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BIOLOGY

FOR VCE

UNITS 1&2

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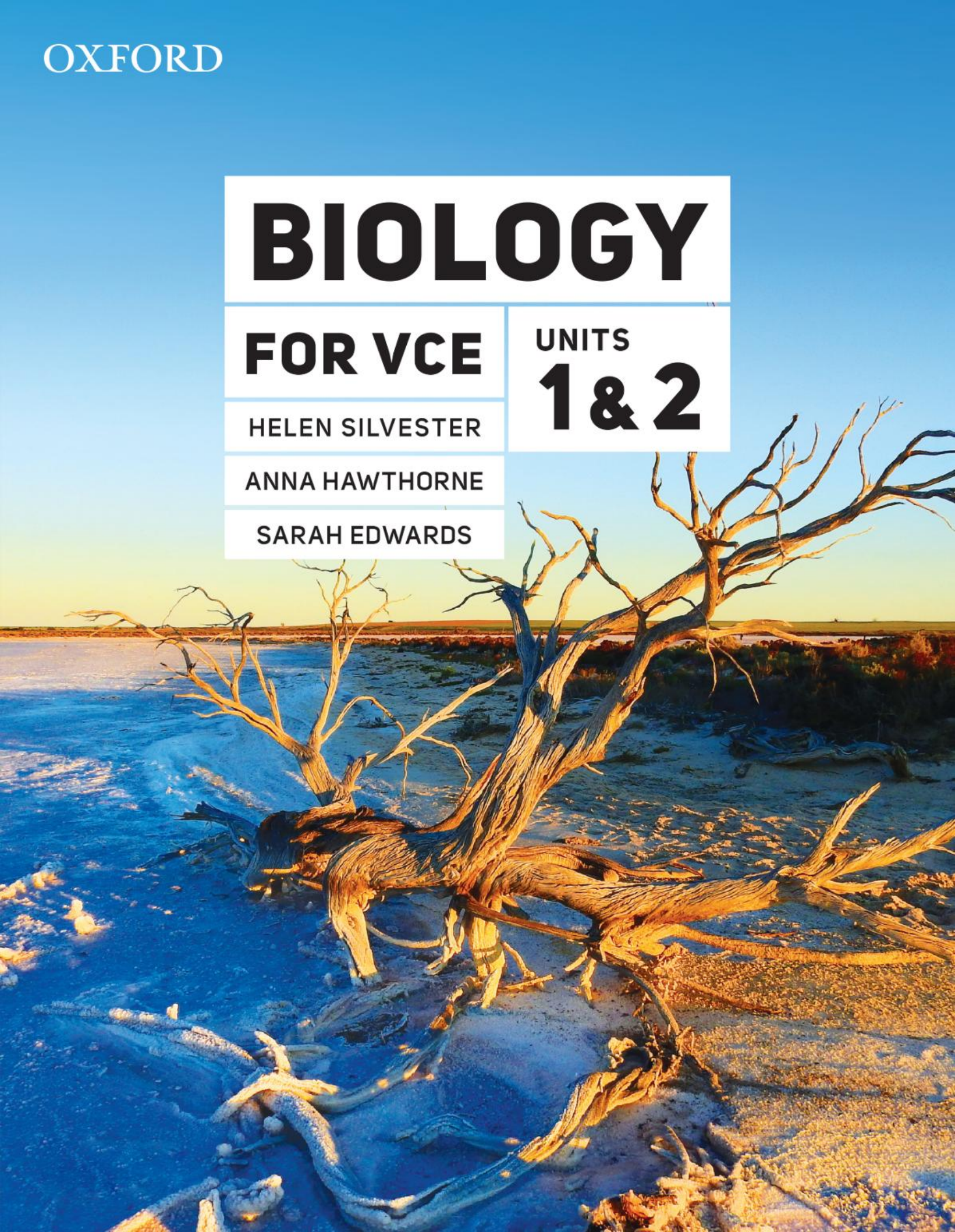

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ABOUT THE AUTHORS AND REVIEWERS

Helen Silvester

Helen Silvester has been an educator for over 20 years, is extremely passionate about writing and reviewing, and has held Head of Science positions in a number of schools. She was shortlisted for the 2014 and 2017 Prime Minister's Secondary Science Prize for Excellence in Science Teaching in Secondary Schools and was Victoria's representative for the BHP Billiton Science Teachers Awards. Helen has also worked as a researcher at Walter and Eliza Hall Institute and the Royal Children's Hospital. Currently, Helen is Director at STEAM-focused Casey Tech School and is a reviewer and moderator of VCE Biology exams.

Anna Hawthorne

Anna Hawthorne has a wide range of experience teaching Secondary Science and VCE Biology. She currently teaches at Mentone Girls' Grammar School, where she was granted an enterprise award to design a Year 10 science elective to incorporate science and enterprise on the foundation of cosmetic chemistry. Anna is also an experienced author of educational resources, having designed lesson sequences and written exam style questions for publishers.

Sarah Edwards

Sarah Edwards has been an educator for over 10 years and has taught at Mentone Girls' Grammar. Sarah has a wealth of experience teaching Science 7–10 and Biology, and was a previous Head of Science in New Zealand. Sarah currently works as a STEAM educator at Casey Tech School.

Dr Gary Simpson

Dr Gary Simpson has a wealth of experience in teaching VCE Biology, Environmental Science and Geography. He currently teaches Junior Science 9–10 at Woodleigh High School and was previously Head of Science. Gary is an exam assessor for Biology and Geography, a Panel Chair for Environmental Science, and a co-author of the VCE Biology Study Designs 'Units 1 & 2 2016–2020' and 'Units 3 & 4 2017–2021'. Gary received ACEL's inaugural Teacher Leader Award in 2007 and was inducted into the Zoos Victoria Hall of Fame in 2015.

Dr Kyi Muller

Dr Kyi Muller is a highly trained biology researcher and educator with more than 8 years' teaching experience. She has a doctorate in marine biology and has worked at Haileybury for 4 years as Head of Science and the Director of Innovation and Entrepreneurship. Kyi now works as a learning designer at Monash University. She is extremely passionate about science education and was previously the Program Director for Curious Minds – an Australian Government initiative to increase access for girls to STEM education. Kyi was also awarded the 2019 Graeme Clarke Science Innovation in Schools Award.

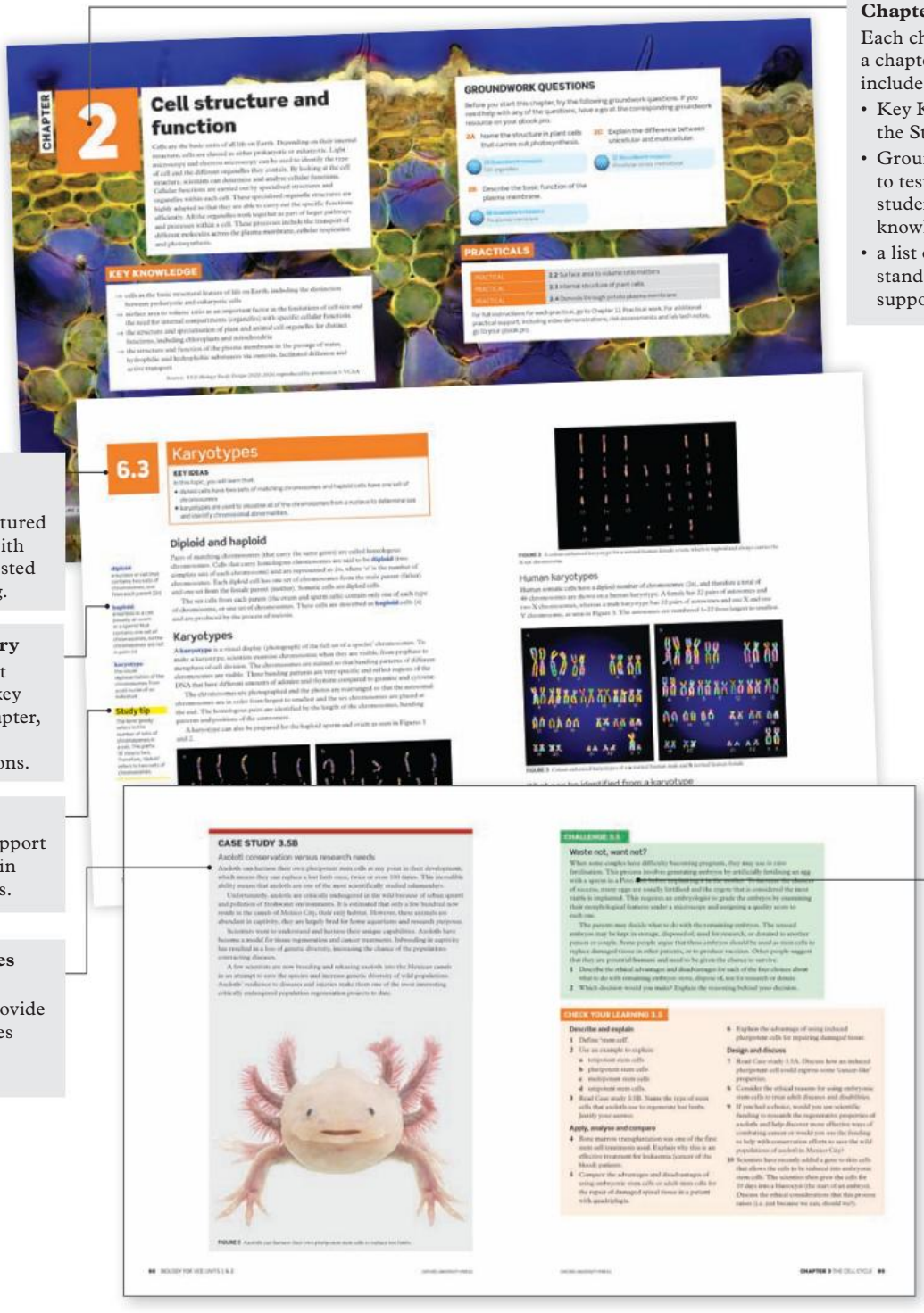
Dr Ngaree Blow

Dr Ngaree Blow is a Noonuccal, Goreng-Goreng, Yorta-Yorta woman living on Wurundjeri country. She is currently working as the Director of First Nations Health for medical education at the University of Melbourne, as well as completing research in the Intergenerational Health team at the Murdoch Children's Research Institute (MCRI). Ngaree completed both her Doctor of Medicine and Masters of Public Health (MD/MPH) degrees concurrently and has a keen interest in public health and paediatric medicine. Ngaree is also a board member of the Australian Indigenous Doctors Association (AIDA) and has been involved in many First Nations health, research and education roles.

Biology for VCE Units 1 & 2 has been developed for the VCE Biology Study Design for 2022–26. This new series offers a suite of resources including Student Books, Workbooks and digital resources that offer teachers and students a clear pathway to VCE Biology success.

Student Books

The Biology for VCE Student Books feature a clear and engaging design, with targeted on-page features to support student understanding and preparation for VCE success.



Chapter opener
Each chapter begins with a chapter opener that includes:
- Key Knowledge from the Study Design
- Groundwork questions to test and support students' assumed knowledge
- a list of no-tech and standard practicals to support key concepts.

Topic-based approach
Content is structured in clear topics with key ideas signposted at the beginning.

Margin glossary
Literacy support is provided for key terms in the chapter, with clear and concise definitions.

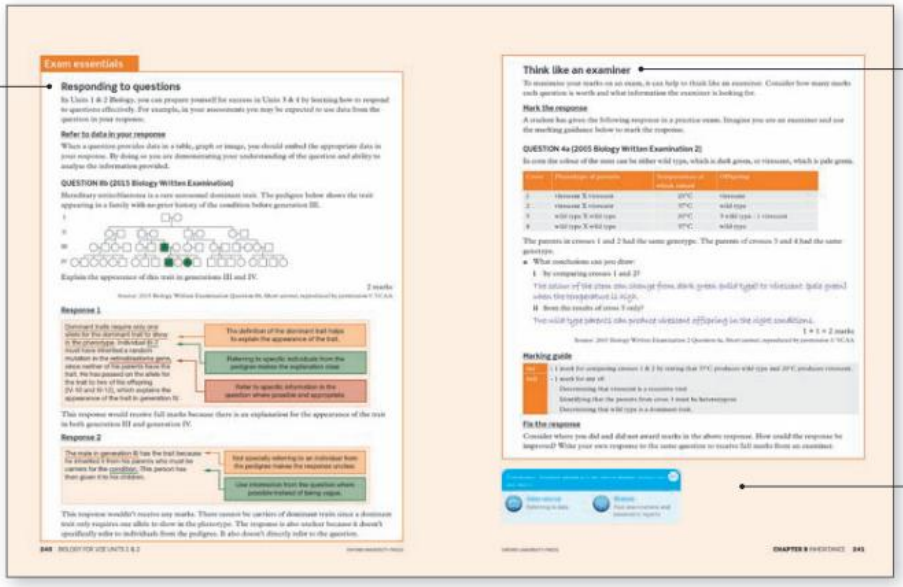
Study tips
Practical tips support student success in SACs and exams.

Case studies
Real-life examples provide opportunities to apply key knowledge.

Challenge questions
Extension questions and scenarios encourage critical thinking.

Worked examples
Detailed worked examples take students through different problems and show them how to solve them.

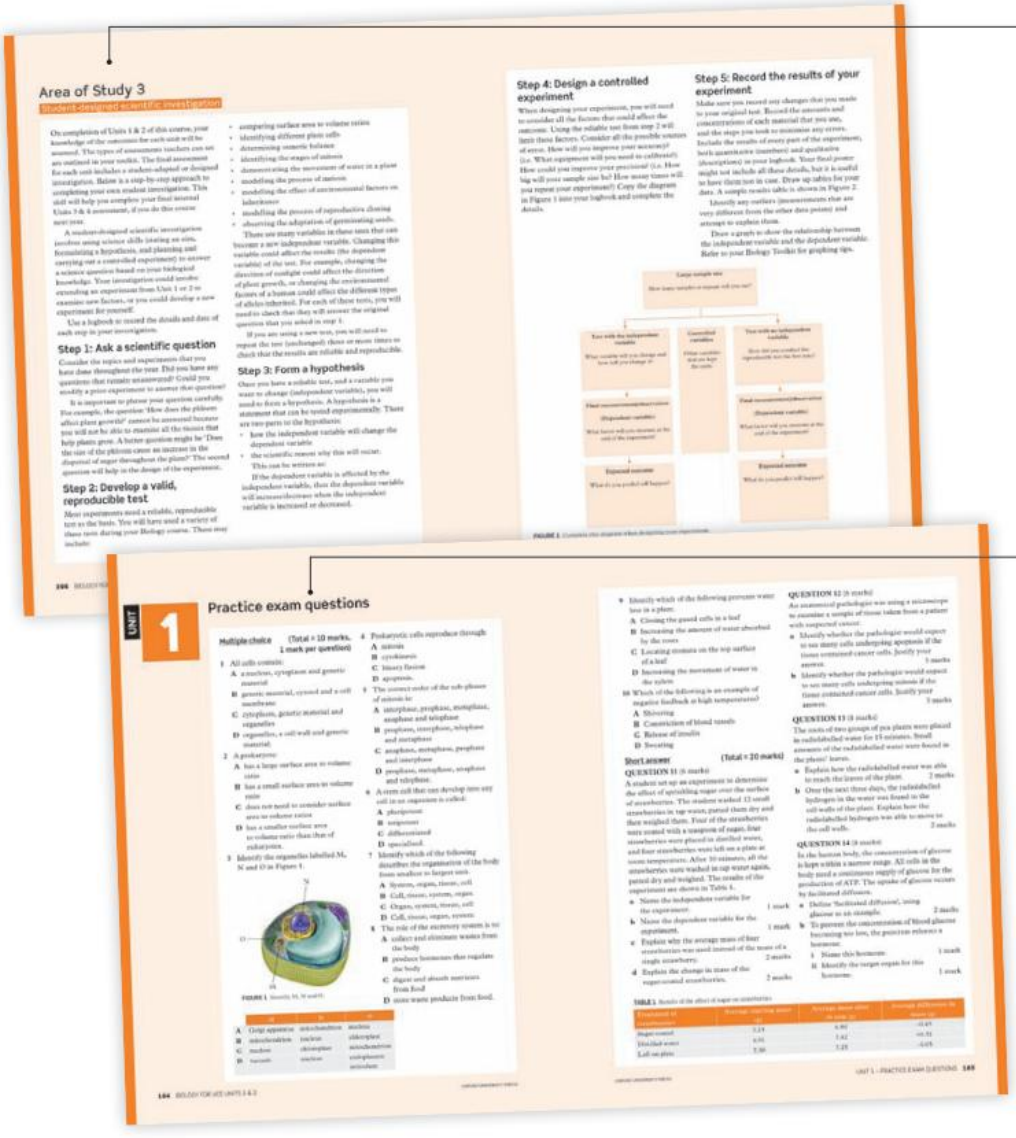
Responding to questions
Provides tips and strategies for maximising marks on exam responses



Think like an examiner
Encourages students to think about how marks are awarded in an exam

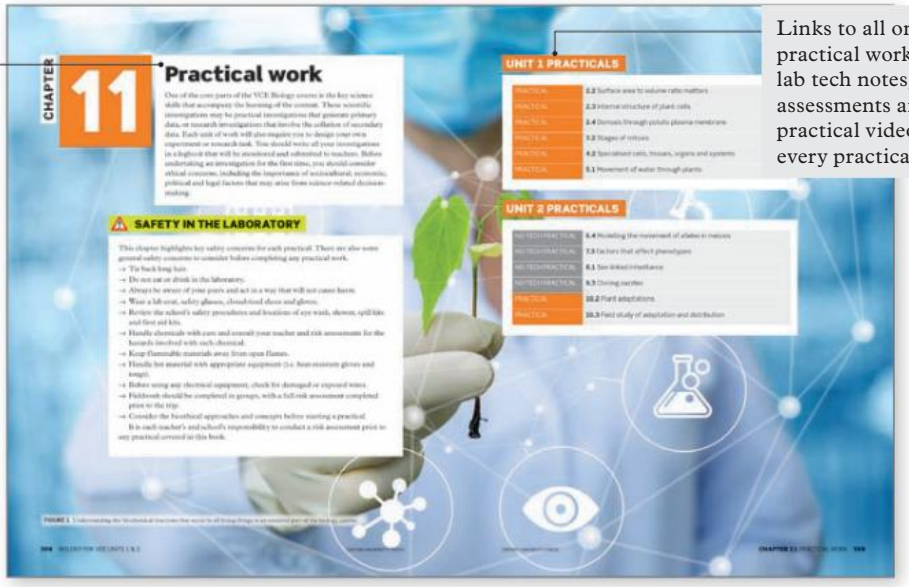
Digital links to your obook pro at the point of learning

Investigation guidance
Step-by-step guidance to help students plan, conduct and present their student-designed scientific investigation.



Practice exam questions
Exam-style questions for students to practise writing responses; includes question sets for Unit 1, Unit 2 and combined Units 1 & 2

Practical work
The practical work includes:
- at least one practical per chapter
- safety guidelines for working in a lab
- no-tech practicals that can be completed outside the lab
- standard practicals that can be completed in any school lab.

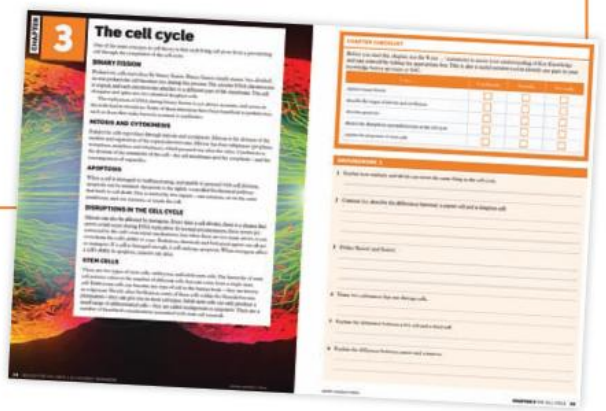


Links to all online practical worksheets, lab tech notes, risk assessments and practical videos for every practical.

Student Workbooks

Biology for VCE Student workbooks are designed to help students succeed in VCE, providing activities and questions to practise for SACs and exams. With an engaging design, full-colour photos and relevant scientific diagrams throughout, these write-in workbooks help students to develop examinable key science skills. The workbooks include:

» a stand-alone **biology toolkit** teaching students how to read and use biological data, how to write and present reports, how to use their logbooks, and how to answer exam questions and read an examiners report
» full **chapter summaries** and chapter checklists for students to self-assess their understanding of Key Knowledge
» **support groundwork questions** to assess student understanding
» four activities per chapter – Case cracker, Data drill, Experiment explorer and Evaluating ethics to **practise key science skills** and **prepare for SACs**
» Unit 1, Unit 2 and Units 1 & 2 **practice exam questions**
» write-in **practical worksheets** from the student book
» **answers to all questions**.

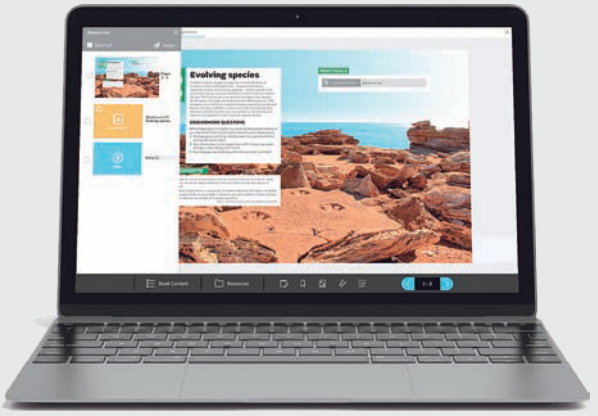


Digital resources

obook pro is Oxford's next generation digital learning resource that offers an interactive digital version of the Student Book with links to additional resources including videos and online assessments. This digital format can be used to immerse students in digital learning, or as part of a blended print and digital approach to learning.

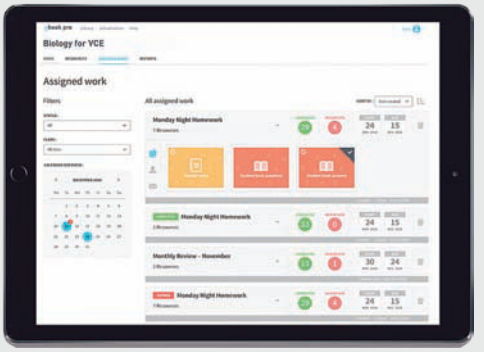
Biology for VCE Units 1&2 Student obook pro is hosted on oxforddigital, the home of Oxford's digital resources.

Student obook pro



Students receive:

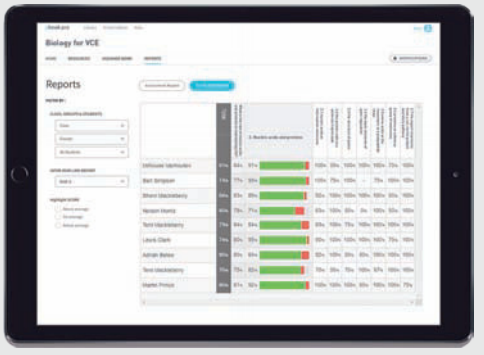
- a complete digital version of the Student Book with interactive note-taking and bookmarking functionality
- integrated Australian Concise Oxford Dictionary look-up feature
- targeted instructional videos for key concepts, practicals and worked examples
- groundwork resources to support assumed knowledge
- interactive assessments to consolidate understanding
- auto-marked practice exam question sets
- integrated QuizletLive sets including real-time online quizzes with live leaderboards
- access to their online assessment results to track their own progress.



Teacher obook pro

In addition to the student resources, teachers receive:

- answers to all questions in the Student Book
- detailed planning resources
- practice exams
- the ability to assign resources and assessments to students
- reporting functionality that tracks student progress and success.



CHAPTER 1

Biology toolkit

Biology is an evolving science that seeks to understand the diversity of life on Earth. Studying biology provides a diverse range of career opportunities, from anthropologist to zoologist. Biologists investigate the different types of organisms, their origins, locations and interactions with other organisms and non-living factors within the environment. Biologists investigate these interactions through observations, measurements and experiments. They formulate hypotheses that can be tested and then modified in a process called the scientific method.

You need to understand the structure of the VCE Biology course so that you can develop and apply biological concepts. This chapter contains a toolkit of ideas and skills to refer to throughout your Units 1 and 2 VCE Biology course.

KEY SCIENCE SKILLS

Throughout VCE Biology Units 1 & 2, you will apply the following key science skills:

→ develop aims and questions, formulate hypotheses and make predictions
→ plan and conduct investigations
→ comply with safety and ethical guidelines
→ generate, collate and record data
→ analyse and evaluate data and investigation methods
→ construct evidence-based arguments and draw conclusions
→ analyse, evaluate and communicate scientific ideas.

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

FIGURE 1 Biology is the study of living things, which sometimes involves observing life under a microscope.

1.1 Biology as a subject

KEY IDEAS

In this topic, you will learn that:

- biology is the study of all living things
- there are many career pathways that stem from studying biology
- the VCE Biology course is made up of four units
- Aboriginal and Torres Strait Islander Peoples – the traditional owners of Australia – have different methods for taking care of the land and producing medicine.

biology
the science of living things, which is divided into different fields that cover the morphology, physiology, anatomy, behaviour, origin and distribution of organisms

Biology is a diverse and evolving science based on the study of all living things. It explores life by investigating the structure, function, origin, development and geographic distribution of organisms. Biologists investigate the processes of living things from the molecular level through to the entire organism, and then consider how those organisms function and interact.

There are many branches of biology, including botany, genetics, immunology, microbiology, pharmacology and zoology, and they can be applied to a wide range of human endeavours.

The five basic principles

All branches of biology are unified by a framework of five basic principles. These principles state the following:

- All living things are composed of cells, the basic units of life.
- All living things require energy, and energy flows between organisms and the environment.
- All living things contain genetic material, the 'barcode' for the structure and function of all organisms.
- All living things must maintain homeostasis, a relatively stable internal environment.
- The concept of evolution unifies all living things.

Biology as a career

Studying biology provides a pathway that can lead to a range of careers. With ongoing advances in technology and biological concepts, career options in biology continue to grow. These include, but are not limited to:

- allied health professional
- bioengineer
- biotechnologist
- ecologist
- medical practitioner
- pharmacologist
- research scientist.

There are also many career opportunities in cross-disciplinary areas such as bushfire research, environmental management and conservation, forensic science, medical research and many other fields.

core skills
basic 'soft skills' required in most careers

All science disciplines, including biology, teach a wide variety of **core skills**, such as:

- problem solving
- teamwork
- research
- critical thinking
- communication
- attention to detail
- innovation.

CASE STUDY 1.1

Meet a scientist

Dr Matthew McKenzie is a Melbourne-based lecturer and scientist. His work focuses on the function of mitochondria (small organelles in cells) and how dysfunctional mitochondria can cause diseases in humans. His love for science began at a very early age by watching science fiction such as *Dr Who* and *Star Wars*. These TV shows and movies engaged Matthew's interest in science and led him to question how things worked. His true love for biology developed when he started his science degree at the University of Melbourne after finishing VCE.

During his science degree, Matthew began specialising in biochemistry and molecular biology and he particularly enjoyed conducting his own experiments in these areas. After finishing his undergraduate degree, he completed an Honours year studying colorectal cancer at the Western Hospital in Footscray. This led to a three-year position as a research assistant working on breast cancer at the Genomic Disorder Research Centre in Melbourne. During this time, he met his eventual PhD supervisor and developed an interest in mitochondrial biology and disease.

FIGURE 1 Dr Matthew McKenzie has a PhD in mitochondrial disease. He is a lecturer and research group head at Deakin University and a research scientist.

After spending time overseas completing his doctorate and postdoctoral studies, Matthew returned to Melbourne to establish his research career. Matthew has established his own independent research laboratory and has received an Australian Research Council Future Fellowship, which provides financial support to continue his research on mitochondrial disease. His laboratory investigates the molecular aspects of mitochondrial disease to better understand how disruption of mitochondria causes problems in patients.

Studying biology can lead to a range of careers, as seen with Matthew's story from completing VCE to leading his own research program and all the career stages in between.

Structure of the VCE Biology course

Weblink
VCE Biology Study Design

The Victorian Curriculum and Assessment Authority (VCAA) sets the Study Design for each VCE subject, and Biology is one of the five science courses that are offered at VCE.

VCE Biology provides you with the opportunity to engage in a range of inquiry tasks to develop key science skills that identify the links between theory, knowledge and practice. By taking this course, you will develop an understanding of how life has evolved and how this has shaped the biodiversity of species on Earth.

Units 1 and 2 are designed to be the first year of the VCE Biology course. They build a foundation of biological concepts for Units 3 and 4. However, Units 1 and 2 are not a prerequisite for Units 3 and 4.

TABLE 1 The VCE Biology course, Units 1–4

Unit	Description
1 How do organisms regulate their functions?	Unit 1 considers life from cell structure and function to multicellular life and the requirements for sustaining life. You will focus on the cell cycle and learn about system regulations in plants and animals.
2 How does inheritance impact on diversity?	Unit 2 looks at how biological information is transferred from generation to generation and how that affects diversity of a species. You will look at asexual and sexual reproduction, including current cloning technologies. You will also look at interdependencies between species, physiological and behavioural adaptations, and contributions from Aboriginal and Torres Strait Islander Peoples' knowledge of Australian ecosystems.
3 How do cells maintain life?	Unit 3 is based on understanding life at a cellular level. You will investigate the structure and function of cells, as well as the nature of biochemical pathways, specifically photosynthesis and cellular respiration, across two areas of study.
4 How does life change and respond to challenges?	Unit 4 considers the continuous changes and challenges for life on Earth. You will investigate the functioning of the immune system and the issues and challenges related to disease. You will also consider how the concept of biological evolution is based on an accumulation of evidence, how speciation occurs through isolation and divergence, and evidence of change through measurements of relatedness between species.

TABLE 2 Units 1 and 2 breakdown of areas of study

Unit 1	
Area of Study	**Description**
1 How do cells function?	This Area of Study focuses on the structure and function of prokaryotic and eukaryotic cells. You will learn about the plasma membrane and the different modes of transport across plasma membranes. You will also learn about the cell cycle from growth to death, stem cells and their role in differentiation, and key events in the cell cycle.
2 How do plant and animal systems function?	This Area of Study explores how systems function through cell specialisation in vascular plants and in animal digestion, and endocrine and excretory systems. You will also consider regulation of water balance and temperature in plants, and blood glucose and water balance in animals.
3 How do scientific investigations develop understanding of how organisms regulate their functions?	In this Area of Study, you will design and conduct an investigation that explores the function and/or regulation of cells and systems.
Unit 2	
Area of Study	**Description**
1 How is inheritance explained?	This Area of Study focuses on key events in meiosis, particularly gamete production. You will investigate patterns of inheritance, genetic crosses and pedigree charts. Trait changes are considered from one gene, many genes and genes interacting.
2 How do inherited adaptations impact on diversity?	This Area of Study considers the advantages and disadvantages of asexual and sexual reproduction. You will consider genetic diversity and structural, physiological and behavioural adaptations. Interdependencies between species and the importance of keystone species are discussed. Aboriginal and Torres Strait Islander Peoples' knowledge of Australian ecosystems is reviewed.
3 How do humans use science to explore and communicate contemporary bioethical issues?	In this Area of Study, you will explore a contemporary bioethical issue related to genetic knowledge, reproductive science, inheritance or adaptations and interdependencies between species that enable them to survive.

Aboriginal and Torres Strait Islander Peoples' knowledge, cultures and perspectives

Within the VCE Biology course, the special relationship **Aboriginal and Torres Strait Islander Peoples** have with waterways, sea, sky and land is acknowledged. It is important to consider and understand the unique history and cultural diversity of Aboriginal and Torres Strait Islander Peoples and the ways of being, knowing, thinking and doing. First Peoples' knowledge of the land has been passed on for generations through song and dance, as well as Dreamtime stories, and there are many things to be learnt from the traditional custodians of Australia.

FIGURE 2 The gum that exudes from the bark of the *Corymbia gummifera* tree is used as an antiseptic by Aboriginal and Torres Strait Islander Peoples.

The traditional custodians of Australia are people who are of Aboriginal and/or Torres Strait Islander descent, and who identify and are accepted as such by the community in which they live. Aboriginal and/or Torres Strait Islander Peoples may also be referred to as Indigenous, First Nations, First Peoples and/or Traditional Custodians/Owners when referring to a collective group. Indigenous Peoples are also identified by their particular Community, Nation, Tribe or Clan that they/their family and/or community recognise.

The knowledge, cultures and perspectives of more than 250 language groups belonging to a particular **Country** or **Place** of Australia are embedded throughout the VCE Biology course, with a specific focus in Units 2 and 4. Area of Study 2, Unit 2, discusses the contribution of Aboriginal and Torres Strait Islander Peoples' knowledge of species in Australian ecosystems. Indigenous Australians have a profound relationship with the land – Indigenous Peoples honour and respect biodiversity. Indigenous Peoples' understanding of traditional seasons, farming and fire practices has allowed for occupation and respect for the land for thousands of years.

Area of Study 1, Unit 4, investigates the impact of European arrival on the spread of diseases, particularly on the Aboriginal and Torres Strait Islander Peoples. Area of Study 2, Unit 4, discusses the migration of modern humans with a focus on Aboriginal and Torres Strait Island Peoples populations migrating into Australia and the connection to Country and Place.

Aboriginal and Torres Strait Islander Peoples
the original inhabitants and custodians of the land now known as Australia, inhabiting this land for more than 65 000 years

Country
an area (not just geographical) that is traditionally owned and looked after by an Aboriginal (and sometimes Torres Strait Islander People) language group or community; a place of spiritual meaning with deep feelings of connection and attachment

Place
a space confined by physical or intangible boundaries occupied and regarded as belonging to individuals or groups of Torres Strait Islander Peoples (and sometimes Aboriginal Peoples); the spaces have varying spiritual meaning to the people

CHECK YOUR LEARNING 1.1

Apply, analyse and compare

1 Investigate a branch of biology that interests you. Research and describe this area of biology and justify your choice.

2 Compare the terms 'Country' and 'Place'.

Design and discuss

3 Discuss the research work of Dr Matthew McKenzie. What is the importance of his current project?

4 Choose one of the following to conduct research on:

- **a** traditional medicines in Australia
- **b** traditional methods of caring for the Australian land
- **c** the migration of Aboriginal and Torres Strait Islander Peoples into Australia.

Present your findings to your class.

1.2 Key science skills

KEY IDEAS

In this topic, you will learn that:

+ the key science skills are important to succeeding in VCE Biology.

Study tip

When formulating hypotheses, consider the relationship between the independent and dependent variables, and make sure the possible outcome is formed from accurate scientific knowledge.

The key science skills are central to the VCE Biology course, across Units 1–4 and over all Areas of Study. They will be essential when you undertake investigations and evaluate research.

These science skills are important for planning and conducting practical investigations, collating and analysing primary and secondary data, organising data in an informed manner, identifying errors and uncertainty, critically evaluating methodology, and researching and communicating scientific ideas. Practising the key science skills is important for succeeding in your assessments, and opportunities for this are available throughout this course.

FIGURE 1 You need to determine how you are going to conduct your investigation and what kind of data you will measure.

Understanding the key science skills

There are seven main key science skills, which you should consider when conducting practical investigations and evaluating research. These are summarised in Table 1.

TABLE 1 The key science skills as outlined by VCAA

Key science skill	VCE Biology Units 1–4
Develop aims and questions, formulate hypotheses and make predictions	• identify, research and construct aims and questions for investigation • identify **independent**, **dependent** and **controlled variables** in controlled experiments • formulate **hypotheses** to focus investigations • predict possible outcomes
Plan and conduct investigations	• determine appropriate investigation methodology: case study; classification and identification; controlled experiment; correlational study; field work; literature review; modelling; product, process or system development; simulation • design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated • work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications
Comply with safety and ethical guidelines	• demonstrate safe laboratory practices when planning and conducting investigations using **risk assessments**, informed by safety data sheets (SDS), and accounting for risks • apply relevant occupational health and safety guidelines while undertaking practical investigations • demonstrate ethical conduct when undertaking and reporting investigations

independent variable
the variable that is changed or controlled in an experiment

dependent variable
the variable being tested and measured in an experiment

controlled variable
a variable that is kept constant in an experiment

hypothesis
a prediction of the outcome of a practical investigation based on accurate scientific knowledge

risk assessment
a document that outlines the potential risks, hazards and subsequent control measures that should be taken to avoid harm

Key science skill	VCE Biology Units 1–4
Generate, collate and record data	• systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources • record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data • organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs • plot graphs involving two variables that show linear and non-linear relationships
Analyse and evaluate data and investigation methods	• process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean • identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data • identify outliers, contradictory or provisional data • repeat experiments to ensure findings are robust • evaluate investigation methods and possible sources of personal errors/mistakes or bias, and suggest improvements to increase accuracy and precision and to reduce the likelihood of errors
Construct evidence-based arguments and draw conclusions	• distinguish between opinion, anecdote and evidence, and scientific and non-scientific ideas • evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation • evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis • use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation • identify, describe and explain the limitations of conclusions, including identification of further evidence required • discuss the implications of research findings and proposals
Analyse, evaluate and communicate scientific ideas	• use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement • discuss relevant biological information, ideas, concepts, theories and models and the connections between them • analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of selected models/theories • critically evaluate and interpret a range of scientific and media texts (including journal articles, mass media communications and opinions in the public domain), processes, claims and conclusions related to biology by considering the quality of available evidence • analyse and evaluate bioethical issues using relevant approaches to bioethics and ethical concepts, including the influence of social, economic, legal and political factors relevant to the selected issue • use clear, coherent and concise expression to communicate to specific audiences and for specific purposes in appropriate scientific genres, including scientific reports and posters • acknowledge sources of information and assistance, and use standard scientific referencing conventions

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

Video
Writing a hypothesis

Formulating a hypothesis

When conducting scientific investigations, you will be required to develop a hypothesis. A hypothesis is developed from a research question. It is written as a testable statement that may include a prediction about the outcome of the investigation.

There is not one correct way to write a hypothesis, but the following steps can be helpful to make sure you include everything you need.

1 Ask a research question. This must be specific and testable. (For example: Does mould grow faster if it is not exposed to light?)
2 Identify the independent and dependent variables in the research question. (In the above example, the rate of mould growth is the dependent variable, and the amount of light is the independent variable.)
3 Write an IF, THEN, BECAUSE statement, which provides a possible explanation for the relationship between the independent and dependent variables.

