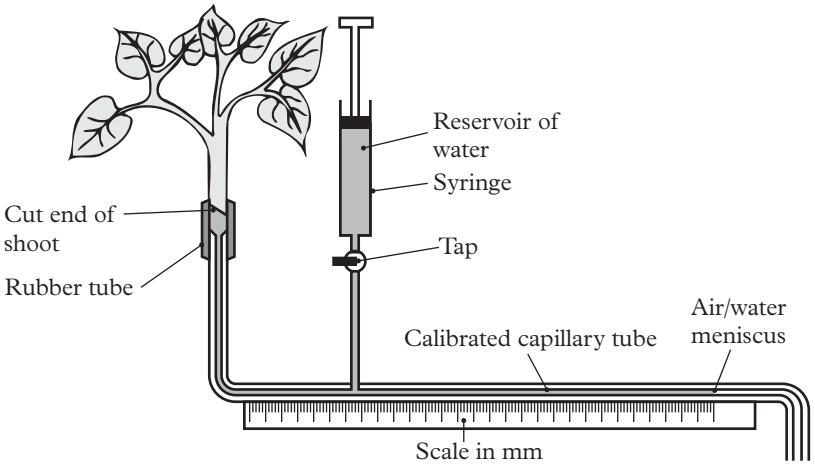


a **Describe** what happened to the rate of carbon dioxide production when the temperature was increased from 5°C to 10°C, and **propose** a reason for this trend. (2 marks)

b **Describe** what happened to the rate of carbon dioxide production when the temperature was increased from 15°C to 20°C, and **propose** a reason for this trend. (2 marks)

c **Identify** the optimum temperature for germinating pea seeds. **Use** evidence from the graph to support your answer. (2 marks)

33 The apparatus shown in the figure is called a potometer and is used to measure transpiration in plants. A tight seal between the base of the plant and the tubing means that when water is lost from the plant, the water level in the calibrated tube decreases.



a **Define** transpiration. (1 mark)

b **Explain** what would happen if the plant shown in the figure did not transpire. (3 marks)

c **Explain** why there is an airtight rubber tube sealing the connection between the water-filled tube and the plant cutting. (2 marks)

d **Describe** the pathway the water takes from the water-filled tube, through the plant to the air. (4 marks)

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34 Rennin is a digestive enzyme that acts on the milk protein casein, causing milk to curdle in the stomachs of mammals such as cattle and sheep. Rennin works by clumping proteins in milk together, so that they stay longer in the intestines, aiding in absorption of nutrients and minerals. An experiment was conducted where rennin was added to milk at different temperatures. Observations were made after 5 minutes and are recorded in the table.

Temperature of milk (°C)	Curdling
4	No
37	Yes
80	No

a **Identify** what type of digestive enzyme rennin is. Justify your answer. (2 marks)

b **Propose** why the milk did not curdle at 4°C. (1 mark)

c **Predict** whether you would expect the milk to be curdled after 2 hours at 4°C. Justify your answer. (2 marks)

d **Explain** why the milk did not curdle at 80°C. (2 marks)

35 An endophyte is an organism, such as a fungus or a bacterium, that lives inside the tissues of plants. An example of this is the ryegrass endophyte *Epichloë* sp., which can be found within the base of ryegrass plants. Because it is a fungus, this endophyte does not photosynthesise. Instead, it takes a portion of the sugars and oxygen produced by the ryegrass to survive. In return, the endophyte increases uptake of water in these plants. Also, its respiratory mechanism increases the amount of CO_2 available to the plant, raising the ryegrass's chance of survival.

a In the table, **identify** whether each input or output of photosynthesis increases, decreases or remains the same in the presence or absence of an endophyte. (10 marks)

Input/output	With endophyte	Without endophyte
Water		
Carbon dioxide		
Sunlight		
Sugars		
Oxygen		

b **Explain** what effect an endophyte would have on the growth of ryegrass. (2 marks)

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UNIT 2

Maintaining the internal environment

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Unit 2 overview

In Unit 2, students explore the ways biology is used to describe and explain the responses of homeostatic mechanisms to stimuli and the human immune system. An understanding of personal and communal responses is essential to appreciate personal lifestyle choices and community health. Students develop scientific skills and conceptual understanding in homeostasis, the immune system and the relationships between global, community and individual immunity. They examine geographical and population data to analyse strategies that may have personal and communal consequences

Unit 2 objectives

1. Describe ideas and findings about homeostasis, thermoregulation and osmoregulation, infectious disease and epidemiology.
2. Apply understanding of homeostasis, thermoregulation and osmoregulation, infectious disease and epidemiology.
3. Analyse data about homeostasis, thermoregulation and osmoregulation, infectious disease and transmission and epidemiology.
4. Interpret evidence about homeostasis, thermoregulation and osmoregulation, infectious disease and epidemiology.
5. Evaluate processes, claims and conclusions about homeostasis, thermoregulation and osmoregulation, infectious disease and epidemiology.
6. Investigate phenomena associated with homeostasis, thermoregulation and osmoregulation, infectious disease and epidemiology.

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Unit 2 Topics

Topic	Module	
Topic 1 Homeostasis – thermoregulation and osmoregulation	**Module 10**	Control and coordination
	Module 11	Thermoregulation and osmoregulation
Topic 2 Infectious disease and epidemiology	**Module 12**	Disease
	Module 13	Epidemiology

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MODULE 10

Control and coordination

Introduction

Each living species has a unique tolerance range of internal factors such as temperature, pH and hydration. The maintenance of the internal environment within these tolerance ranges is called homeostasis. The endocrine and nervous systems of animals respond constantly to internal and external changes to maintain this balance. Feedback loops within and between organs in the body allow continual adjustments to be made to maintain homeostasis.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to control and coordination before you start.

Subject matter

Science understanding

- → Explain how the nervous and endocrine systems use negative feedback to coordinate responses to internal/external stimuli and maintain homeostasis (stimulus-response model).
- → Identify the different types of sensory receptors and their stimuli, including chemoreceptors, thermoreceptors, mechanoreceptors, photoreceptors and nociceptors.
- → Describe the structure and function of nerve cells, including dendrites, soma, body, axon, myelin sheath, nodes of Ranvier, axon terminal and synapse.
- → Distinguish between sensory neurons, interneurons and motor neurons.
- → Explain the passage of a nerve impulse in terms of transmission of an action potential and synaptic transmission, referring to neurotransmitters, receptors, synaptic cleft, vesicles, postsynaptic and presynaptic neurons and signal transduction.
- → Describe how hormones relay messages to cells displaying specific receptors via the circulatory or lymphatic system.

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→ Explain how receptor binding alters cellular activity, recognising that a cell's sensitivity to a specific hormone is directly related to the number of receptors it displays for that hormone.

→ Analyse feedback-control diagrams to identify the stimulus, receptor/s, control centre, effector/s and communication pathway/s in different scenarios.

Science inquiry skills

→ Design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data required to obtain valid and reliable evidence.

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Practicals

oxforddigital **This lesson is available on Oxford Digital.**

Lesson 10.4 The reflex arc

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Lesson 10.1
Homeostasis

Key ideas

- → Organisms must regulate their body systems by monitoring their internal and external environments.
- → Organisms maintain homeostasis according to their tolerance ranges for a variety of abiotic conditions.
- → Homeostasis describes the maintenance of an organism's body systems through positive and negative feedback loops.
- → The stimulus–response model allows organisms to detect environmental changes and respond, to maintain homeostasis.

Learning intentions and success criteria

Homeostasis and tolerance

Organisms must be able to monitor changes in their environment so they can respond in a way that enhances their chance of survival. This includes monitoring and responding appropriately to changes in the external environment, such as temperature, intensity and direction of sunlight, humidity and food availability. Organisms must also be able to monitor their internal environment for factors including hydration, temperature, and concentration of gases and wastes in the bloodstream.



FIGURE 1 Sunflowers move their flowerheads to follow the movement of the sun, which maximises their exposure to sunlight.

tolerance range the range of an environmental factor of an organism from the lowest level to the highest level it can tolerate for survival

homeostasis the self-regulation of a stable internal environment regardless of external environmental conditions

Because an organism's external and internal environments are always changing, the abiotic and biotic factors that influence the organism's survival are constantly fluctuating. Metabolic reactions change the concentration of both essential and waste molecules in the cell and the bloodstream. If the concentrations of these molecules are not kept within an organism's **tolerance range**, it can be harmful to the organism. To survive these continual fluctuations, organisms have developed behavioural, physiological and structural adaptations to keep their internal environment within its tolerance range. **Homeostasis** is the maintenance of a stable internal environment in response to changing internal and external factors. Metabolic reactions occur constantly in cells to maintain homeostasis and enable survival.

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The stimulus–response model

A **stimulus** is any change to the internal or external environment of an organism that triggers a **response** in the organism. Stimuli are detected by **receptors**, which are molecules that monitor the internal and external environments. Receptors that monitor internal environments are located throughout the cells, tissues and organs of the body and can detect changes to factors such as pH, temperature, pressure and gas concentration. Receptors that monitor the external environment are located throughout the skin and organs on the outside of the body, such as the eyes and the ears. These receptors interpret information about the organism's surroundings by detecting changes to factors such as temperature, pressure, light, smell and taste. The continual monitoring of the internal and external environments by receptors allows the **central nervous system (CNS)** to respond to changes and maintain homeostasis.

stimulus
a change in the internal or external environment that can be detected by receptors

response
an organism's reaction to a stimulus

receptor
molecules that monitor internal and external stimuli

central nervous system (CNS)
the coordination centre of vertebrates, consisting of the brain and spinal cord

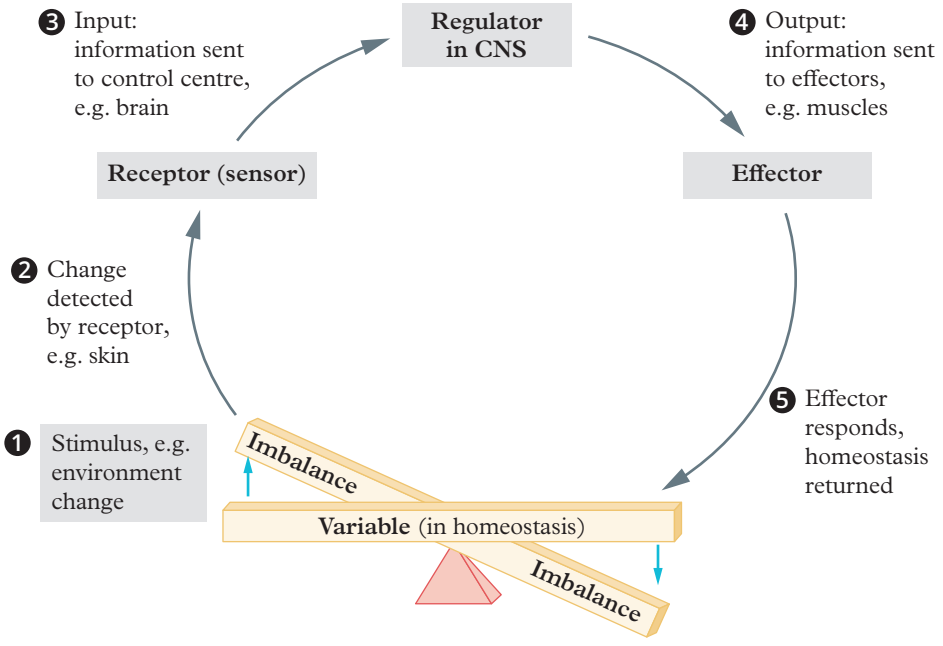


FIGURE 2 The stimulus–response model

When a stimulus is detected, changes to the receptor molecule occur, initiating a signal, which is then sent to the **regulator** in the CNS. The regulator processes the information from the stimulus and sends a response to the appropriate **effector** cells or organs. In animals, effectors are often glands that respond by releasing hormones, or muscles that respond by moving. In plants, responses usually involve the release of hormones produced by cells all around the plant, rather than from a gland.

regulator
the part of the central nervous system that receives a stimulus signal and responds by sending a signal to an effector

effector
the cell or organ (e.g. a gland or a muscle) that responds to a stimulus

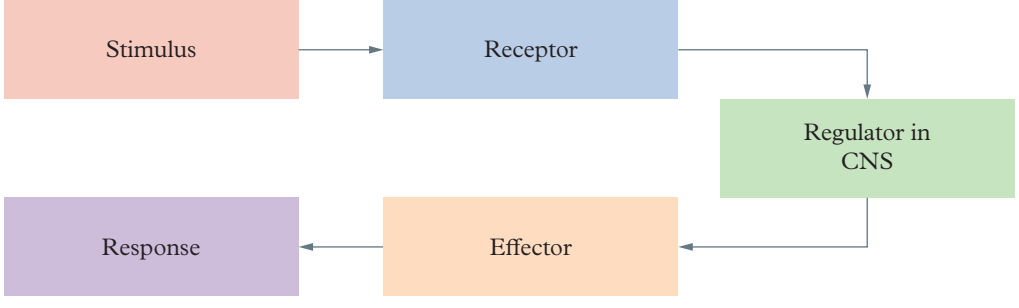


FIGURE 3 Basic components of the stimulus–response model

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Feedback mechanisms



FIGURE 4 Marine iguanas in the Galapagos Islands respond to a reduction in body temperature from swimming in cold water by basking on warm rocks in the sun (a behavioural response).

Changes in a particular factor activate the regulator, which directs the effector to initiate a response that will help return the factor to its optimal range. This response may then act as another stimulus that either stops or maintains the factor, a homeostatic process called **feedback**. Feedback links the parts of the control system, allowing the output of the effector to be regulated by the input to the regulator. There are two types of feedback:

- **negative feedback**, in which the response is slowed or stopped
- **positive feedback**, in which the response is maintained or amplified.

feedback
a process in which the end product or event of a system influences the operation of that system to regulate its activity

negative feedback
a form of feedback in which a signal triggers a process to stop when the optimal range of a factor has been reached

positive feedback
a form of feedback in which a signal triggers the amplification of a process to bring about change in the body

Negative feedback

In many stimulus–response processes, the result of the effector's response opposes the original stimulus. For example, if core body temperature is too high (stimulus), it will trigger a response of vasodilation (widening of blood vessels), which allows the body to lose heat and lower core body temperature. Once core temperature has lowered and returned to normal, this change is detected and acts as a new stimulus that triggers vasodilation to stop (response). This is an example of a negative feedback system: the stimulus (high core temperature) triggers a response (vasodilation) that changes the stimulus (lowered core temperature) and subsequently stops the response (vasodilation), to maintain homeostasis (normal core temperature).

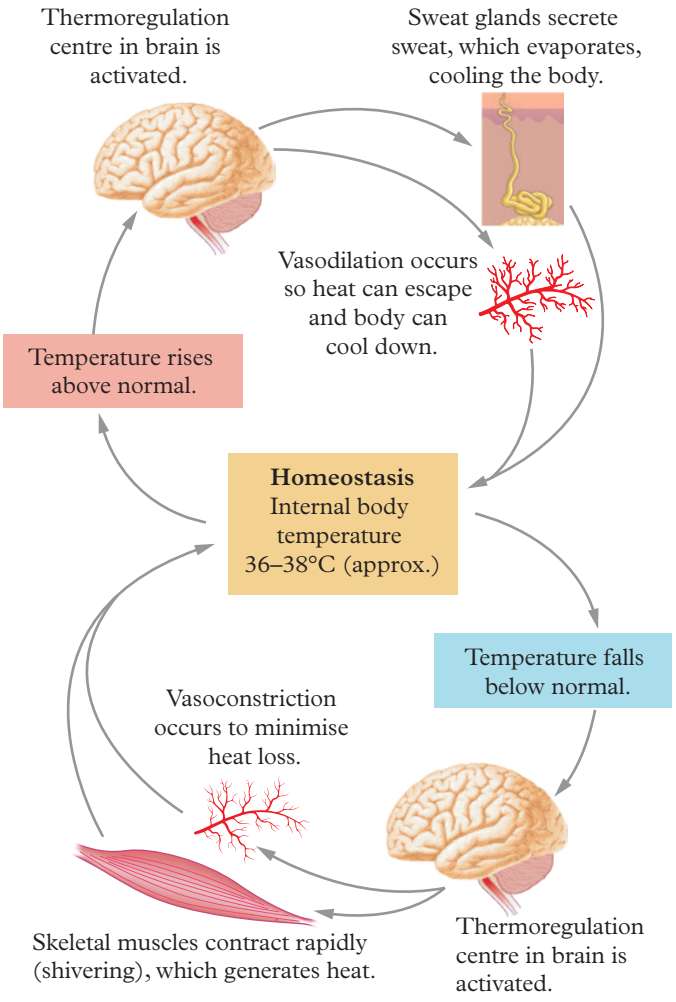


FIGURE 5 Regulation of body temperature is an example of negative feedback.

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Homeostasis in vertebrates is controlled mostly through negative feedback systems. Fluctuations above or below the optimal level of a factor trigger a corrective response, allowing the system to self-adjust to changing conditions. When the stimulus detected indicates that a level is too high, the response of the effector lowers the level. When the stimulus detected indicates that a level is too low, the response of the effector raises the level. Levels of any factor fluctuate slightly above or below the optimal point until they stabilise, and these control systems are managed by the nervous and endocrine systems.

Positive feedback

Positive feedback occurs when the effect of an effector's response amplifies or promotes the original stimulus. An example in human bodies is when a cut or a scratch causes bleeding through a break in the skin. The damaged cells release a chemical that causes platelets to become activated. These platelets release more chemicals that signal for further platelets to be produced and move to the site, resulting in a blood clot that prevents bleeding. Another example of a positive feedback system is the release of hormones that induce labour during childbirth. The presence of the hormones triggers the release of more hormones, and the labour increases in intensity until the baby is born.

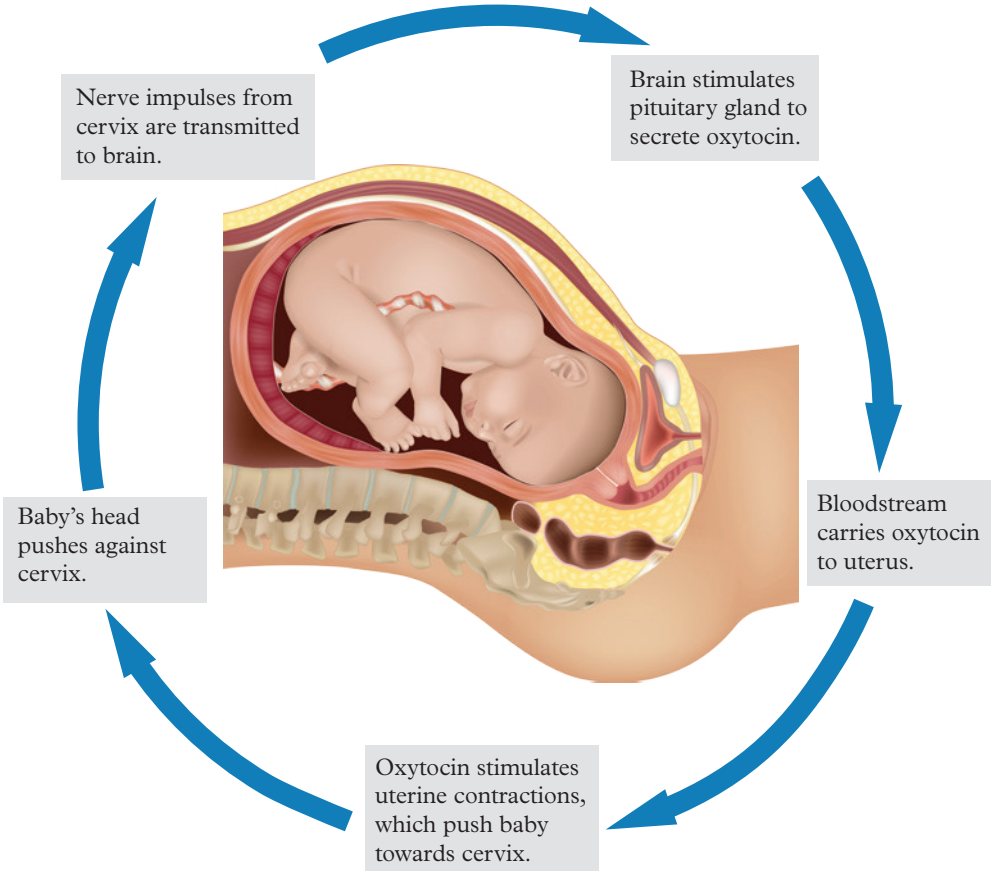


FIGURE 6 Production of oxytocin during childbirth is an example of a positive feedback loop.

The two systems responsible for coordinating responses in animals are the endocrine and nervous systems. These systems maintain homeostasis and survival of organisms through the process of stimulus and response. The stimulus is a detectable change in the external or internal environment, and the response is an appropriate and targeted action. Plants coordinate homeostatic changes either through a direct cellular response to chemical change or the release of hormones that act on target cells or organs.

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Check your learning 10.1

Check your learning 10.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** "homeostasis". (1 mark)
2 **Identify** three stimuli that may trigger a response to maintain homeostasis. (3 marks)

Analytical processes

3 **Contrast** receptors and effectors of the nervous system. (1 mark)
4 **Compare** positive feedback loops and negative feedback loops. (2 marks)

Lesson 10.2
The nervous system

Learning intentions and success criteria

nervous system
a biological system made up of the brain, spinal cord and nerves; sends messages and coordinates actions

action potential
an electrical signal that flows from the soma of a neuron along the axon to the axon terminal, passing information to the next neuron

dendrite
segments branching from the soma of a neuron that detect a stimulus from the environment or other cells

soma
the main body of a cell, containing the cytoplasm and nucleus

axon
a long thin projection from the soma of a neuron (nerve cell) that conducts electrical impulses, called action potentials

axon terminal
a projection at the end of an axon that releases neurotransmitters into the synaptic cleft

Key ideas

- → The structure and distribution of the nervous system within an organism allows communication between organs and response to stimuli.
- → The structure and function of neurons enable a variety of signals to be transported between and within body systems.
- → The generation and propagation of an impulse within a neuron determines how, when and whether a signal is sent through the nervous system.
- → Neurons transmit signals to each other and to other cell types, such as muscle cells.

Neurons

The **nervous system** is a coordinating system that detects stimuli and initiates an appropriate response. It is made up of nerve cells, called neurons, which have a specialised structure that allows electrical impulses to rapidly transmit information around the body. Ion concentrations across the cell membrane of the neuron facilitate the movement of an electrical signal through the neuron, taking information from one neuron and passing it to the next. This process is called an **action potential** and is triggered by stimulation of **dendrites** by surrounding neurons.

The specialised structure of neurons allows the transmission of electrical impulses around the body. Neurons vary slightly in structure according to their purpose but they are typically made up of a **soma** (cell body), dendrites, an **axon** and **axon terminals**. Neurons share some common features but different types are specialised for their unique purpose within the body.

The soma or cell body of a neuron contains the nucleus, large organelles and proteins. Two types of long, thin, cytoplasmic branches extend from the soma: dendrites and axons. Dendrites are often shorter and have many branches, and their main function is to receive input from surrounding cells and molecules. Axons are usually long, and branch into axon terminals at the very end. The role of the axon is to carry electrical impulses from the soma to the cell's axon terminals, where the signal is passed on to adjacent cells.

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Most axons are covered by specialised **Schwann cells**, which produce a protective substance called **myelin** to create a **myelin sheath**. The myelin sheath contains a high concentration of lipids, which provide protection for the axon and insulation of the electrical signal as it passes along the axon. Gaps between Schwann cells expose the axon and allow acceleration of the electrical impulse – these gaps are called **nodes of Ranvier**.

Neurons that detect stimuli are called **afferent (sensory) neurons**. They send information in the form of electrical impulses towards the central nervous system. Neurons that bring about a response by effectors are called **efferent (motor) neurons**. They send information in the form of electrical impulses away from the central nervous system. **Interneurons** in the central nervous system connect afferent and efferent neurons to each other, allowing a stimulus to trigger a response.

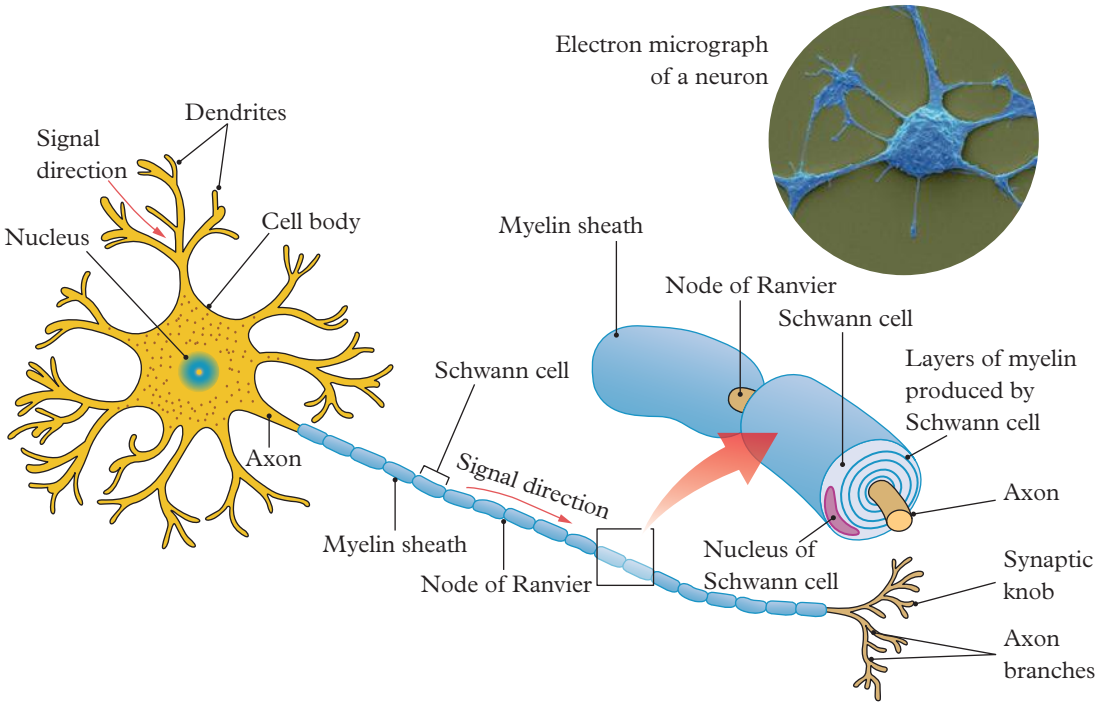


FIGURE 1 The structure of a neuron

Conduction of electrical impulses along neurons

Like all animal cells, neurons have a phospholipid bilayer cell membrane. Chemical and electrical changes along the cell membrane of the neuron allow the conduction of a nerve impulse. Sodium ions (Na^+) and potassium ions (K^+) are present both inside the neuron and surrounding the neuron, with sodium ions slightly more abundant outside the cell and potassium ions slightly more abundant inside the cell. Because sodium ions have a higher electronegativity than potassium ions, the outside of the cell has a positive charge relative to the negative charge inside the cell. This causes the cell to become **polarised** across its cell membrane. In this resting state, the voltage across the cell membrane of the neuron is 70 mV (millivolts). The polarisation of the cell membrane of a neuron at rest is maintained by an integral protein called a **sodium–potassium pump**. Sodium–potassium pumps use energy in the form of ATP to pump sodium ions from the inside to the outside of the cell against the concentration gradient, to maintain the –70 mV voltage across the cell membrane. For every three sodium ions pumped out of the cell by the sodium–potassium pump, two potassium ions are brought into the cell. Neurons in this inactive, polarised state are at their **resting potential**.

Schwann cell
a cell that produces fatty myelin, which makes up the myelin sheath of a neuron

myelin
a lipid-rich substance that coats the axons of neurons

myelin sheath
a layer of myelin that wraps around the axon of a neuron to insulate electrical impulses

nodes of Ranvier
spaces between Schwann cells where the axon is not covered by the myelin sheath; allows acceleration of the action potential along the neuron

afferent neuron
a nerve cell that relays signals from sensory receptors to the central nervous system (sometimes referred to as sensory neurons)

efferent neuron
a nerve cell that relays signals from the central nervous system to effectors such as muscle cells and endocrine glands

interneuron
a type of nerve cell in the central nervous system that relays signals from afferent neurons to efferent neurons in the peripheral nervous system

polarised
the state of a cell when the electrical charge on the inside of the cell membrane is different than that of the extracellular environment

sodium–potassium pump
an integral protein in the cell membrane of animal cells that pumps sodium ions across the cell membrane against the concentration gradient

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resting potential
a polarised state of the cell membrane of a neuron when the inside of the membrane is more negative than the outside; the resting state of a neuron when it is not actively sending a signal

neurotransmitter
a chemical that passes across the synapse between the axon terminal of one neuron to the dendrites of another

Nerve impulses in neurons are generated by sensory cells or the activity of an adjacent neuron. The impulse begins when the dendrites are stimulated and send a chemical signal to the soma of the neuron. The stimulus received by the dendrites causes a change in the electrical potential of the soma and the attached axon. When the change in the electrical potential reaches a critical point, an electrical signal passes along the membrane of the axon to the synapse, where **neurotransmitters** are released to stimulate the next cell. This process of changes in electrical potential allowing an electrical signal to pass along a neuron is called an action potential.

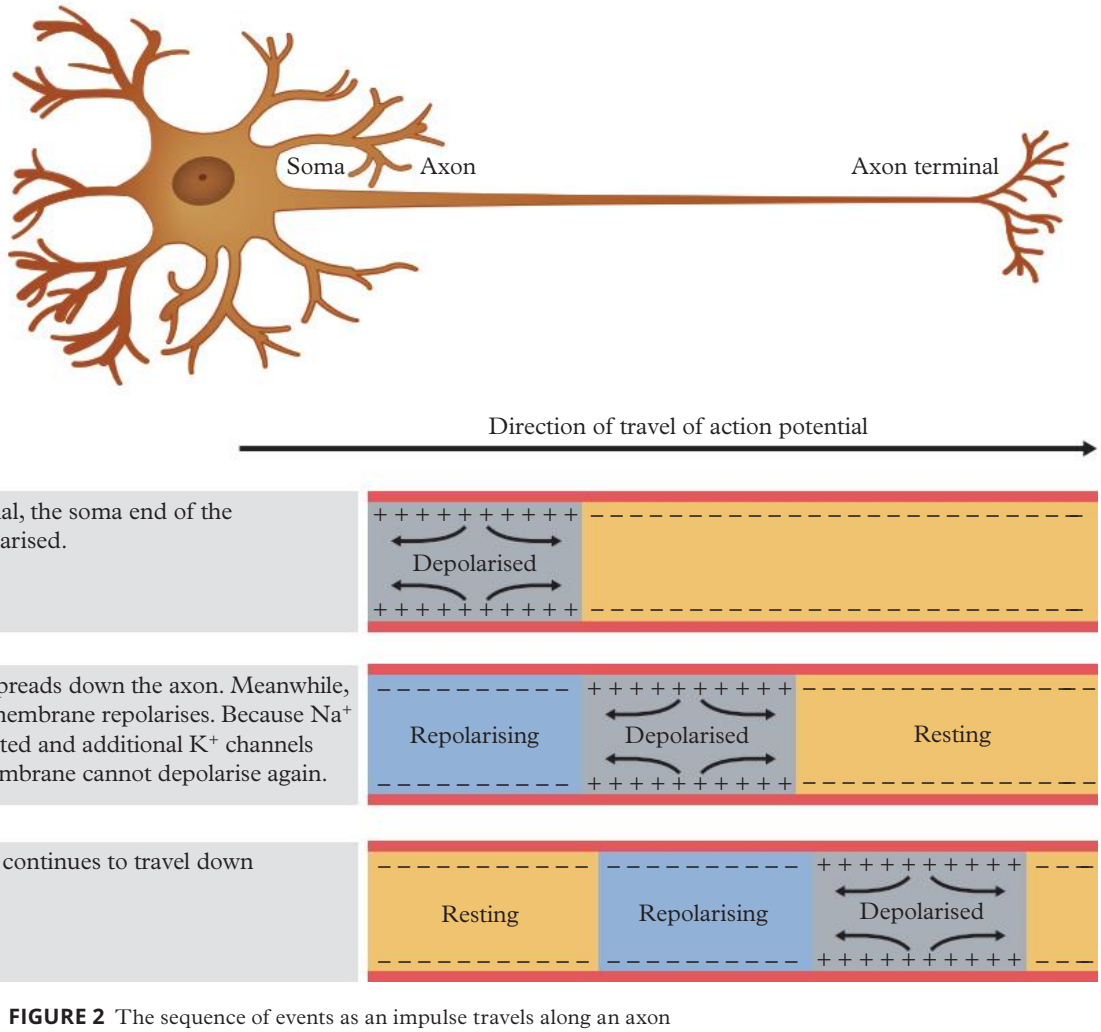


FIGURE 2 The sequence of events as an impulse travels along an axon

Action potential

Initiation and conduction of nerve impulses are the result of changes to the electrical potential difference (voltage) across the cell membrane in the axon of a neuron. These changes in one section of the axon membrane trigger a change in the adjacent section, and so on down the axon until the signal reaches the axon terminals. Immediately following the change in voltage of a section of the membrane, it returns to resting potential. The entire process of a nerve impulse travelling through a neuron via action potential takes approximately six milliseconds.

The conduction of a nerve impulse through the axon of a neuron is like a wave of electrical changes, which we call an action potential, and is summarised as follows:

1 A neuron at rest (not conducting a signal) exists in a polarised state with a negative charge of –70 mV maintained by the sodium–potassium pumps in the cell membrane.

2 A stimulus received by the dendrites depolarises a section of the neuron membrane. Sodium channels in the cell membrane open in response and sodium ions flow into the

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cytoplasm of the neuron. The increased concentration of sodium ions causes the inside of the neuron to have a more positive charge. The influx of sodium ions triggers more sodium channels to open, causing a greater influx of sodium ions and raising the voltage to +40 mV. This depolarisation of the cell membrane allows electrical energy to travel down the axon, creating an action potential.

3 The depolarisation of the membrane moves to the adjacent section of the axon, allowing the signal to move in one direction along the neuron from soma to axon terminals.

4 Following the peak of the action potential voltage (+40 mV), potassium channels open, allowing potassium ions to pass through to the outside of the membrane, restoring its positive charge. Sodium channels close, to prevent sodium entering the cell. **Repolarisation** of the cell membrane occurs, returning it to resting potential.

5 Immediately following the action potential, a temporary **undershoot** of electrical potential difference across the membrane of the axon is caused by the movement of potassium ions. This causes the inside of the cell to be more negative than resting potential, and is called the **refractory period**. Subsequent action potentials cannot occur during the refractory period, until repolarisation is complete and the electrical potential difference returns to –70 mV.

6 Sodium pump function is restored and sodium ions are pumped out of the cytoplasm until resting potential is restored.

The **threshold potential** is the change in electrical potential required across the membrane to trigger an action potential. An action potential will occur in neurons when the voltage across the cell membrane of an axon changes from –70 mV to –55 mV. Changes to voltage that do not reach –55 mV do not trigger an action potential and no signal is sent to the next neuron. An action potential is an **all-or-nothing response**. This means that even if a stimulus generates a greater voltage change than –55 mV, it will produce no greater response in the electrical signal. The threshold potential is either reached and the action potential occurs, or it is not reached and no signal is sent.

The influx of sodium ions in one section of the membrane influences the voltage of adjacent sections of the axon, triggering the movement of the action potential and signal along the axon in a wave-like motion.

repolarisation
the change in membrane potential that occurs after the depolarisation phase of an action potential

undershoot
when a membrane potential briefly becomes more negative than its resting potential

refractory period
a period of time in which the neuron cannot fire another action potential

threshold potential
the level of depolarisation across the cell membrane required to initiate an action potential

all-or-nothing response
describes an action potential, which will occur (neurons will fire at full strength) if the threshold potential is met, or not occur (neurons will not fire) if the threshold is not met

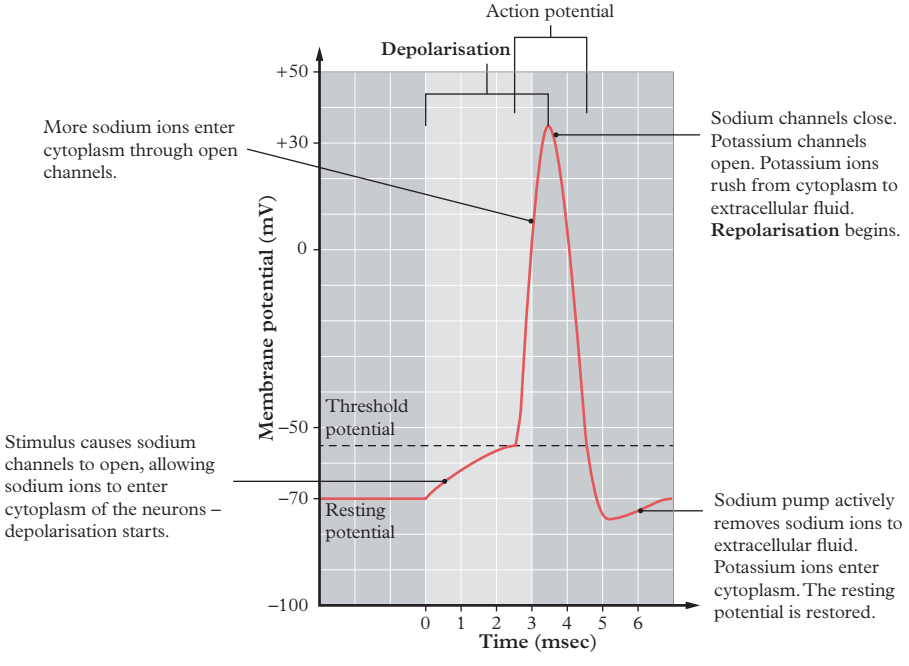


FIGURE 3 Simplified diagram of the depolarisation and repolarisation of the neuron membrane

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Synapses

synapse
the junction between adjacent neurons, or neurons and effectors, where neurotransmitters are released and received

Neurons transmit information to each other by releasing neurotransmitters across the junction between them, called a **synapse**. The synapse extends from the ends of the axon terminal of one neuron, where information is released, to the tips of the dendrites of an adjacent neuron, where information is received. This includes transmission from neuron axon terminals to effectors such as glands and muscles.

The main parts of the synapse are:

- the **pre-synaptic terminal**, which is located at the end of an axon and is the area that releases neurotransmitters into the space between the two neurons
- the **synaptic cleft**, which is the small gap between neurons that the neurotransmitters must cross
- the **post-synaptic membrane**, which is located at the dendrites of another neuron or an effector (e.g. gland or muscle tissue) and is the site that receives the information in the form of neurotransmitters.

pre-synaptic terminal
a specialised area at the end of an axon; contains synaptic vesicles that store neurotransmitters

synaptic cleft
the space between the axon terminals of one neuron and the dendrites of another

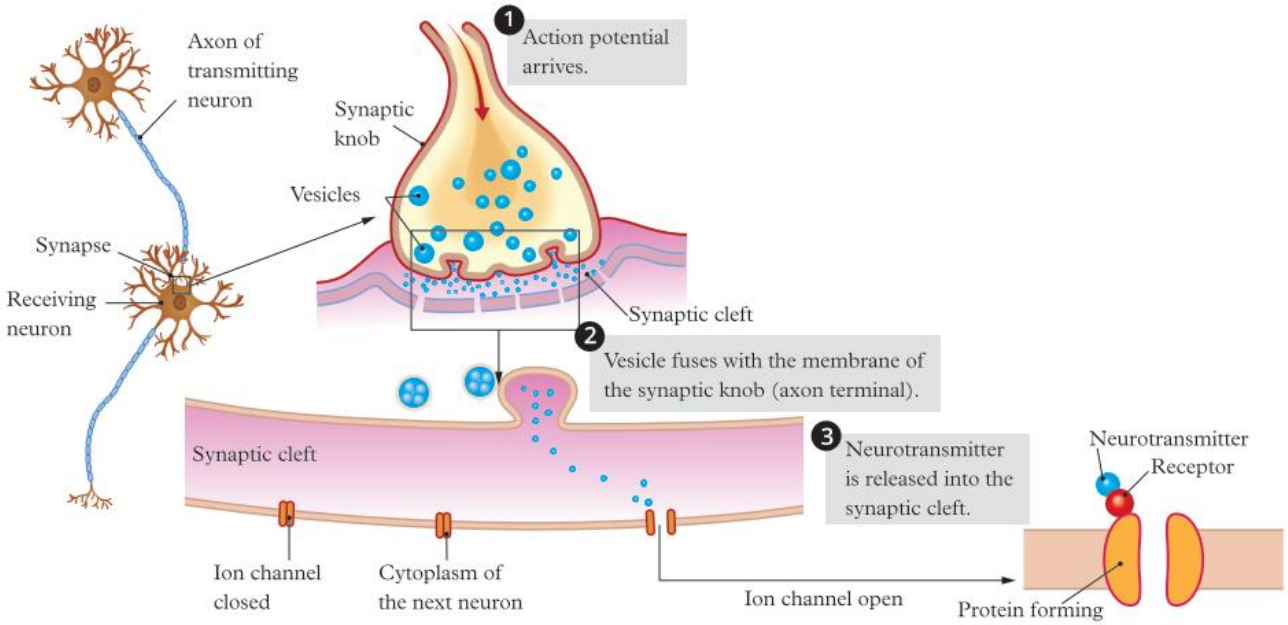


FIGURE 4 General features of neural transmission across a synapse

post-synaptic membrane
a section on the membrane of a post-synaptic neuron; contains areas adapted to receive neurotransmitters

vesicle
a membrane-bound structure that, in neurons, stores neurotransmitters before they are released into the synaptic cleft

Neurotransmitters

Most connections between neurons have a wide synaptic cleft that does not allow the direct electrical flow of an action potential between adjacent neurons. In these synaptic connections, chemical substances called neurotransmitters are released from synaptic **vesicles**, which are membrane-bound structures in the pre-synaptic neuron that store neurotransmitters and release them close to the synaptic cleft. Neurotransmitters released from the pre-synaptic terminal into the synaptic cleft are received by receptors on the post-synaptic terminal of the

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next neuron. The neurotransmitters create a change in the permeability of the cell membrane of the receiving neuron, contributing to its depolarisation and the triggering of an action potential. Receptors are only present on the post-synaptic terminal and so electrical impulses in neurons can flow in only one direction: from dendritic receptors, through the soma and along the axon to the axon terminals. A few different molecules act as neurotransmitters, with two of the most common being **acetylcholine (ACh)** and **noradrenalin**.

acetylcholine (ACh)
a neurotransmitter involved in many functions in the body, including brain function and muscle movement

noradrenalin
a neurotransmitter involved in arousal and the 'fight-or-flight' response

Check your learning 10.2

Check your learning 10.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the integral protein responsible for maintenance of resting potential in a neuron. (1 mark)
2 **Describe** the resting potential of a neuron in relation to charge across the cell membrane and concentration of sodium and potassium ions. (3 marks)
3 **Explain** how signals move between adjacent neurons, if the neurons are not in physical contact. (4 marks)

Analytical processes

4 **Contrast** the role of the pre-synaptic terminal and the post-synaptic membrane. (1 mark)

Lesson 10.3
Organisation of the nervous system

Key ideas

→ The mammalian nervous system is organised into the central and peripheral nervous systems.
→ The brain is part of the central nervous system and communicates with the rest of the body through the brainstem.
→ Sensory pathways between the peripheral nervous system and the central nervous system are made up of afferent neurons, interneurons and efferent neurons.
→ Reflex arcs, or reflexes, are the fastest neural pathways and are an evolutionary adaptation for survival.

Learning intentions and success criteria

Divisions of the nervous system

The nervous system of mammals, including humans, is made up of:

- the brain and the spinal cord, which together are known as the central nervous system (CNS)
- all the nerves and **ganglia** outside the CNS, which together are known as the **peripheral nervous system (PNS)**.

ganglia
clusters of nerve cells

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The central nervous system

The CNS consists of the brain and the spinal cord. The spinal cord attaches at the bottom of the brain and is protected by the bones of the vertebral column (spine). The brain controls almost everything in our body, including our thoughts, emotions, hunger, thirst, breathing, temperature and the way we move our muscles. The primary purpose of the spinal cord is to connect the peripheral nervous system with the brain and, at times, to connect sensory neurons directly to motor neurons to produce reflexes.

The peripheral nervous system

peripheral nervous system (PNS)
the system of nerves that carries stimulus information from receptors to the CNS, and nerves that carry responses from the CNS to effectors

Neurons in the **peripheral nervous system (PNS)** are bundled together into nerves and ganglia. Nerves are bundles of axons or dendrites wrapped in a sheath of connective tissue and myelin. They contain both sensory and motor neurons to transmit signals to and from the CNS. The connective tissue and myelin sheath insulate the nerve impulses, to prevent them from moving between nerves or weakening. Ganglia are bundles of somas (cell bodies) at the beginning of a nerve that receive a stimulus to trigger the action potential.

Neural pathways

Behavioural, motor and chemical responses are brought about by signals sent from receptors in the PNS to the CNS, where a response is coordinated and sent back to the PNS to act on effectors. The three types of neurons involved in neural pathways are afferent (sensory) neurons, interneurons and efferent (motor) neurons.

Sensory (afferent) neurons

Neurons that detect stimuli from the external environment and send the information to the CNS are called afferent or sensory neurons. Afferent neurons detect stimuli such as temperature, pressure, taste, hearing and vision.

Interneurons

Interneurons are located in the CNS and link afferent to efferent neurons, or neurons within the CNS to each other.

Motor (efferent) neurons

Efferent or motor neurons send signals from the CNS to effectors to bring about a response, such as muscle movement or the release of hormones from glands.

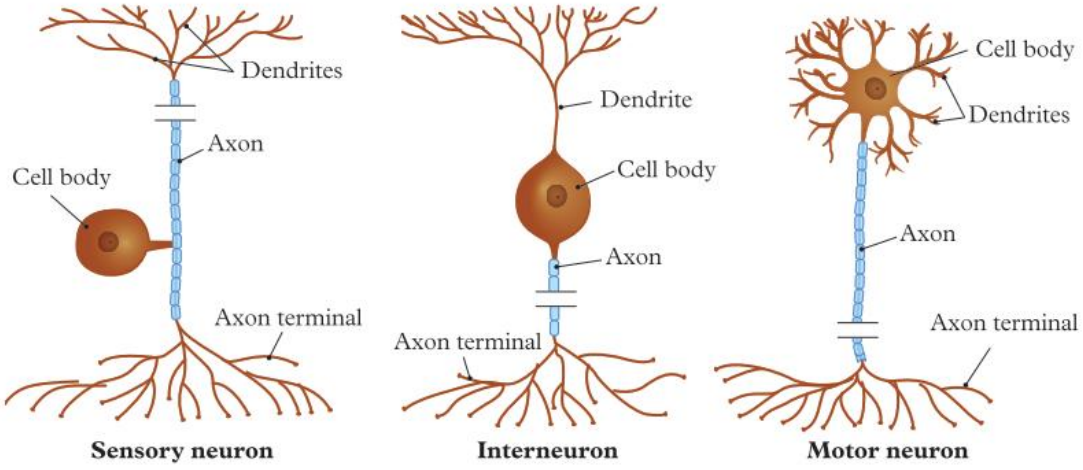


FIGURE 1 Some types of neurons: (A) sensory neurons, (B) interneurons and (C) motor neurons

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Reflex arcs, or reflexes, are the fastest neural pathways and are an evolutionary adaptation for survival. A reflex is a signal that passes from an afferent neuron that has detected a dangerous stimulus almost directly to an efferent neuron to trigger a life-saving response. Because the signal goes through the CNS, it may pass through an interneuron but is not processed by the brain, and the brain may become aware of the stimulus at the same time as the motor response. Examples of reflex arcs are: instantly moving a body part away from burning heat, blinking when something enters the eye, and gagging when choking on food.

reflex arc (reflex)
a neural pathway connecting sensory neurons to interneurons in the spinal cord and directly to motor neurons, to enable a rapid response without processing by the brain, e.g. movement of a limb away from extreme heat

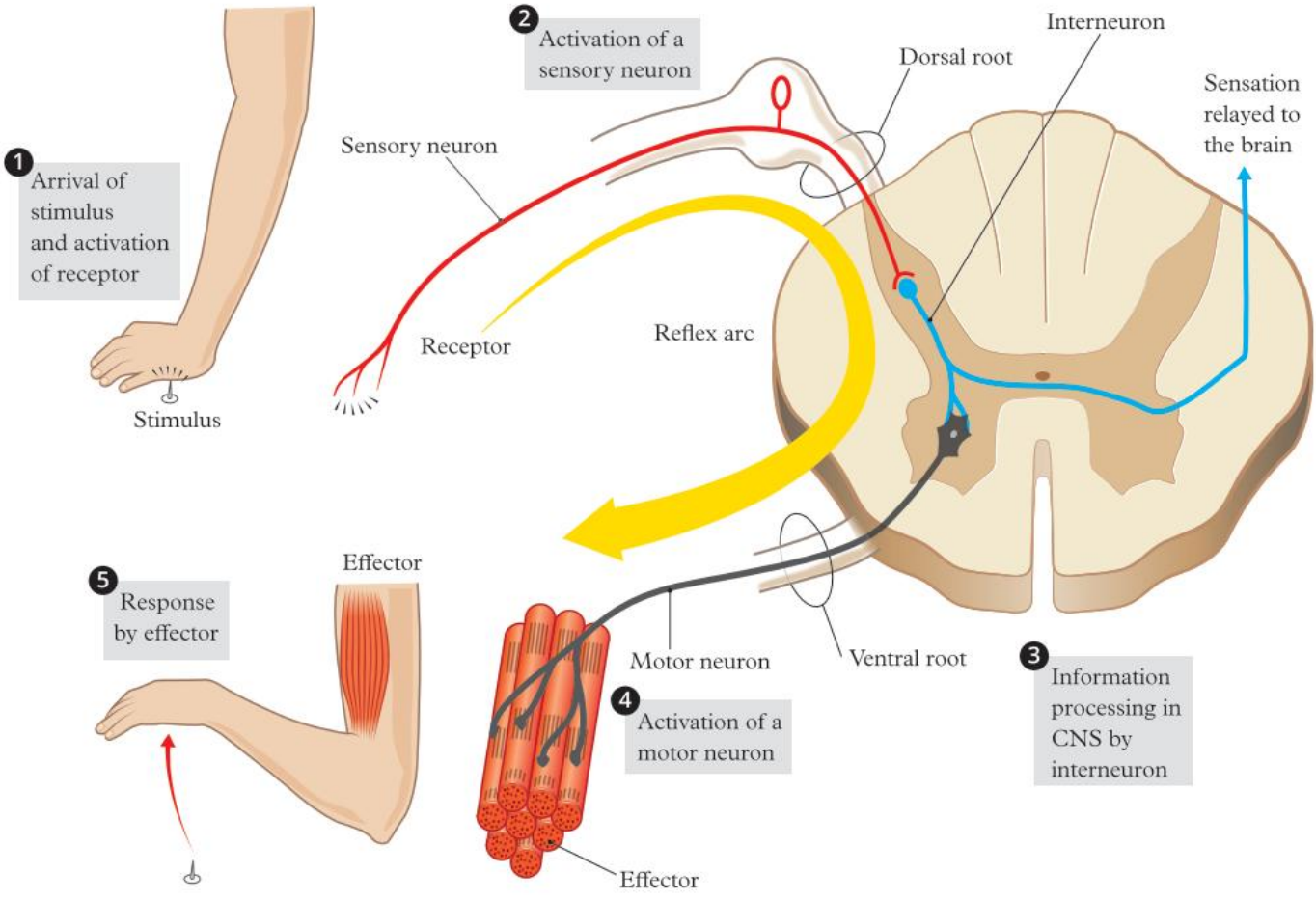


FIGURE 2 A reflex arc. The immediate response is to pull away from the stimulus (pinprick). After the reflex action has occurred, information is also sent to the brain.

Real-world biology

Palmar grasp reflex

Have you ever noticed that if you put your finger into a newborn baby's hand, they will grab your finger tightly? This is a reflex arc known as the palmar grasp reflex. The reflex develops while the baby is still developing in the womb and is replaced at 3 to 6 months of age by voluntary movement of the hands to hold objects. This reflex arc begins when



FIGURE 3 A newborn baby holds tightly onto their mother's finger, due to the palmar grasp reflex.

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mechanoreceptors in the palm of the baby's hand detect touch or pressure. A signal from the mechanoreceptor is sent along the sensory neuron to the spinal cord, where the CNS immediately sends a signal through a motor neuron to contract the hand muscles. This results in the baby immediately grasping anything that comes into contact with their hand. The palmar grasp reflex is thought to be an evolutionary leftover from one of our arboreal (tree-dwelling) ancestors. The ability to grasp an object as a very fast reflex would have allowed babies to hold onto the hair or skin of their parents and stopped them falling out of trees. Nowadays, this interesting reflex arc is mostly used to assess the development of babies.

Apply your understanding

1 **Identify** the three types of neurons involved in the palmar grasp reflex. (3 marks)
2 **Infer** the outcome for the babies of our arboreal ancestors if the palmar grasp reflex had been a conscious movement rather than a reflex. (2 marks)

Skill drill

Designing reaction-time investigations

Science inquiry skill: Planning investigation (Lesson 1.4)

A person's reaction time refers to how long it takes them to respond to a stimulus. The nervous system can respond to stimuli within a fraction of a second, and in some cases that reaction time can be improved. Athletes are often trained to sharpen their reflexes by decreasing their reaction time to different stimuli.

Reaction timers are devices that test hand–eye coordination and can be used to improve a person's reaction time. One form of reaction timer is a reaction wall – a large panel mounted on a wall with lights that have to be touched as soon as they light up. Figure 4 shows a reaction wall where eight lights in a circle randomly switch on, and the user needs to switch them off by quickly hitting the lit-up circle.

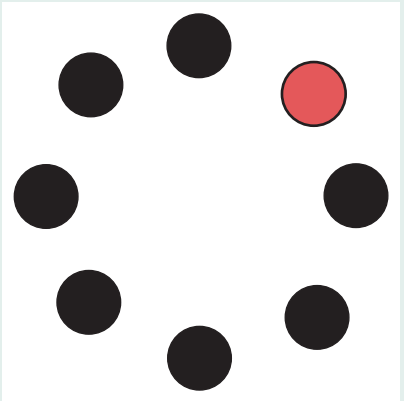


FIGURE 4 A reaction wall uses lights to test an individual's reaction speed.

Practise your skills

1 **Design** an experiment that uses a reaction wall to test your classmate's reaction times and monitor whether their performance changes after repeated practice. In the design of your experiment, include:
   - an aim
   - a hypothesis
   - a method. (3 marks)
2 **Predict** whether the results of this experiment will show an increase, decrease or no change in reaction time. **Justify** your prediction. (2 marks)

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Check your learning 10.3

Check your learning 10.3: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the two components of the central nervous system. (2 marks)

2 **Explain** what a reflex arc is, including the neuron types involved. (4 marks)

Analytical processes

3 **Distinguish** between sensory neurons, motor neurons and interneurons. (1 mark)

4 **Compare** the central nervous system and the peripheral nervous system. (2 marks)

Practical

Lesson 10.4
The reflex arc

Learning intentions and success criteria

This lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.

Lesson 10.5
Sensory receptors

Key ideas

- → Internal and external environmental changes are detected by sensory receptors in the PNS.
- → Sensory receptors send signals through the PNS to the CNS for processing and to coordinate a response.
- → Sensory receptors are specialised for the different types of information they detect, including pressure, temperature, smell, taste, light and movement.
- → Types of sensory receptors are chemoreceptors (taste and smell), mechanoreceptors (movement), thermoreceptors (heat), photoreceptors (light) and nociceptors (pain).

Defining sensory receptors

Learning intentions and success criteria

Sensory organs such as the eyes, ears, nose, mouth and skin contain specialised neurons known as sensory receptors, which detect changes in our external environment. Our internal organs and systems are also monitored by sensory receptors, which relay information about our internal environment to the CNS for interpretation. Sensory receptors are sensory neurons that are specialised to detect particular types of information to be sent as an action potential to the CNS. Sensory neurons are triggered by the stimulus they are specifically

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adapted to detect. For example, sensory receptors in the human eye detect light stimuli, including changes in light intensity and colour, interpreted by our brain as our vision. Sensory stimuli are converted to action potentials in the sensory neurons; the stronger the stimulus, the more action potential signals are sent to the CNS.

Types of sensory receptors

There are many types of sensory receptors, each specialised to detect specific stimuli. In the human body, sensory receptors include (but are not limited to) chemoreceptors, thermoreceptors, mechanoreceptors, photoreceptors and nociceptors.

Chemoreceptors

chemoreceptor
a sensory receptor that detects changes in chemicals

Chemoreceptors are sensory receptors that detect chemical information and send signals along afferent neurons to the CNS. Chemoreceptors may detect chemical stimuli from outside the body, including smell and taste, or from within the body, such as gas (carbon dioxide and oxygen) concentration in the blood. Chemoreceptors that detect taste and smell can help organisms find food and determine whether food is edible. The chemoreceptors responsible for monitoring blood gas concentrations allow the CNS to maintain homeostasis by responding to low oxygen levels by increasing respiratory rate and heart rate.

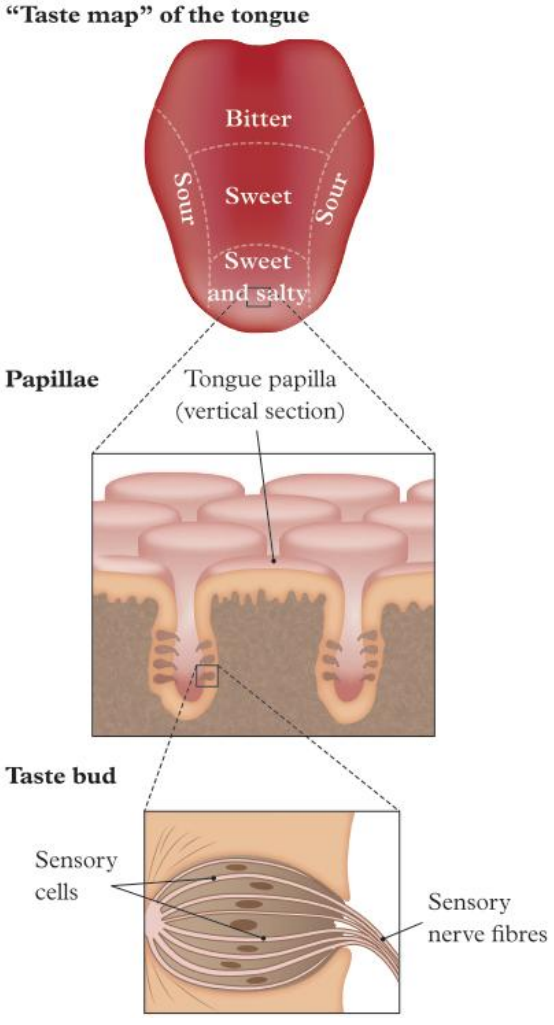


FIGURE 1 Distribution of chemoreceptors on the tongue. The number of receptors and the combination of different types of receptors activated can determine the "taste" a person perceives.

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Thermoreceptors

Thermoreceptors are sensory receptors that detect temperature changes, either in the external environment or within the body. In mammals, one type of thermoreceptor detects an increase in temperature, while another detects a decrease in temperature. Once information is sent from thermoreceptors to the CNS, physiological and behavioural responses are triggered by effectors to return the organism's core temperature to its optimal range. For example, if a thermoreceptor detects a drop in temperature due to a cool breeze at the beach, the CNS may signal erector muscles on the hair shafts to contract, causing goosebumps to form and the hairs on the skin to stand on end.

thermoreceptor
a sensory receptor that detects changes in temperature

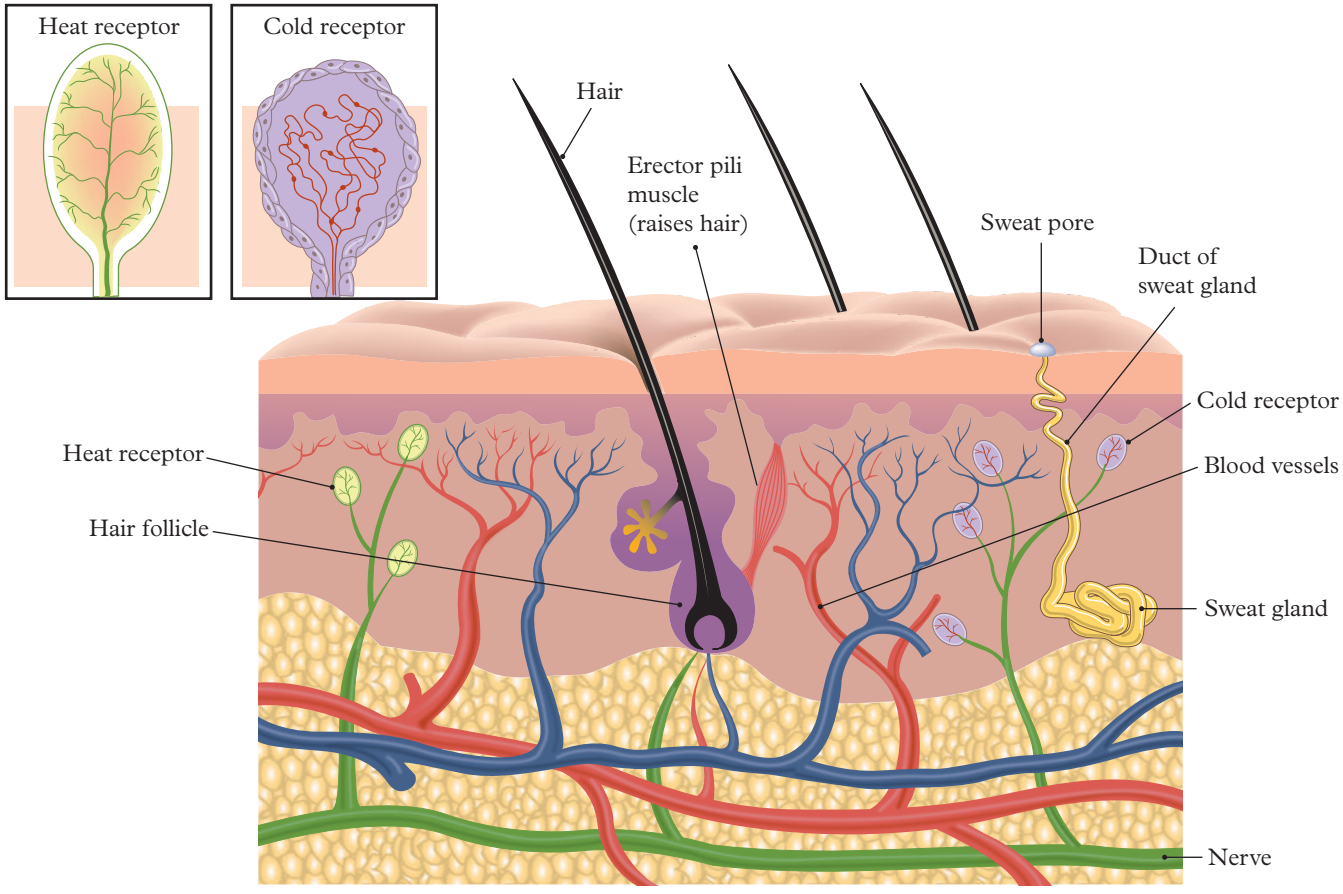


FIGURE 2 Thermoreceptors in the body detect fluctuations in external and internal temperature.

Mechanoreceptors

Mechanoreceptors are predominantly located in the skin, and respond to pressure and touch. Signals sent to the CNS from mechanoreceptors aid in movement and interaction with the physical environment. Some specialised mechanoreceptors are located in the hair and the ears, and translate information about subtle movements and vibrations in mediums such as air.

mechanoreceptor
a sensory receptor that detects changes in pressure and touch

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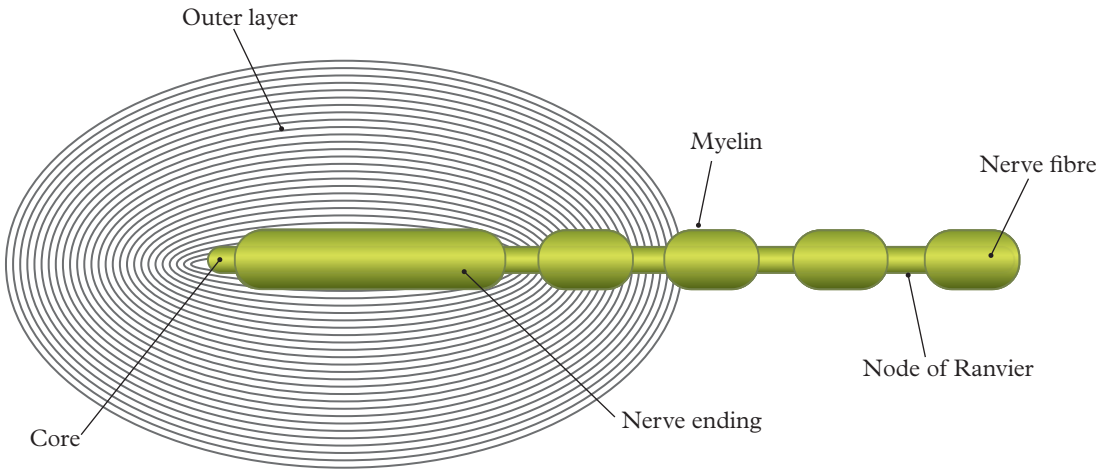


FIGURE 3 A pacinian receptor is a type of mechanoreceptor that detects vibrations.