IF THEN BECAUSE

IF	THEN	BECAUSE
If the independent variable is changed	then the dependent variable will increase/ decrease/grow/be larger than/be smaller than etc.	because of scientific reasoning.

For example, if the amount of sunlight available is reduced, then the rate of mould growth increases because sunlight causes moisture to evaporate from the air, and mould needs moisture in order to grow.

Resource
Risk assessment template

Risk assessments

A risk assessment is a systematic way of identifying hazards and risk factors that could potentially cause harm, and then implementing control measures to avoid those risks. There are different formats to generate a risk assessment, and some programs will automatically generate the risk assessment for you. It is important that you follow the control measures outlined in the risk assessment to ensure the safety of all people involved in the practical investigation.

For example, if you are using a Bunsen burner, you should identify all the possible hazards (e.g. burns) involved. You should then outline the measures you will take to reduce the risks and have a plan in place in case something goes wrong. You can find a blank risk assessment template on your Student obook pro.

CHECK YOUR LEARNING 1.2

Describe and explain

1 Explain the importance of complying with safety and ethical guidelines when planning and conducting practical investigations.
2 Explain why a hypothesis should be written before an experiment is conducted.

Design and discuss

3 An experiment was being conducted to investigate the effect of salinity on the movement of water by osmosis into and out of plant cells. Four different concentrations of salt solution were prepared by mixing salt with water: 0%, 2%, 4% and 6%. A potato was cut into cubes 1 cm × 1 cm × 1 cm. A cube was weighed and then placed into a beaker of 0% salt concentration. The mass of the potato cube was recorded after 5 minutes in the solution. This was repeated for the other salt solutions. Design a hypothesis for this investigation.
4 Design a risk assessment for the practical investigation described in Question 3.
5 A scientist planned a controlled experiment to determine if the temperature of a bedroom affected how much a person sleeps. Suggest a possible hypothesis for this experiment.

1.3 Scientific investigation

KEY IDEAS

In this topic, you will learn that:

- there are different scientific investigation methodologies
- it is important to maintain a logbook during practical investigations
- scientific posters are used to report on an investigation.

primary data
data collected by the investigator from first-hand sources

secondary data
data collected by another person, not the investigator, which is relevant to the scientific investigation

methodology
the approach used to plan and conduct a scientific investigation with justification

aim
the main purpose of the practical investigation

Scientific investigations are a large part of the VCE Biology course. An investigation can be a practical investigation of **primary data** or a research investigation using **secondary data.** An individual, a small group or a class may undertake a scientific investigation. However, all the work for the assessment components (logbook and poster) must be completed individually.

Scientific investigation methodologies

You can conduct your scientific investigation in a variety of ways. You should choose a type of **methodology** that would be valid for the **aim** of the investigation and the research question.

TABLE 1 An overview of the different scientific investigation methodologies and possible research questions

Inquiry method	Inquiry outline
Case study	A good choice when the investigation is based on a certain activity, behaviour, event or problem that contains a real or hypothetical situation. Research question example: 'Could … case study be used to explain …?' For example: Could the 'Genetics of resistance to HIV infection' case study be used to explain why some people remain HIV-negative even when exposed to the virus?
Classification and identification	Classification is investigating phenomena and arranging it into smaller, more manageable groups. Identification is recognising whether phenomena belong to a particular set or are part of a new set. Research question examples: 'Can a key be used to categorise …?' 'Could the … key be adapted to …?' For example: Can a key be used to categorise the classification of the cave beetle species that was newly discovered in 2018?
Controlled experiment	A practical investigation that looks at the relationship between the independent and dependent variables, where all other variables are controlled. Research question examples: 'What is the effect of the (independent variable) on the (dependent variable)?' 'How is the (independent variable) related to the (dependent variable)?' For example: What is the effect of temperature on the rate of liver enzyme activity?

TABLE 1 Continued

Inquiry method	Inquiry outline
Correlation study	An observational investigation in which variables don't have to be controlled, in order to investigate the relationship between the variables and identify factors that have greater importance on those variables. Research question example: 'Does the … have the greatest impact on …?' For example: Does smoking have the greatest impact on the degeneration of nerve cells in Alzheimer's disease?
Field work	Selecting a particular environment beyond the classroom where observations are made and/or experimental investigations are carried out. Sampling techniques are commonly used to gather qualitative or quantitative data. Research question example: 'Does … have an effect on … in (chosen environment)?' For example: Does water temperature have an effect on the distribution of seaweeds in the rockpools of Ricketts Point Marine Sanctuary?
Literature review	Involves researching, gathering and interpreting secondary data. This may be used in preparation for an investigation or to help explain observed events. Research question example: 'Is there evidence of … from scientific investigations to explain …?' For example: Is there evidence of pheromonal cues between *Drosophilia* from scientific investigations to explain how species-specific mating occurs?
Modelling	Involves physically, conceptually or mathematically developing a model that could simulate a concept to assist understanding and knowledge of a particular system. Research question example: 'Can a model be used to …?' For example: Can a model be used to demonstrate the effect of stomach pH on digestive enzyme activity?
Product, process or system development	Involves designing a product, process or system to meet a human need. This should link technological developments to scientific knowledge. Research question examples: 'Is there a more efficient way to …?' 'What if there was a way to …?' For example: Is there a more efficient way to record the oxygen output from a photosynthetic plant than by measuring the carbon dioxide used?
Simulation	Using an existing model to investigate a scientific system by manipulating variables. Simulations are used when variables cannot be controlled in a real system. Research question example: 'What if the … model was used to …?' For example: What if a plant cell observed through a microscope was used to determine the effect of temperature on osmosis?

Logbook

You are expected to keep a logbook for all stages of practical investigations. The logbook can be a physical book maintained in print form, but it may also be digital if your teacher can authenticate that the work is yours.

The first page of the logbook should contain a list of contents and page numbers that you will add to over the year. When you are planning an experiment, your logbook should include the following information:

- lists of ideas (with advantages and disadvantages)
- scientific research (including full references)
- notes on the experimental process
- possible means of collecting data
- raw data or results
- possible interpretations of data.

FIGURE 1 Maintaining a logbook is a critical component of practical investigations.

All items included in your logbook must be clearly documented and dated.

If you use a logbook, it means that all your information is in one place when you come to write a scientific report or prepare a scientific poster. To satisfactorily complete the student-designed practical or research investigation for Outcome 3 of Units 1 and 2, you must submit a logbook.

Scientific poster

Outcome 3 of Unit 1, the student-designed practical or research investigation, requires a demonstration of key science skills and may be presented as a scientific poster. You can produce the poster in print form or electronically. The poster has a maximum of 600 words.

Poster sections

Include the following sections in your poster.

Title and name

The poster title should be written as a question. It should be short and draw interest to the poster. It should reference the variables under investigation and species, if relevant.

The title should include the issue or inquiry under investigation, the experimental approach and the system (for example, an experimental set-up, an organism or a model). Don't forget to include your name!

Introduction

The introduction should include a clear aim, one or two sentences, to state the purpose of the investigation. Then write your hypothesis, which is a statement of the possible outcome of the investigation. Clearly state the independent and dependent variables as well as the direction of the suggested outcome. Then include relevant scientific background to give context to the investigation. Include reliable sources of secondary information and previous investigations that are relevant to the inquiry. If necessary, include definitions and relevant formulas to facilitate greater understanding of the nature of the investigation.

Methodology and methods

In this section, describe the type of investigation, materials and the procedure in such a way that another investigator could replicate the investigation. You may use figures, photos and flow charts to demonstrate the methodology instead of a formal scientific report format.

Study tip

All sections of the poster should be written in a passive voice (avoid pronouns) and past tense (with the exception of the introduction).

This section is authenticated by logbook entries, and the detail and accuracy of those entries will affect the reproducibility of the investigation. You can find more on accuracy of the methodology in Topic 1.4.

Remember, methodology is different from method. Methodology is the rationale for your practical investigation or research. Method is a series of steps or a procedure used to answer your research question(s).

Results

In your results section, select data from the logbook and present it in an appropriate format to show the trend, pattern or relationship between the variables.

There is limited space on the poster, so do not include both a table and a graph that represent the same data set. Sequentially number all graphs, tables and figures in this section, because they are referred to in the discussion section.

You should also briefly state the usefulness of the results in the context of the experiment, and whether or not the hypothesis was supported.

Study tip

Be careful with the use of language in the discussion section. Avoid terms such as 'proved', 'correct' and 'disproved'. Instead, use words such as 'support', 'indicate' or 'suggest'.

Discussion

In the discussion section:

- focus on examining the data and providing explanations that link to accurate scientific understanding
- identify if the data supports, partly supports or refutes the hypothesis
- use the results to examine the relationship between the independent and dependent variables and then make a comparison to the expected results
- explain the significance of the results, derive conclusions and link back to the purpose of the investigation (aim)
- explain the appearance of any outliers or other inconsistencies within the data set
- describe how the results of the investigation link to previous experiments, which relate to the same or a similar area of investigation
- describe any limitations of the experimental design and suggest improvements.

Conclusion

The conclusion describes the main outcome of the investigation. This should be a response to the research/inquiry question. You should make a brief statement that identifies whether the hypothesis was supported. Link your results to relevant underlying scientific concepts. The conclusion summarises the main limitations of the investigation and suggestions for improvement. Include any identification of future work that would refine or extend the results obtained from the investigation. Do not introduce new information in the conclusion.

References and acknowledgements

You must include a list of references in an appropriate format; for example, Harvard or APA. Ask your teacher about the preferred referencing style of your school. You should refer to these references in the body of the poster, as embedded quotations or sourced content. In your acknowledgements, thank any individuals, groups or organisations for specific contributions.

The references and acknowledgements do not count towards the word count.

Formatting the poster

When formatting your scientific poster, you should follow the VCAA poster structure (Figure 2). The centre of the poster should be 20–25% of the poster space and include a summary sentence outlining the outcome of the investigation.

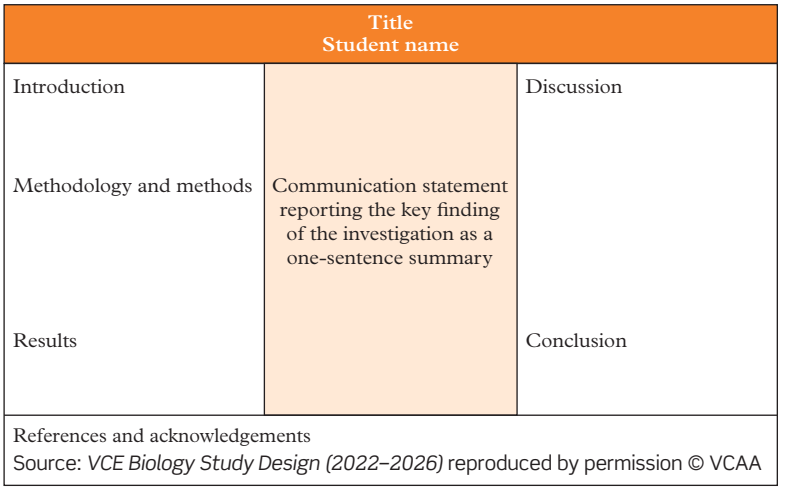


FIGURE 2 The layout for the student poster

Scientific poster checklist

Use the following checklist to make sure you have used the correct writing format for your scientific poster:

- ☐ All sections are written in the third person (passive voice). There should not be any 'I', 'we', 'ours' etc. in your text.
- ☐ All sections, except for the introduction, are written in the past tense. The introduction is written before conducting the experiment so it should be written in present tense.
- ☐ Throughout your poster, key scientific terminology is used to demonstrate your understanding of the investigation.
- ☐ In your discussion and conclusion, terms such as 'proved' and 'correct' have been avoided and instead words such as 'support', 'indicate' and 'suggest' have been used.
- ☐ Concise language is used throughout the poster to maintain the word limit of 600 words.
- ☐ All sections are included: title and name, introduction (including aim and hypothesis), methodology and methods, results, discussion, conclusion, acknowledgements and references.
- ☐ The format follows the VCAA poster structure.
- ☐ The logbook is fully completed, to be submitted with the poster.

CHECK YOUR LEARNING 1.3

Describe and explain

1. Explain why it is important to maintain a logbook for practical investigations.
2. Explain the purpose of the results section of the scientific poster.
3. Identify what is located in the centre of the scientific poster.

Apply, analyse and compare

4. Contrast (explain the difference between) an aim and a hypothesis.
5. Compare the scientific investigation methodologies of controlled experiments and field work.

Design and discuss

6. Design a research question for one of the scientific investigation methodologies described in this topic.
7. An experiment was set up to investigate survival rate in brush-tailed rock-wallabies, *Petrogale penicillata*, in Victoria. Their population, behavioural patterns and reproductive rate, and the weather conditions and availability of food were surveyed over a two-year period. What kind of methodology did this investigation use? Explain your answer.

1.4 Data, measurement and error

KEY IDEAS

In this topic, you will learn that:

- raw data should be organised and presented so it is easy to interpret
- continuous and discrete data are represented differently
- data can be analysed in terms of accuracy, precision, repeatability, reproducibility, validity and true value
- there can be different types of errors, uncertainty and outliers.

raw data
measurements or observations of the dependent variable

table
a form of organising data systematically into columns

qualitative data
data that tends to be non-numerical and is subjective (e.g. hair colour, choice of clothing)

quantitative data
data expressed as a number (e.g. concentration of solutions, temperature)

graph
a way of representing data to visually identify the relationship between the variables

Scientific investigations are important. They aim to develop explanations for natural phenomena. Evidence that is collected needs to be organised and presented in an appropriate manner and then analysed to consider the quality of the data.

Presentation and analysis of data

Raw data can be difficult to interpret. Therefore, raw data must be presented in a way that makes it easy to analyse so that you can draw conclusions.

Tables

Tables can be used to present quantitative and qualitative data. All tables should have a heading that states what the table is showing. The heading usually indicates what the independent and dependent variables are. Each column must have a heading and if you are using numerical data, the units (e.g. minutes, seconds, grams) must also be included.

Qualitative data may show trends and so it is often useful to present qualitative data in tables before comparing or contrasting these results in the discussion.

Quantitative data is displayed as the values of each of the related variables, but this may not clearly show the relationship between the variables. Displaying quantitative data in a table is usually the first step in recording information and allows you to decide on the most appropriate way to graph the data. Once the data is in a table, you can apply various mathematical applications.

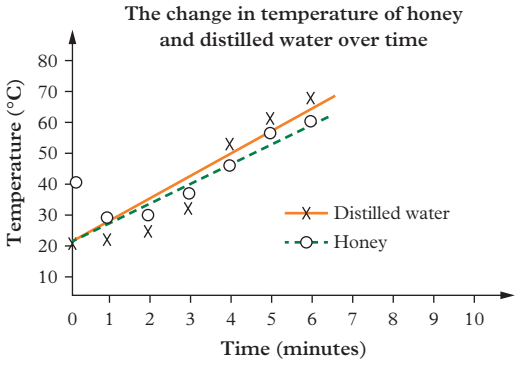


FIGURE 1 This graph displays all the key features of a scientific graph.

Graphs

You can represent your data in a **graph**. When graphing your data, you must consider the following (shown in Figure 1).

- The information on the graph should be easily identified. Make sure you include the heading, axis titles and numbers.
- Include a title that is a descriptive statement and contains the independent variable and the dependent variable.
- Start each axis at zero and make the points on each axis equal in unit size (scaled).
- Clearly label each axis and include the unit of measurement.
- Do not plot the data beyond the axes.
- If there are two sets of data on a single graph, use two different symbols or a coloured key.

Graphing continuous data

Resource
Graphing in Excel

The type of graph used is determined by the type of data present. Continuous data refers to data that can be measured on a scale; for example, time or temperature.

Line graphs

A line graph forms a line when there is a relationship or correlation between the independent and dependent variables. If the line slopes upwards (Figure 2a), it means the independent and dependent variables increase together. This is called a positive correlation. If the line slopes downwards (Figure 2b), the independent variable increases, while the dependent variable decreases. This is known as a negative correlation.

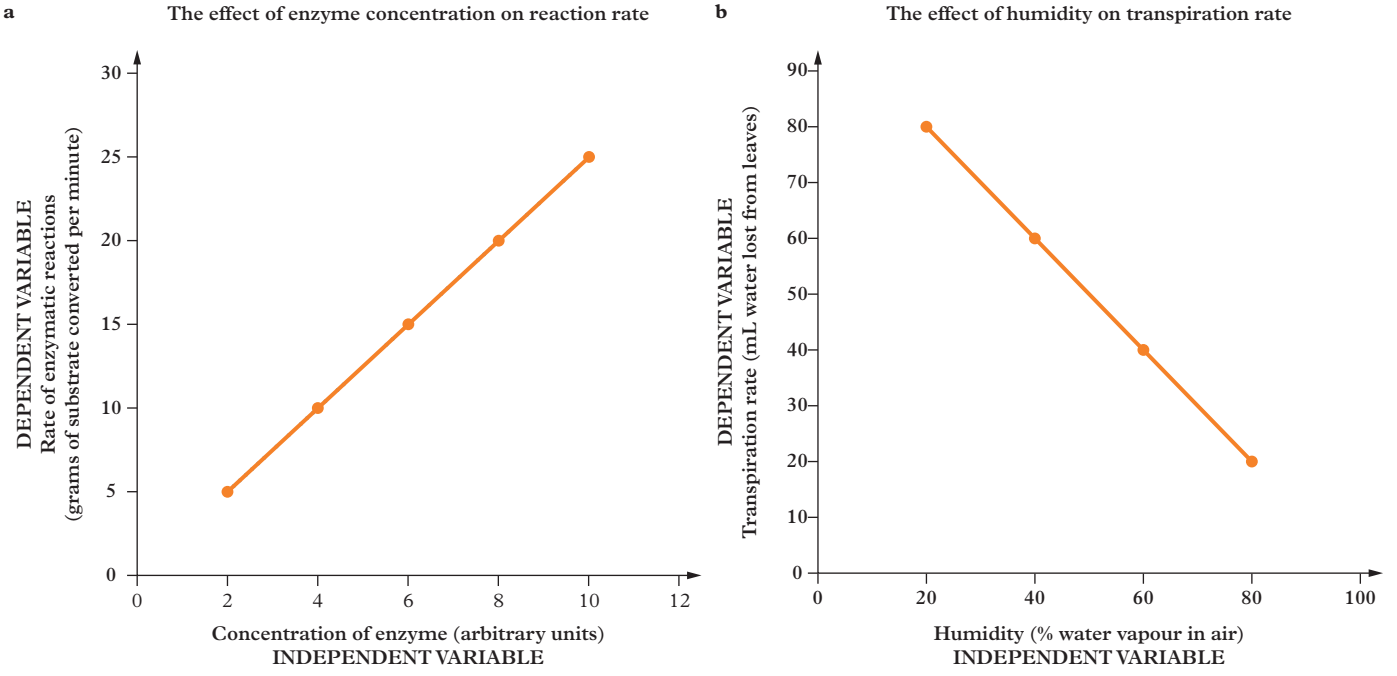


FIGURE 2 **a** An example of a positive correlation in a line graph; **b** an example of a negative correlation in a line graph

Scatterplots

If data points on a graph are not in a line, then a scatterplot is a better choice of graph (Figures 3 and 4). You can draw a line of best fit by eye or input using Microsoft Excel to show the general trend of the data.

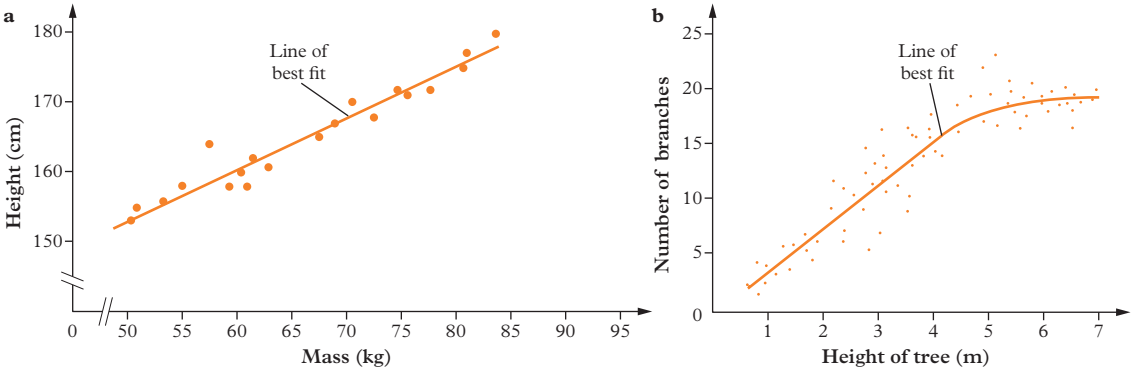


FIGURE 3 Two different lines of best fit in scatter plots

The amount of scatter on either side of a line of best fit indicates the closeness of the variables. The closer the points are to the line of best fit, the stronger the correlation between the variables. When the points are so scattered that you cannot draw a line of best fit, there is no correlation between the two variables.

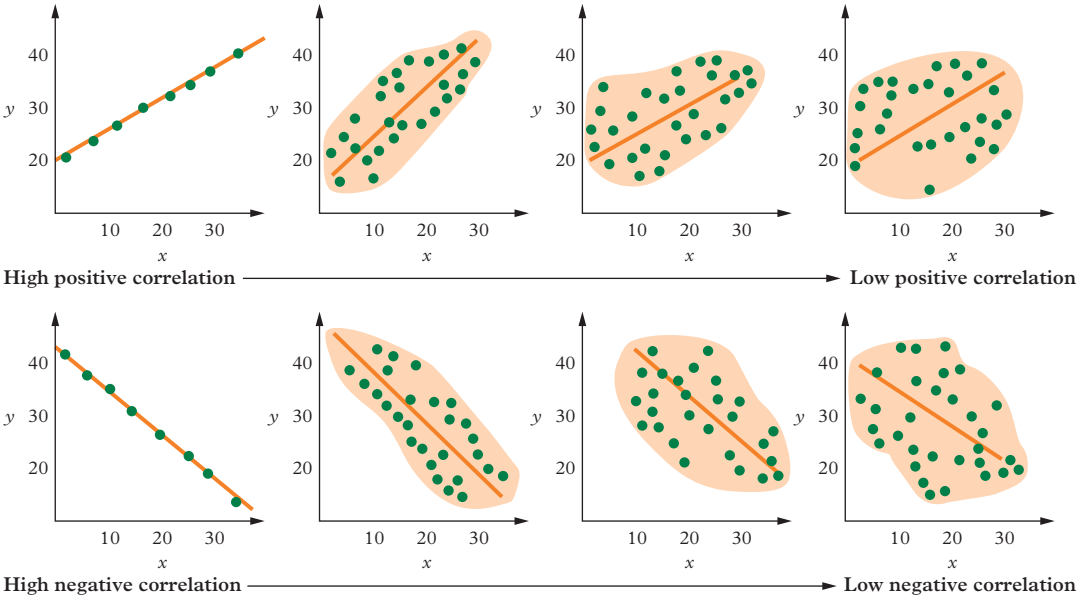


FIGURE 4 Examples of different correlations represented by the amount of scatter in the data

Interpreting line graphs

When describing a graph, you should consider the:

- independent and dependent variables
- type of correlation shown by the graph (e.g. positive, negative or neutral)
- shape of the graph (i.e. linear or curved).

Although there may be a correlation between the two variables, this does not mean that the independent variable caused the change in the dependent variable. Correlation does not mean causation.

Graphing discrete data

When the data is discrete, you can use several types of graph. Discrete data is not related (e.g. the energy content in different food types or individual recovery rates after exercise).

- A column graph shows the distribution of a distinct characteristic within a population (e.g. human blood groups).
- A histogram represents continuous values of the independent variable that are grouped into classes of equal width (e.g. the recovery time after exercise divided into 2-minute intervals, or pulse rates of a population).
- A pie graph is useful for showing the relationship of all the parts of a whole.

Different sets of data are often drawn on the same graph, with different colours or symbols used to compare them.

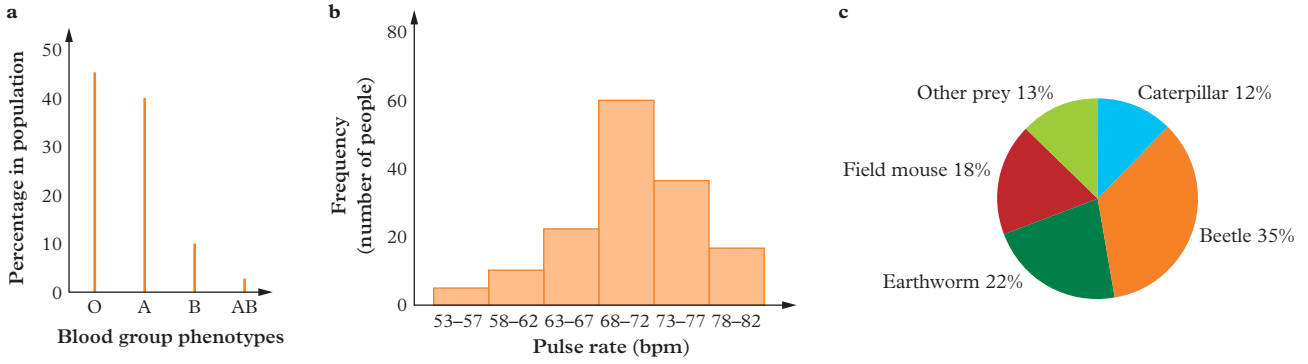


FIGURE 5 Different graphs for discontinuous data: **a** column graph; **b** histogram; **c** pie graph

Data and measurement

When analysing and discussing quantitative data, the accuracy, precision, repeatability, reproducibility, true value and validity need to be considered.

- **Accuracy** describes how close the experimental data is to the 'true' value of the measurement. This can be improved by carefully calibrating the equipment before each experiment.
- **Precision** analyses how close the set of data values are to one another. An experimenter can improve the precision by repeating an experiment or by increasing the sample size.

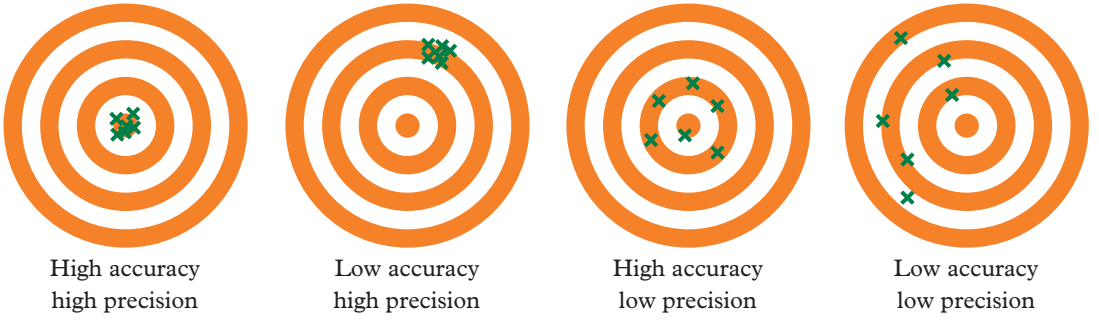


FIGURE 6 Examples of accuracy and precision. Accuracy is not the same as precision.

- **Repeatability** describes the ability for the same data to be produced again by the same experimenter in the same laboratory under the same conditions. Repeatability relies on a detailed and informative method with well-defined variables.
- **Reproducibility** refers to the ability for the same data to be produced by a different experimenter in a different laboratory. Reproducibility also relies on a detailed and informative method with well-defined variables.
- The **true value** is the value that would be obtained had the quantity been measured perfectly. The experimental data is compared with the true value to determine the accuracy of the data.
- The **validity** of the measurement describes whether the experiment will actually answer the scientific question that was asked.

When discussing validity, the experimental design and its implementation should be considered.

accuracy
how close the experimental data is to the true value

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

repeatability
a measure of achieving the same set of data if the experiment was repeated under the same conditions

reproducibility
a measure of achieving the same set of data if the experiment was repeated with a different experimenter in a different laboratory

true value
the value that accurately represents the measurement had the experiment been conducted perfectly

validity
a measure of whether the investigation is sound

Study tip

A mistake caused by incorrect measurements is not the same as experimental error, which relates to problems with the experimental design.

Experimental errors, uncertainty and outliers

Experimental errors should not be confused with human error. An error is defined as the difference between the measurement and the true value. It is also important not to confuse errors with uncertainty. Uncertainty is when a measurement seems unreliable and is associated with doubt.

There are two types of errors to consider in scientific investigations: **random errors** and **systematic errors**.

random error
an error that affects the precision of the data due to an unknown and unpredictable error in the experimental process that in uncertain

systematic error
an error that affects the accuracy of the data by causing the reading to differ from the true value

Random errors

Random errors are unpredictable. They are present in all measurements because they are caused by an error in the measurement process. Random errors reduce the precision of the data. Parallax error is an example of a random error. Parallax error occurs when an observer views an object (e.g. a measuring cylinder containing water) from the wrong angle. The measurement will differ from the true value. You can reduce random errors by doing multiple trials.

Systematic errors

Systematic errors are consistent and repeatable. This type of error reduces the accuracy of the data. Systematic errors are usually caused by faulty equipment or uncalibrated measuring instruments. These errors cause readings to consistently differ from the true value every time they are measured. This means that repeating the experiment does not reduce systematic errors. An example of a systematic error is if you did not zero scales at the beginning of an experiment, and repeated this uncalibrated measurement across all tests.

Study tip

Data presentation, measurement and errors associated with different forms of data can be found in the *Biology for VCE Units 1 & 2 Student Workbook*.

Outliers

A data point that is outside the rest of the data set is called an **outlier**. This abnormal data point may be caused by mistakes made by the experimenter or equipment during the experiment. Always plot outliers in your graph, but they may not be included in the line of best fit. You should attempt to explain the cause of the unexpected data in the discussion section of the scientific investigation. Outliers cannot be simply dismissed, but should be investigated and accounted for. Conducting multiple trials can be a useful way to examine outliers.

outlier
any value that sits outside the data set

CHECK YOUR LEARNING 1.4

Describe and explain

1 State the three types of graphs that can be used to represent discrete data.

2 Identify the error (random or systematic) that affects the accuracy of the data. Explain your answer.

3 Use an example to describe an outlier.

Apply, analyse and compare

4 Compare (discuss the similarities and difference between):
- **a** accuracy and precision
- **b** repeatability and reproducibility
- **c** continuous and discrete data
- **d** uncertainty and error.

5 Explain which type of graph would best represent continuous data that measures the heart rate of an aquatic organism in solutions of different salinities.

Design and discuss

6 Discuss the importance of organising raw data into tables and/or graphs.

1.5 Ethics

KEY IDEAS

In this topic, you will learn that:

- ethical understanding should be applied when undertaking research
- ethical approaches guide discussion and decision-making in research.

Ethical understanding

Ethical understanding is a principle that should be considered across all VCE Sciences. When undertaking student-designed investigations or evaluating research, you must apply an ethical understanding.

Applying an ethical understanding means applying integrity when collecting and analysing data. You need to consider how the investigation will affect the environment and living things. Decisions based on science-related ethical issues take into consideration scientific knowledge, current and future needs as well as sociocultural, economic, political and legal factors.

Some practical investigations involve humans as subjects. In these situations, your teacher is responsible for ensuring the ethical concepts are followed. You are not expected to use animals in this course. You may only use animals if it complies with the law.

Ethical approaches

An ethical approach will help guide your discussions, thoughts and decision-making. Using an ethical approach means that you explore ethical issues in context, consider ethical dilemmas, reflect on the various courses of action and make sure that your final decision-making considers all previous concepts.

There are three types of ethical approaches.

- A consequences-based approach considers the implications of the decision by maximising the positive outcomes and minimising the negative consequences. This can be expressed as 'the end justifies the means'.
- A duty-based, or rules-based, approach means that people have a responsibility to act in a particular way. This approach is not concerned with the consequences of the outcome, as long as the agreed rules were followed during the process.
- A virtues-based approach considers a person's virtue or moral character, not the action. It considers good behaviours and actions. Did the person mean to do the right thing?

integrity
the ethical principle about the commitment to search for knowledge and be honest in the approach

justice
the ethical principle to ensure a fair and equal consideration of all factors

beneficence
the ethical principle of a commitment to minimising risk and doing good

Ethical concepts

When exploring ethical issues and dilemmas, you need to consider ethical concepts to determine the acceptability of particular effects and causes.

- **Integrity** is the commitment to being honest. When researching, it is important to honestly communicate results and research, whether favourable or unfavourable.
- **Justice** is the moral rightness and commitment to fairly assessing claims, means and actions. It means that all are treated equally to make sure moral obligation stands.
- **Beneficence** is the idea that the purpose of a person's action should be to do well and minimise the risk of harm. This involves analysing potential risks against the benefits of the action.

non-maleficence
the ethical principle of avoiding harm or decreasing the amount of harm inflicted

respect
the ethical principle that considers the value of living things and the ability for living things to make their own decisions where possible

- **Non-maleficence** is the idea of avoiding harm. As scientific research may involve harm, any benefits of the course of action must outweigh the resulting harm.
- **Respect** refers to the intrinsic value of all living things, which considers the religious beliefs, cultural heritage, views and opinions, customs, and health and safety of an individual or group. This ethical principle makes sure that living things can make their own decisions and when that capacity is diminished, decisions should be based on empowerment and protection when necessary.

CASE STUDY 1.5

Human–monkey chimeras for organ production

In China, a controversial project that aims to grow human organs from primate embryos is being conducted. A team of scientists is working on this project, trying to develop chimeras (organisms composed of cells from two or more species) by combining primate and human cells. Human–animal chimeras are produced by implanting human stem cells into animal embryos early in development. The goal is to produce human organs in animals as an alternative to organ transplantation.

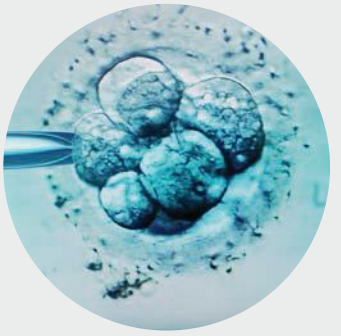


FIGURE 1 Implanting human stem cells into an animal embryo produces a human–animal chimera.

Similar experiments have been conducted on human stem cells and sheep and pig embryos. These experiments were unsuccessful probably because sheep and pigs are only distantly related to humans. Primates are more closely related to humans and share more than 95% DNA sequences.

The main ethical concern regarding this project is the difficulty of restricting human cell growth to just one organ of interest. What should happen if the human–primate chimera developed a human-celled nervous system that had a consciousness and displayed human-like behaviours? At this stage, the human–primate chimera embryos are only kept for a few weeks so the nervous system has not fully developed.

Japan recently legalised the creation of human–animal chimera embryos for transplantation into surrogates to be brought to full term. This essentially means that chimera organisms can be born from surrogates for the purpose of developing human organs. This could take experiments into ethically uncharted territory.

CHECK YOUR LEARNING 1.5

Describe and explain

1 Explain the importance of an ethical understanding in science.
2 Describe the three types of ethical approach.
3 Define the ethical principle of 'respect'.

Apply, analyse and compare

4 Compare (discuss the similarities and difference between) ethical approaches and ethical concepts.
5 Use an example to explain when the ethical principle of integrity would be important in biology.

Design and discuss

6 Discuss the ethical dilemma of Case study 1.5.

1.6 Outcomes

KEY IDEAS

In this topic, you will learn that:

- there are different outcomes for each Area of Study in VCE Biology
- there are different types of assessment tasks.

outcome
the key knowledge and skills needed to demonstrate a satisfactory achievement for an Area of Study

There are six Areas of Study in the Units 1 and 2 Biology course. Each Area of Study has an assessed **outcome**, which is used to determine whether you have satisfactorily demonstrated the key knowledge and skills for the Area of Study. All of these assessments are school-based tasks. In Units 3 and 4, this type of assessment is called a School Assessed Coursework, or SAC. You might also use this term for assessment in Units 1 and 2 at your school.

Unit 1 – Assessment

Outcome 1 (Area of Study 1)

This Outcome will assess your understanding of the structure and function of cells and cell cycle, growth, death and differentiation.

Outcome 2 (Area of Study 2)

This Outcome will assess your understanding of the specialisation of cells and organisation for specific functions in plants and animals, and how they are regulated.

Outcome 3 (Area of Study 3)

For this Outcome, you will design and conduct a practical investigation related to key knowledge from Unit 1 Areas of Studies 1 and/or 2 and make conclusions from primary data. You will be required to use investigation design, scientific evidence, science communication and key science skills to complete this investigation.

Unit 2 – Assessment

Study tip

Ask your teacher for a checklist of the key knowledge that will be assessed in the outcome so that you can thoroughly prepare. Don't forget that the Key Scientific Skills may also be assessed in each Outcome.

Outcome 1 (Area of Study 1)

This Outcome will assess your understanding of chromosomes, genomes, genotypes, phenotypes and patterns of inheritance.

Outcome 2 (Area of Study 2)

This Outcome will assess your understanding of reproduction strategies, adaptations and interdependencies to enhance the survival of species.

Outcome 3 (Area of Study 3)

For this Outcome, you will respond to an investigation of a bioethical issue in genetics, reproductive science or adaptations beneficial to survival.

Assessment task types

For Outcomes 1 and 2 of Units 1 and 2, you will complete an outcome based on one of the following tasks:

- a case study analysis
- a bioinformatics exercise
- a data analysis of generated primary and/or collated secondary data
- reflective annotations of a logbook of practical activities
- media analysis of two or more media sources
- a modelling or simulation activity
- problem solving involving biological concepts and/or skills
- a response to a bioethical issue
- a report of a laboratory or fieldwork activity including the generation of primary data
- a scientific poster.

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Outcome 3 assessments

In Area of Study 3, Unit 1, you will conduct an investigation. In Area of Study 3, Unit 2, you will analyse a bioethical issue. You will be assessed on key knowledge and skills related to the unit of study as well as the key science skills.

Unit 1, Outcome 3 – How do scientific investigations develop understanding of how organisms regulate their function?

Study tip

Methodology is different from method. Methodology is the rationale for your practical investigation or research. Method is a tool used to answer your research question.

This outcome has a focus on the design of the investigation, scientific evidence and science communication. The investigation should consider the type of methodology and methods, generation of data, the accuracy, precision, reproducibility and validity of data as well as the safety and bioethical guidelines. Generated data must be compared to current scientific models or theories. You should analyse the data and identify any errors, account for any limitations of the methodology and record your data in a logbook. In your scientific report, make sure you use scientific terminology and follow the correct conventions.

This outcome can be in the form of a scientific poster (see Topic 1.3 for poster structure and layout), a scientific article or an oral, multimedia or visual presentation. Ask your teacher for guidance as to which format you should use.

FIGURE 1 Collecting and recording data accurately is an important skill for Outcome 3.

FIGURE 2 Scientists use posters to present their research findings at conferences.

Unit 2, Outcome 3 – How do humans use science to explore and communicate contemporary bioethical issues?

For this outcome, you will develop your own question related to an application of genetics, reproductive technologies or adaptation beneficial to survival. You teacher may help you construct your research question but a great starting place is investigating current genetic issues. Articles in science publications, such as *New Scientist*, can help generate ideas, as well as TED talks, announcements of recent discoveries or even changes to government funding related to applications of genetics.

You will be required to collect and analyse secondary data from a range of sources relating to your question. This outcome will assess your ability to use scientific evidence and analyse the validity, reliability, bias and errors of the evidence. You will also be assessed on how you determine the nature of the evidence as either scientific or non-scientific and distinguish primary data from secondary data. It is important to communicate scientific concepts concisely and coherently and in language appropriate to your audience. You will be required to analyse social, economic, legal and bioethical factors related to your issue and reference sources of information appropriately. Since this outcome is based on a bioethical issue, you will be assessed on your ability to apply ethical approaches and concepts related to your topic.

FIGURE 3 A report of your laboratory work can be an assessment task.

CHECK YOUR LEARNING 1.6

Design and discuss

1 Discuss ways to prepare for assessed outcomes.

2 Discuss ways that you can make an investigation method more reliable or valid.

1.7 External examination

KEY IDEAS

In this topic, you will learn that:

+ reading time should be used carefully in an examination
+ there are different strategies for writing time in an examination
+ revision strategies can help you to prepare for assessments.

There is no external examination for this course, but your teacher may set their own formative examination to assess how much you know about the content you learn in this course. Should you progress to the Units 3 and 4 Biology course, you will be assessed by an end-of-year **external examination**, which contributes to 50% of the study score. Therefore, it is important to practise answering exam questions throughout this course.

external examination an external test that assesses your knowledge of a subject

Exam techniques

It is important to use every minute of your time in the examination room.

Using reading time

- First, scan the examination paper to check that all the pages are there and determine the kinds of questions so that you can start to plan your writing time.
- Multiple-choice questions are normally designed to take approximately 1 minute each. So if there are 40 questions in this section, aim to spend approximately 40 minutes on the multiple-choice questions.
- When reading through the short-answer questions, check the mark allocation to get an idea of the time you should spend, which is approximately 1 minute per mark. Read each question carefully and assess the question to consider the key knowledge and/or key science skills that are being assessed.
- Make a mental note of questions that may be more difficult, may take more time to complete or may need further reflection. It is recommended that you complete those questions last to give you more time to consider the responses and possibly more time to write the responses if you have been able to finish the other questions more quickly.

Strategies for writing time

- Read each short-answer question three times. On the first read, try to understand the overall view of the question, and on the second read, try to find the key information. Do the third read after you have written your answer to make sure that you have included everything that is needed.
- Highlight or underline the key words within the question and reflect on those while writing your response or selecting the correct answer.
- For the short-answer questions, consider the concept being addressed and the key scientific terminology you may need to include in your answer.
- Make sure you format your responses as dot points, where each dot point represents a piece of information. It can also be helpful to underline the scientific terminology in your response, to demonstrate clear understanding. Do not repeat the stem of the question in your response.

- Keep track of the time to make sure you are keeping to the plan you set during reading time. If you get stuck on a question, circle it and come back to it later.

Different types of questions

Multiple-choice questions may emphasise a definition or may require you to analyse and interpret data.

multiple-choice question
an examination question that requires you to select the most appropriate option from four possible alternatives

- Only one option is completely correct and the other options may be distractors; therefore, you should read all of the options before selecting the best response.
- If unsure, cross out the options you know are definitely incorrect. This improves your chance of selecting the correct answer.
- Never leave a multiple-choice question unanswered, because you have a 25% chance of selecting the correct response, even if you guess. Marks are not deducted for an incorrect response.

Short-answer questions will most likely be one of the following: name, describe/draw, explain how, explain why, media response or experimental design.

short-answer question
an examination question that requires a written response

- 'Name', 'state', 'list' and 'what is?' questions would be worth 1 mark. Your response should be brief, concise and clear.
- The marks allocated for 'describe' and 'draw' questions reflect how much detail is required and how much time to spend on the response. If you are asked to draw, you can use a pencil but make sure the drawing is clear and labelled. Do not shade or include irrelevant detail in your drawing.
- 'Explain how', 'outline how' and 'state the way' questions are generally worth 2 or more marks. If the question asks for an outline of a process, think about the step-by-step stages of the process. Make sure you use dot points to formulate your response. You can also respond with a labelled diagram. Consider the key terminology you should include in your response before writing it.
- 'Explain why' and 'justify' questions require you to apply key content knowledge and are generally cause-and-effect questions. These questions generally require a higher level of thinking and more detail in the response.
- 'Compare', 'contrast' and 'what are the differences/similarities between' questions require you to compare concepts or key terms. It is a good idea to draw a line down the centre of the space allocated for the response. On one side of the line, describe one term or concept, and on the other side make the comparison with the other term or concept.
- Media response questions assess the application of content as well as analytical and literacy skills. Be clear with your response – many students get off track and go on tangents.
- Experimental design questions assess your understanding of experimental processes. If the question asks you to design an experiment, it is a good idea to answer with a flow chart as shown in Figure 1.

Short-answer questions may also ask you to 'refer to results' or 'use data'. Make sure your response uses quantitative or qualitative data from the results provided in the question. These results may be in a table or a graph or within an article.

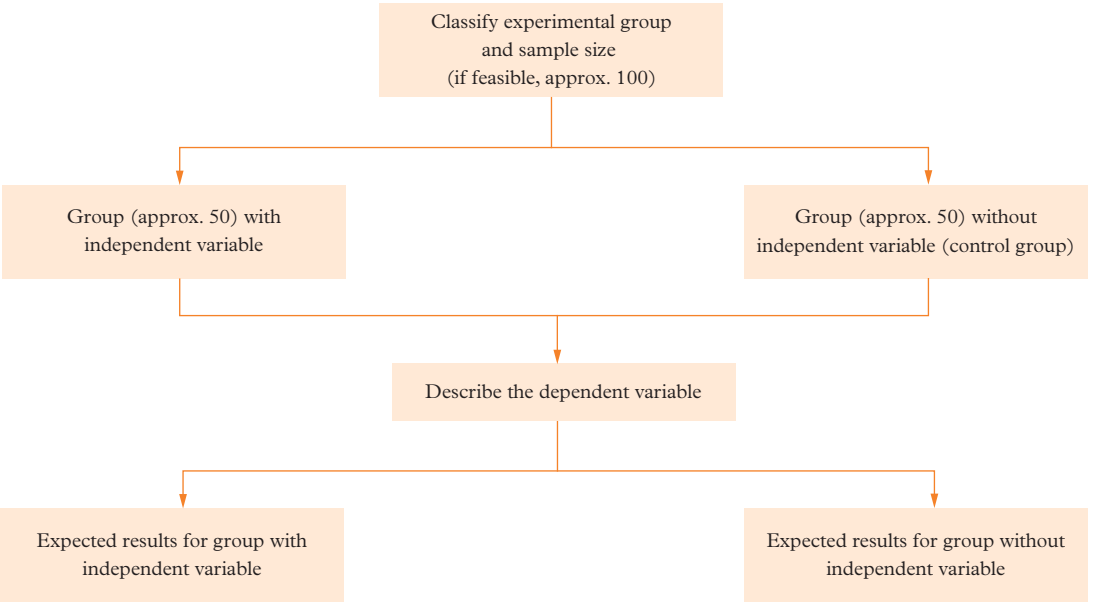


FIGURE 1 A flow chart for planning your experimental design question in the external examination. It is worth including at least two variables that are controlled.

Revision strategies

The key to revising is to start early, which requires organisational and time management skills. Making a study timetable and setting goals are two strategies that can assist with those skills. Each individual learner will have a preferred method of revision. Here are some strategies to consider.

- Use the pomodoro technique where you revise in manageable time chunks such as 20 minutes. Set a goal and work on that task for a set time (20 minutes) and then at the end of that time period stop for a short 5-minute break. Start the timer again and begin on a new task after the break. After several sessions, take a longer break. Using this method can maximise efficiency and productivity because it breaks up the learning into manageable sections.
- Have a study group with peers who are also studying biology. Make sure the group members are those who will motivate you during study sessions.

FIGURE 2 The pomodoro technique is a time-management technique that involves breaking time into manageable chunks.

FIGURE 3 Focus study groups can be a great way to share your questions and listen to different explanations of key concepts.

- Complete a set of practice questions. You may wish to do these under open book or exam-style conditions. Time yourself completing questions to get an idea of time allocation and the pace you should be working at or towards.
- Produce a **mind map** or concept map to overview a concept, Area of Study or unit. This technique will help you to make connections, identify big ideas and visualise concepts.
- Translate a concept or key idea into a flow chart or diagram.

mind map
a graphical way to represent key ideas and relationships between concepts

Work space

Each student will have a space at home where they complete schoolwork and revise. There are important things to consider to make this space an efficient study environment. Where possible, the environment should be silent (or at least quiet) with adequate light and ventilation. The table should be large enough for all of your resources, and you should have a supportive chair. When completing work or revising, it is important to minimise distractions and one of the biggest distractions is a mobile phone. If you know your device distracts you, turn it off, put it on aeroplane mode or leave it in another room.

Study tip

Check out your local and school libraries for suitable quiet spaces where you can study, because you might find you are more productive in this space than at home.

CHECK YOUR LEARNING 1.7

Describe and explain

1 Identify the percentage of the external examination that contributes to the study score for VCE Biology.
2 Explain how you could determine the amount of time you should spend on each question.
3 Explain the pomodoro study technique.

Apply, analyse and compare

4 Explain why a productive workspace is important.
5 Analyse revision techniques and strategies you currently use. Identify two things you might do differently and explain why.

Design and discuss

6 Discuss important considerations when answering short-answer questions.

CHAPTER 1

Review

Chapter summary

1.1
- Biology is a life science, investigating the interactions of living things with living and non-living factors in their environment.
- Aboriginal and Torres Strait Islander Peoples have different methods for taking care of the land and producing medicine.

1.2
- When communicating in science, it is vital to use concise language that is suitable for the specific audience.

1.3
- When developing a research question you first must decide on the methodology because this can determine the style of the question.
- Maintaining a logbook is an essential requirement for scientific investigations.
- Key science skills are used in student investigations.

1.4
- Qualitative data is non-numerical data, whereas quantitative data is numerical data.
- Graphs are used to show relationships between variables.
- Precision, accuracy, repeatability, reproducibility and validity are concepts that must be used to evaluate the data and the methodology of an investigation.
- Systematic errors are consistent and repeatable, and reduce the accuracy of the data. Random errors are unpredictable and uncertain, and reduce the precision of the data.
- Outliers should not be dismissed, but evaluated, investigated and accounted for.

1.5
- Ethical approaches include consequences-based, duty- and/or rule-based, and virtues-based.
- Ethical concepts include integrity, justice, beneficence, non-maleficence and respect.

1.6
- There are ten assessment task types for Outcomes 1 and 2 of Units 1 and 2.
- Unit 1, Outcome 3 is a scientific investigation and Unit 2, Outcome 3 is an analysis of a bioethical issue.

1.7
- Examinations are another form of assessment for Units 1 and 2, assessing key knowledge as well as the key science skills.
- Preparing for an exam requires organisation and effective revision strategies.

Revision questions

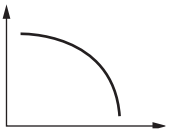
Multiple choice

1 Select the most appropriate methodology to investigate the research question: 'Is there evidence from scientific investigations that suggests genetically modified food causes harm to living organisms?'

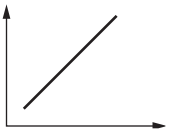
A Modelling
B Controlled experiment
C Literature review
D Simulation

2 A graph is produced to show the relationship between the rate of photosynthesis and temperature. Identify which of the following graphs shows that as the temperature increases, the rate of photosynthesis increases until it reaches a certain point and then starts to decrease.

A



B



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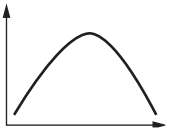
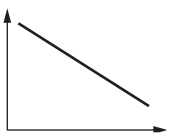


D



3 An investigation was conducted to test the effect of fertiliser on plant growth. The hypothesis stated that if the amount of fertiliser given to a plant is increased, then stem height will increase. Identify the independent variable.

A Change in stem height over the course of the investigation

B Different amounts of fertiliser

C Number of surviving plants

D Amount of water given to each plant

Short answer

Describe and explain

4 Explain the importance of generating risk assessments before undertaking practical investigations.

5 Define 'accuracy'.

Apply, analyse and compare

6 Analyse the significance of the knowledge and skills of Aboriginal and Torres Strait Islander Peoples to VCE Biology.

7 Compare primary and secondary data by drawing a line down the middle of the answer space and writing the key information about primary data on one side and about secondary data on the other side.

Design and discuss

8 Brett undertook an experiment to investigate the effect of caffeine on the germination of mung beans. He set up three dishes, each containing six seeds on cotton wool that had been soaked in a different solution of caffeine in water: 0%, 5% or 15%. Each day, 15 mL of the particular diluted caffeine solution was added to the seeds in the dishes. The numbers of germinated seeds were recorded each day for 3 weeks or until all the seeds had germinated.

a Identify the aim of the investigation.

b Write a hypothesis.

c Identify three controlled variables in this experiment. Justify why each of these variables needs to be controlled.

d Explain what it is meant by a 'controlled' experiment.

d There was only one trial at each concentration. Explain why the precision of this investigation cannot be analysed.

e Design a different experiment to investigate whether temperature affects seed germination. Make sure you include the variables (independent, dependent and controlled), a control group and expected results. You can use the flow chart in Figure 1 of Topic 1.7.

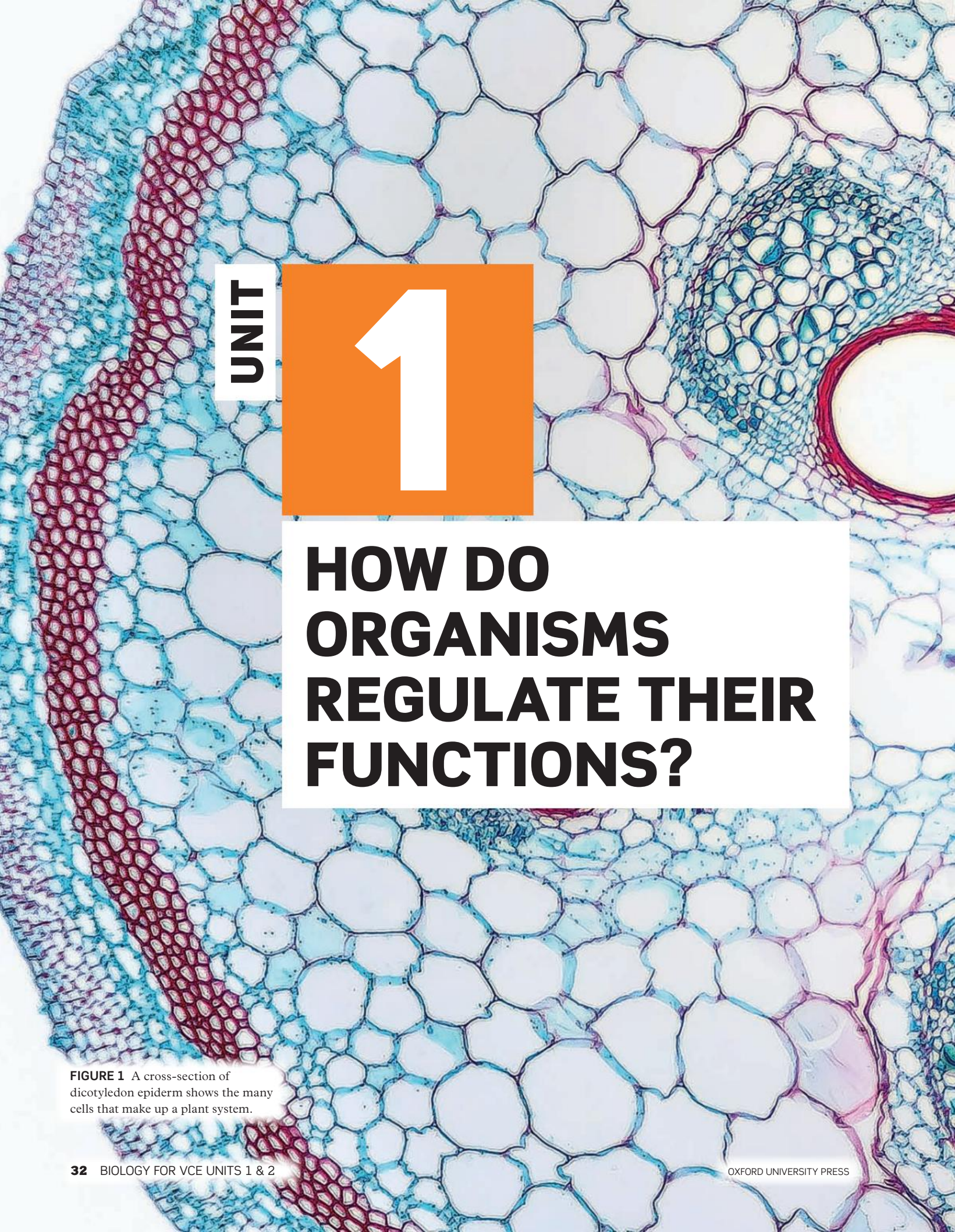
Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.



UNIT 1

HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

FIGURE 1 A cross-section of dicotyledon epiderm shows the many cells that make up a plant system.

Cells are the smallest building blocks of life. A multicellular organism is made up of different types of cells that perform specific functions to keep the organism alive. In order for an organism to grow or repair damage, its cells must be able to replicate. The process of cell division is an important part of the cell cycle, which involves phases of normal growth followed by replication to produce genetically identical daughter cells.

As multicellular organisms get more complex, there is an increasing differentiation of cell types within the organism. This allows for the arrangement of tissues, organs and complex systems. These systems perform a range of functions that are essential for an organism's survival. Multicellular organisms must therefore maintain their internal environment to protect these complex systems of organs and tissues.

Outcomes

On completion of this unit, students should be able to:

→ explain and compare cellular structure and function and analyse the cell cycle and cell growth, death and differentiation

→ explain and compare how cells are specialised and organised in plants and animals, and analyse how specific systems in plants and animals are regulated.

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Area of Study 1	How do cells function?	Chapters 2–3, pages 34–105
Area of Study 2	How do plant and animal systems function?	Chapters 3–4, pages 76–139

CHAPTER 2

Cell structure and function

Cells are the basic units of all life on Earth. Depending on their internal structure, cells are classed as either prokaryotic or eukaryotic. Light microscopy and electron microscopy can be used to identify the type of cell and the different organelles they contain. By looking at the cell structure, scientists can determine and analyse cellular functions. Cellular functions are carried out by specialised structures and organelles within each cell. These specialised organelle structures are highly adapted so that they are able to carry out the specific functions efficiently. All the organelles work together as part of larger pathways and processes within a cell. These processes include the transport of different molecules across the plasma membrane, cellular respiration and photosynthesis.

KEY KNOWLEDGE

- → cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells
- → surface area to volume ratio as an important factor in the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions
- → the structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplasts and mitochondria
- → the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

FIGURE 1 Transverse section of a rhododendron stalk viewed under a light microscope

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

2A Name the structure in plant cells that carries out photosynthesis.

2A Groundwork resource
Cell organelles

2B Describe the basic function of the plasma membrane.

2B Groundwork resource
The plasma membrane

2C Explain the difference between unicellular and multicellular.

2C Groundwork resource
Unicellular versus multicellular

PRACTICALS

PRACTICAL	**2.2** Surface area to volume ratio matters
PRACTICAL	**2.3** Internal structure of plant cells
PRACTICAL	**2.4** Osmosis through potato plasma membrane

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.

2.1 Cell theory

KEY IDEAS

In this topic, you will learn that:

+ cells are the basic unit of life on Earth
+ there are two types of cells: prokaryotic and eukaryotic cells.

Cells: the building blocks of life

For any object to be classified as living, it must have at least one cell. Cells are the smallest structural and functional units of life. Robert Hooke, an English natural philosopher of the 17th century, studied cork under a microscope (Figure 1). He identified the small square structures in the cork, and named them after the rooms ('cells') where monks lived in monasteries.

unicellular
consisting of a single cell

multicellular
consisting of many cells

Some living organisms are **unicellular** – they exist as a single cell. Other organisms are **multicellular** – they are composed of many cells, sometimes even trillions.

FIGURE 1 Robert Hooke's microscope

Cell theory

Before the invention of the microscope, biologists believed in a theory known as spontaneous generation. People believed that maggots appeared spontaneously from rotting meat and tadpoles appeared from a new puddle of water. Eventually this theory was disproved with experiments that showed, for example, that maggots only appeared in meat after flies had laid their eggs. In the 19th century, Louis Pasteur disproved the theory of spontaneous generation. His work demonstrated that all microorganisms arise from pre-existing ones and that if the microorganisms are isolated and destroyed in a sterile environment, no new microorganisms will grow. This became the foundation for **cell theory** and revolutionised the field of medicine with the development of antiseptic techniques.

cell theory
the theory that describes cells as the basic component of all living organisms

Cell theory specifies that:

- all living organisms consist of at least one cell
- all cells arise from pre-existing cells
- cells are the smallest structural unit of life (Figure 2).

This theory is based on both biochemical and microscopic observations and experimentation.

Cell structure

Although cells can be structurally and functionally different, all cells have:

- a **plasma membrane** that separates the internal contents from the external environment
- **cytosol**, which is a fluid made of water, enzymes, ions and salts
- **deoxyribonucleic acid (DNA)**, which carries the genetic information required for DNA replication, cell division and protein production
- **ribosomes** for protein production.

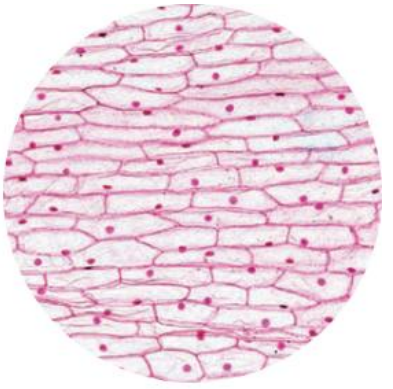


FIGURE 2 Cells are the building blocks of life. These cells are from onion epithelial tissue.

Cell classification

There are two type of cells – **prokaryotic cells** and **eukaryotic cells**.

Prokaryotes

Prokaryotes are extremely small, unicellular organisms that consist of a single prokaryotic cell. Bacteria, cyanobacteria (photosynthetic bacteria) and archaea are all types of prokaryotes. Prokaryotic cells do not have a nucleus or other membrane-bound structures. All of the chemical processes required to sustain life occur within the cytosol of a single cell.

Prokaryotes have the following generalised structures (Figure 3).

- Genetic material is located within the cytosol in a central region of the cell called the **nucleoid** as a single circular **chromosome**.
- Ribosomes are scattered throughout the cytosol for protein production.
- A plasma membrane allows entry and exit of substances.
- A cell wall provides structural support, shape and protection.

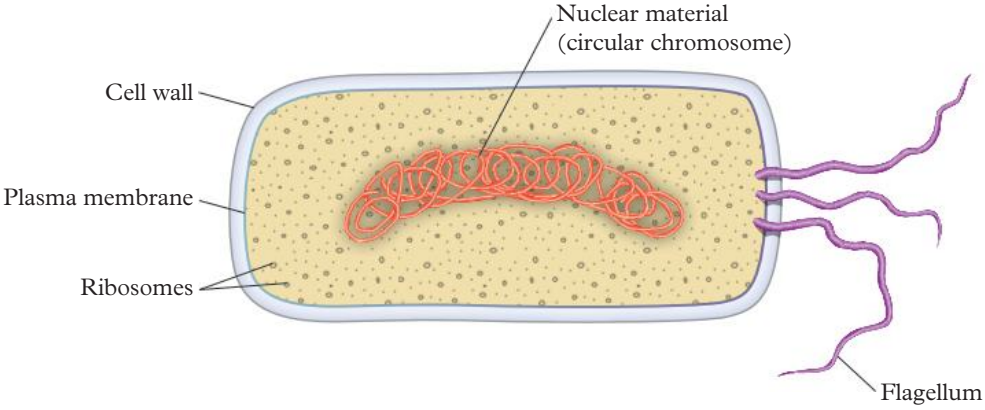


FIGURE 3 The generalised structure of a prokaryotic cell

Although all prokaryotes have these common features, there is a lot of variation between species and groups. Some prokaryotes die in the presence of oxygen, whereas others will only survive if oxygen is present. Some prokaryotes are heterotrophic, which means they feed on other organisms; other prokaryotes are autotrophic and rely on chemosynthesis or **photosynthesis** for their energy.

plasma membrane
the boundary of all cells that separates the cytosol from the external environment and controls the entry and exit of substances

cytosol
the internal fluid component of a cell, excluding organelles

deoxyribonucleic acid (DNA)
the genetic material that carries cellular instructions

ribosome
an organelle in cells where proteins are made

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

eukaryotic cell
a cell that contains a nucleus and other membrane-bound organelles

prokaryote
a single-cell organism made of a prokaryotic cell

nucleoid
a region of a prokaryotic cell where DNA is located

chromosome
a coiled, condensed structure of DNA and associated histone proteins

photosynthesis
the process by which light energy is converted into chemical energy (glucose) in the chloroplasts of plant cells

Bacteria

Bacteria are the most ancient, abundant and diverse organisms on Earth (Figure 4). They consist of a cell wall made of carbohydrates and proteins that provides strength, support and protection. Many bacteria have a sticky capsule surrounding the cell wall that enables them to adhere easily to surfaces.

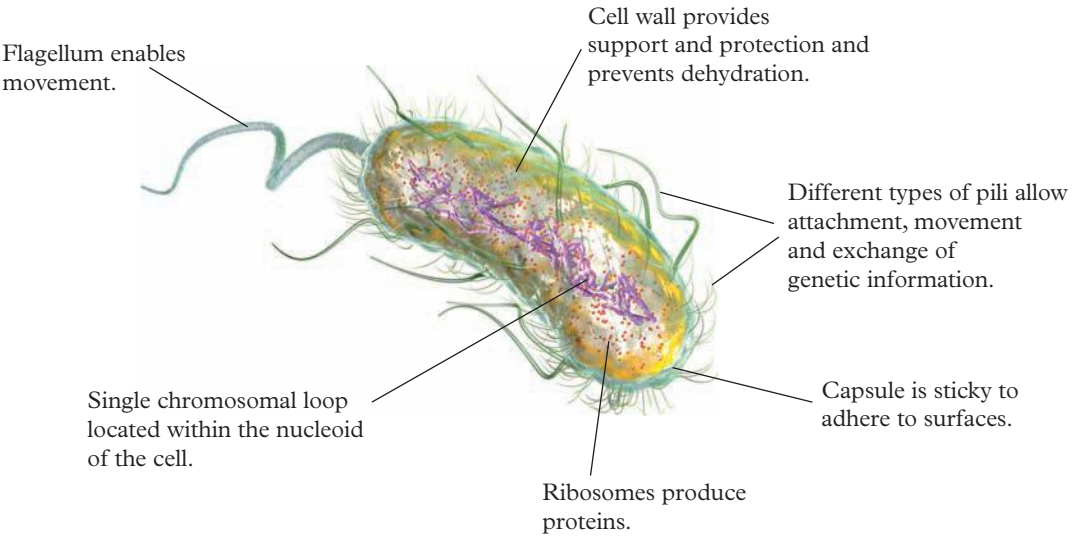


FIGURE 4 Detailed structural components of a bacterial cell

Cellular extensions of bacteria

Bacteria often have specialised structures sticking out from the cell surface that allow them to move around, attach to surfaces and exchange genetic material. These include the following.

- **Flagella** are tail-like extensions from the cell surface that allow some bacteria to move. Often only a single flagellum is shown in images of bacteria, but flagella are regularly found in clusters of 1–4 at one end or both ends of the cell, or spread out to cover the entire cell surface. Flagella work together in a coordinated whip-like motion that enables directional and controlled movement.
- **Pili** are hollow cellular extensions that allow different prokaryotic cells to join with each other to exchange small circular sections of DNA known as **plasmids**. Advantageous mutations such as resistance to antibiotics can be transferred to other bacteria through pili.
- **Fimbriae** are a specific type of pili that are finer, more numerous and less specialised. They give a bacterial cell a hairy appearance and help it attach to surfaces. Even if flagella are not present, when a bacterial cell lands on a surface, fimbriae secrete a sticky glue-like substance that adheres to the surface, allowing individual bacteria to attach to form a colony.

flagellum
a tail-like extension of the bacterial plasma membrane that allows movement; plural *flagella*

pilus
a small extension of the bacterial plasma membrane used to exchange genetic material (plasmids); plural *pili*

plasmid
a small circular piece of extra DNA found in bacterial cells

fimbria
a fine extension of the bacterial plasma membrane that allows the cell to adhere to surfaces; plural *fimbriae*

eukaryote
an organism consisting of eukaryotic cells, such as animals, plants, fungi and protists

organelle
a compartment within the cytoplasm of eukaryotic cell where specialised functions are carried out

cytoplasm
the contents of eukaryotic cells, excluding the nucleus

Eukaryotes

Protists, fungi, plants and animals are all classified as **eukaryotes**. Some species are unicellular and others are multicellular. All eukaryotes contain a nucleus and other membrane-bound **organelles**. These organelles are like small rooms in a house that each have a specific function. Each organelle has a unique environment that allows the cell to concentrate energy and resources where they are needed. The internal content of eukaryotic cells is called the **cytoplasm** because it contains both the cytosol and fluid contained in the organelles. The cytoplasm does not include the nucleus, which contains the genetic material of the cell.

Each group of eukaryotic cells has a unique set of organelles (Figure 5). For example, plant cells have chloroplasts and a cell wall, whereas animal cells do not. Protists are unicellular and often have extensions for movement, much like those of bacterial cells. The cells within a single organism also vary slightly. Multicellular organisms are larger, and need many different cell types, each with a different structure and chemicals for carrying out specialised tasks.

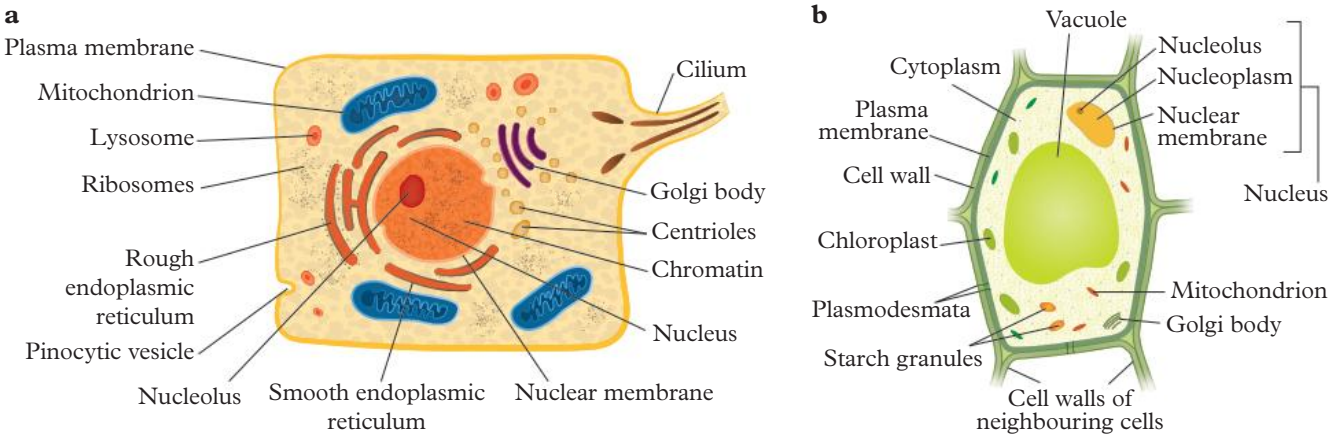


FIGURE 5 A generalised structure of **a** a eukaryotic animal cell and **b** a eukaryotic plant cell

Endosymbiotic theory

According to endosymbiotic theory, eukaryotic cells evolved when a prokaryotic bacterial cell entered ('endo') and became incorporated into a larger cell. This allowed the large cell and the small cell to share energy and resources, resulting in the smaller prokaryotic cell evolving into an organelle of the larger cell.

Most scientists accept this theory as the process that formed mitochondria and chloroplasts within eukaryotic cells. For example, it is thought that aerobic bacteria were consumed by ancestral eukaryotic cells and eventually became the mitochondria of these cells, enabling eukaryotes to carry out cellular respiration within an organelle (Figure 6). Other eukaryotic cells engulfed photosynthetic bacteria, which eventually became specialised chloroplasts, forming photosynthetic eukaryotes that can photosynthesise, such as plant cells and some protists.

Study tip

All eukaryotic cells contain mitochondria for cellular respiration. Chloroplasts are only located within cells that obtain nutrition via photosynthesis.

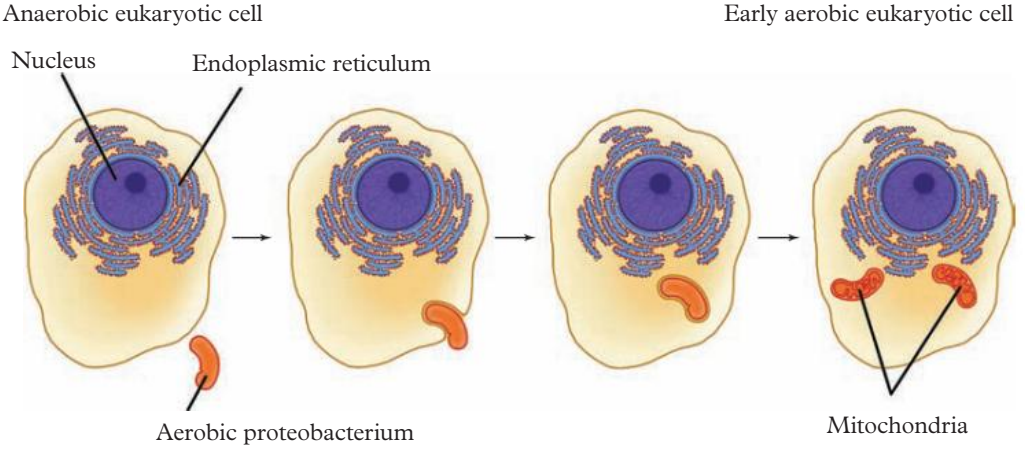


FIGURE 6 The formation of mitochondria according to the endosymbiotic theory of eukaryotic cell evolution

Comparison of prokaryotic and eukaryotic cells

Eukaryotic cells are larger than prokaryotic cells and they contain cytoplasm rather than cytosol (Figure 7). This is because cytoplasm includes the fluid contained in organelles. Prokaryotic cells have free DNA in the cytosol, whereas the DNA of eukaryotic cells is enclosed by a double-layered membrane to form a nucleus. The inclusion of these membrane-bound organelles allows a eukaryotic cell to grow larger than a typical prokaryotic cell. Prokaryotic cells have ribosomes that are free within the cytosol, whereas eukaryotic cells also have ribosomes fixed on the surface of the rough endoplasmic reticulum as well as others that are free within the cytoplasm.

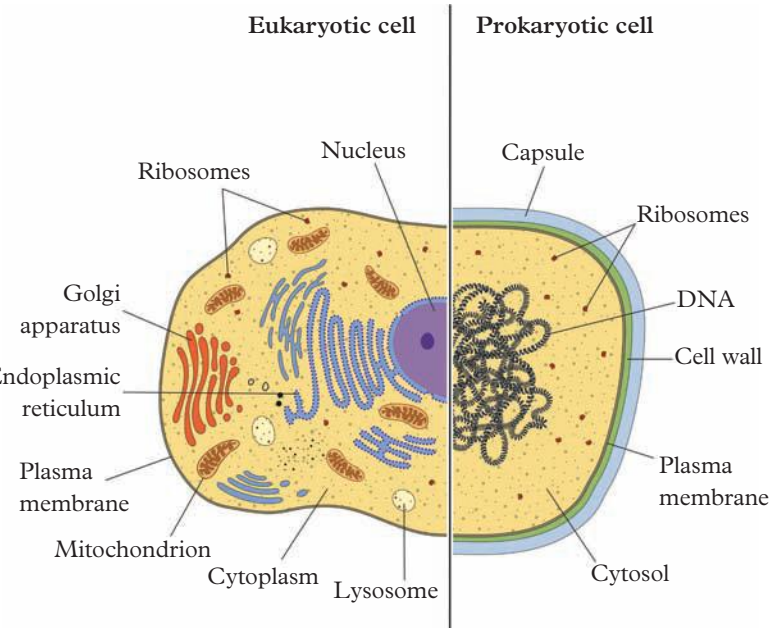


FIGURE 7 A comparison of eukaryotic and prokaryotic cell structure. Note that some eukaryotic cells, such as plant cells, have cell walls.

Study tip

Chloroplasts are not found in every cell of a plant. A leaf cell may contain thousands of chloroplasts, whereas flower petal cells contain none.

TABLE 1 Characteristics of prokaryotic and eukaryotic cells

Feature	Prokaryotic	Eukaryotic			
	Bacteria	Protists	Fungi	Plants	Animals
Nucleus	Absent	Present	Present	Present	Present
Mitochondria	Absent	Present	Present	Present	Present
Chloroplasts	Absent	Present in some forms	Absent	Present	Absent
Mode of nutrition	Heterotrophic or autotrophic (chemosynthesis or photosynthesis)	Photosynthesis or heterotrophic or combination of both	Heterotrophic by absorption	Photosynthesis	Heterotrophic by ingestion
Multicellularity	Absent	Absent in many groups	Present except in yeasts	Present	Present

CASE STUDY 2.1

Human red blood cells

Human red blood cells (Figure 8) are produced in bone marrow and move through the body in blood vessels, transporting oxygen that is bound to a protein called haemoglobin. Red blood cells are an unusual type of eukaryotic cell. They contain no nucleus and are therefore unable to divide. This means they need to be continually produced to replace old red blood cells that are removed and broken down by the liver after approximately 100 days. Red blood cells also do not have organelles associated with making proteins, such as endoplasmic reticulum or the Golgi apparatus. The haemoglobin protein is made in bone marrow when a red blood cell is produced. Red blood cells have no mitochondria because they do not require energy for active cellular functions, as the binding of oxygen is a passive process.