Photoreceptors

photoreceptor
a sensory receptor that detects changes in light wavelength and intensity

Photoreceptors detect details of light wavelength and intensity entering the eye and send this information, in the form of action potentials in neurons, to the brain where it is interpreted as vision. Variations in the types and number of photoreceptors present in the eyes of an animal determine how much detail and which colours it sees.

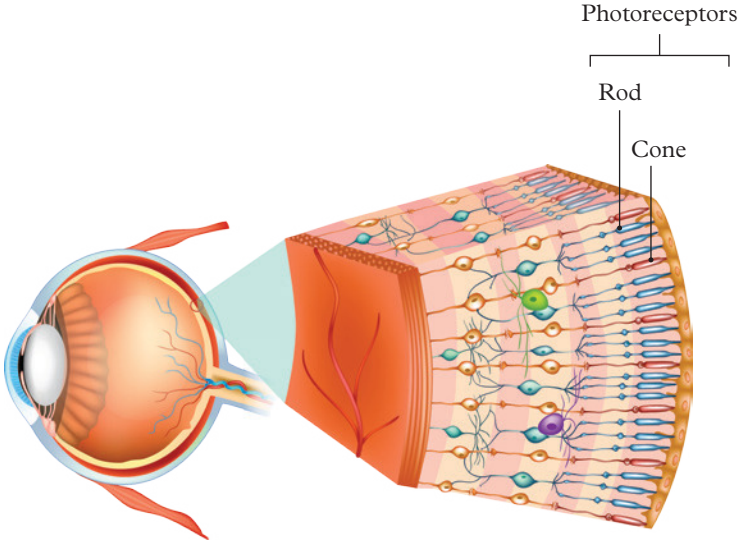


FIGURE 4 Rods and cones at the back of the eye are photoreceptors, able to detect dim and bright light conditions.

Nociceptors

nociceptor
a sensory receptor that detects signals from damaged tissue

Nociceptors are sensory receptors that respond to damage to cells and tissue by sending a signal that is interpreted by the CNS as pain. Nociceptors are in most parts of the body, as damage may occur anywhere, internally or externally. Many types of stimuli can trigger a response in nociceptors, including extremely high or low temperatures, excessive pressure, and some chemicals that can cause tissue damage. For example, a build-up of lactic acid in muscles due to excessive exercise causes the perception of pain, due to signals from nociceptors.

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Challenge

CIPA

Congenital insensitivity to pain and anhidrosis (CIPA) is a rare and dangerous condition in which a person is unable to perceive pain. The nociceptors of people afflicted with this condition are unable to signal or connect to the central nervous system. This means that when a person with CIPA is exposed to a damaging stimulus, they do not register that they are experiencing pain and are likely to remain exposed to the painful stimulus, risking further damage to the affected site of the body.

1 **Explain** how CIPA might impact a person's ability to produce a reflex arc. (2 marks)
2 Use your knowledge of reflex arcs to **contrast** how a person unaffected by CIPA and a person affected by CIPA might respond to touching a boiling hot saucepan. (2 marks)

Check your learning 10.5

Check your learning 10.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the direction of the signal that moves between the central nervous system and sensory receptors. (1 mark)
2 **Identify** the name of the receptor that receives information about light. (1 mark)
3 **Describe** the response of the CNS when it receives a signal from a sensory receptor. (2 marks)
4 **Identify** the sensory receptors in the nose and mouth. (1 marks)
5 **Describe** the function of each of the following sensory receptors:
   a chemoreceptors (1 mark)
   b mechanoreceptors (1 mark)
   c nociceptors (1 mark)
   d photoreceptors (1 mark)
   e thermoreceptors. (1 mark)

Knowledge utilisation

6 **Infer** why sensory receptors within the ear are classified as mechanoreceptors. (1 mark)

Lesson 10.6
Chemical control

Key ideas

→ Hormones are chemical messengers produced by an organism to regulate the activity of cells and organs.
→ Each hormone regulates and controls the activity of specific target cells and tissues.
→ Hormone activity is slow-acting and long-lasting.
→ Signal transduction is a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane.

Learning intentions and success criteria

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Chemical signals

In each living cell, a vast number of chemical reactions are occurring at any given moment. Because some substances are synthesised and others are used, destroyed or removed, the chemical environment in each part of the cell constantly undergoes slight changes. Any change in the chemical environment will affect subsequent chemical reactions and thereby exert some control over them. This simple relationship, which regulates most cellular reactions, forms the basis of more complex chemical regulatory mechanisms.

Cells have special receptor molecules embedded in their membranes and in their cytoplasm. Different types of cells have different types of receptors and so will only respond to specific chemical messages in their environment. For a cell to respond to a stimulus, **signal transduction** must occur. This is when changes occur in a receptor molecule that allow molecular signals from the cell's exterior to be transmitted to its interior. Once this signal is received, an appropriate response can then be made by the cell. Hormone systems are thought to have evolved from this mechanism, where certain cells have become specialised to produce and secrete specific regulatory chemicals.

signal transduction
a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane

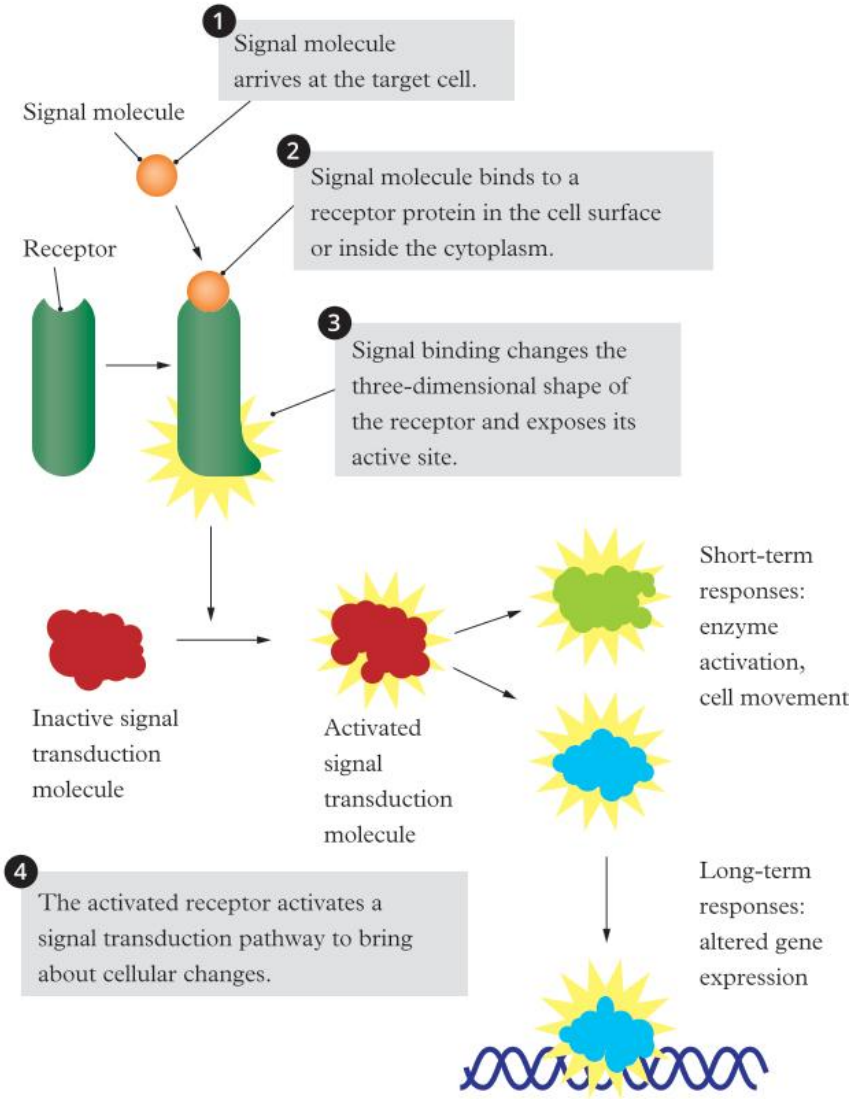


FIGURE 1 The process of signal transduction

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Hormones as chemical signals

Hormones are chemical messengers produced by an organism to regulate the activity of cells and organs. They are produced by cells in very small quantities and transported to cells in other parts of the body. Each hormone regulates and controls the activity of a specific target structure. This may be an individual cell, a muscle or another gland.

hormone
a regulatory chemical of the control and coordination system; capable of bringing about a specific response to a particular stimulus

There are three ways a hormone may bring about a change.

- **Autocrine** hormones bind to receptors in the same cell that produced them. An example is a white blood cell (T lymphocyte) activating itself with an autocrine hormone (IL-2) during an infection.
- **Paracrine** hormones bind to receptors on neighbouring cells. Infected plant cells use paracrine hormones to warn neighbouring cells to protect themselves.
- **Endocrine** hormones travel long distances through the blood supply of animals to reach target cells that have receptors complementary to the shape of the hormone.

Other hormones that act at a distance are **pheromones**. These are released from the body and act as a species-specific signal to other members of the species. Female dogs and insects release sex pheromones into the air when they are ready to mate. The chemical molecules released can be detected at very small concentrations over large distances by the males of their species. Other pheromones are released in urine or specialised glands to mark out territories.

pheromone
a hormone released as an external signal to other members of the species

Some plants also produce pheromones. For example, the growing tip of the primary shoot of the red cedar (*Toona ciliata*) releases a pheromone that attracts the tip moth. The tip moth lays its eggs in the tissues and the emerging larvae feed on them. This prevents further growth from the apex of the plant but stimulates the growth of lateral branches.



FIGURE 2 Terminal shoot of the red cedar (*Toona ciliata*) infected with tip moth larvae

Hormone action

The action of hormones tends to be slow, because hormones travel long distances to their complementary receptors. Also, because some of the released hormone remains even after hormone production has been "switched off", hormone action tends to be long-lasting.

A stimulus causes production and secretion of a hormone appropriate to that stimulus.

- Information about the external environment is relayed to hormone-secreting cells via the nervous system in most animal groups. In plants, cells are directly stimulated by an external cue (e.g. the direction of light).
- Hormone-secreting cells respond directly to changes in their immediate internal environment, often via a circulating fluid (in animals) or diffusion (in plants).

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The hormone is then carried throughout the body. It does not initiate any unique cellular activities, but instead modifies the rates of existing activities. There are two main types of hormones: water-soluble and fat-soluble.

When a water-soluble hormone (proteins or amino acid derivatives) reaches the target organ receptors, glycoprotein molecules on the cell membranes "capture" the hormones. This binding between the receptor molecule and the hormone can:

- couple directly with an ion channel to influence the passage of specific ions into or out of the cell (i.e. they influence the permeability of the cells to particular solutes)
- allow the hormone-receptor molecule to pass across the membrane, where it can be linked to a specific protein or become associated with a particular enzyme to induce or repress their action and, therefore, specific chemical reactions.

Fat-soluble hormones (such as steroids) can pass directly through the cell membrane. In the cytoplasm, they bind with their complementary receptors, allowing them to pass through the pores of the nuclear membrane. The linked hormone and receptor have a particular shape that has an affinity with a specific nucleotide sequence in the DNA. This interaction changes the gene expression of the cell so that specific enzymes are either produced or their synthesis is inhibited; that is, they affect the function of specific genes.

Hormones are often referred to as 'chemical signals', because they cause a change in activity of the target cells. Hormones differ in their molecular structure. Some are proteins and others are steroids. Therefore, different hormones are recognised by different target sites and bring about different chemical reactions.

Other chemical signals in animals

Many types of signals are received by cells. These include neurotransmitters (chemical messengers released from the nervous system), messages from the immune system, growth factors and toxins. As with hormones, only cells with a complementary receptor for that chemical messenger will be influenced by it. The more receptors present for that chemical, the more actively the cell responds to the message.

Signal transduction

signal transduction pathway
a cascade of biochemical reactions inside a cell that eventually reaches the target molecule or reaction; initiated when a molecule (e.g. a hormone) attaches to a receptor on the cell membrane

For a cell to respond to a stimulus, a **signal transduction pathway** must be activated. When a hormone binds to its specific receptor, the receptor rearranges its shape. This change in conformation can signal to other molecules (called secondary messengers) in the cell to change their function. Like a line of falling dominoes, each affecting the next one, the secondary messenger molecules cause changes in the chemical pathways throughout the cell until it results in a final response to the hormone message. These responses include:

- activating or inactivating enzymes
- exocytosis (release) of molecules
- switching genes on or off
- opening or closing protein channels.

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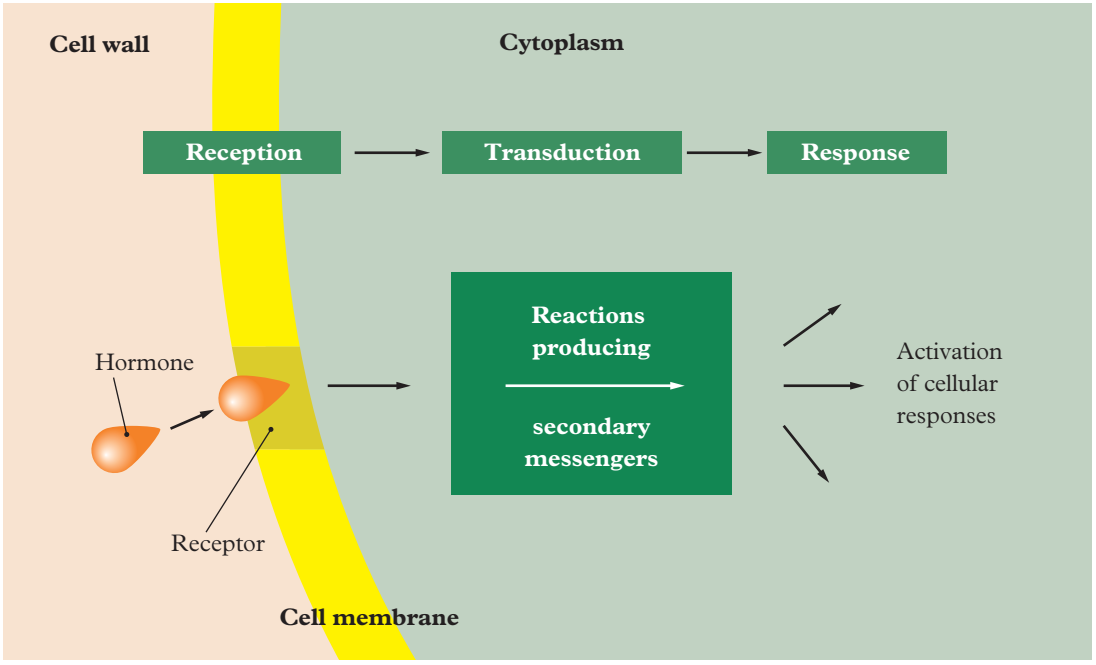


FIGURE 3 Signal transduction of a hormone acting on its target plant cell

The life cycle of receptors

The types of receptors on a cell's surface or in its cytoplasm are determined by the DNA of the cell. DNA molecules contain genes that code for specific receptors (each receptor molecule is a protein). These receptors are either embedded in the cell membrane or are in the cytoplasm. Many types of cell receptors are present in a cell at any one time, and each of these receptor types responds to a different signal. The cell constantly monitors the signals that come in contact with its receptors and adjusts the quantities of each receptor type accordingly.

Membrane receptors can be removed or recycled. When this occurs and there is a reduced presence of a specific receptor type able to detect a certain signal, the cell's sensitivity to that signal will also reduce. This process is termed **down-regulation**. One example of down-regulation in humans is when the body is exposed to high insulin levels in the blood. The number of insulin receptors is down-regulated, reducing the body's sensitivity to the insulin hormone.

If the cell receives a weak signal, more receptors can be synthesised to increase the cell's sensitivity to the message. The increase in the number of those receptors is termed **up-regulation**. For example, during pregnancy, the uterus up-regulates oxytocin receptors. When childbirth starts, the uterus is more sensitive to oxytocin released from the brain.



FIGURE 4 During pregnancy the uterus up-regulates oxytocin receptors.

down-regulation
the process of reducing or suppressing a response to a stimulus by reducing the number of receptors on the cell surface

up-regulation
the process of increasing the response to a stimulus due to an increase in the number of receptors on the cell surface

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Check your learning 10.6

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Retrieval and comprehension

1 **Describe** what happens during a signal transduction pathway. (3 marks)
2 **Define** "hormone". (1 mark)
3 **Explain** why only certain target cells are affected by each type of hormone. (2 marks)
4 **Explain** how a cell can change in response to a hormone. (3 marks)
5 Hormones are not the only chemical signals in a multicellular organism. **Identify** one other type of chemical signal. (1 mark)
6 **Describe** a pheromone. Give an example of an animal pheromone and a plant pheromone. (3 marks)

Analytical processes

7 **Distinguish** between up-regulation and down-regulation of cell membrane receptors. **Explain** how each process is achieved. (3 marks)

Lesson 10.7
The endocrine system

Learning intentions and success criteria

Key ideas

- The endocrine system consists of glands that secrete hormones to regulate body functions and maintain homeostasis.
- Hormones are secreted by glands and act on the recognition sites of specific tissues and cells.
- The hypothalamus is known as the "control centre" of the endocrine system because it releases hormones that stimulate or suppress the release of hormones from the pituitary gland.
- The pituitary gland is known as the "master gland" of the endocrine system because it produces hormones that control the functions of other endocrine glands.

Structures of the endocrine system

endocrine system a system of glands that secrete hormones into the bloodstream to regulate body function and homeostasis

endocrine glands glands in animals that respond to signals from the CNS to release hormones into the bloodstream

The **endocrine system** is the body's messenger system that controls feedback loops through the release of hormones. The endocrine system works alongside the nervous system to coordinate and maintain homeostasis. It is thought that these two systems originated and developed side by side, as the increasing size and complexity of organisms made intercellular communication more important.

In mammals, hormones are produced in ductless **endocrine glands**. These glands pass their secretions directly into the blood vessels until the hormones reach their target tissue or target cells.

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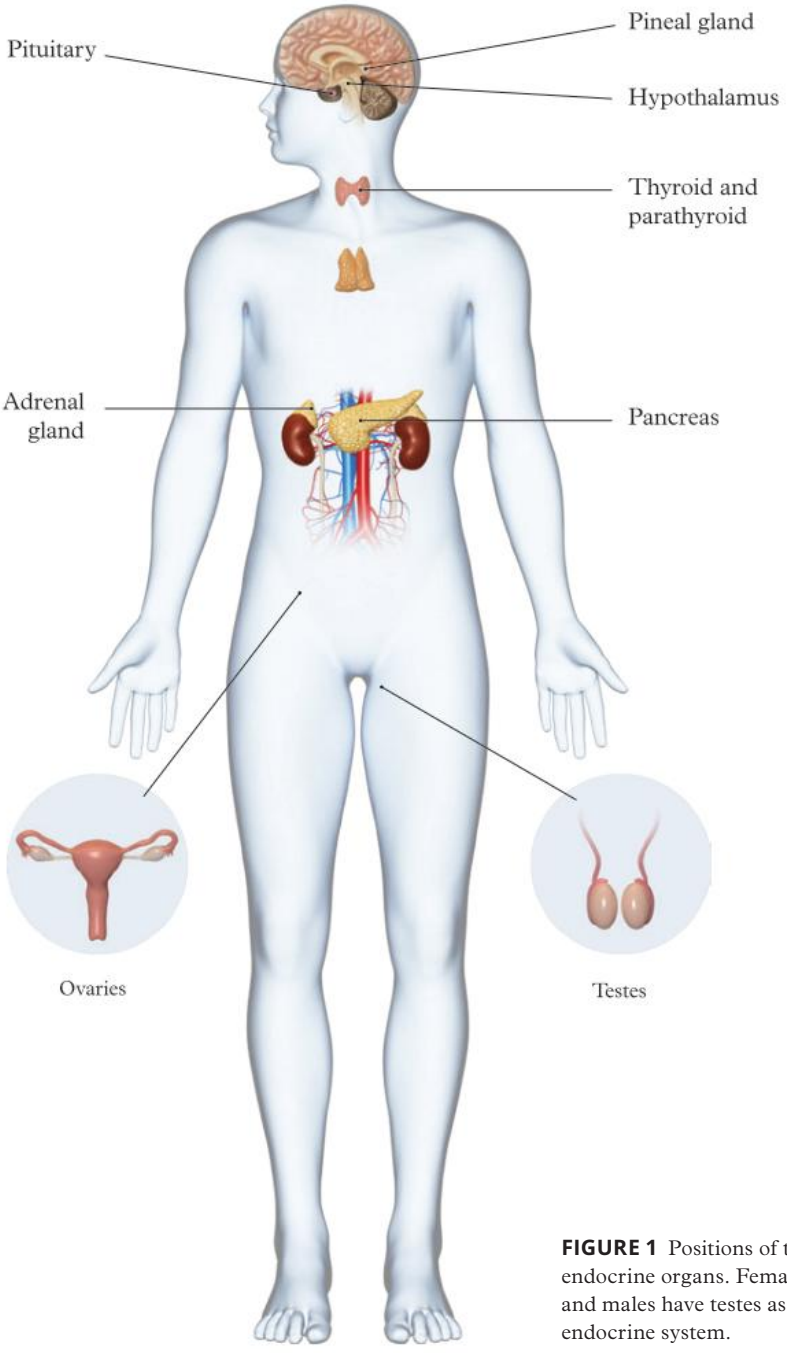


FIGURE 1 Positions of the main endocrine organs. Females have ovaries and males have testes as part of their endocrine system.

Endocrine glands

The main glands of the endocrine system are the **hypothalamus**, **pituitary gland**, thyroid, adrenal gland, pineal gland, pancreas and reproductive organs (testes and ovaries). Despite their physical separation from each other, endocrine glands do not work in isolation. Many hormones interact with each other to bring about a particular response. Stimuli that may trigger the release of a hormone include:

- the presence of a specific metabolite in the blood
- the presence of another hormone in the blood
- stimulation by the autonomic nervous system.

hypothalamus
a gland in the brain that maintains homeostasis of several factors and influences some social and reproductive behaviours

pituitary gland
a gland in the brain that controls growth, metabolism and the activity of other endocrine glands

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Each hormone brings about an effect only on specific body cells. These target cells have recognition sites for specific hormones. A hormone can influence a target cell by:

- changing the permeability of the membrane to specific chemicals
- influencing enzymes located in the membrane
- influencing cell organelles
- activating genes to bring about specific protein production.

Hormones are slow acting compared to the rapid electrical signals of the nervous system. The process of stimulating the release of a hormone into the bloodstream, the hormone travelling through the bloodstream to the target cell, and the response of the target cell, all take time. Because hormones are molecules that travel in the bloodstream until they bind to a target cell, their effect is relatively long-lasting compared to the effect of signals in the nervous system. Some hormones are self-regulating and respond directly to changes in chemicals in the bloodstream. For example, blood sugar levels are detected directly from the bloodstream by the pancreas, which responds by secreting either insulin or glucagon.

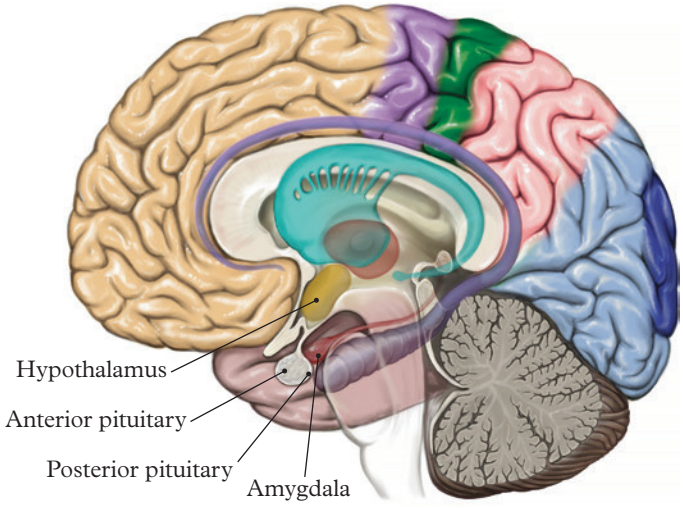


FIGURE 2 The human brain, showing the location of the hypothalamus, amygdala and pituitary gland

Hypothalamus

The hypothalamus is an important part of the human brain. In humans it is located at the base of the brain, roughly behind the nose. It has direct roles in homeostasis and the release of hormones, and it signals to other glands to release hormones. The hypothalamus monitors factors in the brain and other locations in the body by interpreting chemical signals in the bloodstream. It is often referred to as the "control centre" of the endocrine system. The hypothalamus coordinates a response with the pituitary gland to respond to changes detected. Responses triggered by the hypothalamus may be part of a negative or positive feedback system.

Pituitary gland

The pituitary gland is located just below the hypothalamus. It has two lobes.

- The anterior pituitary lobe accounts for 80% of the pituitary gland. It produces and releases hormones.
- The posterior pituitary lobe stores and releases neurohormones produced in the hypothalamus.

The pituitary gland is known as the "master gland" of the body, because it produces hormones that can act all around the body and control the function of other glands in the endocrine system. For example, the anterior pituitary gland releases antidiuretic hormone, which acts on the kidneys to influence osmoregulation and stimulates oxytocin to induce the contractions of childbirth. The pituitary gland also distributes some hormones synthesised by the hypothalamus, including follicle-stimulating hormone, thyroid-stimulating hormone and human growth hormone. Hormones released by the pituitary gland can regulate growth and metabolism and can also switch many other glands on or off, including the thyroid, mammary glands, ovaries and testes.

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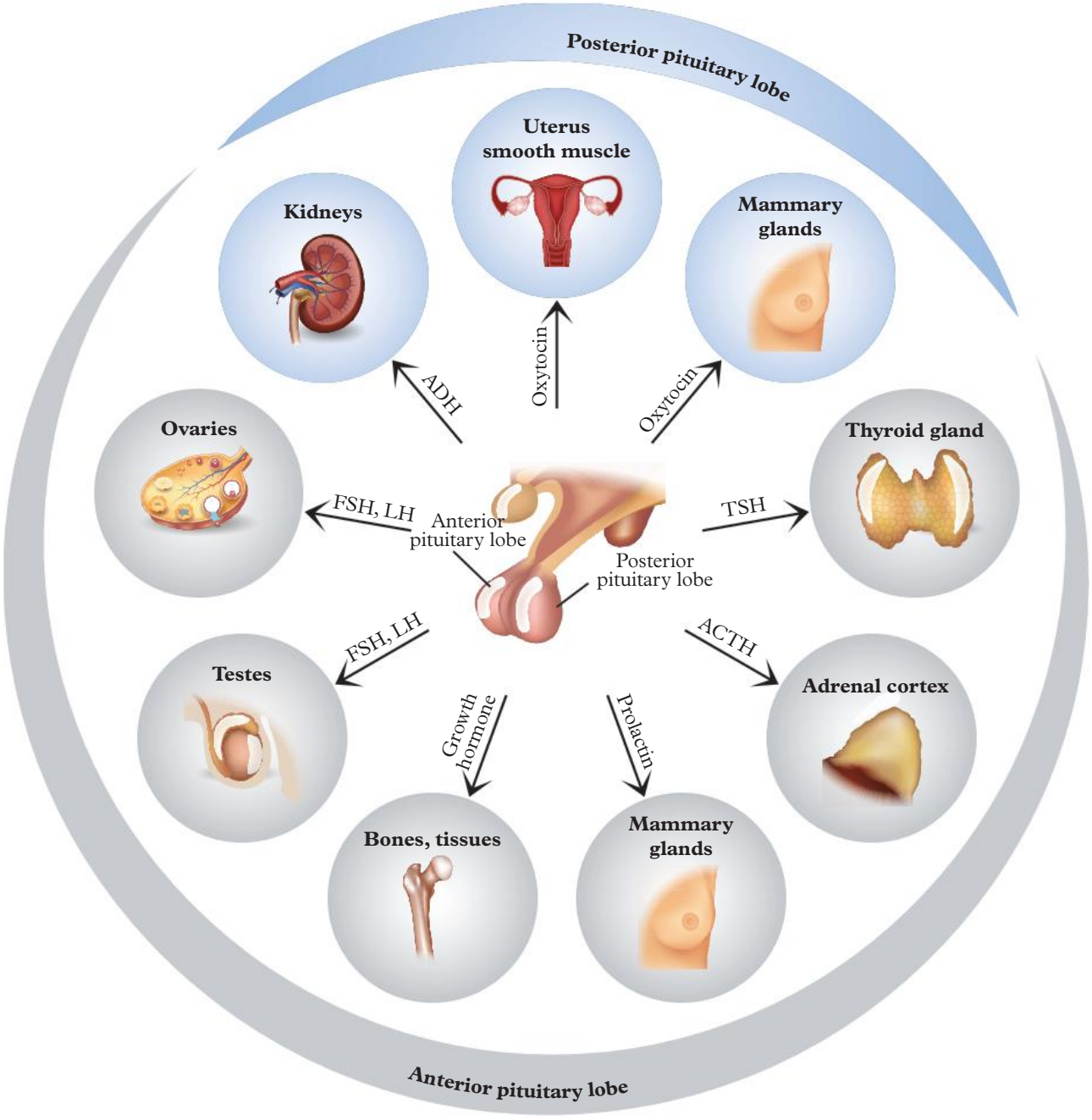


FIGURE 3 Hormones released from the anterior and posterior lobes of the pituitary gland

TABLE 1 The major human endocrine glands, the hormones they produce and their functions

Endocrine gland	Hormone produced	Major function
Hypothalamus	Releasing and release-inhibiting hormones	Controls release of hormones from adenohypophysis (anterior pituitary)
Hypothalamus via neurohypophysis (posterior pituitary)	Oxytocin	Stimulates release of milk and uterine contractions
	Antidiuretic hormone	Stimulates reabsorption of water in kidney

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Endocrine gland	Hormone produced	Major function
Adenohypophysis (anterior pituitary)	Adrenocorticotropic hormone	Stimulates adrenal cortex
	Follicle-stimulating hormone (FSH)	Stimulates development of ovarian follicles and seminiferous tubules
	Luteinising hormone (LH)	Stimulates ovulation, and progesterone and testosterone production
	Melanocyte-stimulating hormone	Stimulates dispersion of pigment (melanin) in the skin of amphibians; stimulates melanin production in humans
	Prolactin	Maintains lactation after pregnancy; maintains secretion of progesterone during pregnancy
	Thyroid-stimulating hormone (TSH)	Stimulates thyroid gland
	Growth hormone	Promotes growth
Thyroid	Thyroxine and tri-iodothyronine	Increases metabolic rate by stimulating cellular respiration; important role in growth, tissue development and differentiation
	Calcitonin	
Parathyroid	Parathyroid hormone	Acts in opposition to calcitonin – brings about removal of calcium from bone; increases reabsorption of calcium in the kidneys, raising blood calcium level
Adrenal cortex	Glucocorticoids, e.g. cortisone	Regulates carbohydrate metabolism
	Mineral steroids, e.g. aldosterone	Regulates salt and water metabolism
Adrenal medulla	Adrenalin, noradrenalin	Prepares animal to meet emergency conditions, e.g. fight, flight or shock, by increasing heart rate and blood supply to skeletal muscles, lungs and liver, and raising blood sugar level
Pancreas	Glucagon	Increases blood sugar level by converting glycogen to glucose
	Insulin	Decreases blood sugar level by stimulating formation of glycogen
Glands in stomach lining	Gastrin	Maintains flow of gastric juice
Glands in duodenum lining	Secretin	Stimulates secretion of intestinal juices
	Pancreozymin	Stimulates secretion of pancreatic juice
	Cholecystokinin	Stimulates release of bile from gall bladder
Ovary	Oestrogens	Initiates and maintains female secondary sexual characteristics; initiates thickening of uterus lining; control FSH and LH secretions
	Progesterone	Maintains thickening of uterus lining; inhibits FSH and LH
Testis	Testosterone	Initiates and maintains male secondary sexual characteristics

Check your learning 10.7

Check your learning 10.7: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the role of endocrine glands in bringing about change in the body. (2 marks)
2 **Describe** the function of the pituitary gland. (1 mark)
3 **Identify** two of the endocrine glands controlled by the pituitary gland. (2 marks)
4 **Identify** three hormones secreted by the posterior pitutary lobe and **identify** which structures they act on in the body. (6 marks)
5 **Explain** what is meant by the endocrine system being "long-lasting" and "slow acting". (2 marks)

Knowledge utilisation

6 "A hormone can act on every cell in the body." **Evaluate** this statement. (2 marks)

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MODULE 10

Lesson 10.8
Review: Control and coordination

Summary

10.1
- Organisms must regulate their body systems by monitoring their internal and external environments.
- Organisms maintain homeostasis according to their tolerance ranges for a variety of abiotic conditions.
- Homeostasis describes the maintenance of an organism's body systems through positive and negative feedback loops.
- The stimulus–response model allows organisms to detect environmental changes and respond to maintain homeostasis.

10.2
- The structure and distribution of the nervous system within an organism allows for communication between organs and response to stimuli.
- The structure and function of neurons enable a variety of signals to be transported between and within body systems.
- The generation and propagation of an impulse within a neuron determines how, when, and whether a signal is sent through the nervous system.
- Neurons transmit signals to each other and to other cell types, such as muscle cells.

10.3
- The mammalian nervous system is organised into central and peripheral nervous systems.
- The brain is part of the central nervous system and communicates with the rest of the body through the brainstem.
- Sensory pathways between the peripheral nervous system and the central nervous system are made of afferent neurons, interneurons and efferent neurons.
- Reflex arcs, or reflexes, are the fastest neural pathways and are an evolutionary adaptation for survival.

10.4
- Practical: The reflex arc

10.5
- Internal and external environmental changes are detected by sensory receptors in the PNS
- Sensory receptors send signals through the PNS to the CNS for processing and to coordinate a response.
- Sensory receptors are specialised for the different types of information they detect, including pressure, temperature, smell, taste, light and movement.
- Types of sensory receptors are chemoreceptors (taste and smell), mechanoreceptors (movement), thermoreceptors (heat), photoreceptors (light) and nociceptors (pain).

10.6
- Hormones are chemical messengers produced by an organism to regulate the activity of cells and organs.
- Each hormone regulates and controls the activity of specific target cells and tissues.
- Hormone activity is slow-acting and long-lasting.
- Signal transduction is a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane.

10.7
- The endocrine system consists of glands that secrete hormones to regulate body functions and maintain homeostasis.
- Hormones are secreted by glands and act on the recognition sites of specific tissues and cells.
- The hypothalamus is known as the "control centre" of the endocrine system because it releases hormones that stimulate or suppress the release of hormones from the pituitary gland.
- The pituitary gland is known as the "master gland" of the endocrine system as it produces hormones that control the functions of other endocrine glands.

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Review questions 10.8A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Homeostasis can be defined as
- **A** a self-regulating process to maintain balance in the body of an organism.
- **B** the release of hormones from a gland to act on a target cell.
- **C** an adaptation that allows endotherms to maintain a constant body temperature.
- **D** the control of water in the body through signals from the hypothalamus to the kidneys.

2 Hormones
- **A** are sent through neurons between the peripheral and central nervous systems.
- **B** are produced by the endocrine system.
- **C** are only produced by the brain.
- **D** act faster than signals in the nervous system.

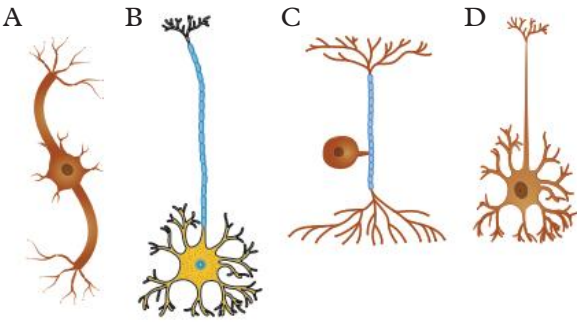
3 Chemoreceptors are sensory receptors that detect
- **A** chemicals.
- **B** pressure.
- **C** temperature.
- **D** light.

4 An example of a positive feedback loop is
- **A** the balance of glucose in the bloodstream.
- **B** vasodilation and vasoconstriction.
- **C** release of ADH.
- **D** the hormonal triggers of childbirth.

5 Which of the following statements concerning feedback mechanisms is correct?
- **A** Positive feedback results in the reversal of an existing condition.
- **B** Positive and negative feedback result in further change in the direction of an existing condition.
- **C** Negative feedback results in the reversal of an existing condition.
- **D** Positive feedback reinforces negative feedback.

6 The function of the pituitary gland is to
- **A** regulate the uptake and use of carbohydrates.
- **B** stimulate the body into a state of readiness for physical exertion.
- **C** regulate growth and influence the activities of the other endocrine glands.
- **D** control the rate of mental and physical development.

7 The diagrams show four types of nerve cells.



Which diagram shows a sensory neuron?
- **A** Diagram A
- **B** Diagram B
- **C** Diagram C
- **D** Diagram D

8 A nociceptor responds to
- **A** mechanical forces such as pressure or distortion.
- **B** extremes in temperature.
- **C** relatively short wavelengths of light.
- **D** signals from damaged tissue or cells.

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Review questions 10.8B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

9 **Describe** the mechanism of a nerve impulse moving along a neuron, from the arrival of the neurotransmitter at the receptor to the release of the cell's own neurotransmitter. Include the following words in your description: signal transduction, ion channels, action potential, dendrites, axon, synapse, vesicle. (4 marks)

10 **Identify** two advantages to the body of controlling physiological processes by the action of hormones compared with nervous control. (2 marks)

Analytical processes

11 **Analyse** which one of the three species (A, B or C) is most likely to possess myelinated nerve fibres, based on the data provided in Table 1. Give a reason for your answer. (2 marks)

Species	Diameter of axon (μm)	Speed of conduction (m/s)
A	7	1.2
B	500	33.0
C	15	90

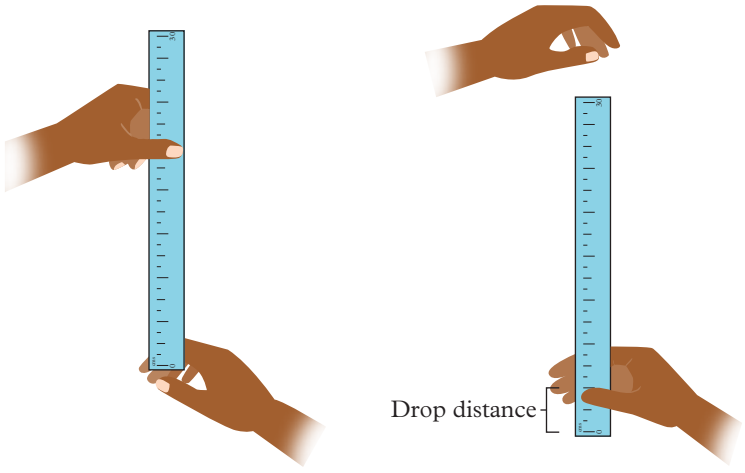
Knowledge utilisation

12 **Discuss** how living organisms detect changes in their environment. (4 marks)

Data drill

Ruler drop test

A teacher is measuring the reaction time of students in a series of ruler drop tests. They want to establish whether reaction time will decrease after practice. In the ruler drop test, each student is given a 30 cm ruler, which is held directly above their open hand. The teacher then instructs the students so that when they see the ruler drop, they must try to catch it as quickly as possible. The teacher starts a stopwatch as soon as the ruler is dropped, and times when the ruler is caught. They also measure the distance that each ruler drops, in centimetres. The greater the number, the further the ruler has passed through the student's hand.



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	Drop distance (cm)					Reaction time (ms)				
Student	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	20	15	10	7	5	225	207	196	185	174
2	25	20	15	12	10	235	218	204	191	180
3	15	10	5	4	3	195	182	170	159	148
4	20	15	10	8	6	220	203	190	178	167
5	25	20	15	10	8	245	228	212	197	184
6	15	10	5	3	2	200	186	173	161	149
7	20	15	10	6	4	210	195	182	170	159
8	25	20	15	11	9	240	223	208	194	181
9	15	10	5	3	2	195	182	170	159	148
10	20	15	10	8	6	400	208	194	182	170

Apply understanding

1 **Identify** the stimulus and the response in this experiment. (2 marks)

2 **Calculate** the average reaction time for each trial. (5 marks)

Analyse data

3 The data table shows that Student 10 took 400 ms to catch a ruler that had a drop distance of 20 cm. **Explain** why this data point may be classed as an outlier and **identify** a possible reason for this outlier occurring in the experiment. (2 marks)

Interpret evidence

4 Based on the average reaction time you calculated for each trial, **draw a conclusion** about what the data suggests about average reaction time in response to practice. (2 marks)

Module 10 checklist: Control and coordination

Quizlet: Revise key terms online to test your understanding

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MODULE 11

Thermoregulation and osmoregulation

Introduction

Living things have adapted to Earth's wide range of ecosystems with varying water availability and temperature ranges. Plants and animals have different strategies for adjusting to the abiotic pressures of their environment. Plants rely primarily on structural adaptations controlled by concentration gradients and hormones to maintain water balance and protect themselves from extremes of temperatures. While animals also benefit from structural adaptations and hormonal signals, they have the additional advantage of a nervous system and the ability to move. This means that animals can change their behaviour to help them survive in their environment.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to thermoregulation and osmoregulation before you start.

Subject matter

Science understanding

- Explain thermoregulatory mechanisms of endotherms, including
  - structural features: brown adipose tissue, insulation
  - behavioural responses: kleptothermy, hibernation, aestivation and torpor
  - physiological mechanisms: evaporative heat loss, thermogenesis and vasomotor control.
- Explain thermoregulation in humans, including the role of sweating, shivering, vasodilation and vasoconstriction using feedback control diagrams.
- Explain osmoregulation in humans, including the role of antidiuretic hormone (ADH) and the kidney using feedback control diagrams.
- Explain how structural and homeostatic mechanisms maintain water balance in plants, including the roles of stomata, vacuoles, cuticle and abscisic acid.
- Interpret data from an experiment comparing the number and distribution of stomata in plants adapted to different environments.

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Science as a human endeavour

→ Appreciate that
- understanding natural systems can lead to advances in technology and engineering. For example, computer models of human thermoregulation responses, including heat transfer, perspiration, respiration and blood flows, have been developed for use in the design of clothing and environments that aim to protect humans from hyper- and hypothermia.

Science inquiry

→ Investigate
- tolerance limits for water or salt balance on plant growth
- structural, behavioural, physiological and/or homeostatic mechanisms used by different species to control heat exchange/metabolic activity/water balance
- the use of hormones in agriculture.

→ Compare the number and distribution of stomata in plants adapted to different environments.

Science inquiry skills

→ Use scientific language and representations to systematically record information, observations, data and measurement error.

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Practicals

oxforddigital **These lessons are available on Oxford Digital.**

Lesson 11.6 The role of the leaf in plant osmoregulation

Lesson 11.7 Investigating tolerance limits for water or salt balance in plant growth

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Lesson 11.1
Thermoregulation

Key ideas

- → Thermoregulation allows organisms to maintain their body temperature within the tolerance range for survival.
- → Metabolic processes produce heat that is lost to the environment; organisms have behavioural strategies and physical features to reduce or increase this heat loss, to maintain homeostasis.
- → Ectotherms gain heat from their environment, while endotherms maintain a stable body temperature by generating heat through metabolic processes.

Learning intentions and success criteria

Thermoregulation

Thermoregulation is the set of processes that maintains an optimal body temperature for the survival of an organism. Different species have varying optimal temperatures and temperature tolerance ranges, depending on their adaptations to the environment. Thermoregulation in warm-blooded animals, such as humans, requires the coordination of the nervous and endocrine systems to exert control over a variety of processes and functions within the body. Maintenance of an optimal body temperature through thermoregulation allows efficient cellular functions and enzymatic reactions. The thermoregulatory strategies of animals can be categorised as behavioural, physiological or structural. Organisms can also be grouped into one of two categories of thermoregulation:



FIGURE 1 Sweating is a thermoregulatory process in humans.

- **ectotherms**, which absorb heat from their external surroundings
- **endotherms**, which generate most of their heat through internal processes.

thermoregulation
the maintenance of internal body temperature within a tolerable range for an individual; may be achieved through behavioural or physiological processes

ectotherm
an animal that maintains its internal body temperature by gaining heat from, and losing heat to, the external environment

endotherm
an animal that maintains a constant internal body temperature in fluctuating environmental temperatures

Ectotherms

Ectotherms obtain most of their heat by absorbing it from their surroundings. Ectotherms are sometimes referred to as cold-blooded. However, their blood is rarely cold. It is, in fact, a similar temperature to that of the surrounding environment. Ectotherms still have an optimal temperature and temperature tolerance range, so they modify their behaviour to maintain an ideal temperature. On a cold morning, for example, a snake might lie on a rock in an open area to absorb as much heat from the sun and the rock as possible. As the sun rises and the temperature increases, the snake's body may approach its maximum tolerable temperature, so the snake will move to a shadier location to increase heat loss. All ectotherms maintain homeostasis of temperature in this way, by balancing heat gained with heat lost to the surroundings.

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FIGURE 2 A red-bellied black snake might lie on a warm rock to absorb heat.



FIGURE 3 Shivering is an endothermic response.

Endotherms

Endotherms are often referred to as warm-blooded. They generate most of their heat through internal metabolic processes, which allows them to survive in a wide range of climatic conditions. They have a variety of physiological strategies to maintain their core temperature within a narrow range. Physiological strategies include coordination between the nervous and endocrine systems to produce responses such as sweating, shivering, vasodilation and vasoconstriction. You will learn more about these strategies in Lesson 11.2.

Challenge

The best of both worlds

Dinosaurs are considered mesotherms ("meso" means half), because they had characteristics of both ectotherms and endotherms. Endotherms grow 10 times faster than ectotherms and their metabolism is 10 times faster. Dinosaurs, however, had a metabolic rate halfway between endotherms and ectotherms.

1 In Table 1, **identify** which characteristics of dinosaurs are similar to those of ectotherms and which are similar to those of endotherms. (2 marks)



FIGURE 4 Fossil skeleton of a *Tyrannosaurus rex*

TABLE 1 Characteristics of dinosaurs

Characteristic of mesotherm	Ectothermic or endothermic characteristic?
Doesn't raise metabolism to keep warm by shivering	
Doesn't maintain a constant temperature	

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Check your learning 11.1

Check your learning 11.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** one advantage and one disadvantage of ectothermic thermoregulation. (2 marks)
2 **Define** the term "thermoregulation". (1 mark)
3 **Describe** one example of an endotherm and list two physiological responses to cold temperatures. (3 marks)

Analytical processes

4 **Compare** the thermoregulatory responses of ectotherms and endotherms to high environmental temperature. (2 marks)

Lesson 11.2
Thermoregulatory mechanisms of endotherms

Key ideas

→ Endotherms have many thermoregulatory mechanisms to maintain their core temperature within a narrow range.
→ Structural features that aid in thermoregulation include: insulating layers of fat (e.g. blubber) and brown adipose tissue.
→ Behavioural responses that aid in thermoregulation include: torpor, extended periods of torpor, and kleptothermy.
→ Physiological mechanisms that aid in thermoregulation include: evaporative heat loss, thermogenesis and vasomotor control.

Learning intentions and success criteria

Maintaining core temperatures

The **core temperature** of endotherms is maintained within a narrow but constant range, allowing reliable functioning of essential enzymes. The movement of muscles requires production of ATP through cellular respiration, which also generates heat. Retention of generated heat allows animals to survive in lower environmental temperatures. Loss of heat allows animals to survive in higher environmental temperatures. To survive in a variety of climates, endotherms have evolved advantageous thermoregulatory mechanisms.

core temperature the temperature of the internal organs in the body

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Structural features

Two structural features of endotherms that act as thermoregulatory mechanisms are insulation and brown adipose tissue.

Insulation

insulator
a structure used to prevent heat loss to the environment

blubber
a thick layer of fat directly beneath the skin of marine animals

An **insulator** is a material or substance that covers something and prevents it from losing heat. Many animals have a layer of fat under their skin to add a layer of insulation. This fat layer builds up in the approach to winter, to minimise heat lost by radiation from the skin to the surrounding air or water. Marine mammals rely heavily on this adaptation and have an extremely thick layer of fat under the skin, called **blubber**. Blubber is advantageous compared to a thicker layer of fur on the outside of the skin, because it allows the skin surface to remain smooth for ease of movement through water. Additionally, marine mammals, such as whales, can draw on this high-energy resource when food is limited. Other animals have layers covering their skin, such as fur or feathers. These additional layers help trap heat close to the body and prevent excess heat from being lost to the external environment.

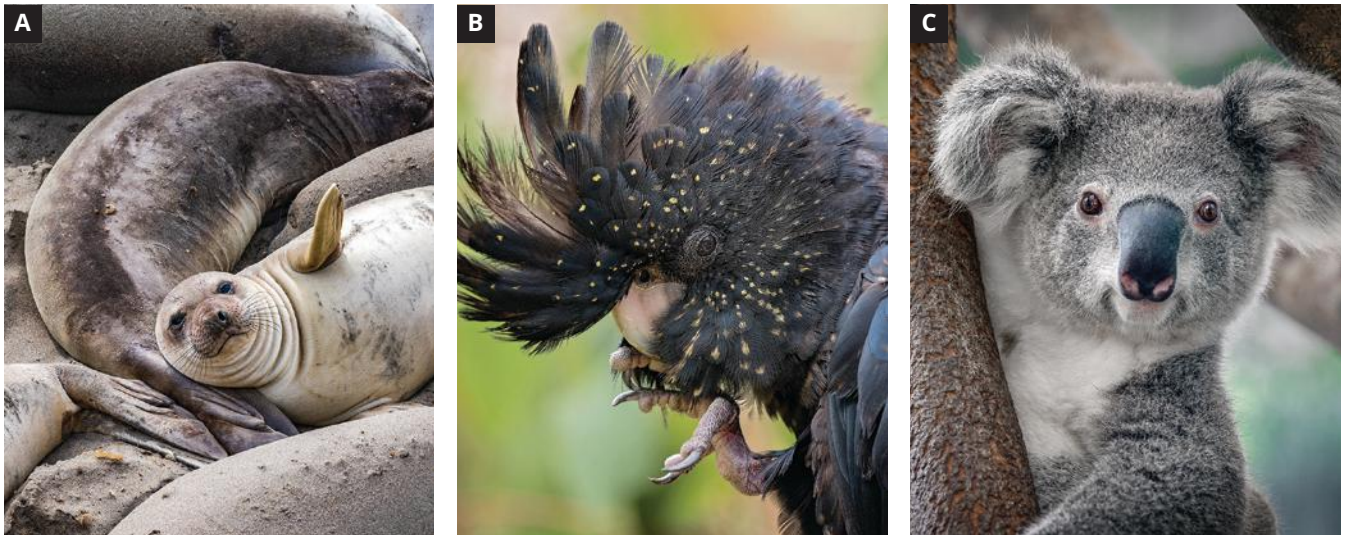


FIGURE 1 Examples of insulating layers in three types of animals: (A) blubber in seals, (B) feathers in cockatoos and (C) fur in koalas

Brown adipose tissue

brown adipose tissue
a type of body fat containing a high concentration of mitochondria to generate energy and heat

Some animals, including humans, have a special type of fat, called **brown adipose tissue**, that can rapidly produce heat. Brown adipose cells have a high concentration of mitochondria, which allows them to produce large amounts of ATP and generate heat. This gives endotherms an advantage over ectotherms, as they can remain active when external temperatures drop. However, they must consume more food to meet the glucose demands of the mitochondria.

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Real-world biology

Brown adipose tissue in newborn babies

Human babies are particularly vulnerable to heat loss, because of their small size and high skin surface area. They are also unable to communicate that they are cold or perform actions such as putting on a jumper. In their first months of life, human babies are also unable to shiver to stay warm. During pregnancy, the body temperature of a baby is maintained by the mother, but after birth babies must thermoregulate themselves to survive their environment. To increase their chances of survival until they develop the ability to shiver in response to cold temperatures, babies are born with deposits of mitochondria-dense brown adipose tissue on their back and chest. The brown adipose cells are dense in mitochondria and generate energy and heat to assist in maintaining the baby's core temperature. It is not only human babies that have brown adipose tissue to assist in thermoregulation; many small mammals also use this physiological strategy to inhabit cold climates.



FIGURE 2 Deposits of brown adipose tissue in a human baby

Apply your understanding

1 **Explain** why being small in size makes a baby vulnerable to heat loss. (2 marks)
2 **Determine** why adults do not need large amounts of brown adipose tissue. (1 mark)
3 **Suggest** three other small mammals that are likely to have brown adipose tissue to support thermoregulation. (3 marks)

Behavioural responses

Animals use a variety of behaviours to regulate their body temperature according to the pressures of their environment. In environments where daytime temperatures are too hot for activity, animals may be active only at night; in colder environments, animals may be more active during daylight hours when it is slightly warmer. Some endothermic behavioural responses that aid in thermoregulation are kleptothermy, torpor, hibernation and aestivation.

Kleptothermy

Kleptothermy is a behaviour seen in many species, including bats and penguins. It involves individuals huddling together to share body heat and reduce heat loss from the group. An example is emperor penguins huddling together on an ice shelf in an Antarctic winter. In these group huddles, the penguins also rotate position from the inside to the outside of the group, to reduce the risk of hypothermia for any one individual.

kleptothermy the sharing of heat between individual animals to maintain thermoregulation

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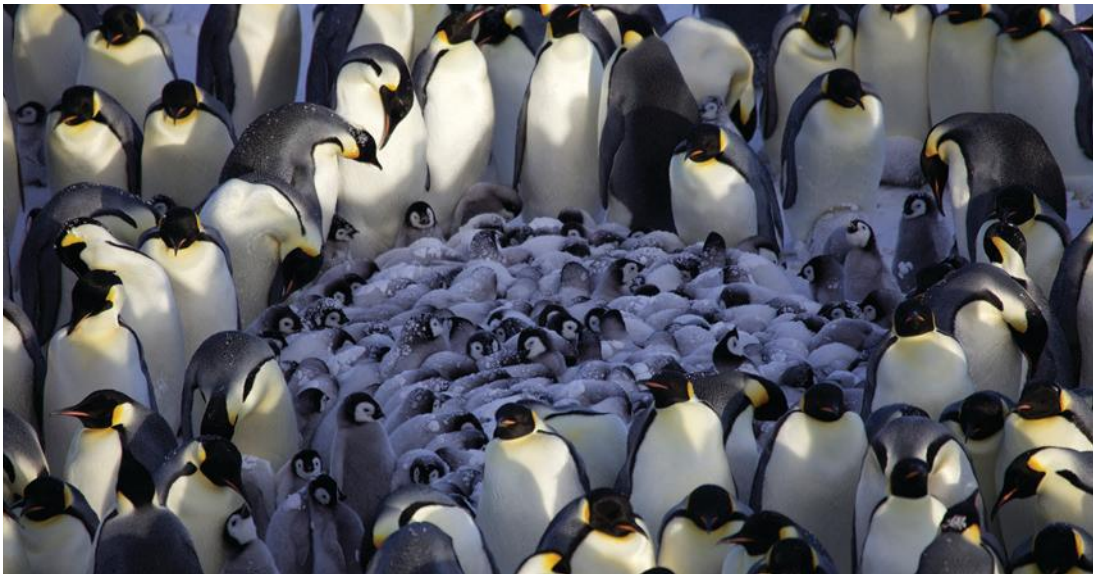


FIGURE 3 An example of kleptothermy is emperor penguin chicks huddling together, surrounded by adults, to protect them from icy Antarctic winds.

Study tip

You might have heard of "kleptomania", a psychological condition that causes people to compulsively steal things they don't need. The prefix "klepto-" means to steal and "thermo-" means heat, so kleptothermy means to steal heat.

Torpor

Some animals respond to short periods of limited resources or inhospitable conditions by entering a state of **torpor**. Torpor is a state of slowed breathing and heart rate, reduced physical activity and minimal response to external stimuli. This allows the animal to conserve energy for a short period of time (hours or days) until environmental conditions or food availability improve.

torpor
a short-term state of reduced activity in an animal, including metabolic rate and movement, triggered by short-term fluctuations in temperature

Hibernation

Hibernation is an extended period of torpor, usually over a winter season, characterised by animals sleeping and reducing their body temperature and metabolic activity. During a state of hibernation, the animal's energy expenditure and temperature are reduced, which reduces demand on its body, allowing the animal's energy reserves to keep it alive for up to six months. In the lead-up to hibernation, animals produce and store large amounts of brown adipose tissue, as this can be used to produce energy and heat at low temperatures. The brain, heart and other essential organs are prioritised, as vasoconstriction draws warm blood away from the extremities to the torso.

hibernation
a long-term state of reduced activity in an animal, including metabolic rate, movement and changes to blood flow, triggered by seasonal drops in temperature

Study tip

Research hibernation and torpor and find some examples of animals that use each of these strategies. Having examples of real animals that use these strategies will provide context to help you remember the difference between them.

Many hibernating animals wake periodically rather than remaining asleep for the duration of their hibernation. This waking is thought to be triggered by the animal's core temperature falling too low, allowing thermoregulation strategies to raise the core temperature to within the tolerance range before the animal goes back to sleep. The main difference between torpor and hibernation is the length of time: torpor is a short-term state (hours or days), while hibernation is a long-term state (months).



FIGURE 4 The short-beaked echidna enters a state of hibernation during cold winters.

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Aestivation

Aestivation is the term for an extended period of torpor in conditions of extreme heat and/or low water availability. Species of amphibians, fish, mammals and reptiles use aestivation to survive hot, dry summers in arid environments, such as deserts and seasonal water bodies. In aestivation, an animal will usually find a cooler or wet spot and enter an extended period of torpor. This avoids the expenditure of energy that would have been needed to cool the animal or to prevent loss of water.

Ranoidea platycephala, also known as the water-holding frog, enters a state of aestivation during periods of drought or dry summers. It stores a large amount of water under its skin and buries itself in the ground. These frogs can stay buried and in a state of aestivation for up to three years.



FIGURE 5 The Australian water-holding frog will enter a period of aestivation when temperatures are too high, or when water availability is too low.

Physiological mechanisms

Physiological mechanisms that aid in thermoregulation include **evaporative heat loss**, **thermogenesis** and vasomotor control.

Evaporative heat loss

Evaporation is the process in which molecules of water change from liquid to gaseous state. To change from liquid to gas, water molecules must absorb heat energy from the surrounding environment; in turn, this cools the surface from which the liquid has evaporated. Evaporative heat loss occurs when water or liquid from an organism is brought to an external surface by panting, sweating or licking of limbs. When liquid is brought to the surface, it evaporates, moving heat energy away from the body to the surrounding environment, cooling the organism.



FIGURE 6 Dogs pant to cool down in hot temperatures.

Thermogenesis

In extremely low temperatures, preventing heat loss may be insufficient to maintain an optimal body temperature. Endotherms produce additional heat in a process called thermogenesis. Heat production can be increased by raising the metabolic rate through rapid muscle contraction (moving around or shivering) and through production of hormones that stimulate metabolic activity.

aestivation
an extended period of torpor in conditions of high temperature and/or low water availability

evaporative heat loss
the process in which heat is lost when a liquid is converted to gas

thermogenesis
the internal generation of heat by an organism

vasodilation
the widening of blood vessels close to the surface of the skin, to increase heat loss to the environment through radiation

vasoconstriction
the narrowing of blood vessels close to the surface of the skin, to reduce heat loss to the environment through radiation

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Study tip

Remember that "constrict" means to squeeze and get smaller, like a boa constrictor squeezing its prey. Remember that "dilate" means to open up and get bigger, the way your pupils dilate to let more light in when you walk into a dark room.

Vasomotor control

Small animals lose heat faster than large animals, due to their high body surface area to volume ratio. The more an animal's body surface is exposed to air, the faster it will lose heat. Animals can minimise heat loss by vasomotor control, which is the ability to control the opening of blood vessels (**vasodilation**) or constriction of blood vessels (**vasoconstriction**). For example, the arms and legs of animals tend to have a high surface area available to lose heat to the surrounding environment. Vasoconstriction in the body's extremities, such as arms and legs, decreases the blood flow to these areas, reducing the temperature gradient between the skin and environment, and slowing the rate of heat loss. Additionally, some animals have a counter-current heat exchange system in their blood vessels. This involves the intertwining of arteries and veins to reduce the temperature of blood moving through the arteries to the extremities as it is transferred to the veins returning to the heart.

Check your learning 11.2

Check your learning 11.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** "kleptothermy" and provide an example. (2 marks)
2 **Define** "torpor". (1 mark)
3 **Explain** why brown adipose tissue is helpful in thermoregulation. (2 marks)
4 **Explain** what happens if the body temperature of a hibernating animal drops too low. (2 marks).
5 **Explain** evaporative heat loss as a thermoregulatory strategy of animals. (3 marks)

Analytical processes

6 **Contrast** hibernation and aestivation. (1 mark)

Lesson 11.3
Thermoregulation in humans

Learning intentions and success criteria

Key ideas

→ The human body uses negative feedback systems to respond to temperatures outside its optimal range and maintain a constant temperature.
→ The hypothalamus in the brain receives information from thermoreceptors and responds by triggering the release of hormones to adjust heat generation and heat loss accordingly.
→ Sweating and vasodilation are mechanisms that are triggered to promote heat loss.
→ Shivering and vasoconstriction are mechanisms that are triggered to generate and conserve heat.

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Thermoregulation to decrease body temperature

Like other endotherms, humans maintain a constant body temperature through negative feedback systems. When the brain detects that the temperature of the body is rising above optimal, it responds by triggering actions that promote heat loss and reduce heat production. If the brain detects that body temperature is too low, it responds by triggering actions that conserve and generate heat.

Thermoreceptors that detect heat and cold are spread throughout the skin, the veins and the hypothalamus in the brain. The hypothalamus receives information from thermoreceptors around the body and acts as a thermostat, responding appropriately to drops and spikes in body temperature. As these signals pass through the brain, a person becomes aware of the change in temperature and can also respond by changing their behaviour (e.g. putting on or taking off a jumper).

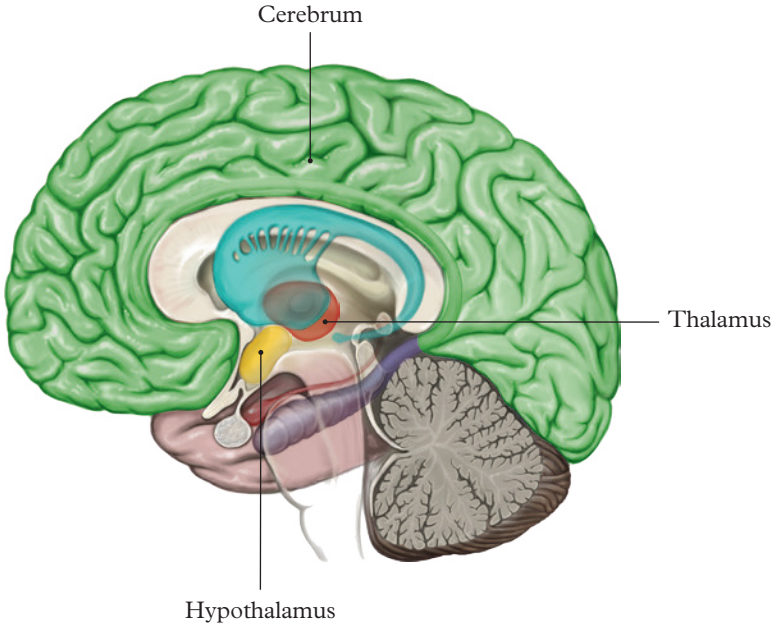


FIGURE 1 The hypothalamus is the region of the brain that controls thermoregulatory mechanisms.

In humans, when body temperature is detected as being higher than usual, thermoregulatory mechanisms such as sweating and vasodilation help return the body to an optimal temperature. These actions are controlled by the heat-loss centre in the hypothalamus.



FIGURE 2 Sweating is a thermoregulatory response to increased body temperature.

Sweating

Sweating is the secretion of water and salt by sweat glands in the skin. It cools the body by evaporative heat loss as the sweat evaporates. Because a large amount of energy is needed to cause sweat to evaporate (from liquid to gas), sweating is an effective method of cooling the body. It is particularly effective for humans, who have little hair and many sweat glands in their skin. Sweating is a less effective method of heat loss in humid conditions, because the reduced diffusion gradient slows the rate of evaporation from the skin.

sweating
a thermoregulatory response that releases liquid from the body's sweat glands

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Vasodilation

As you learnt in Lesson 11.2, vasodilation is the widening of blood vessels. The hypothalamus triggers vasodilation to move blood closer to the skin of the organism. Increasing the amount of blood circulating closer to the skin allows more heat to be lost to the environment through radiation, and through evaporative heat loss in combination with sweating.