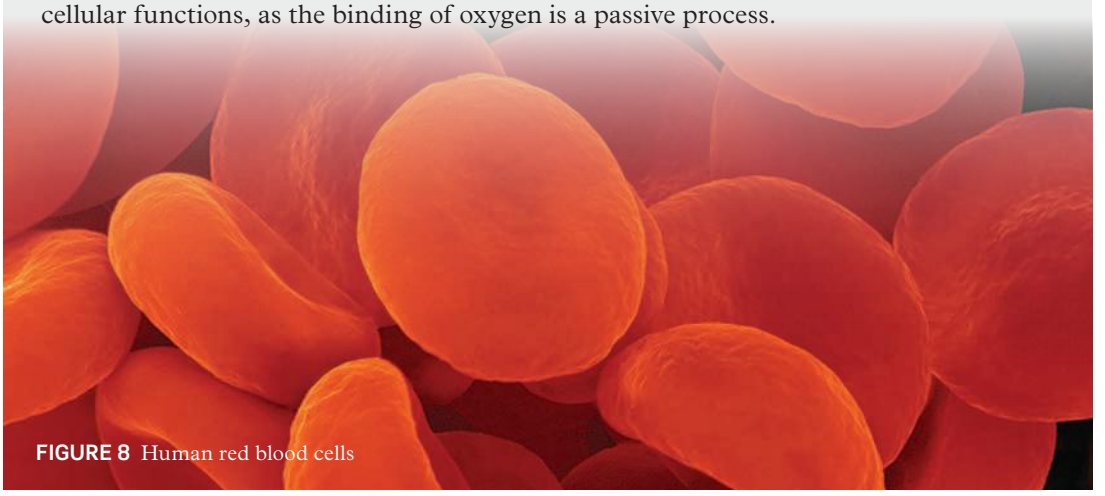


FIGURE 8 Human red blood cells

CHECK YOUR LEARNING 2.1

Describe and explain

1 Explain why cells are described as the basic structural features of life.

2 Describe the differences between cytoplasm and cytosol.

FIGURE 9 An amoeba is a microscopic unicellular organism.

3 Explain how you could identify the cell in Figure 9 as eukaryotic.

4 Describe three components that are required by all cells for them to function correctly.

Apply, analyse and compare

5 Apply your understanding of cell theory to explain why a virus is classified as non-living.

6 Contrast prokaryotic and eukaryotic cells.

Design and discuss

7 Create a diagram of a generalised cell and label all the components possessed by all cells.

8 Read Case study 2.1

a Explain how red blood cells differ from typical eukaryotic cells.

b Suggest why red blood cells are still classified as eukaryotic cells, and not prokaryotic cells.

2.2 Surface area to volume ratio

KEY IDEAS

In this topic, you will learn that:

- surface area to volume ratio limits cell size
- organelles are needed for specific cellular functions.

Cells can be many different shapes and sizes, but very few are large enough to be seen by the human eye without the aid of a microscope. For cells to stay alive, their cytoplasm must exchange nutrients and waste with the external environment. This exchange occurs across the plasma membrane. Prokaryotic cells are much smaller than eukaryotic cells because they do not contain specialised organelles for specific tasks. Eukaryotic cells have compartmentalised organelles with specific roles so that the cell can carry out cellular processes efficiently.

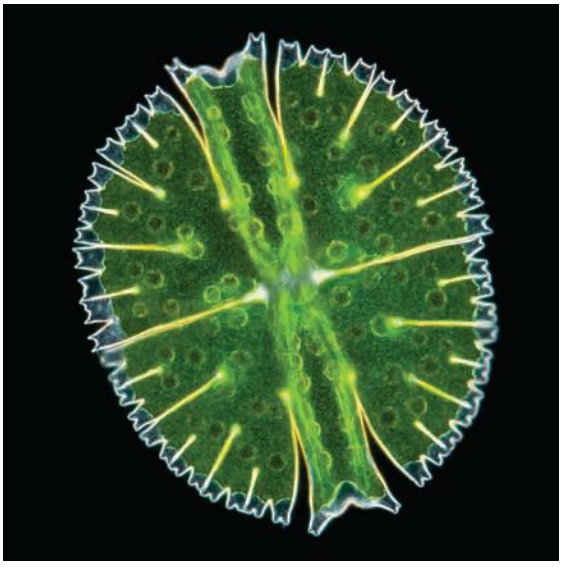


FIGURE 1 The irregular shape of this unicellular organism (called a desmid) maximises the surface area to volume ratio.

Surface area and volume

surface area
the total area of the plasma membrane that diffusion occurs across

volume
the total amount of space in a contained area

Biologists compare the surface area to volume ratio (SA:V) of cells when they compare cell size. **Surface area** refers to the surface area of the plasma membrane, the area surrounding the cell that is exposed to the external environment. **Volume** refers to the space taken up by the internal contents or cytoplasm.

As a cell grows, both the surface area and the volume of the cell increase; however, the cell volume increases more than the surface area. This means that the bigger the cell, the more difficult it is for the cell to exchange nutrients and waste between the centre of the cell and the external environment. Small cells have a larger surface area to volume ratio than large cells. As a result, small cells are better at taking in nutrients and removing waste than large cells. The surface area to volume ratio limits how big a cell can grow.

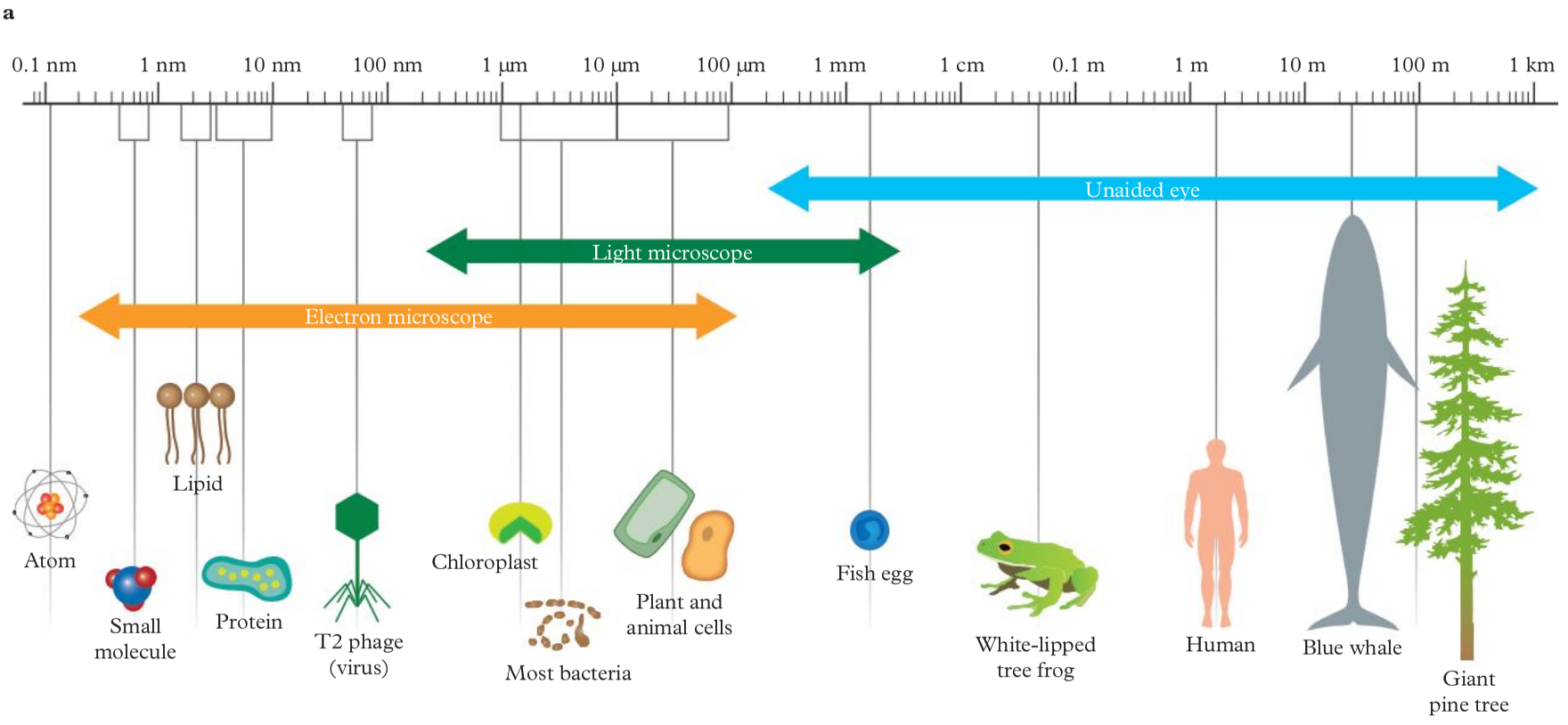


FIGURE 2 Most cells are so small that you need a microscope to see them.

Cell size limitations

As cells grow, their volume increases at a much greater rate than their surface area. Therefore, there is more cytoplasm volume than plasma membrane surface. There are several consequences of increasing cell size.

- The DNA within the nucleus (controlling activities such as protein production) is under higher demand because more cytoplasm and organelles need to be produced, maintained and replaced.
- Growing cells have increased **metabolism** (cellular reactions), which means they produce more waste than smaller cells do. Waste can become toxic if it is not quickly removed from the cell. Large cells have more difficulty removing waste than small cells do.
- Nutrients must be able to reach all regions of the cell and move across the plasma membrane fast enough to accommodate the needs of the entire cell. Small cells with large surface area to volume ratios can move nutrients from their membrane to the centre of the cell much faster than large cells with small surface area to volume ratios.

metabolism
all the chemical processes occurring within a cell

Having more smaller cells or long, thin cells is more efficient than having a single large cell (Figure 3). Most cells reach a particular size and then divide to form more cells.

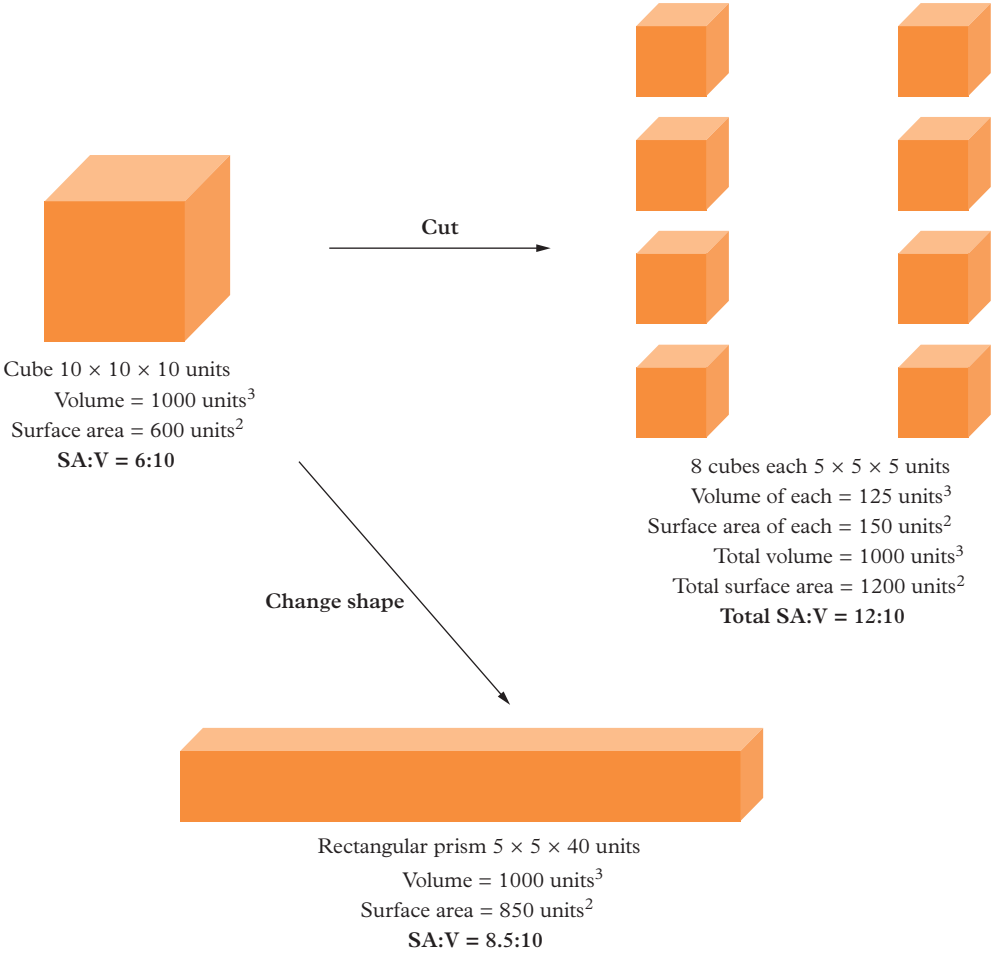


FIGURE 3 Cutting a large cube into smaller cubes demonstrates how an increased number of smaller cells is more efficient than a single large cell because they have an increased surface area to volume ratio.

WORKED EXAMPLE 2.2

CALCULATING SURFACE AREA TO VOLUME RATIO

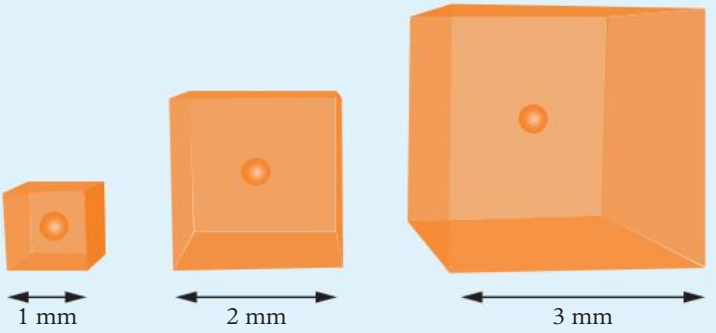


FIGURE 4 As cell size increases, the SA:V decreases because the volume increases more than the surface area.

Consider Figure 4. For each cube, calculate:

a the surface area (mm^2)

b the volume (mm^3)

c SA:V.

SOLUTION

a Calculate the surface area for each cube.

Surface area (mm^2) = length × width × number of sides (cube faces)

Cube length 1 mm:

$$\text{Surface area} = 1 \times 1 \times 6 = 6 \text{ mm}^2$$

Cube length 2 mm:

$$\text{Surface area} = 2 \times 2 \times 6 = 24 \text{ mm}^2$$

Cube length 3 mm:

$$\text{Surface area} = 3 \times 3 \times 6 = 54 \text{ mm}^2$$

b Calculate the volume for each cube.

Volume (mm^3) = length × width × height

Cube length 1 mm:

$$\text{Volume} = 1 \times 1 \times 1 = 1 \text{ mm}^3$$

Cube length 2 mm:

$$\text{Volume} = 2 \times 2 \times 2 = 8 \text{ mm}^3$$

Cube length 3 mm:

$$\text{Volume} = 3 \times 3 \times 3 = 27 \text{ mm}^3$$

c Calculate SA:V. Simplify the ratios by dividing by the highest common factor.

Cube length 1 mm:

6:1

Cube length 2 mm (simplify by dividing by the highest common factor = 8)

24:8 = 3:1 (the second ratio is a simplification of the first ratio)

Cube length 3 mm (simplify by dividing by the highest common factor = 27)

54:27 = 2:1

Video
Worked example 2.2: Calculating surface area to volume ratio

TABLE 1 Surface area to volume ratios for each cube

Cell length (mm)	Surface area (mm^2)	Volume (mm^3)	SA:V
1	6	1	6:1
2	24	8	3:1
3	54	27	2:1

Organelles in eukaryotic cells

Eukaryotic cells have membrane-bound organelles. A membrane enables an organelle to carry out a specialised cellular function; for example, chloroplasts carry out photosynthesis. Organelles contain enzymes and molecules in a unique internal environment that may be different from the surrounding fluid or of any other organelle.

Diffusion

The greater the area taken up by the plasma membrane, the more places there are for substances (e.g. oxygen, carbon dioxide and amino acids) to move randomly across it. However, as the volume of the cell increases, the organelles become spread further apart, increasing the time taken for nutrients to be transported to where they are needed. Organelles that are closer to the plasma membrane surface use these substances before they reach the centre of a cell. Therefore, the size of these cells is limited so that all regions of the cell, including the nucleus, can obtain the substances required for metabolic reactions.

Study tip

Cells that require rapid diffusion are often long and thin rather than square. They have adapted to having a large plasma membrane, increasing surface area without compromising the cytoplasmic volume.

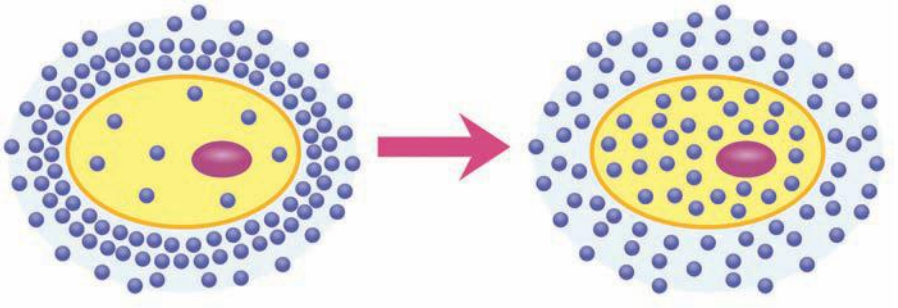


FIGURE 5 Diffusion across a cell membrane

Diffusion pathways

In small cells with a large SA:V, substances can move efficiently into the centre and waste can move out. Most of these substances move by a process of random movement, bumping into each other until they spread evenly across the cellular space. These **diffusion** pathways allow materials to reach all regions of the cell as rapidly as possible.

diffusion the random movement of substances across the plasma membrane from an area of high substance concentration to an area of low substance concentration

Larger cells (with a small SA:V) require more resources than can be provided by their limited surfaces. There is a longer diffusion pathway and the central area of the cell does not receive the substances it needs to function correctly. Ultimately, this means the cell is unable to survive.

You will learn more about diffusion in Topic 2.4.

Cells are adapted for increasing SA:V

As multicellular organisms become larger and more complex, their cells become specialised to carry out one key function. For example, red blood cells are specialised to transport oxygen around the body. They do not pass on messages as nerve cells do, or contract like muscle cells. Specialisiation enables the multicellular organisms to become larger and more complex. This is different from unicellular organisms, which are much more inefficient and in which all cell processes are completed by a single cell.

CASE STUDY 2.2

Cytoplasmic streaming

The cytoplasm of larger eukaryotic plant and animal cells circulates within the cell in a process known as cytoplasmic streaming. The organelles and other components of the cytoplasm flow in a circular motion around the cell. Organelles such as chloroplasts circulate close to the cell wall where gases diffuse into and out of the cell. In this way, carbon dioxide that enters the cell reaches the chloroplasts rapidly for the process of photosynthesis. Often, in larger cells the nucleus does not circulate, but is situated towards the cell membrane rather than centrally within the cell (Figure 6).

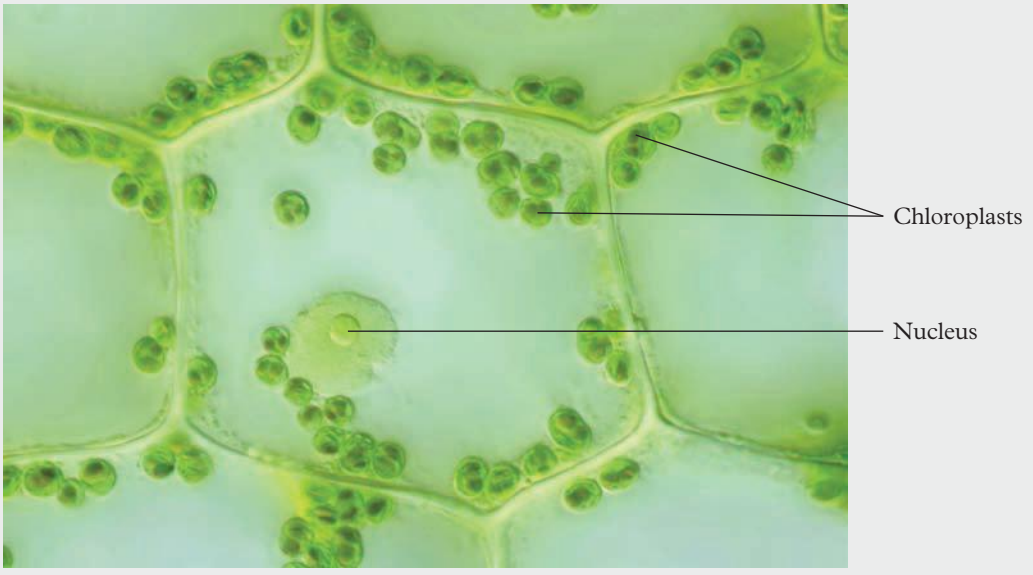


FIGURE 6 In epidermal cells of the aquatic plant *Elodea*, chloroplasts circulate by cytoplasmic streaming.

CHALLENGE 2.2

SA:V in different shapes

Consider the two shapes in Figure 7.

1 Calculate the SA:V of each shape.

2 Explain which shape has the larger SA:V and what this means for the cell.

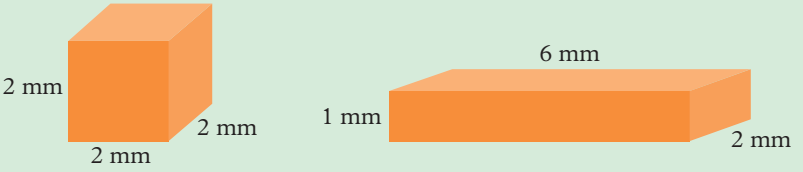


FIGURE 7 Calculate the SA:V of each shape.

CHECK YOUR LEARNING 2.2

Describe and explain

1 Define 'diffusion'.

2 Explain the significance of surface area to volume ratio for cell size.

3 Draw a cell diagram to represent Figure 8 and label the regions of the *Paramecium* that relates to surface area and the area that relates to volume.

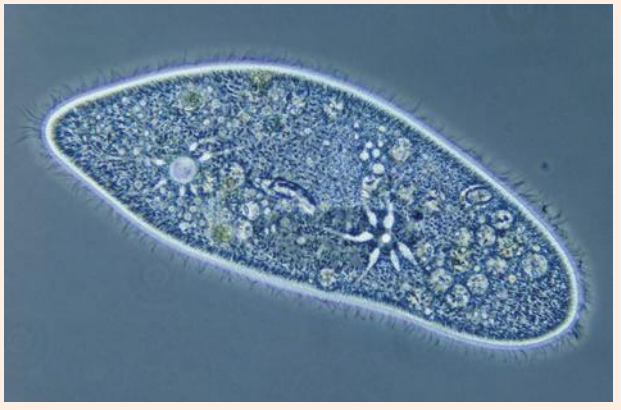


FIGURE 8 A micrograph of a *Paramecium* cell

4 'Cell size is limited.' Explain what is meant by this statement in terms of surface area to volume ratio.

Apply, analyse and compare

5 A student used modelling clay to make models of different 'cells' in the shape of a sphere, a rectangular prism and a flat sheet. All the models had the same volume. Predict which shape(s) would have the:

a largest surface area to volume ratio

b smallest surface area to volume ratio.

6 Apply your understanding of cell size to explain why single-celled protists are generally microscopic in size.

7 Read Case study 2.2.

a Explain the purpose of cytoplasmic streaming.

b Explain why the nucleus in larger cells is often located towards the cell membrane and not in the centre of the cell.

Design and discuss

8 Discuss how different cell types are adapted to maximise surface area without increasing cell volume. Use examples in your discussion.

9 Design a simple experiment to demonstrate how increasing cell size can lead to a longer diffusion pathway. Remember to identify independent, dependent and (at least two) controlled variables for your experiment.

2.3 Cell organelles

KEY IDEAS

In this topic, you will learn that

+ animal and plant cell organelles have specific structures and perform distinct functions.

The organelles in eukaryotic cells allow them to specialise, reducing the amount of energy and resources that are needed to keep the organism alive. Different cell types have different organelles, depending on their function. Microscopes allow us to view and identify organelles as well as describe their location, structure, quantity and characteristics within different cell types.

Organelles are often surrounded by their own membranes and contain internal fluid at a specific pH and the required amounts of ions, water and enzymes to efficiently carry out their function.

Structures in both plant and animal cells

Animal and plant cells have many organelles in common.

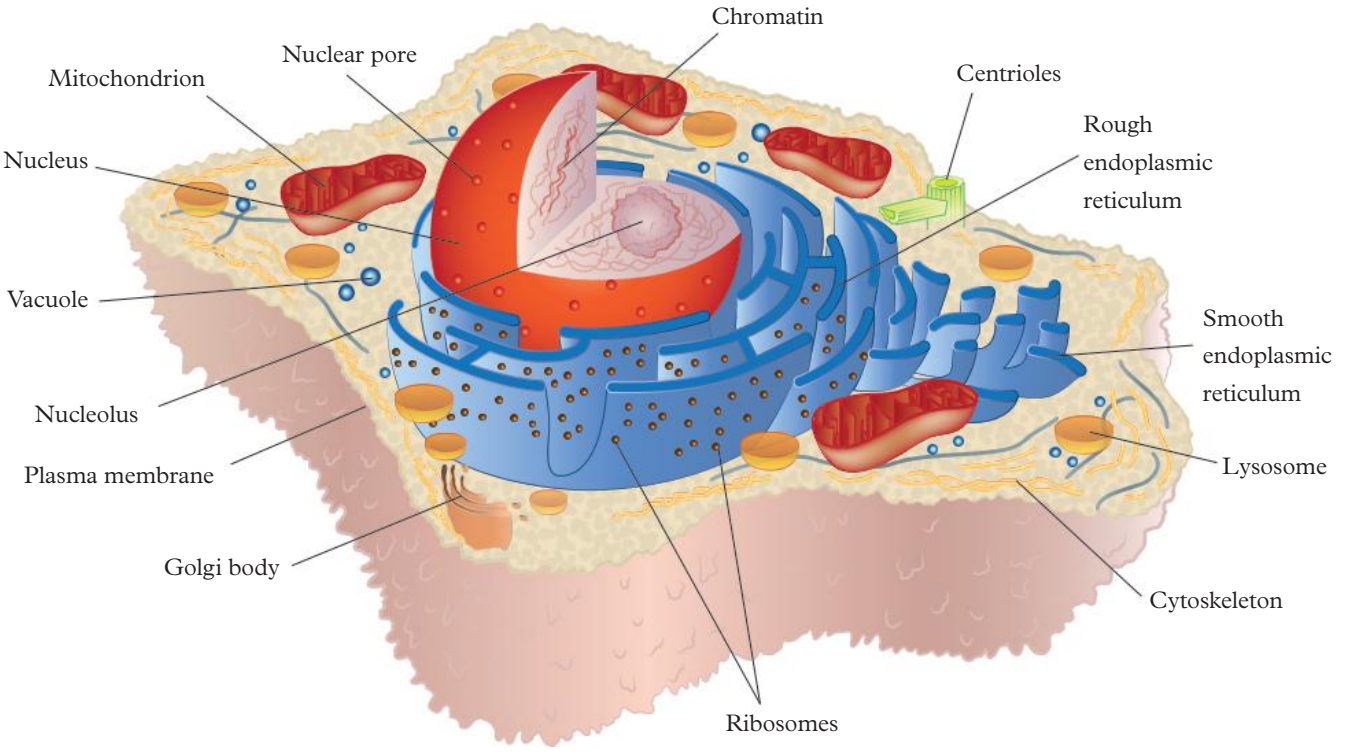


FIGURE 1 A detailed diagram of an animal cell

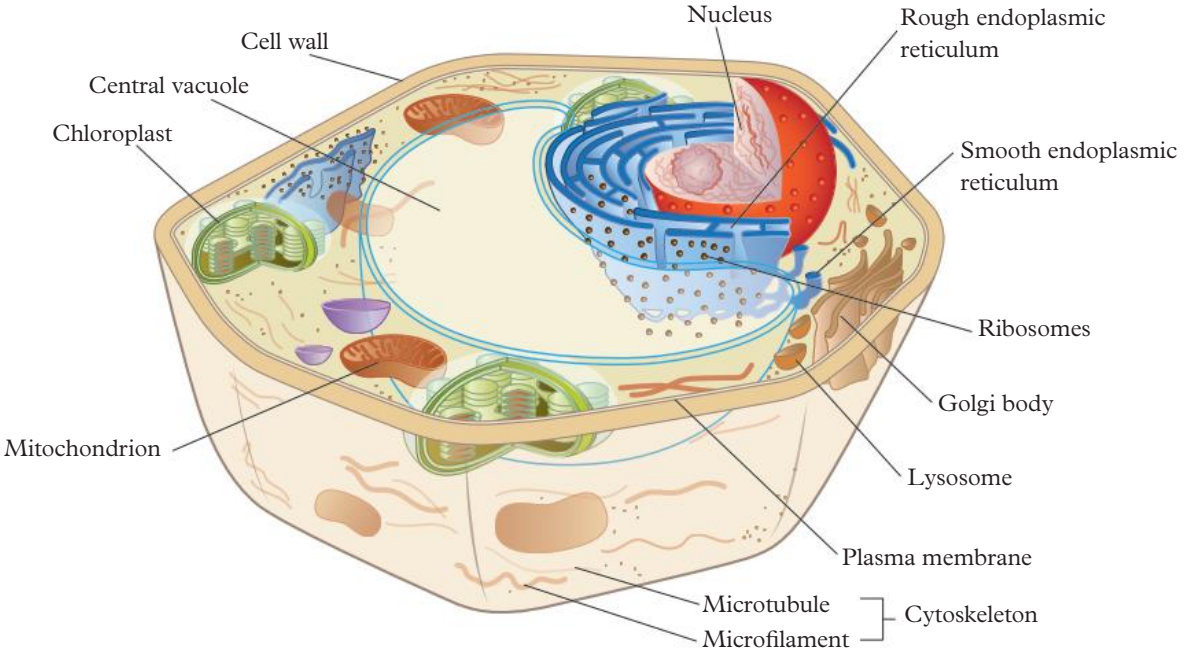


FIGURE 2 A detailed diagram of a plant cell

Plasma membrane

The plasma membrane is a structure surrounding the cytoplasm of all cells (Figure 3). It is a double layer made of phospholipid molecules, proteins, cholesterol and other attached carbohydrates. The plasma membrane controls the entry and exit of different molecules on the basis of their size and chemical properties.

Nucleus

nucleus
an organelle that stores genetic information within DNA; involved in protein synthesis and DNA replication

vacuole
a membrane-bound, fluid-filled organelle used by plants as a fluid reservoir

The **nucleus** is an organelle common to nearly all eukaryotic cells (except adult red blood cells). The nucleus is the largest organelle and is located centrally within most animal cells (Figure 3). In plant cells, the nucleus can be positioned slightly closer to the plasma membrane if a **vacuole** (large storage compartment) is occupying the central region.

Study tip

A common misconception people have about cells is that they are mainly filled with cytosol. But cells are typically packed with organelles.

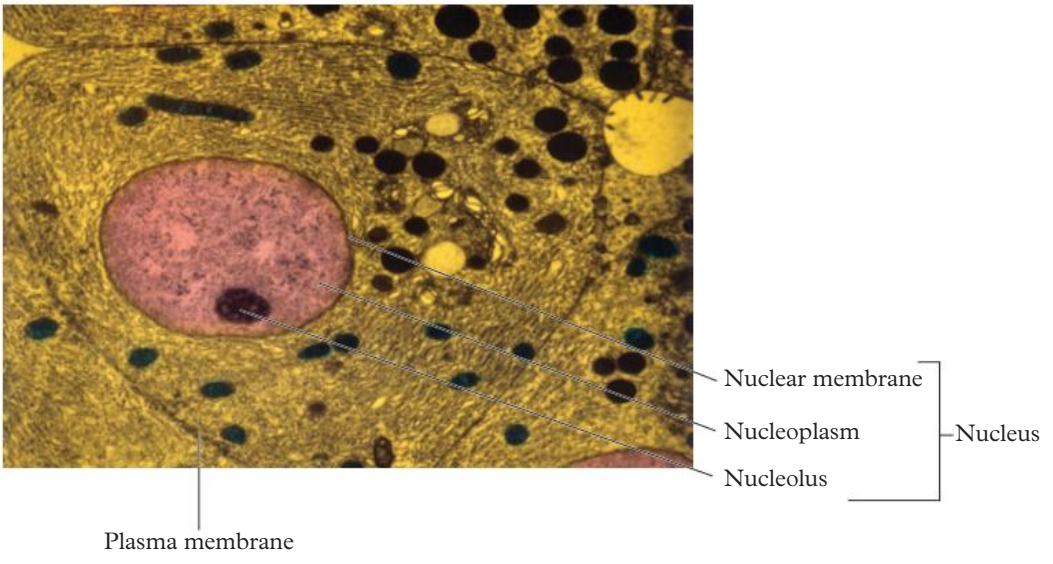


FIGURE 3 An electron micrograph showing the plasma membrane surrounding the cytoplasm of an animal cell

The nucleus contains DNA, the inherited genetic material that regulates all cellular activities, including protein production and cell division. In non-dividing cells, the DNA and associated proteins are loosely coiled, forming a long network of threads called chromatin. The nucleus also has a region called a **nucleolus**, which produces ribosomes. The nucleus is surrounded by a double membrane called the nuclear membrane. In the nuclear membrane are nuclear pores that allow substances to be exchanged between the nucleus and the cytoplasm. Ribosomes made in the nucleolus leave the nucleus, whereas amino acids, hormones and energy molecules such as ATP enter. The outer nuclear membrane is continuous with another organelle called the **endoplasmic reticulum** and therefore they are located next to each other within eukaryotic cells.

nucleolus
the region of the nucleus that produces ribosomes

endoplasmic reticulum
an organelle involved in sorting, modifying and packaging proteins, lipids and steroids

Endoplasmic reticulum

The endoplasmic reticulum is an extension of the outer membrane of the nuclear membrane. It consists of a network of flattened, hollow sacs called cisternae (Figure 4). The endoplasmic reticulum contains many enzymes that are involved in synthesising, transporting and packaging different molecules around the cell.

There are two types of endoplasmic reticulum.

- **Rough endoplasmic reticulum** contains ribosomes scattered over its surface, giving it a rough, dimpled appearance. Ribosomes synthesise proteins that are then modified and packaged as they move through the cisternae before being transported in vesicles to around the cell or becoming part of the vesicle membrane.
- **Smooth endoplasmic reticulum** has a smooth appearance. It is involved in synthesising, modifying and packaging steroids (e.g. the hormone oestrogen) and lipids (e.g. cholesterol) within the cisternae.

rough endoplasmic reticulum
an organelle that produces, modifies and packages proteins synthesised on ribosomes

smooth endoplasmic reticulum
an organelle that produces, modifies and packages steroids, carbohydrates and lipids

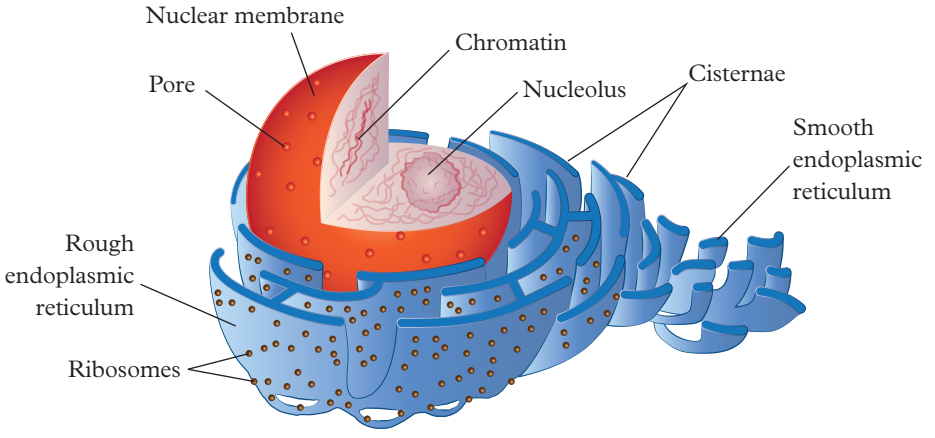


FIGURE 4 A 3D illustration of an endoplasmic reticulum next to the nucleus

Study tip

Rough endoplasmic reticulum has **r**ibosomes attached that synthesise proteins.
Smooth endoplasmic reticulum synthesises **s**teroids, carbohydrates and lipids.

Ribosomes

Ribosomes are small organelles that synthesise proteins. Ribosomes are only visible through an electron microscope (Figure 5). There are thousands of ribosomes in every eukaryotic cell, either on the surface of the rough endoplasmic reticulum or free within the cytoplasm.

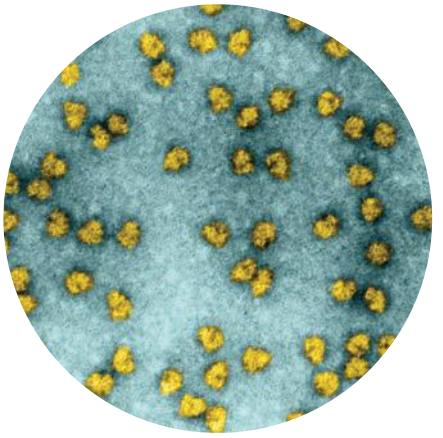


FIGURE 5 Ribosomes are found free within the cytoplasm of all cells.

Golgi bodies

Golgi body
an organelle involved in modifying proteins into their final shapes and transporting them into vesicles

vesicle
a small fluid-filled organelle that transports substances throughout the cytoplasm, fusing with other cellular membranes to release their contents

Golgi apparatus
the combined Golgi body and associated vesicles

Golgi bodies are found in all eukaryotic cells. A Golgi body is made of a stack of flattened sacs called cisternae that act as a collecting, sorting, processing and distribution centre (Figure 6). There are two distinct ends of the Golgi body:

- The site of entry, where **vesicles** from the endoplasmic reticulum that contain partially modified proteins, lipids and steroids fuse. The membranes of the Golgi body enclose the vesicle into the cisternae. As these substances move through the cisternae, they are further processed until they reach the site of exit.
- The site of exit, where fully processed products leave in vesicles that pinch off from the end of the cisternae. These vesicles are bound for the cytoplasm, other organelles or out of the cell.

Golgi body size is constant because while vesicles are fusing at one end, other vesicles are leaving at the other. The term **Golgi apparatus** is used to describe both the Golgi body and its associated vesicles.