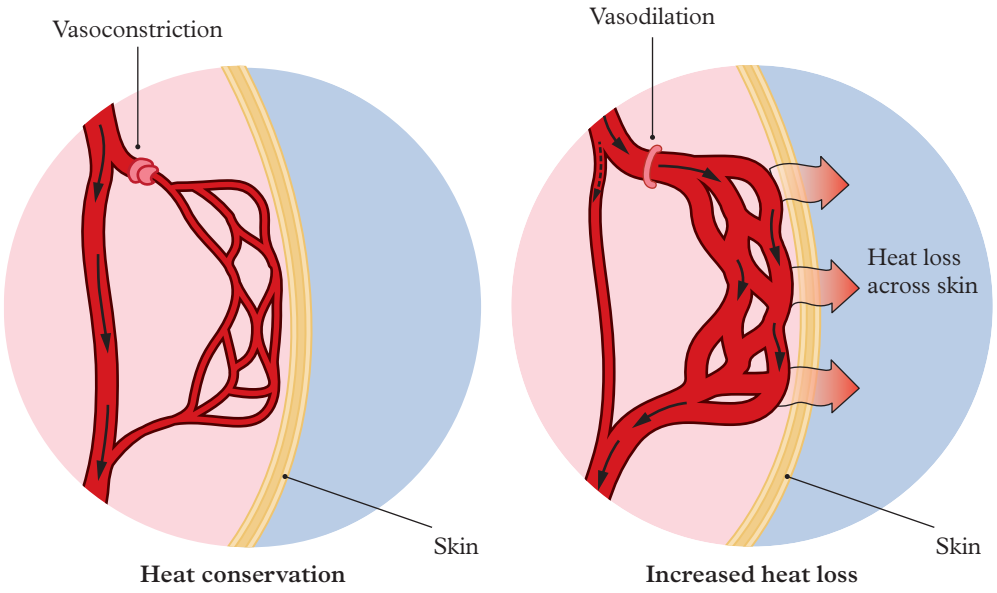


FIGURE 3 Vasoconstriction and vasodilation

Thermoregulation to increase body temperature

The hypothalamus responds to cold temperatures by stimulating the pituitary gland to produce thyroid-stimulating hormone (TSH). TSH triggers the thyroid to release the hormone thyroxine, which acts on various organs and cells to increase the rate of metabolism and heat production. This coordinated response between the nervous and endocrine systems allows endotherms to survive in climates colder than their optimal core temperature. To reach an optimal body temperature, the hypothalamus will also activate its heat-promoting centre to trigger the thermoregulatory mechanisms of shivering and vasoconstriction.

Shivering

shivering
an involuntary motor response that causes muscle contractions to generate heat

Shivering is an involuntary muscular response controlled by the central nervous system that causes muscles in the body to contract and shake. Like all muscle movement, this forced movement of muscles generates heat, which helps to raise the core body temperature.

Vasoconstriction

As you learnt in Lesson 11.2, vasoconstriction is the constriction or tightening of blood vessels. Blood that flows closest to the skin of a human is the most susceptible to losing heat, particularly in cold climates. When the body detects a drop in core temperature, the hypothalamus triggers vasoconstriction to reduce the amount of blood flowing close to the skin. This prevents excessive heat from being lost to the environment.

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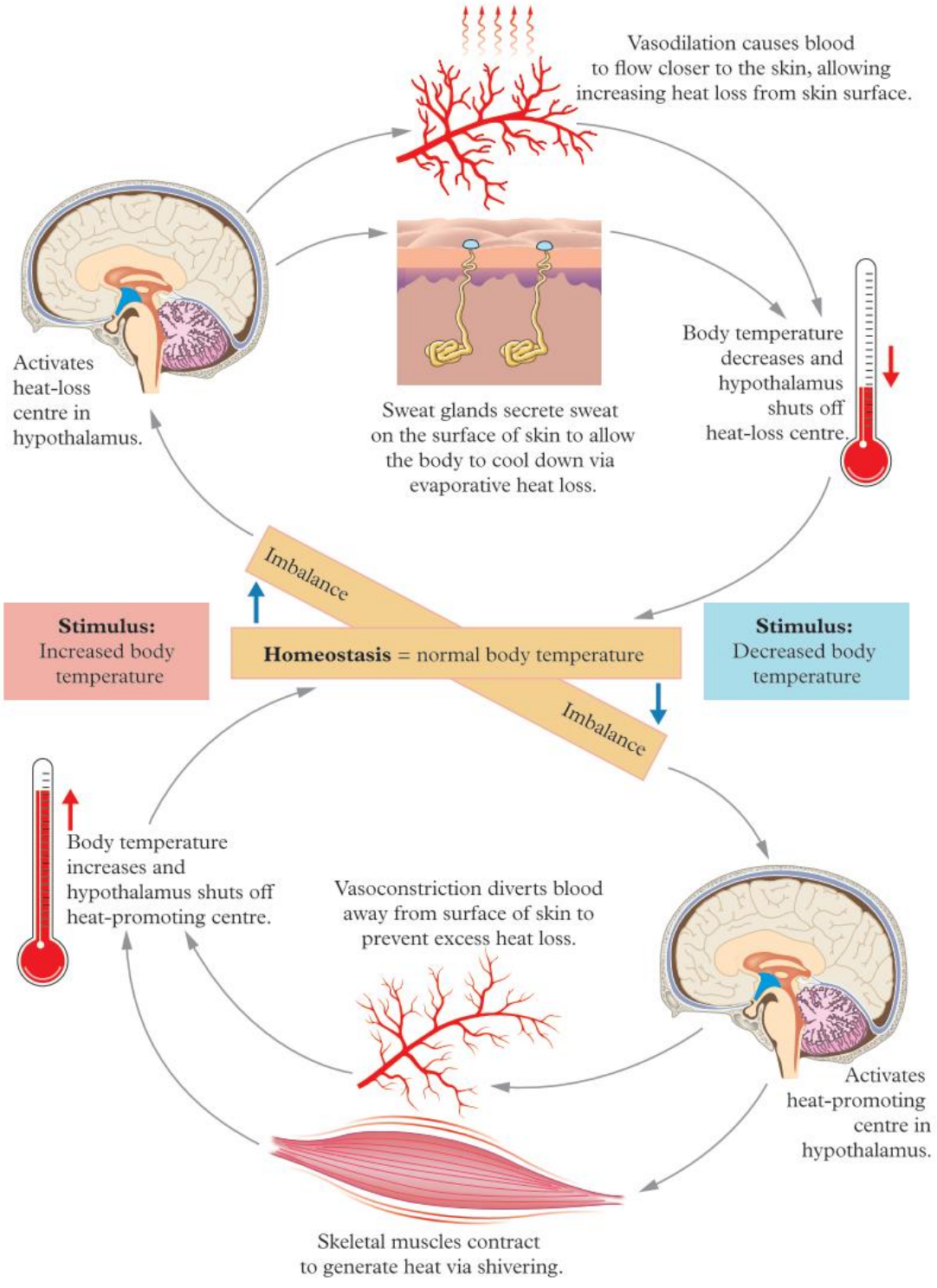


FIGURE 4 Feedback control diagram of thermoregulatory mechanisms in humans

Study tip

Practise drawing flowcharts of feedback loops to help you remember the relationships between receptors, effectors and the control centre.

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Real-world biology

Hypothermia can save the lives of heart attack patients

Intentionally reducing body temperature to treat injury has been recorded as far back as 3000 BCE in Ancient Egypt. While induced hypothermia has been a topic of great scientific debate, it is currently used by medical professionals in some situations, including treatment of heart attack patients. When the heart suddenly stops pumping blood, the available oxygen and waste products in the blood become out of balance. Dangerous levels of waste products may build up even after the heart has been restarted, potentially causing irreversible damage to the brain and other vital organs. When emergency doctors induce hypothermia by cooling the body to between 32 and 34 degrees Celsius, the heart slows and this slows the body's metabolic rate. With less waste produced and less oxygen demanded by metabolism, the body can gradually return to homeostasis before being safely warmed again.

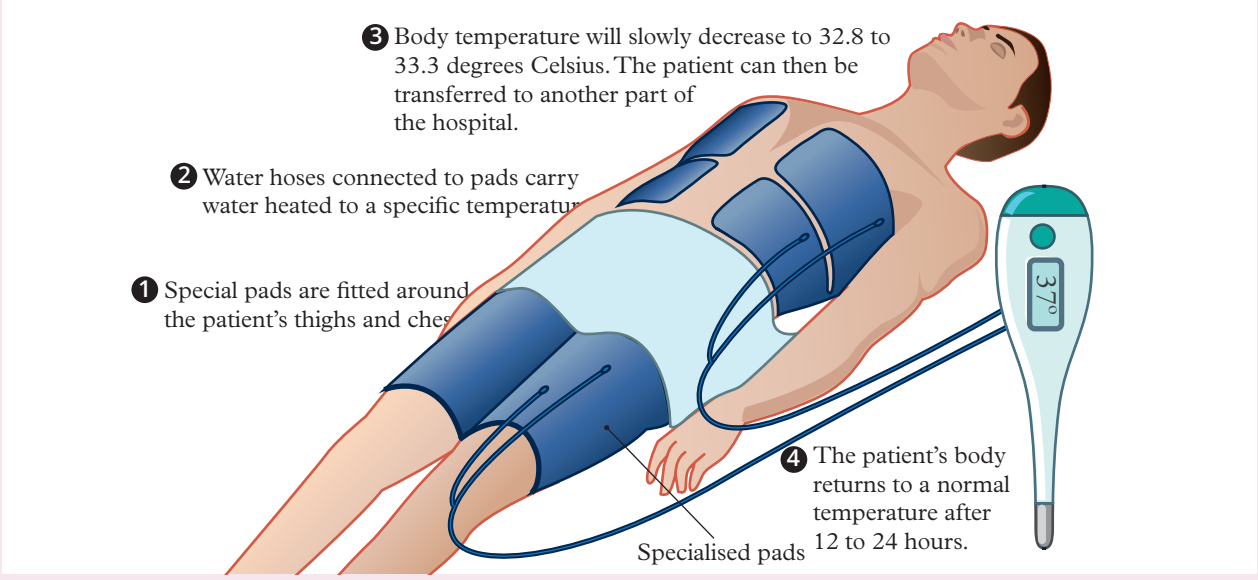


FIGURE 5 Steps involved in inducing hypothermia

Apply your understanding

1 **Explain** why slowing the heart rate reduces metabolic rate. (3 marks)

2 **Identify** one example of a waste product that may build up in the bloodstream if the metabolic rate is not slowed. (1 mark)

Check your learning 11.3

Check your learning 11.3: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** the part of the brain that receives information about temperature. (1 mark)

2 **Summarise** the thermoregulatory mechanisms in humans that cool the body in response to an increase in body temperature. (2 marks)

3 **Summarise** the thermoregulatory mechanisms in humans that warm the body in response to a decline in body temperature. (2 marks)

Knowledge utilisation

4 **Draw a conclusion** about the effect of high temperatures on enzymes in the body if thermoregulation did not occur. (2 marks)

5 **Evaluate** whether the feedback diagram in Figure 4 is an example of a positive or negative feedback loop. (2 marks)

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Lesson 11.4
Osmoregulation in humans

Key ideas

- → Osmoregulation is the process of regulating the balance of water and salts (osmotic balance) in the body.
- → Osmoregulation in humans is controlled primarily through promotion or inhibition of water loss from the kidneys in urine production to remove waste.
- → Nephrons are the main structure of waste removal in the kidneys and allow waste such as urea to be filtered from the blood to produce urine, which collects in the bladder and is excreted through the urethra.
- → The hypothalamus in the brain detects hydration in the bloodstream and produces the hormone ADH to signal to the nephrons whether to retain or release water, to maintain optimal water levels in the body.

Osmoregulation

Learning intentions and success criteria

Water and salts are essential for many cellular processes. However, like many substances in the human body, the ideal balance of water and salt in the body, also known as **osmotic balance**, lies within a narrow range. If the concentration of water or salts is too low or too high, it can disrupt normal body functioning.

osmotic balance the balance of water and salt concentrations in the body

Salts are important for maintaining water balance, which is needed for the functioning of muscles and nerves. When there is too much water in the body, the concentration of salts in the blood can become too low. This is known as low **osmolality**. Excess water can cause cells in the body to swell, and reduced levels of salts can interfere with the functioning of muscles and nerves. Symptoms of **hyponatraemia**, which is when the amount of sodium in the blood is below the optimal level, include headaches, nausea, muscular problems and low blood pressure.

osmolality the concentration of particles dissolved in a fluid

hyponatraemia a condition that results from low levels of sodium in the blood



FIGURE 1 Salts are needed for the proper functioning of muscles and nerves. Low osmolality can result in muscular pain.

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When there is insufficient water in the body, osmolality increases and the concentration of salt in the blood may exceed optimal levels. This imbalance can cause water to be drawn out of cells, causing the cells to shrink and become dehydrated. High osmolality can impair cellular function, and cause symptoms such as dry mouth, weakness and mental confusion. High osmolality can also result in dehydration, electrolyte imbalance and organ dysfunction.

osmoregulation
the physiological regulation of water and salt concentrations in the body

antidiuretic hormone (ADH)
a hormone that triggers the kidneys to release less water, reducing the amount of urine produced

Osmoregulation is the process of regulating the balance of water and salts (osmotic balance) in the body. In humans, osmoregulation is facilitated by the kidneys and **antidiuretic hormone (ADH)**.

The role of the kidneys in osmoregulation

Remember from Lesson 6.3 that the excretory system facilitates the reabsorption of water and salts back into the bloodstream during excretion of liquid waste. Blood enters the kidneys through the renal arteries, which divide into several arterioles that deliver blood to a collection of capillaries, called the glomerulus, at the beginning of each nephron in the kidney. Water, dissolved waste and ions, and a small amount of protein diffuse from the capillaries in the glomerulus into the Bowman's capsule, where the solution begins its passage through the nephron. This solution that passes through the nephron is referred to as the filtrate. Red blood cells and most of the proteins in the blood plasma are retained in the capillaries and do not pass through the nephron.

The filtrate moves through the proximal convoluted tubule, where some proteins, glucose, ions and water are reabsorbed into the bloodstream. As the filtrate moves down the loop of Henle, water and sodium ions are absorbed back into the interstitial fluid and bloodstream. As the filtrate moves around the bend at the bottom and moves back up the loop of Henle, sodium ions are pumped out into the interstitial fluid and bloodstream. Finally, the filtrate reaches the distal convoluted tubule and collecting duct, where more water is reabsorbed before the filtrate moves to the bladder to be excreted as urine.

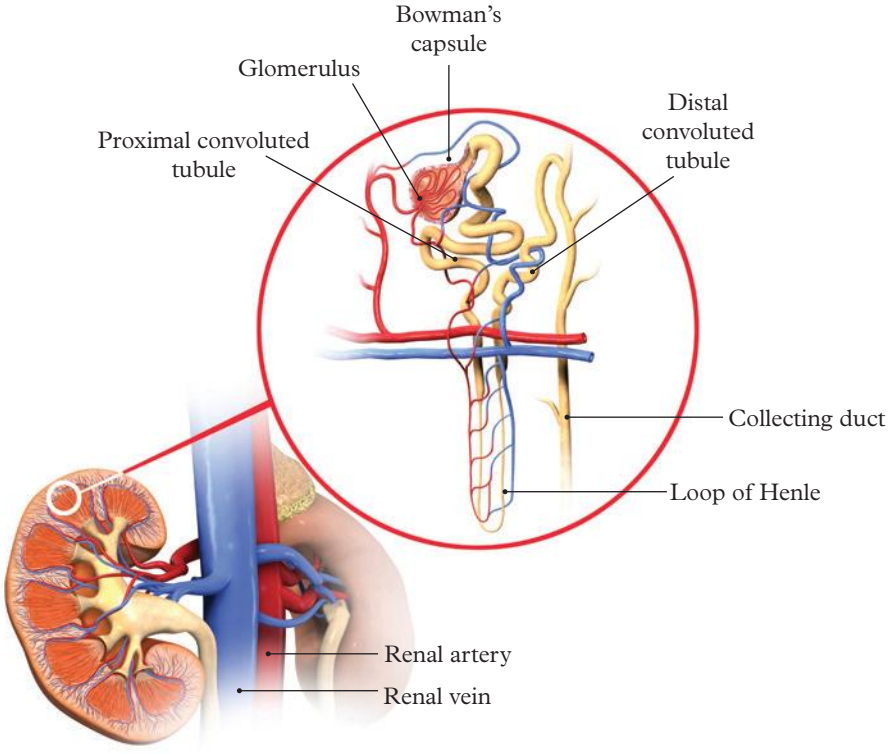


FIGURE 2 The human kidney with detail of a nephron

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The role of ADH in osmoregulation

The amount of water reabsorbed from filtrate at the distal convoluted tubule and collecting duct is controlled by the production of ADH. ADH is produced within the hypothalamus (in the brain) when **osmoreceptors**, receptors that detect changes in osmotic balance, detect low concentrations of water in the bloodstream. The production of ADH triggers the sensation of thirst, and ADH is transferred to the pituitary gland, where it is released into the bloodstream. Once ADH in the bloodstream reaches the kidney, it increases the permeability of the distal convoluted tubule and collecting duct, allowing more water to be reabsorbed by the body. When water is reabsorbed into the bloodstream, the filtrate becomes more concentrated, resulting in darker, more concentrated urine leaving the body. When the osmoreceptors detect that the water concentration in the blood has returned to a normal level in the bloodstream, ADH production is reduced, and water reabsorption in the nephron and the colour of the urine return to normal.

osmoreceptor
a sensory receptor that detects changes in osmotic pressure

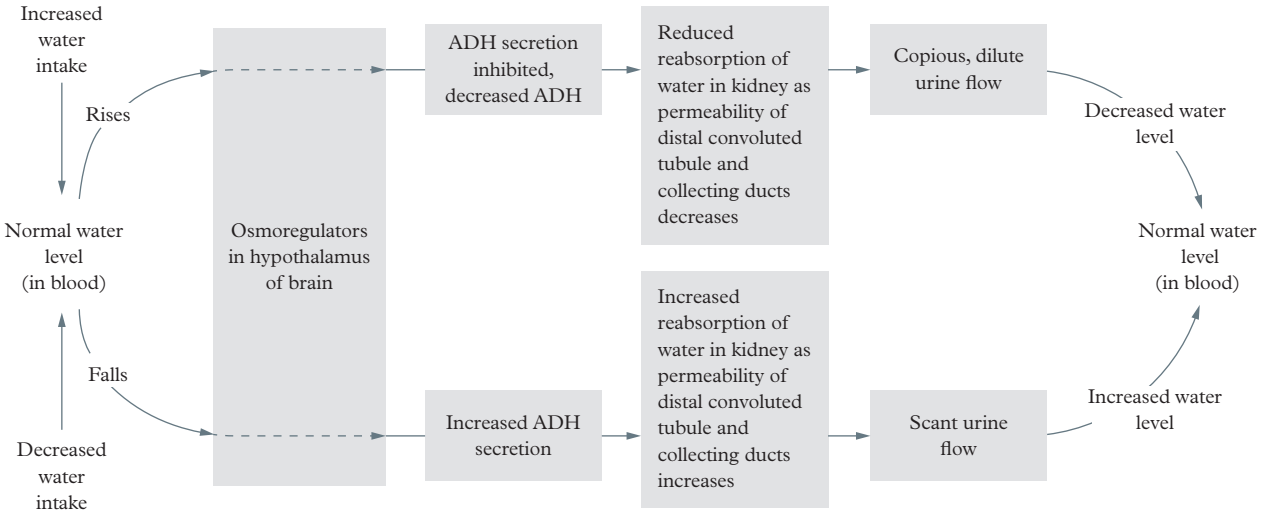


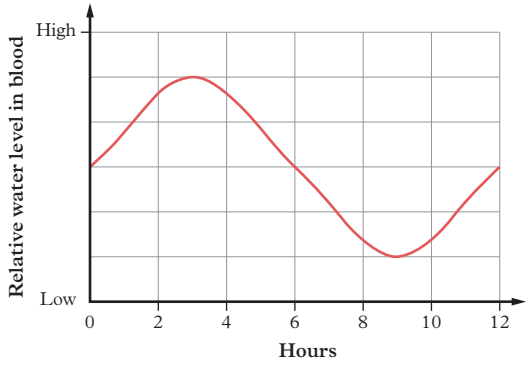
FIGURE 3 Osmoregulation shown in a feedback diagram

Skill drill

Identifying events on a graph

Science inquiry skill: Collecting data (Lesson 1.6)

Antidiuretic hormone (ADH), also known as vasopressin, controls the amount of water in the blood. Osmoreceptor cells in the hypothalamus detect a drop in water levels in the blood, and trigger the pituitary gland to excrete ADH. ADH acts by increasing reabsorption of water in the kidneys.



Practise your skills

1 Copy the graph and **identify** the following events, by labelling each event along the line.
   - **a** ADH is released. (1 mark)
   - **b** ADH is supressed. (1 mark)
   - **c** Osmoreceptors detect a drop in water levels. (1 mark)
   - **d** Osmoreceptors detect a rise in water levels. (1 mark)
   - **e** Urine is dilute. (1 mark)
   - **f** Urine is concentrated. (1 mark)

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Check your learning 11.4

Check your learning 11.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** the role of the kidneys in osmoregulation. (1 mark)
2 **Identify** the components of blood that do not diffuse from the glomerulus into the nephron. (2 marks)
3 **Describe** the locations of ADH production, distribution and action on the body in osmoregulation. (3 marks)
4 **Describe** how waste products in the bloodstream are removed from the body. (3 marks)

Lesson 11.5
Osmoregulation in plants

Key ideas

- → Plants require a reliable source of sufficient fresh water to maintain their transpiration stream and support photosynthesis for energy production.
- → Plants adapted for different water availability can be categorised as mesophytes, hydrophytes, xerophytes or halophytes.
- → Structural mechanisms that aid in maintaining water balance in plants include stomata, vacuoles and the cuticle.
- → Homeostatic mechanisms that aid in maintaining water balance in plants include the production of abscisic acid (ABA).

Learning intentions and success criteria

Water balance in plants

Most plants are fixed in soil, sand or rock, and are therefore unable to move to find water. Instead, they must rely on the water available in the surrounding substrate to be sufficient for transpiration through the xylem. Because the cell wall of plant cells helps prevent the cells from bursting, they are less vulnerable to inundation with water than animal cells. However, plant cells are vulnerable to dehydration, which can cause the cell membrane to retract away from the cell wall, leading to a highly concentrated cytoplasm and cell death. Plants grow in aquatic and terrestrial environments and in a wide range of temperatures, including those where water can be scarce, due to drought, or inaccessible in its solid form as ice. The Earth's water ranges from fresh or brackish (slightly salty) in intertidal regions, to highly salty in the oceans. Plants can be grouped according to the environments they live in and the adaptations they have developed to survive different environments.

- **Mesophytes** have adapted to habitats with a reliable and regular source of fresh water. Mesophytes have no specialised adaptations for obtaining water or preventing water loss, as a constant supply of water is always available.

mesophyte
a plant adapted to a habitat that has a frequent and reliable source of fresh water

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- **Hydrophytes** can live partially or fully submerged in water where sunlight penetrates enough for them to photosynthesise.
- **Xerophytes** have adapted to extremely dry conditions. Xerophytes can be found in areas of extreme heat with little rainfall or in areas of extreme cold where temperatures are rarely high enough for water stored in ice to melt.
- **Halophytes** have adaptations that allow them to survive in water or soil with high salt concentrations. Some halophytes can only live in saline environments. For example, mangroves are obligate halophytes – their adaptations are so specialised to salty water that they are unable to survive if moved to a freshwater environment.

In this lesson you will learn about the different structural and homeostatic mechanisms for maintaining water balance in plants.

hydrophyte
a plant with adaptations that allow it to function with little water

xerophyte
a plant adapted to a dry habitat

halophyte
a plant that has adaptations allowing it to obtain sufficient water in a salty environment

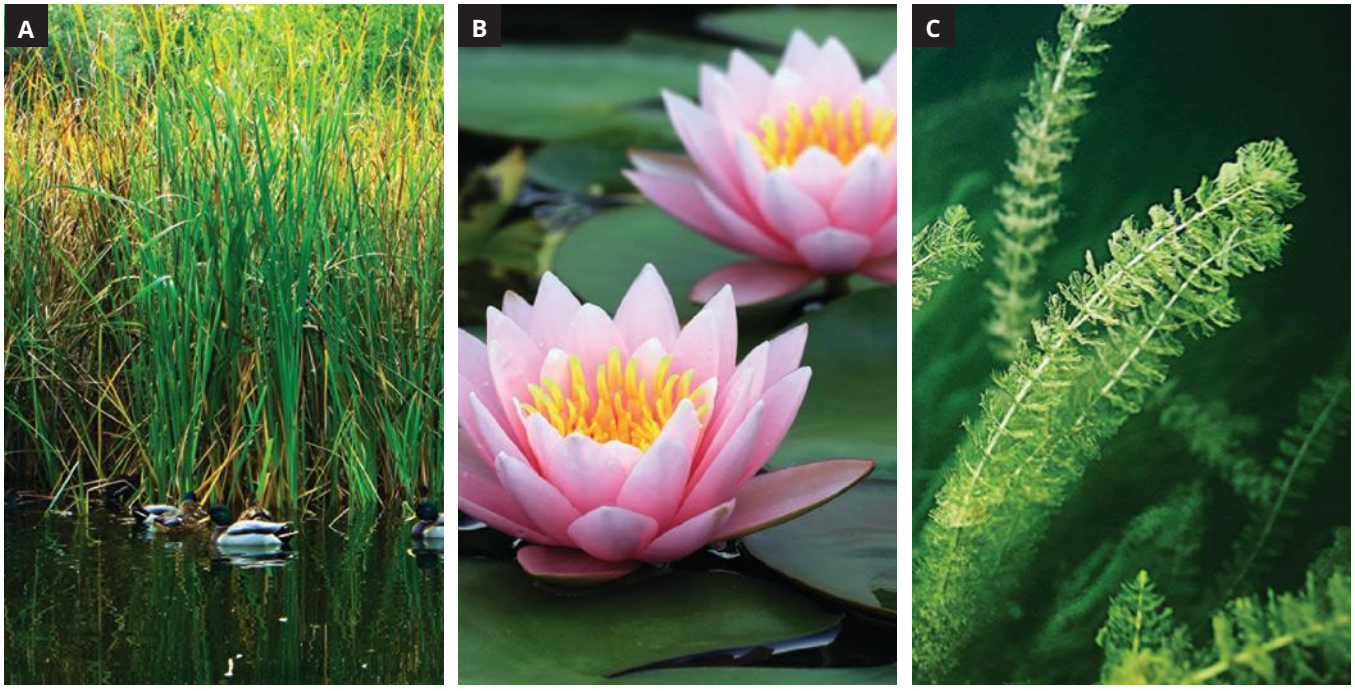


FIGURE 1 Examples of hydrophytes: (A) partially submerged (B) floating (C) fully submerged

Structural mechanisms

Structural mechanisms to regulate water balance in plants include the stomata, vacuoles and the **cuticle**.

cuticle
a protective film made of cutin that covers the outer layer (epidermis) of leaves

Stomata

As you learnt in Lesson 9.2, a stoma consists of two guard cells, and acts as an entry/exit point for water to transpire out of the plant and CO_2 to enter the plant. Changing osmotic pressure in the guard cells opens and closes the stoma. When a plant has excess water, the guard cells swell, causing the stoma to open and water to transpire out from the plant. When a plant is dehydrated, the guard cells shrink, causing the stoma to close, reducing the amount of water lost by transpiration.

Stomatal number and density (number of stomata per unit area of leaf) vary, depending on the environment and conditions a plant is adapted to live in. Table 1 summarises stomatal number and density in plants adapted to different environments.

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TABLE 1 Summary of stomatal number and density in plants adapted to different environments

Type of plant	Number of stomata	Density of stomata	Explanation
Mesophyte	Average	Average	Mesophytes have a readily available supply of water.
Hydrophyte	Variable (can be low to high)	Variable (can be low to high)	Stomatal number and density depend on adaptations to aquatic environments and whether leaves are fully or partially submerged in water. For example, water lilies have numerous stomata on the upper surface of their leaves and no stomata on the underside. Fully submerged leaves of hydrophytes can have no stomata.
Xerophyte	Low	Low	Due to dry conditions, xerophytes have fewer stomata, to prevent water loss. Stomata can also be "sunken" into the epidermis to prevent excess water loss in response to heat. Some xerophytes only open their stomata at night when the external environment is cool, to prevent water loss.
Halophyte	Low to average	Low to average to high	Halophytes grow in saline environments where water availability can be variable. High salt concentrations around a plant can range from scarce to high.

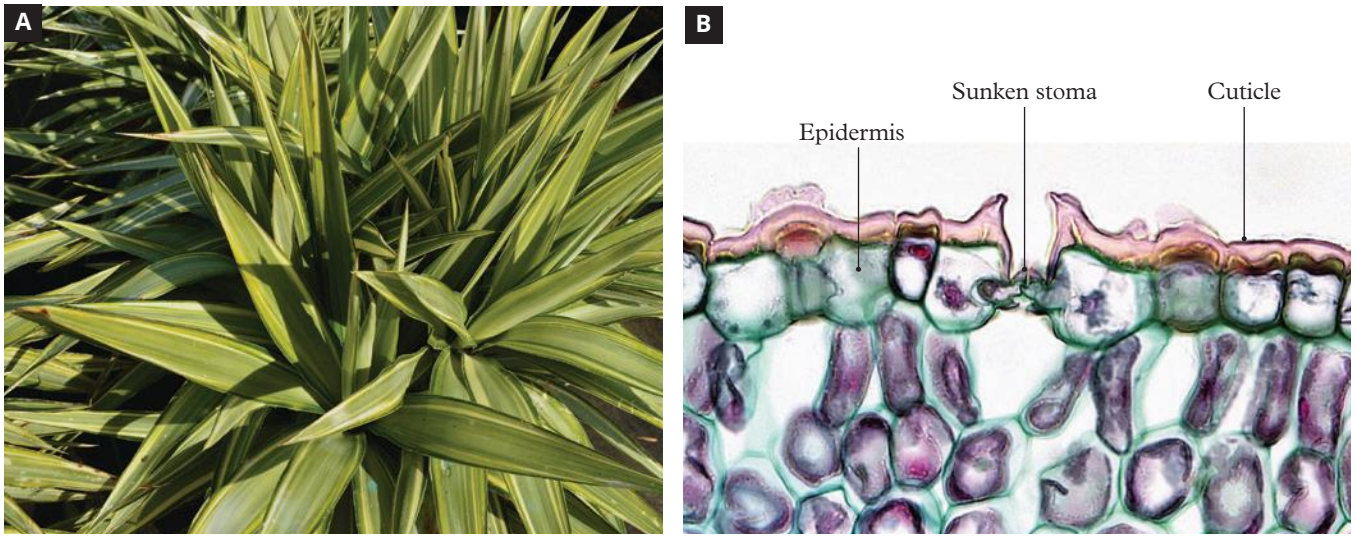


FIGURE 2 (A) Yucca trees are xerophytes adapted to hot climates. (B) A yucca leaf under the microscope, showing a sunken stoma

Vacuoles

Recall from Lesson 2.2 that compared to animal cells, plant cells have a large central vacuole in the centre of the cell. The central vacuole in a plant has two major functions.

turgor pressure the pressure exerted by fluid in a plant cell as it presses the plasma membrane against the cell wall

- It maintains **turgor pressure** (pressure from fluid within a cell that presses the cell membrane against the cell wall).
- It stores water and nutrients.

Both these functions of the central vacuole are important for plants to maintain water balance. Because vacuoles control turgor pressure, they are important in providing the plant with rigidity, and they regulate the swelling or shrinking of cells (including guard cells, which control the opening and closing of stomata). Vacuoles also act as "storage tanks" for water, for when the plant needs it.

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Cuticle

The outermost layer of a plant's leaf is called the leaf cuticle. The leaf cuticle plays an important role in plant osmoregulation. It provides a protective barrier to prevent the plant from losing water. The cuticle is made of cutin, a polymer that consists of fatty acids and glycerol, which provides structural integrity to the leaf. The permeability of the leaf cuticle influences how much water is lost in dry or hot conditions. Plants with a highly permeable leaf cuticle are more vulnerable to losing water in arid conditions, and plants with low leaf cuticle permeability are less susceptible to losing excess water.

Some plants have an extra layer of wax on top of the cuticle. Because wax is hydrophobic, this waxy cuticle acts as an extra barrier preventing water from passing easily through the leaf. Additionally, a waxy cuticle can help to reflect light and heat away from the plant, helping reduce the rate of transpiration.



FIGURE 3 *Eucalyptus* leaves have a waxy cuticle to prevent water loss.

Homeostatic mechanisms

All living organisms, including plants, have homeostatic mechanisms to maintain balance in their internal environment. An example of a homeostatic mechanism in plants that aids osmoregulation is the regulation of the plant hormone **abscisic acid (ABA)**.

abscisic acid (ABA)
a plant hormone that regulates numerous aspects of plant growth, development and stress responses

Abscisic acid

Some plants produce ABA, a plant hormone that regulates several processes including stomatal opening and closing. When these plants experience heat stress or dehydration, ABA is released and acts on ion channels in the leaf guard cells, causing the guard cells to release water and lose turgidity, which closes the stomatal pores. This helps to reduce the rate of transpiration, so the plant can conserve water in times of water stress. When plants are relieved of water stress and rehydrated, production of ABA decreases, allowing regular stomatal opening and closing.

Check your learning 11.5

Check your learning 11.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** why plants must be so highly adapted to efficiently using water compared to animals. (1 mark)
2 **Explain** why xerophytes are likely to have fewer stomata than mesophytes. (1 mark)
3 **Describe** two ways in which a waxy cuticle helps to conserve water in plants. (2 marks)
4 **Describe** two ways in which the vacuole plays a role in maintaining water balance in plants. (2 marks)
5 **Explain** the role of abscisic acid in allowing plants to survive in arid environments. (2 marks)

Analytical processes

6 **Compare** hydrophytes and xerophytes. (2 marks)

Knowledge utilisation

7 A researcher is investigating the number of stomata on the leaves of two hydrophyte species. They notice that one species only has stomata on the lower surface of the leaves, while the other species has no stomata at all on the leaves. **Propose** a reason for this difference in stomatal number. (1 mark)

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Practical

Lesson 11.6

The role of the leaf in plant osmoregulation

Learning intentions and success criteria

This lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class.

Practical

Lesson 11.7

Investigating tolerance limits for water or salt balance in plant growth

Learning intentions and success criteria

This lesson is available on Oxford Digital. It is also provided as part of a printable resource that can be used in class

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MODULE 11

Lesson 11.8
Review: Thermoregulation and osmoregulation

Summary

11.1
- Thermoregulation allows organisms to maintain their body temperature within the tolerance range for survival.
- Metabolic processes produce heat that is lost to the environment; organisms have behavioural strategies and physical features to reduce or increase this heat loss, to maintain homeostasis.
- Ectotherms gain heat from their environment, while endotherms maintain a stable body temperature by generating heat through metabolic processes.

11.2
- Endotherms have many thermoregulatory mechanisms to maintain their core temperature within a narrow range.
- Structural features that aid in thermoregulation include: insulating layers of fat and brown adipose tissue.
- Behavioural responses that aid in thermoregulation include: torpor, extended periods of torpor, and kleptothermy.
- Physiological mechanisms that aid in thermoregulation include: evaporative heat loss, thermogenesis and vasomotor control.

11.3
- The human body uses negative feedback systems to respond to temperatures outside its optimal range and maintain a constant temperature.
- The hypothalamus in the brain receives information from thermoreceptors and responds by triggering the release of hormones to adjust heat generation and heat loss accordingly.
- Sweating and vasodilation are mechanisms that are triggered to promote heat loss.
- Shivering and vasoconstriction are mechanisms that are triggered to generate and conserve heat.

11.4
- Osmoregulation is the process of regulating the balance of water and salts (osmotic balance) in the body.
- Osmoregulation in humans is controlled primarily through promotion or inhibition of water loss from the kidneys in urine production to remove waste.
- Nephrons are the main structure of waste removal in the kidneys and allow waste such as urea to be filtered from the blood to produce urine, which collects in the bladder and is excreted through the urethra.
- The hypothalamus in the brain detects hydration in the bloodstream and produces the hormone ADH to signal to the nephrons whether to retain or release water, to maintain optimal water levels in the body.

11.5
- Plants require a reliable source of sufficient fresh water to maintain their transpiration stream and support photosynthesis for energy production.
- Plants adapted for different water availability can be categorised as mesophytes, hydrophytes, xerophytes or halophytes.
- Structural mechanisms that aid in maintaining water balance include stomata, vacuoles and the cuticle.
- Homeostatic mechanisms that aid in maintaining water balance include the production of abscisic acid (ABA).

11.6
- Practical: The role of the leaf in plant osmoregulation

11.7
- Practical: Investigating tolerance limits for water or salt balance in plant growth

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Review questions 11.8A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Organisms that are able to maintain a stable internal temperature are called
   A animals.
   B ectotherms.
   C endotherms.
   D mammals.

2 Animals that slow their breathing, heart rate and physical activity for short periods of time to conserve energy in extreme environments are said to be in a state of
   A kleptothermy.
   B hibernation.
   C homeostasis.
   D torpor.

3 Strategies for increasing heat loss in high temperatures include
   A aestivation, nocturnal activity and vasodilation.
   B kleptothermy, nocturnal activity and sweating.
   C aestivation, sweating and vasoconstriction.
   D aestivation, kleptothermy and vasodilation.

4 The main organ for osmoregulation in humans is
   A the bloodstream.
   B the kidney.
   C antidiuretic hormone (ADH).
   D the glomerulus.

5 The component of blood that is unable to pass from the bloodstream into the nephron is
   A filtrate.
   B ions.
   C plasma.
   D red blood cells.

6 The structure that detects the amount of water in the bloodstream is the
   A glomerulus.
   B hypothalamus.
   C kidney.
   D nephron.

7 Halophytes are plants that are suited to living
   A in cold conditions.
   B in dry conditions.
   C in salty conditions.
   D submerged in fresh water.

8 Plants that do not have a waxy cuticle on the surface of their leaves are likely to be
   A halophytes.
   B hydrophytes.
   C mesophytes.
   D xerophytes.

Review questions 11.8B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

9 **Explain** the function of the nephron in the kidneys, from the glomerulus through the loop of Henle to the collecting duct and the bladder. (4 marks)

10 **Explain** the role of antidiuretic hormone in maintaining homeostasis in the human body. (3 marks)

Knowledge utilisation

11 Kleptothermy is a strategy used by penguins to stay warm on the ice in Antarctica. **Infer** why this would not be an effective strategy for reptiles, such as lizards. (2 marks)

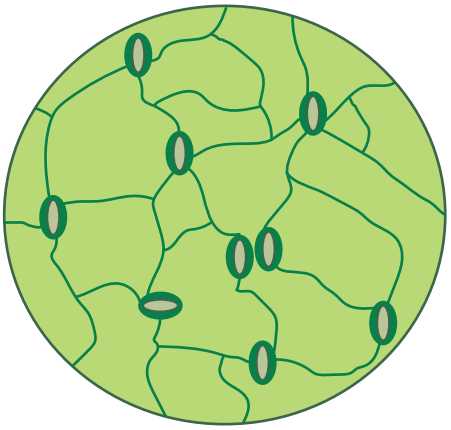
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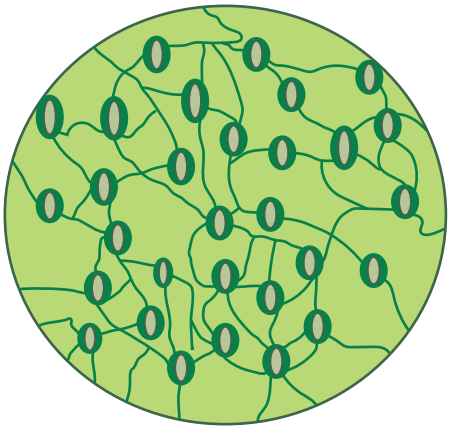
Data drill

Comparing stomatal density in plants adapted to different environments

Stomatal density is the number of stomata per unit area of leaf. It is calculated by counting the number of stomata visible in a microscope's field of view and then dividing this number by the area of the field of view. A researcher is comparing the stomatal density of two plant species adapted to different environments. What they see in the microscope under ×400 magnification is shown below.



Species A



Species B

Apply understanding

1 **Identify** the number of stomata for Species A and Species B. (2 marks)

2 If the radius (r) of the field of view is 0.24 mm, **calculate** the stomatal density for Species A and Species B using the following:
- Area = πr^2
- Stomatal density = number of stomata ÷ area. (4 marks)

Analyse data

3 **Identify** which species had the lowest stomatal density. (1 mark)

Interpret evidence

4 **Deduce** which of Species A or Species B is likely to be a xerophyte (a plant adapted to drier conditions). **Justify** your answer. (3 marks)

Module 11 checklist: Thermoregulation and osmoregulation

Quizlet: Revise key terms online to test your understanding

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UNIT 2

Topic 1 Review

Multiple choice

(1 mark each)

1 Negative feedback describes a process that occurs
- **A** along a concentration gradient.
- **B** to slow or stop a response.
- **C** only in the central nervous system.
- **D** within neurons.

2 The fatty layer that surrounds the axon of a neuron to insulate the electrical signal is called the
- **A** axon terminal.
- **B** dendrite.
- **C** myelin sheath.
- **D** Schwann cell.

3 The solution of water, ions and dissolved waste products that moves through the nephron is called
- **A** blood.
- **B** filtrate.
- **C** plasma.
- **D** urine.

4 Neurons with a voltage of –70 mV across their cell membrane are said to be
- **A** at resting potential.
- **B** depolarised.
- **C** firing an action potential.
- **D** repolarising.

5 Efferent neurons are nerve cells that
- **A** are also known as sensory neurons.
- **B** are found only in the central nervous system.
- **C** detect changes in the external environment.
- **D** relay signals from the central nervous system to muscles and glands.

6 Vasodilation is one of the body's responses to
- **A** high temperatures.
- **B** low temperatures.
- **C** pain.
- **D** pressure.

7 Reflex arcs are
- **A** an evolutionary adaptation for survival.
- **B** signals sent through afferent neurons to the central nervous system.
- **C** signals sent from the central nervous system through efferent neurons.
- **D** the signal sent along a neuron.

8 Osmolarity refers to the balance of
- **A** hydration in the body.
- **B** nutrients in the body.
- **C** osmosis.
- **D** water and salt concentrations in the body.

9 Antidiuretic hormone (ADH) is involved in
- **A** egg release from the ovaries of female humans.
- **B** osmoregulation.
- **C** transmission of signals between neurons at the synapse.
- **D** vasodilation for the purpose of thermoregulation.

10 Molecules that cross the synaptic cleft from the axon terminals of one neuron to the dendrites of another are called
- **A** electrons.
- **B** ions.
- **C** neurotransmitters.
- **D** vesicles.

11 The change in electrical potential energy across the cell membrane that is required to trigger an action potential is called
- **A** the absolute refractory period.
- **B** repolarisation.
- **C** resting potential.
- **D** threshold potential.

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12 Brown adipose tissue
- **A** covers the body of marine mammals to keep them warm in the water.
- **B** has more mitochondria than other types of adipose tissue.
- **C** is the scientific term for a collection of fat cells.
- **D** is found only in adults.

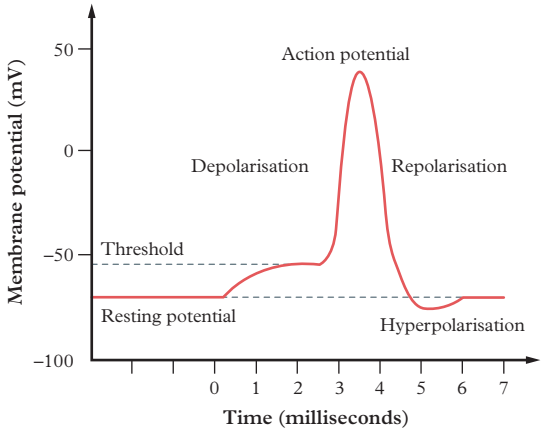
13 An animal that maintains a constant internal temperature in fluctuating environmental temperatures is known as
- **A** an endotherm.
- **B** an ectotherm.
- **C** cold-blooded.
- **D** a eukaryote.

14 The tube that excretes urine to the outside of the body is called the
- **A** bladder.
- **B** nephron.
- **C** ureter.
- **D** urethra.

15 Motor neurons are
- **A** also known as efferent neurons.
- **B** connectors between afferent and efferent neurons.
- **C** found only in the brain.
- **D** the types of nerve cells responsible for detecting movement.

Short response

16 The graph shows the membrane potential of the axon of a neuron throughout an action potential. (7 marks)



- **a** **Determine** whether a membrane potential of −60 mV is sufficient to trigger an action potential. **Justify** your response, using information from the graph. (3 marks)
- **b** **Identify** the time (in milliseconds) when another action potential may occur. (1 mark)
- **c** **Explain** why the membrane potential is a negative value during resting potential. (3 marks)

17 **Identify** the location of electrical and chemical signals within and between neurons. (2 marks)

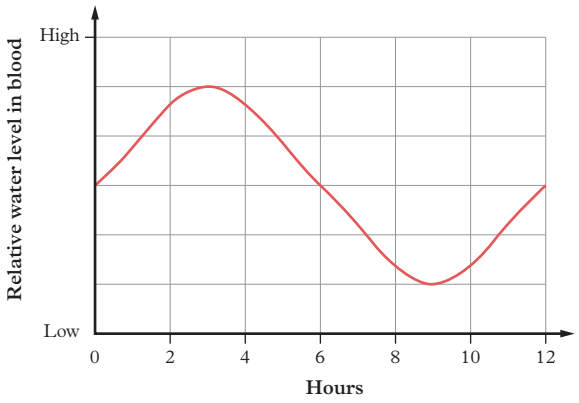
18 **Describe** the function of the loop of Henle in the kidney. (3 marks)

19 **Explain** how ectotherms maintain their body temperature when the external temperature becomes lower than ideal. (3 marks)

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20 The graph shows the relative water level in blood over a 12-hour period. (9 marks)



a **Identify** how many hours have passed when the water level in the blood is at its peak and at its lowest. (2 marks)

b **Suggest** which mechanisms may be occuring to maintain osmoregulation in this organism. Refer to the graph to **justify** your response. (4 marks)

c **Explain** why the relative water level in the blood does not remain steady throughout the day. (3 marks)

21 **Describe** the stimulus–response model. (3 marks)

22 **Explain** how brown adipose tissue is advantageous to animals that live in cold climates. (4 marks)

23 **Contrast** torpor and aestivation. (1 mark)

24 **Describe** how a negative feedback loop works, and provide one example. (3 marks)

25 **Contrast** vasodilation and vasoconstriction. (1 mark)

26 **Explain** how the body maintains homeostasis, using one example of a negative feedback loop. (5 marks)

27 **Explain** how shivering is an example of a thermoregulatory process. (4 marks)

28 **Explain** the role of ADH in osmoregulation. (4 marks)

TOTAL MARKS

/66 marks

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MODULE 12

Disease

Introduction

Disease is a physiological abnormality or significant disruption to the health of an individual. It can be caused by a variety of factors, such as genetic predisposition, environmental conditions, poor nutrition and pathogens. Diseases caused by pathogens are termed "infectious diseases" and these can be contagious or non-contagious, depending on the causative agent and its mode of transmission. Pathogens are parasitic organisms. Some infectious diseases are caused by non-living organic particles, such as prions and viruses.

Plants and animals have a number of natural defence mechanisms against pathogens. These are both physical and chemical in nature. In vertebrates, the immune response is composed of: the innate (non-specific) response, which includes barriers to prevent pathogen entry; the inflammatory response; and adaptive (specific) immune responses to specific pathogens that result in the production of antibodies and memory cells. Immunity can be passive or acquired, and acquired either naturally or artificially.

Prior knowledge



Prior knowledge quiz Check your understanding of concepts related to disease before you start.

Subject matter

Science understanding

- → Distinguish between infectious and non-infectious disease.
- → Identify key features of prions, viruses, bacteria, fungi, protists and parasites.
- → Explain how adherence factors, invasion factors, capsules and toxins affect pathogenesis.
- → Explain how host cells recognise self from non-self.
- → Identify the three lines of defence in vertebrates
  - – the innate immune response: skin and mucous membranes (non-specific)
  - – inflammatory response and complement system (non-specific)
  - – adaptive immune response (specific).

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- → Describe the inflammatory response, including the roles of
  - prostaglandins and vasodilation
  - neutrophils and macrophages
  - natural killer cells.
- → Explain the adaptive immune response, including the
  - humoral response (B lymphocytes, antibodies)
  - cell-mediated response (T lymphocytes)
  - role of memory cells.
- → Compare active and passive immunity, both naturally acquired and artificially acquired.
- → Interpret long-term immune response data.
- → Describe the innate immune responses in plants, including
  - physical defence strategies: barriers and leaf structures
  - chemical defence strategies: plant defensins and production of toxins.

Science inquiry skills

- Analyse data to identify trends, patterns and relationships; recognising error, uncertainty and limitations of evidence.

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Lesson 12.1
Non-infectious and infectious disease

Key ideas

- → Disease is any physiological abnormality or significant disruption to the "normal" health of an organism.
- → Non-infectious diseases cannot be spread from an affected individual to another individual.
- → Infectious diseases are caused by invasion by a pathogen, and can be spread from one host to another either directly or indirectly.
- → Pathogens are biological agents that spread disease.
- → Parasites are cellular organisms that obtain nutrients from a host and rely on a host for survival.
- → An endemic disease is one that exists in a population at regular low levels. An epidemic occurs when a larger than normal number of individuals in a particular locality are infected by a disease at a particular time. If the disease spreads to other countries, it is termed a pandemic.

Understanding health and disease

Learning intentions and success criteria

A healthy individual is one that can function well physically, mentally and socially. What is considered healthy depends on age, vulnerability to disease, sensitivity to pain, physical activity and emotional state. Maintenance of health is aided by the following:

- genes, which control the process of protein synthesis and contain instructions for maintaining normal body functioning
- mitosis, which is regulated by genes and produces identical cells as part of the cell cycle, allowing dead cells to be replaced
- cell differentiation, which follows mitosis and switches certain genes on or off so that a cell can specialise in a certain function
- cell specialisation, which ensures that all the functions of a multicellular organism are carried out efficiently and that all cell types work together to maintain a healthy organism.

Factors that disrupt the regular functioning of these processes can lead to a significant disruption of health, also known as **disease**.

disease
an abnormal condition of an organism or part of an organism in which the normal functions of the body are disrupted

Disease can be broadly defined as any physiological abnormality or significant disruption to the "normal" health of an organism. Onset of disease will often result in the dysfunction of a part or parts of the body. Disease can result from non-living (abiotic) environmental factors, such as mineral nutrient deficiency, drought, lack of oxygen, extreme temperatures and pollution. It can also result from living (biotic) factors that may be present within an individual organism or caused by another organism.

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Diseases can be classified into one of two categories:

- **non-infectious** – not caused by infectious agents, and cannot be spread from one individual to another
- **infectious** – caused by invasion of the body by another organism or biological agent and can be passed, directly or indirectly, from one individual to another.

non-infectious disease
disease that cannot be passed from one individual to another

infectious disease
disease that can be passed from one individual to another

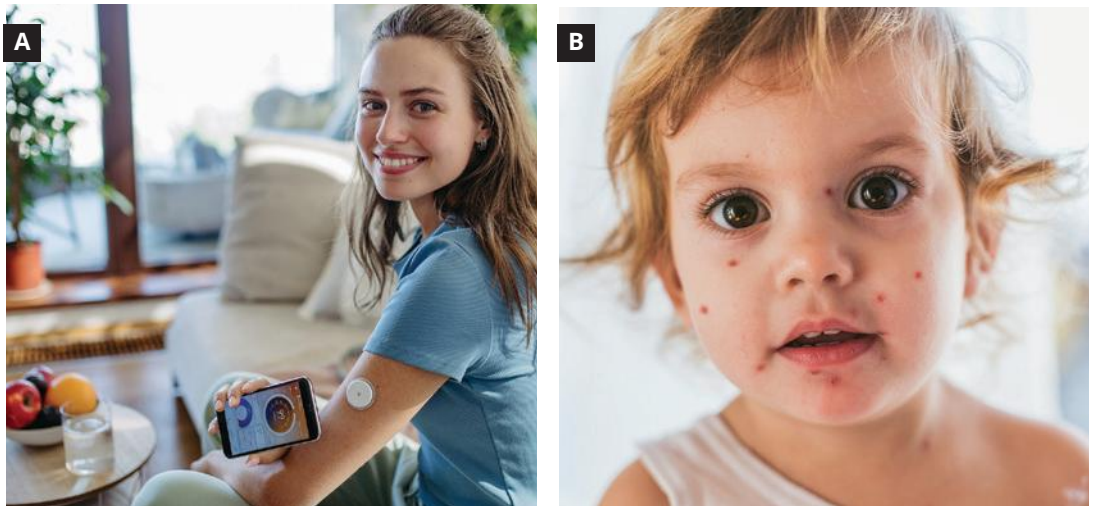


FIGURE 1 (A) Diabetes is a non-infectious disease. (B) Chickenpox is an infectious disease.

Study tip
Disease is the result of disruption of homeostasis – body function is disrupted, leading to illness.

Non-infectious diseases

Non-infectious diseases are not caused by infectious agents and so cannot be spread from the affected individual to another. They stem from the **malfunctioning** of cellular processes that disrupt homeostatic mechanisms or the structure and function of body parts. Causes of non-infectious diseases include **genetic diseases**, **environmental conditions** and nutrition.

malfunctioning
not functioning correctly

genetic disease
a disease that results from a change in a gene and may be inherited

environmental condition
a factor in the external surroundings (biotic and abiotic) that surrounds and affects the survival and development of an organism or population

inherited condition
a condition that can be passed from parent to offspring

Genetic diseases

Genetic diseases are **inherited conditions** that have been passed on to offspring through genes inherited from the DNA of their parents. Examples of genetic diseases are some cancers, autoimmune diseases, cardiovascular disease, diabetes, sickle-cell anaemia and cystic fibrosis. Inheriting the specific genes linked to a disease can increase the likelihood of offspring developing that condition – this is called genetic predisposition. However, being genetically predisposed to a disease or condition does not guarantee that an individual will be affected by that disease.

Environmental conditions

Environmental conditions are factors in the external surroundings that can affect the survival and development of an organism or population. Examples are heavy metal poisoning, electromagnetic radiation, industrial pollution and drug use. Lead and mercury are heavy metals that are particularly dangerous when consumed. Mercury poisoning usually results from industrial waste washing into the sea, where it is taken into the food web. People who experience mercury poisoning from regularly eating contaminated seafood may suffer from paralysis, brain damage and widespread neurological effects. Lead poisoning can come from a variety of sources and results in vomiting, cramps, paralysis and brain damage. Other types of industrial pollution can result in carbon dioxide or carbon monoxide poisoning, or mesothelioma caused by inhalation of asbestos dust. Increased exposure to high levels of electromagnetic radiation has been linked to the development of certain forms of cancer.

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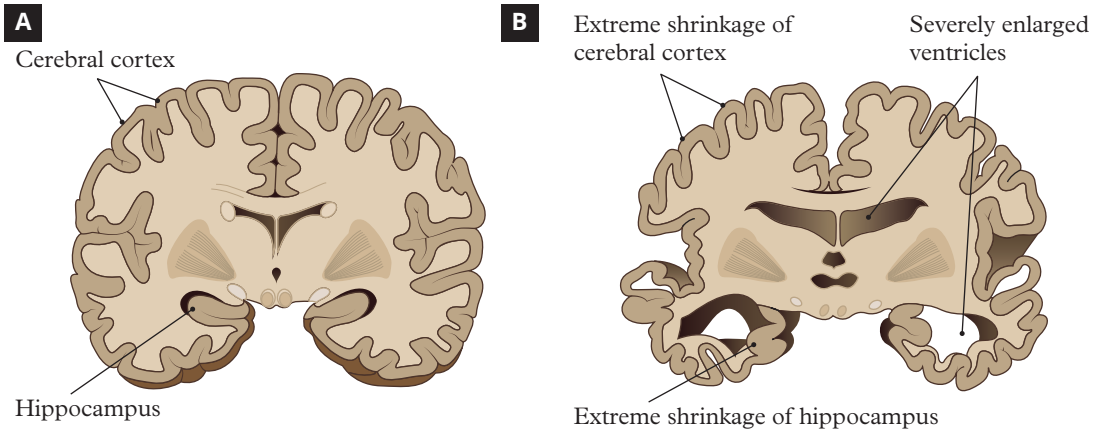


FIGURE 2 Brain sections: (A) normal and (B) with mercury poisoning

Drug use can also disrupt the normal functioning of cellular and metabolic processes. Alcohol can potentially lead to death due to liver damage. It has been shown that babies born to women who over-consumed alcohol during pregnancy are at risk of developing a range of conditions including foetal alcohol syndrome, which may contribute to developmental and learning problems. Tobacco consumption is also linked to a higher incidence of lung cancer. Use of other drugs, such as amphetamines and opioids, can affect the regular functioning of the brain.



FIGURE 3 Old paint often contains lead. Scraping this paint off without proper protective measures (e.g. gloves, face mask) can result in lead poisoning.

nutritional disease
a disease resulting from deficiencies or excesses in the diet

undernutrition
a diet in which the individual is not getting enough calories, protein or micronutrients

Nutritional diseases

Nutritional diseases are caused by an inadequate diet. **Undernutrition** occurs when there is an insufficient amount of one or more essential nutrients in an individual's diet, or when the amount of food a person consumes is insufficient. For example, scurvy is caused by a lack of vitamin C in a person's diet. Scurvy can result in weakness, fatigue, increased risk of bleeding and swelling of gums. Table 1 lists some essential nutrients, their functions and deficiency diseases.

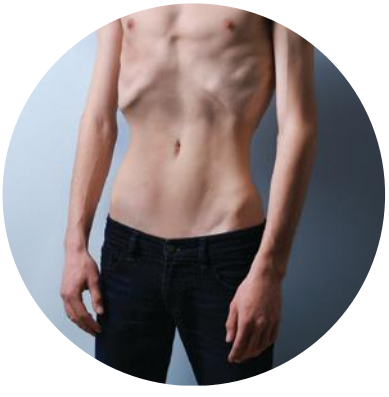


FIGURE 4 Undernutrition can occur when the amount of food a person consumes is insufficient.

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TABLE 1 Human nutrient requirements

Nutrient	Function	Source	Deficiency disease
Carbohydrate	Energy source	Grains, fruits, vegetables, dairy, legumes	**Malnutrition**
Protein	Formation of cell membrane, antibodies, enzymes, growth, energy source	Meat, fish, milk, beans	Kwashiorkor; degeneration of liver and pancreas
Fat	Energy source, insulation	Butter, oils, nuts	Malnutrition
Vitamin A	Pigment production in retina of eye, healthy cells lining respiratory tract	Egg yolk, fish oil, carrot	Night blindness, infections of respiratory lining
Vitamin B group (up to 12 vitamins)	Involved in many chemical reactions (e.g. respiration)	Whole grain, cereals, liver	Beriberi; muscular weakness and paralysis
Vitamin C	Keeps tissues in good repair	Citrus fruits, berries, raw vegetables, potato	Scurvy; pain in joints and muscles; bleeding gums
Vitamin K	Blood clotting	Green vegetables	Haemorrhage
Calcium	Bone and teeth formation, blood clotting, nerve conduction, muscle contraction	Dairy products, bread, beans, almonds, some green vegetables	Brittle bones and teeth
Phosphorus	Bone and teeth formation	Milk	Brittle bones and teeth
Iodine	Thyroxine production (hormone that controls metabolic rate)	Seafood, sea salt or iodised salt	Goitre (swelling in the neck); slow metabolic rate; congenital hypothyroidism in infants
Iron	Haemoglobin production	Liver, egg yolks, some green vegetables	Anaemia; not enough red blood cells; oxygen shortage
Sodium	Osmotic balance, nerve conduction	Most foods	Muscle cramps
Potassium	Muscle contraction, nerve conduction, osmotic balance	Most foods	Muscle cramps

malnutrition
health problems caused by a poor diet where nutrients are either deficient or excessive

overnutrition
a form of malnutrition in which one or more nutrients is oversupplied

pathogen
a biological agent that causes disease or illness

contagious
describes an infectious disease that is transmitted between individuals by physical contact with a diseased individual or by casual contact with their secretions or objects touched by them, or by an airborne route

non-contagious
describes an infectious disease that is not able to be transmitted directly between individuals of the same species; rather, it is spread by exposure to pathogens in the environment, vectors, infected animals or uncontrolled microbe growth

Overnutrition occurs when an individual consumes too much of one or more type of nutrients. For example, excessive consumption of fats and carbohydrates in the diet can lead to obesity (which is linked to heart disease and diabetes). Other examples are over-consumption of salt, which can cause hypertension (high blood pressure) and over-consumption of sugar, which can increase the risk of developing type 2 diabetes.

Infectious disease

Infectious diseases are caused by invasion of body tissue by **pathogens** (from the Greek "pathos" meaning suffering and "gignomai" meaning cause), which are biological agents that produce disease. Infectious diseases that are **contagious** involve the direct or indirect spreading of a pathogen from an infected individual to a healthy individual. Infectious diseases may also be **non-contagious**, when the pathogen is not easily spread from an infected person to an uninfected person; instead, the infection comes from pathogens occurring in nature, from uncontrolled growth of normal body microorganisms, or from the bite of an infected animal or insect.

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Pathogens

Most pathogens are cellular, meaning they are living organisms, such as bacteria, fungi, protozoans and different types of worms. You will learn more about living pathogens in Lesson 12.2. Other pathogens are non-living organic agents, such as prions and viruses, which you will learn about in Lesson 12.3. Pathogens are usually host-specific, meaning they will only invade and live in one type of host organism. However, some pathogens are able to cross between species. For example, the Ebola virus can affect a variety of primates, including humans, monkeys, gorillas and chimpanzees.



FIGURE 5 Ebola virus can affect a variety of primates.

Parasites

Parasites are cellular organisms that obtain their nutrients from a **host**. The host species is another organism that the parasite can take refuge in and acquire nutrients from. In doing this, parasites often cause damage to the host organism. There are two types of parasites:

- **ectoparasites**, which live on the outside of the host's body
- **endoparasites**, which live inside the host's body.

An example of an ectoparasite is fleas (Figure 6A). Fleas have a piercing mouthpart that can penetrate the skin and enter the blood capillaries. They live on the outer surface of their host's skin, and can bite through the skin to feed on the blood of their host for nutrients. An example of an endoparasite is hookworms (Figure 6B). Hookworms live inside the alimentary canal of their host's digestive system, feeding on nutrients in the digestive tract. Regardless of whether a parasite lives inside or outside the host, it is usually an advantage for parasites to keep their host alive. If the host dies, it is highly likely that the parasite will also die, unless it has some means of moving to another host.

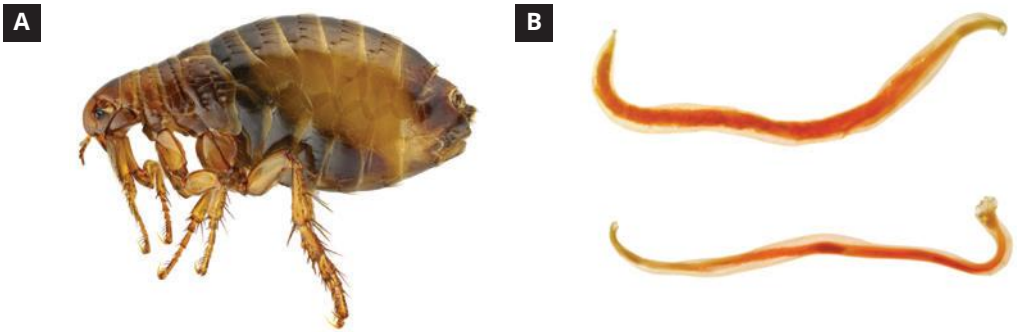


FIGURE 6 Two types of parasite: (A) flea (an ectoparasite) and (B) hookworm (an intestinal endoparasite)

Parasites are found among all the kingdoms of life, and have a large array of host organisms. A **primary host** is the organism in which the parasite remains to maturity, so it can reproduce and spread infection. Some parasites use another organism to move from one host to another. The organism used in this transfer is called a **vector**. The vector may be a **secondary host** in the parasite's life cycle, and thus essential for its survival, or it may act as a means of transport – a **reservoir host**. It is common for endoparasites to have a secondary host in their life cycle. A **carrier** is an individual that is infected by a pathogen but does not exhibit disease symptoms and can continue to pass on the disease to other individuals.

parasite
an organism that lives in or on another organism and derives nourishment from the host

host
an organism that harbours a parasite

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)

endoparasite
a parasite that lives in the internal organs or tissues of its host

primary host
a host in which the parasite reaches maturity and, if possible, reproduces sexually

vector
any agent that carries and transmits an infectious pathogen into another living organism

secondary host
a temporary host for a parasite

reservoir host
an organism that can harbour a pathogen indefinitely with no ill effects

carrier
a person or organism infected with an infectious disease agent or gene, but who displays no symptoms of the disease

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Many parasites do not cause disease – they are not in themselves pathogens. For example, the mosquito is an ectoparasite but not a pathogen. It is, however, a vector for many other pathogens, such as malaria and Zika virus. Understanding the life cycle of parasites allows strategies to be developed to control their transmission – this is discussed further in Module 13.

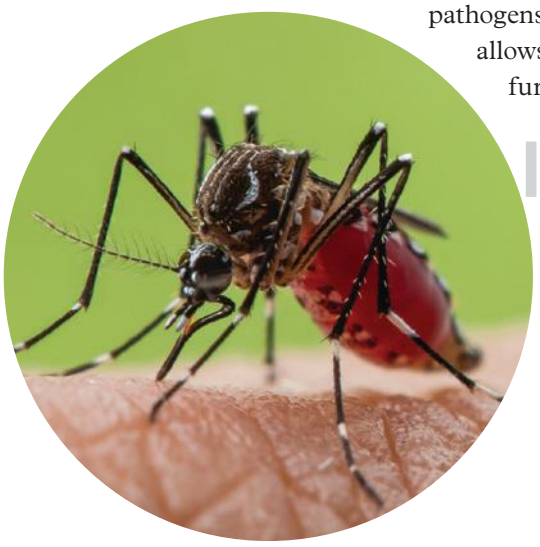


FIGURE 7 Mosquitoes are often vectors for pathogens such as the yellow fever virus and Zika virus.

Categories of infectious disease

An infectious disease that can pass directly between two individuals of the same species is termed "contagious" (e.g. the influenza virus or "flu" in humans). Non-contagious infectious diseases are not spread directly from person to person. They can be caused by:

- exposure to the pathogen from the environment (e.g. drinking water contaminated with a pathogen)
- an infected animal bite (e.g. rabies)
- contact with a vector (e.g. mosquitoes carrying Zika virus, Figure 7)
- microbes in or on the body that begin to grow uncontrollably (e.g. urinary tract infections that result from the *Escherichia coli* bacterium spreading from the colon to the urethra).