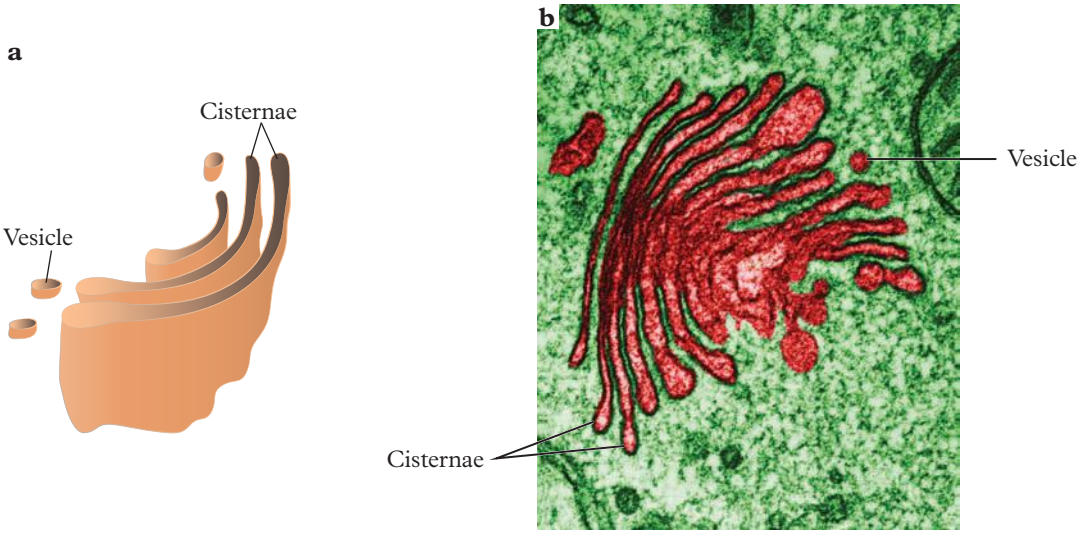


FIGURE 6 **a** An illustration of the two distinct ends of a Golgi apparatus where vesicles either fuse or pinch off. **b** An electron micrograph of a Golgi apparatus.

Vesicles

Vesicles are small membrane-bound organelles that transport substances around a cell. They are formed from organelles such as the endoplasmic reticulum and Golgi body. Vesicles fuse with other organelles, vacuoles or the plasma membrane to release their contents.

Mitochondria

Cellular respiration takes place in organelles called mitochondria (singular: **mitochondrion**). These organelles are highly specialised with separate membranes and regions that contain the right enzymes and molecules for specific reactions to take place (Figure 7). The entire mitochondrial structure is either cigar-shaped or spherical (e.g. in liver cells). This provides a large surface area to volume ratio for the efficient uptake and release of materials.

Mitochondria have an inner and an outer membrane. The outer membrane controls the passage of materials into and out of the mitochondrion. The inner membrane is highly folded to form protrusions called **cristae** that increase the surface area of this membrane. The cristae contain the molecules responsible for ATP production. Within the centre of the inner membrane is a fluid-filled region known as the **matrix**. This contains ribosomes, circular DNA molecules and molecules required for many of the steps in aerobic cellular respiration.

cellular respiration
a process carried out by mitochondria in which glucose is converted into usable energy (ATP)

mitochondrion
an organelle found in all eukaryotic cells for cellular respiration

cristae
projections of the mitochondrial inner membrane

matrix
the fluid-filled space within the inner mitochondrial membrane

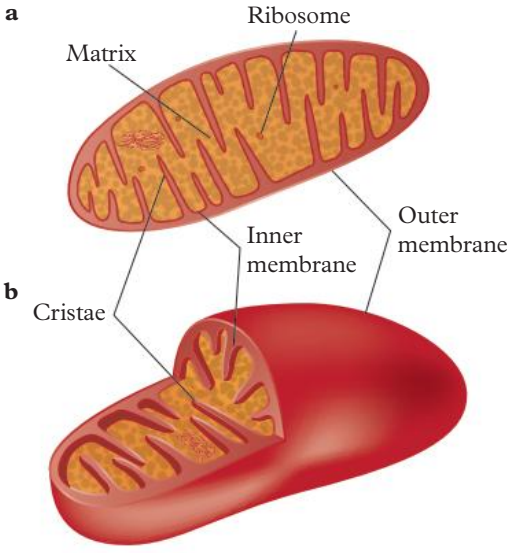


FIGURE 7 The structure of a mitochondrion: **a** longitudinal section and **b** cut-away view

Lysosomes

Lysosomes are specialised vesicles that are produced by the Golgi bodies of animal cells. Lysosomes store digestive enzymes that are able to break down (digest) substances. Lysosomes become activated when they fuse with a particular organelle, which enables them to digest old, faulty or non-functional organelles, proteins and DNA, breaking them down into simple molecules (Figure 8). White blood cells contain many lysosomes to break down bacteria that they engulf.

lysosome
a specialised vacuole containing digestive enzymes to break down old, damaged organelles and cellular components as well as substances taken into the cell

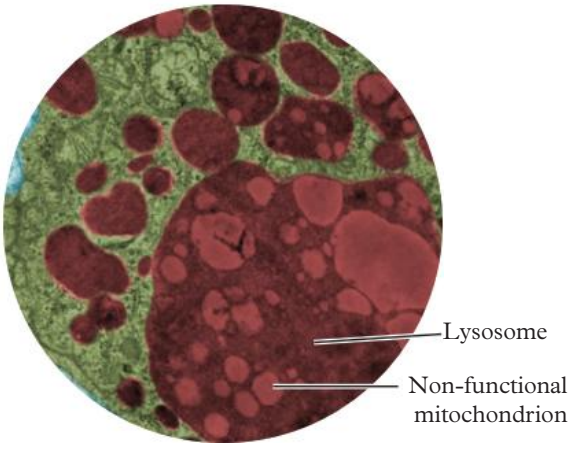


FIGURE 8 An electron micrograph of lysosomes digesting many non-functional mitochondria

Vacuoles

Vacuoles are fluid-filled storage organelles, bound by membranes. They can be a wide range of sizes and look different under a microscope depending on their contents, such as starch or digestive molecules. The number of vacuoles in a particular cell depends on the type of cell and its function.

Centrosome

centrosome
an organelle made up of two centrioles

centriole
an organelle made up of microtubules that are involved in mitosis

When a cell reproduces, the **centrosome** plays an important role in this process. The centrosome is an organelle consisting of two **centrioles** that lie perpendicular to each other beside the nucleus of animal cells (Figure 9). Each centriole is a hollow tubular structure made up of microtubules. These microtubules produce the spindle fibres that separate the DNA/chromosomes when a cell is dividing.

Single centrioles are also located at the base of cellular extensions that aid in movement, such as **cilia** or flagella. The centriole is involved in the formation of the cilia or flagella by assisting in mitosis. Plant cells do not contain a centrosome; however, the cells of some lower-order plants, such as mosses and ferns, can have individual centrioles if cilia or flagella are present.

cilia
hair-like extensions of the plasma membrane of some eukaryotic cells that require movement

When centrioles are absent or destroyed, cell division still occurs, although more errors occur and the process of mitosis is much slower.

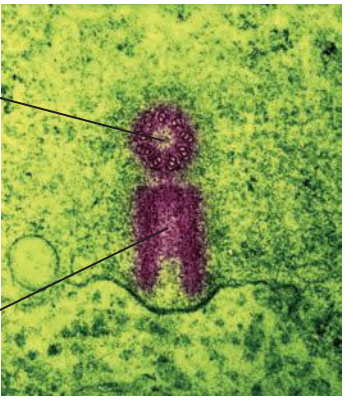


FIGURE 9 An electron micrograph of a centrosome, consisting of two centrioles lying perpendicular to each other

Cytoskeleton

cytoskeleton
the internal skeleton of the cytoplasm – a support network of interconnected microscopic fibres and tubes

microtubules
a component of the cytoskeleton made of tubulin

microfilaments
a component of the cytoskeleton made of actin

Many organelles move within the cytoplasm in an orderly fashion. They are held in place by a series of fine filaments inside the cell called the **cytoskeleton**. The internal skeleton consists of **microtubules** and **microfilaments**.

Structures unique to plant cells

Several features are only found in plant cells, including cell walls, chloroplasts, plant vacuoles and plastids.

Cell wall

cell wall
the outer protective and support structure of plant cells

The **cell wall** is a non-living, rigid component of all plant cells on the exterior surface of the plasma membrane. As the cell grows, the cell wall becomes longer and wider. The cell wall contains cellulose in a framework of microtubules. It provides structural support, maintains a uniform cell shape and protects the cytoplasm. Other molecules, such as lignin, are also included in the cell wall. The lignin creates a waterproof layer and provides rigidity to the more flexible cellulose. Within the cell wall are spaces that water and mineral salts can move through, and small channels called **plasmodesmata**, which join neighbouring cells together (Figure 10).

plasmodesmata
structures that join the cell walls of neighbouring plant cells together

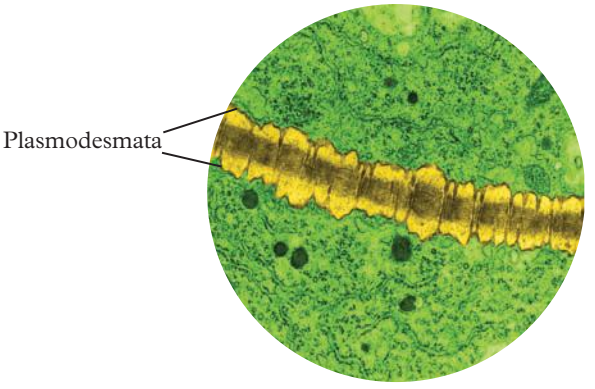


FIGURE 10 An electron micrograph of the cell wall between two neighbouring cells. It contains plasmodesmata that join the cells together.

Chloroplasts

Photosynthesis takes place in **chloroplasts** (Figure 11). Only the photosynthetic cells of producers contain chloroplasts. These organelles are highly specialised and have separate compartments that contain the pigments and other molecules required for photosynthesis.

Each chloroplast has a double membrane that allows the controlled entry and exit of molecules. The outer membrane is permeable, allowing ions and small molecules to pass through. The inner membrane is impermeable and many molecules can only enter and exit with the help of transporter proteins.

Within the chloroplast are stacks called grana. Each granum (singular) stack consists of green membrane-bound discs called **thylakoids**. The membranes of each thylakoid produce the pigment **chlorophyll**, which gives the chloroplast its green colour. The grana are surrounded by a fluid called **stroma**. Having numerous, flattened stacks of thylakoids maximises the production of chlorophyll and helps with light absorption. These stacks are joined by an interconnected series of tubes called lamellae that space the grana apart within the chloroplast, which maximises light absorption even further.

chloroplast
an organelle of plant cells that carries out photosynthesis

Study tip

The space in the chloroplast is called the stroma. It is important that you know how to spell it correctly and not confuse it with a pore in leaves, which is called a stoma.

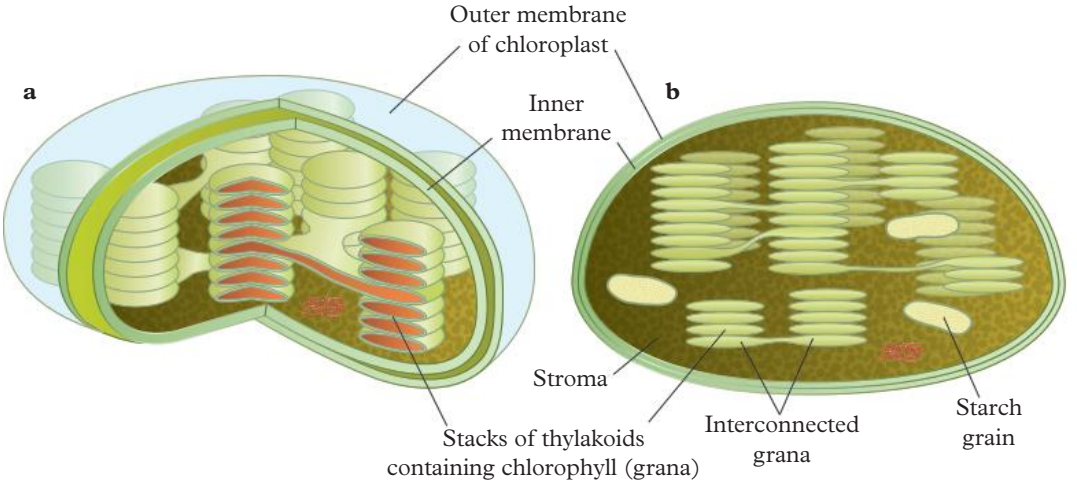


FIGURE 11 Chloroplast structure: **a** cut-away view and **b** transverse section

thylakoid
a disc-shaped sac within chloroplasts where chlorophyll is produced

chlorophyll
a pigment in chloroplasts that absorbs particular wavelengths of light for photosynthesis

stroma
the fluid region of chloroplasts

Plant vacuoles

Plant vacuoles are fluid-filled organelles surrounded by a membrane called a **tonoplast** (Figure 12). They are important storage structures in plant cells that vary greatly in size and content and act as reservoirs of ions, pigments and water. The vacuoles of some plant cells also store carbohydrates or proteins, which can be used by mitochondria for energy production when photosynthesis is limited. Vacuoles are involved in maintaining water balance in specialised leaf cells called guard cells. These cells control gas exchange in a leaf by changing size, which produces a gap between two cells that allows gases to enter or exit.

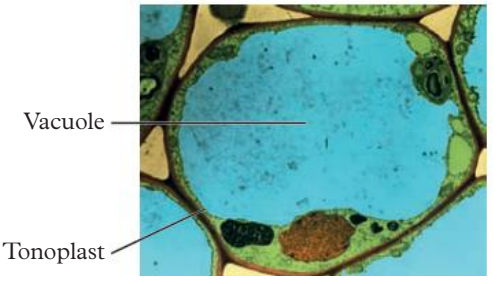


FIGURE 12 An electron micrograph of a vacuole in a plant cell

tonoplast
a membrane of the large central vacuole of plant cells

Plastids

plastid
an organelle in plant cells that produces and stores pigments and starch

Plastids produce and store different substances such as pigments and starch (Figure 13). Plastids develop from protoplasts into:

- chloroplasts, in photosynthetic tissue. They contain chlorophyll and carry out photosynthesis
- amyloplasts, in plant tissues such as roots. They are starch storage plastids that can convert glucose into starch and starch back into glucose when it is required for cellular respiration
- chromoplasts, in plant tissues such as fruit and flowers. They contain pigments involved in colour and scent production.

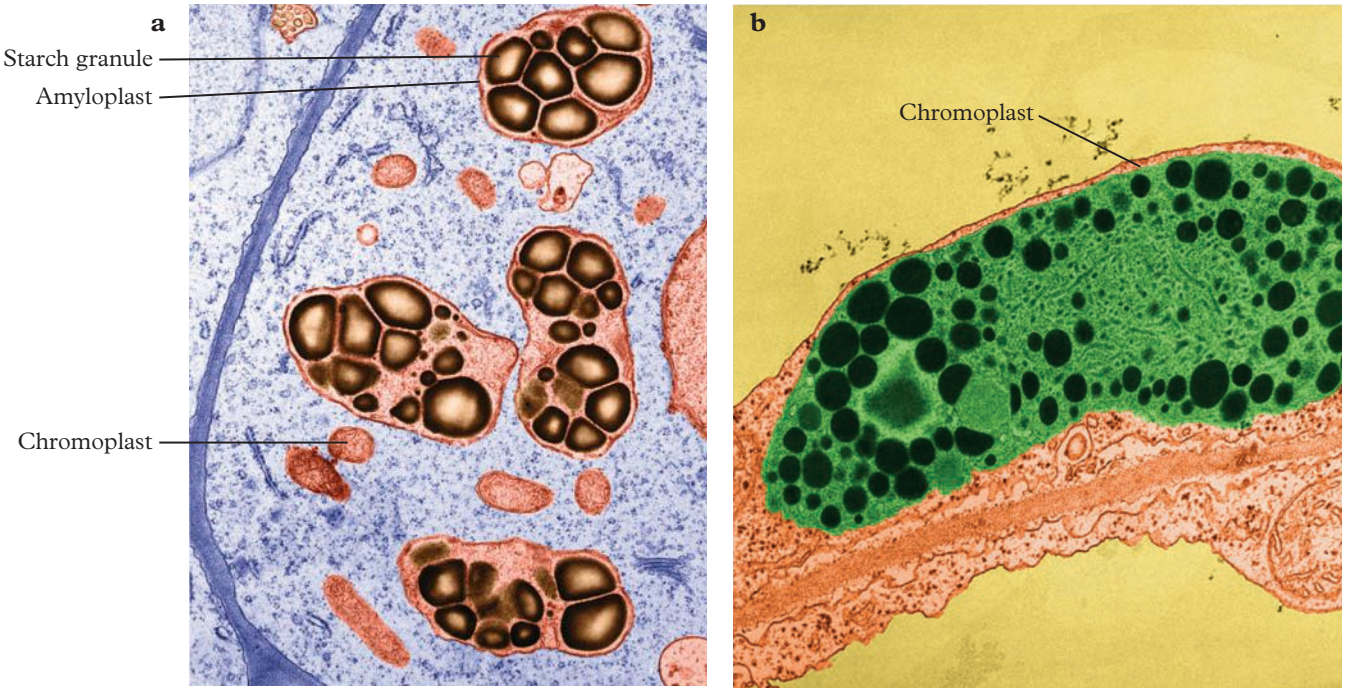


FIGURE 13 Transmission electron micrographs of **a** amyloplasts storing starch within a root cap cell and **b** a chromoplast

CASE STUDY 2.3

Industrial use of cell walls

Wood comes from the central, dead part of tree trunks where lignin is embedded in the cellulose walls of the dead tissue. The properties of these molecules make wood an ideal building material. Wood can support buildings for years and is used in the construction of buildings, bridges, furniture and tools.

Cellulose is used in the manufacture of a variety of textiles. Linen, produced from the flax plant (*Linum usitatissimum*), is one of the oldest textile fibres known. The fibres are obtained from the bark of the stalks. The bark is removed by retting, a process in

which the stalks are subjected to partial decomposition by bacteria. After the fibres are mechanically separated from the wood, they are spun and woven.

Hemp fibres from the plant *Cannabis sativa* are prepared in a similar manner. These fibres are used to produce a range of textile materials from fine fabrics to coarse ropes. The seed hairs of the cotton plant (*Gossypium*) are almost pure cellulose and therefore do not need the same preparation as the stalks of flax and hemp. For this reason, cotton succeeded linen and hemp as a fabric material.

In recent years, there has been growing interest in the production of hemp. Genetically engineered crops of *Cannabis* species that do not produce the narcotic drug are currently being grown in Tasmania. Unlike cotton plants (Figure 14), they are not subject to pest attack and can grow in less fertile soils with lower water content. Therefore, they are a more 'environmentally friendly' crop than cotton. Also, since the whole stalk produces usable fibre, it is a more productive crop than cotton, from which only the seed head is used.

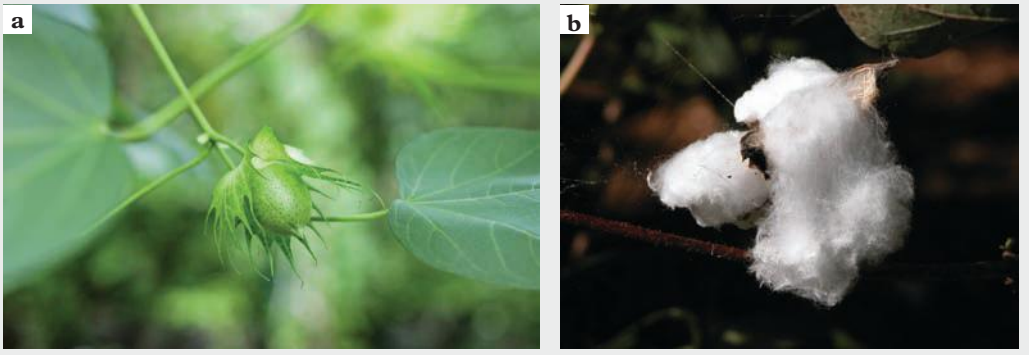


FIGURE 14 **a** Unripe cotton and **b** a ripe cotton ball

CHECK YOUR LEARNING 2.3

Describe and explain

1 Define 'organelle'.
2 Explain why muscle cells contain larger numbers of mitochondria than epithelial (skin) cells.
3 Describe the function of rough and smooth endoplasmic reticulum.
4 Describe the different roles of chloroplasts and mitochondria.

Apply, analyse and compare

5 Suggest how substances can enter and exit a chloroplast if the inner membrane is impermeable.
6 Create a chart with the headings 'Transport', 'Structure' and 'Production'. Organise each organelle into one of these categories according to its overall function.
7 Create a Venn diagram to compare and contrast the organelles in plant and animal cells.

Design and discuss

8 Discuss why endoplasmic reticulum and Golgi apparatus are close to the nucleus of eukaryotic cells.
9 Read Case study 2.3. Discuss the role of cellulose in giving plants and materials such as wood and hemp their structure.

2.4 Transport across the plasma membrane

KEY IDEAS

In this topic, you will learn that:

- the structure of the plasma membrane is described by the fluid mosaic model
- substances are transported across the plasma membrane by osmosis, facilitated diffusion and active transport.

Study tip

In the term 'plasma membrane', 'plasma' describes the fluid of the cytoplasm. 'Plasma membrane' is preferred to 'cellular membrane' because many organelles also have membranes.

Every cell is enclosed by a plasma membrane that acts as a boundary, protecting and separating the cytoplasm from the extracellular fluid that surrounds the cell. The plasma membrane is semipermeable, which means it allows some substances to move in and out of the cell but not others. Substances are transported across the plasma membrane by different modes of passive or active transport.

Fluid mosaic model of the plasma membrane

The fluid mosaic model was proposed in the early 1970s and describes the composition and structure of the plasma membrane (Figure 1).

The model describes the plasma membrane as being made of thousands of lipids, proteins and carbohydrate molecules. The composition of every plasma membrane is a mosaic of different molecules that are unique to a particular cell type.

The plasma membrane has a fluid nature, where molecules are free to move laterally within their side of the bilayer. This is important for diffusion and when particular proteins need to congregate together in a specific area. The main molecule is a type of lipid called a **phospholipid**.

phospholipid
a molecule consisting of a phosphate head and a lipid tail; a key molecular component of the plasma membrane

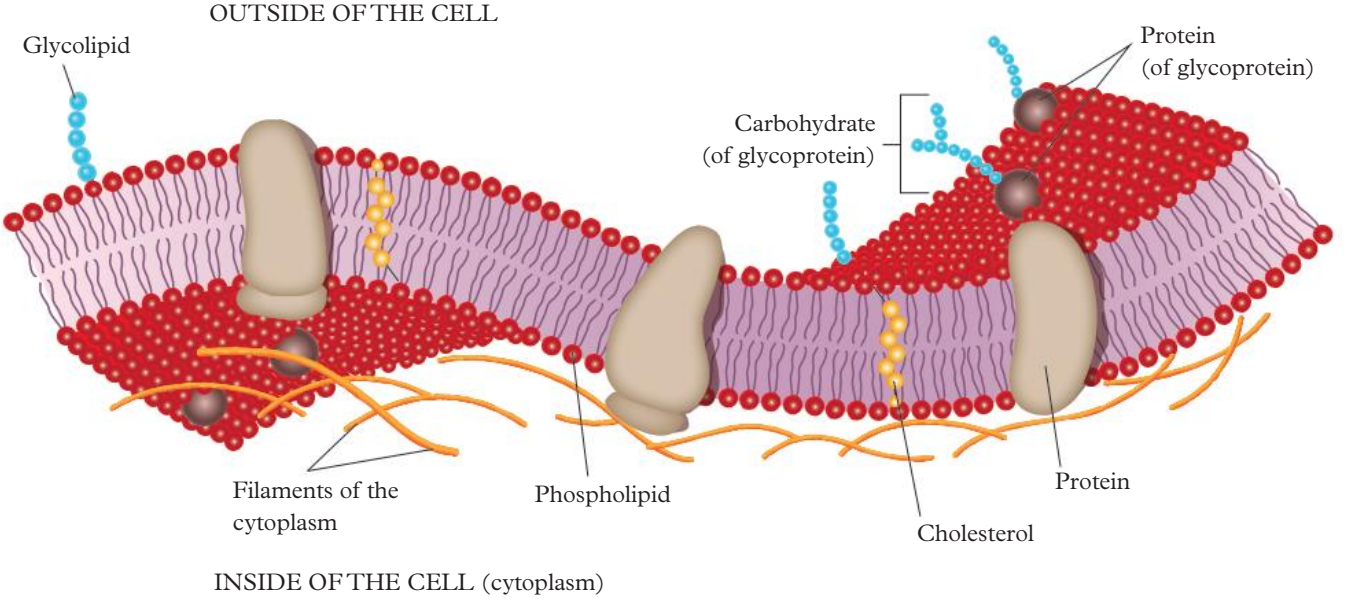


FIGURE 1 The fluid mosaic model describes the structure of the plasma membrane.

Lipids of the plasma membrane

There are many different types of lipids in the plasma membrane. These primarily include phospholipids and cholesterol.

Phospholipids

Phospholipids consist of a phosphate head and two fatty acid tails. Phospholipids naturally arrange themselves into a double layer, or **bilayer**, due to the different chemical properties of the phosphate heads and fatty acid tails.

bilayer
a double layer

- The phosphate heads are polar and **hydrophilic** ('water-loving'). They are naturally attracted to water.
- The fatty acid tails are non-polar and **hydrophobic** ('water-fearing'). They are naturally repelled by water.

hydrophilic
'water loving'; a molecule that attracts water

hydrophobic
'water fearing'; a molecule that repels water

When plasma membranes form within an aqueous, or watery, environment, such as the cytosol of cells, the phospholipids naturally arrange themselves in pairs, one on either side of the bilayer.

The phosphate head of one phospholipid is exposed to the inner cytosol, whereas the phosphate head of the other phospholipid is exposed to the watery environment outside of the cell. The fatty acid tails of the two phospholipid molecules face each other in the centre of the bilayer away from the water on either side of the cell (Figure 2).

Phospholipids often have one straight fatty acid tail and one that kinks or bends. This prevents the phospholipids from packing together too tightly. When a phospholipid's fatty acid tail kinks, it is called 'unsaturated'; the bend in the tail prevents the phospholipid packing tightly together with other phospholipids in the plasma membrane. When a phospholipid's tails are straight, they are called a 'saturated'.

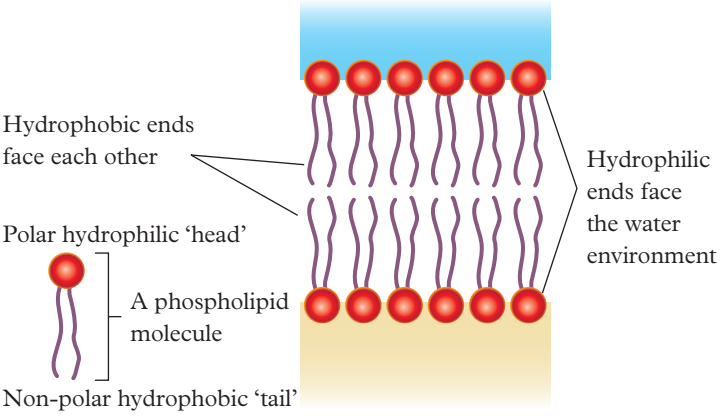


FIGURE 2 The structure of a single phospholipid and multiple phospholipids making up the plasma membrane

Cholesterol

Cholesterol regulates the fluidity or fluid movement of the membrane. It also reduces the permeability, or how easily molecules move through the plasma membrane. Its role is to keep the phospholipids together and prevent them from packing together too tightly when temperatures are low. If cholesterol was not present, there would be limited control over the entry and exit of substances across the plasma membrane. Large molecules such as glucose would be able to enter continuously rather than being controlled.

cholesterol
a steroid molecule that regulates the fluidity of the membrane

The plasma membranes of animal cells can have as much as 25% cholesterol. The plasma membrane of plant cells does not contain cholesterol. In plants, a different sterol (steroid molecule) carries out a similar function.

Cholesterol can come from:

- diet – animal cells take up cholesterol molecules from the extracellular (outside) environment
- synthesis – animal cells can synthesise cholesterol when they cannot obtain the required amount through the diet.

Proteins of the plasma membrane

Proteins are sequences of amino acids that are folded into specific shapes. Each shape is specific to the function of the protein.

Many different types of proteins are embedded within the phospholipid bilayer. Each protein plays a different role – cellular transport, signalling or maintaining the shape of the cell. The quantities and types of membrane protein vary according to cell type and specialisation. Membrane proteins are grouped into two major types depending on how they attach to the plasma membrane. These are **peripheral proteins** and **integral proteins** (Figure 3).

peripheral protein
a protein attached to one side of the plasma membrane, or to other proteins

integral protein
a protein of the plasma membrane that spans from one side of the cell to the other

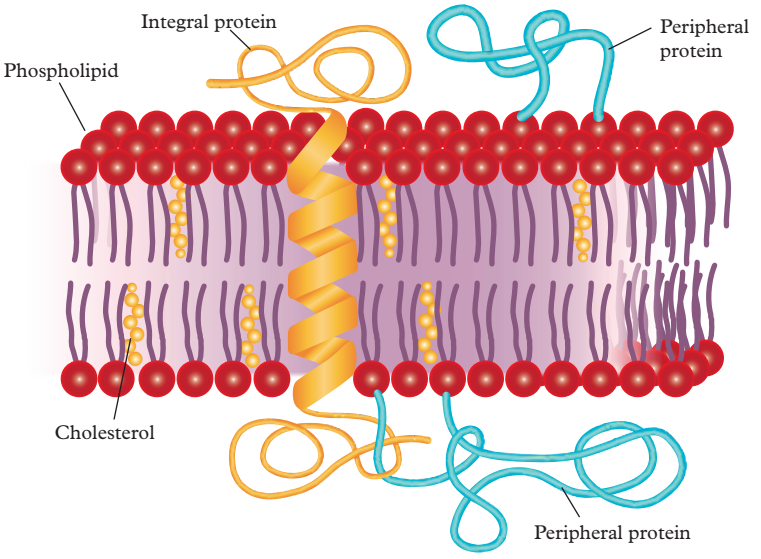


FIGURE 3 The location of peripheral and integral proteins within the plasma membrane

Integral proteins

Integral proteins are embedded within the phospholipid bilayer. Some of these (transmembrane) proteins span from one side of the plasma membrane to the other. Integral proteins have a hydrophilic polar region at each end and a central hydrophobic non-polar region that lies within the fatty acid tail region of the phospholipid bilayer. Integral proteins can be involved in transporting large molecules such as glucose into the cell. Aquaporin is an integral protein that plays a role in regulating the transport of water into and out of cells (Figure 4).

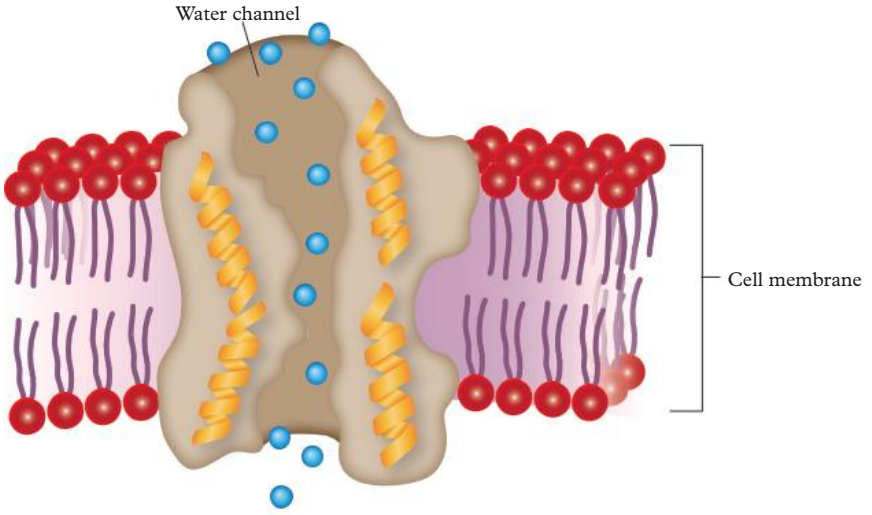


FIGURE 4 Aquaporin helps regulate the transport of water into and out of a cell.

Peripheral proteins

Peripheral proteins are loosely attached to the inner or outer surface of the plasma membrane. They never span the phospholipid bilayer. Some peripheral proteins interact with the phosphate heads of the phospholipid bilayer; others are attached to integral proteins embedded within the plasma membrane (e.g. ankyrin, Figure 5).

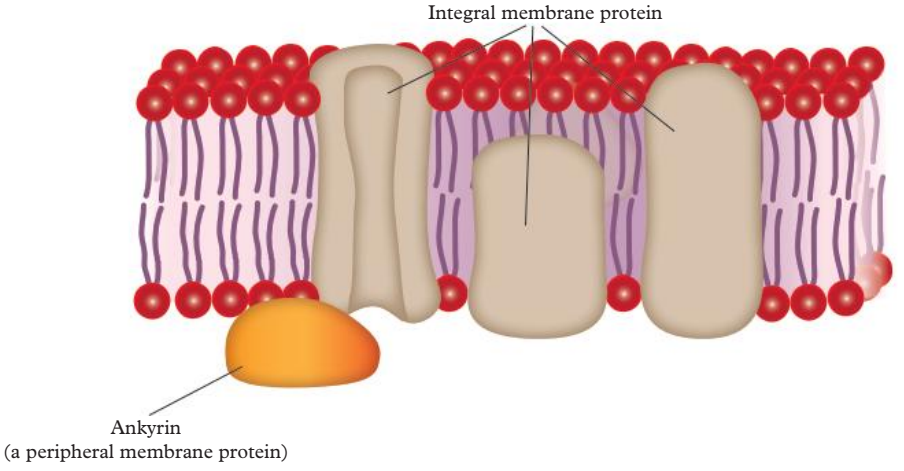


FIGURE 5 Ankyrin is a peripheral protein that links the cytoskeleton to integral proteins on the cell's inner membrane surface, providing structural support.

Carbohydrates of the plasma membrane

Proteins and lipids on the outer plasma membrane surface often have short carbohydrate molecule chains attached to them, forming **glycoproteins** and **glycolipids**.

Study tip

Peripheral proteins are located on the **peri**phery of the membrane, whereas **int**egral proteins are **int**ernally located within the membrane.

glycoprotein
a protein of the plasma membrane with short carbohydrate chains attached

glycolipid
a lipid of the plasma membrane with short carbohydrate chains attached

Glycoproteins and glycolipids have three key functions. They:

- act as a receptor that binds to messenger molecules such as hormones (Figure 6)
- help maintain a stable membrane structure by forming hydrogen bonds with water molecules in the extracellular fluid
- act as recognition molecules for other cells to recognise each other.

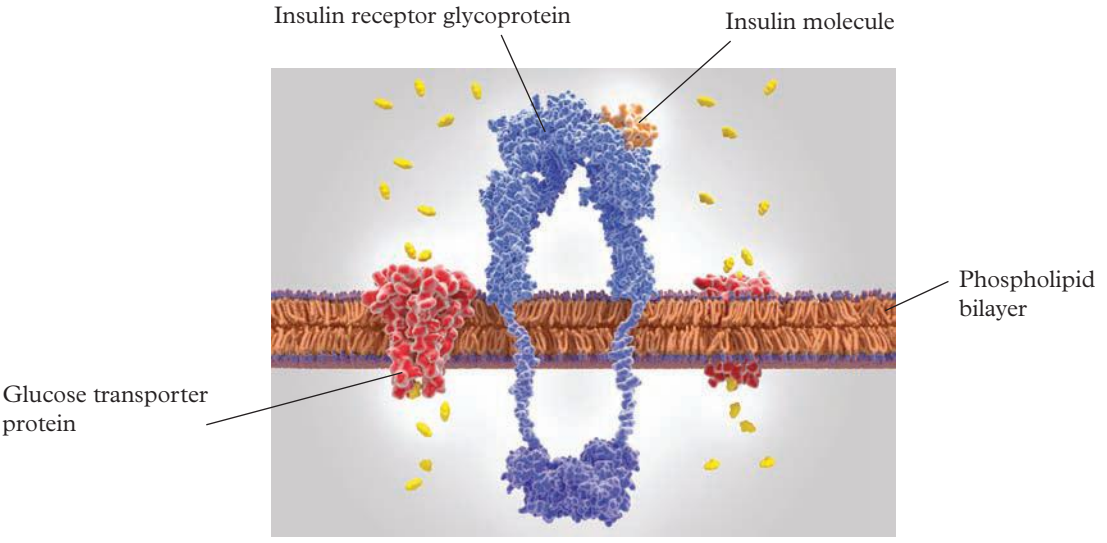


FIGURE 6 Insulin receptors are glycoproteins (blue) located on specific cell types. When insulin (orange) binds to the receptor, a signal is sent to the cell that triggers a series of biochemical reactions, enabling glucose to leave the cell via glucose transporter proteins (red)

Transport across the plasma membrane

facilitated diffusion passive movement of a substance through carrier or channel proteins from an area of high concentration to an area of low concentration

osmosis 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

equilibrium when equal numbers of a specific molecule are either side of the plasma membrane

The plasma membrane is selectively permeable. Molecules such as oxygen, glucose and carbon dioxide can move across the phospholipid bilayer by different modes of transport. The plasma membrane is impermeable to large molecules, such as proteins, which cannot be transported into the cell. How substances move across the plasma membrane depends on their size, concentration and chemical composition.

Passive transport

A molecule is transported passively across the membrane when no extra energy is needed. This passive transport usually occurs as the molecules move from an area of high concentration to an area of low concentration (down the concentration gradient). How they move across the membrane depends on the size of the molecule. Small hydrophobic molecules and gases move by diffusion, whereas larger polar molecules move by **facilitated diffusion**. Water molecules move by a specialised diffusion process known as **osmosis**.

Diffusion

Diffusion is the movement of molecules from an area of higher concentration to an area of lower concentration until **equilibrium** is reached. This is when the molecules are at equal concentrations on each side of the membrane.

For a molecule to be moved across the plasma membrane by diffusion, it must be:

- small enough to fit between the phospholipids of the plasma membrane
- hydrophobic or non-polar, so that it can freely move between the hydrophobic phospholipid tails in the bilayer membrane (Figure 7).

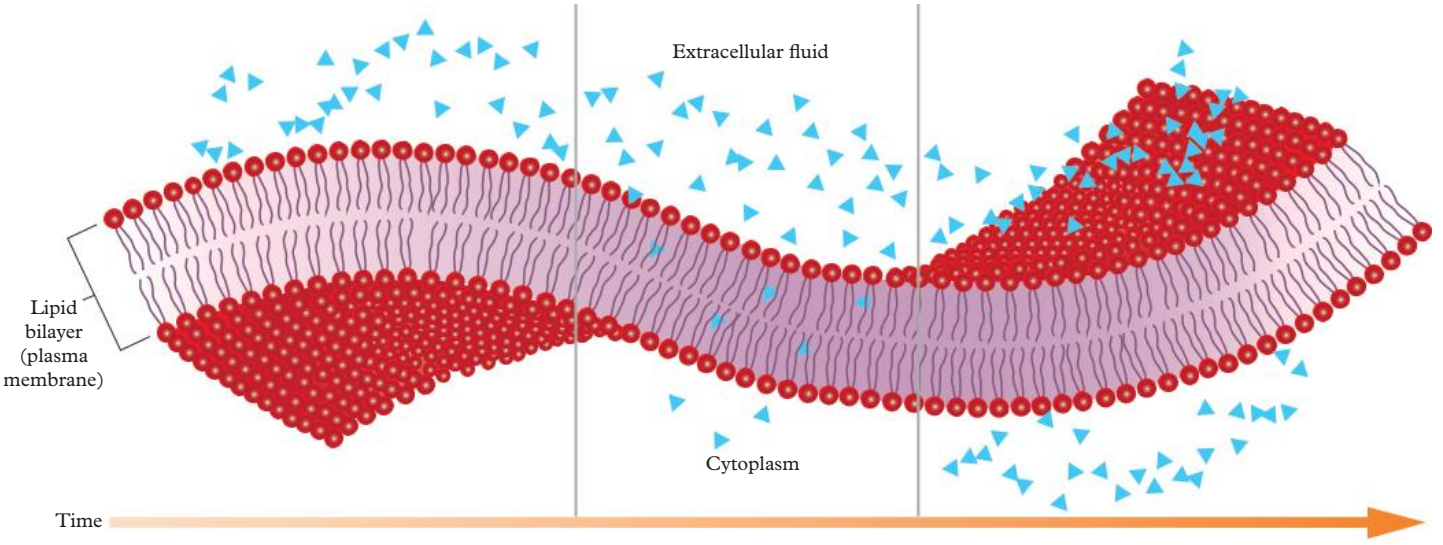


FIGURE 7 Diffusion of molecules from high to low concentration occurs until equilibrium is achieved.

The concentration of molecules on either side of the plasma membrane is constantly changing. New molecules are constantly arriving in the extracellular (outside) area of a cell, while chemical reactions in the cytosol constantly use or produce new molecules.

For example, oxygen is continually at a higher concentration in the extracellular fluid than in the cytosol. This is because it is continually used in cellular respiration, which occurs intracellularly. Oxygen continually diffuses across the phospholipid bilayer from the extracellular fluid to the cytosol.

carrier protein
an integral protein that changes shape to transport molecules across the membrane

channel protein
an integral protein that allows molecules to cross through the membrane

Facilitated diffusion

Large hydrophilic, or polar, molecules or charged molecules cannot dissolve in the phospholipid bilayer because of their size or 'water-loving' properties. Molecules such as glucose, amino acids and ions need different types of embedded integral proteins to facilitate (help) their movement across the membrane.

- **Carrier proteins** bind to specific molecules such as amino acids and glucose. Once the molecule is bound to it, the carrier protein changes its shape so that the molecule can move through the membrane. For example, glucose is transported by a specific carrier protein called the glucose transporter protein (Figure 8).
- **Channel proteins** control the diffusion of other molecules such as some ions. These molecules are unable to pass through the hydrophobic region of the phospholipid bilayer. When the molecule binds to its specific channel, the channel opens, allowing the ion to pass through the membrane.

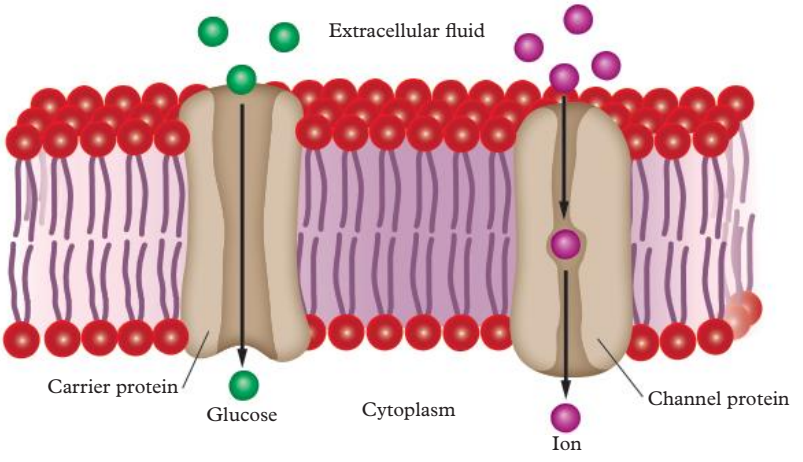


FIGURE 8 Carrier proteins and channel proteins facilitate the diffusion of molecules such as glucose and ions across the plasma membrane by allowing selected passage.

Osmosis

hypotonic solution
a solution that has a lower concentration of solutes than within the cell

hypertonic solution
a solution that has a higher concentration of solutes than within the cell

isotonic solution
a solution that has the same solute concentration as within the cell

protein pump
an integral protein that actively transports molecules across a membrane against a concentration gradient

turgid
swollen

plasmolysis
the process by which a plant cell membrane pulls away from the cell wall as water is lost from the cell via osmosis

flaccid
limp

lyse
burst

Study tip

Hypotonic solutions make cells overflow with water, causing them to form a swollen O shape. 'Where salt goes, water flows' means the water moves towards the highest salt concentration.

Osmosis is the diffusion and facilitated diffusion of water across the plasma membrane. Water is a polar molecule, which means it has a slight positive charge at one end and a slight negative charge at the other end. Although water is a small molecule, it is repelled by the hydrophobic lipid tails of the phospholipid bilayer. This can slow the movement of water across the plasma membrane.

As the amount of salts in a solution increases, the relative proportion of water molecules decreases. Many of the water molecules gather around the charged salt particles, meaning they are no longer free to move across the membrane. This means a concentrated solution of charged solute particles will attract and keep more water molecules than a low concentration. This process of passive movement of water molecules across a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration is called osmosis.

The concentration of solute molecules in the extracellular environment is often compared to the cytosol. These comparisons are called **hypotonic**, **hypertonic** and **isotonic** (Table 1).

Active transport

Active transport requires energy to transport materials across the plasma membrane from an area of low concentration to an area of high concentration (against the concentration gradient). Substances can be transported by **protein pumps** or within vesicles that fuse or pinch off from the plasma membrane.

Protein pumps

Integral proteins within the plasma membrane can actively pump molecules into or out of a cell against a concentration gradient. This requires ATP to bind to the protein, providing the energy to change the shape of the protein and allowing the molecule to then pass through (Figure 9).

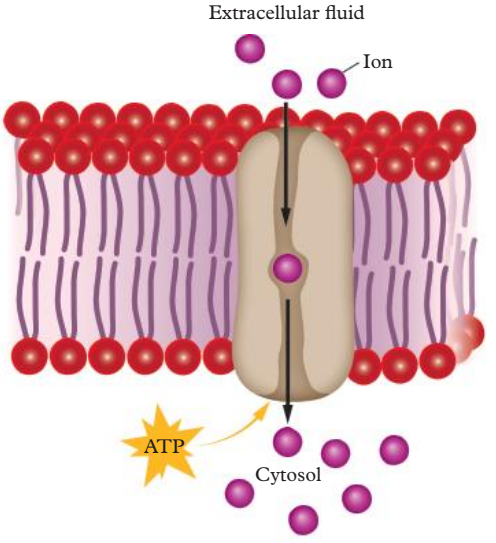
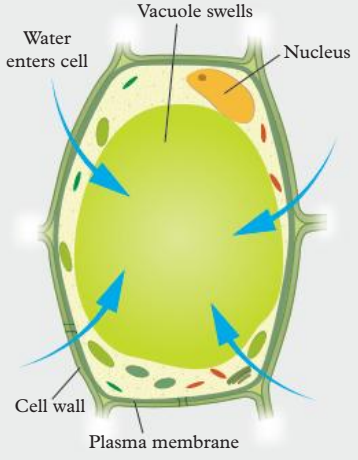
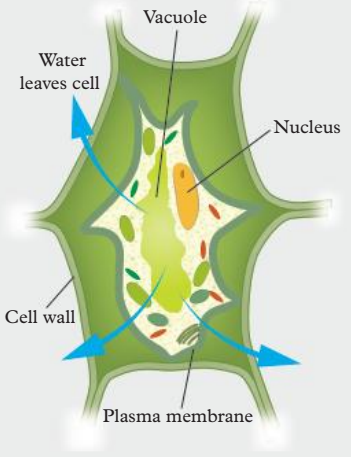
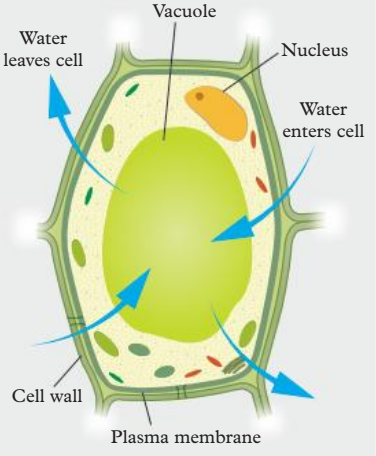
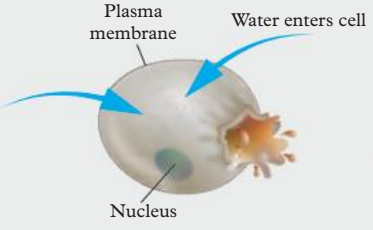
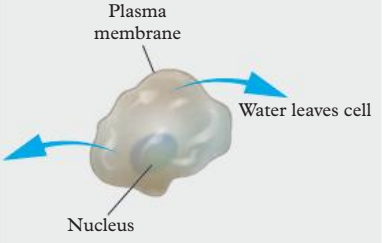
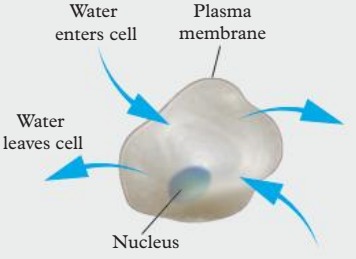


FIGURE 9 Protein pumps transport molecules from a low concentration to a high concentration using energy (ATP).

TABLE 1 The different solutions within the extracellular fluid surrounding plant and animal cells

	Hypotonic solution	Hypertonic solution	Isotonic solution
Concentration of solutes compared with cytoplasm	Extracellular fluid has a lower solute concentration than the cytoplasm.	Extracellular fluid has a higher solute concentration than the cytoplasm.	Extracellular fluid is the same concentration as the cytoplasm.
Concentration gradient of water	Extracellular fluid has higher water concentration than cytoplasm because of higher solute concentration in cell.	Extracellular fluid has lower concentration of water than cytoplasm because of higher solute concentration outside cell	Extracellular fluid same concentration as cytoplasm
Direction of diffusion	Water diffuses into the cell by osmosis.	Water diffuses out of the cell by osmosis.	Water diffuses in and out at an equal rate by osmosis.
Plant cells	Plant cell becomes **turgid**. Cell volume increases and the plasma membrane is pushed against the cell wall.  This is optimal for plant cells because it provides structural support.	Plant cell undergoes **plasmolysis**. The plasma membrane pulls away from the cell wall as the cell volume decreases.  	Plant cell becomes **flaccid** in this condition because the plasma membrane is not pushed against the cell wall.  This results in plants wilting.
Animal cells	Animal cells **lyse** or burst. As cell volume increases, the plasma membrane bursts and the cytoplasm spills out.  	Animal cells become shrivelled (crenated) as the cell volume is reduced.  	Animal cell shape and volume is maintained. This is an optimal condition for animal cell shape and structure. 

Endocytosis

endocytosis
active transport of macromolecules into the cell via vesicle formation from the plasma membrane

phagocytosis
a form of endocytosis where solid macromolecules are transported into the cell

Endocytosis is a type of bulk transport that enables macromolecules (large molecules) to be brought into an animal cell fully enclosed within a vesicle. The process uses energy to fold the plasma membrane inwards, pulling the macromolecule with it. Once surrounded by the plasma membrane, the macromolecules are enclosed and a vesicle separates from the plasma membrane and starts travelling through the cytoplasm. This process allows substances to be kept separate from the cytosol so they can be delivered to a particular organelle.

There are two main types of endocytosis (Figure 10).

- **Phagocytosis** is commonly known as 'cell eating'. This occurs when the substance entering the cell is a large, solid molecule such as a food particle or bacterial cell. Phagocytosis is how white blood cells surround and engulf bacteria and how single-celled protists feed. The vesicle containing the bacterial cell or food particle then fuses with a lysosome to be digested.

Study tip

Phagocytosis and pinocytosis do not occur in plant cells because of the relatively inflexible cell wall.

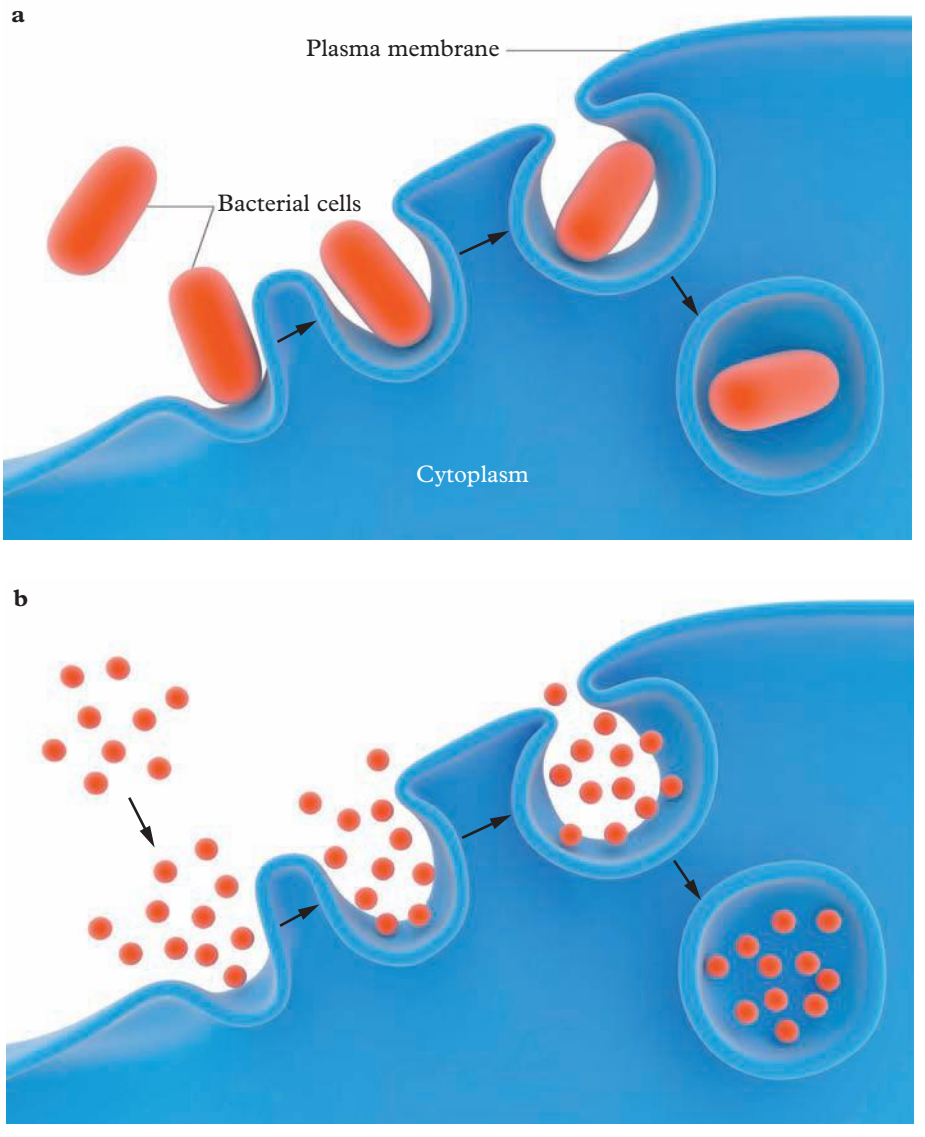


FIGURE 10 Endocytosis by **a** phagocytosis and **b** pinocytosis uses vesicles to allow the active transport of substances into a cell.

- **Pinocytosis** is commonly known as 'cell drinking'. This occurs when the substance entering the cell is a liquid. Pinocytosis is common in cells in the intestinal tract of animals or the root hair cells of plants, which require large volumes of fluid containing particular solutes. Sometimes, pinocytosis is triggered by receptors located in the plasma membrane.

pinocytosis
a form of endocytosis where fluid is transported into the cell in a vesicle

Exocytosis

Exocytosis is a type of bulk transport that enables macromolecules to exit the cell. The process uses energy to allow vesicles to fuse with the plasma membrane and release their contents into the extracellular environment. During exocytosis, the substance (e.g. a protein or a hormone) is kept separate from the cytosol so it can be secreted from the cell without interfering with the chemical reactions in the cytosol.

exocytosis
active transport of substances out of the cell through the fusion of vesicles and the plasma membrane

The secretory pathway

Secretion involves many organelles working together, in a step-by-step series of processes that produces secretory vesicles that fuse with the plasma membrane and secrete their contents (Figure 11). These organelles include the:

- rough endoplasmic reticulum and ribosomes for protein production
- smooth endoplasm reticulum for lipid, steroid production
- Golgi apparatus to modify and package the molecules for transport
- vesicles for transport between these organelles and the plasma membrane.

These secretions are often hormones that circulate in the bloodstream and trigger responses in other cells, or proteins that are incorporated into the membrane or secreted for use in other cells.

Study tip

Endocytosis means **en**tering the cytoplasm, whereas **ex**ocytosis means **ex**iting the cytoplasm.

Study tip

Make sure you understand exocytosis. You will need to understand this concept for Units 3 & 4.

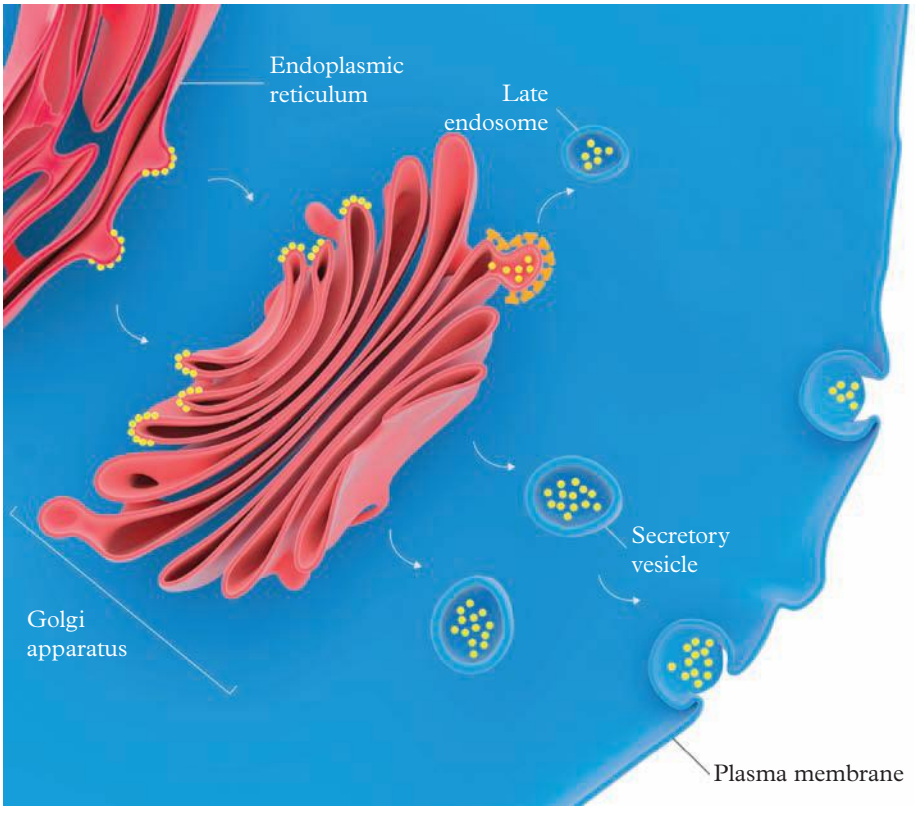


FIGURE 11 The secretory pathway showing secretory vesicles fusing with the plasma membrane to then release secretions by exocytosis

TABLE 2 Summary of the different modes of transport across the plasma membrane

Mode of transport	Direction of transport	Energy	Requirement	Examples
Diffusion	From high to low concentration	No	Concentration gradient	Oxygen, carbon dioxide
Facilitated diffusion (carrier and channel proteins)	From high to low concentration	No	Concentration gradient and protein	Glucose, amino acids, ions
Osmosis	From low solute concentration to high solute concentration	No	Concentration gradient	Water only
Protein pumps	From low to high concentration	Yes	Energy and protein	Glucose, amino acids and ions
Endocytosis	From extracellular fluid to cytoplasm	Yes	Energy and vesicle formation	Macromolecules
Exocytosis	From cytoplasm to extracellular fluid	Yes	Energy and vesicle fusion	Macromolecules

CASE STUDY 2.4

Osmosis in *Paramecium*

Paramecium is a single-celled protist that lives in freshwater ponds. The pond water is a hypotonic environment because it has a lower concentration of solutes than in the cytoplasm. This means that water is constantly moving into the *Paramecium* cell. This maintains the water content within the *Paramecium* at optimal levels. *Paramecium* have specialised structures called **contractile vacuoles** that fill with water and then contract to squeeze the water out (Figure 12). This is a form of active transport that uses energy to force water in the opposite direction to the concentration gradient and back into the surrounding water. If this structure was not present, the *Paramecium* cell would lyse.

contractile vacuole
a structure in some protists, which is involved in controlling the amount of water in a cell

FIGURE 12 A *Paramecium* cell showing two contractile vacuoles that are at different stages of releasing their water contents.

CHECK YOUR LEARNING 2.4

Describe and explain

1 Explain the terms 'fluid' and 'mosaic' when describing the structure of the plasma membrane.

2 Draw a phospholipid and label the two components.

3 Describe the processes of endocytosis and exocytosis.

4 Define 'pinocytosis'.

Apply, analyse and compare

5 Compare (i.e. discuss the similarities and differences between) passive and active modes of transport.

6 Several Antarctic ice-fish (*Trematomus bernacchii*) were kept in two tanks at a research facility in Antarctica. The tanks were set to temperatures of 0°C and 6°C for 15 days. Five randomly selected fish were then sampled from each tank and directly from the Antarctic waters (–1°C), and the plasma membranes of their cells were studied.

The fish from the 0°C tank and the Antarctic water had consistently high levels of cholesterol and unsaturated fatty acid tails in their plasma membranes.

The fish from the 6°C tank had noticeably reduced levels of cholesterol and higher proportions of saturated fatty acid tails in their plasma membranes (Figure 13).

Apply your understanding of plasma membrane structure and function to suggest a reasons for these results.

7 Read Case study 2.4. Apply your knowledge to explain how *Paramecium* cells maintain water content at optimum levels.

Design and discuss

8 Outline a simple experiment that could be used to explain the process of diffusion without using a cell.

9 A cell has a solute concentration of 8%. The cell is placed into a saturated salt solution containing 28% salt.

a Determine what type of solution the cell is placed in.

b Determine the direction of water movement and explain your reasoning.

c Discuss the potential consequences of this solution for both animal and plant cells.

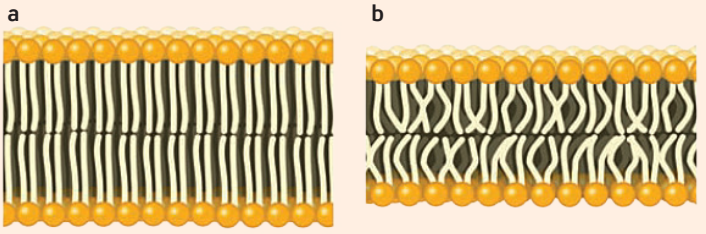


FIGURE 13 **a** Phospholipids with straight (saturated) tails and **b** Phospholipids with kinked (unsaturated) tails.

CHAPTER 2

Review

Chapter summary

2.1
- Cell theory describes cells as the basic structural feature of all living organisms.
- Living organisms can be unicellular or multicellular.
- Prokaryotic cells do not have a nucleus or other membrane-bound organelles. Their DNA is free within the cytosol.
- Eukaryotic cells have a nucleus and other membrane-bound organelles that carry out specialised roles within the cell.

2.2
- Cells are limited to a small size because they have a large surface area to volume ratio. As cell size increases, volume increases more than surface area.
- Large cell size results in a slower rate of diffusion of materials into and out of the cell, causing toxins to accumulate.
- Eukaryotic cells have membrane-bound organelles that carry out specialised functions.

2.3
- Eukaryotic cells consist of a plasma membrane, a nucleus, an endoplasmic reticulum, ribosomes, a Golgi apparatus, vesicles, mitochondria, lysosomes, vacuoles, a centrosome and a cytoskeleton.
- Plant cells contain a cell wall, chloroplasts, plastids and a large central vacuole, which are not present in animal cells.

2.4
- The fluid mosaic model describes the structure and function of the plasma membrane and its composition of phospholipid bilayer with embedded cholesterol and proteins.
- Some substances such as oxygen are transported between the phospholipid molecules by simple diffusion, whereas others must pass through protein molecules because of their chemical composition or large size.
- Water is transported across the plasma membrane by a specialised form of diffusion called osmosis.
- Energy (ATP) must be used to transport some molecules across the membrane against a concentration gradient This is known as active transport.
- Endocytosis is the active transport of large molecules into a cell, whereas exocytosis is the transport of large molecules out of a cell.
- Secretions such as hormones are produced and transported out of a cell by the secretory pathway, which involves ribosomes, endoplasmic reticulum, Golgi apparatus and secretory vesicles that eventually fuse with the plasma membrane to release the secretion out of the cell by exocytosis.

Revision questions

Multiple choice

1 The Golgi body consists of:
- **A** hollow tube-like sacs with ribosomes dotted on the surface
- **B** digestive enzymes within a spherical membrane
- **C** compartmentalised discs that are stacked to form grana
- **D** a stack of flattened sacs called cisternae.

2 Plastids include:
- **A** chloroplasts, amyloplasts and chromoplasts
- **B** grana, stroma and thylakoids
- **C** lipids, digestive enzymes and starch
- **D** chloroplasts, mitochondria and vesicles.

3 All cells contain:
- **A** DNA, a nucleus, a plasma membrane and lysosomes
- **B** a nucleus, lysosomes, cytosol and ribosomes
- **C** ribosomes, a nucleus and a plasma membrane
- **D** a plasma membrane, cytosol, ribosomes and DNA.

4 Bacteria are an example of a:
- **A** unicellular prokaryotic cell
- **B** multicellular prokaryotic cell
- **C** unicellular eukaryotic cell
- **D** multicellular eukaryotic cell.

5 As cell size increases:
- **A** surface area increases more than the volume of the cell increases
- **B** the rate of diffusion increases
- **C** the surface area to volume ratio decreases
- **D** cellular process are able to occur more rapidly because there is more volume.

6 Water molecules are passively transported from a low salt concentration to a high salt concentration across the plasma membrane by:
- **A** facilitated diffusion
- **B** active transport
- **C** osmosis
- **D** endocytosis.

7 Diffusion:
- **A** requires energy because it is an active process
- **B** involves the movement of materials from a low concentration to a high concentration
- **C** actively pumps substances across the plasma membrane
- **D** requires no energy because materials move from areas of high concentration to areas of low concentration.

8 Cell theory says that:
- **A** all living organisms have at least one cell
- **B** cells are the smallest unit of living things
- **C** all cells come from pre-existing cells
- **D** all of the above.

9 Proteins are synthesised:
- **A** within large storage vacuoles
- **B** within the plasma membrane
- **C** on ribosomes
- **D** in the vesicles of the Golgi apparatus.

10 Two structures found in plant cells but not animal cells are:
- **A** cell membranes and chloroplasts
- **B** cell membranes and plastids
- **C** cell walls and vesicles
- **D** cell walls and chloroplasts.

Short answer

Describe and explain

11 Explain why cells are described as the basic unit of life.

12 Identify the features that are used to classify a cell as prokayrotic.

13 Describe the location and function of the nucleolus.

14 Explain why the cells of a leaf contain many chloroplasts but the cells of the plant root system do not contain any chloroplasts.

15 Define 'hydrophilic' and 'hydrophobic'

16 Describe the function of mitochondria.

17 Name three structures that are only found in plant cells (not animal cells) and describe their function.

18 Describe the process of facilitated diffusion via carrier proteins and protein channels.

19 Describe two differences between passive and active transport of substances across the plasma membrane.

Apply, analyse and compare

20 A student wrote the following statement about cell size.

'As cell size increases, cellular metabolism decreases as a result of increasing surface area to volume ratio.'

Analyse this statement to determine whether you agree with it or not. Give detailed reasons for your decision.

21 A eukaryotic cell was shown to have a large number of lysosomes. Apply your understanding of lysosomes to suggest reasons for this.

22 Suggest a reason why animal cells do not contain cell walls as plant cells do.

23 Compare the locations of the endoplasmic reticulum and Golgi apparatus.

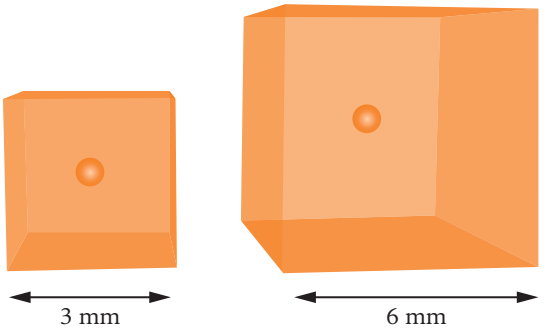


FIGURE 1

24 The two cubes in Figure 1 represent the size of cells.

- **a** Calculate the:
  - **i** surface area of each (mm^2)
  - **ii** volume (mm^3) of each
  - **iii** SA:V of each.
- **b** Compare the SA:V of each cell and comment on how the SA:V would impact each cell's function.

25 Contrast the processes of active transport, osmosis and facilitated diffusion.

26 Examine Figure 2.

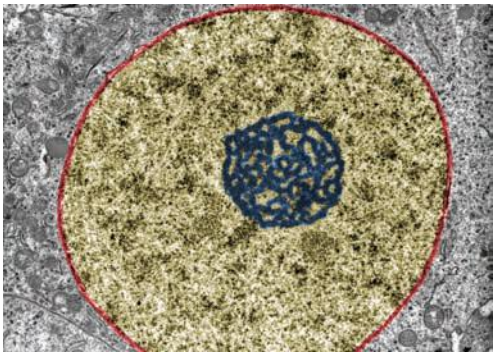


FIGURE 2

- **a** Identify the organelle shown.
- **b** Name the blue structure within the organelle.
- **c** Name the structure that looks like a red line around the outside of the organelle.

27 Examine Figure 3.

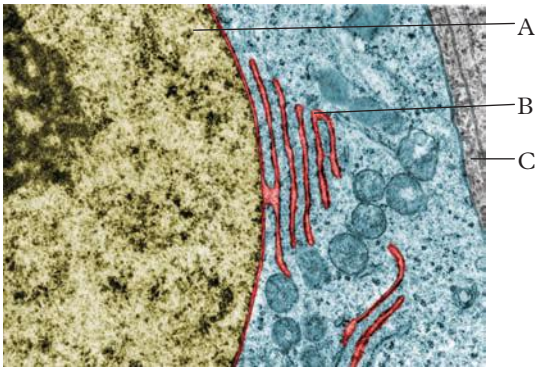


FIGURE 3

a Identify the organelles labelled A, B and C.

b Is the cell in Figure 3 a prokaryotic or eukaryotic cell? Justify your response.

Design and discuss

28 Use an example to discuss how a muscle cell has adapted to be longer without compromising the rate of diffusion in and out of the cell.

29 Draw a simple labelled diagram of a chloroplast and a mitochondria. Explain how the internal structure of each relates to its overall function.

30 Discuss the roles that different organelles play in the production, transport and secretion of a hormone out of cell.

31 A group of students was asked to investigate the question: what will happen to the water content of a piece of cucumber when it is placed in a glass of distilled water compared to a glass of salty water? Using your understanding of osmosis, design an experiment based on the following.

a Identify the independent and dependent variables of the experiment.

b Identify a list of materials for the experiment.

c Outline the method for the experiment.

d Identify at least two controlled variables for the experiment.

e Identify two safety risks and describe how these will be controlled in the experiment.

f Explain what measures are included in the method to ensure the data collected is valid and reliable.

g Write a hypothesis for the experiment.

Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments, you may be expected to compare or contrast two different cells, examples or situations. Remember the difference between the terms 'compare' and 'contrast'. When comparing two examples, you need to describe how they are similar, and how they are different. When contrasting two examples, you only need to describe how each is different from the other.

Writing a good compare or contrast answer

In your answer, it is important to mention both examples that you have been asked to compare, contrast or distinguish between. A common mistake is to mention one example, but not the other. A simple solution is to draw a line down the middle of the answer section. Describe the key features of one example on one side of the line, and the key features of the other example on the other side of the line. This will make sure you provide a complete answer to the question.

QUESTION 2a (2003 Biology Written Examination 1)

Helicobacter pylori is a bacterium.

a i Cells can be classified as prokaryotic or eukaryotic. To which group do bacterial cells belong?

ii Name one feature which distinguishes prokaryotic organisms from eukaryotic organisms. 2 marks

Source: 2003 Biology Written Examination 1, Question 2a, Short answer, reproduced by permission © VCAA

Response 1

a i Prokaryotes

ii

Prokaryotic cells	Eukaryotic cells
Genetic material in the cytoplasm	Genetic material in a nucleus

A one-word answer is enough because you are only asked to identify which of the two words is correct.

This would be an acceptable format for organising a comparison response. It clearly covers both prokaryotic and eukaryotic cells.

This answer would receive full marks because it is correct and it names one way the two cells are different from each other. The format of part ii makes sure both examples are mentioned in the response.

Response 2

a i Bacterial cells have a nucleus and so are a prokaryote.

Ii Prokaryotes have their genetic material in the cytoplasm.

'Prokaryote' is correct, but this additional information is incorrect, making the whole answer wrong.

Although this information is correct, it does not distinguish prokaryotes from eukaryotes. Both need to be mentioned in the answer.

This answer would not receive any marks. The incorrect information in part i undermines the correct information. In part ii, although the information is correct, it does not provide the information required by the question.

Think like an examiner

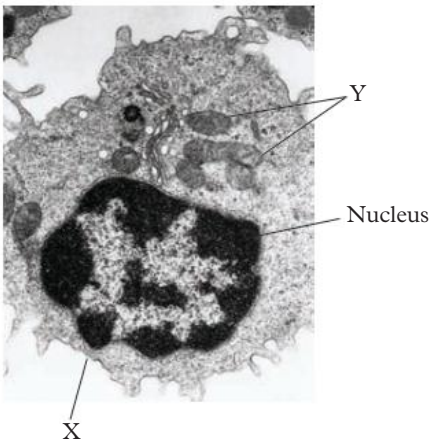
To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 1a,b (2012 Biology Written Examination 1)

The electromicrograph below shows a portion of a cell.



a Name and describe the structure of X. 2 marks

It is a membrane: a phospholipid bilayer.

b What would you look for to determine whether a cell is from an animal or a plant? 2 marks

I would look for a cell wall as all plants have cell walls.

Source: Adapted from 2012 Biology Written Examination 1, Question 1a,b, Short answer, reproduced by permission © VCAA

Marking guide

1a	2 marks for: Name: cell membrane Description: phospholipid bilayer
1b	1 mark for: Plant cells have cell walls and animal cells do not.

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 an examiner.

Check your Student obook pro for these digital resources and more:

Video
Comparing and contrasting

Weblink
Past examinations and examiners' reports

CHAPTER 3

The cell cycle

All multicellular organisms need to replicate their cells to grow, replace and repair their bodies. The cell cycle is a process that involves phases of normal growth followed by replication to produce genetically identical daughter cells. When this process goes wrong, cells can undergo abnormal growth and replication, which results in cancerous cells. At different stages of cell division, there are cellular checkpoints that control division and prevent abnormal growth.

KEY KNOWLEDGE

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

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

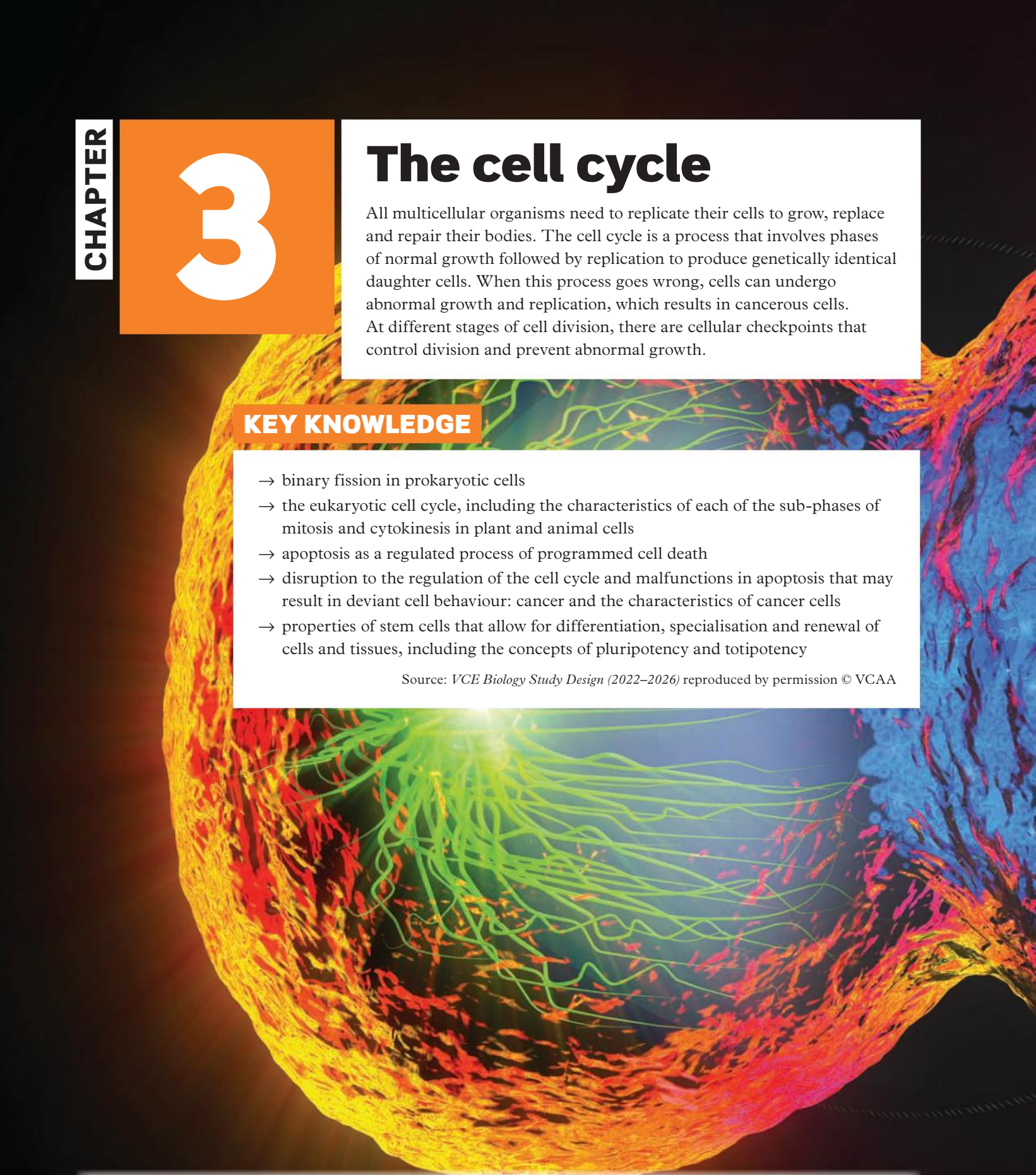


FIGURE 1 The cell cycle describes the life cycle and replication of a cell. This image is of binary fission – one cell has replicated its genetic material and the two daughter cells are splitting apart.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

3A Explain why a multicellular organism might need new cells.