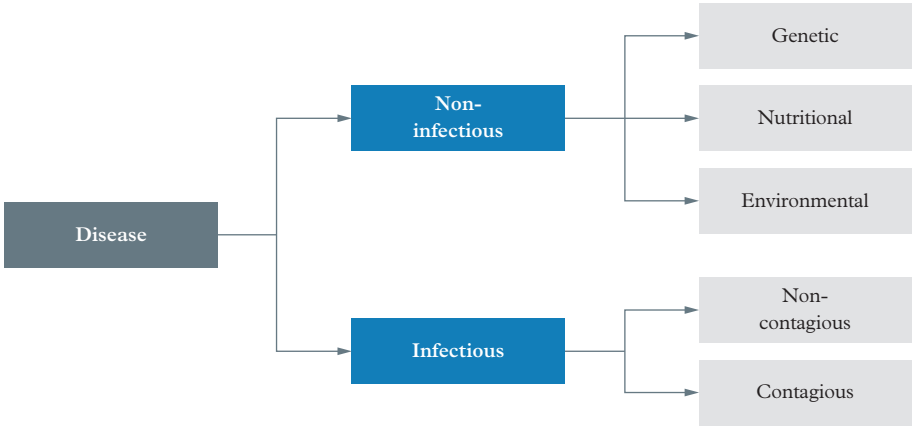


FIGURE 8 Summary flowchart for classifying disease

endemic
describes a disease that is constantly present at low levels in organisms of a certain group or living in a particular location

epidemic
a disease that occurs at higher rates than would be expected in a community or region during a given period

pandemic
an epidemic of infectious disease that has spread across a large region (e.g. multiple continents) or worldwide

Many diseases exist at low levels in the community at all times. For example, influenza moves through a population at regular low levels. When a disease exists in this manner it is described as **endemic**. An **epidemic** of a particular disease occurs when a larger than normal number of individuals in a particular locality are infected by a disease at a particular time. If the disease spreads to other countries, it is termed a **pandemic**.



Endemic
Disease consistently exists in a population at low levels



Epidemic
A large increase in the number of cases of a disease in a population or locality



Pandemic
An epidemic that spreads to different countries or regions

FIGURE 9 Endemic, epidemic and pandemic are terms used to classify the prevalence and spread of disease in populations.

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Table 2 gives some examples of infectious and non-infectious human diseases.

TABLE 2 Examples of disease in humans

Type of disease	Pathogen	Examples
Infectious		
Caused by non-living organic particles	Prion	Creutzfeldt–Jakob disease (CJD)
	Virus	Measles, rabies
Caused by microorganisms	Protozoan	Malaria, trypanosomiasis
	Fungus	Ringworm, athlete's foot
	Bacterium	Cholera, tuberculosis
Caused by larger organisms	Parasitic worms	Ascarisis, schistosomiasis, tapeworm
Non-infectious		
Nutritional deficiency diseases		Beriberi, pellagra, kwashiorkor
Metabolic disorders		Diabetes
Degenerative diseases		Coronary heart disease, arthritis
Cancer		Skin cancer, breast cancer
Inherited diseases		Sickle-cell anaemia
Occupational or industrial diseases		Silicosis
Mental disorders		Depression, alcoholism

Check your learning 12.1

Check your learning 12.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** "disease". (1 mark)

2 **Describe** the causes of non-infectious disease. (3 marks)

3 Using an example, **describe** a pathogen. (1 mark)

Analytical processes

4 **Distinguish** between infectious and non-infectious disease, giving examples of each. (3 marks)

5 A fly may be a vector of a certain parasite but not a host for that parasite. Other organisms may be both a vector and a host to the disease. **Compare** the terms "secondary host" and "vector". (2 marks)

6 **Distinguish** between contagious and non-contagious disease. (1 mark)

Knowledge utilisation

7 "All pathogens are parasites, but not all parasites are pathogens." **Discuss** this statement, giving examples. (4 marks)

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Lesson 12.2
Non-living pathogens

Key ideas

- → Viruses are non-living particles composed of nucleic acid covered in a protein coat.
- → When a virus invades a cell, it causes the host cell to produce more virus particles.
- → Many human diseases are caused by viruses, with influenza being the most virulent. Many viruses are able to cross hosts from animals to humans.
- → Some diseases result from abnormal prion proteins, which cause normal proteins to become dysfunctional.

Learning intentions and success criteria

Viruses

Not all infectious diseases of animals are the result of living pathogens. Many diseases are caused by biological agents that are non-living.

virus
a non-living infectious microbe that requires a host cell to replicate

Viruses are infectious microbes that consist of a nucleic acid (DNA or RNA) encased by a protein coat. They are a tiny 30–300 nanometres in size and are considered non-living because they cannot perform the metabolic activities that are characteristic of living things. Unlike living organisms, viruses do not have their own organelles (e.g. ribosomes), and this prevents them from being able to reproduce alone. Instead, viruses invade the cells of living organisms and use the host cell's ribosomes to construct new viruses. All viruses require a living host, so they can replicate.

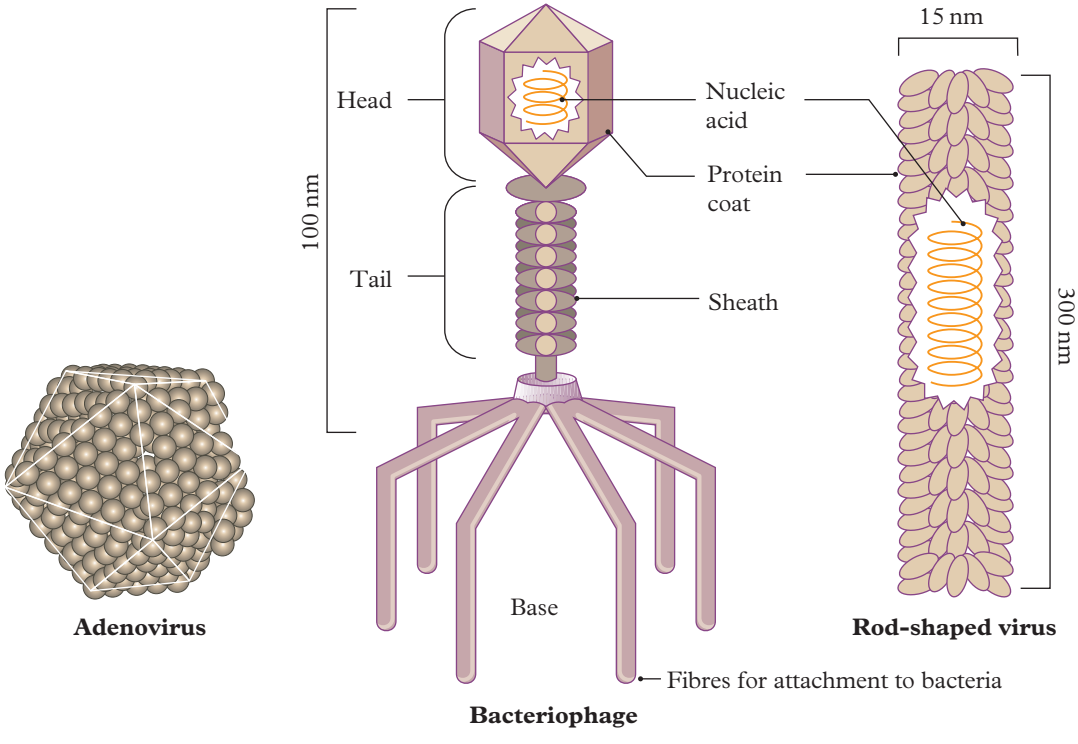


FIGURE 1 Structures and sizes of some viruses

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Viral replication and transmission

When a virus invades the cells of another organism, it can instruct the host cells' nucleic acid to produce more virus particles. It does this by "switching off" the host's DNA and using its own nucleic acids to instruct the cell to make copies of itself. Eventually, the host cell produces so many copies of virus particles that the cell ruptures, releasing the copies of the virus, which can then infect new cells. When viruses are outside a host cell, they form a crystal that can survive extreme conditions for many years. These inert (inactive) particles can be transmitted to the cells of a host organism through air, water or food, or by direct contact with an infected host. Many viruses are transmitted by disease-carrying organisms, called vectors, which include mosquitoes and ticks. Viruses have been found to parasitise all known living organisms.

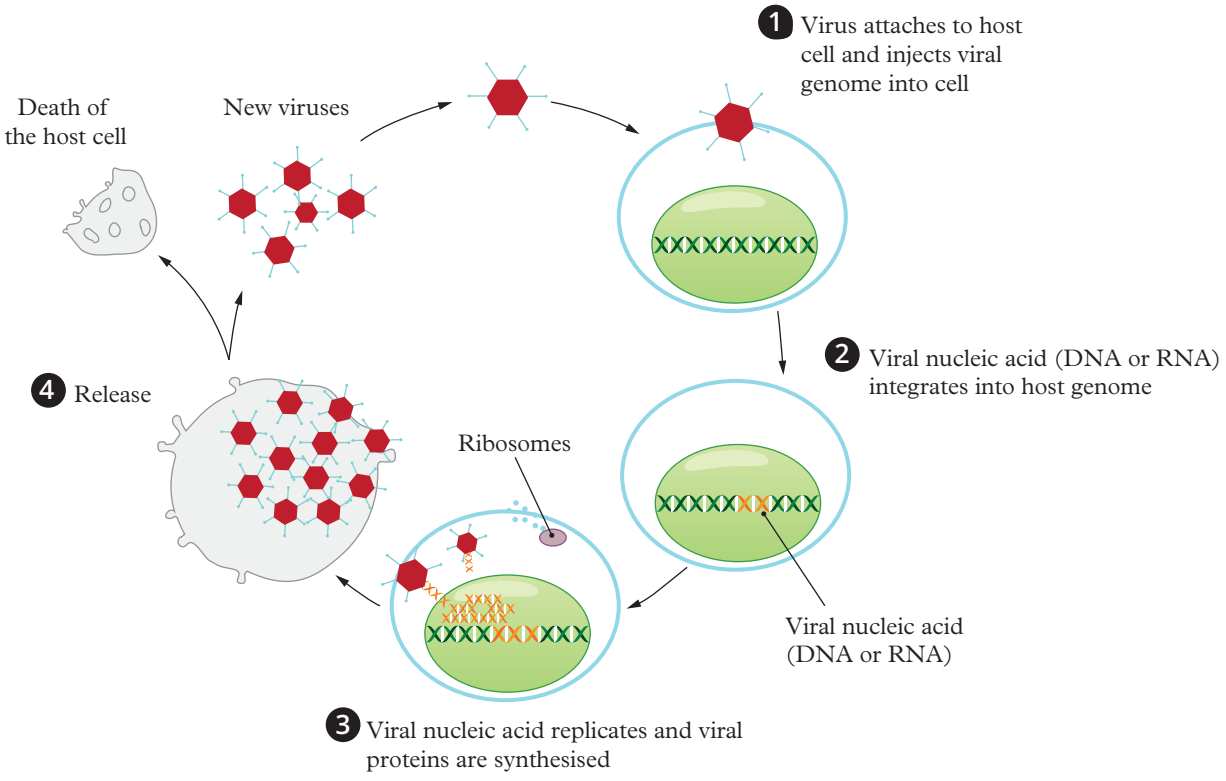


FIGURE 2 Replication phases of a virus

Viral infection

The composition of the protein coat surrounding a virus determines the type of cells that the virus can invade. Before a virus can enter a cell, it must first adhere to it. This means different types of viruses can only infect the cells of specific types of organisms. For example, a virus that infects dogs is unlikely to infect a human. Additionally, different viruses cause specific symptoms and impacts in their host. For example, the Herpes simplex type 1 virus causes cold sores in people, while the *Varicella zoster* virus causes chickenpox. While viruses are specific, viral nucleic acids can undergo mutations. When this occurs, a virus that could previously only affect one type of organism may mutate in a way that allows it to infect another type of organism. Mutation also can also result in a virus having multiple variants. For example, the influenza virus has four variants.

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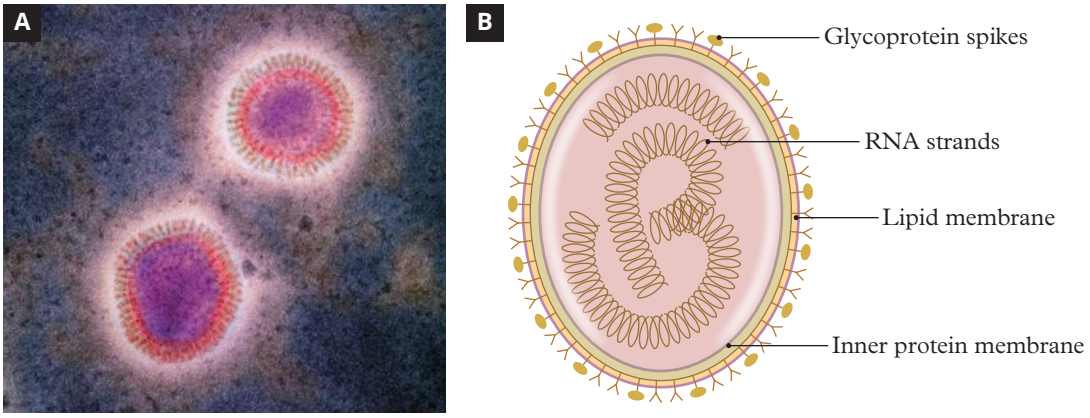


FIGURE 3 Influenza virus: (A) electron micrograph and (B) structure of the virus

Prior to the development of farming, humans were hunter-gatherers who travelled in small groups over large areas in search of game and other food. If a particular group was infected by a virus, the disease did not spread to other groups, due to their isolation. About 10,000 years ago, some groups took up growing crops and domesticating certain animals. People settled in one place and the population of some areas started to increase. Records from fossil bones indicate that these people were more susceptible to disease than their hunting relatives. The close association between humans and their animal stock allowed mutations and transfer of animal viruses to humans. The animals had, over time, developed immunity to these viruses and so did not exhibit diseases. The human population, however, did not have this resistance and the subsequent diseases rapidly killed large numbers of people. The viruses that caused measles, tuberculosis and smallpox were transferred from cattle. Influenza and whooping cough viruses came from domesticated pigs and ducks.

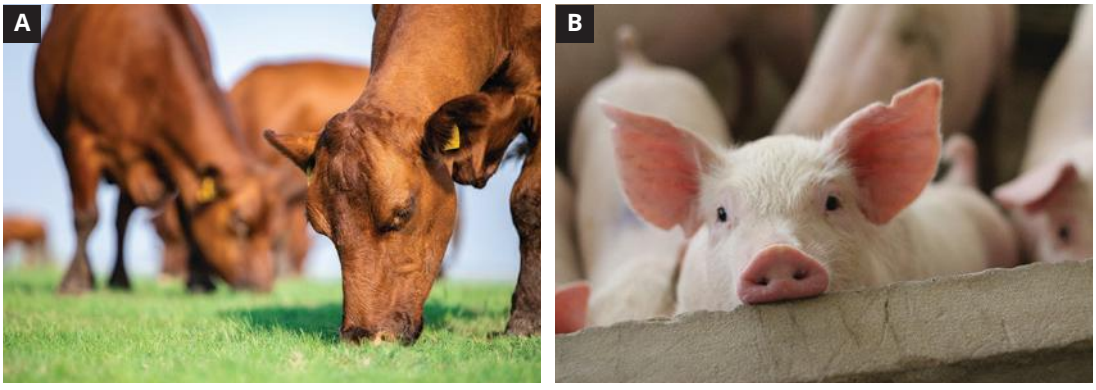


FIGURE 4 Mutations can enable viral infections to be transferred from one type of animal to another. (A) The viruses that cause measles, tuberculosis and smallpox transferred to humans from cattle. (B) Influenza and whooping cough viruses came from domesticated pigs and ducks.

incubation period the time it takes for a pathogen to increase to sufficient numbers in the body to produce symptoms of the disease

Outbreaks of new viral strains originating from domestic ducks in Asian countries continue to occur. Travel between countries is now common. Because many influenza viruses have an **incubation period** (the time for viral numbers to increase sufficiently to produce the symptoms of disease) of up to 14 days, an infected person can contract the disease in one country and travel to several other countries before becoming aware that they have the disease. This person could, in their daily contact with others, infect thousands of people, all of whom could take the infection to another part of the world and in turn be in contact with new individuals, many of whom could also become infected. In the first 6 months of the COVID-19 pandemic, an estimated 30,000 people became infected with the pneumonia-like SARS-CoV-2 virus in Australia, of whom around 900 died from the infection. Coronavirus disease was first reported in humans in December 2019 in the Wuhan Province of China,

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and is believed to have originated from a mutated form of a similar virus found in bats before passing to humans via an intermediate animal host (presumably a pangolin). Worldwide, it is estimated that over three million people had died from COVID-19 infection by the end of 2020.

Records of viral infections in past ages are not accurate, and the causes can often only be gauged by the symptoms as described at the time. Prior to the nineteenth century, most viral epidemics were attributed to yellow fever, smallpox and measles. The first pandemic of influenza was recorded in 1847. Since then, probably because of greater (and faster) mobility between countries, many more viral pandemics, resulting in large numbers of deaths, have occurred.

TABLE 1 Major epidemic and pandemic viral outbreaks

Disease	Location	Date	Estimated death toll
Influenza	Worldwide	1887–90	1,000,000
Spanish influenza (H1N1)	Worldwide	1918–20	75,000,000
Asian influenza (H2N2)	Worldwide	1957–58	2,000,000
Hong Kong influenza (H3N2)	Worldwide	1968–69	1,000,000
HIV/AIDS	Congo Basin	1960–present	> 30,000,000
SARS coronavirus	Asia, Canada	2002–03	775
Swine influenza (H4N1)	Worldwide	2009	14,289
Measles	Congo	2011–present	4,500
Dengue fever	Pakistan	2011–present	350
Yellow fever	Darfur, Sudan	2012–13	847
Middle East Respiratory Syndrome	Worldwide	2012	449
Ebola	West Africa	2013–16	>11,300
Zika virus*	Worldwide	2015–17	
Yellow fever	Africa	2016	Hundreds
SARS-CoV-2 Coronavirus	Worldwide	2019-present	>6,800,000 (as of 2023)

*Although not directly resulting in death, this virus has been linked to microencephaly in babies whose mothers contracted the disease during pregnancy. This has been reported only in South America.

Challenge

Influenza

During the flu season, an individual may suffer from influenza more than once. **Propose** why this may occur. (1 mark)

Prions

Prions are a type of non-living pathogen that cause degenerative brain disease. They are proteins that trigger other proteins in the brain to fold in an abnormal way. Transmissible spongiform encephalitis (TSE) is a group of diseases in which the brain of the affected organism gradually develops holes (like a sponge). The cause of this group of diseases in mammals (including humans) was unknown until a London doctor named Tikvah Alper started researching scrapie, a type of TSE in sheep. She found that destroying the nucleic acid (DNA and RNA) in affected tissue was not effective in decreasing the infectiousness of scrapie. However, through further testing she discovered that individual proteins in the tissue were responsible for the disease.

prion
an abnormal form of a normally harmless protein, found in the brain; causes a variety of fatal neurodegenerative diseases in animals, including humans

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Prion action

Normal cells in the brain contain a protein called PrP^{C}. Prions (proteinaceous infectious particles – PrP^{SC}) are proteins that have the same amino acid sequence as PrP^{C}. However, prions are folded to form a different structure (Figure 5). It is thought that prions can rearrange the structure of normal PrP^{C} proteins so that their structure also becomes abnormal. The abnormally structured PrP^{SC} proteins then group together to form plaques (called amyloids) that disrupt normal brain tissue function.

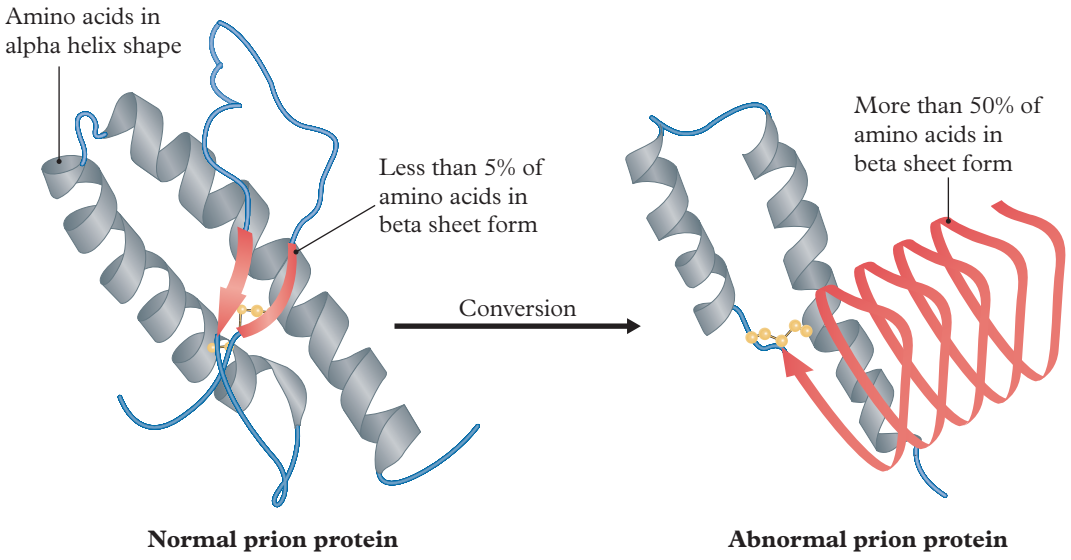


FIGURE 5 Normal proteins are infected by abnormal prion pieces (red), which convert the entire protein to the abnormal prion form.

The disruption results in the brain tissue having a spongy appearance (Figure 6) in an individual with Creutzfeldt–Jakob disease (CJD). Many of the diseases associated with prions have a name that reflects the effect of that disease on the brain. For example, symptoms of bovine spongiform encephalopathy (mad cow disease, BSE) include convulsions, poor balance and coordination, and behaviour changes. All known prion diseases are untreatable and fatal.

Prion diseases

Normal protein is similar in mammals, and a large variety of mammals are susceptible to prion diseases (Table 2). There are, however, slight differences between the proteins in different species. This reduces the likelihood that a disease will spread from one species to another. However, an exception to this was seen in the BSE or "mad cow disease" epidemic in the United Kingdom and parts of Europe between 1986 and 2000.

During the 1980s, the method of cattle feed production was altered, with cow feed containing animal remains (meat and bone meal) being produced. It is thought that this change to cattle feed introduced a scrapie disease agent from an infected cow or sheep

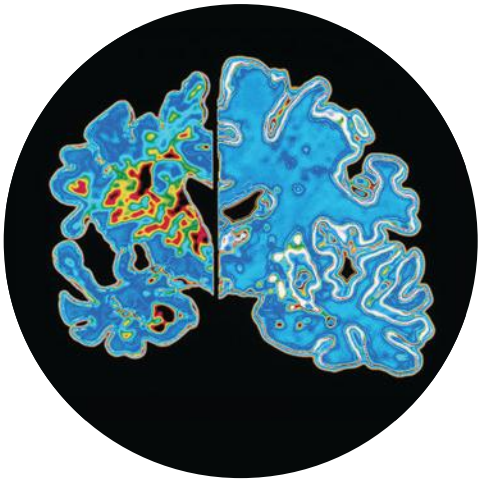


FIGURE 6 Comparison of a section of normal brain tissue (right) and tissue infected with CJD (left)

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and allowed it to survive and contaminate cattle, causing a wave of BSE in cattle. At the time neither scrapie nor BSE was thought to be a risk to humans. However, after brain tissue from BSE-infected cattle made its way into the human food supply, particularly as sausages and hamburger meat, during the height of BSE infections, over 200 young people died from a variant of Creutzfeldt–Jakob disease (vCJD), a rare form of TSE.



FIGURE 7 It is thought that (A) scrapie, which affects sheep, contributed to the occurrence of (B) BSE in cattle, which contributed to the occurrence of (C) vCJD in humans.

The new variant of CJD was found to contain the same prion strain found in BSE and was found in lymphatic tissue and brain tissue in affected people. It was proposed that the ingested abnormal prions from BSE were taken up by lymphoid tissues of the digestive tract and passed to the central nervous system via the **autonomic nervous system**. Once in the brain, the process of converting normal protein to abnormal prion protein was accelerated. People who contract vCJD show increasing signs of memory loss, have difficulty controlling movement and often lapse into a coma.

autonomic nervous system the system that controls the actions of the inner (visceral) body tube; not under conscious control. Two types of motor nerves are involved: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action

Until 2015, it was thought that all known mammalian prion diseases were caused by abnormal strains of the same membrane protein (PrP^C). It was then discovered that multiple system atrophy (MSA) was likely to be caused by an abnormal folding of a different membrane protein (alpha-synuclein). MSA results from deterioration of the parts of the brain that regulate internal body functions, digestion and motor control. Many other neurological diseases may be shown to be the result of prions. These are summarised in Table 2.

TABLE 2 Diseases in mammals caused by prions

Animal affected	Disease
Sheep, goat	Scrapie
Cattle	Bovine spongiform encephalopathy (BSE, mad cow disease)
Mink	Transmissible mink encephalopathy (TME)
White-tailed deer, elk, mule deer, moose	Chronic wasting disease (CWD)
Cat	Feline spongiform encephalopathy (FSE)
Nyala, oryx, greater kudu	Exotic ungulate encephalopathy (EUE)
Human	Creutzfeldt–Jakob Disease (CJD)
	Variant Creutzfeldt–Jakob Disease (vCJD)
	Familial Creutzfeldt–Jakob Disease (fCJD)
	Iatrogenic Creutzfeldt–Jakob Disease (iCJD)
	Sporadic Creutzfeldt–Jakob Disease (sCJD)
	Gertsmann–Straussler–Scheinker Syndrome (GSS)
	Fatal familial insomnia (FFI)
	Familial spongiform encephalopathy

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Check your learning 12.2

Check your learning 12.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** the structure of a virus. (1 mark)
2 **Explain** why viruses and prions are considered non-living. (2 marks)
3 **Describe** the life cycle of viruses. (4 marks)
4 **Explain** why a viral infection can rapidly become a pandemic. (2 marks)
5 **Identify** the features of prions and how they are transmitted. (2 marks)

Lesson 12.3
Living pathogens

Key ideas

- → Pathogens may be microbes (bacteria, protists or fungi) or macroorganisms (e.g. flukes, tapeworms or roundworms).
- → Many microbes and macroorganisms are pathogens of humans, their domesticated animals and cultivated plants. Some pathogens are transmitted via the air, in contaminated food or water, or by a vector.
- → Protists are animal-like, unicellular eukaryotes, and some cause fatal diseases such as malaria and African sleeping sickness.
- → Most macroscopic endoparasites of humans are flatworms (e.g. tapeworms) or roundworms (hookworm, *Ascaris*). Untreated, diseases from these worms can be fatal.

Learning intentions and success criteria

Bacteria

Many pathogens are living, reproducing organisms. There are many types of living pathogens. In this lesson you will learn how organisms such as bacteria, protists, fungi and some parasites can cause disease.

bacteria
microscopic unicellular organisms that lack a distinct nucleus

Bacteria are some of the smallest living organisms (between 0.5 µm and 10 µm in diameter). Although some bacteria exist as groups of cells or in long strands, bacterial cells do not specialise for a particular function. Instead, the cells are only loosely held together. They are so small that their internal structure can only be viewed using high-powered electron microscopes. Despite their small size and simple structure, bacteria have continually thrived in all environments throughout the existence of life on Earth. It is estimated that:

- a single handful of soil contains more bacteria than the total number of people who have ever lived
- the skin of an average person has 10^5 bacterial cells per square centimetre
- the human gut contains 10^{11} bacterial cells per gram of contents (the large intestine normally holds 1 kg of material).

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FIGURE 1 A single handful of soil contains more bacteria than the total number of people who have ever lived.

Bacterial structure

Bacteria are prokaryotic cells that have no true nucleus or membrane-bound organelles. They have a single, circular strand of DNA and several small segments of DNA, called **plasmids**. Metabolic activities occur in the cytoplasm. The entire cell is enclosed by a wall composed of the glycoprotein **murein**. Different types of bacteria have different forms of cellular respiration (aerobic, anaerobic or both) and methods of gaining nutrition (chemosynthetic, photosynthetic or heterotrophic). This allows bacteria to live in diverse environments. Most bacteria are harmless, and many are essential for the continued existence of life on Earth.

plasmid
a small, circular molecule of DNA that differs from a cell's chromosomal DNA

murein
a glycoprotein (protein–carbohydrate complex) that forms the cell wall in bacteria

Bacteria can be identified by growing them on a culture medium such as agar jelly or in a nutrient broth, under controlled environmental conditions. Individual bacteria can grow and divide rapidly, producing colonies of millions of bacteria. The colonies of many bacteria have a characteristic colour and shape, which assists in their identification (Figure 2). This process can be used to distinguish between the different groups of bacteria.



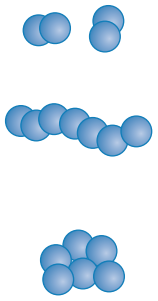
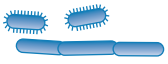
FIGURE 2 The colonies of many bacteria have a characteristic colour and shape.

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Table 1 summarises the basic shapes of bacteria.

TABLE 1 Basic shapes of bacteria

Bacterial shape	Image	Examples
Cocci – spherical (singular: coccus)		*Diplococcus* join together in pairs. • *D. pneumoniae* causes pneumonia. • *Streptococcus* join to form a chain – many *Streptococcus* species infect the upper respiratory tract. • *S. pyogenes* – scarlet fever • *S. thermophilus* – gives yoghurt its creamy texture. • *Staphylococcus* join together in bunches. • *S. aureus* (golden staph) – different strains cause boils, pneumonia, food poisoning and other infections.
Bacilli – rod-shaped (singular: bacillus)		*Bacillus typhosus* causes typhoid fever. *Bacillus anthracis* causes anthrax. *Escherichia coli* lives in symbiosis in the gut.
Spirilla – spiral-shaped (singular: spirillum)		The spirochete (a fine spirillum) *Treponema pallidum* causes syphilis.
Vibrio – comma-shaped		*Vibrio cholerae* causes cholera.
Rickettsiae – rod-shaped		*Rickettsia* cause typhus and are often carried on the body louse (a vector). (Note: They are similar in size to the smallest bacilli and cocci, but they are classified into a different group because they cannot survive outside living cells; they are actually the smallest known cell.)

Skill drill

Calculating the number of bacteria in a population

Science inquiry skill: Processing and analysing data (Lesson 1.8)

Enteric bacteria live within the guts of animals, including humans. Many are not pathogenic and are, in fact, important for gut health. The uniform temperature and constant supply of nutrients allows bacteria to grow in their millions.

Bacteria can reproduce, on average, every 20 minutes. This means that, if a single bacterium is placed in an incubator with a large supply of nutrients, after 20 minutes there will be two bacteria, and after another 20 minutes there will be four, then eight and so on.

To calculate the number of bacteria in a population:

number of bacteria at the start of the growth period $\times$ $2^{\text{number of divisions}}$

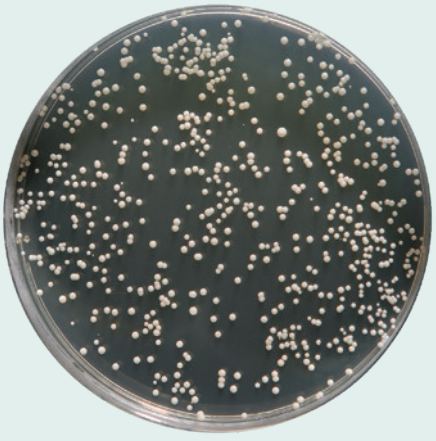


FIGURE 3 Bacterial colonies growing on an agar plate

Practise your skills

1 From a single bacterium, **calculate** the number of bacteria present after 24 hours. (2 marks)

2 From 10 bacteria, **calculate** the number of bacteria present after 8 hours. (2 marks)

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Pathogenic bacteria

Some strains of bacteria are harmful to humans, domesticated animals or cultivated plants. These pathogenic strains of bacteria can spread in many ways (e.g. direct contact with contaminated surfaces, eating contaminated food, transmittal by infected animal or insects). Once inside the body, they may cause disease by producing poisonous chemicals (toxins), by disrupting the host's metabolism or by damaging tissues. For example, some *Clostridium* species can cause food poisoning by releasing a toxin into foods such as meat (Figure 4). When food containing the toxin is eaten, the toxin can affect the nervous system, causing problems with vision, paralysis or even death.

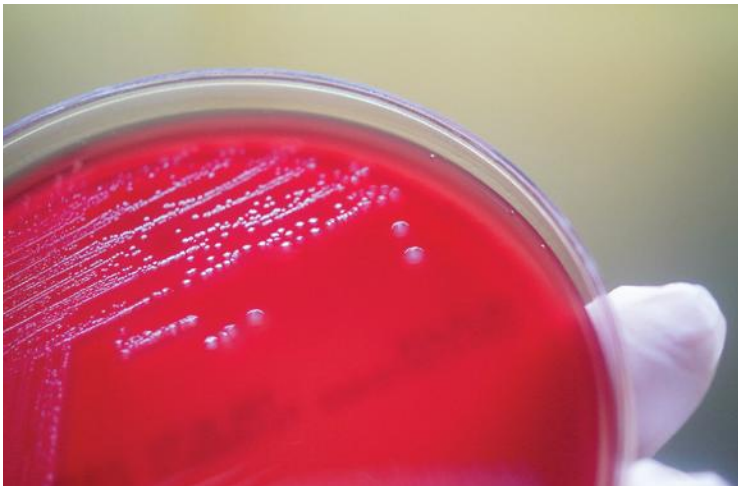


FIGURE 4 *Clostridium perfringens* colonies grown on blood agar

Like viruses, many bacteria will only affect specific parts of the body. For example, the bacterium that causes bacterial dysentery produces a powerful toxin that affects the cells of the large intestine. This results in loss of blood with the faeces as well as diarrhoea. Other bacteria can affect more than one type of tissue. The bacterium *Treponema pallidum*, which causes syphilis, initially causes inflammation of the penis or vulva but can travel to, and affect, all parts of the body, including the brain.

Study tip

The system for naming species consists of two parts: the genus name and the species name. An example is *Treponema pallidum. Treponema* is the genus name, and *pallidum* is the species name.



FIGURE 5 Chains of *Anthrax* bacilli in the blood

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Real-world biology

The Black Death

The bubonic plague pandemic of 1347–1352, known as the Black Death, was one of the most deadly in history, resulting in the deaths of approximately half the population of Europe at the time. This disease is caused by the bacillus bacterium *Yersinia pestis*, found in Oriental rat fleas (*Xenopsylla cheopis*), which feed on humans and rats. The disease passes between organisms through flea bites. Plague can affect people in three ways.

- **Bubonic plague** (the most common form) occurs when the bacteria infect the lymphatic system. This causes painful swelling of the lymph glands, which begin to bleed and so become purple-black and rupture into foul-smelling lesions. Eventually the victim's nervous system collapses, and death follows. Modern antibiotics are effective against bubonic plague if it is treated early.
- **Pneumonic plague** occurs when the bacteria infect the lungs. It is the most serious form of plague. It does not respond readily to antibiotics.
- **Septicaemic plague** occurs when the bacteria multiply in the blood. This can occur from a direct flea bite or from untreated bubonic or pneumonic infection.

Plague epidemics and pandemics have occurred for thousands of years. The first recorded case was in China in 224 BCE. Since then, there have been many serious outbreaks. Five million people in Europe, Western Asia and Africa died between 165 and 180 CE and up to 50 million died in Europe between 541 and 542 CE. The Black Death was the most significant outbreak – between 1347 and 1352 CE, 75 to 100 million people died in Europe. Although the disease receded, it never completely went away and is still prevalent in 20 countries. Recently, severe outbreaks have occurred in Central Africa and parts of South America. An epidemic is more likely to occur in highly populated, urban areas with poor sanitation. As with other microorganisms with a high reproductive rate, *Yersina pestis* has many mutant forms and some of its genes have been acquired from other bacteria and viruses. There has been rapid evolution of the bacterium, allowing it to survive in many different environments.



FIGURE 6 (A) Electron micrograph of *Yersinia pestis* (B) *Xenopsylla cheopis*, the oriental rat flea

Apply your understanding

1 **Identify** the pathogen and the vector of the bubonic plague. (2 marks)

2 **Describe** the features of the bubonic plague pathogen and how these features influenced the epidemic potential of the disease. (2 marks)

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Protists

Protists are organisms that belong to the kingdom Protista. The Protista are a diverse group of eukaryotes, and most are unicellular. They are not fungi, plants or animals. Protists are divided into the animal-like protozoa, the plant-like algae and the fungus-like slime moulds.

Protozoa are heterotrophic protists that are divided into four main phyla. Three of these phyla are distinguished by how they move.

- Rhizopoda move by **pseudopodia**. A pseudopodium is a footlike extension of the cell membrane.
- Zoomastigina move by a **flagellum**, a long hair-like appendage that helps propel a cell forward.
- Ciliophora move by **cilia**, small eyelash-like structures that move back and forth.

protist
a eukaryotic organism that is not an animal, land plant or fungus

pseudopodium
a temporary foot-like extension of the cell membrane of some protozoans, resulting in a flowing movement of the protozoan; plural pseudopodia

flagellum
a whip-like extension of the cell, used in locomotion by some bacteria, protozoa and spermatozoa; plural "flagella"

cilium
a hair-like extension of the cell membrane; plural cilia

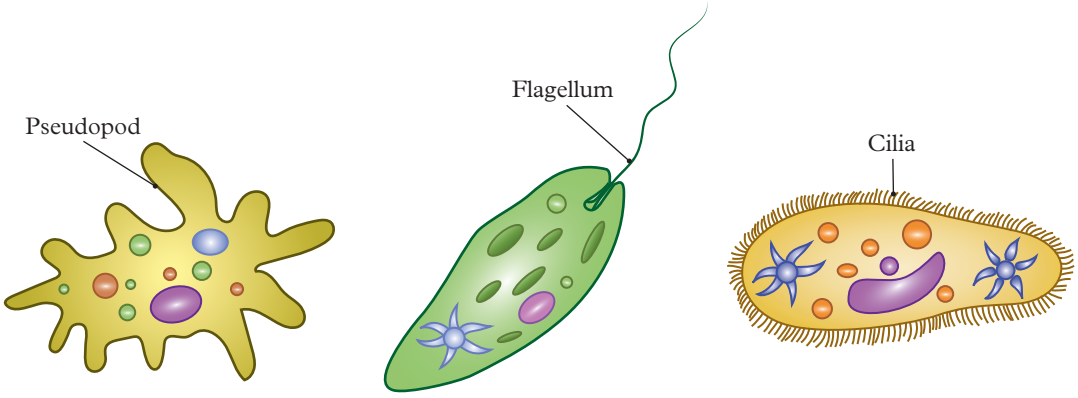


FIGURE 7 Structural features used to classify protozoa

The fourth phylum of protozoa, the Apicomplexa, are all parasites of animals and have complex life cycles involving both sexual and asexual phases. All protozoa live in moist environments.

TABLE 2 Animal-like protists and their features

Type of protist	Features
Protozoa	• Aquatic or endoparasites • Unicellular • Heterotrophic eukaryote
Phylum Rhizopoda	• Move by pseudopodia • Irregular shape • Engulf food by phagocytosis anywhere on the membrane • Mostly free-living
Phylum Zoomastigina	• Move using one or more flagella • Definite shape • Food intake at base of flagellum only • Free-living or parasitic
Phylum Ciliophora	• Move by cilia • Definite shape • Food intake in one place only, the "gullet" • All free-living
Phylum Apicomplexa (sporozoans)	• No locomotion • Definite shape • All parasites • Have complex life cycles

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Pathogenic protists

amoeba
a microscopic unicellular protozoan that belongs to the rhizopodan order; plural amoebae

Amoebae are single-celled organisms and a type of rhizopod. An example of an amoeba that is a human pathogen is *Balamuthia mandrillaris*, which lives in soil and fresh water. It can enter the body through open wounds or through inhalation of dust containing the amoeba. Once the amoeba is inside the body, infection will usually spread from the lungs or the nerve fibres, and the amoeba will attack the central nervous system for nutrients. This attack causes lesions in the brain and eventually necrosis (death of tissue), leading to death. *Balamuthia* infection is rare, with only 200 cases reported since its discovery in the 1990s (Figure 8).



FIGURE 8 *Balamuthia mandrillaris* is an amoeba that causes a deadly infection.

Malaria is caused by a protozoan that hides inside human cells to avoid the immune system. Humans are the secondary host, while mosquitos are the primary host for the parasite, *Plasmodium* (phylum Apicomplexa). The parasite undergoes sexual reproduction in the digestive tract of the *Anopheles* mosquito, and asexual reproduction in both the human liver and blood cells. Malaria is endemic in many Mediterranean and tropical regions of the world.

There are 200 to 400 million cases of malaria annually, with more than 80% occurring in Africa. Every year, hundreds of thousands of people die of the disease, and survivors usually suffer from a wide range of other infections due to their weakened resistance.

Examples of common protist diseases in humans are given in Table 3.

TABLE 3 Some common protozoan diseases of humans

Disease	Symptoms	How transmitted
African sleeping sickness	Headache, fever, enlargement of lymph nodes, drowsiness leading to coma	The tsetse fly takes up *Trypanosoma* from the blood of an infected person. The parasite multiplies in the fly's salivary glands. It is injected into another person when the fly feeds on human blood.
Giardiasis	Diarrhoea, bloating, flatulence, vomiting	Food or water contaminated with *Giardia lamblia*
Vaginitis	Inflammation and irritation of the vagina in women and urethra in men	Usually sexual intercourse, although the disease-causing flagellate, *Trichomonas vaginalis*, can survive for several days in moisture in towels or in droplets on toilet seats.
Amoebic dysentry	Fever, nausea, vomiting, diarrhoea	Food or water contaminated with *Entamoeba histolytica*
Malaria	Anaemia, fever alternating with shivering	The *Anopheles* mosquito is the primary host of *Plasmodium*.

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Fungi

Fungi are eukaryotic heterotrophs that have cell walls made from a substance called chitin and reproduce with spores. All fungi, except unicellular forms (yeasts), are composed of filaments called hyphae, which penetrate their organic substrate. Fungi may be decomposers or parasites, or found in association with a plant (lichen). Fungi are classified by how their spores are formed.

fungus
a eukaryotic organism that belongs to the kingdom Fungi; plural "fungi"



FIGURE 9 Different types of fungi: (A) the unicellular *Trichophyton mentagrophytes*, (B) the mushroom *Mycena interrupta*, (C) the yeast *Candida albicans*

Pathogenic fungi

Pathogenic fungi use hyphae to enter host cells. The fungus feeds by extracellular digestion – it secretes enzymes into the substrate, and the small molecules released are absorbed by the hyphae. Only a few types of fungi are pathogenic to humans. The most common fungal infections are:

- ringworm – usually a single fungal spore from *Trichophyton* or *Epidermophyton* germinates on the skin and the hyphae spread out, digesting and absorbing the nutrients from skin cells. This causes inflammation of the skin, which may become very itchy or sore and appears as an increasing circle of red tissue, as the fungus spreads. As fruiting bodies are formed, spores may be transferred directly to another person or via towels or clothing
- athlete's foot (tinea) – *Tinea pedis* primarily grows on the skin between the toes, although it may spread to other parts of the foot (Figure 10). It is common in people who wear shoes and socks that do not allow perspiration from the feet to evaporate. Thus, athletes who spend hours training are particularly susceptible to infection. Because athletes share change rooms and showers, the fungus can spread rapidly from person to person
- thrush (*Candida albicans*) – a yeast that infects the mouth, throat, intestines and vagina, where it grows as a white patch on the moist tissues (Figure 11). In the vagina, the symptoms are intense itchiness and an unpleasant discharge. Vaginal thrush can be transferred from mother to baby during birth

  Candida can be kept in check by bacteria that normally inhabit these regions, so a person may not be aware that they are harbouring the fungus. If these bacteria are killed by antibiotics, or if the person's resistance is lowered due to other illness or malnutrition, over 60 different disease conditions can occur. The membranes of the epithelial cells lining the intestine can become more permeable, allowing the entrance of larger, partially digested proteins into the bloodstream. An immune reaction to these proteins can result in food allergies. *Candida* can change from the single-celled shape and produce a mass of hyphae that penetrate the intestinal wall and move throughout the body via the bloodstream. Rapidly growing colonies of this fungus produce toxins. Forms of arthritis, depression, mood swings and severe allergic responses have been attributed to candidiasis infection.

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FIGURE 10 Athlete's foot (tinea)



FIGURE 11 Oral thrush on the tongue of a newborn baby

Macroparasites

flatworm
a soft-bodied, flattened invertebrate in the phylum Platyhelminthes

roundworm
a nematode worm that infests the intestines of humans or other mammals

fluke
a parasitic flatworm in the class Trematoda

tapeworm
a ribbon-like parasitic worm in the class Cestoda

Most macroscopic endoparasites of humans are either **flatworms** (phylum Platyhelminthes) or **roundworms** (phylum Nematoda).

Diseases caused by flatworms

Flatworms are dorsoventrally (top to bottom) flattened animals that include both free-living and parasitic forms. The main human parasites are **flukes** and **tapeworms**. Both have a very complex life cycle involving a vertebrate and an invertebrate host. Flukes have a leaf-like body and two suckers and are generally quite small. Tapeworms have an elongated body, some reaching up to 10 metres in length, and a highly modified head that attaches to the host's gut wall by suckers and a series of hooks.

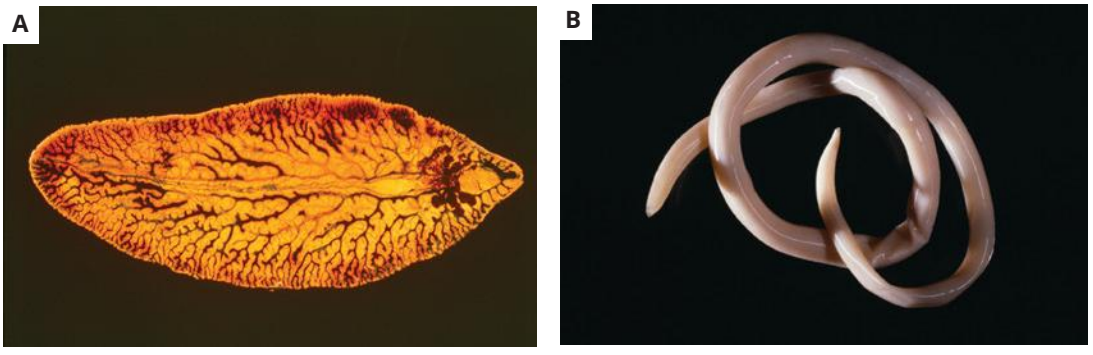


FIGURE 12 Two macroparasites: (A) flatworm and (B) roundworm

The life cycles of many flukes, such as *Schistosoma* (human blood fluke) and *Fasciola*, are similar. Although *Fasciola* is most common in sheep, it can also occur in humans. In both primary hosts the adult fluke, a hermaphrodite, lives in the liver and bile ducts. The eggs are released with the bile into the intestines and pass out with the faeces. If the eggs land on moist grass and are eaten by the appropriate type of water snail, the cycle continues. The eggs hatch and the larvae feed on the snail tissues before undergoing asexual reproduction. Again, the larval form of the parasite leaves the snail's body. This larva, however, swims to a stalk of grass, climbs above water level and forms a protective cyst. When sheep graze, or humans eat watercress, they may ingest the cysts. Inside the intestine, the cyst coating breaks down to release the larva, which burrows through the intestinal wall into the blood vessels.

In farming communities in Australia, it was common to feed offal from slaughtered sheep to the farm dogs. Since this practice has been outlawed, the incidence of the sheep liver fluke has decreased.

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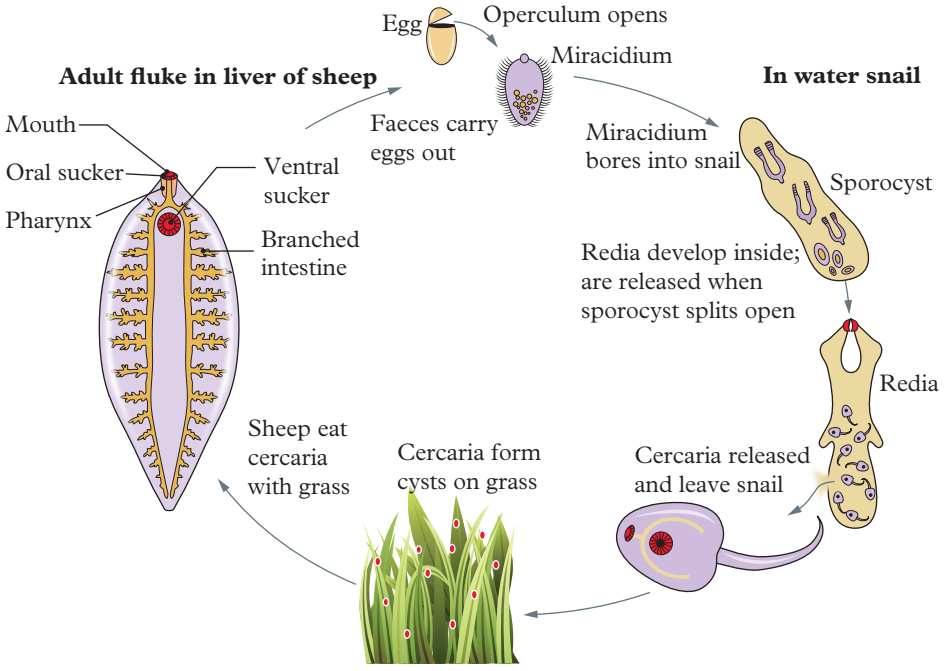


FIGURE 13 The life cycle of a liver fluke (*Fasciola hepatica*) is similar to that of a blood fluke.

Adult *Taenia* tapeworms are the largest endoparasites of humans, growing to several metres in length in the small intestine. Although their waste products can be absorbed into the human bloodstream, causing illness, their main effects are host malnutrition and obstruction of the bowel.

Most of the organs of the tapeworm have degenerated; the body consists of a series of sections (proglottids) effectively filled with reproductive organs. The proglottids are formed from the head end (scolex) continuously throughout the life of the tapeworm. These new proglottids are pushed back as still more are formed. The scolex is an attachment organ, firmly fixed to the intestinal wall with suckers and, in some species, hooks. A thick, mucus-covered cuticle covers the entire body, preventing digestion by the host's enzymes while still absorbing the digested food in which it is bathed.



FIGURE 14 *Taenia* scolex, immature and mature proglottids

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Challenge

Macroparasites

Infectious diseases caused by macroparasites are more prevalent in countries with small economies. Using an example of a macroparasite, **propose** (with justification) why this is the case. (2 marks)

Diseases caused by roundworms

Roundworms (phylum Nematoda) occur in enormous numbers in a great variety of habitats. Most are free-living in moist soil and decomposing organic matter on the bottom of lakes and oceans; others are parasites of plants and animals. Humans are hosts to about 50 species of roundworms. Few people have escaped contracting pinworms during their childhood. Due to its low severity this infection is more an annoyance than a disease. More serious diseases caused by roundworms occur in tropical and subtropical regions. They include elephantiasis (mosquito vector), onchocercariasis (water-breeding fly vector), ascariasis and hookworm, which are spread directly from person to person through faecal contamination of food or water.

Skill drill

Independent and dependent variables

Science inquiry skill: Understanding the scientific method (Lesson 1.3)

Francesco Redi experimented with decaying meat and the presence of maggots. He noted that if flies could not get to the meat, maggots didn't appear. This debunked the theory of spontaneous generation.

Louis Pasteur demonstrated how heating wine to between 50°C and 60°C killed bacteria and prevented lactic acid forming.

Robert Koch found a way to test whether a particular microorganism was responsible for a specific disease. He extracted *Bacillus anthracis* from a sheep suffering from anthrax, cultured it and injected it into mice, which then developed anthrax.

Practise your skills

1 **Determine** the dependent and independent variables of each experiment. Copy and complete the table to provide your answer. (6 marks)

TABLE 1 Redi, Pasteur and Koch's experimental variables

Experimenter	Independent variable	Dependent variable
Francesco Redi		
Louis Pasteur		
Robert Koch		

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Check your learning 12.3

Check your learning 12.3: Complete these questions online or in your workbook.

1 **Describe** how bacteria may cause disease in their host, using an example to support your response. (2 marks)
2 **Describe** how bacterial diseases are transmitted. (1 mark)
3 **Identify** two macroparasites that are transmitted via contaminated water, and describe the symptoms in the infected person. (4 marks)
4 **Explain** whether thrush is caused by an ectoparasite or an endoparasite. (2 marks)
5 One group of protozoans, Phylum Apicomplexa, is only found as parasites of animals. **Determine** which feature of these organisms is compatible with this mode of living. (1 mark)

Lesson 12.4
Pathogenesis

Key ideas

→ Pathogenesis is the series of steps by which a pathogen causes disease in a host.
→ The virulence of a pathogen refers to its ability to cause disease.
→ Virulence factors are molecules that can contribute to the survival of a pathogen, and therefore its pathogenesis. They include adherence factors, invasion factors, capsules and toxins.

Learning intentions and success criteria

Pathogenesis and virulence

Pathogenesis is the process or mechanisms by which pathogens cause disease, from initial contact with the host, to the development and progression of the disease. The **virulence** of a pathogen is its ability to cause disease. It is a measure of the severity of the disease that a particular pathogen can induce in the host, and includes how many individuals the microorganism infects, how quickly it spreads through the body and how many hosts die due to the infection. For example, influenza is more virulent than the common cold virus, because more people become very sick or die as a result of the "flu".

For an organism to cause disease, it must:

- enter the host
- multiply in the host's tissues
- resist, or not stimulate, the host's defence mechanisms, and
- damage the host.

pathogenesis
the series of steps by which a pathogen causes disease in a host: adhesion, colonisation, invasion, evasion of host defences, and damage to host tissues

virulence
the ability of a pathogen to cause disease or damage to its host

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Virulence factors

virulence factor
a molecule that can contribute to the survival of a pathogen

Virulence factors are molecules that can contribute to the survival of the pathogen, and therefore its pathogenesis. They are typically proteins and include adherence factors, invasion factors, capsules and toxins.

Adherence factors

adherence factors
specialised molecular components on the surface of a pathogen that increase its ability to attach to the surface of other cells or structures

adhesin
a protein on the surface of bacteria that helps them adhere to other cells or to inanimate surfaces

Before a pathogen can cause disease, it must first enter the host. For this to occur, the pathogen must adhere (stick) to a molecule on the membrane of the host cell. This provides a starting point for the microorganism to penetrate tissues and colonise the host. **Adherence factors** are specialised structures on the surface of a pathogen cell that allow it to bind and maintain attachment to a host cell.

An example of an adherence factor is when a pathogen produces small surface glycoprotein molecules, called **adhesins**, which attach to specific receptors on the host cell's membrane. Another example of an adherence factor can be in seen some bacteria, such as *Streptococcus* species, which have fine structures called fibrillae that can bind to human epithelial cells. Some bacteria, such as *Escherichia coli*, have specific adhesive organelles, called pili, that allow them to bind to almost all human cells.

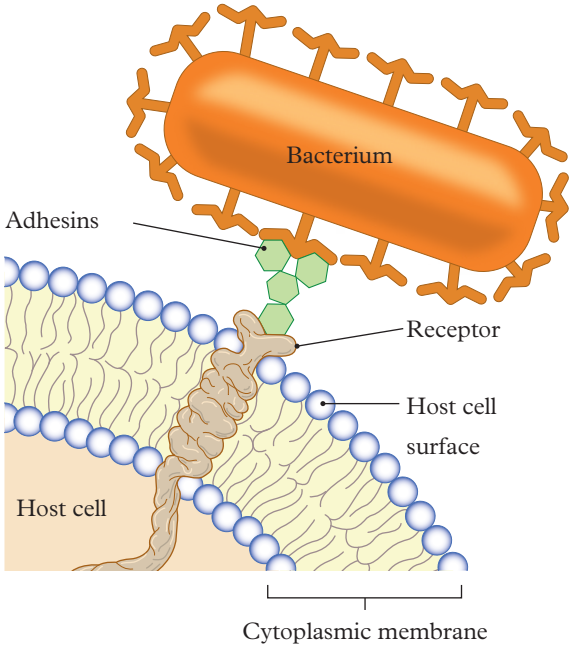


FIGURE 1 A bacterium attaching to the host cell by adhesins

Invasion factors

invasion factor
a protein that allows a pathogen to invade a host cell

Invasion factors are proteins that allow pathogens to enter cells. Many microorganisms must insert themselves into their host's cells. To achieve this, many produce proteins that help to disrupt the host cell membranes or stimulate endocytosis into the host cells. For example, *Yersinia* is a genus of bacteria that requires entry into epithelial cells in the gut. To do this, *Yersinia* produces a protein called invasin, which allows the bacteria to bind to and invade epithelial cells. Another example of an invasion factor is the spike (S) protein in the SARS-CoV-2 strain of coronavirus. These spike proteins bind to a host cell receptor called ACE2. After the spike protein binds to the ACE2 receptor, the virus can inject its RNA into the host cell.

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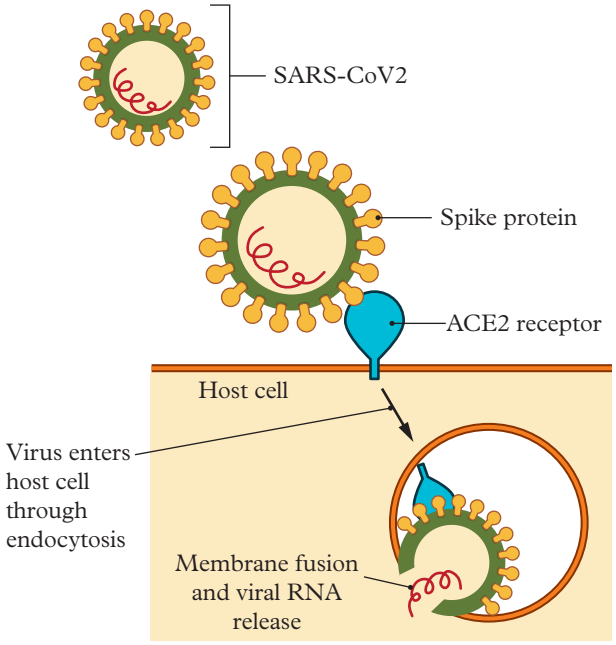


FIGURE 2 The spike protein produced by SARS-CoV-2 is an invasion factor that facilitates viral entry into a host cell.

Capsules

Many bacteria have a **capsule**, a specialised structure composed of polysaccharides that coats the outside of the cell wall (Figure 3). Capsules protect bacterial cells by shielding the bacteria from toxins and from desiccation (drying out). Additionally, capsules can assist with adhesion to host cells and help the pathogen evade the host's immune system by cloaking molecules that may have otherwise triggered an immune response, such as phagocytosis by white blood cells.

capsule
the outermost layer of some prokaryotic cells, made of polysaccharides; plays a role in adhering to surfaces, substances and other bacteria

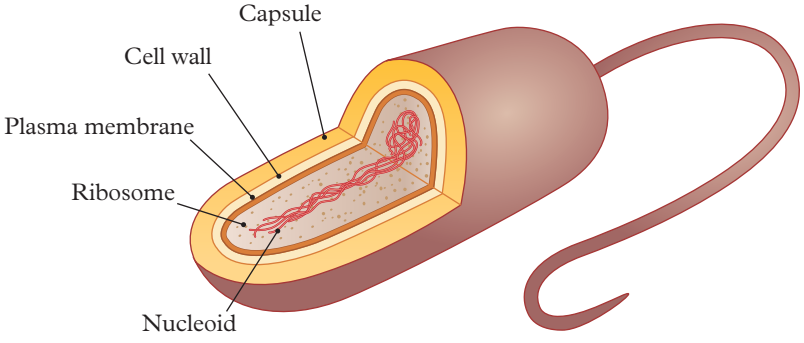


FIGURE 3 A bacterial capsule encases the cell walls of the bacterium and protects the cell.

Toxins

Toxins produced by pathogens are proteins that poison host cells and cause tissue damage. Many bacteria and fungi produce toxins so they can damage host tissue to acquire nutrients needed for the pathogen's survival. There are two main types of toxins: endotoxins and exotoxins.

toxin
a protein produced by pathogens that poisons host cells

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Endotoxins

endotoxin
a pathogen's toxin that is bound to its outer membrane and is not freely liberated into the surrounding medium

Endotoxins are lipopolysaccharides bound to the outer membrane of the pathogen. When the pathogen is damaged or destroyed by the host, the endotoxin is released and causes an inflammatory response in the host (Figure 4).

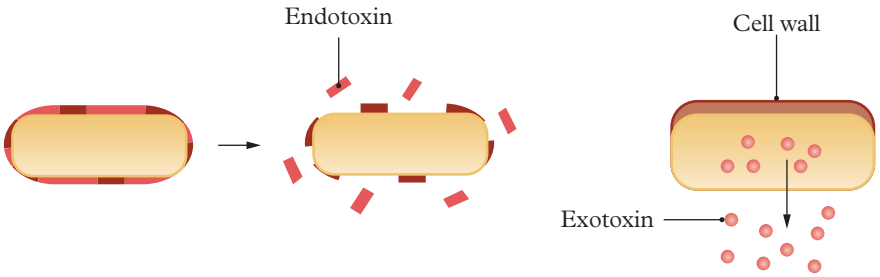


FIGURE 4 Endotoxins are bound to the outer membrane of a pathogen. Exotoxins are produced inside the pathogen and released into the external environment.

Exotoxins

exotoxin
a protein produced and released by a pathogen

Exotoxins are proteins produced and released by the pathogen. Different toxins are secreted by different species. They are named descriptively to show where the toxin acts (e.g. neurotoxins affect the nervous system, haemolysin causes red blood cells to rupture). The two most potent known exotoxins are the tetanus toxin secreted by the bacterium *Clostridium tetani*, and the botulinum toxin produced by *Clostridium botulinum*.

Exotoxins act in different ways. They can:

- damage cell membranes by altering the movement of ions into or out of the cell or by inhibiting protein production and so causing cell death
- interfere with cell signalling, by disrupting the cell cytoskeleton (and thus the membrane), disrupting the proteins involved in transduction, or blocking or altering the signalling pathways
- affect the immune response by provoking the release of enormous amounts of inflammatory chemicals, which can result in toxic shock syndrome.



FIGURE 5 *Clostridium tetani* is found in soil, ash, on skin and on rusty tools.

Check your learning 12.4

Check your learning 12.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** how adherence factors increase the virulence of pathogens. (2 marks)
2 **Describe** the structure and function of bacterial capsules. (2 marks)
3 **Describe** the function of toxins and how they aid the survival of pathogens. (2 marks)
4 **Explain** how virulence factors affect the pathogenesis of a disease. (2 marks)

Knowledge utilisation

5 A highly virulent pathogen will often not infect as many people as a mildly virulent pathogen. **Propose** reasons for this. (2 marks)

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Lesson 12.5
The immune response

Key ideas

- → There are three lines of immune defence: the innate immune response, the inflammatory response and complement system, and the adaptive immune response.
- → The innate immune response is a system of non-specific defence mechanisms including physical barriers such as skin, chemicals in the blood, and white blood cells that attack foreign cells in the body.
- → The inflammatory response is the body's response to an injurious agent. It is characterised by swelling, pain and/or heat.
- → The complement system is a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter.
- → The adaptive immune response is a specific immune response that is "learned" when a person's immune system encounters foreign "invaders" and recognises non-self substances (antigens) – the response generates special chemicals (antibodies) to neutralise a specific pathogen.



Learning intentions and success criteria

immune system
an organism's host defence system, comprising many biological structures and processes that protect against disease

innate immune response
a system of non-specific defence mechanisms including physical barriers (e.g. skin), chemicals in the blood, and white blood cells that attack foreign cells in the body

inflammatory response
a response of the body to an injurious agent, characterised by swelling, pain and/or heat

complement system
a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter

adaptive immune response
an immune response that is not present at birth but is "learned" when person's immune system encounters foreign invaders and recognises non-self substances (antigens) – the system then generates special chemicals (antibodies) that neutralise the pathogen

Pathogen entry and the immune system

Pathogens can enter the body through natural openings or via wounds and breaks in the skin. Each of the natural openings leads to a tube lined with soft, moist membranes that are breeding havens for many pathogens. These openings include:

- the eyes, where pathogens can enter through contact and dust (e.g. conjunctivitis)
- the nose, where airborne organisms can enter through inhalation (e.g. tuberculosis, the common cold, influenza, measles)
- the mouth, where pathogens can enter through contaminated food, drink, utensils (e.g. cholera, bacillary dysentery, tapeworm, salmonella food poisoning)
- the urinary, reproductive and anal passages, where pathogens can enter by contact (e.g. gonorrhoea, HIV, syphilis, candidiasis).

Unbroken human skin has a remarkable protective ability against microorganisms. The larvae of *Schistosoma*, hookworm, and the fungi that produce tinea and ringworm, are among the few pathogens that can enter unbroken human skin. Pathogens may also enter a host through vectors that penetrate the skin (e.g. mosquitoes) or through contaminated needles used for injection (which can spread HIV and hepatitis). Many pathogens, such as the bacteria that cause tetanus and septicaemia, enter the body through scratches and abrasions.

For a pathogen to cause disease, it must first enter the appropriate host cell and then, in most cases, multiply. To do this, it must overcome host defences that have evolved to prevent this. The body's different defences to protect against pathogens and disease are known as the **immune system**. The immune system has three lines of defence, and each plays a specific role in defending the body:

1 the **innate immune response**
2 the **inflammatory response** and the **complement system**
3 the **adaptive immune response**.

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The innate immune response

The first line of defence against pathogen invasion is the innate immune response. This response is present in all animals and is sometimes referred to as "natural immunity". It is always active and does not require any special preparation to prevent infection. It includes both physical barriers, such as the skin, and chemical barriers, such as mucus secreted by mucous membranes, to prevent pathogens causing disease. The innate immune response is considered a form of **non-specific immunity** as it does not target any one specific type of pathogen but instead protects against a broad range of potential pathogens.

non-specific immunity
immunity that an organism is born with and protects against all pathogens rather than specific pathogens

The role of skin in the innate immune response

The skin is the first point of defence and the body's main barrier against pathogen infection. It protects the internal organs against external elements and pathogens. The outer layer of the skin, the epidermis, is made up of closely packed cells. This structure forms a tough physical barrier that, when intact, is difficult for pathogens to penetrate. The outermost layer of skin cells is dry and sheds regularly, which helps remove pathogens attached to the surface of the skin.



FIGURE 1 The skin is the body's largest barrier against pathogen infection.

The skin also contains sebaceous (oil) and sweat glands. Sebaceous glands secrete sebum, an oily substance, onto the surface of the skin, which makes the skin's surface more acidic. Beneficial bacteria can live on the oil secreted by sebaceous glands, while the acidity of sebum helps prevent the growth of pathogenic bacteria and fungi on the skin. Sweat secreted by sweat glands also contains antibacterial and antifungal substances. The skin also hosts several beneficial and harmless bacterial species, which compete with pathogenic species for space and resources.

mucous membranes
membranes that line various cavities in an organism's body and cover the surface of internal organs

mucus
an aqueous fluid that is secreted by and covers mucous membranes

antibody
a gamma globulin protein in the blood or lymph; produced by B-lymphocytes as an immune defence against foreign agents (antigens)

The role of mucous membranes in the innate immune response

Mucous membranes are the moist inner linings of some of the body's organs and cavities. Examples of cavities and organs with mucous membranes are the nostrils, mouth, lungs and stomach. Different mucous membranes secrete different substances that help fight pathogen infection. For example, the nostrils secrete **mucus**, a sticky fluid that can catch pathogens and stop them from reaching cells and tissues. Mucus also contains enzymes that can break down bacteria, and **antibodies** that can stop pathogen action. The mouth secretes saliva, which contains antimicrobial agents that can kill some harmful species of bacteria. Like the skin, mucous membranes are colonised by beneficial bacteria, which compete with pathogenic species for resources.

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FIGURE 2 (A) The nostrils secrete mucus. (B) The mouth secretes saliva.

Study tip

The word "skin" should not be used on its own to mean a physical barrier, as the skin may have small wounds or breaks. It must be described as "intact skin" to indicate that it is an effective barrier to pathogens.

The inflammatory response

If a pathogen makes it through the first line of defence, the second line of defence is triggered. The body's second line of defence consists of the inflammatory response and the complement system. Both these defence mechanisms are non-specific: they react in the same way for any pathogen.

The inflammatory response is the immune system's response to harmful pathogens, damaged cells, toxins and radiation. The inflammatory response includes the detection of harmful foreign stimuli (e.g. pathogens) and the initiation of healing processes that help to remove harmful stimuli and repair damage.

Detection of injury and pathogens

All cells in an organism have special protein molecules, called the major histocompatibility complex (MHC), on their outer membrane. MHC acts as a self-marker or identity tag. There are two types of MHC proteins:

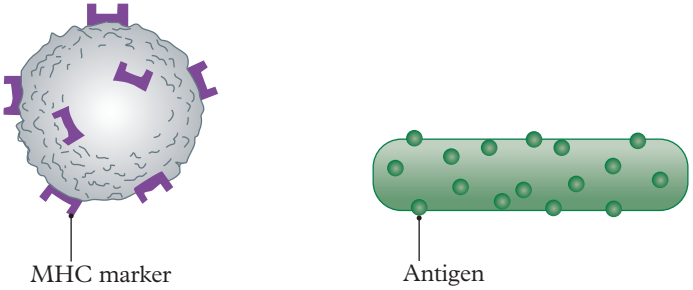
- MHC I – found on all cells in the body
- MHC II – found only on certain cells, such as **macrophages** and **B-lymphocytes** and used to recognise foreign cells.

The immune system can therefore recognise which cells are "self" by detecting body cells that have the same MHC I on their surface. Cells that do not contain the specific MHC I for the individual are not recognised and are therefore attacked by the immune system. Pathogens such as viruses, parasites, fungi and bacteria do not contain the specific host identification marker. Any non-self-marker is known as an **antigen** (Ag) to the host organism and will trigger the immune response.

macrophage
a type of white blood cell that engulfs and kills microorganisms, removes dead cells and triggers the action of other immune cells

B-lymphocyte
a white blood cell that does not pass through the thymus as it matures; involved in antibody formation

antigen
a protein on the surface of matter that is foreign to the body



Immune cells recognise cells with the correct MHC marker as "self".

Recognition of an antigen triggers an immune response.

FIGURE 3 MHC markers are used to identify "self" cells, while antigens trigger an immune response.

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Removal of harmful stimuli and healing

The inflammatory response involves a variety of cellular components and processes that work to attack pathogens and initiate healing. It includes:

- prostaglandins and vasodilation
- neutrophils and macrophages
- natural killer cells.

Prostaglandins and vasodilation

prostaglandin
a chemical released from damaged cells that directs blood flow to an injured area

Prostaglandins are a group of chemicals released by a variety of cells when an area of the body is infected or damaged by pathogens. One of the primary roles of prostaglandins is to initiate the widening of blood vessels, known as vasodilation (Lesson 11.2). Vasodilation allows blood flow to be directed to the site of injury or infection. The increased amount of blood in the injured area causes the area to become red, swollen and warm – common signs of inflammation. Vasodilation also assists in bringing increased numbers of phagocytes into the area to help destroy pathogens at the site of injury or infection.

Prostaglandins also increase the permeability of blood vessels, which helps transport other immune cells and proteins from blood to tissue, to help fight infection. Finally, prostaglandins can also work to induce fever, raising the body's temperature to fight off pathogens.



FIGURE 4 Prostaglandins can trigger vasodilation to direct blood flow to the site of an injury, causing swelling and redness.

Neutrophils and macrophages

Neutrophils and macrophages are both types of white blood cells (leucocytes) that play a significant role in the immune process. They are both phagocytes (able to perform phagocytosis) to engulf foreign invaders such as pathogens and harmful substances. A sac of enzymes (a lysosome) within these phagocytic cells fuses with the engulfed pathogen, causing it to be digested.

neutrophil
a phagocytic, granulocytic white blood cell

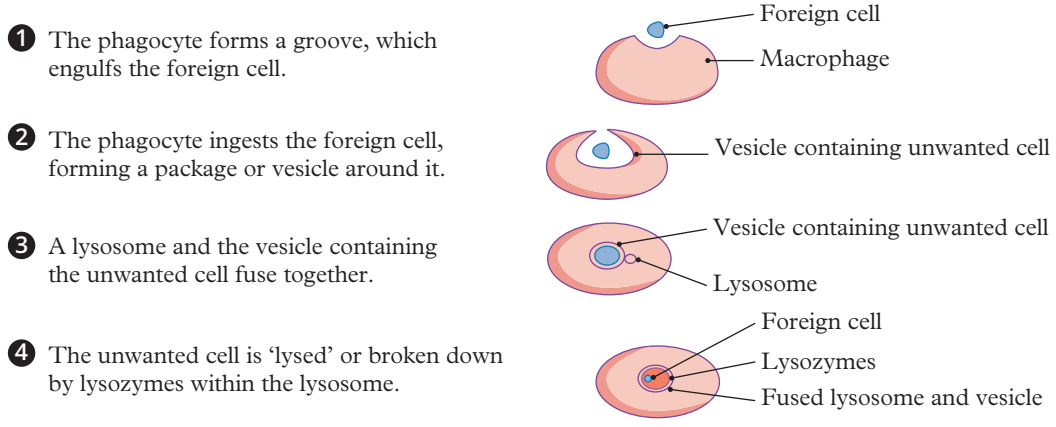


FIGURE 5 Phagocytosis occurs when a macrophage engulfs a foreign cell, forming a vesicle around it so it can digest the invader.

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Neutrophils are the most abundant white blood cell in humans and the first to arrive at sites of infection (Figure 6). They have a short lifespan and when they die, due to bacterial toxins, they form pus.

Macrophages are scavengers that remove dead cells as well as foreign invaders such as pathogens (Figure 7). They arrive at a site of infection after neutrophils but stay longer, to continue engulfing dead cells and invaders. Macrophages can be fixed or wandering. Fixed macrophages are found in areas vulnerable to pathogen infection, such as the lungs and intestines. Wandering macrophages are found in several areas of the body, as they move through blood and lymph nodes to help detect invaders. Macrophages also release signals to recruit more immune cells to an area to assist with healing.

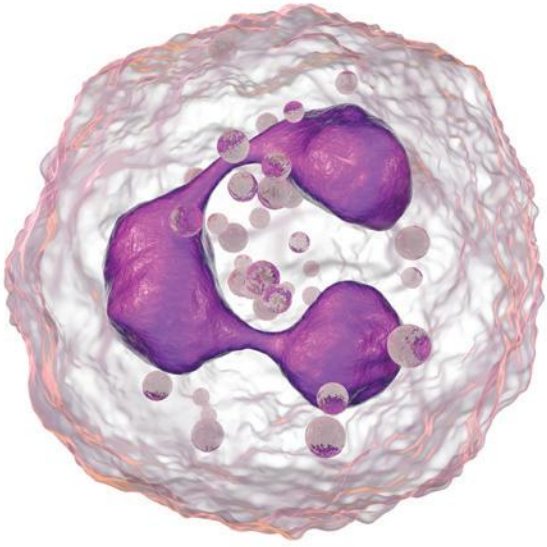


FIGURE 6 A neutrophil is often one of the first phagocytes to arrive at the site of an infection.



FIGURE 7 A macrophage seeks out and engulfs bacteria in a process called phagocytosis.

The key events during the inflammatory response are summarised in Figure 8.

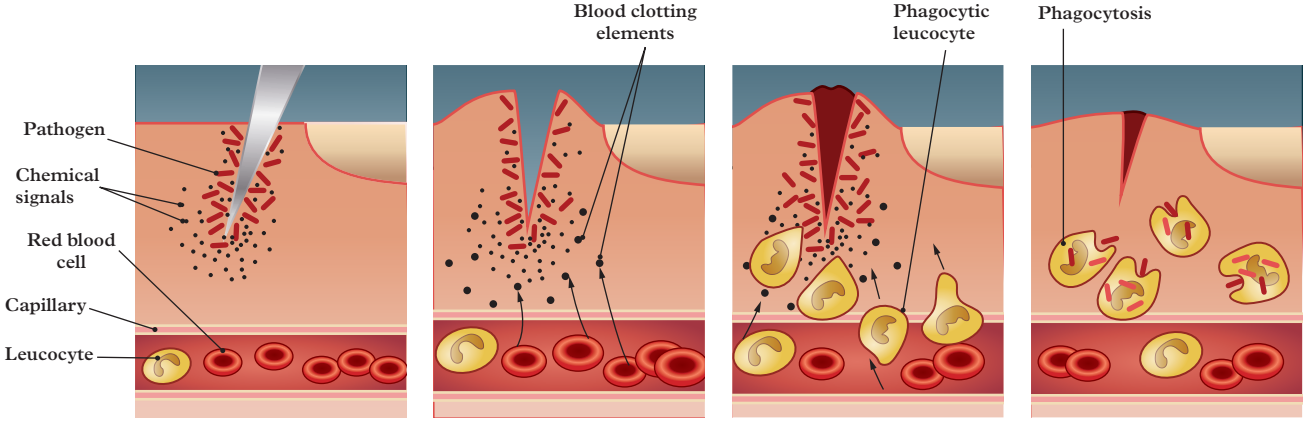


FIGURE 8 Some of the key events that occur during the inflammatory response

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Natural killer cells

lymphocyte
a white blood cell in the lymphatic system

Lymphocytes are a type of small white blood cell in the lymphatic system. They play a significant role in the immune system. The lymphatic system is a series of vessels that pass tissue fluid through lymph nodes before returning it to the blood circulatory system. Pathogens become trapped in the lymph nodes, where they are systematically attacked by both lymphocytes and macrophages.

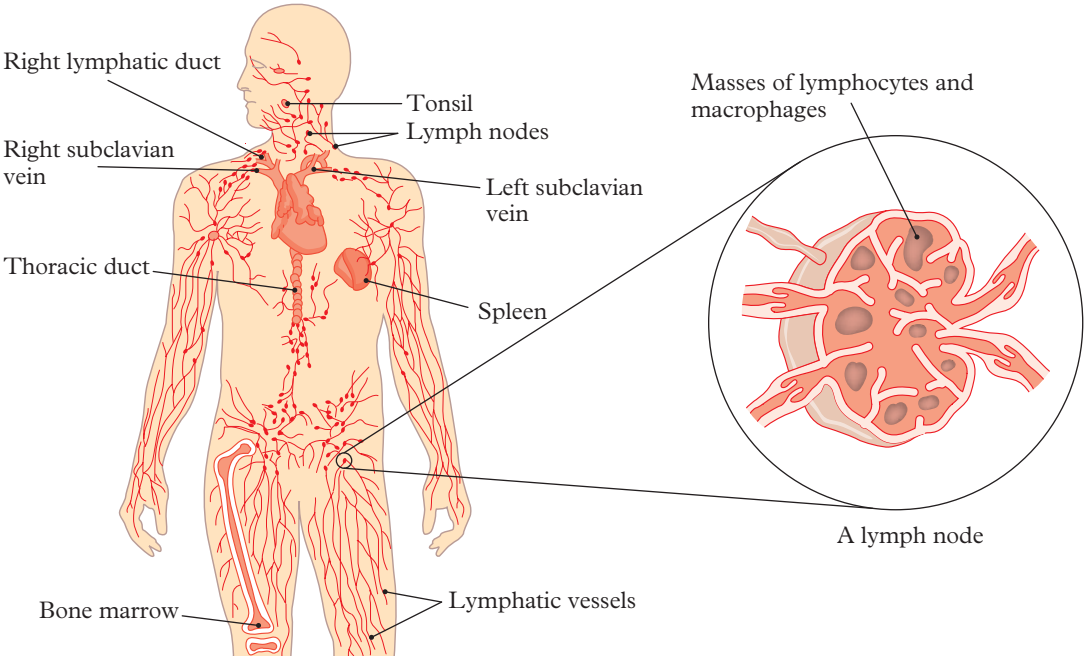


FIGURE 9 The human lymphatic system

natural killer (NK) cell
a specialised lymphocyte involved in the innate immune response; induces apoptosis in tumour cells and virus-infected cells

apoptosis
programmed cell death

Natural killer (NK) cells are specialised lymphocytes involved in the inflammatory response. Like macrophages, NK cells are non-specific, as they lack antigen-specific binding receptors on their cell surface. These cells can detect virus-infected and cancerous host cells and induce the host cell to undergo controlled cell death, termed **apoptosis**. By doing so, NK cells help limit the spread of the disease.

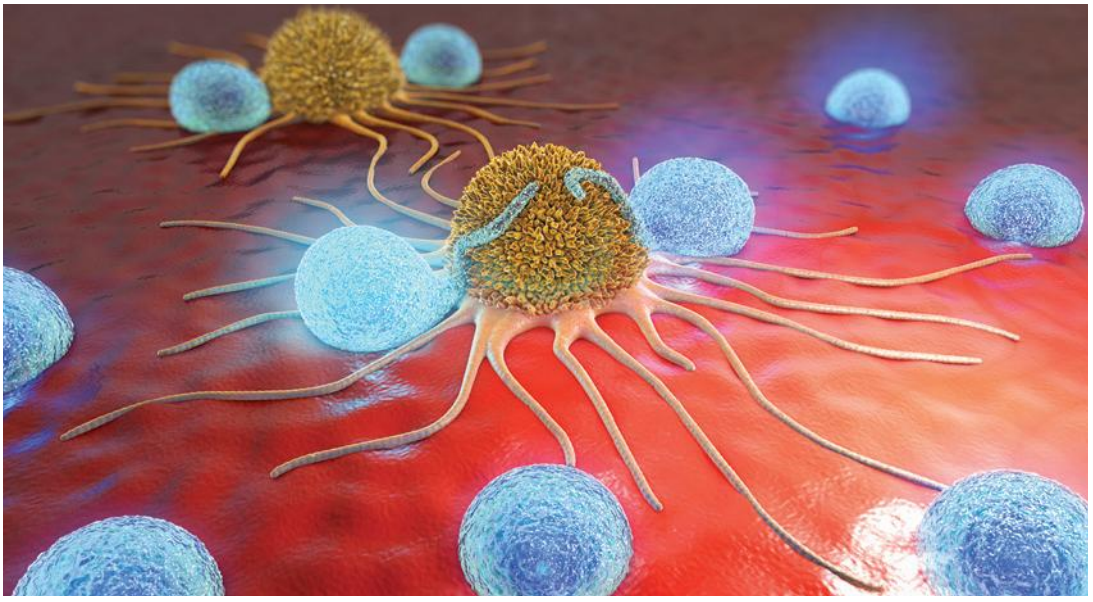


FIGURE 10 Natural killer cells can identify cancerous cells that have lost their MHC 1 markers.

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The complement system

The complement system consists of about 20 types of proteins that are formed in the liver. They are normally found in the blood plasma and intercellular spaces. Each type is produced in an inactive form and, when activated, can undergo a series of changes (termed a cascade) that results in parts of the protein being removed. Each step in the cascade produces a chemical that may react with a specific chemical on the foreign matter.

There are three pathways through which the protein complement can be activated on pathogen surfaces (Figure 11). The first pathway is activated by antibodies attaching to a pathogen's antigen. In the second pathway, a chemical, lectin, attaches to the pathogen and this attachment activates the complement protein. In the third pathway, a complement protein recognises specific chemicals on the bacterial surface.

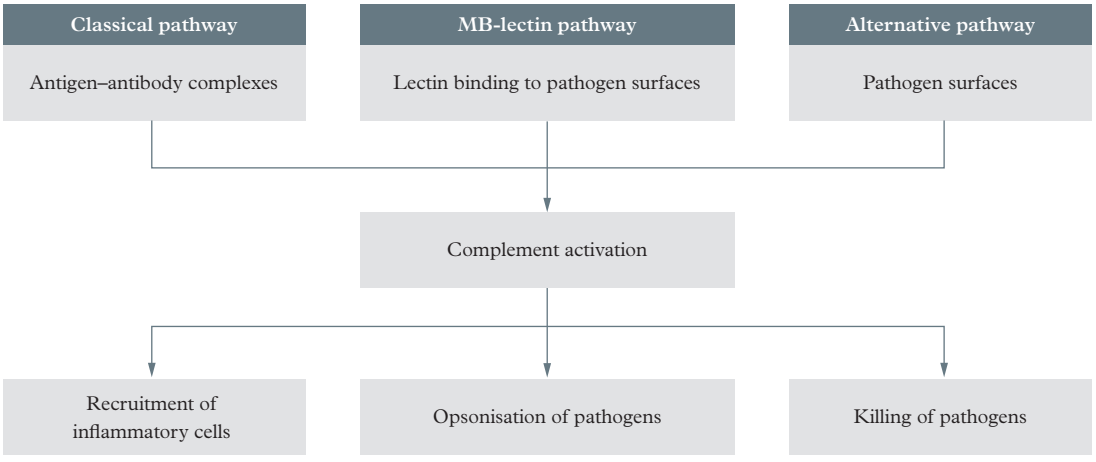


FIGURE 11 The three pathways of complement activation

In each case, the complement may trigger:

- phagocytosis, by signalling phagocytes (opsonisation)
- direct destruction, by the cascade's terminal enzyme "punching" holes in a bacterium's wall and causing it to burst
- agglutination, by altering the surface of the bacterial cells and causing them to stick together, thus aiding phagocytosis
- neutralisation of viruses, by direct attack
- cell signalling, causing neutrophils and macrophages to move to the pathogen
- activating mast cells and basophils to release substances that lead to increased blood flow and increased leakage of complement proteins, to help inactivate or immobilise bacteria
- inflammation.

The complement system has the potential to cause damage to the body's own cells, and so its activation needs to be tightly regulated. This is achieved by complement control proteins that are present at a higher concentration in the plasma than the complement proteins themselves. Some of these control proteins are also present on the membranes of self-cells to prevent them being targeted.

The adaptive immune response

The adaptive immune response needs to be "primed" before it can be fully effective – that is, it needs to form a record of past exposure of the body to potentially dangerous molecules and pathogens. This last line of defence specifically targets foreign substances on pathogens or proteins on cancerous cells.

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T-lymphocyte
a lymphocyte that has passed through the thymus during maturation

humoral response
immunity conferred to an individual through the activity of B-lymphocytes and their progeny, which produce circulating antibodies in response to the presence of an antigen and recognise the substance upon subsequent exposure

The adaptive immune system distinguishes two groups of foreign substances:

- antigens – molecules on the surface of viruses and foreign cells
- self cells that display abnormal MHC self-marker proteins (from antigens that have been engulfed and broken down, or from virus-infected and tumour cells that are actively synthesising foreign proteins).

These two groups of molecules are detected as foreign to the body by specialised white blood cells called lymphocytes. Lymphocytes enter the bloodstream from the bone marrow and follow one of two pathways as they mature. Those that pass through the thymus gland become sensitised and form **T-lymphocytes** or T-cells. Lymphocytes that do not pass through the thymus are called B-lymphocytes or B-cells.

The humoral response

B-lymphocytes are a special group of white blood cells. They congregate in lymph nodes, the tonsils, spleen, appendix and specialised areas (Peyer's patches) in the gut. The **humoral response** is a specific immune response that involves the activation of B-lymphocytes to produce and clone antibodies. When B-lymphocytes encounter a particle with a non-self antigen on its surface, they produce a gamma globulin molecule. The gamma globulins contain five classes of immunoglobulin or antibodies that differ in the amino acid sequence of one part of the gamma globulin molecule. The specific sequence is initiated by the B-lymphocyte in response to a particular antigen. The antibodies produced by each B-lymphocyte will recognise the shape of only one antigen molecule.

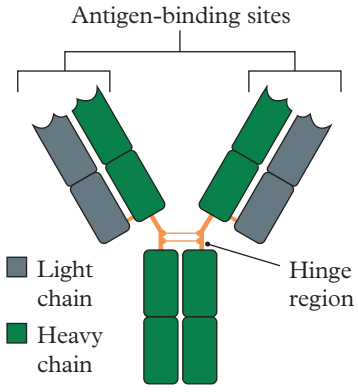


FIGURE 12 Antibodies are quaternary proteins with two heavy chains and two light chains. The hinged regions of antibodies provide the flexibility to link pathogens together.

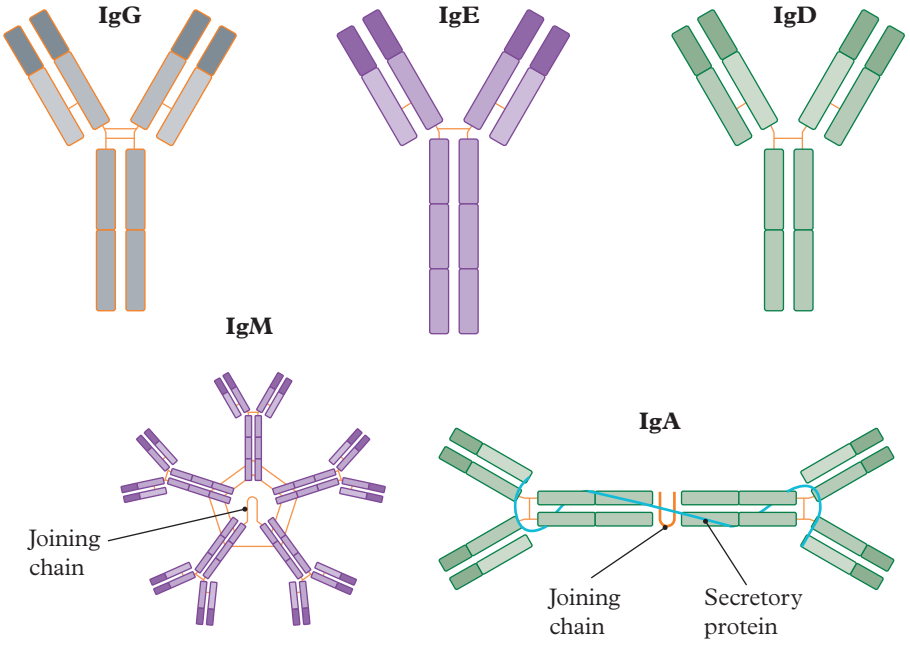


FIGURE 13 There are five main types of antibodies. Each plasma cell only produces a single kind of antibody.

When an antibody binds with an antigen, it may:

- block parts of the pathogen needed to survive (neutralisation)
- cause the foreign matter to agglutinate (stick together) to facilitate phagocytosis
- cause the foreign matter to break up and dissolve (precipitation)
- produce an antitoxin to the pathogen's toxins (complement activation).

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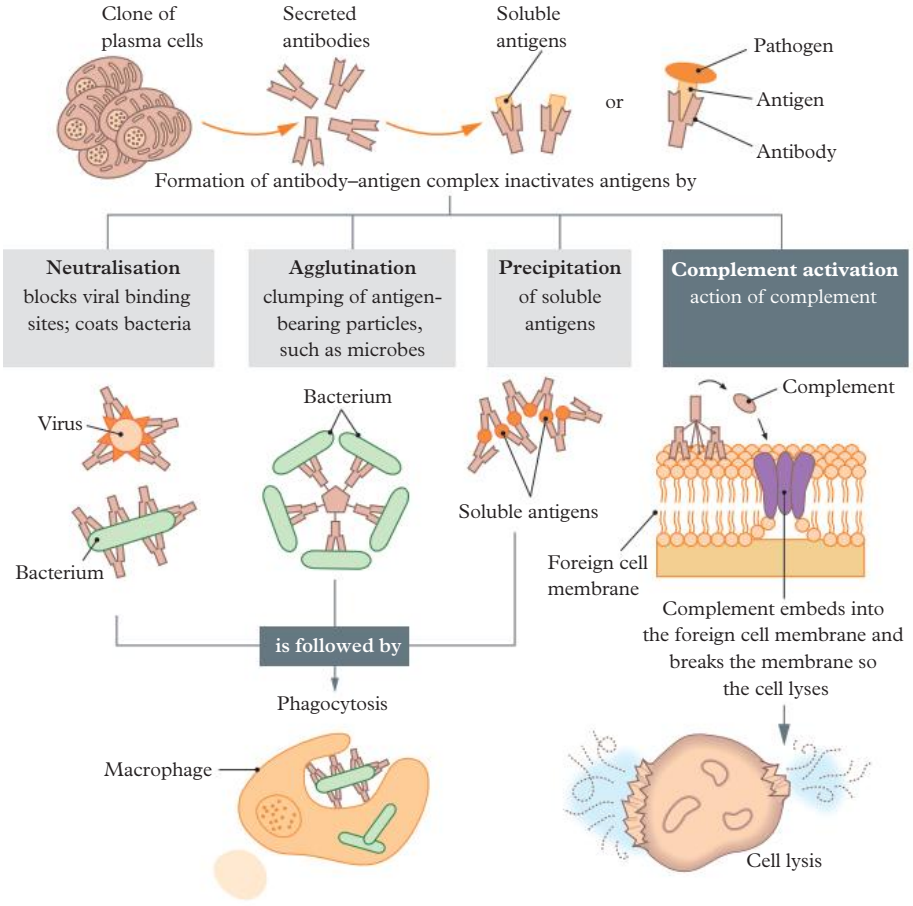


FIGURE 14 Antibodies produced by B-lymphocytes can perform a variety of actions to fight off pathogens.

plasma cell
a cell developed from activated B-lymphocytes that makes large numbers of a specific antibody

memory B-cell
a small, long-lived B-lymphocyte that has previously encountered a given antigen; on re-exposure to the same antigen, it rapidly initiates the immune response

After an antigen has bound to the complementary receptor on the B-lymphocyte and the B-lymphocyte has come in contact with cytokines produced by helper T-cells, B-lymphocytes are activated to rapidly divide and produce many identical cells. These cells can differentiate into two cell types: plasma cells and memory B-cells (Figure 15).

Plasma cells are mature B-lymphocytes that produce and secrete large numbers of antibodies that have combining sites complementary to a particular antigen. Other B-lymphocytes become memory cells called **memory B-cells**. These cells persist long after the original antigen has been removed or destroyed, and become new antibody-producing plasma cells in reinfection.

When a memory B-cell is produced, antibodies bind to its plasma membrane and act as receptors. If a complementary antigen binds to the antibody receptor, a message is passed to the memory B-cell. Memory B-cells often act as antigen-presenting cells and help activate T-lymphocytes (in the cell-mediated response). This can help accelerate the immune response the second time a pathogen attacks.

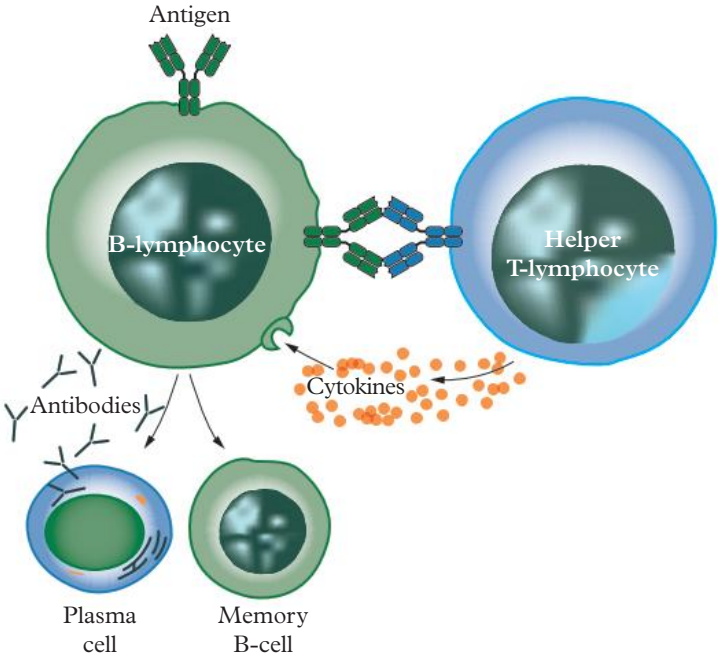


FIGURE 15 B-lymphocytes can differentiate into either plasma cells or B-memory cells.

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When a memory B-cell detects an antigen, it reproduces and differentiates into more plasma cells more quickly than unspecialised B-lymphocytes. This rapid response can prevent infection spreading through the body.

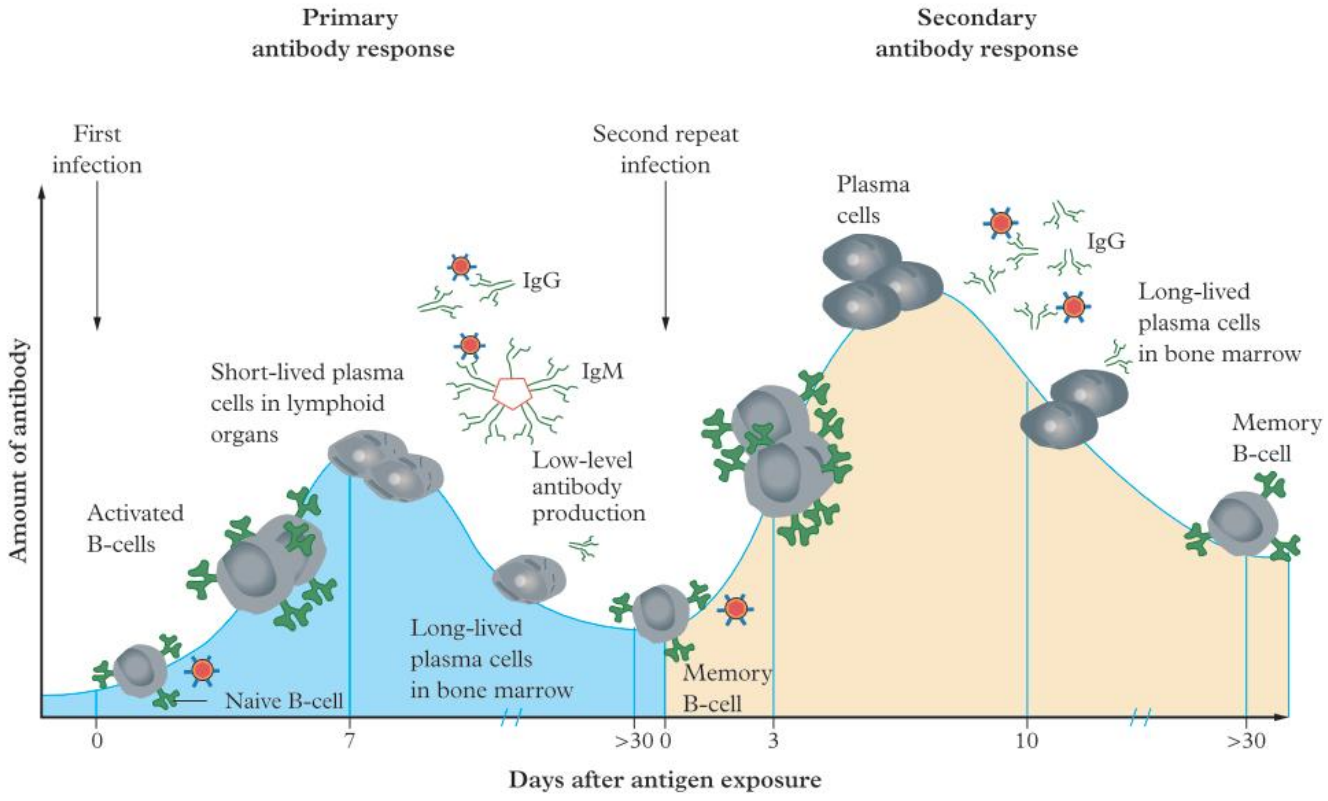


FIGURE 16 Memory B-cells can produce a larger number of antibodies the second time an antigen presents itself in the body.

The cell-mediated response

cell-mediated response
antigen activation of T-lymphocytes in the thymus to release soluble proteins to inactivate a pathogen

antigen-presenting cell (APC)
an immune cell that processes and presents an antigen for T-lymphocyte recognition

helper T-lymphocyte
a type of T-lymphocyte that stimulates the activity of other immune cells by producing cytokines

cytotoxic T-lymphocyte
a type of T-lymphocyte that kills cancerous cells and virus-infected cells

The **cell-mediated response** is an adaptive immune response that involves T-lymphocytes to remove infected or cancerous cells. When a cell becomes infected by a pathogen, it processes the pathogen's antigen and presents the antigen on the surface of its cell membrane. Other cells that present antigens on their surface are macrophages, B-cells and dendritic cells. These cells are referred to as **antigen-presenting cells (APCs)**. Antigens stimulate the production of T-lymphocytes in the thymus gland. In the thymus, mature T-lymphocytes differentiate into different cell types.

Helper T-lymphocytes are activated by antigens presented on the MHC II markers of APCs (e.g. macrophages, B-cells). Once activated, helper T-lymphocytes undergo clonal proliferation, producing more helper T-lymphocytes, which release cytokines. Cytokines produced by helper T-lymphocytes can activate B-lymphocytes (to stimulate antibody production) and activate **cytotoxic T-lymphocytes**.

Cytotoxic T-lymphocytes are activated by antigens presenting on cells with MHC I markers and by cytokines produced by helper T-lymphocytes. Once activated, these cells kill cancerous, virus-infected or damaged cells by producing cytotoxic molecules (perforin and granzyme) that can initiate apoptosis (cell death) in an infected cell (Figure 17). Cytotoxic T-lymphocytes will not attack APCs, as they present an MHC II marker.

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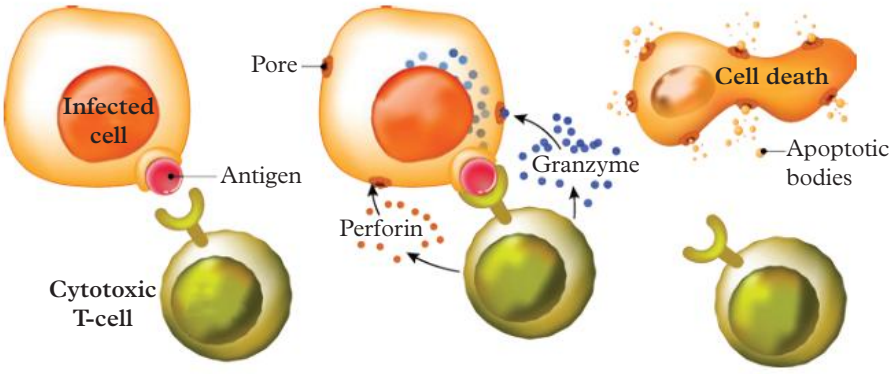


FIGURE 17 Cytotoxic T-lymphocytes produce cytotoxic molecules (perforin and granzyme) to initiate apoptosis in infected cells.

Other T-lymphocytes include:

- **suppressor T-lymphocytes**, which switch off the immune response and suppress the activity of other immune cells when they are no longer needed.
- **memory T-lymphocytes**, which are formed after infection and remain present to recognise the antigen if it is reintroduced, providing long-term immunity.

T-lymphocytes are responsible for reactions such as graft rejections, delayed hypersensitivity and resistance to cancer. Although T-lymphocytes and B-lymphocytes are capable of producing independent immune responses, they sometimes work together.

The HIV virus attacks helper T-lymphocytes, thus inhibiting the whole immune system. A person with AIDS is therefore vulnerable to all kinds of diseases. It has also been found that mental stress, bereavement, loneliness and depression affect the operation of the lymphocytes and reduce T-lymphocyte activity.

suppressor T-lymphocyte
a type of T-lymphocyte that regulates the actions of some other lymphocytes to prevent over-activity of the immune system

memory T-lymphocyte
a long-lived T-lymphocyte that has previously encountered a given antigen; on re-exposure to the same antigen, rapidly initiates the immune response

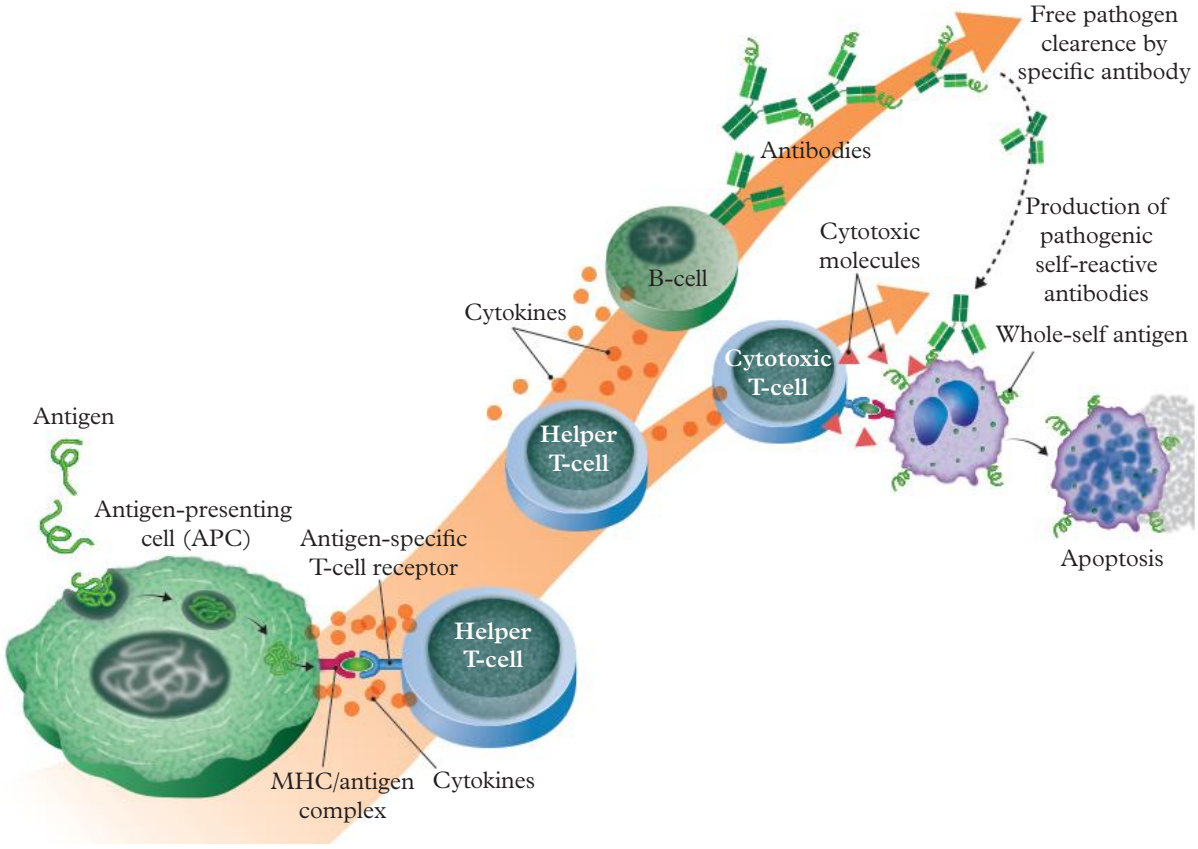


FIGURE 18 The cell-mediated response involves the recognition of antigens, which activates helper T-lymphocytes and cytotoxic T-lymphocytes.

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Figure 19 summarises the body's defences against disease.

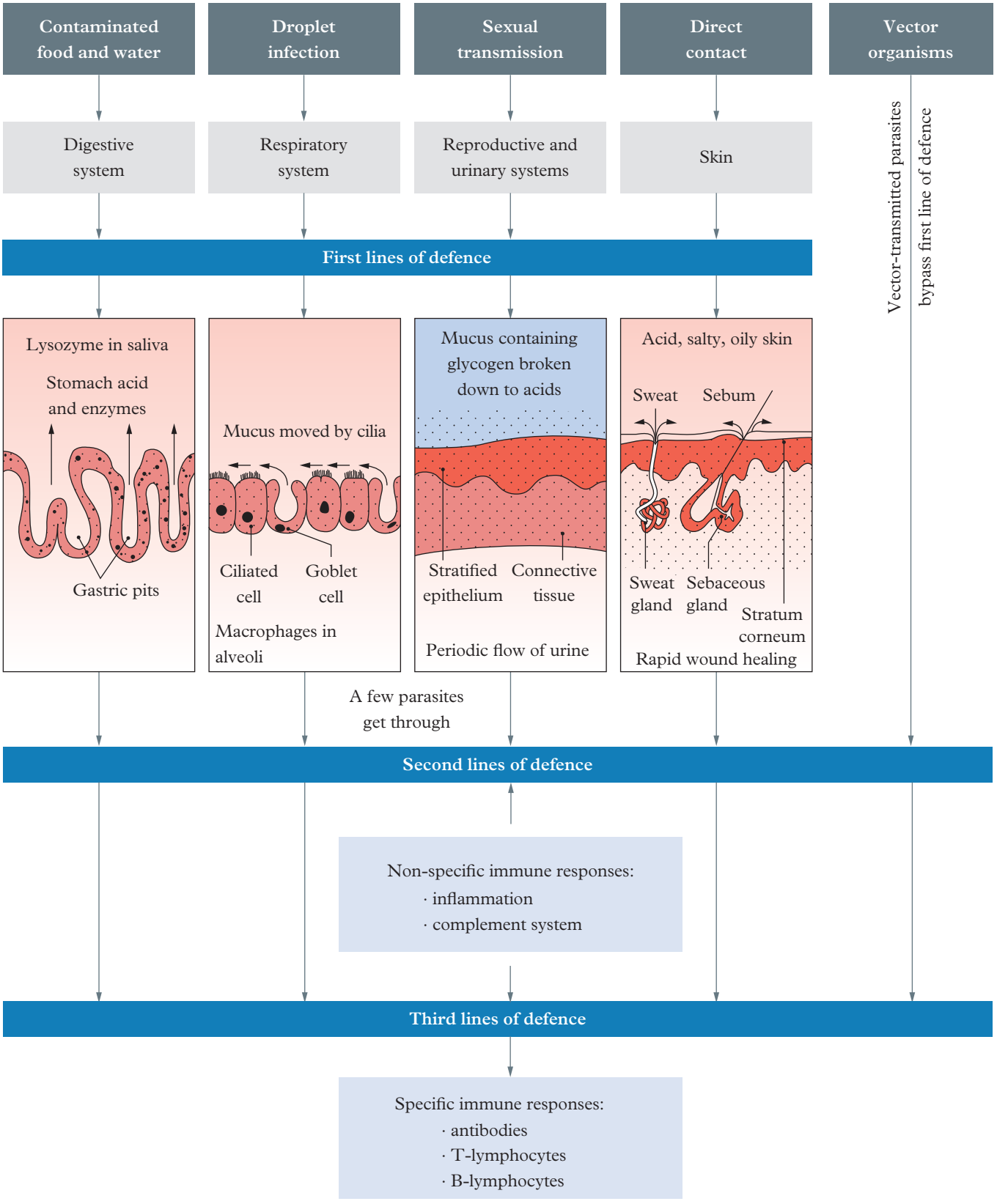


FIGURE 19 The body's defences against disease

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The components of the adaptive immune response are summarised in Table 2.

TABLE 2 Summary of components of the adaptive immune response

Component	Description	Role
Antibodies	Proteins produced by the body when it detects specific antigens. Different antigens stimulate the production of different corresponding antibodies.	Bind with antigens, causing them to clump together to form an antibody–antigen complex. An antibody–antigen complex is more easily recognised and destroyed by macrophages than antigens alone.
B-lymphocytes	Special kind of lymphocytes. Produced in bone marrow. Control (humoral) antibody-mediated immunity.	When a B-lymphocyte recognises an antigen, it is cloned to produce a mass of identical cells. The B-lymphocytes work as antibody producers (plasma cells) or memory cells, which provide long-term immunity.
T-lymphocytes	Special kind of lymphocytes. Produced in the bone marrow. Mature in thymus gland. Control cell-mediated immunity.	Cytotoxic T-lymphocytes produce toxic substances that destroy cells that have been invaded by a pathogen. They defend the body from cancer cells and transplant tissue. Helper T-lymphocytes help B-cells divide rapidly. Suppressor T-lymphocytes turn off the immune response and suppress the production of antibodies when they are not needed. Memory T-lymphocytes recognise the antigen if it is reintroduced, providing long-term immunity.

Real-world biology

Transplant rejection

Thanks to advances in medical technology, it is possible to replace a diseased organ from one individual with a healthy organ from another individual. In kidney transplants, this usually involves the transfer of a single kidney from a healthy living donor. Both recipient and donor are able to survive with a single kidney. The success of the transplant depends on the compatibility of the donor and recipient cells. Only identical twins have exactly the same MHC I markers on their cells. Closely related individuals generally have similar antigens, due to their similar genetic backgrounds; however, inheriting different sets of genes from each of their parents will result in some differences. The tissues of potential recipients are carefully examined to ensure their markers are as closely matched as possible to that of the donor. The closer the MHC I compatibility between donor and recipient, the smaller the immune response. Low compatibility can result in tissue or organ rejection (graft-versus-host disease). Most recipients are treated with immunosuppressant drugs to prevent the action of the immune system and its rejection of the transplanted organ. This can delay rejection for many years.



FIGURE 20 Patient undergoing kidney transplant

Apply your understanding

1 **Describe** the immune response in a patient receiving transplanted donor tissue. (3 marks)

2 **Describe** why your identical twin would be the safest option for an organ transplant. (2 marks)

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Check your learning 12.5

Check your learning 12.5: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Describe** ways in which pathogens can enter the body. (4 marks)
2 **Define** "immune system". (1 mark)
3 **Explain** how host cells recognise self from non-self and the importance of this in the immune response. (4 marks)
4 **Describe** the inflammatory response. (6 marks)
5 **Explain** the role of memory cells in the immune response. (4 marks)

Analytical processes

6 **Contrast** the specificity of the three lines of defence in vertebrates. (3 marks)
7 **Contrast** an antigen and an antibody. (1 mark)

Knowledge utilisation

8 a **Explain** why B-lymphocytes and T-lymphocytes are considered part of the adaptive immune system rather than the innate immune system. (2 marks)
b **Predict** how B-lymphocytes and T-lymphocytes would be involved in the body's response to:
i an infected cut on a finger (2 marks)
ii virus-infected cells (2 marks)
iii a grafted kidney. (2 marks)

Lesson 12.6
Immunity

Key ideas

- Immunity is the ability to resist disease. It can be acquired actively or passively.
- Natural active immunity can occur when memory T-lymphocytes and B-lymphocytes have formed following infection.
- Artificial active immunity can be achieved by vaccination with inactivated antigens.
- Passive immunity results from the intake of antibodies. They may be acquired naturally, by placental diffusion or from breast milk when a baby feeds (natural), or acquired artificially by an injection of antibodies from a previously infected individual (artificial).
- Immunological tolerance is the ability of some organisms to tolerate cells other than their own, provided they are introduced to the organism during the early stages of its development or in supervised, minute amounts at later stages.

Learning intentions and success criteria

Natural and passive immunity

Individuals may recover from disease caused by pathogens as a result of the immune responses of the B-lymphocytes and T-lymphocytes. Due to the formation of memory cells for a particular pathogen, the body builds up resistance or immunity to further attacks by the

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same type of organism. This is termed **natural active immunity**. "Natural" refers to the individual being exposed to the living pathogen, and "active" refers to the production of the memory cells.

Natural passive immunity is obtained when a mother is exposed to the living pathogen (natural) and then passes her antibodies to the foetus through the placenta. As the baby does not produce memory cells, the immunity is termed "passive". These antibodies are also present in the first "milk" (**colostrum**) secreted after birth. This immunity lasts for only a short time after birth, but further antibodies are contained in the mother's milk.

natural active immunity
immunity that occurs when a person is exposed to a live pathogen and develops a primary immune response, which leads to immunological memory

natural passive immunity
antibody-mediated immunity conveyed to a foetus or infant by the mother

colostrum
the first form of milk produced by the mammary glands of mammals (including humans) immediately following delivery of a newborn



FIGURE 1 Antibodies are present in colostrum.

Immunity can also be acquired artificially. Injection of an individual with deactivated antigens, or parts of antigens, can induce the immune system to react and ultimately produce memory cells. This vaccination or immunisation allows an individual to acquire **artificial active immunity**. Three general types of antigens used in vaccines are:

- sterile bacterial exotoxins
- sterile, dead microorganisms
- living infectious microorganisms whose ability to cause serious infection has been altered.

artificial active immunity
active immunity acquired by vaccination with a vaccine containing active antigens, to prevent the development of a disease in the future

Vaccines

A **vaccine** is produced to target a specific pathogen, usually from a cultured sample. The pathogen is either killed or genetically altered so that it is no longer harmful. Once injected into an individual, the immune system reacts to the foreign antigen on the pathogen's surface and forms memory cells that last for a period of time. The body's defence system is thereby "sensitised" and immunity is achieved without the individual having to suffer the effects of infection by the pathogen. If the immunised person or animal becomes infected by the pathogen during that time, the memory cells quickly recognise it and the immune reaction is rapid enough to prevent the disease developing.

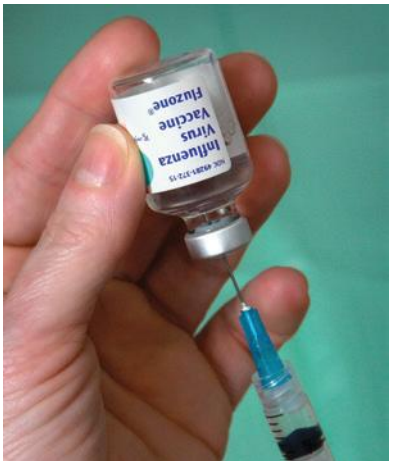


FIGURE 2 The vaccine for influenza is not effective permanently.

vaccine
a biological suspension administered to provide artificial acquired immunity against a particular disease

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Vaccines against viruses are more difficult to produce than those for bacteria, because viruses undergo rapid changes to their protein coats and, therefore, their antigens. So an influenza vaccination from one year could be ineffective in preventing people from contracting a different form of flu in the following year. Also, because viruses are not living organisms, they cannot be killed. To produce the virus in adequate numbers for a vaccination program, a living host or tissue culture is required. The virus's nucleic acid core is removed or chemically destroyed, leaving just the antigenic protein coat, so the viral particle cannot cause a host cell to produce more viral particles. When a vaccine is produced, it must undergo rigorous testing to ensure it is effective.

TABLE 1 Types of vaccines and their effectiveness

Disease	Type of vaccine	Effectiveness *	Possible complications if the disease is contracted
Diphtheria (bacterial)	Toxoid	Almost 100% for 10 years	Nerve, heart problems, death
Influenza (viral)	Altered	One season	Respiratory, cardiac problems, death
Measles (viral)	Weakened**	95% for at least 21 years	Blindness, deafness, encephalitis, death
Mumps (viral)	Weakened	90% for 12 years	Sterility in males, inflammation of male and female sex organs
Poliomyelitis (viral)	Weakened (Sabin), and nucleic acid destroyed (Salk)	95% for 10 years	Paralysis, lameness
Rubella (viral)	Weakened	95% for 16 years	Possible foetal deafness and/or blindness if a pregnant woman contracts the disease in the first 12 weeks of pregnancy
Human papillomavirus (viral)	Synthesised viral particles	Long term if given to 12- to 13-year-old boys and girls	Cervical cancer in females and penile cancer in males; also throat and/or anal cancer
Tetanus (bacterial)	Toxoid	100% for 10 years	Respiratory, cardiac problems, death
Whooping cough (pertussis) (bacterial)	Killed	70 to 80% for 2 to 10 years	Pneumonia, convulsions, encephalitis, death in infants
Meningococcal C disease (meningitis) (bacterial)	A conjugate vaccine composed of a carrier protein attached to an antigen made from the coat of the bacteria***	Individuals 1 to 19 years: one dose gives long-term immunity. Infants 6 weeks to 4 months: need three doses of the vaccine for long-term immunity. Infants 1 to 12 months: need two doses of the vaccine for long-term immunity.	Meningitis (inflammation/swelling of the lining of the brain) Septicaemia (blood poisoning)

*Effectiveness is for adults or from teenage years on.
**Weakened pathogens are altered to decrease infection. Many bacterial pathogens are killed for vaccination. A toxoid is an inert toxin of the type produced by the bacterium in question.
***This vaccine has been introduced as a free vaccine for 1- to 19-year-old individuals in response to the increased incidence of meningococcal C disease in recent years.

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Serums

Serums contain antibodies to specific antigens. In the case of serious infections, such as diphtheria and tetanus, the reaction to the bacterial toxin may be too fast for the individual to develop antibodies. Specific antibody serums are administered to counteract the infection and produce immediate resistance. In the case of most snake or spider bites, serums containing the antibodies to the specific toxins in the venom are produced (antivenom).

This is termed **artificial passive immunity**. This type of immunity typically lasts for a year or so.



FIGURE 3 Injection of a snake antivenom serum can provide artificial passive immunity.

serum
a suspension of pre-formed antibodies administered to provide artificial passive immunity against a particular disease

artificial passive immunity
immunity acquired by injection of serum containing antibodies into an individual who may have been infected with a particular pathogen

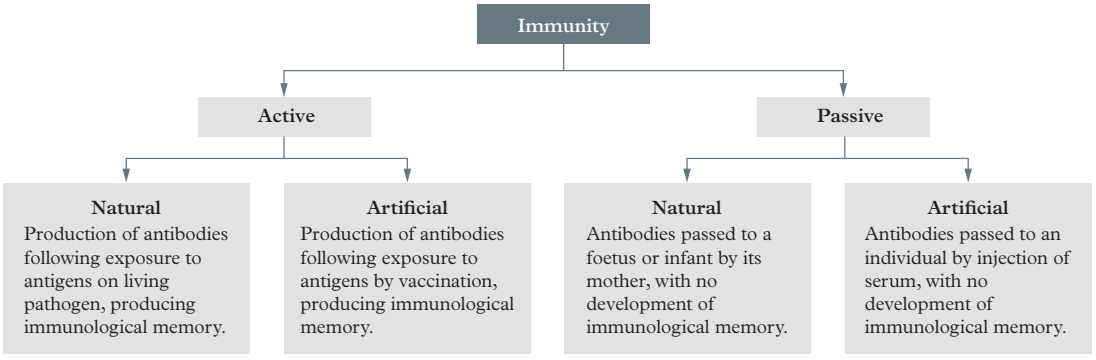


FIGURE 4 Summary of the different types of immunity

allergen
an antigen that causes an allergic reaction in an organism

immunological tolerance
the body's failure to mount an immune response to an antigen

Immunological tolerance

Experimental evidence indicates that the ability of lymphocytes to distinguish "self" from "non-self" is learned over time. This principle has been applied to some people who have an allergy to bee stings. Under medical supervision, it has been possible to introduce very small amounts of the bee venom to the allergic individual. Over time, the immune system learns that the **allergens** in the bee venom are not dangerous and starts producing a special type of T-lymphocyte that suppresses the rest of the immune cells. This condition is known as **immunological tolerance**. It is possible to develop this tolerance if:

- the animal receiving the antigen is very young
- the dose of antigen is high
- the antigen has a low molecular weight
- the dose of antigen is prolonged or repeated.

The process by which immunological tolerance develops is shown in Figure 5.

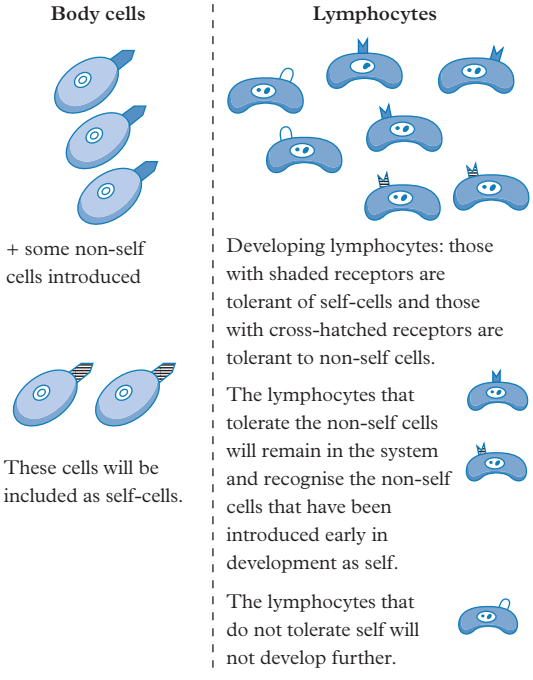


FIGURE 5 The development of immunological tolerance

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Diseases of the immune system

autoimmune disease
a disease in which the body produces antibodies that attack its own tissues

haemolytic anaemia
a form of anaemia due to haemolysis, the abnormal breaking down of red blood cells

Autoimmune disease occurs if an organism loses its ability to distinguish "self" from "non-self". As a result, the individual's immune system manufactures antibodies against certain of its own cells. Cells of the blood, liver, kidneys, endocrine glands and stomach lining are most susceptible. Some autoimmune diseases can be treated with immune-suppressive drugs to prevent destruction of healthy cells. These drugs are similar to those used in grafting when a tissue or organ comes from another individual.

Haemolytic anaemia occurs when antibodies are formed against the individual's own red blood cells. The red blood cells break down after only a few days in circulation instead of the normal 100 to 120 days. The body cannot produce enough red blood cells to compensate for the large number being broken down. This results in a much depleted oxygen supply to the cells.

Interferons

interferon
a small protein- and glycoprotein-signalling molecule produced by lymphocytes in response to infection and other biological stimuli

Many animals, including humans, produce a group of substances in response to viral infections. These small protein molecules, collectively termed **interferons**, prohibit further increase in viral numbers. Interferon prevents viral DNA instructing the host cell to produce more virus particles. Each species produces a specific interferon. Unlike other proteins, interferons are resistant to excessive heat and acidity.

Check your learning 12.6

Check your learning 12.6: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** how memory B-cells or memory T-cells are formed. (4 marks)
2 **Describe** two ways in which a person can become immune to a pathogen. (2 marks)
3 **Describe** what a vaccine is, using an example. (2 marks)

Analytical processes

4 **Compare** naturally acquired and artificially acquired immunity. (2 marks)

Knowledge utilisation

5 Travellers to Africa are given immunoglobulin injections against hepatitis A infection. **Deduce** the type of immunity that has been conferred. (1 mark)

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Lesson 12.7
Plant immune responses

Key ideas

- → Plants are subject to pathogenic attack by viroids, viruses, bacteria, fungi, oomycetes, slime moulds, roundworms and parasitic plants.
- → Plant physical defences against pathogens include bark and waxy cuticles.
- → If pathogens breach a plant's physical barriers, the plant can respond with secondary metabolites, which are often toxic compounds that may harm the pathogen.
- → Plant chemical defences again pathogens include defensins and toxins.

Plant pathogens

Learning intentions and success criteria

Like animals, plants can be infected with pathogens. All humans depend, either directly or indirectly, on plants for food. Plants also provide many non-food products such as wood, dyes, textiles, medicines, cosmetics, soaps and industrial chemicals. Pathogenic infections of plants therefore directly affect the human population. The main plant pathogens are **viroids** (RNA molecules without a protein coat), viruses, bacteria, fungi, fungus-like oomycetes, protozoa, nematodes (roundworms) and parasitic plants. **Ectoparasites**, such as insects and mites, affect plant growth by eating the tissues. This may make the plant more susceptible to pathogen entry through wounds. Some ectoparasites are vectors for pathogens.

viroid
an RNA molecule without a protein coat

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)



FIGURE 1 A banana plant with bunchy top disease



FIGURE 2 Panama disease in the stem of a banana plant

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In Australia, diseases of bananas have resulted in financial loss to growers and food shortage for consumers. Bunchy top is a viral infection that attacks conducting tissue in newly emerging leaves in banana plants in south-east Queensland and northern New South Wales. It results in short, narrow leaves that stand more upright than normal. A sap-sucking aphid is the vector for the virus. All banana plants in the area have to be destroyed to prevent further spread.

Bananas can also be affected by Panama disease, which is caused by a fungus (*Fusarium* sp. TR4 variety) and causes wilting of the plant by blocking water-conducting vessels. This disease destroyed a large proportion of commercial Cavendish banana crops in the Northern Territory in 1997 and in a plantation in Tully, North Queensland, in 2015. Because the fungus can remain in the soil for decades, the plants must be destroyed and the property quarantined, to prevent soil movement to other properties.

Two types of oomycetes also affect Australian crops. *Phytophthora cinnamomi* causes die-back in avocadoes and eucalypts (particularly the jarrah forests of Western Australia) as well as affecting flowering rhododendrons, azaleas and camellias. *Phytophthora citrophthora* causes collar rot in a variety of fruit trees, resulting in cracking and oozing of sap from the bark at the base of the trunk.

TABLE 1 Some additional plant pathogens and their effects

Pathogen	Plant affected and symptoms
Viroids	Potatoes – spindle-tuber disease
	Tomatoes – twisted leaves, stunted growth
Viruses	Large number of species – stunted growth
Tobacco mosaic virus	Members of the melon family – distorted fruit, mosaic leaf pattern
Squash mosaic virus	Rice plants – mottled and stunted leaf growth
Rice mosaic virus	
Bacteria	More prevalent in tropics and subtropics
Erwinia	Soft rot
Agrobacterium	Stone fruit – tumours (on stems)
Pseudomonas syringae	Gladioli bulbs – scabs
	Tomatoes – reduced fruit production
Fungi	A large range cause black spot on roses, gerberas and strawberries, grey mould on flowering annuals, dollar spot in lawns, downy mildew and powdery mildew on leaves.
Thielaviopsis	Cancer root, black root rot
Sclerotmia sclerotiorum	Cotton rot
Claviceps purpurea	Dutch elm disease
Urstilago	Smut
Puccinia	Rusts on cereals and grasses
Armillaria	Ringbark the roots of trees
Slime moulds	Cabbages – club root
Plasmodiophora	Potatoes – powdery scab
Spongospora	
Nematodes (roundworms)	Affect roots (e.g. tomato) and bulbs (e.g. daffodil)
Globodera	Potato cyst
Root knot	Affects uptake of water and nutrients for normal growth in a wide variety of plants
Parasitic plants	Compete with the host plant for nutrients
Mistletoe	Extract nutrients from the host plant
Dodder	Transmit viruses

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Plant defences against pathogens

Plants have a range of innate mechanisms to inhibit entry, detect invading organisms and stop them before they cause extensive damage. Most plant pathogens are host-specific or only infect a related group of plants. For example, the family Solanaceae includes tobacco, potato and tomato plants, all of which can be infected by the tobacco mosaic virus. Other groups of plants are not susceptible to this virus. Some pathogens have evolved mechanisms to overcome or avoid the plant's defences. Plant defence mechanisms may be physical, such as barriers and leaf structure, or chemical, such as production of defensins and toxins.