3A Groundwork resource
Multicellular organisms

3B How many chromosomes are there in human body cells?

3B Groundwork resource
Chromosomes

3C Explain why cell division and cell multiplication mean the same thing in biology.

3C Groundwork resource
Cell division

PRACTICALS

PRACTICAL	**3.2** Stages of mitosis

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.

3.1 Binary fission

KEY IDEAS

In this topic, you will learn that:

+ the cell cycle produces new cells from existing cells
+ reproduction of prokaryotic cells occurs through binary fission.

Study tip

It is important to describe daughter cells as 'genetically identical to the parent cell' rather than 'identical to the parent cell'. This is because the daughter cells may have different numbers of individual organelles from the parent cell or other daughter cells and so are not completely identical.

biogenesis
the production of new living organisms from other living organisms

cell cycle
the process of a cell growing, dividing and dying

binary fission
a form of asexual reproduction in which the parent cell splits into two equal-sized daughter cells

The cell cycle

All cells come from pre-existing cells (**biogenesis**). Single-celled organisms reproduce through the process of cell division. Multicellular organisms grow from the division of a single cell (a fertilised egg), which continues to divide and grow to become a whole organism. This process needs to continue throughout a multicellular organism's life to maintain normal day-to-day function, growth and repair. An example of this is the constant production of red blood cells by the stem cells in your bone marrow.

The process of cell division is an important part of the **cell cycle**, from the first time a cell is formed from the division of its parent cell, until its own division to produce two new daughter cells.

For division to be successful, each daughter cell must be genetically identical to its parent. This means the DNA of each parent cell must first make a copy of itself before the cell can divide into two.

Binary fission

Prokaryotes (bacteria) have a single circular DNA molecule that carries their genetic material. Copying this DNA is the first step in the cell division that is called **binary fission** (Figure 1).

During binary fission, a cell grows to almost twice its size before splitting into two equal-sized daughter cells. Prokaryotes do not have a nucleus, so their genetic material is located in the cytoplasm of the cell.

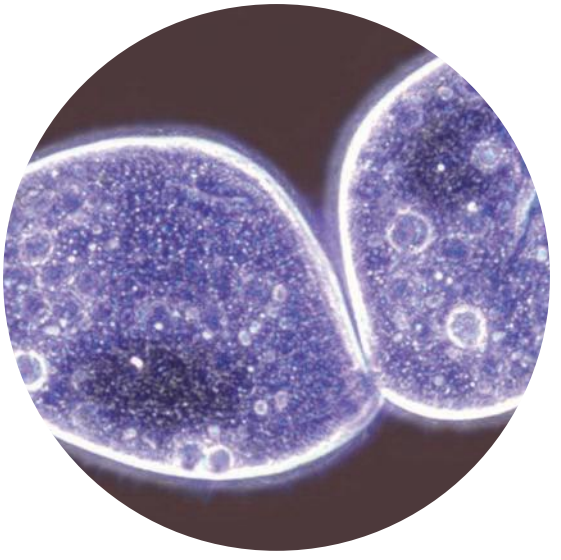


FIGURE 1 Binary fission occurs when a cell divides into two equal-sized daughter cells. Here, *Paramecium aurelia* is going through binary fission.

The DNA that makes up a prokaryote's genetic material is more than 500 times longer than the cell. To fit inside the cell, the DNA molecule is tightly wound around proteins to form a chromosome. When the prokaryote replicates, the DNA molecule unwinds to make a single copy of itself. Each copy of DNA then attaches to a different part of the cellular membrane. As the cell grows longer (elongates), the two chromosomes are pulled apart. Once the elongated cell is large enough, the plasma membrane pinches in the centre, dividing the bacterial cell in half. A new cell wall forms around the two genetically identical daughter cells (Figure 2).

Binary fission has many benefits. Only one parent cell is needed to produce two cloned daughter cells. Binary fission can also occur rapidly, producing many daughter cells in a short time. For example, some bacteria can double their numbers in as little as 20 minutes. Worked example 3.1 demonstrates the effect of this rapid bacterial growth.

The disadvantage of binary fission is that genetically identical daughter cells are all affected in the same way by changing environmental conditions. This is an advantage to humans when antibiotics are used to treat a bacterial infection. If one of the bacterial cells is vulnerable to the antibiotics, then they all will be.

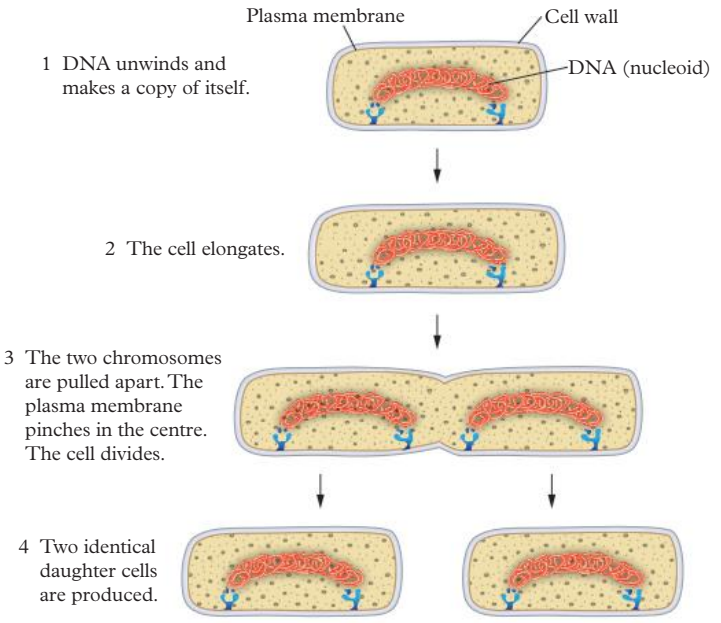


FIGURE 2 Prokaryotic cells divide by binary fission to produce two genetically identical daughter cells.

WORKED EXAMPLE 3.1

CALCULATING NUMBER OF CELLS

A person sneezed while preparing dinner and one bacterial cell from the sneeze fell onto the warm food. The food containing the bacterial cell was then left on the bench for 2 hours before being put into the fridge, where it took another hour to cool to below 4°C and for the cells to stop reproducing. If the single bacterial cell was able to reproduce (and double in number) every 20 minutes before it cooled to below 4°C, how many bacterial cells would be present in the food?

SOLUTION

One cell doubles every 20 minutes. After 1 hour, the cell has doubled three times and after 3 hours, the cell has doubled nine times.

To calculate the number of cells at the end of 3 hours, use the formula:

$$\text{Number of cells} = 2^n$$

where n represents the number of replications.

Number of cells after 3 hours = 2^9

= 512 bacterial cells

Video
Worked example 3.1: Calculating number of cells

CASE STUDY 3.1

Antibiotic resistance

The replication of DNA molecules is not always accurate and errors can be made. In most cells, the errors are detected and repaired.

Some errors can be useful for the organism. For example, a change in the DNA can make a bacterium resistant to an antibiotic. When all the other bacterial cells are dying, the newly resistant bacteria will survive and reproduce. This can mean a patient starts to get well, but then, after a short period of time, the sickness returns again.

Bacteria can pass on their antibiotic resistance through the exchange of a type of DNA called a plasmid. This DNA found in plasmids is not part of the cell's chromosome, but it can carry sections of DNA that allow the cell to be resistant to a specific antibiotic. Bacterial cells can exchange plasmids with each other through direct cell contact or by a hair-like bridge called a pilus (Figure 3). When a bacterial cell replicates its chromosome, it also makes copies of the plasmid to pass on to both daughter cells.

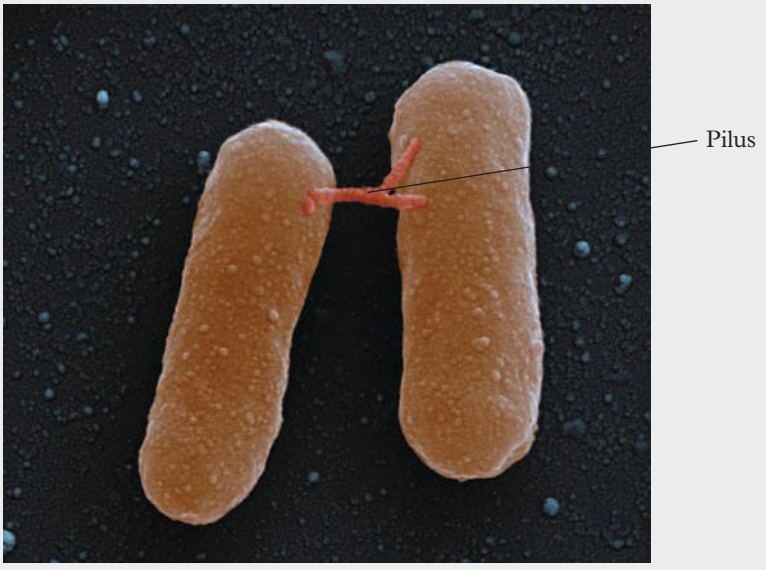


FIGURE 3 Bacteria can pass extra genetic material (plasmids) from other cells through the pilus.

CHECK YOUR LEARNING 3.1

Describe and explain

1 Explain the term 'genetically identical daughter cells'.

2 Define 'binary fission'.

3 Describe the process of binary fission. Use a series of diagrams to illustrate your answer.

Apply, analyse and compare

4 Compare the advantages and disadvantages of binary fission.

5 Read Case study 3.1. Explain how bacteria can pass on antibiotic resistance to their daughter cells or to other bacterial cells.

Design and discuss

6 Discuss why it is important that food is not left out of the fridge for too long.

7 Design a poster that explains how to avoid food contamination.

3.2 Mitosis and cytokinesis

KEY IDEAS

In this topic, you will learn that:

- the reproduction of eukaryotic cells occurs through mitosis and cytokinesis
- interphase has three phases – G1 (normal cell growth and function), S (DNA synthesis) and G2 (rapid cell growth and protein synthesis)
- mitosis has four sub-phases – prophase, metaphase, anaphase and telophase
- cytokinesis is the physical separation of a parent cell into two daughter cells.

interphase
the phase cells undergo in their everyday lifecycles

G1 checkpoint
the point in the cell cycle when a cell is assessed for the health of its organelles so it can proceed to the G2 phase

quiescent
in a period of rest or dormancy

apoptosis
programmed cell death

chromatin
the DNA and proteins that can be wound tightly to form a chromosome

Study tip

Interphase used to be called the resting stage of the cell cycle. However, the cell is not resting but busy making proteins and undergoing chemical reactions for an organism's metabolism.

semi-conservative replication
a process where each strand of the previous DNA is used to form a complementary new strand

The eukaryotic cells that make up multicellular organisms must reproduce over the lifetime of the organism. Reproduction occurs through mitosis and cytokinesis, which must be very organised to prevent damage. There are many chromosomes in a nucleus that can easily become tangled or broken during replication. When somatic cells undergo division, the daughter cells must contain the same number of undamaged chromosomes as the parent cell. Between each cycle of replication, the somatic cell must perform the normal functions that are required by the organism. This phase of normal functioning is called **interphase**.

Interphase

Eukaryotic cells mostly exist in the first gap phase (G1) of interphase. During this phase, the cells undergo everyday metabolic activities.

G1 phase

The G1 phase is usually the longest phase of the cell cycle. During the G1 phase, the cell becomes larger and synthesises the proteins and organelles that it needs to stay alive. How long a cell stays in this phase depends on the type of cell. Some cells can be forced to remain in this phase if they are deprived of nutrients or resources. When this occurs, the cell is described as entering the G0 phase.

Before a cell can leave the G1 phase, the number and health of the organelles and the structure and function of the DNA are carefully checked. If a cell fails at the **G1 checkpoint**, a protein called p53 is produced in large quantities. This forces a cell to become **quiescent** (dormant) while the DNA is repaired or, if the cell cannot be repaired, undergo a process of organised cell death (**apoptosis**). If the cell passes the G1 checkpoint, it will be able to replicate its DNA.

S phase

During the S phase of interphase, the cell replicates the genetic material (DNA). A human somatic cell has 46 double-helix molecules of DNA called **chromatin**. Before a cell can replicate, it must copy each DNA molecule. This occurs when the double-stranded DNA helix unwinds and then separates into single strands.

Each single strand of the DNA molecule is then used to form a new complementary strand of DNA, which results in two daughter molecules. Each daughter molecule contains one strand from the old DNA molecule and one new strand. This is known as **semi-conservative replication** (half the molecule is conserved from the old molecule) (Figure 2). This effectively doubles all DNA from the G1 phase.

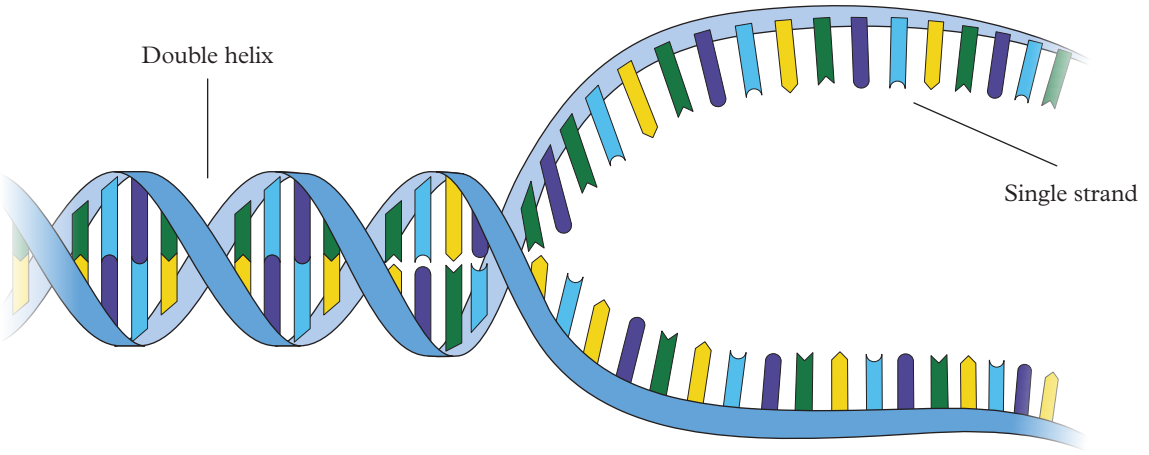


FIGURE 1 During DNA replication, the double-stranded helix unwinds and separates into single strands.

Each daughter molecule of DNA winds itself around proteins called histones to prevent any tangling of the now double amounts of DNA. The two daughter molecules remain connected at a central point called a **centromere**. The cell is now ready to begin the Gap 2 (G2) phase of interphase.

centromere the centre of a chromosome

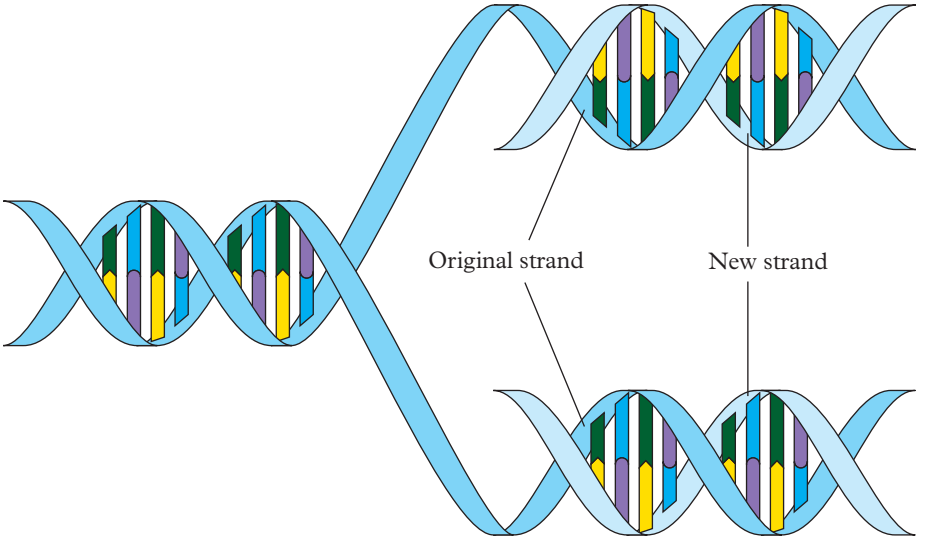


FIGURE 2 DNA replication is described as semi-conservative. In each daughter molecule, half the DNA comes from the original molecule and half is newly formed.

G2 phase

This final stage of interphase is when the cell starts rapidly growing and synthesising proteins for the start of mitosis. This includes proteins responsible for spindle formation. Not all cells undergo G2 phase; instead they move straight from S phase to mitosis.

G2 checkpoint the point in the cell cycle when a cell is assessed to see if the new DNA strands were made correctly

As in G1, there is an important checkpoint – the **G2 checkpoint**. The DNA molecules must be checked to make sure the synthesis of the new strands was correct. Any mistakes need to be repaired or the cell will apoptose (die). If the checkpoint is cleared, the cell starts mitosis.

Mitosis

Mitosis is the organised division of the nucleus of the cell. There are four stages in mitosis: prophase, metaphase, anaphase and telophase (Figure 3).

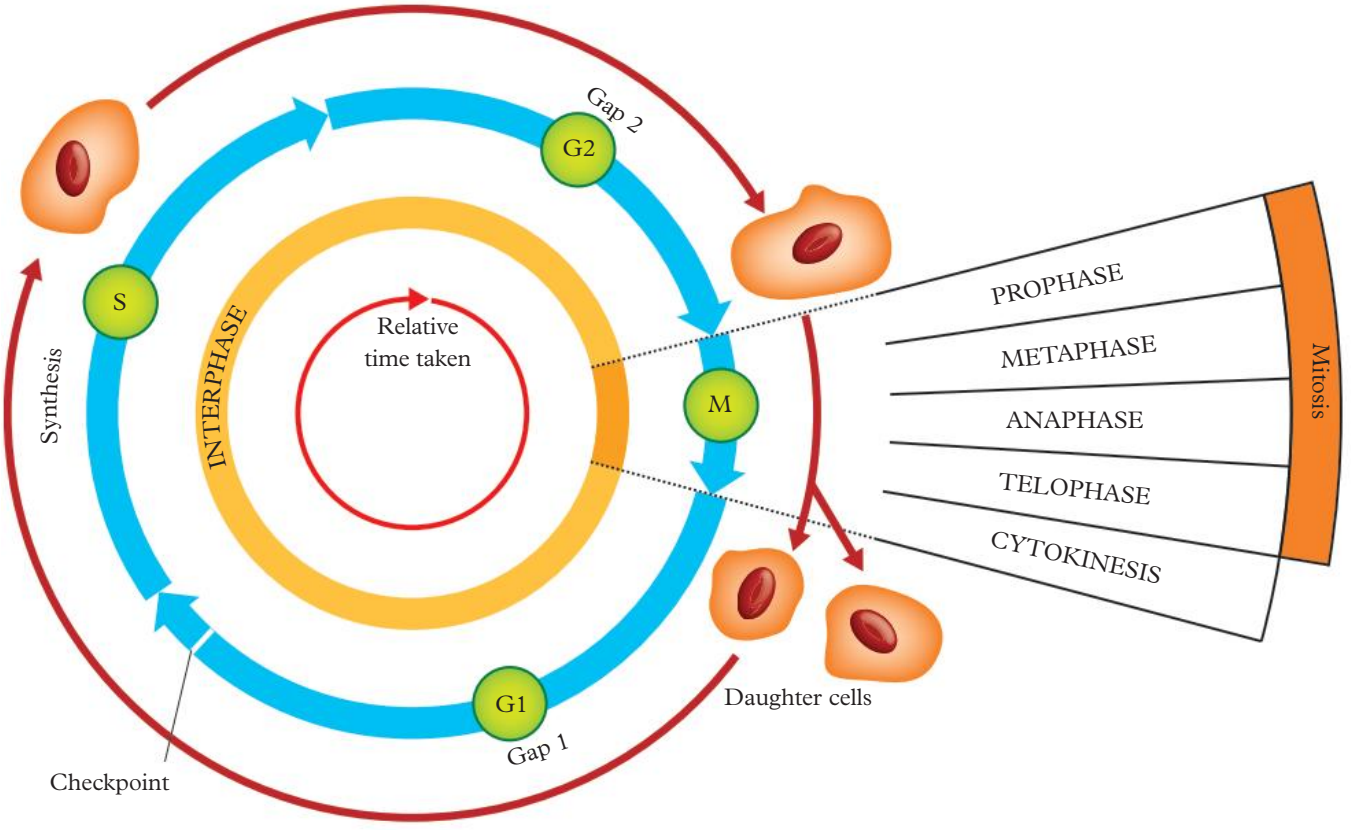


FIGURE 3 The cell cycle. Interphase is the period between two episodes of mitosis.

Prophase

In **prophase**, chromatin continues to wind into a condensed form of DNA called a **bivalent chromosome**. Each chromosome has a distinctive 'H' shape in which two parallel 'sister' **chromatids** are joined at the centromere (Figure 4).

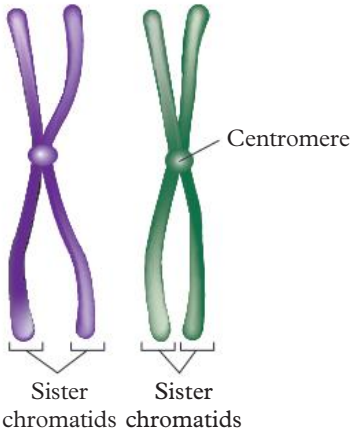


FIGURE 4 A bivalent chromosome is made up of two sister chromatids joined at the centromere.

prophase
a stage of mitosis when DNA coils into chromosomes

bivalent chromosome
a pair of chromatids connected by a centromere

chromatid
one strand of a bivalent chromosome

Study tip

In **m**etaphase, chromosomes are linked down the **m**iddle of a cell. In **a**naphase, chromosomes are moving **a**way from each other.

spindle
thread-like proteins that attach to the centromere of chromosomes in order to move them during mitosis

While the DNA molecule is condensing into a chromosome, the nuclear membrane breaks down and a number of protein threads spread from one end of the cell to the other. These protein threads link together at each cell pole to form a **spindle** (Figure 6).

Metaphase

During **metaphase**, the newly formed chromosomes migrate to the centre (equator) of the cell. One of the protein threads that form the spindle then attaches to the centromere of each chromosome. At this point, **checkpoint M** checks that the spindle fibre is correctly attached to each centromere before the cell progresses to the next stage.

Study tip

Anaphase and telophase are the only phases when the number of chromosomes in a human cell is 92. In all of the other phases, the bivalent chromosome contains two chromatids.

metaphase
a stage of mitosis when chromosomes move to the centre of the cell

checkpoint M
the point in the cell cycle just before anaphase when all sister chromatids are checked that they are attached correctly to the spindle microtubules

Anaphase

During **anaphase**, the sister chromatids of each bivalent chromosome separate at the centromere. This breaks apart the distinctive 'H' shape into two individual (identical) DNA molecules and each chromatid becomes a single, independent chromosome. The spindle fibres pull each identical chromosome to opposite poles of the cell. This occurs for each of the 46 chromosomes in a human cell. The result is 46 individual chromosomes at each pole of the cell.

anaphase
a stage of mitosis when the chromosomes separate at the centromere and move to opposite sides of the cell

Telophase

After the 46 chromosomes reach each end of the cell, they gather together, and a new nuclear membrane is formed and the spindle fibres break down. Once protected by the nuclear membrane, the chromosomes unravel to form chromatin. The new daughter nuclei are genetically identical to each other.

Cytokinesis

During the end of mitosis, **cytokinesis** begins. In animal cells, this involves a constriction at the centre of the cell called **cleavage**. This is similar to a belt tightening around a waist. Eventually the membrane meets in the middle (cleaves) and forms two genetically identical daughter cells.

cytokinesis
a stage in mitosis and meiosis when the cell divides into two daughter cells

cleavage
the process of splitting of a cell to form two daughter cells

In plant cells, cytokinesis involves the formation of the beginning of a new plasma membrane and cell wall between the new nuclei. This cell plate spreads to the outside of the cell until the two new daughter cells are separated from each other.

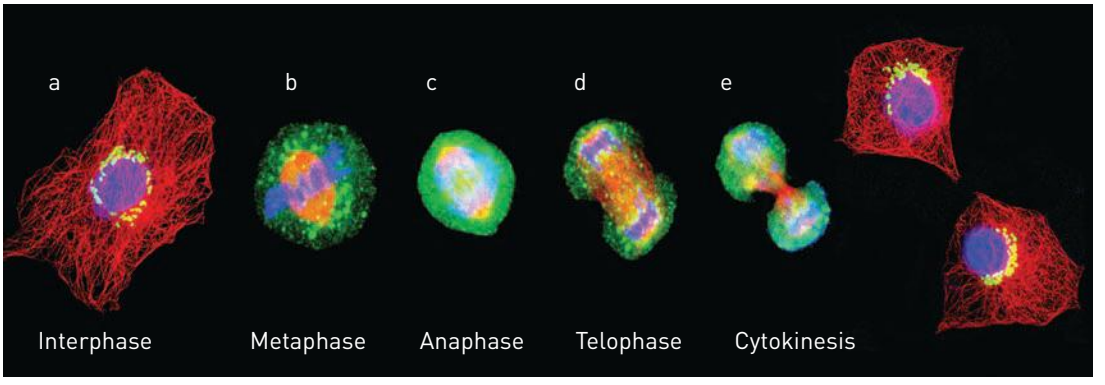


FIGURE 5 These animal cells are undergoing mitosis. They have been stained with a fluorescent stain to show the separation of DNA. **a** The cell is at the end of interphase. **b** The blue chromosomes line up along the middle of the cell and attach to the yellow spindle during metaphase. **c** Yellow spindles are contracting and separating two chromatids at the centromere during anaphase. **d** The nuclear membrane re-forms around the two sets of DNA in telophase. **e** Cytokinesis occurs when the plasma membrane divides in two.

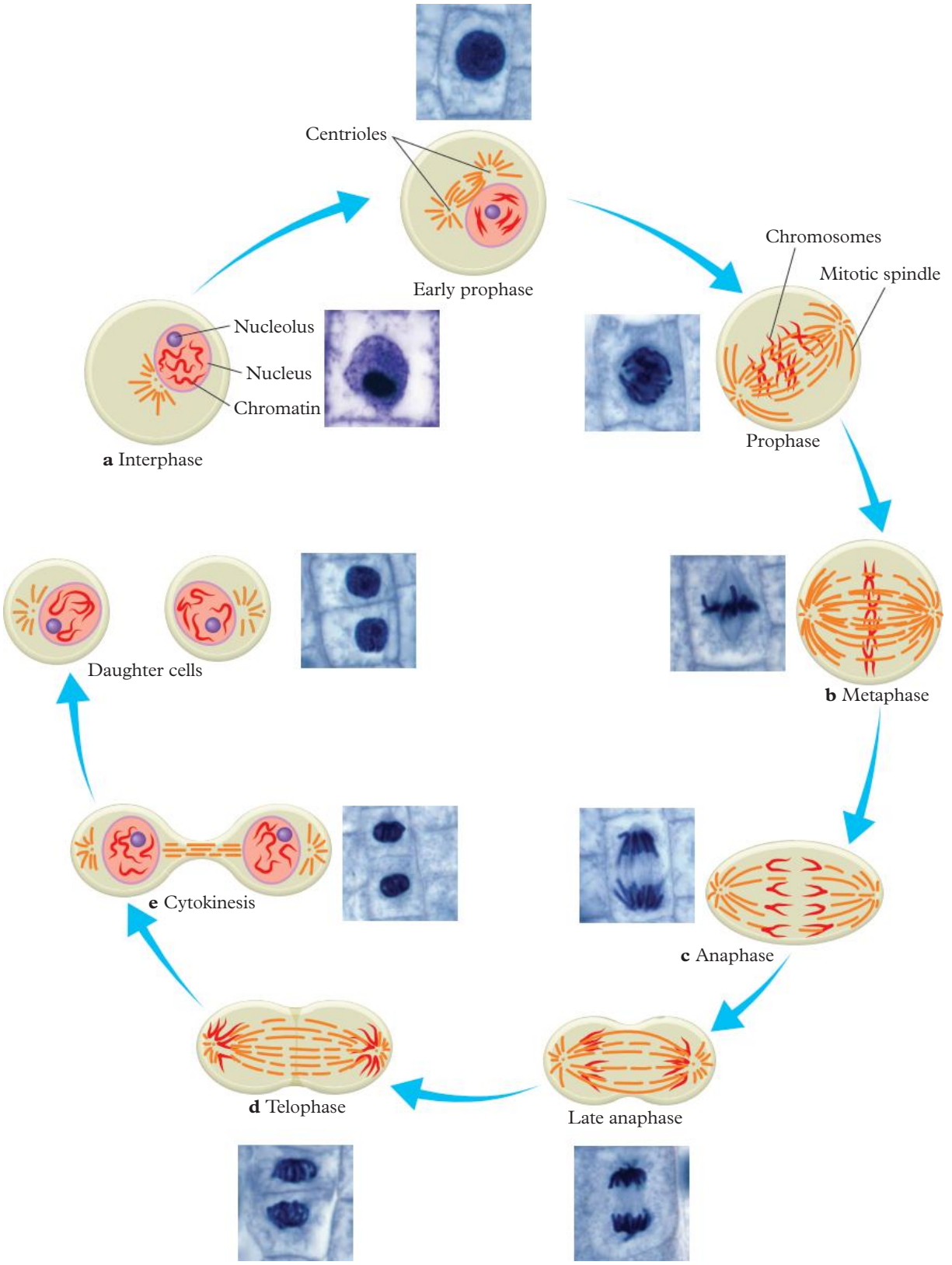


FIGURE 6 The phases of mitosis and cytokinesis occurring in an animal cell (diagrams) and a plant cell (electron micrographs)

CASE STUDY 3.2

Variations in the cell cycle

Although cytokinesis normally follows mitosis, there are exceptions. For example, the formation of skeletal muscle fibres in vertebrate animals results from mitosis without cytokinesis. These cells often have many nuclei in a single cell (Figure 7).

Other cells constantly go through the cell cycle of growth, mitosis and cytokinesis for their entire existence. For example, red blood cells do not have a nucleus and live for about 120 days. Bone marrow cells need to constantly divide so that there are enough red blood cells in the body.

A third category of cells only divides to produce the exact number of cells required for growth and replacement. For example, human liver cells rarely divide after the liver has reached a certain size. If some of the liver is surgically removed, this triggers the existing cells to divide until the liver regains its original size.

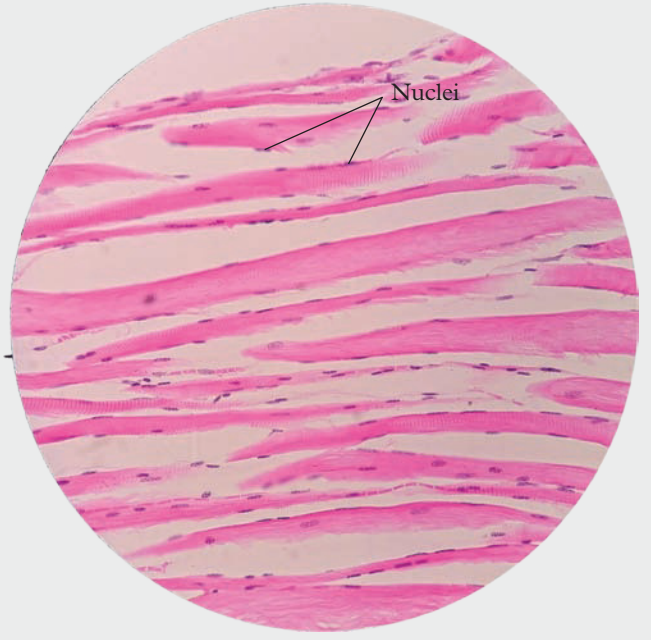


FIGURE 7 Skeletal muscle cells often have many nuclei.

CHECK YOUR LEARNING 3.2

Describe and explain

1 Describe each stage of mitosis.
2 Explain the difference between the S phase and G2 phase in interphase.
3 Describe the three different checkpoints that ensure that the cell cycle progresses correctly.
4 Identify the phase of mitosis shown in Figure 8.

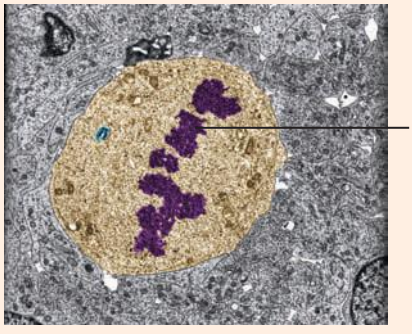


FIGURE 8 A stage of mitosis

Apply, analyse and compare

5 Compare cytokinesis in a plant cell and an animal cell.
6 Read Case study 3.2 and compare the process of mitosis and cytokinesis in muscle fibres to the process in standard eukaryotic cells.

Design and discuss

7 Design a picture showing each stage of mitosis. Discuss what occurs at each stage.
8 A student claimed that a cell at metaphase and anaphase was the easiest to identify. Suggest why prophase might be more difficult to identify than metaphase and anaphase.

3.3 Apoptosis

KEY IDEAS

In this topic, you will learn that:

- apoptosis is a natural, regulated process of programmed cell death
- internal or external signals can lead a cell to apoptose.

The normal functioning of an organism involves the process of interphase and the reproduction of cells through mitosis and cytokinesis. When a cell is damaged and cannot be repaired, or is not required anymore, its death needs to be regulated so that it doesn't damage any other cells in the process.

If a cell is exposed to toxins or extreme temperatures or is damaged, it can swell and eventually lyse, meaning the membrane breaks and the contents are released. This can cause the surrounding cells to become damaged and also die. This process of swelling and breaking apart is called necrosis. To prevent this from happening, cells need to have a safe, organised cell death pathway. Programmed cell death (apoptosis) is important when there is an excess of cells; for example, when an infection is under control and high levels of white blood cells are no longer needed, or when the body needs to remove a virus-infected cell.

The signal that starts the process of apoptosis can come from an internal (intrinsic) or external (extrinsic) source (Figure 1).

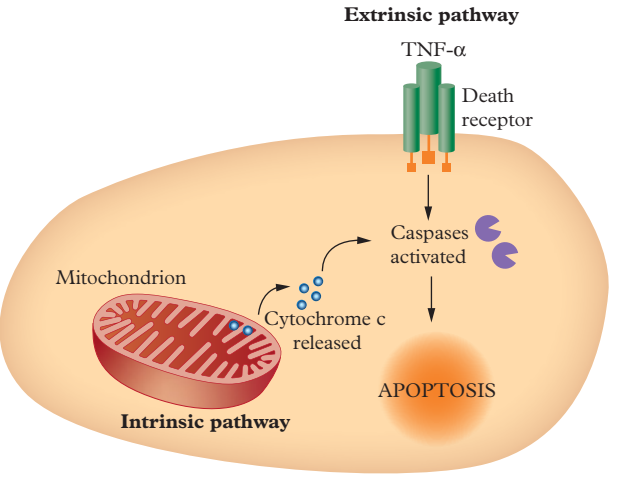


FIGURE 1 Apoptosis can be activated through an intrinsic or extrinsic pathway.

Intrinsic pathway to apoptosis

intrinsic pathway a biochemical pathway occurring completely within a cell that triggers apoptosis

cytochrome c a small protein on the inner membrane of mitochondria, which is involved in the electron transport chain of aerobic cellular respiration

The **intrinsic pathway** to cell death involves internal processes. These may be in response to cell damage that is irreparable.

Mitochondrial damage

Cytochrome c is a small protein found on the inner membrane of mitochondria, where it plays a part in aerobic cellular respiration. When a mitochondrion is damaged, cytochrome c leaks into the cytoplasm, where it can activate apoptosis.

DNA damage

A cell's DNA is regularly checked by a multitude of repair enzymes. If the DNA is damaged, the protein p53 attempts to repair the damage and blocks the cell cycle from progressing, giving the DNA more time to repair. If the DNA cannot be repaired, p53 initiates apoptosis in the cell by activating the mitochondria to release cytochrome c into the cytoplasm.

Extrinsic pathway to apoptosis

Some cells in the immune system can release signalling molecules that cause other cells to apoptose. **Tumour necrosis factor-α (TNF-α)** is one of these signalling molecules released by white blood cells. Whereas other TNFs have roles in fighting disease and inflammation, TNF-α has been linked directly to apoptosis. It binds to a **death receptor** on the surface of other cells and starts a series of internal chemical pathways that results in the activation of p53 and ultimately leads to release of cytochrome c and apoptosis.

tumour necrosis factor-α (TNF-α)
a signalling molecule that has roles in inflammation and apoptosis

death receptor
a receptor on the surface of a cell that initiates the death of a cell

Stages of apoptosis

Once apoptosis has been initiated, the cell goes through a series of stages.