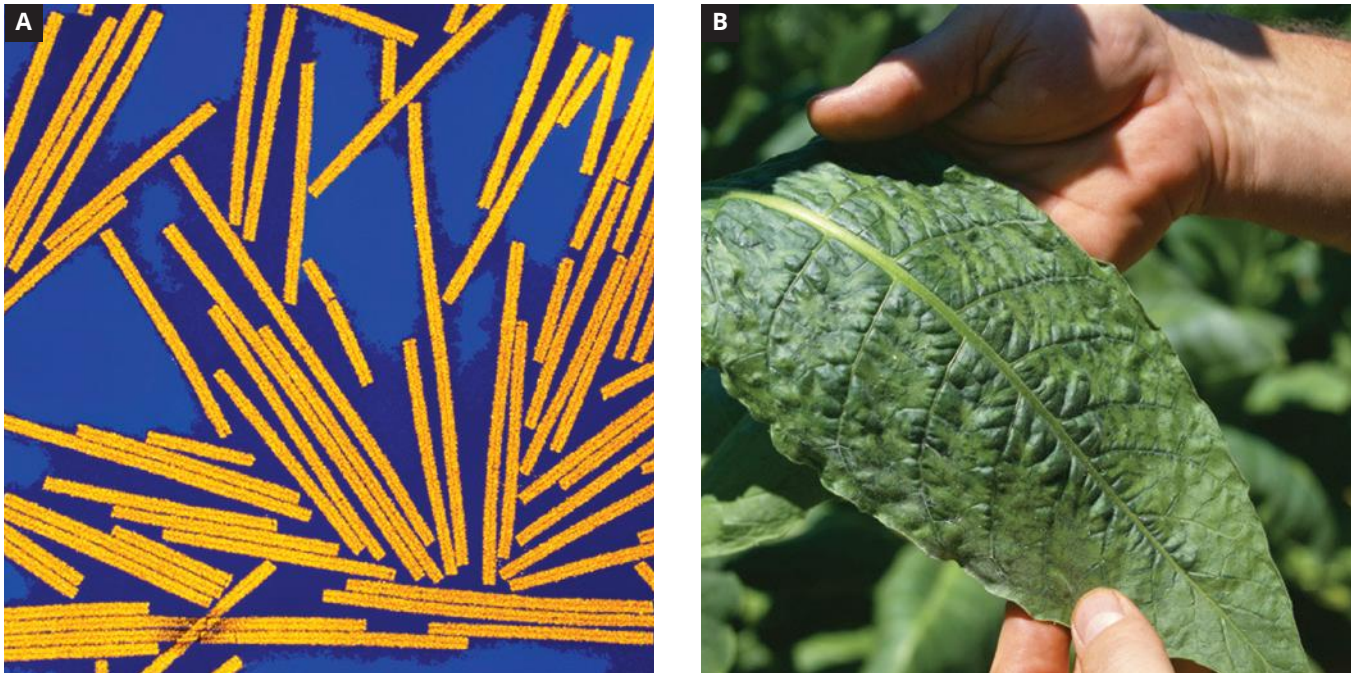


FIGURE 3 Tobacco mosaic virus: (A) virus particles, and (B) effect on the leaf. This virus was the first to be identified (1930), although its effects were first noticed in tobacco crops in the 1800s. The virus affects over 350 species, causing stunting, mosaic pattern of light and dark green (or yellow and green), with yellow streaking or spotting on the leaves and malformation of leaves or growing points.

Physical defence strategies

Many plants have impenetrable barriers, such as bark, waxy cuticles and cell walls, which are resistant to many pathogens, although some pathogens can infect young leaves that have thin cuticles. Because plants can be attacked by other organisms, such as insect pests and herbivores, many have leaf hairs (often containing chemicals) to defend themselves. Others have thorns (modified branches), spines (modified leaves) or prickles (outgrowths of the epidermis) to protect against grazing animals. These features also act as barriers to pathogens. Some plants have a thick waxy cuticle on their leaves, which hang vertically. This prevents the formation of a moisture film on the leaf surface. Dry surfaces inhibit infection by bacteria, fungi and nematodes, as these organisms need water to survive while they adhere to the cell's surface. Vertical surfaces, however, are more prone to windborne pathogens.

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FIGURE 4 (A) Bark and (B) waxy leaves that hang down are two physical barriers that help protect plants against infection by pathogens.

Stomata are natural openings in plants that are potential entry points for pathogens and their vectors. Stomatal size relative to the size of the pathogen may be important. For example, mandarins are resistant to citrus cancer because their stomata are too small for the causative agent to enter.

Chemical defence strategies

plant defensin
a protein produced by a plant to inhibit development of fungi, bacteria and viruses

Certain plants produce **plant defensins**. These are small proteins that inhibit the development of fungi, bacteria and viruses. Some plant defensins accumulate during normal development, while others are induced by a plant wound. For example, MsDef1 is a plant defensin produced by alfalfa (Figure 5). It protects the plant against several fungal pathogens by destabilising the fungal cell membranes, causing leakage of contents and eventual cell death.

toxin
a chemical compound produced by plants to protect against herbivores and pathogens

Some plants also produce **toxins**, which are chemical compounds that deter or fight against herbivores and pathogens. There are many types of plant toxins, and each toxin acts in a specific way. It can interfere with the metabolic processes of pathogens or herbivores by interfering with enzyme action, breaking down cell membranes, disrupting neurotransmission or producing other toxic effects. For example, nicotine is a neurotoxin produced by tobacco plants (Figure 6). Nicotine is extremely toxic to herbivorous species; when consumed, it disrupts the nervous system functioning of insects and herbivores, causing muscle spasms and overstimulation of neurons.



FIGURE 5 Alfalfa produces the plant defensin MsDef1 to protect against fungal pathogens.

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FIGURE 6 Tobacco plants produce the toxin nicotine, which is neurotoxic to many herbivorous species.

Another example of a plant toxin is a group of chemicals called saponins, which are produced by a range of plant species including peas, soybeans, spinach, clematis and quinoa (Figure 7). Saponins bind to cholesterols in the plasma membranes of pathogenic species and cause the cells to lose their structural integrity and undergo lysis. Saponins can also give plants a bitter taste and cause digestive discomfort to herbivores, which helps to deter herbivore species from consuming the plant.

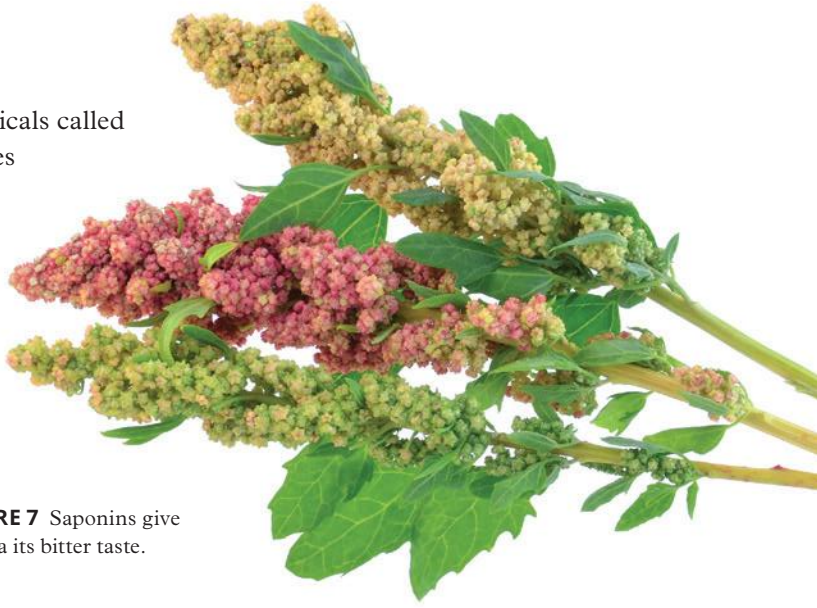


FIGURE 7 Saponins give quinoa its bitter taste.

Check your learning 12.7

Check your learning 12.7: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** why diseases in plants can have a significant impact on human survival. (2 marks)

2 **Identify** and **describe** a plant pathogen. Include the method of infection and the effects of the disease. (4 marks)

3 **Identify** two plant diseases that are of economic significance to humans. For each disease, name the pathogen that causes the disease, and how the disease affects the plant. (6 marks)

4 **Describe** how the physical defence strategies of barriers and leaf structure defend plants against a large variety of pathogens. (2 marks)

5 **Describe** how the production of toxins protects a plant from infection. (2 marks)

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MODULE 12

Lesson 12.8
Review: Disease

Summary

12.1
- Disease is any physiological abnormality or significant disruption in the "normal" health of an organism.
- Non-infectious diseases cannot be spread from an affected individual to another individual.
- Infectious diseases can be spread from an infected individual to another individual.
- Pathogens are biological agents that spread disease.
- Parasites are cellular organisms that obtain nutrients from a host and rely on a host for survival.
- An endemic disease is one that exists in a population at regular low levels. An epidemic occurs when a larger than normal number of individuals in a particular locality are infected by a disease at a particular time. If the disease spreads to other countries, it is termed a pandemic.

12.2
- Viruses are non-living particles composed of nucleic acid covered in a protein coat.
- When a virus invades a cell, it causes the host cell to produce more virus particles.
- Many human diseases are caused by viruses, with influenza being the most virulent. Many viruses are able to cross hosts from animals to humans.
- Some diseases result from abnormal prion proteins, which cause normal proteins to become dysfunctional.

12.3
- Pathogens may be microbes (bacteria, protists or fungi) or macroorganisms (e.g. flukes, tapeworms or roundworms).
- Many microbes and macroorganisms are pathogens of humans, their domesticated animals and cultivated plants. Some pathogens are transmitted via the air, in contaminated food or water, or by a vector.
- Protists are animal-like, unicellular eukaryotes, and some cause fatal diseases such as malaria and African sleeping sickness.
- Most macroscopic endoparasites of humans are flatworms (e.g. tapeworms) or roundworms (hookworm, *Ascaris*). Untreated, diseases from these worms can be fatal.

12.4
- Pathogenesis is the series of steps by which a pathogen causes disease in a host.
- The virulence of a pathogen refers to its ability to cause damage to its host.
- Virulence factors are molecules that can contribute to the survival of a pathogen, and therefore its pathogenesis. They include adherence factors, invasion factors, capsules and toxins.

12.5
- There are three lines of immune defence: the innate immune response, the inflammatory response and complement system, and the adaptive immune response.
- The innate immune response is the system of non-specific defence mechanisms including physical barriers such as skin, chemicals in the blood, and white blood cells that attack foreign cells in the body.
- The inflammatory response is the body's response to an injurious agent. It is characterised by swelling, pain and/or heat.
- The complement system is a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter.
- The adaptive immune response is a specific immune response that is "learned" when a person's immune system encounters foreign "invaders" and recognises non-self substances (antigens) – the response generates special chemicals (antibodies) to neutralise a specific pathogen.

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12.6
- Immunity is the ability to resist disease. It can be acquired actively or passively.
- Natural active immunity can occur when memory T-lymphocytes and B-lymphocytes have formed following infection.
- Artificial active immunity can be achieved by vaccination of inactivated antigens.
- Passive immunity results from the intake of antibodies. They be acquired naturally, by placental diffusion or from breast milk when a baby feeds (natural), or acquired artificially by an injection of antibodies from a previously infected individual (artificial).
- Immunological tolerance is the ability of some organisms to tolerate cells other than their own, provided they are introduced to the organism during the early stages of its development or in supervised, minute amounts at later stages.

12.7
- Plants are subject to pathogenic attack by viroids, viruses, bacteria, fungi, oomycetes, slime moulds, roundworms and parasitic plants.
- Plant physical defences against pathogens include bark and waxy cuticles.
- If pathogens breach a plant's barriers, the plant can respond with secondary metabolites, which are often toxic compounds that may harm the pathogen.
- Plant chemical defences again pathogens include defensins and toxins.

Review questions 12.8A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Phagocytes are best described as
- **A** complex chemical compounds consisting of molecules with large numbers of atoms.
- **B** arrangements of protein molecules with digestive properties similar to those of enzymes.
- **C** living cells that reproduce rapidly at points of bacterial invasion.
- **D** living cells able to ingest bacteria and cell pieces.

2 Which one of the following statements about antibodies is correct?
- **A** They are molecules on the outer surface of a pathogen that can initiate an immune response.
- **B** They combine with phagocytes to form cells that are resistant to invading particles.
- **C** They are produced in response to the stimulus of bacteria and viruses entering the body.
- **D** They are produced by antigens present in the body.

3 A non-infectious disease may be caused by all of the following *except*
- **A** an inherited condition.
- **B** drug abuse.
- **C** prions.
- **D** malnutrition.

4 Infectious diseases may be
- **A** caused by overnutrition or undernutrition.
- **B** contagious or non-contagious.
- **C** a dysfunction of the body due to environmental pollution.
- **D** a result of poor lifestyle choices.

5 The virulence of a pathogen refers to
- **A** its ability to infect a range of different organisms.
- **B** the independence of its ability to resist the host's immune system.
- **C** its ability to cause damage to its host's tissues
- **D** the variety of toxins all pathogens can produce.

6 Viruses
- **A** are molecules of protein surrounding a nucleic acid core.
- **B** can be considered living because they can reproduce.
- **C** can infect other organisms but only cause disease in humans.
- **D** can only be transmitted through direct contact from an infected to a non-infected individual.

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7 Which of the following is correct?

	Barrier	Method of defence
A	Skin	Oil and sweat glands produce antiviral substances.
B	Mucous membranes	The cells produce substances that inhibit the growth of pathogens.
C	Skin	The acidity of skin makes it inhospitable to all microbes.
D	Mucous membranes	All secrete mucus to defend against pathogens.

8 The difference between the innate and adaptive immune systems is that the innate immune system
- **A** needs the stimulation of a pathogen to bring about a response.
- **B** is always working and does not require any special preparation to prevent infection.
- **C** involves T-lymphocytes that engulf and destroy pathogens.
- **D** is stimulated by the complement system of proteins.

9 An example of natural passive immunity is
- **A** diffusion of antibodies across the placenta from foetus to mother.
- **B** diffusion of antibodies across the placenta from mother to foetus.
- **C** injection of sterile, dead pathogens.
- **D** formation of memory cells to an antigen.

10 The blood types of humans are classified according to two blood group systems, the ABO system and the Rhesus (Rh) system. These groups are identified by the presence or absence of antibodies in the plasma, and antigens on the surface of red blood cells. For example, a person with B type blood has B type antigen on the surface of their red blood cells, and has anti-A antibodies, as their immune system has never been exposed to A type antigen.
The table gives the proportion of Australians who have each of the blood groups.

Blood group	Percentage of Australian population (%)
A+	31
A–	7
B+	8
B–	2
AB+	2
AB–	1
O+	40
O–	9

Which antibodies would be present in the blood of people in the Australian population with the rarest blood group?
- **A** anti-A antibodies only
- **B** anti-B antibodies only
- **C** anti-A and anti-B antibodies
- **D** no antibodies

11 Mercury poisoning can cause paralysis and brain damage. What type of illness is this?
- **A** infectious disease
- **B** environmental exposure
- **C** genetic disease
- **D** metabolic disease

12 *Bordetella pertussis* is a bacterial pathogen that causes whooping cough. *B. pertussis* produces a protein that is excreted by the cell. The protein disrupts the host's immune response by inhibiting the actions of infected cells that would attract and recruit immune cells in defence. Determine the type of protein.
- **A** adhesion
- **B** invasion factor
- **C** endotoxin
- **D** exotoxin

13 Identify which of the following is *not* a type of antigen used in vaccines.
- **A** sterile bacterial exotoxins
- **B** dead microorganisms
- **C** living, fully pathogenic microorganisms
- **D** living microorganisms that have been altered to remove pathogenicity

14 A patient visits their doctor complaining of being short of breath and lacking in energy. The doctor notes that the patient is quite pale. Which nutrient is the patient likely to be deficient in?
- **A** iron
- **B** sodium
- **C** phosphorus
- **D** carbohydrate

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Review questions 12.8B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

15 **Define** the term "antigen". (1 mark)

16 **Describe** which structural features of a tapeworm enable it to survive in its host. (3 marks)

17 **Explain** how invasion factors increase the virulence of a pathogen. (6 marks)

18 **Explain** why it is useful for B-lymphocytes to be highly variable, but essential that helper T-lymphocytes do not change. (4 marks)

19 **Explain** why an injection of ready-made antibodies is called "passive" immunity. (2 marks)

20 **Explain** the importance of host cell self-recognition, using an example of an autoimmune disease to support your response. (4 marks)

21 **Explain** the cell-mediated response to an infectious disease. (5 marks)

22 **Describe** the chemical defence strategies of the immune response in plants. (4 marks)

23 Some vaccines provide long-term immunity, while others are only effective for a short period.

Explain why immunity may not last for the life of an individual after infection or vaccination. (3 marks)

Analytical processes

24 **Compare** active and passive immunity. (2 marks)

Knowledge utilisation

25 Many women suffer from high blood pressure during pregnancy. Using the definition of disease, **determine** whether this increase in blood pressure would be considered a disease compared to high blood pressure in non-pregnant people. (2 marks)

26 Scientists wanted to test the hypothesis that a given B-lymphocyte makes only one specific antibody against an antigen. They injected an animal simultaneously with two different antigens. After waiting for the animal's immune system to respond, they took a sample of blood. From the blood, they isolated single plasma cells and tested whether each one produced antibodies to one or both of the antigens.

Predict the results you would expect for the B-lymphocytes based on your knowledge of the immune system, giving reasons to support your predictions. (4 marks)

27 The Hendra virus was discovered in 1994 after the death of 13 horses and a trainer in Queensland. Horses become infected after coming into contact with the bodily fluids of flying foxes. Humans, such as trainers and veterinarians, are most at risk when they come into contact with a horse's bodily fluids.

a **Determine** the primary host of the Hendra virus. (1 mark)

b **Determine** the secondary host of the Hendra virus. (1 mark)

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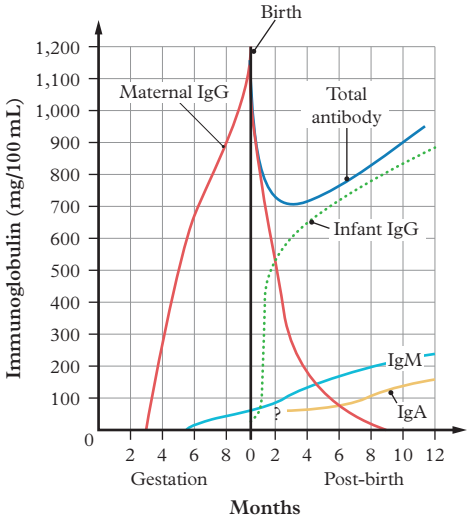
Data drill

Analysing antibody data

Prior to birth, antibodies in the mother are passed to the infant via the placenta. After birth, the infant starts making their own antibodies, while also receiving maternal antibodies from breast milk, which help protect the infant until their immune defences are developed. The graph shows the levels of different forms of antibodies (Ig) in an infant, from three months prior to birth to 18 months old.

The table shows some of the characteristics of the different types of antibodies in body fluids.

	Type of antibody				
	IgG	IgA	IgM	IgD	IgD
Ability to cross placenta	Yes	No	No	No	No
Present in saliva and tears	No	Yes	No	No	No
Present in milk	Yes	Yes	No	No	No
Active against viruses	Yes	Yes	Some	No	No
Active against some bacteria	Yes	Yes	Yes	No	No
Involved in allergy reactions	No	No	No	No	Yes



Apply understanding

1 **Identify** the age when maternal IgG is no longer detectable in the infant. (1 mark)

2 **Determine** when the newborn infant has the greatest chance of infection by bacteria, supporting your response with information from the graph. (2 marks)

Analyse data

3 With reference to the graph, **describe** the changes in how immunity is acquired, from prior to birth to 12 months after birth. (4 marks)

Interpret evidence

4 Information about the levels of IgA has been deleted from the graph until 2 months after the birth. **Predict** when IgA would first be detectable in the infant, giving reasons to support your response. (4 marks)

Module 12 checklist: Disease

Quizlet: Revise key terms online to test your understanding

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MODULE 13

Epidemiology

Introduction

To control or prevent disease, the causative agent for the disease must first be identified. Identification of disease is achieved through epidemiological studies. The method used to identify the pathogen causing an infectious disease varies according to the organic particles or organisms causing it. Monitoring a disease at the local, national and global levels is important in determining vector control measures, predicting the spread of the disease and establishing vaccination programs. Various means are available to control disease within a community. Quarantine and border control are significant in preventing the entry and spread of disease within and between countries. Personal hygiene and contact tracing are also important control measures. Treatment of disease is mainly by chemical means, with most active ingredients derived from plants or animals (natural or synthetic). Antibiotics are produced by various species of fungi and bacteria, and are effective against bacterial infections only. Misuse of antibiotics has resulted in some strains of bacteria becoming resistant to them.

Prior knowledge

Prior knowledge quiz Check your understanding of concepts related to epidemiology before you start.

Subject matter

Science understanding

- → Interpret data from an experiment investigating the effect of an antimicrobial agent on the growth of a microorganism.
- → Describe modes of disease transmission, including direct contact, contact with body fluids, contaminated food, contaminated water and disease-specific vectors.
- → Explain how the following factors affect the spread of disease
  - persistence of pathogens within host
  - transmission mechanism
  - proportion of the population that are immune or have been immunised
  - mobility of individuals in the affected population.

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→ Explain how personal hygiene measures, contact tracing and quarantine are used to control the spread of disease.
→ Analyse data to
  – predict outbreaks
  – determine the source of an outbreak
  – infer the mode of disease transmission
  – determine the effectiveness of different strategies in controlling the spread of disease.

Science as a human endeavour

→ Appreciate that
  – for thousands of years, First Nations peoples' knowledges of natural antiseptics and bush medicines have been used to prevent and treat infections
  – scientific advancement and the development of complex models often requires contribution from multiple individuals across a range of disciplines
  – Australia has an advantage over many other countries because its borders are easier to protect against the influx of disease-carrying materials and organisms. However, as global trade and air travel become more prevalent, it is increasingly important for Australia to protect its agriculture industry and environment through quarantine measures. These include surveillance, monitoring, examination and clearance activities and conform to policies and protocols that are based on scientific data and risk analysis
  – mass vaccination programs are more successful when informed by disease outbreak models

Science inquiry

→ Investigate
  – the effect of an antimicrobial agent on the growth of a microorganism (via the measurement of zones of inhibition) in either a laboratory or virtual context
  – how the transmission of disease is facilitated by regional and global movement
  – the effectiveness of health programs for the prevention and eradication of infectious diseases, e.g. smallpox, influenza, polio, smallpox, Ebola, cholera, malaria.
→ Explore
  – how First Nations peoples' knowledges of natural antiseptics and bush medicines are used to prevent and treat infections.

Source: *Biology 2025 v1.1 General Senior Syllabus* © State of Queensland (QCAA) 2024

Practicals

oxforddigital **This lesson is available on Oxford Digital.**

Lesson 13.3 Testing the effect of an antimicrobial agent on the growth of a microbial organism

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Lesson 13.1
Transmission of disease

Key ideas

- → Epidemiology is the scientific study of factors that determine and influence the frequency and distribution of disease, injury and other health-related events.
- → The transmission of disease can occur through direct or indirect contact with the source of infection.
- → Direct contact includes the transmission of a pathogen through physical touch, contact with infected body fluids and the spread of airborne droplets.
- → Indirect contact includes the transmission of a pathogen through consuming contaminated food or contaminated water, and by infection via a vector.
- → The spread of disease is also influenced by factors such as the persistence of the pathogen within the host, the transmission mechanism, the proportion of the population who are immune or have been immunised, and the mobility of individuals in the affected population.

Learning intentions and success criteria

Epidemiology

Epidemiology is the scientific study of the factors that determine and influence the frequency and distribution of disease, injury and other health-related events in a defined human population. The purpose of epidemiology is to establish programs to prevent and control the development and spread of these health-related events. Epidemiology can be used to evaluate health services and preventative programs or to identify individuals who are at high risk of contracting disease. In this lesson you will look at modes of disease transmission and factors that affect the spread of disease.

epidemiology
the study and analysis of the distribution (who, when, where) and determinants of health and disease conditions in defined populations

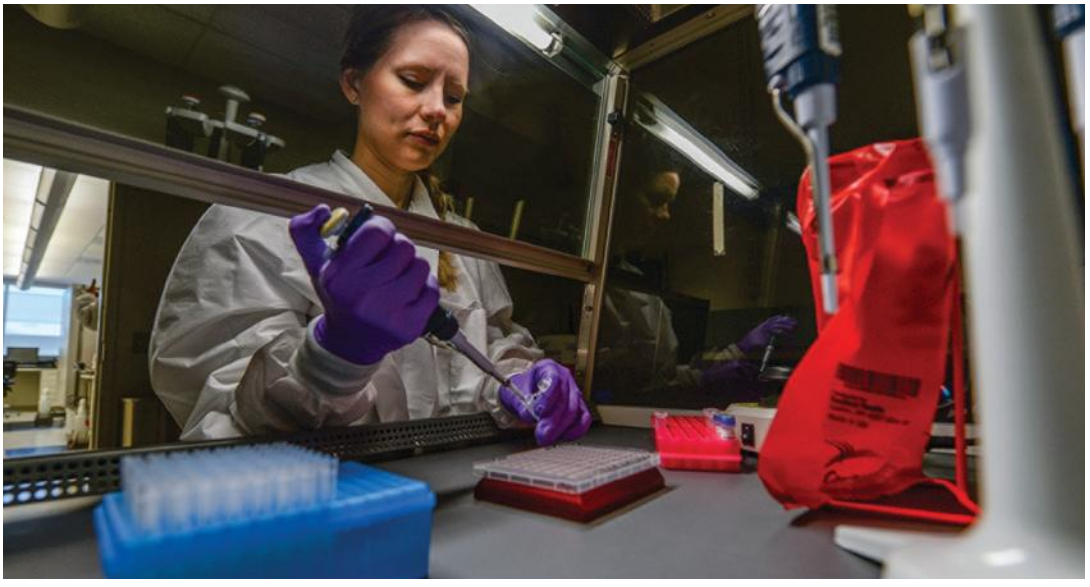


FIGURE 1 Epidemiologists study the distribution and causes of health-related states or events (including disease), to develop ways of controlling these problems.

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Modes of disease transmission

pathogen
a biological agent that causes disease or illness

There is more than one mode of transmission of **pathogens** between individuals. Disease-causing pathogens can be spread directly or indirectly from the infection source to healthy individuals.

Direct contact

direct contact
spread of infectious disease through physically touching, exchanging bodily fluids with, or inhaling droplets from, an infected individual

droplet spread
the movement of small amounts of fluid (e.g. saliva) containing a pathogen being spread to another individual through coughing, sneezing or talking

Direct contact is the transmission of a pathogen that occurs when an infected person comes into close contact with another susceptible person, allowing the pathogen to transfer. Direct contact can occur through:

- physical touch – for example, shaking hands, hugging, kissing, sexual intercourse
- contact with infected body fluids – such as blood, saliva, faeces, sweat, tears, breast milk, semen, vaginal fluids
- **droplet spread**.

An example of transmission through direct contact is cold sores, which are caused by herpes simplex virus 1 (HSV-1). Cold sores can spread from an infected person to another person through physical contact with a cold sore blister or through the exchange of saliva containing the virus. Kissing is a common means of transferring the HSV-1 virus between individuals. It is estimated that 67% of the world's population are affected by HSV-1. Other pathogens can be passed from mother to child via the placenta or the vaginal canal during birth. Pathogens such as the influenza virus can pass directly from an infected person into small water droplets in the air, which can then be inhaled by an uninfected person if they are in close proximity.

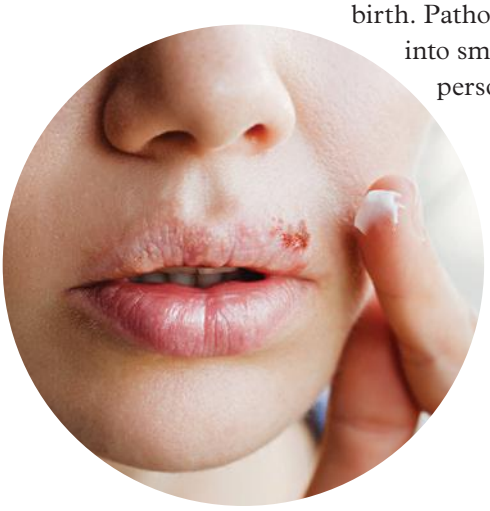


FIGURE 2 HSV-1 is often transmitted through direct contact.

Indirect contact

indirect contact
a means by which infectious disease can spread without direct contact with the infected person, e.g. airborne droplets, contaminated objects, soil, food or water, or by animal or vector transmission

Infections can also be spread through **indirect contact**, where the pathogen can be spread to a healthy individual without them coming into direct contact with an infected person. Many pathogens can survive in air, soil and other substrates for long periods and may cause disease once transferred to a healthy individual. Forms of indirect transmission of disease include:

- consuming contaminated water
- consuming contaminated food
- disease-specific vectors.

Consuming contaminated water

Water contaminated with bacteria (e.g. *Vibrio cholerae*, which causes cholera) can infect anyone who drinks that water. Many diseases are spread by water, through consumption of contaminated water or via a vector. In Australia, clean drinking water is often taken for granted. All major towns and cities have strict treatment and quality control of household water supplies. This is not the case in many parts of the world, particularly in developing countries, where people may need to rely on local streams or wells for water. Contamination of these waters by human and domestic animal wastes frequently occurs. Moving water can swiftly transport microorganisms over large distances. Even in places where there is sterilised, reticulated (piped) water, defects in pipes, flooding and other factors can result in contamination of water supplies.

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Cholera, an intestinal disease common in tropical Africa and Asia, is caused by a bacterium that enters a person's body in drinking water or in contaminated food. The bacterium produces toxins that cause diarrhoea and vomiting. Even after all food contents have been voided from the person's body, there is constant elimination of digestive juices. The fluid to produce these juices is withdrawn from other body tissues. Death is a result of dehydration and loss of potassium. In many places where cholera is endemic, human faeces are collected and used as manure for growing vegetables. Bacteria from an infected person are rapidly transferred via the vegetables to other people. Flies that move between the house and garden can transfer bacteria from plants to food. In other areas, toilets are built over the banks of streams or rivers and the flowing water carries the wastes away. The cholera bacteria reproduce in these warm waters, and water used downstream for drinking or watering vegetables can be contaminated, resulting in further infections.



FIGURE 3 In many parts of the world, people do not have access to clean drinking water.

Consuming contaminated food

Like water, food that is contaminated with a pathogen may cause disease in anyone who consumes the food. Food poisoning often occurs because food is kept too long or stored incorrectly, allowing pathogenic species to grow. Some decomposing bacteria in food may release toxins, which then affect the person who eats the spoilt food. Some pathogens can be passed from animal to person when the person handles faeces from the animal, if some faeces are transferred to the person's hands and then to food during food preparation. Contagious diseases can be unwittingly transferred from people preparing food, as they can be carriers of disease without displaying any symptoms. Strict laws govern the cleanliness of commercial food preparation areas. All people working in the industry must wear special protective clothing and disposable gloves.



FIGURE 4 Poor kitchen hygiene can result in food poisoning and increase the populations of vectors of disease (e.g. cockroaches, flies, rats).

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Disease-specific vectors

Other diseases are spread through specific vectors. For example, *Aedes aegypti* mosquitoes carry Dengue virus, while *Anopheles* mosquitoes carry the *Plasmodium* that causes malaria. Occasionally, pathogens that are normally only transmitted from animal to animal are transferred to humans – this is termed **zoonosis**. Some zoonotic pathogens are spread by **vector**s, especially those that consume blood. These types of vectors can play a major role in passing pathogens from one host to another.

zoonosis
an infectious disease that is transmitted from animals to humans



FIGURE 5 A mosquito is a vector organism because it can carry and transmit diseases to other organisms.

Factors affecting the spread of disease

The spread of disease (through direct or indirect contact) is also influenced by factors including the following:

- persistence of the pathogen within the host
- transmission mechanism
- proportion of the population who are immune or have been immunised
- mobility of individuals in the affected population.

Pathogen persistence within the host

pathogen persistence
a pathogen's ability to survive within a host organism after infection

Pathogen persistence describes the length of time and the conditions in which a pathogen can survive within a host. Pathogens with high pathogen persistence can survive for an extended time. This gives the pathogen more time to infect new cells within the host and increases the period during which an infected individual may transmit the pathogen to others. For example, once a person becomes infected with human immunodeficiency virus (HIV), they are infected for life. This means they are at risk of transmitting the disease to others who come into contact with their infected body fluid. Fortunately, treatments such as antiretroviral therapy (ART) are available to HIV-affected individuals and are effective in preventing the spread of HIV.



FIGURE 6 Antiretroviral therapy is an effective treatment in managing and reducing the transmission of HIV.

Pathogens with low pathogen persistence are unable to survive for long within a host. To survive, these pathogens must infect individuals rapidly. For example, norovirus infection is typically cleared from a host within three days. Despite its low persistence, norovirus brings on symptoms (vomiting and diarrhoea) quickly and is highly contagious. It can also survive in the environment and on surfaces for longer periods of time, allowing it to be transmitted through indirect contact.

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Transmission mechanism

Specific transmission mechanisms affect the rate at which disease spreads. Diseases that spread through direct contact tend to spread more slowly unless there is regular direct contact, of the specific type required, between infected and non-infected individuals. For example, genital herpes (HSV-2) is spread through skin-to-skin contact with an affected genital area (usually through sexual contact). The specific type of contact required for HSV-2 transmission limits its spread in a population.

Airborne pathogens tend to spread more easily, especially in crowded or dense areas. For example, diseases such as COVID-19, influenza and the common cold can survive in the air in droplets from infected people, and will often spread rapidly in a population. The rate of spread of a disease that is transmitted by vectors will vary depending on the vector population and how likely it is that the vector will infect hosts. For example, in Nigeria there are large populations of *Anopheles* mosquitoes, which are the vector for malaria. Nigeria has the highest incidence of malaria cases in the world. Because Australia is free of *Anopheles* mosquitoes, it is also free of endemic malaria.



FIGURE 7 Airborne pathogens tend to spread more easily, particularly in dense or crowded areas.

Proportion of the population that are immune or have been immunised

The spread of a disease is also influenced by the proportion of people in the population who are immune to the disease or have been immunised. There are always a few people in a population who are especially vulnerable to an infectious disease. These include individuals who are immunosuppressed (e.g. people with AIDS or transplanted tissue), very young children, the elderly, individuals who are unable to be vaccinated due to allergies, and individuals at high risk of severe complications if they become infected. These individuals must rely on the immunity of others around them to protect them from the disease. The greater the proportion of people in a population who are immune or immunised against a disease, the less likely it is that the disease will spread.

Herd immunity can help prevent the spread of disease. Herd immunity exists when a large enough percentage of the population is immune to an infection that the disease is limited in its ability to spread in that population. Herd immunity can be achieved through vaccination (Lesson 12.6). For example, most people in Australia receive the measles, mumps and rubella (MMR) vaccine by the age of two. This high rate of immunisation reduces the spread of measles in Australian populations, even among those who are unvaccinated. Depending on the type of disease, different rates of vaccination in the population are needed to achieve herd immunity. For example, to prevent the spread of smallpox, a vaccination rate of 80% would be effective. To prevent the spread of measles, 95% of the population needs to be vaccinated, because measles is more contagious than smallpox.

herd immunity a form of indirect protection from infectious disease that occurs when a large percentage of a population is immune to an infection, thereby providing a measure of protection for individuals who are not immune

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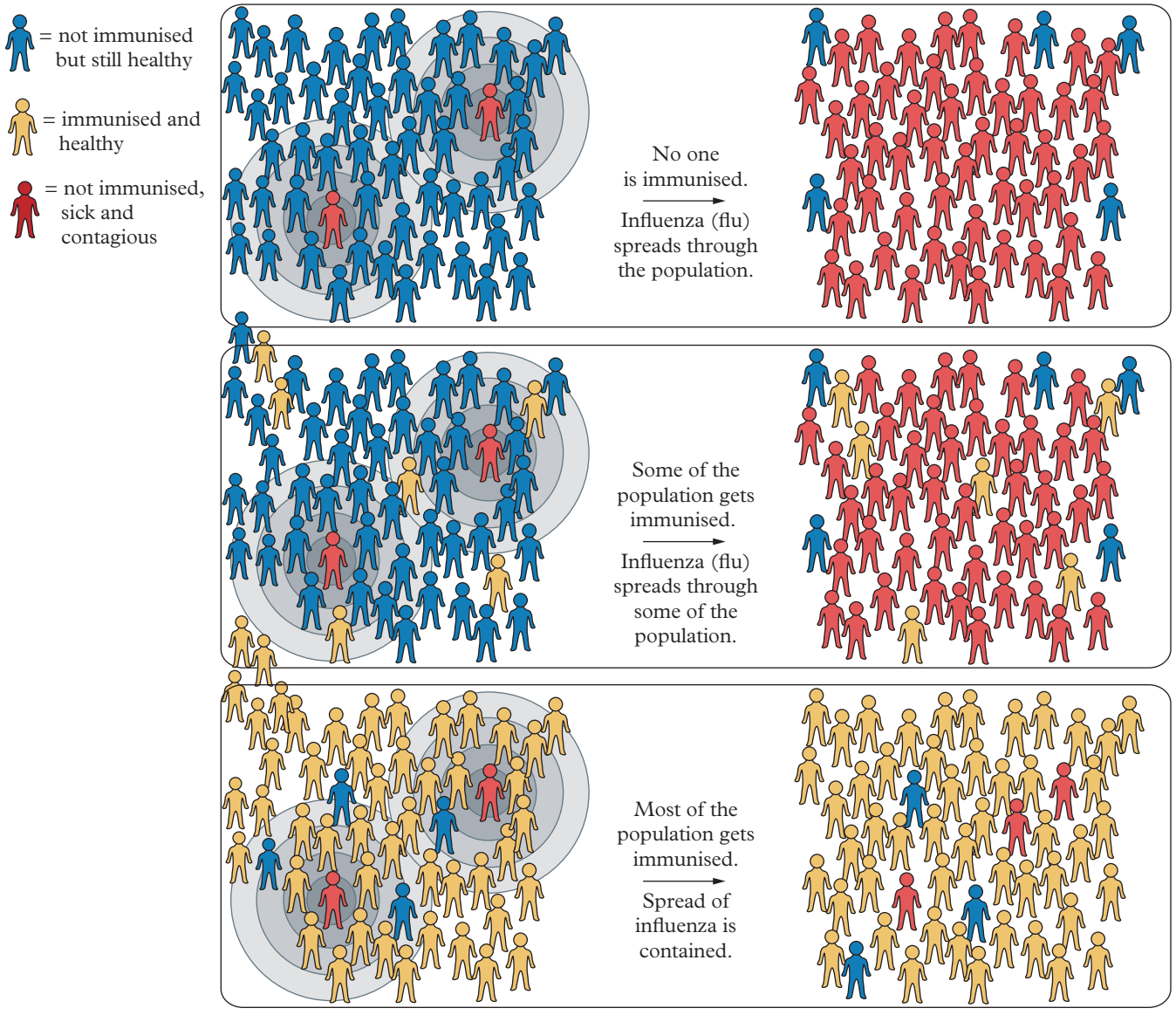


FIGURE 8 The greater the number of people in a population who are vaccinated against a disease, the less likely it is that the disease will spread.

Mobility of individuals in the affected population

mobility
the movement of people within and between populations

Mobility describes how frequently and far an individual will travel within and between different populations. The more mobile individuals are, the more likely they are to contract a disease or transmit a disease to their own or another population.

Patterns of human travel and trade of goods have changed dramatically over the last century. It was once unusual for people to move beyond their local area. There were, however, some significant trade routes (e.g. the Silk Road, and shipping between China and Europe in the fourteenth century). Diseases such as the plague were widely spread as a result of these trade movements (Figure 9).

Regional travel within and between areas of a country is now common for recreation and work. Tourists can return to their home countries and inadvertently bring back pathogens picked up from overseas. Large numbers of people travel overseas on business. Huge volumes of goods are transported between countries in large shipping containers, inadvertently carrying new vectors for disease.

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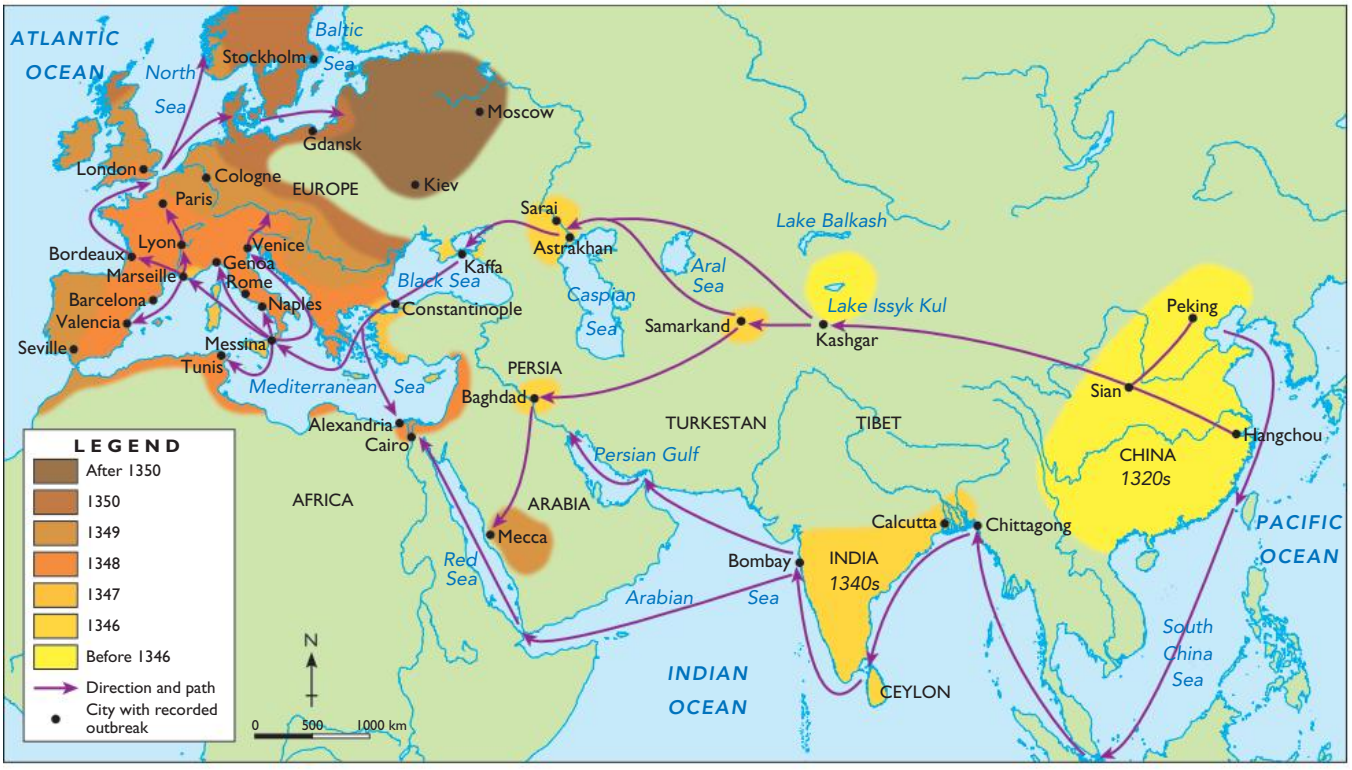


FIGURE 9 The fourteenth century land and sea routes that resulted in the spread of the plague from China to Europe

Air travel can play an important role in global outbreaks. For example, during the COVID-19 pandemic, COVID-19 was first localised to the Wuhan area of China. Once it spread rapidly through this population, individuals carrying COVID-19 travelled to other parts of world, spreading the disease globally.

The less mobile individuals are, the less likely they are to contract and spread disease. **Quarantine** involves the isolation and travel restriction of individuals who may have encountered or been infected by a disease. Quarantine measures help to reduce mobility, in order to limit the spread of disease in populations. You will learn more about quarantine in Lesson 13.2.

quarantine
strict isolation of an individual, imposed to prevent the spread of disease

Check your learning 13.1

Check your learning 13.1: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Define** the term "epidemiology". (1 mark)
2 **Describe** the modes of disease transmission. (6 marks)
3 Over the past 100 years, the spread of infectious diseases has increased dramatically and globally. **Explain** how mobility of vectors and infected individuals has contributed to this spread. (3 marks)
4 **Explain** how pathogen persistence can affect the spread of disease. (4 marks)
5 **Explain** the concept of herd immunity and how it affects the spread of disease. (4 marks)
6 **Explain** how a pathogen having multiple transmission mechanisms can affect the spread of disease. Use an example in your response. (4 marks)

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Analytical processes

7 **Distinguish** between direct and indirect contact. (1 mark)

8 **Determine** the mode of transmission in the examples below.

a A person contracts chickenpox after shaking hands with an infected individual. (1 mark)

b A person contracts salmonella after consuming chicken that was not cooked to the correct temperature. (1 mark)

c A person contracts malaria after being bitten by a mosquito carrying *Plasmodium*. (1 mark)

d A person contracts Epstein-Barr virus (EBV) after kissing and exchanging saliva with an infected individual. (1 mark)

e A person contracts cholera after drinking water collected from a stagnant pool. (1 mark)

Lesson 13.2
Controlling the spread of disease

Key ideas

- → Measures to control the spread of disease include personal hygiene measures, contact tracing and quarantine.
- → Good personal hygiene and rigid hygiene standards at food preparation outlets are significant deterrents to the spread of infectious disease.
- → Contact tracing involves identifying and providing advice to individuals infected with a disease and the contacts they may have spread the disease to.
- → Quarantine is the isolation of individuals infected with a disease; it can occur at a local, national or international level.
- → Treatments that may be administered to treat disease include plant-derived chemicals, antibiotics and chemicals produced by other organisms.

Learning intentions and success criteria

Personal hygiene measures

The spread of disease can be minimised by implementing prevention and control measures.

Personal hygiene is important in reducing the risk of contracting pathogens. People continually touch objects that have been previously touched by others or may harbour pathogens, such as doors and seats of public toilets, money, pets and taps. All have the potential to transfer pathogenic organisms. Examples of personal hygiene measures to limit the spread of disease are summarised in Table 1.

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TABLE 1 Examples of personal hygiene measures and how they help reduce the spread of disease.

Personal hygiene practice	How it reduces the spread of disease
Sneezing into elbow instead of hands	Limits droplets containing bacteria or viruses from being spread to others through the air or on hands.
Wearing a face mask when sick with a virus or during cold and flu season	Limits the spread of pathogens transferring into the air. Protects individuals from inhaling airborne pathogens.
Regular washing of hands with soap and water after using the toilet and before eating	Many microorganisms stick to small droplets of oils released by skin glands. Water alone will not remove these. Soap affects surface tension so the area of contact between oil and skin is reduced, and the oil and microorganisms can be washed away.
Correctly storing food and disposing of food that has gone bad	Both contagious and non-contagious diseases can result from contaminated food. Some decomposing bacteria in food release toxins, which then affect the person eating the spoilt food.
Cooking meat to the correct temperature	Heat generated in the cooking process can kill the larvae of tapeworms, flatworm parasites and other pathogens that can be passed on to humans from meats.
Food safety laws, including wearing special protective clothing and disposable gloves	Prevents the spread of pathogens from the surface of skin to food consumed.
Keeping kitchens and food preparation areas free from vermin or infestation	Vermin such as cockroaches, flies and rats can be disease vectors. Keeping homes/kitchens free of these can prevent the spread of disease.

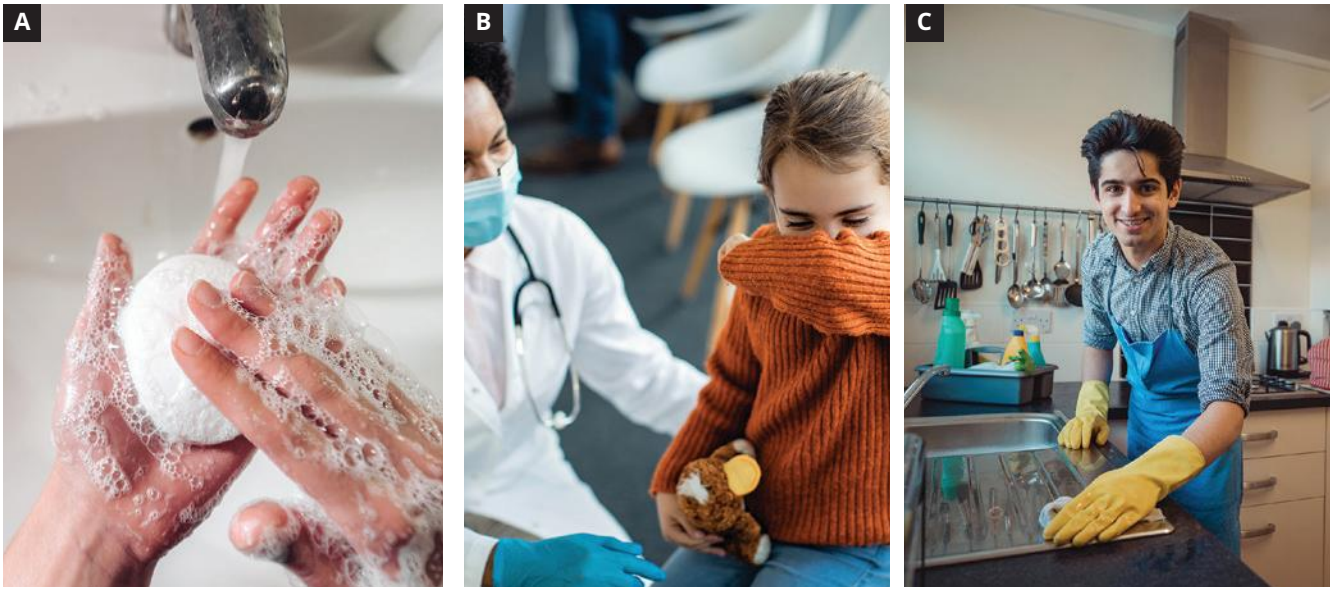


FIGURE 1 Personal hygiene measures to help reduce the spread of disease include (A) washing your hands with soap, (B) sneezing into your elbow instead of your hands and (C) keeping food preparation areas clean.

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Contact tracing

contact tracing
a process that identifies people who have been exposed to an infected person

Contact tracing is a public health strategy that involves identifying people who have come into contact with a person who is known to be infected by a disease. If a disease outbreak occurs, health officials attempt to trace all contacts of the original infected person. By identifying who is at risk of spreading an infectious disease and the areas they have travelled to, health officials can implement other restrictions to prevent further spread as well as predict where further infections may occur.

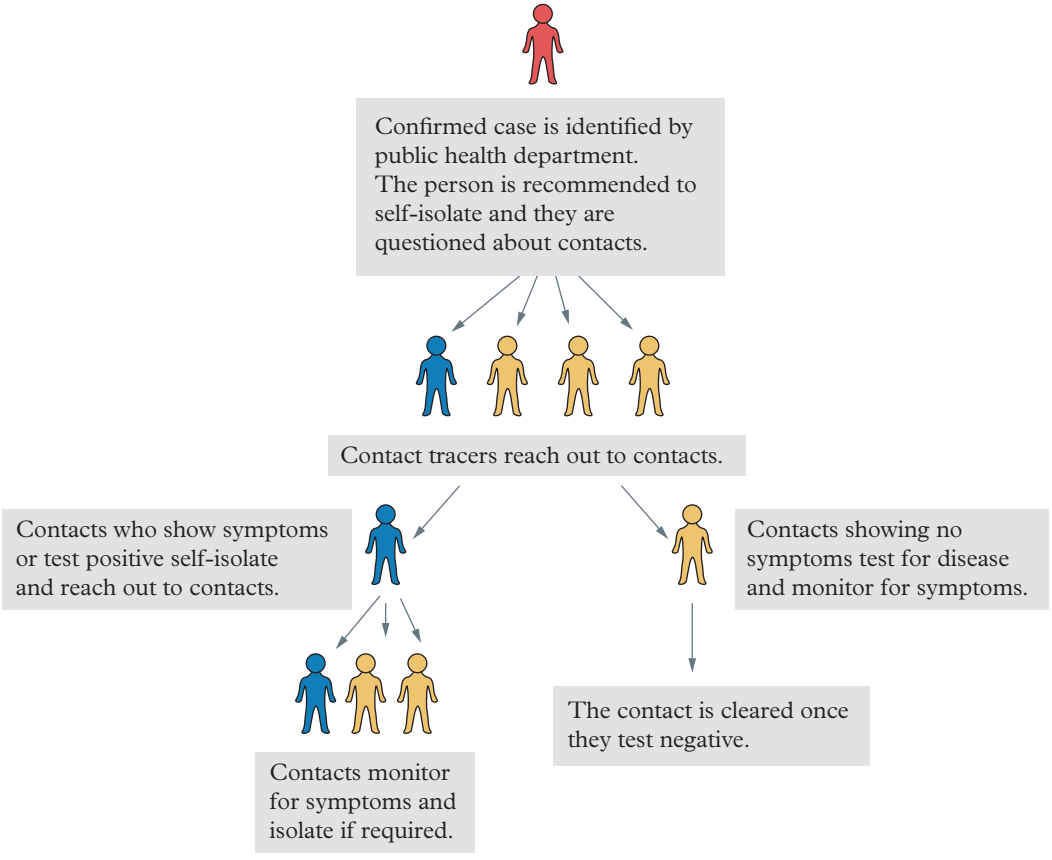


FIGURE 2 Contact tracing helps track down potential future infections and prevent the spread of disease.

For example, in 2017 there was a small outbreak of measles that affected 11 people. Eight of these people were linked to a particular building in Melbourne, where they had come into contact with the original infected person. All these people were quarantined to prevent the spread of the disease. Contact tracing was also used to manage the spread of the SARS-CoV-2 virus in Australia. Individuals who had come into contact with people infected with COVID-19 were traced and monitored.

Quarantine

The word "quarantine" is derived from a phrase meaning 40 days. It relates to the idea that 40 days is adequate time for a disease to pass and treatment to be completed. The 40 days is no longer strictly adhered to and varies from disease to disease. Quarantine can be applied locally, nationally or internationally.

At a local level, individuals who have a contagious disease should ideally be isolated from other people. Many bacteria and viruses pass from person to person in airborne droplets of water. Isolation reduces the chance of this occurring by minimising the number of people with whom the infected person comes in contact. The period of isolation depends on the

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incubation period of the pathogen as well as the length of time of infection. For example, a person infected with chickenpox must be kept isolated until all skin lesions have dried. For serious contagious diseases (e.g. Ebola), patients are kept in special hospital isolation wards. Only hospital staff can attend the patient, usually in special biohazard clothing, and they undergo a sterilisation treatment when they leave the ward to prevent spread of the pathogen.



FIGURE 3 Patients infected by serious contagious diseases are kept in special hospital isolation wards.

For serious outbreaks within a community, further action is taken. Schools, aged care facilities and public places may be closed. Often, there is a period between contraction of a pathogen and symptoms of disease appearing. This means an apparently healthy person could be contagious. Preventing large assemblies of people can help minimise the spread of the disease.

Quarantine is important at both state and federal levels in Australia. To prevent the spread of exotic plants and animals, and the pathogens they may carry, there are sometimes limitations on what may pass between states or regions within a state. For example, only livestock that have recently been sprayed to destroy ticks can pass from Queensland into New South Wales or from coastal areas of Queensland into western, tick-free areas.

All sites of international entry – ports, airports and mail exchanges – are also controlled. Aeroplanes are sprayed with insecticide on arrival. Clearance of passengers, cargo and other effects by quarantine officers is of major importance. Many airports use thermal cameras to screen arriving passengers for fever. Animals imported into Australia, including insects, fish, birds and mammals, and even semen for artificial insemination, are placed into special quarantine stations for a specified time to ensure they are not carrying disease. All plants or their parts (e.g. fruit, seeds, honey) must pass quarantine inspection, and possibly treatment and a period in isolation, as do objects made from plant material.

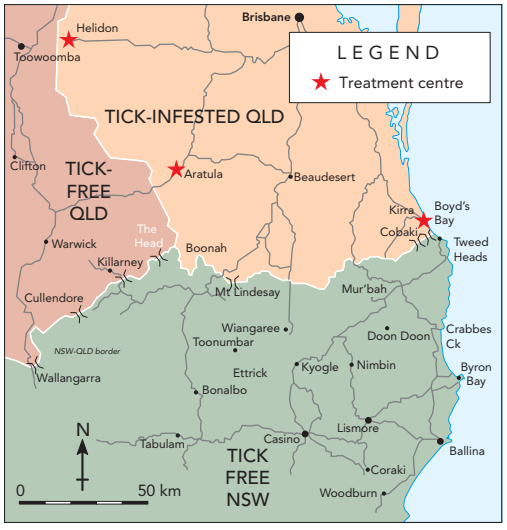


FIGURE 4 Tick areas in South East Queensland. Stock not sprayed prior to transport will be sprayed at the areas labelled with a star (e.g. Helidon) before they can enter a tick-free zone.

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The cabins of passenger planes arriving in Australia from certain regions of the world are sprayed before people can disembark, to kill any aerial pathogens. Passengers travelling from certain countries or at certain times are also given special consideration. For example, during the mad cow epidemic in the United Kingdom (in the 1980s and 1990s), all passengers had to declare whether they had been to a farm; if they had, their footwear was sterilised. Similarly, passengers from certain parts of Africa must have all shoes and boots sterilised. If coming from areas where a disease is rife (e.g. yellow fever in Tanzania), the passenger must have a current vaccination card for that disease, otherwise they are placed in quarantine. People are checked if they show fever symptoms, particularly if they are coming from an area with a virulent influenza epidemic.



FIGURE 5 An Australian quarantine station: (A) plant greenhouses, (B) dog runs, (C) horse stables

Biosecurity stations have been set up along Australia's northern regions, where a variety of animals (e.g. horses, cattle, pigs, poultry and insects) are kept. Regular blood tests are performed on these "sentinel" animals to monitor diseases that may have come from South-East Asia or the Pacific region via migrating animals. A range of other procedures, such as management of ballast water (which may contain disease-causing pathogens or pests) released from international ships, also exist.

Although Australia's border controls have been effective in preventing the spread of diseases and pests, they are not infallible. Not all entry into Australia can be controlled along its thousands of miles of coastland. Many pathogens are carried by birds and flying foxes that migrate between Asia and Australia. Sailing boats moving between the Pacific islands and Australia often pull into small coastal towns. This means they might avoid surveillance and, as a result, biosecurity checks.

Challenge

Vector movement

Coastal regions from the New South Wales border north to Broome in Western Australia are tick infested. Movement of stock from Queensland into New South Wales or west of the Great Dividing Range is controlled and can occur only if the stock have been sprayed to kill any ticks they may be harbouring. **Propose** two reasons for this control. (2 marks)

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Public health programs

Public health programs are very important in disseminating information and implementing control measures. **Vaccination** is another measure to prevent the contraction and spread of disease. Programs that encourage all children to be vaccinated before starting childcare or school improve herd immunity. Needle-exchange centres for drug users have helped prevent the spread of HIV and hepatitis through people sharing needles. The spread of insect-borne disease is reduced by programs that advise of breeding sites for vectors.

public health program
a program undertaken by organisations to prevent disease, prolong life and promote human health through informed choices

vaccination
injection of a killed or weakened microbe, or parts of a microbe, in order to stimulate the immune system against the microbe, thereby preventing disease



FIGURE 6 Mass vaccination programs help to reduce the spread of disease.

Real-world biology

Eradicating disease

Smallpox was a contagious infectious disease caused by the smallpox virus. It was a serious disease that caused symptoms such as fever, sores on the skin and in the mouth, and fatigue. It caused millions of deaths before its eradication in 1980. In 1967, the World Heath Organization set out to eradicate smallpox through an intense public health campaign, including widespread immunisation using the smallpox vaccine. The last case of smallpox was in 1977 in Somalia. The smallpox campaign still stands as a profound success story of the effectiveness of public health campaigns.

Apply your understanding

1 **Identify** the factors that led to the prevention and eventual eradication of smallpox. (2 marks)

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Treating diseases



FIGURE 7 Grass can act as a natural laxative to alleviate digestive issues in cats.

Animals have long been known to use natural remedies to alleviate ill health. Examples are domestic cats eating grass, and birds and primates deliberately ingesting kaolin clay to cure intestinal upsets. Early humans also developed knowledge and understanding of the curative aspects of particular plants. Even today, approximately 60% of the world's population does not have regular access to pharmaceutically produced medicines. Instead they may need to rely on plants for preventing and treating illness. In South America, for example, 1300 plant species are used for medicinal purposes. The number of plant species used in healing in other parts of the world is staggering – in India 2500 species, in South-East Asia approximately 6500 species, and in China 5000 species. Chinese herbalists can be found in most cities throughout the world. Many plants in Australia have also been used by First Nations peoples as medicinal treatment. In recent times, there has been a resurgence in investigating native Australian plants for possible drug applications, particularly those with **antimicrobial** properties.

antimicrobial describes a substance that kills or inhibits the growth of microorganisms, such as bacteria

chemotherapy the treatment of disease using chemicals that have a specific toxic effect on disease-producing microorganisms (e.g. antibiotics) or that selectively destroy cancerous tissue

Chemotherapy

Although the term **chemotherapy** is now applied to the injection of specific chemicals to prevent cell division, and therefore cancer growth, it is more generally defined as the use of chemicals to prevent and cure diseases and disorders. Many of these chemicals have been isolated from living organisms. Once the active components have been identified, they can often then be synthesised in the laboratory. Others, such as sulphonamides, are purely synthetic. Sulphonamides were widely used in the mid to late 1900s to treat urinary and bowel infections and pneumonia.

Plant chemicals

Plant chemicals with healing properties are known as secondary plant products, because they are not involved in creating carbohydrates, proteins or lipids. These secondary products are actively made by the plant, and at least some are thought to be adaptations to protect the plant. They act by mimicking existing chemicals that inhibit or stimulate natural processes, or by producing an antibiotic or antiseptic to protect the plant from infection.

Studies of particular plants, isolation of their active ingredients and rigorous testing have resulted in the development of approximately 40% of all prescription drugs. The identification and isolation of active ingredients from plants have allowed the production of synthetic drugs. However, not all plant chemicals can be synthesised. For example, digitalis, a heart stimulant that slows down and strengthens the heartbeat and has saved millions of lives, is still produced from dried foxglove (*Digitalis purpurea*) leaves. After the Second World War, the anti-malarial drug quinine, produced from the bark of the *Cinchona*



FIGURE 8 The term "chemotherapy" is most commonly used to describe a treatment administered to cancer patients; however, it also refers to the use of chemicals to prevent and cure other diseases or disorders.

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tree, was replaced by synthetic products. In recent years, however, malarial parasites have shown increasing resistance to these drugs. Quinine has had a revival as the only effective drug against certain *Plasmodium* strains. Less than 10% of the active higher plant chemicals used in prescriptions are commercially prepared by synthesising them. This is either because scientists have not yet found a way to synthesise them or because they can be more economically produced by growing the plants.



FIGURE 9 Foxglove (*Digitalis purpurea*)

Real-world biology

Bush medicine

For tens of thousands of years, First Nations peoples have used traditional methods of treating disease, passing their knowledge on through the generations. Many of these treatments were sourced from Australian flora, and so are termed "bush medicines". They contain antibacterial and anti-inflammatory properties that could be used to prevent and treat infections. Examples of bush medicines are tea-tree oil from *Melaleuca* trees, which is a strong antiseptic that can be used to treat many fungal infections, and Kakadu plums, which are a rich source of vitamin C and can be used for a variety of health benefits, from boosting immunity to lowering blood pressure. *Eucalyptus* leaves, used to create antiseptic tonics for treating a variety of illnesses, are used in smoking ceremonies, a highly significant ritual of some First Nations peoples, as a means of cleansing the people present and the surrounding area of the ceremony, and to encourage good health. Recent clinical studies have shown that compounds from *Eucalyptus* plants have the potential to treat and prevent a wide range of diseases, including as an antimicrobial against bacterial infections and as pain relief for muscle and joint injuries.



FIGURE 10 Kakadu plum

Apply your understanding

1 **Explain** how knowledge of traditional medicines, such as First Nations bush medicine, can be used to inform modern medical practices. (1 mark)

Antibiotics

Plants are not the only organisms that can have therapeutic effects. Many modern **antibiotics** are produced naturally by various species of bacteria or fungi, or they can be artificially synthesised from their natural products. Antibiotics are chemicals that interfere with either the metabolism or the structure of bacterial cells. Some ways in which antibiotics destroy bacteria are by interfering with:

- cell wall structure (e.g. penicillin)
- cell membranes (e.g. amphotericin)
- synthesis of proteins (e.g. streptomycin and tetracycline)
- synthesis of nucleic acids (e.g. rifampicin).

antibiotics chemicals that destroy bacterial cells by interfering with their metabolism or structure

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FIGURE 11 *Penicillium* fungi growing on agar

It is probable that production of these chemicals is a defence mechanism of one species to prevent competition for resources. Antibiotics have selective toxicity – they act only on bacteria other than the one producing it. Some antibiotics are broad spectrum, acting on a range of bacteria (e.g. tetracycline), while others are specific to a particular type. This difference has been used in the commercial production of antibiotics.

The antibiotics streptomycin and aureomycin are produced by bacteria. Several antibiotics are produced from fungi. Penicillin (used to combat many Gram-positive bacteria and staphylococcal infections) is produced from several species of *Penicillium*, notably *P. notatum* (Figure 11).

Since the discovery of penicillin in 1929, much research has been conducted into the production of antibiotics by bacteria and fungi, and into their purification and ability to act on specific pathogenic bacteria. Now there is an antibiotic treatment for most diseases caused by bacteria. The success of these treatments over the past century has been responsible for a massive decrease in many potentially lethal infections, such as tuberculosis.

Antibiotic resistance

antibiotic resistance
the ability of bacteria to resist the effects of an antibiotic to which they were previously sensitive

This success in producing antibiotics has led to a major problem – **antibiotic-resistant** strains of bacteria have developed. Bacteria are able to evolve resistance because they have:

- an extremely large population size
- a short generation time
- an unusually flexible genetic system.

Bacteria have a single, circular chromosome composed of DNA, and spontaneous changes (mutations) can occur in sections of this DNA (i.e. in genes). A change can be neutral (have no effect), harmful to survival, or beneficial (e.g. resistance to an antibiotic). Because bacteria can divide rapidly in a favourable environment, any beneficial mutation can spread within a population very quickly. Although bacteria do not reproduce sexually, they have three mechanisms for transferring genes from one individual to another.

Some bacteria can take up segments of naked DNA from their environment (e.g. DNA released when the cell wall/membrane from another bacterium or organism has been destroyed) and incorporate it into their chromosome. In this way, the bacterial DNA is transformed. If a bacterium is infected with a non-lethal virus, some of the bacterial DNA can be incorporated into the viral particles it produces. If these viruses infect a new bacterium, the host can pick up and incorporate the transported bacterial DNA into its chromosome in the process of transduction. Conjugation is a process whereby genes can be transferred between two bacterial cells that are temporarily joined by extensions of their membranes, called pili. In addition to the main chromosome, bacteria have other small circular DNA molecules, called plasmids. Plasmids replicate separately from the bacterial chromosome and are important in conjugation transfer. One group of plasmids (R-plasmids) carry genes for antibiotic-destroying enzymes. These can be passed to non-resistant individuals of the same or a different species of bacteria.

Bacteria can therefore become resistant to one or more antibiotics by:

- mutations that are passed from generation to generation
- uptake of resistant genes during transformation

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- transfer of resistant bacterial genes by viruses in transduction
- exchange of genes during conjugation
- movement of R-plasmids between bacteria.

This resistance has not developed as a cumulative tolerance of the bacteria to the drug, but as a chance mutation. For example, some bacteria in a population have an enzyme capable of breaking down a drug (e.g. penicillin). In the presence of penicillin, non-resistant forms are destroyed, and resistant forms survive. The greater the quantity and frequency of penicillin use, the higher the proportion of resistant forms left in the population. Because the resistant gene can be transferred between different species, a pathogen can be resistant to the antibiotic even before the antibiotic is used against it (Figure 12).

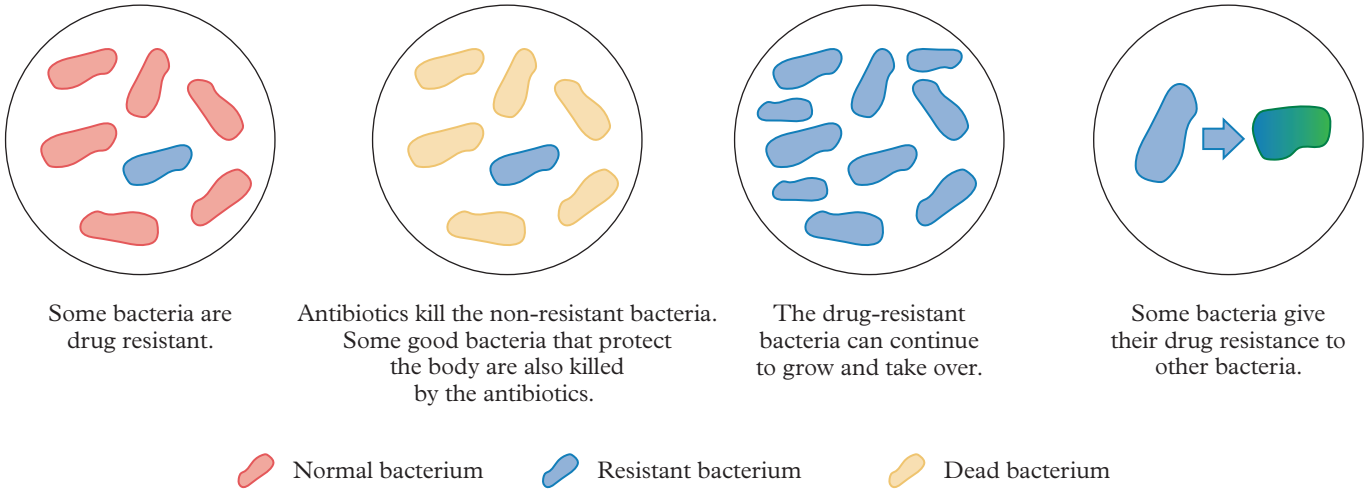


FIGURE 12 Some bacteria can become resistant to antibiotics.

Taking antibiotics for a non-bacterial infection or as a precaution increases the likelihood that antibiotic-resistant forms will develop. Similarly, if an incomplete course of prescribed antibiotics is taken, not all the invading bacteria will be killed. Because they will continue to reproduce, there is a good chance that a random mutation will occur that will confer resistance to the drug.

Chemicals produced by other organisms

Other chemicals produced by fungi can be used to treat other pathogens. Griseofulvin, produced by *Penicillium griseofulvum,* has antifungal properties; fumagillin, produced by *Aspergillus fumigatus*, is frequently used against amoebic dysentery.

Although some antiviral drugs disrupt a virus's ability to adhere to or leave a host cell, most treatment of viral infections relies on boosting the individual's immune system through rest and taking vitamin C and zinc.

Although only a small fraction of marine organisms has been examined, many valuable chemicals have been found in them. A sea squirt, for example, produces a substance that is active against a broad range of viruses responsible for such diseases as colds, influenza, herpes and meningitis. Serum from horseshoe crabs can isolate tumour cells from the blood of cancer victims. Shark livers contain lipids thought to increase human resistance to cancer. Over 500 marine organisms have been found to produce chemicals that have the potential to combat cancer.

Terrestrial animals have provided fewer chemicals to medicine. Bee venom is used to treat arthritis, and captopril, produced from the venom of a Brazilian snake, aids in controlling hypertension.



FIGURE 13 Bee venom can be used to ease the pain of arthritis.

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Check your learning 13.2

Check your learning 13.2: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Identify** three personal hygiene measures and explain how they can prevent the spread of disease. (6 marks)
2 **Explain** why it is important to wash your hands with soap and water rather than just water. (2 marks)
3 **Explain** how quarantine is used to control the spread of disease, using an example. (3 marks)
4 **Explain** how contact tracing is used to control the spread of disease. (3 marks)
5 **Identify** three plants that produce chemicals that are of medicinal value to humans. (3 marks)
6 **Describe** the ways in which plant and animal chemicals (active ingredients) can act on human pathogens. (2 marks)
7 **Explain** the function of antibiotics and why they are not prescribed for viral infections. (2 marks)
8 **Explain** the term "antibiotic resistance". (2 marks)
9 Despite stringent federal quarantine control, some diseases still enter Australia from overseas. **Describe** how this could occur. (2 marks)

Practical

Lesson 13.3

Testing the effect of an antimicrobial agent on the growth of a microbial organism

Learning intentions and success criteria

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Lesson 13.4
Predicting, identifying and monitoring disease

Key ideas

- → Certain diseases must be reported to state and federal authorities. Other diseases are notifiable to the World Health Organization to reduce pandemic outbreaks.
- → Mathematical models developed from surveillance data can predict the likely outcomes of disease outbreaks.
- → Viruses are non-living particles that can only be cultivated in living cells.
- → Bacteria and pathogenic fungi are living cells and can be cultivated on a nutrient agar medium in a Petri dish under sterile conditions.
- → Different groups of bacteria can be distinguished using growth inhibition by specific antibiotics and staining techniques (Gram stain or fast-acid stain). Identification to species level is achieved by DNA analysis.

Using data to predict, identify and monitor disease

Learning intentions and success criteria

Governments and scientists concerned about the global spread of diseases first met at the International Sanitary Conference in 1851. Over the next 70 years, the participants developed programs to deal with pandemics of cholera, yellow fever and bubonic plague. After the Second World War, this group of governments and people expanded and became the World Health Organization.

World Health Organization data shows that, in 2015, 26.6% of 56.4 million deaths worldwide were attributed to heart disease and stroke. These diseases have remained the leading cause of death globally since 2000 regardless of socio-economic status, although the death rate due to stroke is lower in high-income economies, probably as a result of better medical facilities. Non-infectious diseases cause 70% of deaths globally. It is therefore crucial that the causes of these diseases be identified, so treatments or preventative measures can be developed.

In the past, many connections were made between a disease and its possible cause, but the evidence was not scientific. In the nineteenth century, for example, people embarking on long sea voyages often suffered from scurvy. It was found that a daily intake of lime juice (high in vitamin C) reduced the incidence of this illness. Now, studies involving the



FIGURE 1 The World Health Organization headquarters are in Geneva, Switzerland.

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FIGURE 2 Epidemiological studies may examine how factors such as age affect the chances of surviving disease.

collection and careful statistical analysis of data assist the causal identification of diseases.

Epidemiological studies include how common the disease is (the number of people affected), what proportion of the population is affected, how many people in the population died as a result of the disease, and what other factors might have affected their chances of survival (e.g. age, gender, race, diet, geographic location, lifestyle, and family history of the disease).

In any study, conclusions regarding risk cannot be drawn from purely clinical data (i.e. the number of sick people seen) but must relate to all members of a population. In most cases, it is impractical to try to study the entire population, so a large **random sample** of the population is used. This allows comparisons to be made – for example, the incidence of lung cancer in people who smoke cigarettes versus non-smokers, or the rate of mesothelioma in people with or without exposure to asbestos.

random sample sample of individuals from a larger population chosen in a way where everyone is equally likely to be selected

In this lesson, you will learn how data analysed from epidemiological studies can help:

- predict outbreaks
- determine the source of an outbreak
- infer the mode of disease transmission
- determine the effectiveness of different strategies in controlling the spread of disease.

Predicting outbreaks

Predicting outbreaks involves epidemiologists using data to estimate the locations and times in which disease may occur. The types of data used to help predict outbreaks can vary. Environmental data on factors such as temperature, rainfall and humidity can be used to make predictions about pathogen or vector populations known to be affected by these environmental factors. For example, weather patterns can be used to predict mosquito populations. In countries affected by mosquito vectors, this can be used to predict outbreaks of diseases such as malaria, yellow fever and Dengue.



FIGURE 3 Data from weather stations can be used to predict vector populations.

Historical data can also be analysed to look for patterns in disease transmission. For example, historical data on the spread of influenza in Australia shows that transmission of influenza is highest between May and September. This information can be used not only to predict an outbreak of influenza, but also to help prevent transmission. For example,

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governments may encourage workplaces to offer annual flu vaccines at the start of May, to limit contraction and spread of the disease.

Population data such as population density, immunisation rates and data on the mobility of individuals can also be used to predict the likelihood of a specific disease outbreak. For example, during the COVID-19 pandemic, cities with highly dense populations, such as New York, were predicted to have high transmission rates of the virus.



FIGURE 4 Flu season in Australia is between May and September.

Models to predict disease

Most models for predicting the spread of an infectious disease are mathematical in nature. Two measures used in analysing disease are:

- **mortality rate** – the rate of death per population size. This is usually represented as a proportion (e.g. per 1,000,000 individuals).
- **case fatality ratio** – the number of deaths among those who have contracted the disease. This is usually expressed as a percentage.

For example, in a population of 3.5 million, if 70 of the 210 reported cases died of a particular infectious disease:

$$\text{mortality rate} = \frac{70 \times 1{,}000{,}000}{3{,}500{,}000} = 20 \text{ per million}$$

$$\text{and case fatality ratio} = \frac{70 \times 100}{210} = 33.3\%$$

Because case fatality ratios do not depend upon actual population size, health organisations can make some predictions about the severity of an outbreak. By comparing these figures across country groups, they can be used to predict the spread of disease outbreaks to other countries, and whether to impose travel restriction advice to particular countries.

The **SIR model** is a basic model used to analyse the spread of disease. It uses an advanced mathematical formula that examines:

- the proportion of a population that is susceptible to a particular infection (**S**),
- how many of these people go on to become infectious (**I**), and
- the proportion of these who then recover (**R**), and in what time frame.

This model assumes that the population being investigated does not change (i.e. births, deaths, immigration and emigration are not considered), that a single infected person introduces the disease into the population, and that there is no incubation period.

With the advent of complex computer programming and its massive processing power, this basic model can now generate models that also consider such factors as weather, human travel, trade patterns and warfare.

mortality rate
the ratio of deaths in an area to the population of that area; expressed per 1000 per year

case fatality ratio
the proportion of deaths within a designated population of "cases" (people with the disease) over the course of the disease

SIR model
a method that models or tracks the numbers of susceptible, infected and recovered individuals during an epidemic



FIGURE 5 The SIR model can help determine the levels of vaccination needed to protect a population.

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One of the important features of the SIR model is that it can be used to predict the level of vaccination needed to protect a population. The SIR model also makes it possible to predict the spread of an infectious disease in a totally susceptible population (i.e. no one is vaccinated against the pathogen). R_0 is a measure of the number of people who become infected by a single person with the disease. This varies depending on the disease and the mode of transmission. Malaria, for example, is transmitted by mosquitoes, and one mosquito can transfer the pathogen from one infected person to a large number of people in a short time. AIDS, which is transferred from person to person only in body fluids, has a lower transmission rate among a particular contact group of individuals.

For a disease with an R_0 of 2 (e.g. hepatitis C and Ebola), each infected person is likely to infect two other people, whereas one person with mumps (R_0 of 10) will infect 10 other people.

The proportion of the population that needs to be vaccinated to prevent the spread of the pathogen can be worked out using the formula:

$$VT = 1 - \frac{1}{R_0}$$

where VT is the proportion of the population that needs to be vaccinated.

The R_0 value for some common diseases is shown in Table 1.

TABLE 1 The value of R_0 for some common diseases

Disease	R_0
AIDS	2 to 5
Smallpox	3 to 5
Measles	16 to 18
Malaria	> 100

Skill drill

Using models to predict disease

Science inquiry skill: Processing and analysing data (Lesson 1.8)

An emerging disease has caused 32 deaths out of 100 reported cases in a population of 100,000 people. Epidemiologists have determined that the disease has an R_0 of 6.

Practise your skills

1 **Calculate** the mortality rate per million people. (1 mark)
2 **Calculate** the case fatality ratio of this disease. (1 mark)
3 **Determine** the proportion of the population that needs to be vaccinated to prevent the spread of the disease. (1 mark)

Determining the source of non-infectious outbreaks

To determine the source of an outbreak, scientists need to first determine whether the source of the outbreak is infectious or non-infectious. For non-infectious diseases, a number of key questions must be investigated, to determine whether key factors in a population contribute to the cause and spread of the disease.

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1 Is there a significant statistical correlation between the disease and the proposed cause? For example, it has been shown that deaths due to lung cancer are significantly higher in smokers than in non-smokers, which implies a high correlation between smoking and lung cancer. With further information, it can be concluded that smoking is a cause of lung cancer.
2 Is the cause–effect relationship consistent across all other variable characteristics, such as age, occupation, gender, geographical location and race? For example, the correlation of smoking with a higher incidence of lung cancer is observed across all variables.
3 Is there a temporal sequence or direct timeline – that is, does the proposed cause occur before the onset of the disease? The incidence of lung cancer began to increase 10 years after rates of cigarette smoking began to rise. This typically corresponds with the time between exposure to cancer-causing chemicals (in cigarette smoke) and the onset of cancer.
4 Does an increase in exposure to the proposed cause mean an increased risk of the disease? It has been found that the death rate due to lung cancer is higher in heavy smokers than in less regular smokers.
5 Do the trends observed have a plausible relationship or explanation of why this factor causes clinical symptoms? The chemicals in cigarette smoke have been identified as carcinogens. Therefore, it is plausible that they cause lung cancer.



FIGURE 6 Simulated comparison of the lungs of a smoker and a non-smoker

For many non-infectious diseases, this approach has been used to determine the cause, whether inherited, environmental or nutritional.

Determining the source of infectious outbreaks

For infectious diseases, scientists need be able to identify the type of pathogen causing the disease. Depending on the nature of the pathogen, different identification techniques must be used for:

- identifying macroparasites and protists
- identifying bacterial and fungal pathogens
- identifying viruses
- using Koch's postulates.

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FIGURE 7 Some pathogens can be identified from microscopic examination of blood samples.

Identifying macroparasites and protists

Macroparasites and protists can be readily seen with the naked eye or through a light microscope. Intestinal worms lay uniquely shaped and sized eggs that can be identified from a faecal smear. Intestinal protozoans can be identified in a similar way. Other pathogens can be easily identified by microscopic examination of blood samples. Micropathogens (prions, viruses, bacteria and many fungi), on the other hand, need more specialised methods of identification. Prions are identified using chemical analysis of blood proteins.

Identifying bacterial and fungal pathogens

Bacterial and fungal pathogens can be isolated from host cells by centrifuging tissue samples and filtering the smaller pathogens from the host cells. The pathogenic cells are then cultured on nutrient agar jelly in a Petri dish. Similarly, the plates can be smeared with blood serum or scrapes of tissue. Sterile conditions are employed to ensure that the culture is not contaminated with airborne organisms.

Bacteria and fungi (including moulds and yeasts) grow well on nutrient agar plates. Single cells of these organisms reproduce and form colonies. Different types of cells produce colonies with distinctive features or colony morphology. Basic characteristics of this morphology include their colour or shape, the elevation or surface of the colony, the smoothness of the edges and even the odour of the colony. Figure 8 shows some examples of shape, elevation and edge margin.

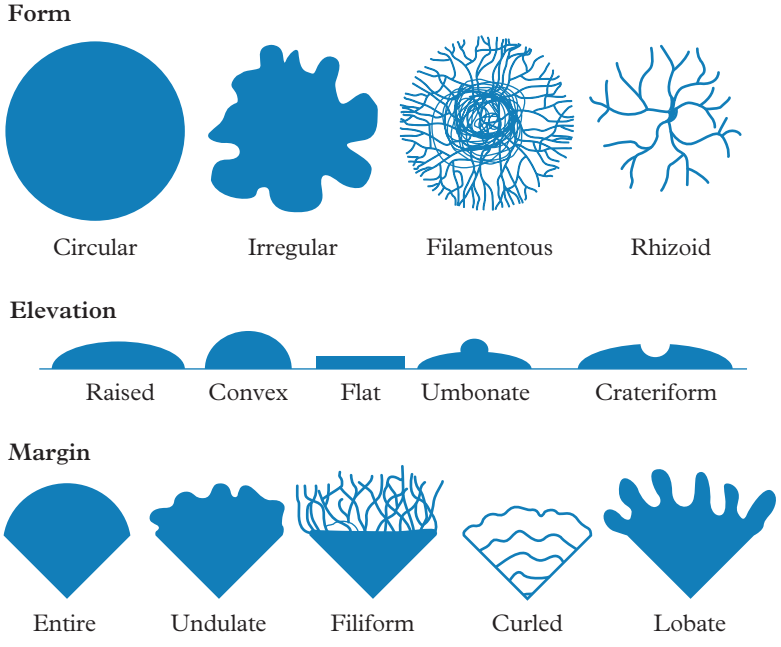


FIGURE 8 Some morphological features of colonies of bacteria and fungi

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Most bacterial colonies are roughly circular in shape and are coloured white, cream or yellow.



Bacillus subtilis *Staphylococcus aureus*

FIGURE 9 Some bacterial colonies growing on agar plates

Antibiotics are molecules that kill bacteria or block their growth. Each antibiotic works in a different way, depending on the presence of specific antigens on the bacteria. When special filter papers, each impregnated with a different antibiotic, are laid over the bacterial colonies growing on agar, particular antibiotics will inhibit the growth of the bacteria. This inhibition can be seen by a zone clear of bacteria around that specific antibiotic (Figure 10). This allows the identification of the bacteria by noting their susceptibility to the antibiotic.



FIGURE 10 Clear zones around the antibiotic-impregnated discs indicate inhibition of bacterial growth.

Further identification can be achieved by staining the colonies. Gram-staining determines two major groups of bacteria – Gram-positive (Figure 11A) and Gram-negative (Figure 11B) – depending on the chemicals present in the outer cell wall. Another important identifier is the shape of the bacterium. A bacterial cell can be spherical (known as coccus; a pair or a chain of cells is known as cocci), rod-shaped, or spiral or comma-shaped. Some fungus-like bacteria, *Mycobacterium*, have a Gram-negative result because they have a waxy surface on their cell walls, which prevents uptake of the stain. Identifying these bacteria requires an alternative, fast-acid (pink) stain (Figure 11C).

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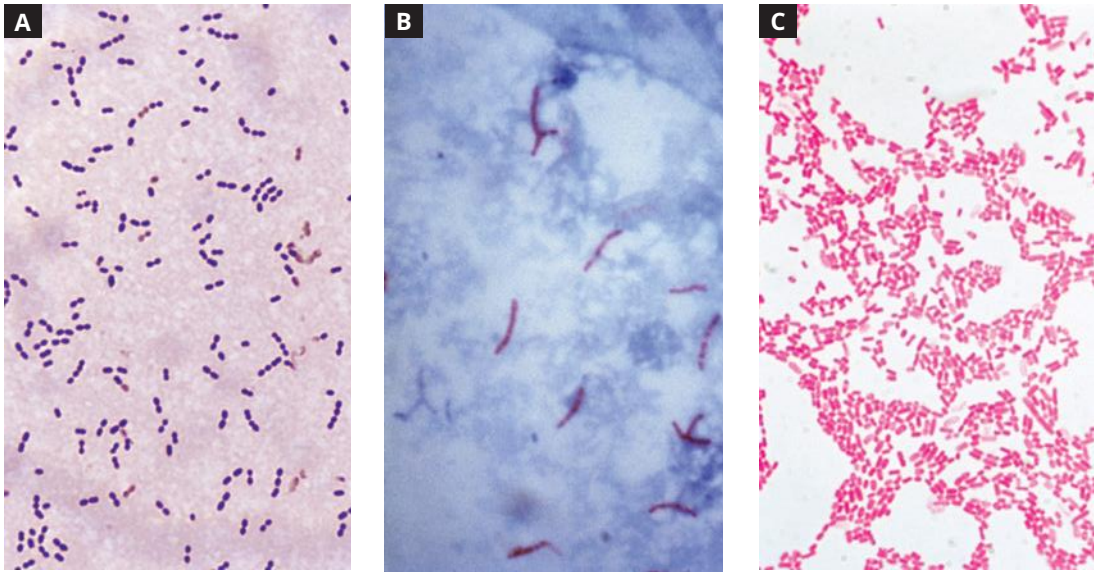


FIGURE 11 Staining of bacterial samples: (A) Gram-positive (purple) *Streptococcus pneumoniae,* (B) Gram-negative (pink) *Escherichia coli,* (C) fast-acid stained *Mycobacterium tuberculosis*

These staining techniques are useful for identifying the genus of the bacterium, but not the species within the genus – a *Mycobacterium* can be differentiated from a *Streptococcus* by staining, but differentiation of the exact species requires DNA analysis.

Yeast colonies also have a circular shape, and some look remarkably like bacterial colonies. For example, *Candida albicans*, which causes thrush, has white, round colonies (Figure 12). Microscopic examination of individual cells will determine whether they are prokaryotic (no nucleus and therefore a bacterium) or eukaryotic (nucleus present and therefore a fungus).

Moulds grown on an agar plate often appear whitish grey with fuzzy edges (Figure 13). They usually turn a different colour from the centre outwards. The cell structure, method of spore formation and general body function can be determined using a microscope. Fungi can be further tested by growing them on selected media or by enzymatic reactions.



FIGURE 12 *Candida albicans* colonies on an agar plate



FIGURE 13 Mould colony of *Aspergillus* species

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Identifying a virus

Viruses are difficult to identify in a laboratory, because they cannot survive on their own. Instead they must be grown in a liquid culture with host cells. Because each virus can only bind to the host cell that contains the correct adhesion molecule, trial and error may be required to determine a suitable type of host cell.

Once the virus can be grown in a host cell, different strategies are used to identify it, depending on the purpose of identification. Often a virus causes specific changes to the host's cells – a **cytopathic effect** – and this can be seen under a light microscope. If these changes are seen in the cultured host cells, then the virus can be identified. Other techniques include X-ray diffraction, electron microscope examination and DNA analysis.

cytopathic effect
a degenerative change in the appearance of cells

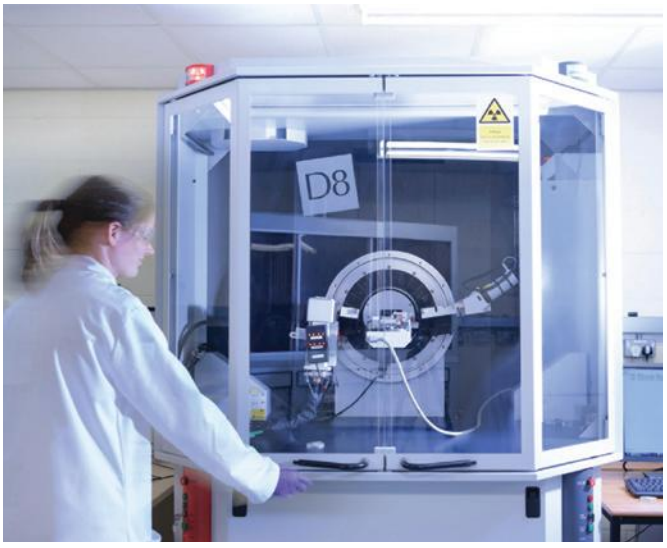


FIGURE 14 An X-ray diffraction machine



FIGURE 15 An electron microscope can be used to detect a virus

Koch's postulates

Once a pathogen has been isolated and identified, techniques using **Koch's postulates** are employed to ensure that the organism is responsible for the disease. These postulates, or criteria, are as follows:

Koch's postulates
general criteria that assess whether an organism is the cause of a disease

1. The microbe is present in organisms with the disease but not in healthy organisms.
2. The microbe is isolated from the diseased organism and cultured in pure form (i.e. with no other microorganisms present).
3. When this cultured microbe is injected into a healthy organism, the organism develops the disease symptoms.
4. The microbe is re-isolated from the experimentally infected organism and again cultured. This new culture shows only the original form of microbe.

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Inferring the mode of disease transmission

Different types of data can also be analysed to determine the mode of disease transmission (Table 2).

TABLE 2 Different types of data and how they can be used to help establish the mode of disease transmission

Type of data	How data can be used to establish mode of transmission
Epidemiological data (e.g case studies, information collected from contact tracing)	• Examining case studies of disease occurrence can help to identify common factors between affected individuals (e.g. if all affected individuals obtained water from the same source, this suggests the disease is spread through contaminated water). • Information gathered from contact tracing can help establish commonalities in the behaviours or interactions of individuals (e.g. if it was observed that many non-infected individuals became infected after being in proximity with infected individuals, this suggests transmission through direct contact).
Demographic data (e.g. age, occupation, gender, etc)	• Establishing whether there is a higher incidence of disease in certain demographics can help determine the mode of transmission (e.g. if workers who regularly handle asbestos have a higher incidence of mesothelioma, this suggests that exposure to asbestos particles contributes to the onset of mesothelioma).
Genetic and molecular data (e.g. data on the genetic make-up of pathogens, hosts and their molecular responses)	• Data that sequences pathogens can trace transmission pathways. Also, studying host genetics can reveal how susceptible a host is to a specific pathogen (e.g. genetic data has shown that an individual with one copy of the sickle cell gene is less likely to be affected by malaria than an individual with two copies of the sickle cell gene).
Behavioural data (e.g. data on the behaviour, lifestyle factors and social interactions of individuals)	• Analysing behavioural data can help establish whether behaviour or lifestyle factors contribute to transmission of disease (e.g. if data showed that unaffected sexual partners of individuals infected with Zika virus contracted Zika after sexual intercourse with their partner, this would establish that the disease does not just spread through the bite of mosquito vectors but also through contact with infected body fluids).



FIGURE 16 Asbestos removalists have to wear specialised PPE to prevent them from inhaling asbestos particles in the air.

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Real-world biology

John Snow and the cholera outbreak

Cholera is an extremely virulent disease caused by the bacterium *Vibrio cholerae*. It is spread by the consumption of contaminated food or water. In 1854, a severe outbreak of cholera in London killed 616 people. At the time, it was thought that the disease was spread by particles in the air. This was debunked by the physician John Snow, who instead traced the cause of the disease to a contaminated water source – a water pump in Broad Street. Snow tracked all cases of cholera (Figure 1) and concluded that the pattern of the disease suggested the water people were consuming from a nearby pump was infected. Snow started a public health campaign that led to the pump no longer being used and, subsequently, a decline in the disease.

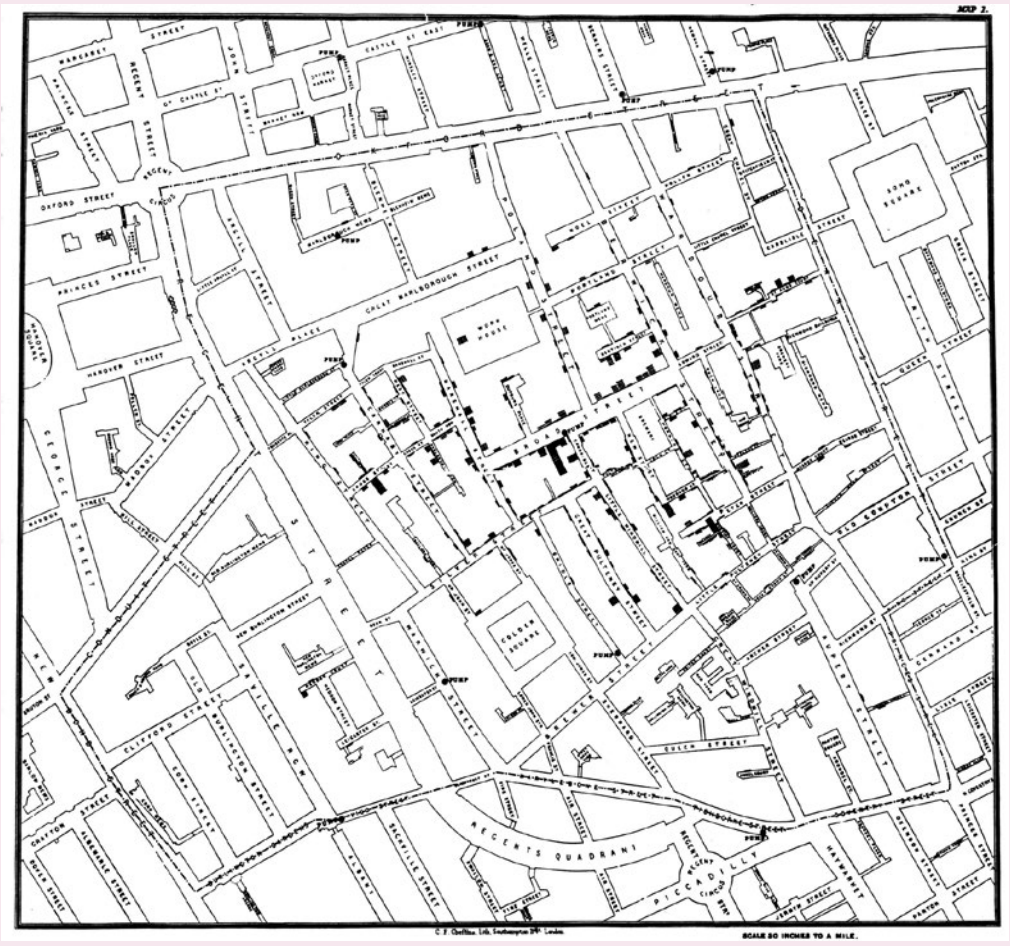


FIGURE 17 Dot map of cholera cases during the 1854 outbreak in Soho, London

Apply your understanding

1 Using the steps that need to be followed to reach an epidemiological conclusion, **explain** how Snow was able to conclude that the cholera outbreak was caused by a contaminated water source. (3 marks)

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Real-world biology

Typhoid Mary

Mary Mallon was born in Northern Ireland in 1869. At the age of 15, she migrated to the United States, where she eventually found work as a cook for well-to-do families in New York. It is not known where Mary was first exposed to typhoid, but in 1900 she started cooking for a new family. Within two weeks, family members became sick with typhoid. Mary herself did not show any symptoms of the disease (fever and diarrhoea). Within a year, Mary needed to move on (as family members started dying). The family members of her new employers also contracted typhoid, and the laundress died. In the third family Mary cooked for, seven out of eight members of the family contracted the disease. This pattern of asymptomatic (no symptoms) Mary cooking for new families who then contracted the disease continued for seven years, before a typhoid researcher named George Soper investigated the outbreak.



FIGURE 18 Typhoid Mary poster

Despite several confrontations with the health authorities, Mary denied that she was the cause (carrier) of the typhoid outbreaks. She was jailed several times for refusing to stop cooking and spreading the disease. Eventually, she was placed in quarantine at the Riverside Hospital for the last 23 years of her life. It is thought that "Typhoid Mary" was responsible for at least three deaths and over 50 infections as a result of being a typhoid carrier.

Apply your understanding

1 **Determine** the factors that established Mary as the source of the outbreak of typhoid. (3 marks)

2 **Infer** the mode of transmission of typhoid. (1 mark)

Evaluating the effectiveness of strategies for controlling the spread of disease

Once the source and mode of transmission of a disease have been established, government and public health agencies can implement strategies such as public health campaigns, education on personal hygiene measures, vaccinations, contact tracing and quarantine in an attempt to reduce the spread of the disease. The effectiveness of strategies used in controlling the spread of disease can be evaluated through comparison of data, controlled studies and statistical analysis. Table 3 summarises how these methods can be used to evaluate the effectiveness of a strategy or treatment.

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TABLE 3 Methods of data analysis used to evaluate the effectiveness of a strategy or treatment for controlling disease

Method of evaluation	Example
Comparing data Comparing data on the incidence or transmission rates of a disease before and after a control measure has been applied, or comparing data between different control measures	During the COVID-19 pandemic, researchers compared data on transmission rates before and after different lockdown measures were implemented in various countries. The comparison showed that countries that enforced stricter lockdown rules had slower rates of transmission than those with more lenient lockdown rules. This suggests that stricter lockdowns are effective in reducing the transmission of COVID-19.
Controlled studies Conducting and analysing data from studies that test whether a strategy influences the number of cases of disease or test whether a treatment is effective in managing symptoms of disease	During COVID-19 vaccine development, clinical trials involved some participants receiving an active vaccine and others receiving a placebo. Results showed that the vaccine group had fewer cases of COVID-19, demonstrating the effectiveness of the vaccine.
Statistical analysis Using statistical models to determine whether changes in the number of cases observed can be attributed to the control measure used	Water, sanitation and hygiene (WASH) interventions are often implemented to manage outbreaks of cholera. A meta-analysis of data from articles studying WASH strategies found that household water treatment (HWT) interventions, such as chlorination and filtration, reduced the risk of cholera by 47%.

Check your learning 13.4

Check your learning 13.4: Complete these questions online or in your workbook.

Retrieval and comprehension

1 **Explain** why it is mandatory for some diseases to be reported to the World Health Organization. (2 marks)

2 **Describe** a cytopathic effect and how it is used. (2 marks)

3 **Identify** some of the morphological features of a bacterial colony that are used to identify bacteria. (3 marks)

4 **Describe** what causes the different reactions of certain bacteria to Gram stain (2 marks).

5 Certain bacteria and the yeast *Candida* both form smooth, white colonies. **Describe** the differences between them. (2 marks)

6 **Describe** how data from disease monitoring is used. (2 marks)

7 **Describe** three types of data that can be used to infer the mode of disease transmission. (3 marks)

8 **Explain** why the value of R_0 varies according to the type of pathogen and its mode of transmission. (2 marks)

9 **Explain** how comparing data can be used to evaluate the effectiveness of a strategy for reducing the spread of disease. (2 marks)

Knowledge utilisation

10 **Predict** the likelihood of an epidemic occurring in a population in which:

a no one is vaccinated against the disease (1 mark)

b most people are vaccinated against the disease. (1 mark)

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MODULE 13

Lesson 13.5
Review: Epidemiology

Summary

13.1
- Epidemiology is the scientific study of factors that determine and influence the frequency and distribution of disease, injury and other health-related events.
- The transmission of disease can occur through direct contact or indirect contact with the source of infection.
- Direct contact includes the transmission of a pathogen through physical touch, contact with infected body fluids and the spread of airborne droplets.
- Indirect contact includes the transmission of a pathogen through consuming contaminated food or contaminated water, and by infection via a vector.
- The spread of a disease is also influenced by factors such as the persistence of the pathogen within the host, the transmission mechanism, the proportion of the population who are immune or have been immunised, and the mobility of individuals in the affected population.

13.2
- Measures to control the spread of disease include personal hygiene measures, contact tracing and quarantine.
- Good personal hygiene and rigid standards at food preparation outlets are significant deterrents to the spread of infectious disease.
- Contact tracing involves identifying and providing advice to individuals infected with a disease and the contacts they may have spread the disease to.
- Quarantine is the isolation of individuals infected with a disease; it can occur at a local, federal or international level.
- Treatments that may be administered to treat disease include plant-derived chemicals, antibiotics and chemicals produced by other organisms.

13.3
- Practical: Testing the effect of an antimicrobial agent on the growth of a microbial organism

13.4
- Certain diseases must be reported to state and federal authorities. Other diseases are notifiable to the World Health Organization to reduce pandemic outbreaks.
- Mathematical models developed from surveillance data can predict the likely outcomes of disease outbreaks.
- Viruses are non-living particles that can only be cultivated in living cells.
- Bacteria and pathogenic fungi are living cells and can be cultivated on a nutrient agar medium in a Petri dish under sterile conditions.
- Different groups of bacteria can be distinguished using growth inhibition by specific antibiotics and staining techniques (Gram stain or fast-acid stain). Identification to species level is achieved by DNA analysis.

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Review questions 13.5A Multiple choice

Review questions: Complete these questions online or in your workbook.

(1 mark each)

1 Factors that aid in the transmission of pathogens do *not* include
- **A** small droplets of water in the air.
- **B** global wind patterns.
- **C** direct contact with an infected individual.
- **D** contaminated food and water.

2 Pandemics have *not* been caused by
- **A** regional travel within a country.
- **B** increased tourism.
- **C** movement of goods between countries.
- **D** migration of certain animals.

3 Epidemiology is the
- **A** identification of species from their genome.
- **B** use of X-ray diffraction to determine the molecular structure of pathogens.
- **C** ability to rapidly make multiple copies of segments of DNA.
- **D** identification of the causes of disease.

4 Globally, the leading cause of human deaths is
- **A** non-infectious diseases, of which the prime cause is smallpox.
- **B** non-infectious diseases, of which the prime cause is heart disease and stroke.
- **C** infectious diseases, of which the prime cause is influenza.
- **D** infectious diseases, of which the prime cause is cholera.

5 R_0 is a measure of the number of people who become infected by each person with a disease. This parameter
- **A** varies depending on the disease and the mode of transmission.
- **B** varies depending on the disease but not the mode of transmission.
- **C** is the same for all diseases that have the same mode of transmission.
- **D** is the same for all diseases irrespective of the mode of transmission.

6 Quarantine refers to
- **A** the 40-day period of isolation of a person with a disease to ensure the disease is no longer viable.
- **B** the 40-day period of isolation of a diseased person to ensure treatment is completed.
- **C** the isolation period for a person, animal or plant to ensure non-transmission of an infectious disease or a potential infectious disease.
- **D** the isolation of all people with a contagious disease in a special hospital ward.

7 For some planes that arrive in Australia from overseas, the passenger cabins are sprayed prior to disembarkation. The purpose of this is to
- **A** provide deodorant to passengers after being in stagnant air for a long time.
- **B** reduce stress in the passengers before they pass through quarantine.
- **C** attempt to reduce ectoparasites on the passengers.
- **D** attempt to eliminate airborne pathogens.

8 Antibiotics
- **A** can be used to treat all the effects caused by pathogens.
- **B** are only effective against bacterial and viral infections.
- **C** are toxic to all bacteria.
- **D** each have selective toxicity to specific bacteria.

9 Identify the morphological features of the yeast colonies shown.



- **A** circular, raised, entire
- **B** irregular, umbonate, entire
- **C** circular, umbonate, entire
- **D** circular, crateriform, undulate

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10 Calculate the mortality rate of a disease per million people, if 125 of the 250,000 people in the population die.
- **A** 0.05%
- **B** 125 people per 250,000
- **C** 500 per million
- **D** 1 in 2000

11 Alcohol-based hand sanitiser gels have been used since the 1980s, but have risen in popularity in the last decade. Tests have shown that they are as effective as soap and water and are useful when there is no safe water available. Identify the role of hand sanitiser in managing disease.
- **A** preventative measure
- **B** control measure
- **C** quarantine measure
- **D** biosecurity measure

12 Conjugation is a common way for a bacterium to obtain antibiotic resistance. Define conjugation.
- **A** the dividing of bacterial cells
- **B** the transformation of bacterial DNA
- **C** the transduction of DNA from viruses
- **D** the transfer of DNA from one cell to another that is temporarily joined to it

Review questions 13.5B Short response

Review questions: Complete these questions online or in your workbook.

Retrieval and comprehension

13 **Define** "contact tracing". (1 mark)

14 **Describe** how vector organisms affect the spread of disease. (2 marks)

15 **Explain** how public health programs control and/or prevent disease. (2 marks)

16 **Describe** the role of the Australian Quarantine and Inspection Service in preventing infectious disease outbreaks. (2 marks)

17 Between 2000 and 2022, people who had lived in England during the mad cow epidemic were not permitted to donate blood in Australia. **Explain** the rationale behind this. (2 marks)

18 Recently a number of miners have developed black lung disease. **Describe** how an epidemiological study could determine the cause of this disease. (3 marks)

19 The bacterium *Staphylococcus aureus*, or "golden staph", causes a range of pus-forming infections through the production of toxins. Some strains of this bacterium are highly adapted to hospital environments because they are resistant to a large number of antibiotics, and are highly dangerous for individuals recovering from surgery. Strains of this bacterium found outside the hospital environment are sensitive to antibiotics. **Describe** how different sensitivity to antibiotics has occurred in these strains. (3 marks)

20 In 1957, scientists in England discovered a natural substance, now known as interferon, that interferes with viral replication. Interferon is produced in the cells of infected humans (and closely related species, such as chimpanzees) within 2 hours of viral infection. Antibody production takes 7 to 10 days after infection. Nearly all cell types can synthesise interferon, but it cannot be synthesised in embryos less than 3 months old. The production of interferon is variable among different people.
- **a** The mosquito-borne Zika virus may not have serious effects on a pregnant woman. Her unborn child, however, may die or suffer microencephaly (a condition in which the brain is significantly undeveloped). **Explain** this occurrence. (3 marks)
- **b** Some people rarely suffer from viral infections, while others constantly contract diseases such as colds and influenza. **Identify** what factors might contribute to this difference. (3 marks)

21 Herd immunity refers to the resistance of a population to disease through immunity, often achieved by vaccination. The probability of someone catching a contagious disease from someone infected depends on the vaccination rate, and it is expressed as a ratio. For instance, when a population is 99% vaccinated, the probability of encountering someone unvaccinated is 1:100.
- **a** If 95% of a population is vaccinated for a bacterial disease, **calculate** the probability that the first person you meet is unvaccinated. Provide your final answer as a ratio. (1 mark)

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b If 80% of a population is vaccinated for a viral disease, **calculate** the probability that the first person you meet is unvaccinated. Provide your final answer as a ratio. (1 mark)

Analytical processes

22 **Compare** the use of historical data and environmental data to predict outbreaks of disease. (2 marks)

23 In March 2017, a vaccine against malaria developed by researchers at Griffith University, Queensland, passed early human trials.

a Assuming that the R_0 for malaria is 100, **determine** what percentage of any given population would need to be vaccinated to prevent the spread of this disease. (1 mark)

b **Describe** factors that would affect the success of such a vaccination program in countries where malaria is most prevalent. (4 marks)

Knowledge utilisation

24 The table below shows the incidence of avian influenza A (H5N1) in humans at a particular time.

a **Calculate** the mortality rate and case fatality rate for each group of countries, to complete the table. (1 mark)

b **Contrast** the mortality rates and case fatality ratios for the groups of countries. (1 mark)

c **Identify** two possible explanations for the differences in mortality rates in the country groups. (2 marks)

d **Determine**, with reasons, whether you would recommend issuing travel warnings to tourists for any of the countries listed. (2 marks)

e **Dicusss** how personal health measures may reduce the likelihood of contracting the disease. (4 marks)

Group of countries	Total population	Reported cases	Fatalities	Mortality rate (per 100,000,000)	Case fatality ratio (%)
A Cambodia, Thailand, Vietnam	164,326,409	123	66		
B Indonesia	234,693,997	96	76		
C Azerbaijan, Djibouti, Egypt, Iraq, Nigeria, Turkey	322,641,106	59	26		
D China, Laos	1,328,373,886	26	17		

Data drill

Antibiotics

Many strains of bacteria have developed resistance to commonly used antibiotics. Microbiologists are experimenting with new substances that may have antimicrobial properties. The disc method of testing antibiotics and antibiotic-resistant bacteria involves impregnating a small disc of filter paper with a substance and placing it on an agar plate with bacteria. If bacterial growth is inhibited, after 48 hours there will be a clear zone around the disc where there has been little to no growth. Six new substances have been isolated from Australian fungal species. Their potential for future use as antibiotics is being tested.



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TABLE 1 Zone of inhibition by penicillin, for five bacterial species

Substance	Zone of inhibition (diameter, mm)				
	Escherichia coli	*Staphylococcus aureus*	*Pseudomonas aeruginosa*	*Bacillus subtilis*	*Clostridium botulinum*
Trial 1	22	19	0	3	11
Trial 2	20	28	0	8	9
Trial 3	21	16	0	1	7
Average	21	21	0		9
Standard error	±0.6	±3.6	±0	±2.1	±1.2

TABLE 2 Resistance of five bacterial species to six new substances

Substance	Bacterial species				
	Escherichia coli	*Staphylococcus aureus*	*Pseudomonas aeruginosa*	*Bacillus subtilis*	*Clostridium botulinum*
1	+	+	+	–	–
2	+++	–	–	+	+
3	–	–	–	–	+++
4	+++	++	+	–	+
5	+	+++	–	+	–
6	+++	++	–	++	++
Penicillin	+++	+++	–	+	+++
Doxycycline	+	++	–	+	++

'–' indicates no resistance '+' indicates resistance ('+++' = highest resistance)

Apply understanding

1 **Calculate** the average zone of inhibition for penicillin action on *Bacillus subtilis*. (1 mark)

Analyse data

2 **Contrast** the statistical accuracy of the results of penicillin action on *Escherichia coli* and *Staphylococcus aureus*. (1 mark)

Interpret evidence

3 **Determine** which substance might be worth purifying into an antibiotic for patients suffering from botulism, an illness caused by *C. botulinum*. Give reasons to support your response. (2 marks)

4 Many strains of golden staph (*S. aureus*) have developed resistance to penicillin and penicillin derivatives (such as ampicillin and amoxycillin). **Identify** an alternative substance that could be developed into an antibiotic for golden staph. **Justify** your response. (2 marks)

Module 13 checklist: Epidemiology

Quizlet: Revise key terms online to test your understanding

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UNIT 2

Topic 2 Review

Multiple choice

(1 mark each)

1 A larger than normal number of individuals in a particular locality being infected by a disease at a particular time is referred to as
- **A** a pandemic.
- **B** an epidemic.
- **C** genetic disease.
- **D** non-infectious disease.

2 "Droplet spread" is a type of disease transmission called
- **A** direct transmission.
- **B** immunisation.
- **C** indirect transmission.
- **D** vector transmission.

3 Parasites obtain nutrients
- **A** by consuming sugars produced by plants.
- **B** by eating dead and decaying matter.
- **C** by photosynthesis.
- **D** from their host.

4 In terms of vector-borne disease, which of the following can be classified as a carrier?
- **A** a human infected with malaria
- **B** a mosquito that can carry malaria but is not currently infected
- **C** the bloodmeal taken by a mosquito from a human infected with malaria
- **D** the *Plasmodium* protozoan that causes malaria infection

5 Which of the following is *not* an infectious disease?
- **A** influenza
- **B** iron deficiency
- **C** malaria
- **D** the common cold

6 Vitamin C deficiency can be classified as which of the following?
- **A** genetic disease
- **B** infectious disease
- **C** nutritional disease
- **D** pathogenic disease

7 Antibodies being passed from mother to baby during pregnancy is an example of
- **A** active artificial immunity.
- **B** active natural immunity.
- **C** passive artificial immunity.
- **D** passive natural immunity.

8 Herd immunity describes the
- **A** ability of a pathogen to spread between different species.
- **B** limited spread of disease due to the high vaccination rate of a population.
- **C** movement of disease within a herd of cattle.
- **D** number of people infected within a community at a given time.

9 The immune cells responsible for producing memory cells are called
- **A** antibodies.
- **B** antigens.
- **C** B-lymphocytes.
- **D** T-lymphocytes.

10 Natural killer cells fight disease by
- **A** destroying pathogens through endocytosis.
- **B** making copies of antibodies.
- **C** raising the body temperature of the organism.
- **D** triggering apoptosis in virus-infected cells.

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11 Isolating and restricting the travel of individuals who may have been exposed to an infectious disease is called
- **A** epidemiology.
- **B** herd immunity.
- **C** indirect contact.
- **D** quarantine.

12 The major histocompatibility complex is
- **A** composed of protein markers on the outside of cells.
- **B** needed to break down pathogens engulfed through endocytosis.
- **C** recognised as an antigen by the immune system.
- **D** triggered by white blood cells when an antigen is detected.

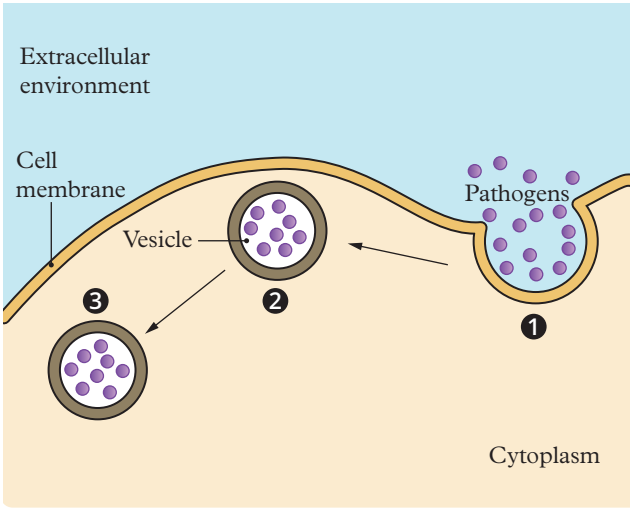
13 The inflammatory response involves the activation of
- **A** neutrophils and macrophages.
- **B** T-lymphocytes and B-memory cells.
- **C** vaccines and antibodies.
- **D** vasoconstriction and reduced heart rate.

14 Which of the following is an example of a vector of human disease?
- **A** bacteria
- **B** contaminated water
- **C** intestinal worms
- **D** ticks

15 The complement system is a part of the immune system that
- **A** adapts to specific pathogens.
- **B** consists of proteins formed in the liver.
- **C** is secreted by skin cells to support the physical barrier provided by the epidermis.
- **D** responds to vaccines.

Short response

16 The image shows the movement of pathogens into a cell of the immune system. (3 marks)



- **a** **Identify** the name of this process. (1 mark)
- **b** **Suggest** what type of immune cell is depicted in this image. (1 mark)
- **c** **Explain** how pathogens are destroyed once they are inside the cell cytoplasm. (3 marks)

17 **Describe** how disease can be spread through water, and provide one example of a disease that can be spread this way. (3 marks)

18 **Explain** how quarantine can effectively minimise transmission of disease. (4 marks)

19 **Classify** the modes of transmission in the table as direct or indirect contact. (5 marks)

Mode of transmission	Direct or indirect?
Airborne droplets through sneezing	
Sexual contact	
Infection through mosquito bites	
Drinking contaminated water	
Physical touch	

20 **Describe** how contact tracing can reduce the number of infections during a pandemic. (3 marks)

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21 **Identify** the characteristics of bacteria that allow them to readily develop antibiotic resistance. (3 marks)

22 **Contrast** endoparasites and ectoparasites, and give an example of each. (3 marks)

23 **Describe** a pathogen and provide two examples. (3 marks)

24 **Describe** how each of the following personal hygiene measures reduce disease transmission:

- cooking food to high temperatures
- washing hands with soap and water after using the toilet
- wearing a face mask when unwell and when travelling on public transport. (3 marks)

25 **Explain** how mosquitoes can act as vectors that transmit disease to humans. (4 marks)

26 **Contrast** the terms "vector" and "reservoir" with respect to disease transmission. (1 mark)

27 **Explain** the role that air travel plays in the transmission of disease. (5 marks)

TOTAL MARKS

/60 marks

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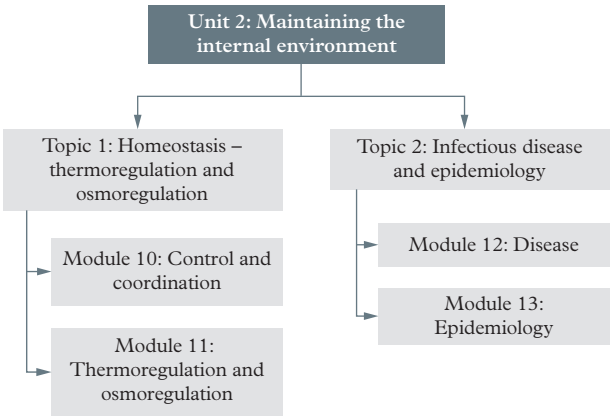
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UNIT 2

Review

Part A – Revisit and revise

Part A of the Unit review asks you to reflect on your learning and identify areas in which you need more work.



Part B – Exam essentials

Now that you've completed your revision for Unit 2, it's time to learn and practise some of the skills you'll need to answer exam questions like a pro! To help you, our expert authors have created the following advice and tips to help you maximise your results on the end-of-year examination.

Exam tip 1: Respond with detail and use scientific language

Some marks rely on sufficient detail and use of scientific terms from the syllabus. A response can be correct but lose marks if it does not contain the correct term or a detailed explanation. To prepare for this, you can do the following:

- Build a list of the scientific terms you are likely to need, and practise defining them and using them in a variety of responses.
- Practise writing out all you know about a concept using all the scientific terminology you can think of, then go back to your notes or textbook and look for terms you may have missed or misused and detail you can add. Write the improved response.

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See it in action

Read the exam question and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

QUESTION 1 (1 mark)

Marielle works as a kitchen hand at a restaurant. During her shifts she will often go between spending time collecting food from the walk-in refrigerator to spending time stocking and preparing food in the warm kitchen. Marielle's body initiates several actions to ensure her body maintains a stable internal temperature. Name the regulatory process that enables the body to maintain a steady internal body temperature despite changes in external conditions.

Complete response

Thermoregulation

1 mark awarded for identifying the specific scientific term used to describe the regulatory process that enables the body to maintain a steady internal body temperature despite changes in external conditions.

Incomplete response

Homeostasis

No marks awarded; the specific scientific term for the process that allows the body to regulate internal temperature is "thermoregulation". While thermoregulation is a homeostatic mechanism, "homeostasis" is not specific enough to be awarded a mark in this question.

Think like an assessor

To maximise your marks on an exam, it can help to think like a QCAA assessor. Consider how many marks each question is worth and what information the assessor is looking for.

A student has given the following response in a practice exam. Imagine you are a QCAA assessor and use the marking guide to mark the response.

QUESTION 2 (1 mark)

During winter seasons, many animals enter a state of hibernation. Define hibernation.

Hibernation is when an animal enters a long period of sleep.

Marking guide

Question 2	• Definition identifies that hibernation as an extended period of torpor and includes characteristics such as sleep, a reduction in body temperature and a reduction in metabolic activity. [1 mark]

Fix the response

Consider where you did and did not award marks in the response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

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Exam tip 2: Read questions carefully

During an exam, you may feel under pressure to get through all the questions as quickly as you can. However, rushing through questions can lead to missing key terms or cognitive verbs in a question. You should read each question carefully to ensure you have identified what you need to provide in your response, in order to address the question without missing elements. Here are some tips to help you.

- Use your perusal time well. This is your first opportunity to read through the questions in the exam. If you pick up on a key term or instruction in the question, make a mental note of it.
- During writing time, be sure to re-read each question and underline key terms, instructions and cognitive verbs.
- After you have written your response, re-read the question a final time to ensure that your response has appropriately addressed all elements of the question.

See it in action

Read the exam question and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

QUESTION 3 (2 marks)

There are many cells in the human immune system that work to eliminate infected cells. Name one of these cells and describe how it works to eliminate an infected cell. (2 marks)

Complete response

1 mark for correctly identifying a cell type that eliminates infected cells.

A macrophage, which uses phagocytosis, the engulfment of a foreign cell, to capture infected cells and digest them

1 mark for describing how the selected cell type eliminates an infected cell.

Incomplete response

1 mark for correctly identifying a cell type that eliminates infected cells.

Natural killer (NK) cells work to eliminate infected cells.

Response is not awarded a second mark, as it does not describe how natural killer cells work to eliminate infected cells.

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QUESTION 4 (2 marks)

Plants have evolved several defence strategies to protect themselves from infection and injury. Identify one chemical defence strategy used by plants and describe how it protects the plants from pathogens.

One plant defence strategy includes barriers such as bark, which provides a thick casing over the plant that makes it difficult for pathogens to enter the internal structures of the plant.

Marking guide

Question 4	• Identifies a chemical defence strategy [1 mark] • Describes how the selected chemical defence strategy protects the plant from pathogen invasion or infection [1 mark]

Fix the response

Consider where you did and did not award marks in the response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

Exam tip 3: Use data to support your response

Some questions that include data sets such as graphs and tables may instruct you to "refer to data" or "use evidence from the data" to support your answer. This means that your response must include values or trends that are presented in the data set. Even if your response is correct, if you have not referred to the data after being instructed to, you will lose marks.

See it in action

Read the exam question on the next page and see how the tip has made a difference between a response that has scored full marks and a response where marks have been lost.

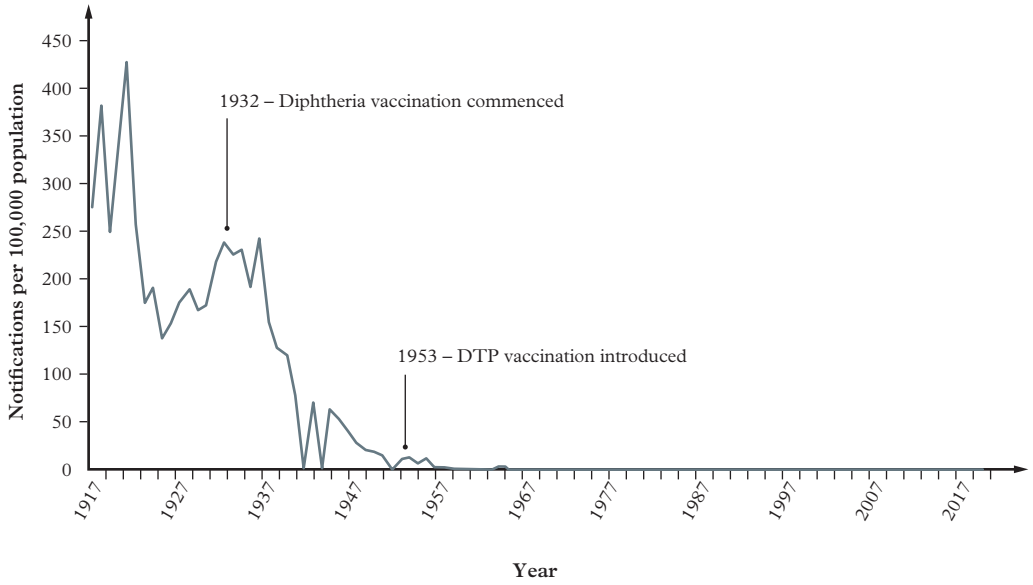
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QUESTION 5 (3 marks)

Diphtheria is an infectious disease transmitted via the transfer of body fluids through sneezing, coughing and open wounds. Approximately 10% of individuals infected with diphtheria will die from the disease. While it can affect people of all ages, it was most often found in children. The causative agent, *Corynebacterium diphtheriae,* was identified in the 1920s and a vaccination program was first implemented in1932. In 1953, the vaccination program in Australian schools was updated to include a combination vaccine for diphtheria, tetanus and whooping cough (DTP).

Referring to Figure 1, describe the effectiveness of the diphtheria vaccination program in Australian schools.



Complete response

1 mark for identifying a steady low incidence of diphtheria following introduction of DTP vaccination.

1 mark for identifying trend in graph after first implementation of diphtheria vaccine.

After the diphtheria vaccination program commenced in 1932, the rate of diphtheria infections began decreasing steadily until it was almost eradicated from the population. There were some spikes of diphtheria in 1942, but after 1953, when the DTP vaccination was introduced into Australian school vaccination programs, the rate of diphtheria decreased again and has remained under control ever since. This decline in cases provides evidence that diphtheria vaccination programs in Australian schools are effective in controlling the incidence of diphtheria.

1 mark for identifying how trends in data support the effectiveness of the diphtheria vaccination program.

Incomplete response

Figure 1 provides evidence that diphtheria vaccination programs in Australian schools are effective in controlling the ncidence of diphtheria.

No marks awarded for this question. While the student has stated that the evidence supports the effectiveness of diphtheria, they have not described the data and explained how this data supports the effectiveness of the vaccination program.

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A student has given the following response in a practice exam. Imagine you are a QCAA assessor and use the marking guide to mark the response

QUESTION 6 (4 marks)

Figure 2 shows changes in urine osmolality and urine production in response to increasing concentrations of ADH. Describe the effect that increasing ADH concentration has on urine osmolality and urine production, using data from Figure 2 to support your answer.

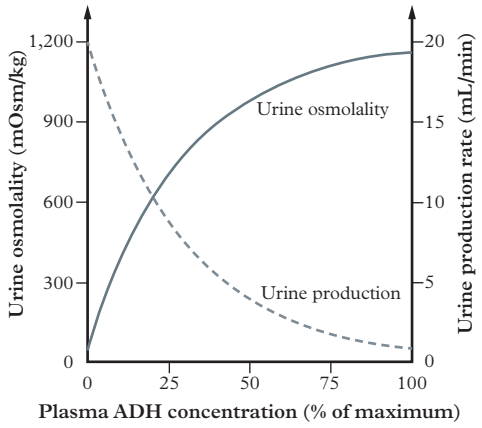


Figure 2 Changes in urine osmolality and urine production in response to increasing concentrations of ADH

As ADH concentration increases, urine osmolality increases. As ADH concentration increases, urine production rate decreases.

Marking guide

Question 6

- Identifies that an increase in ADH concentration results in a decrease in urine production rate [1 mark]
- Identifies points from the data displayed to support that an increase in ADH concentration results in a decrease of urine production rate [1 mark]
- Identifies that an increase in ADH concentration results in an increase of urine osmolality [1 mark]
- Identifies points from the data displayed to support that an increase in ADH concentration results in an increase of urine osmolality [1 mark]

Fix the response

Consider where you did and did not award marks in the response. How could the response be improved? Write your own response to the same question to receive full marks from a QCAA assessor.

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Part C: Practice exam questions

Now it's time to put the tips and advice you've learned into practice while you complete these exam-style questions! You will complete two papers as part of your external examination: Paper 1 tests you on multiple-choice and short-response questions, and Paper 2 tests you on more complex, multi-part short-response questions.

Multiple-choice

1 A synapse is the site of communication between
- **A** two axons.
- **B** two dendrites.
- **C** an axon and a dendrite.
- **D** the central and peripheral nervous systems.

2 Experimentally it is found that the rate of heat loss from a rat is greater than that of an elephant. The best explanation for this observation is that
- **A** small animals eat proportionally more than large animals.
- **B** the simple structures of smaller mammals compared to larger mammals means they are not able to conserve heat.
- **C** small mammals have a larger surface area-to-volume ratio than large mammals.
- **D** small mammals are more active than large mammals.

3 A pandemic occurs when
- **A** a particular infectious disease spreads through many countries at the same time.
- **B** many individuals in a population contract the same disease.
- **C** the pathogen can multiply rapidly.
- **D** a reservoir host is incapacitated.

4 Identification of a viral cause of disease is difficult because
- **A** viruses are too small to be seen through a microscope.
- **B** viruses can only be cultured in living tissue.
- **C** cytopathic effects are only caused by bacteria.
- **D** it can only be achieved by gene sequencing of the viral nucleic acid.

5 In the modelling of infectious diseases, "mortality rate" refers to
- **A** the number of deaths from the disease.
- **B** the rate of death per population size for the disease.
- **C** the number of deaths among those that have contracted the disease.
- **D** the percentage of individuals that have contracted the disease.

6 In thermoregulation,
- **A** thermoreceptors are the effectors.
- **B** the control centre is the hypothalamus.
- **C** the receptors are connected to blood vessels.
- **D** the response is initiated by thermoreceptors.

7 Which of the following types of sensory receptors detect details of light wavelength and intensity entering the eye?
- **A** chemoreceptors
- **B** thermoreceptors
- **C** mechanoreceptors
- **D** photoreceptors

8 The set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane is best known as
- **A** thermoregulation.
- **B** osmoregulation.
- **C** signal transduction.
- **D** homeostasis.

9 In the endocrine system,
- **A** the pituitary gland acts as the control centre.
- **B** hormones act faster than the electrical signals transmitted in the nervous system.
- **C** the posterior pituitary lobe accounts for 80% of the pituitary gland and functions to produce and release hormones.
- **D** target cells have recognition sites for specific hormones.

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10 Salicylic acid (SA) is a plant hormone with a role in defence. On contact with a pathogen, SA is released, which triggers defensive responses in nearby cells. Which type of hormone is SA an example of?

A autocrine
B paracrine
C endocrine
D exocrine

11 A bacterium that is spherical in shape can be described as

A coccus.
B spirillum.
C bacillus.
D vibrio.

12 The humoral response involves activation of

A T-lymphocytes.
B B-lymphocytes.
C histamine.
D antigens.

13 Which of the following is an example of a non-living agent of disease?

A protists
B bacteria
C viruses
D fungi

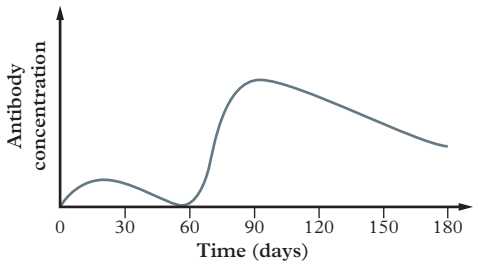
14 Plasma cells differentiate from

A memory B-cells.
B helper T-cells.
C B-lymphocytes.
D cytotoxic T-cells.

15 Brown adipose tissue contains high concentrations of

A ribosomes.
B nuclei.
C mitochondria.
D chloroplasts.

16 The following graph shows an individual's antibody concentration over time.



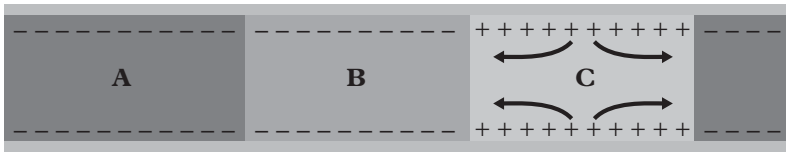
Secondary exposure to an antigen would have occurred at

A 0 days.
B 90 days.
C 180 days.
D 60 days.

17 What is the main method ectotherms use to regulate their body temperature?

A food metabolism
B behavioural responses
C physiological responses
D structural features

18 The diagram represents an action potential travelling along an axon. Which one of the following statements about the diagram is true?



A The axon membrane is resting at point A, repolarising at point B and depolarising at point C.
B The axon membrane is resting at point C, repolarising at point B and depolarising at point A.
C The axon membrane is resting at point B, repolarising at point A and depolarising at point C.
D The axon membrane is resting at point A, repolarising at point C and depolarising at point B.

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19 *Bordetella pertussis* is the bacterial pathogen that causes whooping cough. *B. pertussis* produces a protein that is excreted by the cell. The protein disrupts the immune response by inhibiting the actions of infected cells to attract and recruit immune cells in defence. Determine the type of protein.

A adhesin
B invasion factor
C endotoxin
D exotoxin

20 An antigen is

A a Y-shaped protein produced by B-lymphocytes.
B any agent that transmits an infectious pathogen to another living organism.
C a non-self protein of the surface of an invading pathogen.
D the process of engulfing a bacterium carried out by a macrophage.

Short response

21 **Identify** three characteristics of skin that aid the prevention of infection. (3 marks)

22 **Describe** how quarantine can be used to control the spread of disease. (2 marks)

23 **Define** homeostasis. (1 mark)

24 Parasites need at least one host to survive. **Describe** two problems that can threaten a parasite's chance of survival. (2 marks)

25 **Contrast** infectious and non-infectious diseases. (1 mark)

26 **Distinguish** between positive and negative feedback. (2 marks)

27 **Explain** how a host's immune cells are able to fight pathogens and foreign material without attacking the host's own cells. (2 marks)

28 **Compare** torpor and aestivation. (3 marks)

29 **Describe** the three pathways of complement activation in the immune system. (3 marks)

30 Herd immunity refers to the resistance of a population to a disease through immunity, often achieved by vaccination. The probability of someone catching a disease from an infected person depends on the vaccination rate, and is expressed as a ratio. For instance, when a population is 99% vaccinated, the probability of encountering someone who is unvaccinated is 1:100.

a If 95% of a population is vaccinated against a disease, **calculate** the probability that the first person you meet is unvaccinated. Provide your final answer as a ratio. (1 mark)
b If 80% of a population is vaccinated against a disease, **calculate** the probability that the first person you meet is unvaccinated. Provide your final answer as a ratio. (1 mark)

31 Hendra is a virus that was discovered in 1994 after the death of 13 horses and a trainer in Queensland. Horses become infected after coming into contact with the bodily fluids of flying foxes. Humans, such as trainers and veterinarians, are most at risk of contracting the virus when they come into contact with a horse's bodily fluids.

a **Determine** the primary host of the Hendra virus. (1 mark)
b **Determine** the secondary host of the Hendra virus. (1 mark)

32 Kiff is walking to work one winter morning and he is feeling extremely cold. His body is shivering as he walks, and his hands feel cold to the touch.

a **Explain** how shivering works as a thermoregulatory mechanism to conserve heat. (2 marks)
b **Explain** the thermoregulatory mechanism that might be causing Kiff's hands to feel cold and how this mechanism works to prevent excessive loss of heat. (3 marks)
c When Kiff enters his heated office, he begins to feel excessively warm and begins to sweat. **Explain** how sweating acts as thermoregulatory mechanism to reduce body temperature. (2 marks)

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33 During a bike ride on a hot day, India is feeling thirsty. She goes to take a drink of water from her bag, but realises she has forgotten her water bottle. She will need to wait until she cycles back home before she can have a drink of water.

- **a** **Identify** the name of the type of receptor responsible for detecting changes in water levels in India's blood. (1 mark)
- **b** **Explain** whether the concentration of ADH in India's blood on her way home would be higher or lower than normal. **Justify** your answer. (2 marks)
- **c** **Describe** how the concentration of ADH identified in part b would impact the excretion of urine. (1 mark)
- **d** When India returns home, she drinks a litre of water. **Identify** what would happen to the secretion of ADH after India drinks enough water to feel hydrated. **Justify** your answer. (2 marks)
- **e** **Identify** whether the ADH feedback loop is an example of a positive or negative feedback mechanism. **Justify** your answer. (2 marks)

34 Malaria is caused by a single-celled parasite called *Plasmodium*, which is transmitted to humans by *Anopheles* mosquitoes. The parasite infects red blood cells, growing and multiplying within the red blood cells until they rupture. If an *Anopheles* mosquito bites a malaria-infected person and then bites a non-infected person, that person can then become infected.

- **a** **Define** what a vector is and identify the vector of malaria. (2 marks)
- **b** **Explain** why malaria is considered an infectious disease but not a contagious one. (1 mark)
- **c** Infectious diseases can re-emerge in different ways. **Evaluate** whether malaria can re-emerge after being controlled in a population, and if so, how. (2 marks)
- **d** **Describe** two control measures that may be effective in controlling the spread of malaria in a population. **Justify** your answer. (4 marks)

35 A researcher is investigating the stomatal densities of two plant species, a water lily and a sunflower. After calculating the stomatal densities for the upper side and lower side of the leaf for each plant sample, they realise they have forgotten to label their samples. The calculated stomatal densities for the samples are provided in the table.

Plant sample	Stomatal density (stomata/mm^2)	
	Upper side of leaf	Lower side of leaf
Sample 1	420	0
Sample 2	198	140

- **a** Use data from the table to **infer** which plants sample 1 and sample 2 correspond to. **Justify** your answer. (4 marks)
- **b** **Propose** what type of environment each plant is adapted to live in, based on their stomatal densities. (2 marks)

36 Before there was a vaccine for varicella-zoster virus (the virus that causes chickenpox), some parents would arrange "pox parties" where otherwise healthy children would play with an infected child. This would greatly increase the chance of their children contracting chickenpox through exposure to the virus by droplet spread or by touching an infected sore. Chickenpox is milder in children than it is in adults (where it may develop into shingles). Pox parties also allowed parents to plan for the illness that follows. Now that there is an effective vaccine for chickenpox, pox parties are discouraged by medical professionals.

- **a** **Identify** whether chickenpox is spread through direct or indirect contact. **Justify** your answer. (1 mark)
- **b** Chickenpox is typically only caught once in a lifetime. Some people with compromised immune systems can catch chickenpox more than once. Using your knowledge of the adaptive immune system, **explain** why most people only contract the disease once. (2 marks)
- **c** A person's immunity to chickenpox can build after becoming infected from another individual or by receiving the chickenpox vaccine. **Evaluate** whether these forms of immunity are active or passive, and natural or artificial. (2 marks)

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MODULE 14

Practical manual

Introduction

The QCAA Biology General Senior Syllabus outlines a number of suggested practicals for completion in Units 1 and 2. All practicals are included in this module.

Suggestions for methodology and materials have been supplied in this module, and the practicals are listed in the tables. However, the following is not prescriptive; schools may complete the practicals in any other form suited to their resources.

The experiments in this module have been trialled and cautions of obvious hazards given; however, it is the legal obligation of the individual teacher to carry out their own risk assessment prior to students undertaking any practical activity.

If you are unsure of any procedures in the lab, or need any clarification for a practical, consult your teacher and/or lab technician.

This module will highlight key safety concerns within each practical, but there are some general safety concerns to be considered before completing any practicals.

- → Long hair must be tied back.
- → Do not eat or drink in the lab.
- → Always be aware of others around you and act sensibly.
- → Wear a lab coat, safety glasses, closed-toed shoes and gloves.
- → Review the school's safety procedures and the location of eye wash, shower, spill kits and first aid kits.
- → Handle all chemicals with care, and consult your teacher and the risk assessments for the hazards involved with each chemical.
- → Keep open flames away from flammable materials.
- → Handle hot materials with the appropriate equipment (e.g. heat-resistant gloves or tongs).

It is each teacher's and school's responsibility to conduct a risk assessment prior to any practical covered in this book.

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oxforddigital **Full lessons for this module are available on Oxford Digital. They are also provided as part of a printable resource that can be used in class.**

Unit 1 Practicals

Lesson 1.7	Using a light microscope
Lesson 2.3	Preparation and examination of wet mount specimens
Lesson 2.4	Identifying organelles from electron micrographs
Lesson 2.7	Modelling the selectively permeable membrane
Lesson 2.9	The effect of surface area-to-volume ratio on the rate of diffusion
Lesson 3.3	Organisation of cells into tissues, organs and systems
Lesson 4.3	The effect of enzyme concentration on the rate of reaction
Lesson 6.3	The effect of temperature on the rate of reactions of an enzyme
Lesson 6.4	The effect of pH on the rate of enzyme reaction
Lesson 7.4	Investigating respiration
Lesson 9.3	Stomatal function
Lesson 9.5	The passage of water through flowering plants
Lesson 9.6	Factors affecting the rate of transpiration

Unit 2 Practicals

Lesson 10.4	The reflex arc
Lesson 11.6	The role of the leaf in plant osmoregulation
Lesson 11.7	Investigating tolerance limits for water or salt balance in plant growth
Lesson 13.3	Testing the effect of an antimicrobial agent on the growth of a microbial organism

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Glossary

A

abiogenesis
the theory that living organisms formed from non-living matter

abiotic factors
non-living environmental factors, such as sunlight, temperature and water availability

abscisic acid (ABA)
a plant hormone that regulates numerous aspects of plant growth, development and stress responses

accuracy
how close a measurement is to its true value

acetaldehyde
an organic compound that forms as an intermediate compound between pyruvate and ethanol during alcoholic fermentation

acetylcholine (ACh)
a neurotransmitter involved in many functions in the body, including brain function and muscle movement

acetyl-CoA
a biomolecule involved in metabolism; the substrate that enters the Krebs cycle

action potential
an electrical signal that flows from the soma of a neuron along the axon to the axon terminal, passing information to the next neuron

activation energy
the energy needed to start a chemical reaction

active site
the portion of an enzyme in contact with the substrate; at this stage it has a specific shape that corresponds to the shape of at least a portion of the substrate molecule

active transport
the movement of materials into and out of a cell, usually against a concentration or ionic gradient, requiring cellular energy (ATP)

adaptive immune response
an immune response that is not present at birth but is "learned" when person's immune system encounters foreign invaders and recognises non-self substances (antigens) – the system then generates special chemicals (antibodies) that neutralise the pathogen

adenosine diphosphate (ADP)
the nitrogen base adenine bound to two phosphate groups, each bond requiring an input of energy

adenosine triphosphate (ATP)
an organic chemical able to store and release large amounts of energy; consists of the nitrogen base adenine bound to three phosphate groups

adherence factors
specialised molecular components on the surface of a pathogen that increase its ability to attach to the surface of other cells or structures

adhesin
a protein on the surface of bacteria that helps them adhere to other cells or to inanimate surfaces

adhesive forces
the attractive force between molecules that are different to each other; in this context the attractive forces between water molecules and the xylem cell walls

adult stem cell
a partially differentiated animal cell, responsible for repair and maintenance of the adult body

aerobically
occurring in the presence of oxygen

aerobic respiration
the complete conversion of glucose to carbon dioxide and water in the mitochondria of cells with oxygen present, resulting in the release of a large amount of energy (net gain of 36 ATP)

aestivation
an extended period of torpor in conditions of high temperature and/or low water availability

afferent arteriole
the arteriole leading into a structure, e.g. the glomerulus of the kidney

afferent neuron
a nerve cell that relays signals from sensory receptors to the central nervous system (sometimes referred to as sensory neurons)

affinity
the extent to which a substance tends to bind or attach to another

alimentary canal
a continuous tubular pathway of the digestive system by which food enters the body via the mouth and unused materials are expelled through the anus

allergen
an antigen that causes an allergic reaction in an organism

all-or-nothing response
describes an action potential, which will occur (neurons will fire at full strength) if the threshold potential is met, or not occur (neurons will not fire) if the threshold is not met

allosteric site
a region on an enzyme, separate from the active site, where a molecule may bind, altering the shape of the active site

alternative hypothesis
a hypothesis that predicts an effect or relationship between variables

alveoli
small, thin-walled air sacs in the lungs that allow inhaled oxygen to enter the bloodstream and carbon dioxide to leave the bloodstream; singular "alveolus"

amino acid
a building block of protein; consists of an amino group (NH_2), a carboxyl (acid) group (COOH), a variable (R) group and a hydrogen atom attached to a carbon atom

ammonia
an inorganic nitrogen compound; in animals, a toxic product of the breaking down of excess amino acids

amoeba
a microscopic unicellular protozoan that belongs to the rhizopodan order; plural amoebae

amylase
an enzyme that stimulates the conversion of polysaccharides to disaccharides

anabolism
chemical reactions in which large molecules are built up, usually with a net input of energy

anaerobically
occurring in the absence of oxygen

anaerobic respiration
cellular respiration in the absence of oxygen, resulting in a net gain of 2 ATP and lactic acid (in animals), or ethyl alcohol and carbon dioxide (in plants, fungi and bacteria)

anaphase
the third stage of cell division, in which sister chromatids separate and are pulled to opposite poles of the cell

antibiotic
a drug used to treat bacterial infections

antibiotic resistance
the ability of bacteria to resist the effects of an antibiotic to which they were once sensitive

antibody
a gamma globulin protein in the blood or lymph; produced by B-lymphocytes as an immune defence against foreign agents (antigens)

antidiuretic hormone (ADH)
a hormone that triggers the kidneys to release less water, reducing the amount of urine produced

antigen
a protein on the surface of matter that is foreign to the body

antigen-presenting cell (APC)
an immune cell that processes and presents an antigen for T-lymphocyte recognition

antimicrobial
describes a substance that kills or inhibits the growth of microorganisms, such as bacteria

anus
the end of the alimentary canal, through which faeces (undigested food) are egested

apical meristem
the growing point of the tip of the root and stem in vascular plants

apoptosis
programmed cell death

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arteriole
a small branch of an artery that breaks up into capillaries

artery
a thick-walled blood vessel that carries blood away from the heart; the main artery leaving the heart is the aorta; the smallest arteries are arterioles, which lead to capillaries

artificial active immunity
active immunity acquired by vaccination with a vaccine containing active antigens, to prevent the development of a disease in the future

artificial passive immunity
immunity acquired by injection of serum containing antibodies into an individual who may have been infected with a particular pathogen

assimilation
the incorporation of simple organic molecules, or products of digestion, into complex constituents of the organism

autoimmune disease
a disease in which the body produces antibodies that attack its own tissues

autonomic nervous system
the system that controls the actions of the inner (visceral) body tube; not under conscious control. Two types of motor nerves are involved: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action

axon
a long thin projection from the soma of a neuron (nerve cell) that conducts electrical impulses, called action potentials

axon terminal
a projection at the end of an axon that releases neurotransmitters into the synaptic cleft

B

bacteria
microscopic unicellular organisms that lack a distinct nucleus

bibliography
a list of all references used

biology
the study of all living and once-living organisms on Earth

bladder
a storage organ for urine in vertebrate animals

blastula
a hollow ball of cells resulting from division in an animal zygote

blood
the transporting medium in animal bodies; in mammals, it is composed of plasma, platelets, and red and white blood cells

blubber
a thick layer of fat directly beneath the skin of marine animals

B-lymphocyte
a white blood cell that does not pass through the thymus as it matures; involved in antibody formation

Bowman's capsule
the area of the mammalian kidney nephron in which ultrafiltration of the blood occurs

bronchi
the branches of the trachea that direct air to each lung; singular "bronchus"

bronchioles
the branches of tube between the bronchi and alveoli in the lungs

brown adipose tissue
a type of body fat containing a high concentration of mitochondria to generate energy and heat

C

cambium
a layer of actively dividing plant cells

capillary
a fine blood vessel with walls only one cell thick; capillaries permeate the body tissues and pressure causes plasma to pass out into the tissue fluid

capsule
the outermost layer of some prokaryotic cells, made of polysaccharides; plays a role in adhering to surfaces, substances and other bacteria

carbohydrate
a molecule of carbon hydrated with water; the general formula for monosaccharides is $(CH_2O)n$ (C:H:O = 1:2:1) and for polysaccharides is $(C_6H_{10}O_5)n$ (less hydrogen and oxygen because of glycosidic bonds)

carbonic acid
a type of acid produced when carbon dioxide is dissolved in a solution; lowers the pH of the blood

carrier
a person or organism infected with an infectious disease agent or gene, but who displays no symptoms of the disease

carrier protein
a protein in the cell membrane that transports a molecule across the phospholipid bilayer through an enzyme-like structural change

case fatality ratio
the proportion of deaths within a designated population of "cases" (people with the disease) over the course of the disease

case study
a detailed investigation that focuses on a specific individual, group or occurrence to better understand it

catabolism
chemical reactions in which large molecules are broken down into smaller ones, usually with the release of energy

catalyst
a substance that increases reaction rate without being consumed or changed by the reaction

causation
a cause–effect relationship in which a change in one variable directly results in change in another variable

cell
the basic unit of life, able to perform all fundamental processes of life

cell cycle
the continuous cycle of growth and division in cells

cell interaction
any form of communication or exchange between cells

cell-mediated response
antigen activation of T-lymphocytes in the thymus to release soluble proteins to inactivate a pathogen

cell membrane
a selectively permeable barrier that controls the movement of substances into and out of the cell

cell movement
the migration of cells from one location to another

cell proliferation
the formation of new cells via cell division

cell specialisation
the process in which a generic cell develops the structures needed to function as a specific type of cell

cellular respiration
the breaking down of glucose in cells to release energy; may occur with oxygen (aerobic) or without oxygen (anaerobic)

cell wall
a rigid structure surrounding plant, fungal and prokaryotic cells; provides protection and support for the cell; made up of murein (prokaryotic cells), cellulose (plant cells) or chitin (fungal cells)

central nervous system (CNS)
the coordination centre of vertebrates, consisting of the brain and spinal cord

centriole
an organelle that produces spindle fibres, which separate the chromosomes during mitosis

centromere
the point of attachment of two chromatids

chemical digestion
the hydrolysis of complex organic molecules into smaller units that are small enough to pass through cell membranes; mediated by enzymes specific to each chemical

chemical energy
the energy stored within molecular bonds that is released during a chemical reaction

chemoreceptor
a sensory receptor that detects changes in chemicals

chemosynthesis
the process in which reactions of inorganic substances are used to provide energy for the synthesis of organic compounds

chemotherapy
the treatment of disease using chemicals that have a specific toxic effect on disease-producing microorganisms (e.g. antibiotics) or that selectively destroy cancerous tissue

chloroplast
a plastid (small membrane-bound organelle containing pigment) in the cells of green plants; contains chlorophyll on membranous grana, and enzymes in the liquid stroma; a photosynthetic organelle

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chlorophyll
a pigment molecule that allows plants to convert radiation in sunlight to glucose as an energy source

cholesterol
a steroid in animals; an important component of cell membranes and a precursor molecule for other steroids

chromatid
a replicated chromosome, still attached to the original at the centromere

chromatin
the nucleoprotein (complex of DNA bound around proteins) of chromosomes seen as fine, dispersed threads of genetic material and found in eukaryotic cells

chromosome
a thread-shaped body consisting of nucleic acid (usually DNA) and protein (except in bacteria)

chunk feeder
an animal that ingests large pieces of food

chylomicron
small droplets of lipids, glycerol and fatty acids enclosed in a protein coat; involved in the absorption of products of fat digestion in the alimentary canal directly into the lymphatic system

cilia
microscopic hairlike projections from the cell membrane that pulse, causing currents in the surrounding fluid

cilium
a hair-like extension of the cell membrane; plural cilia

circulatory system
the body system including the heart and blood vessels that is involved in transporting circulatory fluid, such as blood, around the body

closed circulatory system
a circulatory system where blood is always contained within blood vessels and the heart

coenzyme A
a coenzyme in biochemical reactions; reacts with pyruvate to form acetyl-CoA

cohesive forces
the attractive force between molecules allowing them to clump together; in this context the attractive forces between water molecules

collecting duct
a duct into which waste materials from each nephron in the kidney drain

colonial
composed of many unicellular organisms joined into a cluster, where each individual cell can carry out all the functions necessary for life

colostrum
the first form of milk produced by the mammary glands of mammals (including humans) immediately following delivery of a newborn

companion cell
a phloem cell that contains mitochondria to produce ATP energy to supply phloem vessels with energy

comparative investigation
an investigation that compares two or more conditions to identify similarities and/or differences

competitive inhibitor
a substance that occupies the active site of an enzyme and prevents the normal substrate from binding

complement system
a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter

complete anaerobe
an organism that does not need oxygen for cellular respiration

concentration gradient
a difference in the concentration of a solution at two different points, e.g. across a barrier such as a cell membrane

conclusion
a summary of the findings and results obtained from an investigation

confounding factor
an uncontrolled variable that has a systematic effect on the value of the dependent variable; if a confounding variable exists, no valid conclusions about the research can be drawn

consumer
an organism that must consume other living organisms for energy; also known as a heterotroph

contact tracing
a process that identifies people who have been exposed to an infected person

contagious
describes an infectious disease that is transmitted between individuals by physical contact with a diseased individual or by casual contact with their secretions or objects touched by them, or by an airborne route

controlled experiment
an experiment in which a control group or standard acts as a reference for the experimental group, in which only one variable is different from that in the control group

controlled variable
a variable that is kept constant by the experimenter to negate any effects it may have on the dependent variable

core temperature
the temperature of the internal organs in the body

correlation
the relationship between two variables

correlational investigation
an investigation that is run to determine whether a statistical relationship exists between two variables

cortex
the outer part of a vertebrate kidney; contains the Bowman's capsule, glomerulus and convoluted tubules of the nephron

cuticle
a protective film made of cutin that covers the outer layer (epidermis) of leaves

cytokinesis
the division of a cell after mitosis

cytopathic effect
a degenerative change in the appearance of cells

cytoplasm
cell contents not including the nucleus

cytotoxic T-lymphocyte
a type of T-lymphocyte that kills cancerous cells and virus-infected cells

D

data
quantitative or qualitative information; facts and statistics

database
a large, organised collection of data

daughter cell
a cell produced by the division of a parent (mother) cell

decomposer
an organism that breaks down dead and decaying matter for energy

denaturation
the process in which the weak links or bonds in a biological molecule (i.e. proteins, carbohydrates) break down

dendrite
segments branching from the soma of a neuron that detect a stimulus from the environment or other cells

deoxyribonucleic acid (DNA)
a molecule found in nearly all living cells which contains the genetic information responsible for the development and function of an organism

dependent variable
a variable whose value is dependent on another variable

descriptive investigation
an investigation that aims to describe the characteristics of a phenomenon

diaphragm
a sheet-like structure of muscle and connective tissue located between the lungs and the abdomen

diffusion
the movement of molecules from an area of greater concentration to an area of lower concentration

digestion
the process of physically and chemically breaking down food into smaller, usable substances that can be absorbed into the bloodstream

digestive system
the body system involved in physically and chemically breaking down food into smaller molecules able to pass into the bloodstream

dipeptide
a molecule formed by the bonding of two amino acids

direct contact
spread of infectious disease through physically touching, exchanging bodily fluids with, or inhaling droplets from, an infected individual

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disaccharide
a molecule composed of two chemically bound monosaccharides (e.g. sucrose)

disease
an abnormal condition of an organism or part of an organism in which the normal functions of the body are disrupted

distal convoluted tubule
the part of the nephron that joins the loop of Henle to the collecting duct; responsible for the reabsorption of sodium, potassium, phosphate and calcium ions under the control of hormones

double circulatory system
a system of blood vessels where the blood passes through the heart twice in a single circuit around the body

down-regulation
the process of reducing or suppressing a response to a stimulus by reducing the number of receptors on the cell surface

droplet spread
the movement of small amounts of fluid (e.g. saliva) containing a pathogen being spread to another individual through coughing, sneezing or talking

duodenum
first section of the small intestine; receives partially digested materials from the stomach

dynamic equilibrium
a state of balance that exists when the amount of a particular substance entering a cell is the same as the amount leaving it

E

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)

ectotherm
an animal that maintains its internal body temperature by gaining heat from, and losing heat to, the external environment

effector
the cell or organ (e.g. a gland or a muscle) that responds to a stimulus

efferent neuron
a nerve cell that relays signals from the central nervous system to effectors such as muscle cells and endocrine glands

egestion
the removal of undigested food (faeces) from the alimentary canal

electron microscope
a microscope that uses a beam of electrons to form an image of the viewed specimen

electron transfer chain
a series of coenzymes along which high-energy electrons pass, releasing energy to form ATP at each step in the chain; the final stage in aerobic cellular respiration in which most ATP molecules are formed

embryonic stem cell
an undifferentiated, totipotent or pluripotent cell in the early embryo

emulsify
break up large lipid particles into small droplets

endemic
describes a disease that is constantly present at low levels in organisms of a certain group or living in a particular location

endergonic
describes a chemical reaction involving the absorption of energy

endocrine glands
glands in animals that respond to signals from the CNS to release hormones into the bloodstream

endocrine system
a system of glands that secrete hormones into the bloodstream to regulate body function and homeostasis

endocytosis
the movement of materials into the cell

endoparasite
a parasite that lives in the internal organs or tissues of its host

endotherm
an animal that maintains a constant internal body temperature in fluctuating environmental temperatures

endotoxin
a pathogen's toxin that is bound to its outer membrane and is not freely liberated into the surrounding medium

energy
the capacity to do work

environmental condition
a factor in the external surroundings (biotic and abiotic) that surrounds and affects the survival and development of an organism or population

enzyme
a biological catalyst, produced by living cells, that changes the rate of chemical reactions in living organisms

enzyme inhibitor
a molecule that binds to an enzyme and blocks its activity

epidemic
a disease that occurs at higher rates than would be expected in a community or region during a given period

epidemiology
the study and analysis of the distribution (who, when, where) and determinants of health and disease conditions in defined populations

epithelium
body tissue that forms the lining of all internal and external surfaces in the body

erythrocyte
a red blood cell

essential nutrient
a nutrient that must be ingested and absorbed because it cannot be synthesised by the organism

ester bond
a bond formed by condensation between a fatty acid (removal of OH) and glycerol (removal of H)

ethanol
an alcohol with the formula C_2H_5OH formed from the breaking down of glucose in plants, yeasts and bacteria

ethanol fermentation
a biological process in which glucose is converted into cellular energy, with ethanol and carbon dioxide as byproducts

eukaryote
an organism whose cells contain membrane-bound organelles

eukaryotic cell
a cell that contains membrane-bound organelles

evaporative heat loss
the process in which heat is lost when a liquid is converted to gas

evidence
data, observations or facts obtained from research

excretion
the removal of metabolic wastes from the body

exergonic
describes a chemical reaction in which energy is released

exhalation
the movement of air out of the lungs, caused by relaxation of the diaphragm

exocytosis
the movement of materials out of the cell

exotoxin
a protein produced and released by a pathogen

experimental investigation
an investigation that involves manipulating one or more variables to determine whether this results in a change in another variable

experimental test
an experiment in which a single variable is compared with that of a control group

experimental variable
the single factor under investigation in a controlled experiment; also known as an independent variable

externally valid
in relation to investigation results, applicable to other settings outside the investigation

extracellular
located outside the cell

extracellular fluid
body fluid outside the cells of any multicellular organism; enables the transport of materials between cells and maintains a constant environment for cellular processes

extraneous variable
a variable other than the independent variable that may cause changes in the value of the dependent variable

extrapolation
an estimation of a value based on extending a known sequence of values beyond the values that are certainly known

F

facilitated diffusion
the passive movement of molecules loosely bound to carrier molecules through the cell membrane from an area of high solute concentration to an area of low solute concentration

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fact
information that has been verified by observation or experimentation

faeces
a compacted, undigested food mass that is voided from an animal

fatty acid
a compound (RCOOH) formed between a carboxyl (COOH) group and a chain of hydrocarbons of variable length (R)

feedback
a process in which the end product or event of a system influences the operation of that system to regulate its activity

fermentation
the anaerobic breaking down of sugar by bacteria and yeasts to form ethyl alcohol, carbon dioxide and two ATP

filtrate
the fluid that is left after water, ions and small molecules have been filtered out of the blood into the glomerulus of the kidney

flagellum
a whip-like extension of the cell, used in locomotion by some bacteria, protozoa and spermatozoa; plural "flagella"

flatworm
a soft-bodied, flattened invertebrate in the phylum Platyhelminthes

fluid mosaic model
a description of how molecules are arranged in the cell membrane; "mosaic" refers to the many types of molecules (including phospholipids) that make up the structure of the membrane; "fluid" refers to the constant movement of the phospholipids and other molecules that make up the membrane

fluke
a parasitic flatworm in the class Trematoda

fungus
a eukaryotic organism that belongs to the kingdom Fungi

G

ganglia
clusters of nerve cells

gastrula
the early embryonic stage in animals, formed from the ingrowth of cells at one end of the blastula to produce a double layer of cells from which future tissues and organs develop

gene
a segment of DNA that codes for a specific protein and provides the instructions for the formation of a cell

generalisability
the extent to which findings can be applied to other situations or populations

genetic disease
a disease that results from a change in a gene and may be inherited

glomerulus
a capillary knot in the Bowman's capsule through which ultrafiltration of blood (plasma minus protein) into the nephron of the mammalian kidney occurs

glycerol
a structural component of lipids

glycogen
a branched carbohydrate made from many glucose units, which animals use as an energy reserve

glycolysis
the first stage in cellular respiration; occurs in the cytoplasm and results in the gain of 2 ATP and 2 pyruvate molecules; does not require oxygen

glycoprotein
a protein with attached polysaccharides, used in signalling, cell-to-cell communication and tissue formation

glycosidic bond
a bond formed by condensation between two monosaccharides

Golgi apparatus
a membranous stack of cisternae involved in the packaging and secretion of cell products

grana
a stack of thylakoids found within chloroplasts; surrounded by the stroma; a single stack is a "granum"

graph
a pictorial representation that displays values and data in an organised way

guard cells
a pair of specialised cells in the epidermis of leaves that control gas exchange in plants by opening and closing stomata

H

haemoglobin
an iron-containing protein in red blood cells; binds to oxygen for transport around the body

haemolymph
the circulatory fluid in organisms that have an open circulatory system; is a mixture of blood and extracellular fluid

haemolytic anaemia
a form of anaemia due to haemolysis, the abnormal breaking down of red blood cells

halophyte
a plant that has adaptations allowing it to obtain sufficient water in a salty environment

helper T-lymphocyte
a type of T-lymphocyte that stimulates the activity of other immune cells by producing cytokines

hepatic portal vein
the vein that transports absorbed food molecules directly from the small intestine to the liver

herd immunity
a form of indirect protection from infectious disease that occurs when a large percentage of a population is immune to an infection, thereby providing a measure of protection for individuals who are not immune

heterotroph
literally, "other-feeder"; an organism that derives its energy by consuming other living organisms

hibernation
a long-term state of reduced activity in an animal, including metabolic rate, movement and changes to blood flow, triggered by seasonal drops in temperature

homeostasis
the self-regulation of a stable internal environment regardless of external environmental conditions

hormone
a regulatory chemical of the control and coordination system; capable of bringing about a specific response to a particular stimulus

host
an organism that harbours a parasite

humoral response
immunity conferred to an individual through the activity of B-lymphocytes and their progeny, which produce circulating antibodies in response to the presence of an antigen and recognise the substance upon subsequent exposure

hydrophilic
describes substances that dissolve readily in water

hydrophobic
describes substances that are insoluble in water

hydrophyte
a plant adapted to a habitat that is partially or completely submerged in water

hypertonic
a solution with a higher solute concentration than its surroundings

hyponatraemia
a condition that results from low levels of sodium in the blood

hypothalamus
a gland in the brain that maintains homeostasis of several factors and influences some social and reproductive behaviours

hypothesis
a statement that attempts to answer questions raised by observations and can be tested by experimentation

hypotonic
a solution with a lower solute concentration than its surroundings

I

ileum
the last and largest section of the small intestine

immune system
an organism's host defence system, comprising many biological structures and processes that protect against disease

immunological tolerance
the body's failure to mount an immune response to an antigen

incubation period
the time it takes for a pathogen to increase to sufficient numbers in the body to produce symptoms of the disease

independent variable
the variable that is changed or controlled in a scientific experiment

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index
a composite measure that summarises and compares multiple variables and presents these factors as a single number

indirect contact
a means by which infectious disease can spread without direct contact with the infected person, e.g. airborne droplets, contaminated objects, soil, food or water, or by animal or vector transmission

induced-fit model
a model that suggests that the active site of an enzyme, after initially attracting a specific substrate, changes to suit the substrate's shape, which in turn also affects the shape of the substrate

infectious disease
disease that can be passed from one individual to another

inflammatory response
a response of the body to an injurious agent, characterised by swelling, pain and/or heat

information and communication technologies (ICT)
computer and other technologies that process information to perform a range of tasks

ingestion
consumption of materials by an organism

inhalation
the movement of air into the lungs, caused by contraction of the diaphragm

inherited condition
a condition that can be passed from parent to offspring

innate immune response
a system of non-specific defence mechanisms including physical barriers (e.g. skin), chemicals in the blood, and white blood cells that attack foreign cells in the body

inorganic compound
a chemical compound that does not contain carbon (except for carbonates and cyanides) or carbon–hydrogen bonds

insulator
a structure used to prevent heat loss to the environment

integral protein
a protein within the structure of the cell membrane

interferon
a small protein- and glycoprotein-signalling molecule produced by lymphocytes in response to infection and other biological stimuli

interneuron
a type of nerve cell in the central nervous system that relays signals from afferent neurons to efferent neurons in the peripheral nervous system

interphase
stage in the cell cycle in which the cell grows, stores energy and replicates chromosomes

interpolation
an estimation of a value within two known values in a sequence of values

intracellular
located within the cell

in-text references
references that appear in the flow of body text; also known as citations

invasion factor
a protein that allows a pathogen to invade a host cell

isotonic
a solution with an equal solute concentration to its surroundings

K

kinetic energy
the energy of motion

kleptothermy
the sharing of heat between individual animals to maintain thermoregulation

Koch's postulates
general criteria that assess whether an organism is the cause of a disease

Krebs cycle
a cyclic series of chemical reactions in the mitochondria of cells: two acetyl-CoA molecules are converted to citric acid; with the addition of six water molecules, the citric acid releases six carbon dioxide molecules as waste and 16 hydrogen atoms; the hydrogen atoms are transferred to carrier molecules; two ATP are formed

L

lactic acid
an organic acid with the formula $C_3H_6O_3$ formed by the breaking down of glucose during anaerobic cellular respiration in animals

lactic acid fermentation
a biological process in which glucose is converted into cellular energy, with lactate as a byproduct

leucocyte
a white blood cell

light-dependent reactions
the first stage of photosynthesis, in which light energy is converted into ATP and NADPH

light-independent reactions
the second stage of photosynthesis, in which ATP and NADPH are used to convert CO_2 into glucose

light microscope
a microscope that uses visible light and lenses to magnify viewed specimens

lignin
a polymer produced by plant cells to provide strength to xylem cells

limitation
a factor or condition that can affect the validity and/or reliability of results

line graph
a graph of data linking two variables, where one variable is plotted on the *y*-axis and the other on the *x*-axis and the points are connected in a line

line of best fit
a trendline that gives an approximation of the linear relationship between two variables

lipase
the general term for an enzyme involved in the hydrolysis of lipids

lipid
a macromolecule made up of fatty acids and glycerol

lock-and-key model
a model that suggests that the substrate and active site of an enzyme are complementary in shape and fit together like a lock and key

logbook
an organised record of investigation ideas, events, results and interpretations

loop of Henle
an area between the proximal and distal convoluted tubules of the nephron in the mammalian kidney; a counter-current multiplier whereby high salt concentration in the tissue fluid is maintained, resulting in diffusion of water from the filtrate to the surrounding blood capillaries

lungs
a pair of organs in the body that enable gas exchange, to supply the body with oxygen and remove carbon dioxide

lymph
tissue fluid that has been taken up by lymphatic vessels to be returned to the blood (vascular system); contains a high volume of white blood cells

lymphatic vessel
a tubular structure that carries lymph from tissues to the blood circulatory system

lymphocyte
a white blood cell in the lymphatic system

lysosome
an organelle that contains digestive enzymes involved in intracellular digestion

M

macromolecule
a large, complex molecule or polymer consisting of repeated smaller subunits (monomers)

macrophage
a type of white blood cell that engulfs and kills microorganisms, removes dead cells and triggers the action of other immune cells

malfunctioning
not functioning correctly

malnutrition
health problems caused by a poor diet where nutrients are either deficient or excessive

mean
the average of a set of numbers in a data set

measure of central tendency
summary statistic that represents a central point in a data set

measure of variability
summary statistic that describes the spread of data in a data set

mechanoreceptor
a sensory receptor that detects changes in pressure and touch

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medulla
the inner layer of a vertebrate kidney; contains loops of Henle and collecting tubules

medulla oblongata
the part of the brain that coordinates aspects of respiration

memory B-cell
a small, long-lived B-lymphocyte that has previously encountered a given antigen; on re-exposure to the same antigen, it rapidly initiates the immune response

memory T-lymphocyte
a long-lived T-lymphocyte that has previously encountered a given antigen; on re-exposure to the same antigen, rapidly initiates the immune response

mesophyte
a plant adapted to a habitat that has a frequent and reliable source of fresh water

metabolism
all the chemical reactions occurring within a cell

metaphase
the second stage of cell division, in which the chromosomes align in the middle of the cell and spindle fibres attach to the centromeres

microscopic
so small that it can only be seen with a microscope

microvillus
a projection from the surface of cells; forms a brush border that increases the surface area of the cell membrane; plural "microvilli"

mitochondrion
a membrane-bound cellular organelle; has enzymes for cellular respiration on inner folded membrane (cristae), and a fluid matrix; plural "mitochondria"

mitosis
nuclear division resulting in daughter cells with the same number and types of chromosomes as in the parent cell

mobility
the movement of people within and between populations

monomer
a molecule that can bond to other identical molecules to form a large molecule (polymer)

monosaccharide
a monomer of carbohydrates

mortality rate
the ratio of deaths in an area to the population of that area; expressed per 1000 per year

mouth
the opening of the anterior region of the alimentary canal, through which food is ingested

mucous membranes
membranes that line various cavities in an organism's body and cover the surface of internal organs

mucus
an aqueous fluid that is secreted by and covers mucous membranes

multicellular
composed of many cells

multipotent stem cell
a stem cell that can only differentiate into a limited number of closely related cell types

murein
a glycoprotein (protein–carbohydrate complex) that forms the cell wall in bacteria

myelin
a lipid-rich substance that coats the axons of neurons

myelin sheath
a layer of myelin that wraps around the axon of a neuron to insulate electrical impulses

myoglobin
a protein in the muscles that can bind to oxygen

N

natural active immunity
immunity that occurs when a person is exposed to a live pathogen and develops a primary immune response, which leads to immunological memory

natural killer (NK) cell
a specialised lymphocyte involved in the innate immune response; induces apoptosis in tumour cells and virus-infected cells

natural passive immunity
antibody-mediated immunity conveyed to a foetus or infant by the mother

negative feedback
a form of feedback in which a signal triggers a process to stop when the optimal range of a factor has been reached

nephron
the functional unit of the vertebrate kidney

nerve
a bundle of dendrites and axons wrapped in connective tissue; transmits information between the peripheral and central nervous systems

nervous system
a biological system made up of the brain, spinal cord and nerves; sends messages and coordinates actions

neurotransmitter
a chemical that passes across the synapse between the axon terminal of one neuron to the dendrites of another

neutrophil
a phagocytic, granulocytic white blood cell

nociceptor
a sensory receptor that detects signals from damaged tissue

nodes of Ranvier
spaces between Schwann cells where the axon is not covered by the myelin sheath; allows acceleration of the action potential along the neuron

non-competitive inhibitor
a substance that binds to the allosteric site of an enzyme and permanently reduces or blocks an enzyme's activity

non-contagious
describes an infectious disease that is not able to be transmitted directly between individuals of the same species; rather, it is spread by exposure to pathogens in the environment, vectors, infected animals or uncontrolled microbe growth

non-essential nutrient
a nutrient that can be synthesised by an organism

non-infectious disease
disease that cannot be passed from one individual to another

non-scientific idea
an idea or theory that is not based on empirical evidence and has not been tested or supported by the scientific method

non-specific immunity
immunity that an organism is born with and protects against all pathogens rather than specific pathogens

noradrenaline
a neurotransmitter involved in arousal and the 'fight-or-flight' response

nuclear envelope
the membrane that encloses the nucleus and is structurally similar to the cell membrane; allows the transport of specific molecules into and out of the nucleus; must be broken down for cell division to occur

nucleoid region
in prokaryotic cells, the region within the cell in which genetic material is located; not bounded by a membrane

nucleolus
a spherical area within the nucleus that is the site of ribosome production; contains RNA and proteins

nucleoplasm
a protoplasm within the nuclear membrane; contains DNA, RNA and proteins; involved in control of cell activities through protein production and cell division

nucleus
control centre of the eukaryotic cell

null hypothesis
a hypothesis that predicts no effect or no relationship between variables

nutrient
any substance used as food by an organism

nutritional disease
a disease resulting from deficiencies or excesses in the diet

O

open circulatory system
a circulatory system where the circulatory fluid is not entirely contained within vessels but is pumped into a body cavity

organ
a group of different tissues bound together to perform a particular function

organelle
a subcellular structure that has at least one specific function

organic compound
a complex carbon compound formed by living things; usually a macromolecule

organism
a living thing

osmolality
the concentration of particles dissolved in a fluid

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osmoreceptor
a sensory receptor that detects changes in osmotic pressure

osmoregulation
the physiological regulation of water and salt concentrations in the body

osmosis
the movement of water through a selectively permeable membrane, from a region of low solute concentration to a region of high solute concentration, to counteract the difference in solute concentration

osmotic balance
the balance of water and salt concentrations in the body

osmotic potential
the potential for water to move through a permeable membrane from an area of low solute concentration to an area of high solute concentration

overnutrition
a form of malnutrition in which one or more nutrients is oversupplied

oxygen debt
the amount of oxygen required to convert the lactic acid produced during anaerobic respiration to pyruvate

P

pandemic
an epidemic of infectious disease that has spread across a large region (e.g. multiple continents) or worldwide

parasite
an organism that lives in or on another organism and derives nourishment from the host

partial anaerobe
an organism that can undergo a period of anaerobic cellular respiration when oxygen is at low levels or in short supply

passive transport
the movement of materials into and out of a cell without the expenditure of energy

pathogen
a biological agent that causes disease or illness

pathogenesis
the series of steps by which a pathogen causes disease in a host: adhesion, colonisation, invasion, evasion of host defences, and damage to host tissues

pathogen persistence
a pathogen's ability to survive within a host organism after infection

Pearson's correlation coefficient (*r*)
a measure of the strength of the linear relationship between two continuous variables

peer review
the process in which experts evaluate the quality, relevance and validity of another researcher's work prior to its publication

peptide bond
a bond formed from condensation between two amino acids, where hydrogen (H) is lost from the amino group and a hydroxyl group (OH) from the carboxyl group

percentage
a number expressed as a fraction of 100

peripheral nervous system (PNS)
the system of nerves that carries stimulus information from receptors to the CNS, and nerves that carry responses from the CNS to effectors

peripheral protein
a protein attached to, or partially embedded in, the cell membrane

peristalsis
waves of contraction and relaxation in the muscular walls of the alimentary canal, aiding in mechanical digestion and moving food along its length

phagocytosis
"cell eating": engulfing of a solid material by a cell through extension of the cell membrane over the particle, and formation of a food vacuole

phagosome
a small food vacuole that encapsulates a phagocytosed particle for digestion

pheromone
a hormone released as an external signal to other members of the species

phloem
vessels within a plant that transport sugar produced by photosynthesis to other parts of the plant; phloem vessels may carry dissolved sugars in any direction within the plant, by active transport (ATP energy)

phloem fibre
a long, thin cell that gives strength and flexibility to phloem

phospholipid
the major unit of the phospholipid bilayer, composed of a hydrophilic phosphate head and hydrophobic fatty acid tails; provides structure for the cell and helps separate the cytoplasm from the external environment

phospholipid bilayer
the main structure of the cell membrane, consisting of two layers of phospholipids arranged with the hydrophilic heads facing the internal and external fluid environments

phosphorylation
the addition of a phosphate group to a molecule; can be non-cyclic (e.g. formation of ATP) or cyclic (e.g. the cyclic flow of electrons along the electron transfer chain from chlorophyll, the released energy being used in the formation of ATP)

photolysis
the process of light energy breaking the bonds between atoms in molecules

photon
a packet of energy in sunlight that can excite electrons

photoreceptor
a sensory receptor that detects changes in light wavelength and intensity

photosynthesis
the series of reactions that converts light energy into chemical energy in the form of glucose; summarised as $6CO_2 + 6H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2$

photosystem I
a structure made of proteins containing chlorophyll; located in the thylakoid membrane in chloroplasts; facilitates production of NADPH from NADP+

photosystem II
a structure made of proteins containing chlorophyll; located in the thylakoid membrane in chloroplasts; facilitates photolysis of water to produce oxygen gas and hydrogen ions

physical digestion
the breaking down of food into small units by the crushing or cutting actions of mouthparts (in invertebrates), teeth, muscles and so on.

pili
in many prokaryotes, small hair-like projections that are used for adhesion to surfaces, other bacteria and host cells

pinocytosis
"cell drinking": formation of channels in the cell membrane that take in fluid at their base

pinosome
a vesicle filled with extracellular fluid, brought into the cytoplasm through pinocytosis

pituitary gland
a gland in the brain that controls growth, metabolism and the activity of other endocrine glands

plant defensin
a protein produced by a plant to inhibit development of fungi, bacteria and viruses

plasma
the liquid component of blood; contains water, salts, hormones and waste materials such as carbon dioxide

plasma cell
a cell developed from activated B-lymphocytes that makes large numbers of a specific antibody

plasmid
a small, circular molecule of DNA that differs from a cell's chromosomal DNA

plasmolysis
the shrinkage of the cytoplasm of a plant cell away from the cell wall as a result of loss of water from the cell by osmosis

pluripotent stem cell
a stem cell that can differentiate into any cell type within a broad group

polarised
the state of a cell when the electrical charge on the inside of the cell membrane is different than that of the extracellular environment

polypeptide
a macromolecule formed by the union of many amino acids

polysaccharide
a complex carbohydrate composed of many monosaccharides bonded together

population
the group that scientists wish to draw conclusions about

positive feedback
a form of feedback in which a signal triggers the amplification of a process to bring about change in the body

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post-synaptic membrane
a section on the membrane of a post-synaptic neuron; contains areas adapted to receive neurotransmitters

potency
the ability to differentiate into other cell types

potential energy
stored energy

precision
how close a set of data values are to each other

prediction
forecast of a future event based on similar known events

pre-synaptic terminal
a specialised area at the end of an axon; contains synaptic vesicles that store neurotransmitters

primary data
firsthand data collected from an experiment designed to answer the specific research question

primary host
a host in which the parasite reaches maturity and, if possible, reproduces sexually

primary structure
the first level of structure of protein molecules; a chained linear sequence of amino acids

prion
an abnormal form of a normally harmless protein, found in the brain; causes a variety of fatal neurodegenerative diseases of animals, including humans

producer
an organism that produces its own energy by absorbing light energy and converting it into a usable form; also known as an autotroph

prokaryote
an organism without a membrane-bound nucleus or membrane-bound organelles

prokaryotic cell
a cell that does not contain a membrane-bound nucleus or membrane-bound organelles

prophase
the first stage of cell division, in which the chromosomes condense, sister chromatids join together and the nucleolus and nuclear membrane dissolve

prostaglandin
a chemical released from damaged cells that directs blood flow to an injured area

protease
the general term for an enzyme involved in the hydrolysis of proteins

protein
a macromolecule consisting of one or more polypeptide chains; may be folded, branched and/or cross-linked at intervals

protein channel
a channel that passes through the centre of a protein; its lining is hydrophilic and it is the site of facilitated diffusion of large or highly polarised molecules

protein-mediated active transport
the transport of molecules or ions against a concentration gradient via specific proteins; requires energy (ATP) and is therefore considered "active"

protist
a eukaryotic organism that is not an animal, land plant or fungus

proximal convoluted tubule
the tubule of the kidney nephron arising from the Bowman's capsule and leading to the loop of Henle; responsible for the reabsorption of glucose, sodium chloride and water

pseudopodium
a temporary foot-like extension of the cell membrane of some protozoans, resulting in a flowing movement of the protozoan; plural pseudopodia

public health program
a program undertaken by organisations to prevent disease, prolong life and promote human health through informed choices

pulmonary circulation
the circulation of deoxygenated blood from the right side of the heart to the lungs, and the return of oxygenated blood from the lungs to the left side of the heart

pyramid
the bundle of collecting ducts in the mammalian kidney

pyruvate
the product of glycolysis; used to synthesise many metabolic pathways

Q

qualitative
descriptive

quantitative
measured

quarantine
strict isolation of an individual, imposed to prevent the spread of disease

quaternary structure
the fourth level of structure of a protein molecule; exists when more than one polypeptide chain is folded into a three-dimensional molecule

R

random error
an error due to the limitations (uncertainty) of the measurement equipment, and the uncontrollable effects of the method and the environment on the measurement

random sample
sample of individuals from a larger population chosen in a way where everyone is equally likely to be selected

random sampling
a sampling procedure in which every member of the population has an equal chance of being selected for the sample

rate of diffusion
the speed at which various substances diffuse into or out of a cell

ratio
a measure that compares the magnitude of two quantities in terms of how many times one value is contained within the other

reactant
a substance that is present at the start of a reaction and changes as the reaction proceeds

receptor
molecules that monitor internal and external stimuli

reflex arc (reflex)
a neural pathway connecting sensory neurons to interneurons in the spinal cord and directly to motor neurons, to enable a rapid response without processing by the brain, e.g movement of a limb away from extreme heat

refractory period
a period of time in which the neuron cannot fire another action potential

refute
contradict or not support (in relation to the hypothesis)

repolarisation
the change in membrane potential that occurs after the depolarisation phase of an action potential

regulator
the part of the central nervous system that receives a stimulus signal and responds by sending a signal to an effector

reliability
the extent to which a measurement, test or investigation produces consistent results

renal artery
the blood vessel entering the kidney

renal pelvis
a funnel-shaped expanded area where the ureter leaves the kidney

renal vein
the blood vessel leaving the kidney

repeatability
the extent to which the same results can be produced by a researcher when the experiment is performed again under the same conditions

replicate
a result obtained from repetition of a measurement using the same methodology, conditions and materials

reproducibility
the degree to which the same results can be generated by other researchers using different equipment and methods in different laboratory settings

reservoir host
an organism that can harbour a pathogen indefinitely with no ill effects

respiratory system
the body system that delivers oxygen to the body and expels gaseous wastes such as carbon dioxide

response
an organism's reaction to a stimulus

ribosome
a complex molecular structure found in all cells which creates proteins in a process called protein synthesis

rough endoplasmic reticulum (rough ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cell; proteins are synthesised on ribosomes

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roundworm
a nematode worm that infests the intestines of humans or other mammals

RuBisCO
an essential enzyme in photosynthesis; catalyses carbon fixation and oxygenation

S

saccharide
a sugar compound

sample
a subset of the population of interest in a study

saturated
describes a lipid in which the carbon atoms are linked by single bonds only (C–C)

scale
the relationship between the actual size of an object/specimen/area and how it is presented in a depiction

scatterplot
a graph in which the values of two variables are plotted along two axes, the pattern of the resulting points revealing whether a relationship (correlation) exists

Schwann cell
a cell that produces fatty myelin, which makes up the myelin sheath of a neuron

scientific idea
an idea or theory that is based on empirical evidence and has been tested or supported by the scientific method

scientific law
a scientific theory that has been continually upheld by experimentation; a statement based on repeated experimental observations

scientific method
the testing of hypotheses by controlled experimentation

scientific theory
a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment

secondary data
secondhand data obtained from other sources

secondary host
a temporary host for a parasite

secondary structure
the second level of structure of protein molecules; the local arrangement of a protein backbone that has been stabilised by intramolecular hydrogen bonding

self-renewal
the ability to divide to produce more stem cells

serum
a suspension of pre-formed antibodies administered to provide artificial passive immunity against a particular disease

shivering
an involuntary motor response that causes muscle contractions to generate heat

sieve tube
a transport vessel made up of a long chain of sieve elements attached end-to-end at the sieve plate; allows passage of cytoplasm carrying dissolved organic molecules around the plant

signal transduction
a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane

signal transduction pathway
a cascade of biochemical reactions inside a cell that eventually reaches the target molecule or reaction; initiated when a molecule (e.g. a hormone) attaches to a receptor on the cell membrane

simple diffusion
the unaided movement of molecules or ions across a differentially permeable membrane from an area of high solute concentration to an area of low solute concentration

SIR model
a method that models or tracks the numbers of susceptible, infected and recovered individuals during an epidemic

smooth endoplasmic reticulum (smooth ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cell; lipids and steroids are produced here

sodium–potassium pump
an integral protein in the cell membrane of animal cells that pumps sodium ions across the cell membrane against the concentration gradient

soma (cell body)
the main body of a cell, containing the cytoplasm and nucleus

solute
the substance that is dissolved in a solution

solvent
the liquid in which other substances (solutes) are dissolved to form a solution

Spearman's rank (*p*)
a measure of the strength and direction of a monotonic relationship between two variables

standard deviation
a measure that describes how far, on average, scores are different from the mean

standard error
the standard deviation of the sampling distribution of a statistic

starch
a complex carbohydrate made up of many glucose units joined by glycosidic bonds

stem cell
a cell that is capable of forming different cell types

steroids
a class of lipid molecules that have a distinct chemical structure that contains four fused carbon rings

stimulus
a change in the internal or external environment that can be detected by receptors

stomata
openings created by guard cells in the leaf of a plant; allow gas exchange and water evaporation from the transpiration stream; singular "stoma"

stratified sampling
a sampling procedure in which population is divided into strata and random samples are selected from each stratum

stroma
the colourless fluid contained within a chloroplast that surrounds the grana and contains enzymes used in the light-dependent reaction of photosynthesis

student's *t*-test
a statistical test used to determine whether the difference between the means of two groups is statistically significant

substrate
the molecule(s) that an enzyme reacts with to form an enzyme–substrate complex

summary statistic
a value that provides a summary of a data set

support
agree with (in relation to the hypothesis)

suppressor T-lymphocyte
a type of T-lymphocyte that regulates the actions of some other lymphocytes to prevent over-activity of the immune system

surface area-to-volume ratio (SA:V)
the ratio of a cell's surface area compared to its volume, a critical factor in the survival of cells; cells with greater surface area in proportion to their volume are able to transport nutrients and wastes of metabolic processes more efficiently

sweating
a thermoregulatory response that releases liquid from the body's sweat glands

synapse
the junction between adjacent neurons, or neurons and effectors, where neurotransmitters are released and received

synaptic cleft
the space between the axon terminals of one neuron and the dendrites of another

system
different organs working together to perform a specific function

systematic error
an error that causes readings to deviate from the true value by a consistent amount and in the same direction each time a measurement is made; it is affected by the accuracy of the measurement process

systematic sampling
a sampling procedure in which samples are selected based on a systematic interval from a randomly chosen starting point

systemic circulation
the circulation of oxygenated blood from the left side of the heart to the body cells, and the return of deoxygenated blood from the body cells to the right side of the heart

T

table
a format for presenting data in rows and columns

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tapeworm
a ribbon-like parasitic worm in the class Cestoda

telophase
the fourth stage of cell division, in which sister chromatids reach the ends of the cell and unravel back to chromatin, and the nuclear membrane and nucleolus re-form

tertiary structure
the third level of structure of a protein molecule; exists when a polypeptide chain is folded into a three-dimensional molecule

thermogenesis
the internal generation of heat by an organism

thermoreceptor
a sensory receptor that detects changes in temperature

thermoregulation
the maintenance of internal body temperature within a tolerable range for an individual; may be achieved through behavioural or physiological processes

threshold potential
the level of depolarisation across the cell membrane required to initiate an action potential

thylakoid
membrane-bound, disc-shaped structures found in chloroplasts; the site of the light-dependent reactions of photosynthesis

tissue
a group of cells of the same cell type, performing a function

tissue fluid (extracellular fluid)
fluid formed from plasma that has been pushed out through the walls of capillaries under arterial pressure; surrounds the cells, providing a medium for exchange between blood and the cells

T-lymphocyte
a lymphocyte that has passed through the thymus during maturation

tolerance range
the range of an environmental factor of an organism from the lowest level to the highest level it can tolerate for survival

torpor
a short-term state of reduced activity in an animal, including metabolic rate and movement, triggered by short-term fluctuations in temperature

totipotent stem cell
an undifferentiated cell that can later differentiate into any type of cell

toxin
a chemical compound produced by plants to protect against herbivores and pathogens

trachea
a tube that moves air from the mouth and nose to the lungs; also known as the windpipe

tracheid
the thinnest tubes of xylem for transporting very small amounts of water; unperforated and lignified

transcription factors
proteins that switch particular genes on or off

translocation
the movement of organic materials around a plant in phloem vessels by active transport

transpiration stream
the stream of water that enters the plant from the soil into the roots and travels through the xylem before evaporating through the stomata

transport system
a system of vessels responsible for the movement of materials throughout an organism

triglyceride
a lipid formed from one molecule of glycerol and three molecules of one or more types of fatty acids

true value
the value of a measurement if it were measured perfectly

turgor pressure
the pressure exerted by fluid within a plant cell as it presses the plasma membrane against the cell wall

U

uncertainty
the degree to which the result of a measurement does not reflect the exact (true) value of what is being measured

undernutrition
a diet in which the individual is not getting enough calories, protein or micronutrients

undershoot
when a membrane potential briefly becomes more negative than its resting potential

unicellular
composed of a single cell

unipotent stem cell
a stem cell that can only form one cell type on division

unsaturated
describes a lipid in which the carbon atoms are linked by one or more double bonds (C=C)

up-regulation
the process of increasing the response to a stimulus due to an increase in the number of receptors on the cell surface

urea
a water-soluble nitrogenous excretory product of protein breakdown

ureter
a duct that leads from the kidney to the bladder

urethra
a tube running from the bladder to the body's exterior; in human females, it eliminates urine; in human males, it is joined by the vas deferens, so it eliminates semen as well as urine

urine
the excretory fluid produced in the kidney; contains metabolic wastes (urea, salts) in a watery solution

V

vaccination
injection of a killed or weakened microbe, or parts of a microbe, in order to stimulate the immune system against the microbe, thereby preventing disease

vaccine
a biological suspension administered to provide artificial acquired immunity against a particular disease

vacuole
a cellular inclusion or space within a cell; small in animal cells (food storage or digestion), large in plant cells (storage and osmotic control)

validity
a measure of whether an investigation is sound and measures what it is intended to measure

variance
a measure of how spread data is from the mean

vasoconstriction
the narrowing of blood vessels close to the surface of the skin, to reduce heat loss to the environment through radiation

vasodilation
the widening of blood vessels close to the surface of the skin, to increase heat loss to the environment through radiation

vector
any agent that carries and transmits an infectious pathogen into another living organism

vein
a thin-walled blood vessel that carries blood towards the heart; the smallest veins begin at the capillaries; the largest vein in animals is the vena cava, which enters the heart

ventricle
one of two muscular chambers of the heart that blood out of the heart into the arteries

venule
a thin-walled vessel that directly connects capillaries to veins

vesicle
a membrane-bound structure that, in neurons, stores neurotransmitters before they are released into the synaptic cleft

vessel element
pitted, narrow tubes for transporting small amounts of water within the xylem; reinforced with lignin to provide strength

villus
a finger-like projection of the lining of the small intestine; increases the surface area available for absorption; plural "villi"

viroid
an RNA molecule without a protein coat

virulence
the ability of a pathogen to cause disease or damage to its host

virulence factor
a molecule that can contribute to the survival of a pathogen

virus
a non-living infectious microbe that requires a host cell to replicate

W

working hypothesis
the most successful hypothesis of a particular investigation

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X

xerophyte
a plant with adaptations that allow it to function with little water

xylem
vessels that transport water and dissolved minerals from the roots of a plant to the leaves, allowing the passage of water upwards through the plant in the transpiration stream

xylem fibre
non-living xylem cells that provide strength and support to water-carrying xylem vessels and tracheids; do not transport water themselves

xylem parenchyma
the only living cells of the xylem tissue in plants; transport water and nutrients and store carbohydrates, oils and tannins

Z

zoonosis
an infectious disease that is transmitted from animals to humans

zygote
a fertilised egg cell that has the potential to form all the cells of an organism

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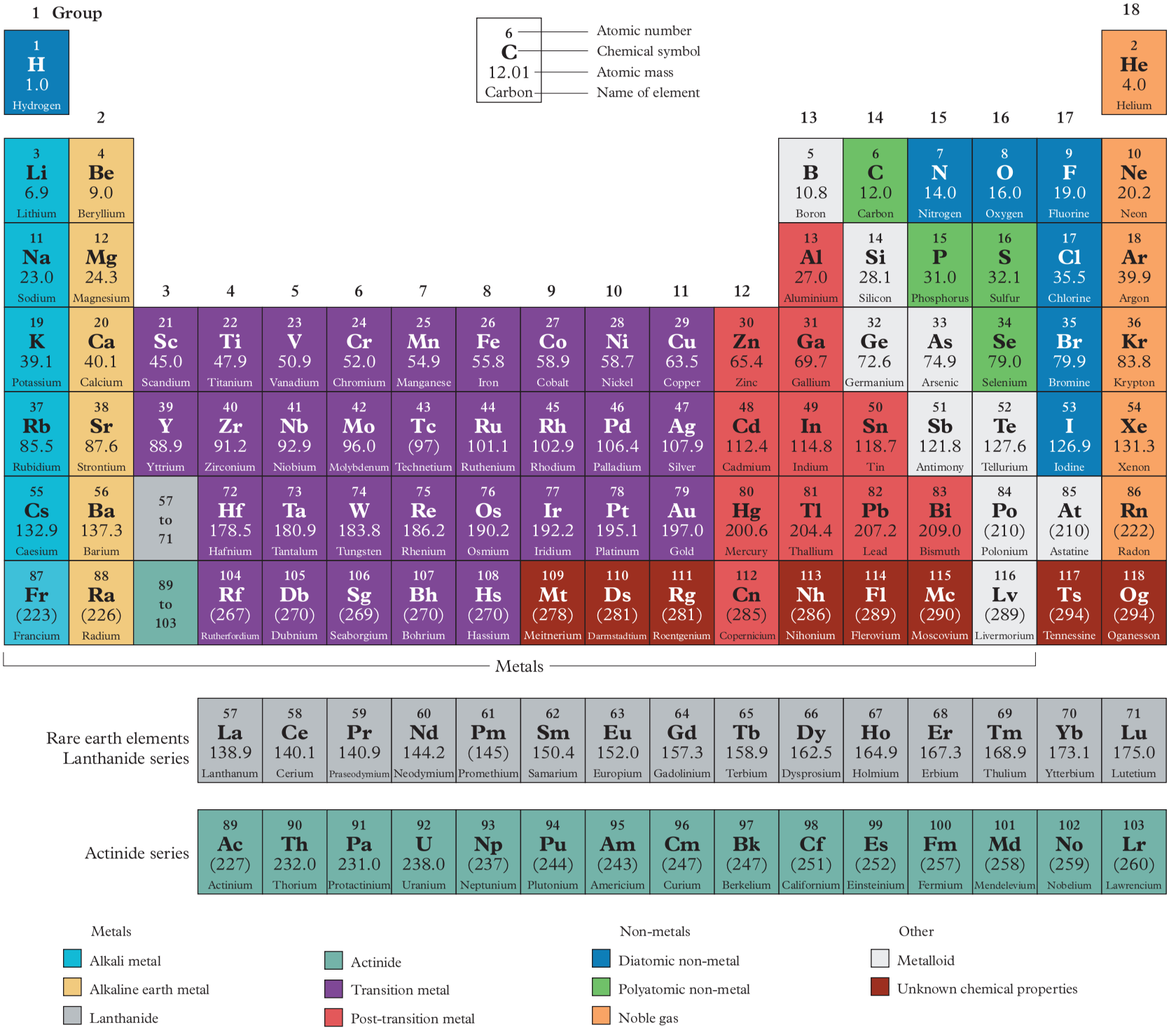
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Appendix: Periodic table



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