- A series of enzymes called **caspases** are activated. These enzymes start breaking apart the cytoskeleton of the cell.
- The cell starts shrinking.
- The DNA is broken down.
- The cell membrane forms small bulges called **blebs**. These contain the partly broken down organelles of the cell.
- The blebs become fully surrounded by the membrane and break off from the rest of the cell to form **apoptotic bodies**.

caspases
protease enzymes that are responsible for many steps in the apoptosis pathway

bleb
a bulge of cellular contents on the outside of an apoptotic cell

apoptotic body
a bleb that has separated from a cell but is still enclosed in membrane

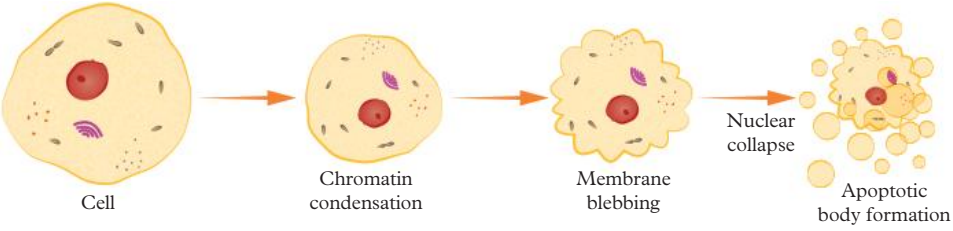


FIGURE 2 Apoptosis is a form of programmed cell death that allows a cell to safely form apoptotic bodies from blebs.

Once all of the cell contents have separated into individual blebs, they are endocytosed by white blood cells in the immune system.

If apoptosis is not controlled, excessive cell death can occur. Uncontrolled cell death (called necrosis) can cause toxic molecules to be released, and damage the surrounding healthy cells. A cell can limit its chances of apoptosis by producing inhibitors such as BCl-2 or decreasing the production of caspases.

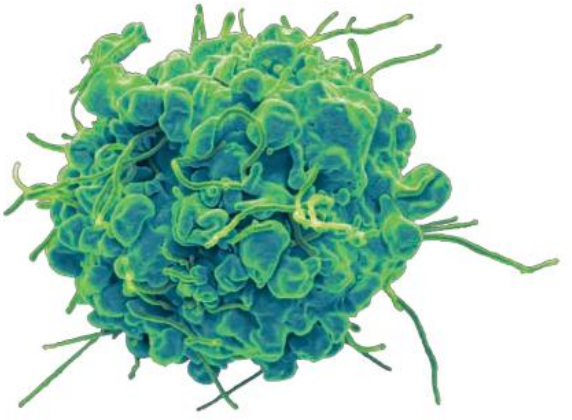


FIGURE 3 This apoptotic cell is undergoing blebbing.

CHALLENGE 3.3

Webbed fingers

Apoptosis plays a vital part in the development of an embryo (<11 weeks) and a foetus (>11 weeks). Five weeks after conception, the embryo begins to develop arms and legs. Tiny limb buds grow and elongate to form hand plates. At eight weeks, the cells between the fingers and toes apoptose, leaving five digits. Many genes are involved in this process.

1 Explain what could have occurred during development to result in the condition shown in Figure 5.

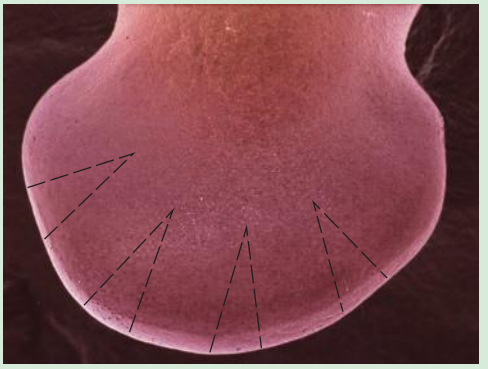


FIGURE 4 The hand plate of an embryo and the site of apoptosis to form five fingers

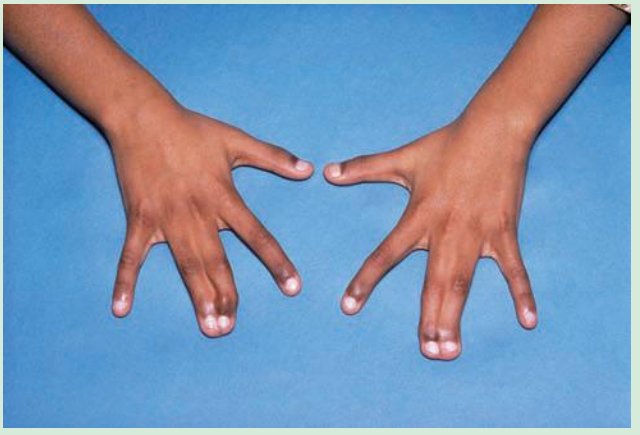


FIGURE 5 This person has the condition of webbed fingers.

CHECK YOUR LEARNING 3.3

Describe and explain

1 Describe when a cell might undergo apoptosis.

2 Describe the stages of apoptosis.

3 Explain how caspases are involved in apoptosis.

Apply, analyse and compare

4 Compare the intrinsic and extrinsic pathways of apoptosis.

5 Compare necrosis and apoptosis.

Design and discuss

6 Research different outcomes that may occur when too much apoptosis happens in in the human body.

7 Discuss how apoptosis could play a role after the immune system has defeated a bacterial infection.

3.4 Disruption to the cell cycle

KEY IDEAS

In this topic, you will learn that:

- the action of mutagens or genetic predispositions can disrupt the cell cycle
- disruptions of the cell cycle can result in uncontrollable cell division such as cancer
- malfunctions in apoptosis can produce deviant cell behaviour.

The cell cycle generally functions very efficiently, but sometimes it malfunctions, which can cause many issues for an organism. For example, every time a cell replicates its DNA, approximately three errors occur. Most of these errors are detected and repaired, but some remain and become permanent (mutations). DNA can also become damaged through normal metabolic activities or by environmental factors such as radiation or chemicals. Cells themselves can become damaged through complications with apoptosis.

Mutagens

mutagen something that causes a mutation, either chemical, physical or biological

Mutagens are agents that cause a permanent change in the DNA sequence. Mutagens include radiation, chemicals and biological agents. Many mutagens can cause deviant cells that eventually lead to cancer or characteristics of cancer cells.

Radiation

Radiation is a form of energy that consists of electromagnetic waves or high-energy particles. Some forms of radiation (such as radio waves) are very low energy and harmless, whereas others (such as UV light or X-rays (Figure 1)) can cause changes in the DNA sequence.

FIGURE 1 X-rays can cause DNA mutations.

FIGURE 2 Cigarette smoke contains chemicals that cause DNA mutations.

Chemicals

Chemical agents include some of the chemicals in cigarette smoke (Figure 2), mustard gas (which has been used in chemical warfare) and nitrogen oxides. These chemicals react with the genetic material in cells, resulting in a permanent change in the DNA sequence.

Biological agents

Viruses are small non-living particles that consist of genetic material surrounded by a protein coat (Figure 3). Viruses are considered to be non-living because they cannot reproduce independently. Instead, they need to insert their genetic material into a host cell and use the host's organelles to reproduce. Occasionally, the genetic material of the virus can be inserted in an important section of DNA. This can result in the disruption of the normal functioning of the cell.

FIGURE 3 Viruses are biological agents that can cause DNA mutations.

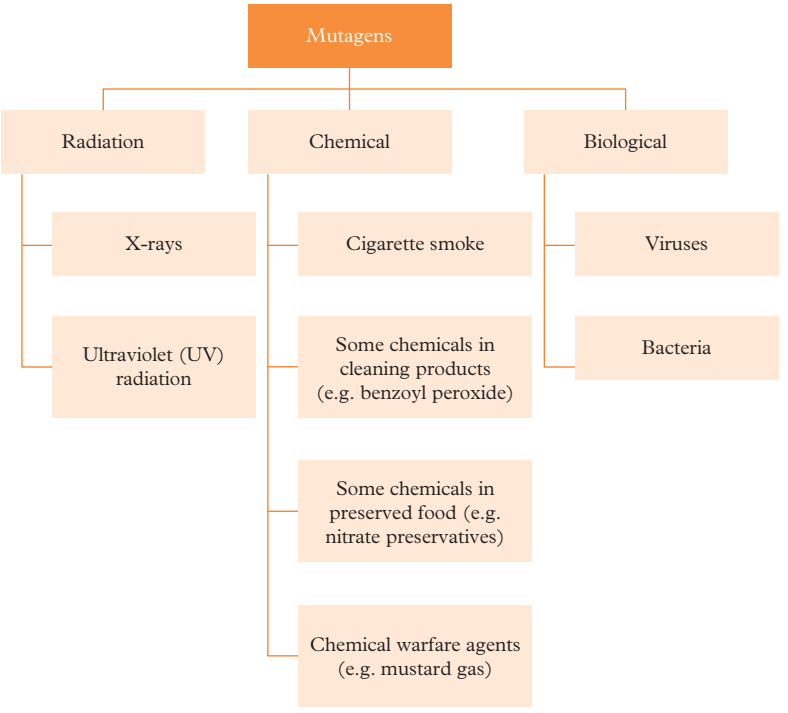


FIGURE 4 There are different types of mutagens that can disrupt the cell cycle.

Disrupting the cycle

Mutagens can cause changes in DNA, which can make the chromosomes unstable. The chromosomes may break or rearrange, which, in turn, affects the way a cell responds to its chemical signals.

Other agents may change the sequence of the DNA, which affects the unique code that is responsible for protein synthesis. Some of these changes are lethal or cause serious disease, but not all changes in the DNA sequence cause a cell to become cancerous. Many of these permanent changes (**mutations**) have little or no effect on the cell's function. The location of a mutation, the size of the mutation and the compounding effect of previous mutations ultimately determine the biological consequences.

mutation
a permanent change to the DNA sequence

A silent mutation is a mutation that causes no change to the amino acids produced by a sequence of DNA in the cell. Other mutations can have a large effect on a cell. A mutation in a section of DNA that is responsible for controlling the checkpoints of the cell cycle can have a significant impact on the cell's function. An example of this is the section of DNA that codes for the p53 protein, which acts as a tumour suppressor. A healthy cell does not need p53, and so the levels remain low. When a cell is damaged, more p53 is produced, preventing the cell from undergoing mitosis until the DNA is repaired. If the cell cannot be repaired, the p53 can force the cell to undergo an organised cell death (apoptosis). If there is a mutation in the section of DNA that produces the p53 protein, then the protein will not be produced, and the cell will be able to continue to produce more defective cells.

Malfunctions in apoptosis

Within each cell of a multicellular organism is a series of genes that regulate apoptosis. There is a careful balance between the genes that activate apoptosis and those that suppress apoptosis. In many cases, a permanent change or mutation to the cell's DNA can upset this balance. Often the organism's immune system identifies the damaged cell and signals the death receptor pathway, resulting in apoptosis of the cell. Occasionally, the genes that initiate apoptosis have also mutated, preventing the cell from undergoing programmed cell death. This allows the cell to grow and reproduce indefinitely. Further mutations can result in the cell growing uncontrollably, causing cancer.

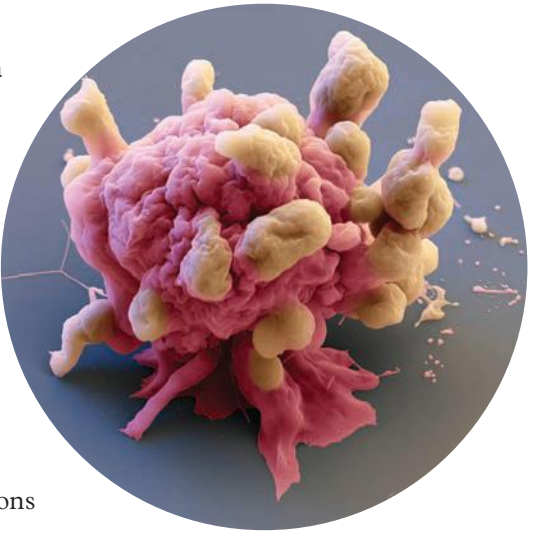


FIGURE 5 This cell is undergoing apoptosis.

Cancer

A single change in the DNA sequence does not cause a cell to become cancerous. Most changes are repaired by special proteins such as the BRCA1 or BRCA2 protein. If there is a lot of damage, then some changes may be missed, causing the permanent change that is a mutation.

Characteristics of cancer cells

Because cell replication is highly regulated, a cell cannot become cancerous unless at least five mutations of specific parts of the DNA have occurred. Six of these changes are outlined below.

1. A cancer cell is self-sufficient. Most cells need external signals from other cells before they can undergo mitosis. Cancerous cells can signal themselves to divide.
2. A cancer cell blocks signals that control the checkpoints of mitosis. Proteins such as p53 can prevent mitosis. A mutation in the section of DNA responsible for producing p53 will allow a cell to divide at any time.
3. A cancer cell avoids apoptosis. This is possible because of a mutation in the DNA that controls the cell's apoptotic pathway.
4. A cancer cell is able to undergo limitless cell cycles. Cancerous cells can divide an unlimited number of times, whereas there is a limit to the number of times healthy cells can divide.

5 A cancer cell has access to nutrients through a good blood supply. Most cancerous cells can encourage blood vessels to grow around them.
6 A cancer cell is able to migrate (metastasise) around the body.

Cancer cells kill the surrounding cells, either by smothering them or by using all the surrounding nutrients. This blocks the normal functioning of the body, resulting in the diseased state.

Genetic risks of cancer

People in some families have a higher than average risk of getting cancer. There are several reasons for this. The members of these families may have inherited mutations in the DNA that is responsible for one of the six changes above. More than 50% of cancers involve missing or damaged sections of DNA that produces the p53 protein. Inheritance of this mutation is rare, but people with this mutation have a higher risk of developing cancer. Other people can inherit mutations in the DNA responsible for repairing DNA.

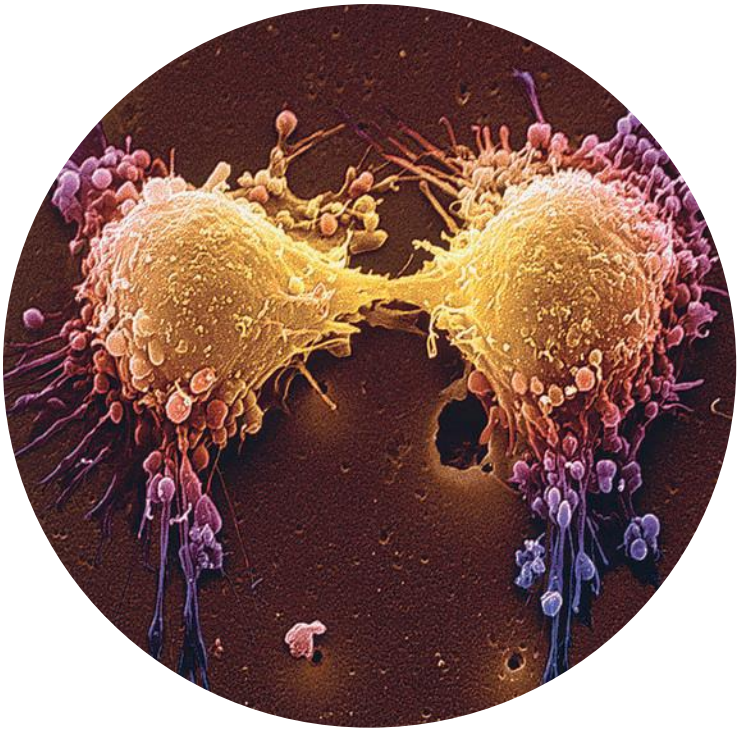


FIGURE 6 The final stages of cancerous cells dividing

CHALLENGE 3.4

BRCA mutations

Two sections of DNA called BRCA (BReast CAncer gene) code for the BRCA1 and BRCA2 proteins. These proteins are responsible for repairing errors in DNA. The errors may be a result of the environment (chemical, viral or radiation mutagens) or part of the regular replication process. If these errors cannot be repaired, then they become permanent mutations. Over time, the mutations can accumulate, causing the six changes that can result in a cell becoming cancerous. Because breast tissue in females regularly undergoes mitosis, people who inherit these mutations can have a higher risk of developing breast cancer.

1 Will all people who inherit the BRCA1 or BRCA2 mutations develop breast cancer? Use your knowledge from this chapter to explain your reasoning.

CHECK YOUR LEARNING 3.4

Describe and explain

1 Define ‘mutagen’.
2 Name and provide examples of the three main types of mutagens.
3 Define ‘mutation’.
4 Define ‘apoptosis’.
5 Explain how mutations contribute to an increased risk of a person developing cancer.

Apply, analyse and compare

6 Compare the functions of the p53 protein with that of the BRCA protein.

Design and discuss

7 Discuss the link between smoking and lung cancer.
8 Discuss how understanding the apoptosis pathway can help develop treatments for cancer.

3.5 Stem cells

KEY IDEAS

In this topic, you will learn that:

- stem cells are specialised cells that can differentiate into more than one type of cell
- the two main types of stem cells are embryonic and adult stem cells
- stem cells can be totipotent, pluripotent or multipotent
- the use of embryonic stem cells involves bioethical considerations.

Multicellular organisms consist of a large number of different types of cells that communicate and work together to ensure the survival of the whole organism. Each cell has a specific function, controlled by its genetic material and the chemical messengers that surround it.

Damaged cells need to be replaced. For example, when the skin is damaged, each of the different cells that make up the layers of the skin (epidermis, dermis and hypodermis) along with the nerves, lymph vessels and sweat glands need to be replaced quickly before bacteria can cause damage. Each layer requires a different type of cell with their own specialised functions. The most efficient way for all of these cells to be produced at the same time is through the use of stem cells.

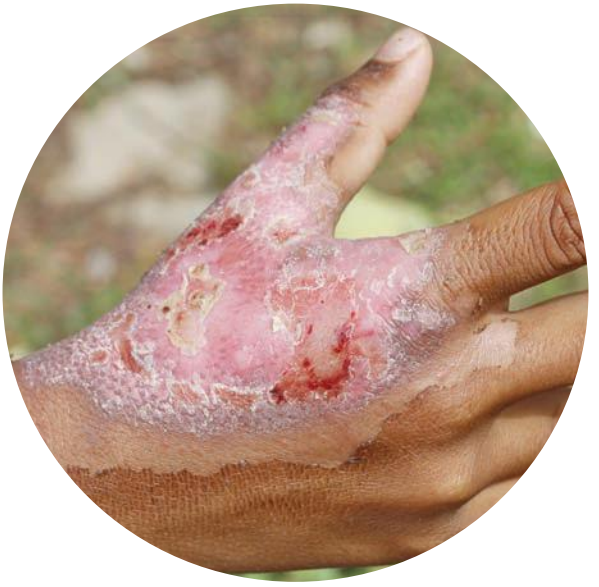


FIGURE 1 Damaged skin cells can only regenerate in humans if the damage is no deeper than the epidermis layer; otherwise, scar tissue forms.

Types of stem cells

stem cell
a cell that is capable of forming different cell types

Stem cells are undifferentiated cells, effectively blank canvases that can be anything the body needs them to be. Stem cells divide to produce daughter cells that can either continue as stem cells or differentiate into specialised cells with specialised functions. These unique cells have three main characteristics. Stem cells:

- can continue to reproduce themselves for long periods
- are undifferentiated
- can produce differentiated cells with specialised functions.

There are two main types of stem cells: embryonic and adult stem cells.

Embryonic stem cells

Embryonic stem cells are found in an embryo, from a zygote to the inner cell mass of a blastocyst. These cells can use almost any part of their genetic material. This means they can become any type of specialised cell in the body and can endlessly reproduce themselves.

Embryonic stem cells are more flexible than adult stem cells in how they reproduce and the types of differentiated cells they can become. Embryonic stem cells are used as treatments for diseases such as Parkinson's disease and even in spinal cord injuries. Scientists have discovered that the placenta has higher concentrations of embryonic stem cells than the umbilical cord.

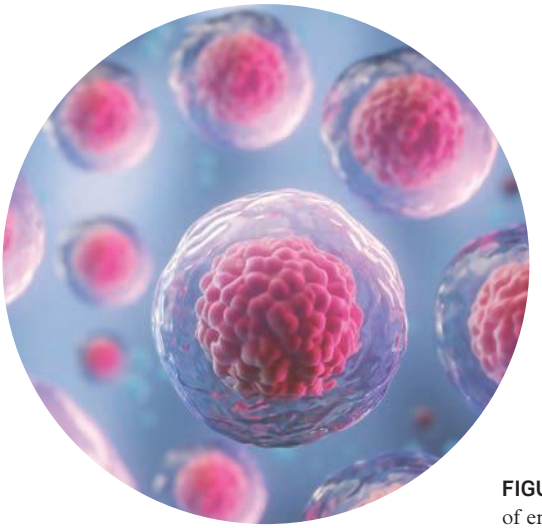


FIGURE 2 A 3D rendering of embryonic stem cells.

Adult stem cells

Adult stem cells can reproduce themselves. They can also produce daughter cells that can become more than one cell type. However, adult stem cells are more limited than embryonic stem cells. Each adult stem cell can only produce a small range of differentiated cells. For example, in the lining of the intestines, there are stem cells at the base of deep folds. As older cells at the top of the fold die and are shed from the lining, the stem cells at the base produce new cells that differentiate into replacement cells. Adult stem cells are in bone marrow (producing red blood cells, white blood cells and platelets), the spinal cord, dental pulp, blood vessels, skeletal muscle, skin epithelia, the liver and many more locations.

Hierarchy of cell potency

Cell potency is a way of describing the number of different cell types a stem cell can produce. Cells with higher levels of potency can produce more cell types than cells with a lower potency.

Totipotent stem cells

Totipotent stem cells can produce cells that can differentiate into any cell type in the organism. These cells are only found in early stage embryos, from a zygote to a morula. Once the embryo has reached the blastula stage, the cells of the inner cell mass cannot become placental cells, and therefore are no longer called totipotent.

totipotent stem cell
an undifferentiated cell that can later differentiate into any type of cell

Pluripotent stem cells

The inner cell mass of a blastula is pluripotent. **Pluripotent stem cells** can differentiate into most of the cell types in a multicellular organism, except placental cell types. The production of these cells occurs in a series of stages (starting with the germ layers), gradually limiting the possible cell types the stem cell can become.

pluripotent stem cell
a stem cell that can differentiate into any cell type within a broad group

Multipotent stem cells

Multipotent stem cells are usually only found in adults. Their ability to produce different cell types is often limited. For example, the stem cells in the bone marrow can produce any of the cells in the blood (red blood cells, white blood cells and platelets), but they cannot produce any other cell type.

multipotent stem cell
a stem cell that can only differentiate into a limited number of closely related cell types

Unipotent stem cells

unipotent stem cell
a stem cell that can only form one cell type on division

The most common cells in the human body are fully differentiated cells or **unipotent stem cells**. When they reproduce, their daughter cells have the same function as the parent cell. They can only be used for the regeneration of their own kind of cells.

Study tip

Totipotent stem cells can form the **tot**al range of cells. **Pluri**potent stem cells can form **plur**al or many cells. **Multi**potent stem cells can form **multi**ple types of cells. **Uni**potent stem cells can only form **one** type of cell.

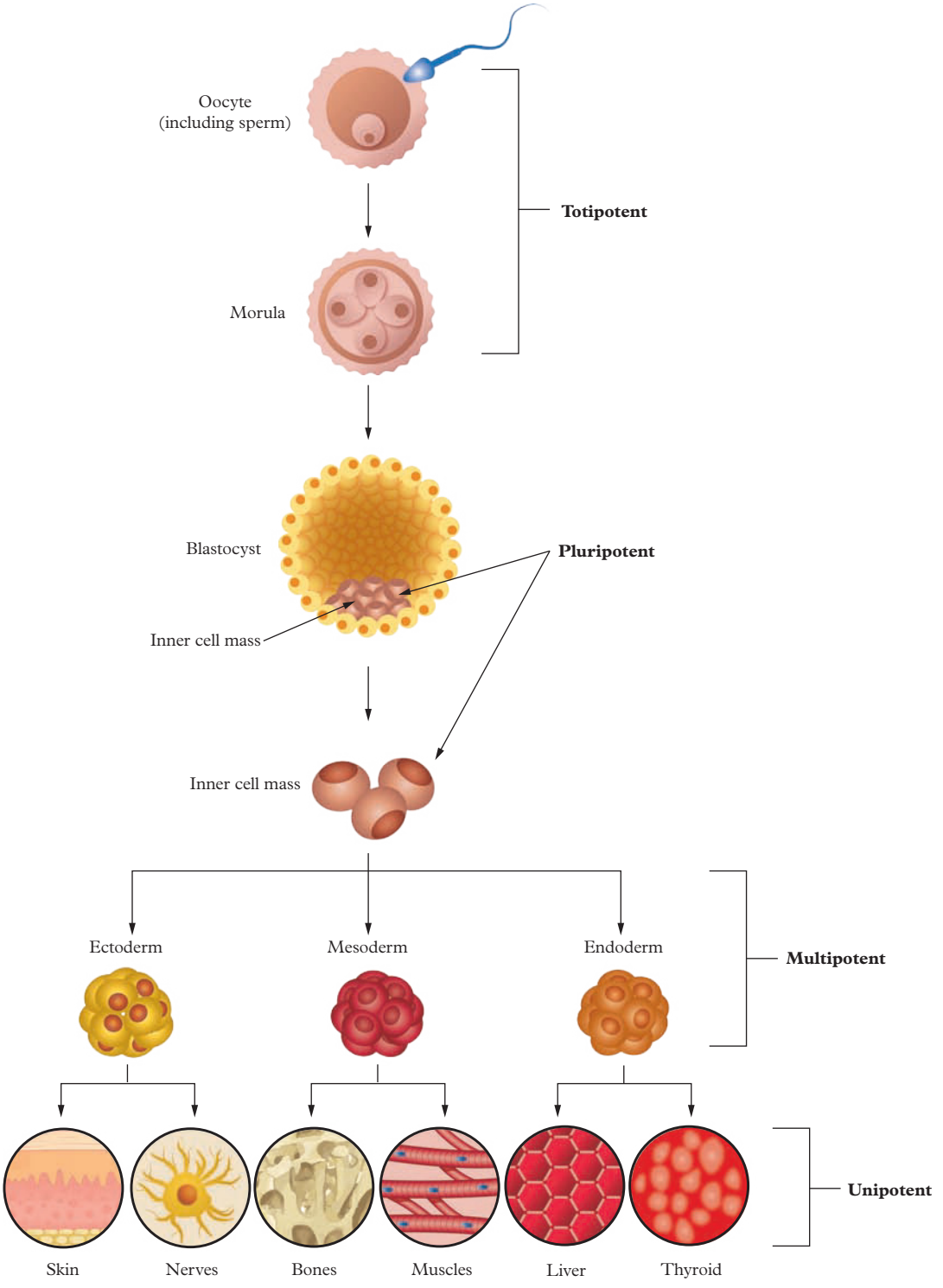


FIGURE 3 The process of forming the different cells that become more specialised with each step

Bioethical considerations

There are bioethical concepts to consider when using embryonic stem cells. Stem cell research offers great hope for treatment of diseases such as diabetes, spinal cord injury and Parkinson's disease. However, many people are opposed to the used of human embryos. Some ethical considerations are outlined in Case studies 3.5A and 3.5B and Challenge 3.5.

CASE STUDY 3.5A

Induced pluripotent cells

There are ethical considerations that may stop people using embryonic stem cells. Because of this, scientists have looked at ways of using adult stem cells and have developed a method of forcing (inducing) a multipotent adult cell to become a pluripotent cell. This is done by using a virus to introduce new genetic material into donor adult cells. The new genetic material causes inactive DNA to become active, giving the cells the chance to differentiate into a new type of cell. In this way, skin cells have become induced pluripotent cells that differentiated into new heart muscle cells and even started synchronised beating.

This process is not easy. It is only 0.01–0.1% efficient, which means that only one cell in 1000–10 000 is transformed into a pluripotent cell. It has been suggested that many of these cells could start undergoing uncontrolled growth and form tumours. There have been some human trials in using these cells to repair aged-related muscular degeneration, with limited success.

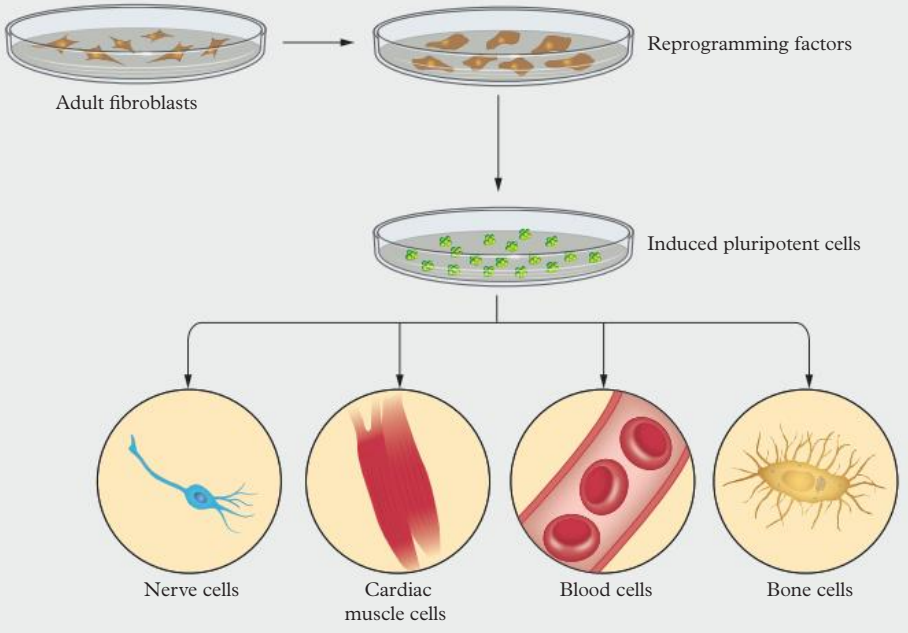


FIGURE 4 Adding new genetic material to differentiated adult cells can induce pluripotent abilities.

CASE STUDY 3.5B

Axolotl conservation versus research needs

Axolotls can harness their own pluripotent stem cells at any point in their development, which means they can replace a lost limb once, twice or even 100 times. This incredible ability means that axolotls are one of the most scientifically studied salamanders.

Unfortunately, axolotls are critically endangered in the wild because of urban sprawl and pollution of freshwater environments. It is estimated that only a few hundred now reside in the canals of Mexico City, their only habitat. However, these animals are abundant in captivity; they are largely bred for home aquariums and research purposes.

Scientists want to understand and harness their unique capabilities. Axolotls have become a model for tissue regeneration and cancer treatments. Inbreeding in captivity has resulted in a loss of genetic diversity, increasing the chance of the populations contracting diseases.

A few scientists are now breeding and releasing axolotls into the Mexican canals in an attempt to save the species and increase genetic diversity of wild populations. Axolotls' resilience to diseases and injuries make them one of the most interesting critically endangered population regeneration projects to date.

FIGURE 5 Axolotls can harness their own pluripotent stem cells to replace lost limbs.

CHALLENGE 3.5

Waste not, want not?

When some couples have difficulty becoming pregnant, they may use *in vitro* fertilisation. This process involves generating embryos by artificially fertilising an egg with a sperm in a Petri dish before implanting it in the mother. To increase the chances of success, many eggs are usually fertilised and the zygote that is considered the most viable is implanted. This requires an embryologist to grade the embryos by examining their morphological features under a microscope and assigning a quality score to each one.

The parents may decide what to do with the remaining embryos. The unused embryos may be kept in storage, disposed of, used for research, or donated to another person or couple. Some people argue that these embryos should be used as stem cells to replace damaged tissue in other patients, or to produce vaccines. Other people suggest that they are potential humans and need to be given the chance to survive.

1 Describe the ethical advantages and disadvantages for each of the four choices about what to do with remaining embryos: store, dispose of, use for research or donate.

2 Which decision would you make? Explain the reasoning behind your decision.

CHECK YOUR LEARNING 3.5

Describe and explain

1 Define 'stem cell'.

2 Use an example to explain:

- **a** totipotent stem cells
- **b** pluripotent stem cells
- **c** multipotent stem cells
- **d** unipotent stem cells.

3 Read Case study 3.5B. Name the type of stem cells that axolotls use to regenerate lost limbs. Justify your answer.

Apply, analyse and compare

4 Bone marrow transplantation was one of the first stem cell treatments used. Explain why this is an effective treatment for leukaemia (cancer of the blood) patients.

5 Compare the advantages and disadvantages of using embryonic stem cells or adult stem cells for the repair of damaged spinal tissue in a patient with quadriplegia.

6 Explain the advantage of using induced pluripotent cells for repairing damaged tissue.

Design and discuss

7 Read Case study 3.5A. Discuss how an induced pluripotent cell could express some 'cancer-like' properties.

8 Consider the ethical reasons for using embryonic stem cells to treat adult diseases and disabilities.

9 If you had a choice, would you use scientific funding to research the regenerative properties of axolotls and help discover more effective ways of combating cancer or would you use the funding to help with conservation efforts to save the wild populations of axolotl in Mexico City?

10 Scientists have recently added a gene to skin cells that allows the cells to be induced into embryonic stem cells. The scientists then grew the cells for 10 days into a blastocyst (the start of an embryo). Discuss the ethical considerations that this process raises (i.e. just because we can, should we?).

CHAPTER 3

Review

Chapter summary

3.1
- All cells come from pre-existing cells through the cell cycle.
- Prokaryotic cells reproduce through binary fission.

3.2
- Eukaryotic cells reproduce by mitosis and cytokinesis.
- Interphase has three phases – G1 (normal cell growth and function), S (DNA synthesis) and G2 (rapid cell growth and protein synthesis).
- Mitosis has four subphases – prophase, metaphase, anaphase and telophase.
- Cytokinesis is the division of the cytoplasm to form two genetically identical daughter cells.

3.3
- Apoptosis is a natural, regulated process of programmed cell death.
- Internal or external signals can lead a cell to apoptose.

3.4
- The action of mutagens or a genetic predisposition can disrupt the cell cycle.
- Disruptions of the cell cycle can result in uncontrolled cell division such as cancer.
- Malfunctions in apoptosis may result in deviant cells and complications such as cancer.

3.5
- Stem cells are specialised cells that can differentiate into more than one type of cell.
- There are two types of stem cells: embryonic and adult stem cells.
- Stem cells can be described as totipotent, pluripotent, multipotent or unipotent.
- There are bioethical concepts to consider when using embryonic stem cells.

Revision questions

Multiple choice

1 Identify which of the following describes binary fission.
- **A** One cell splits into two similar cells.
- **B** One cell splits into many genetically identical cells.
- **C** Two cells split into many similar cells.
- **D** One cell splits into two genetically identical cells.

2 Identify which of the following does *not* occur in a cell undergoing binary fission.
- **A** Duplication of the DNA
- **B** Formation of pairs of chromosomes
- **C** Pinching in of the cell membrane
- **D** Production of two genetically identical daughter cells

3 A chromosome in a prokaryote is a:
- **A** series of linear segments of DNA
- **B** small section of DNA called a plasmid
- **C** single circular section of DNA
- **D** length of protein involved in replication.

4 In which phase does a cell spend most of its time?
- **A** Interphase
- **B** Prophase
- **C** Metaphase
- **D** Cytokinesis

5 Apoptosis cannot kill which of the following?
- **A** Cells infected with viruses
- **B** Cells with DNA damage
- **C** Cancer cells
- **D** Immune cells

6 Name the phase of mitosis shown at A in Figure 1.
- **A** Interphase
- **B** Prophase
- **C** Metaphase
- **D** Anaphase

FIGURE 1 A phase of mitosis

7 During cytokinesis in a plant cell:
- **A** the membrane pinches at the middle of the cell
- **B** the chromosomes divide at the centromere
- **C** a new membrane and cell wall form at the cell plate
- **D** the DNA condenses into chromosomes.

8 Identify which of the following is involved in the apoptosis pathway in response to mitochondrial damage.
- **A** Death receptor
- **B** Cytochrome c
- **C** Tumor necrosis factor-α
- **D** Protein p53

9 Sunburn is skin damage caused by overexposure to ultraviolet light. This is an example of a:
   A chemical mutation
   B genetic risk factor
   C radiation mutagen
   D biological mutagen.

10 Stem cells with higher levels of potency can produce more cell types than cells with lower potency. Which of the following has the highest cell potency?
   A Multipotent stem cells
   B Totipotent stem cells
   C Unipotent stem cells
   D Pluripotent stem cells

Short answer

Describe and explain

11 Describe the process of binary fission in prokaryotic cells.

12 Define:
   a centromere
   b chromosome
   c chromatid
   d chromatin.

13 Describe the three subphases involved in the interphase stage of the cell cycle.

14 Define:
   a mitosis
   b cytokinesis.

15 Describe the six requirements for a cell to be characterised as cancerous.

16 Describe the subphases involved in mitosis and cytokinesis.

17 Explain why mitosis and cytokinesis are important for eukaryotic organisms.

18 Explain how the structure and function of DNA are checked during the cell cycle.

19 Outline the process of apoptosis.

20 Explain how stem cells are able to 'specialise'.

Apply, analyse and compare

21 Compare the duration of interphase and mitosis in the cell cycle.

22 Cigarettes are described as containing 'chemical mutagens'. Explain what is meant by this term and how chemical mutagens can disrupt the cell cycle.

FIGURE 2 Cigarette smoke contains many chemical mutagens.

23 A cell that is undergoing mitosis must first replicate its DNA. Suggest why this needs to occur.

24 If 10 bacterial cells landed on food, calculate how many bacterial cells there would be after 2 hours at room temperature. Assume each cell doubles every 20 minutes.

25 Explain the difference between an adult stem cell and an embryonic stem cell.

26 Compare cytokinesis in plant cells and animal cells.

27 Protein p53 is involved in regulating the cell cycle. If DNA is damaged, the p53 protein prevents the cell from undergoing mitosis. Instead, the p53 protein causes the cell to undergo apoptosis.
   Consider how an inability to produce tumour protein p53 increases the chances of a person developing cancer.

28 Compare intrinsic and extrinsic pathways to apoptosis. Identify an example of each.

29 Compare pluripotency and totipotency in stem cells.

Design and discuss

30 The alternative to apoptosis is the cell breaking open and spilling its contents over surrounding cells. Suggest why an organised cell death is preferable in a multicellular organism.

31 If two members of a family who smoke develop lung cancer, does this mean their children are at a higher risk of developing cancer? Provide evidence to support your answer.

32 Many overseas trials offer stem cell transplants to treat patients. One potential treatment for heart disease involves injecting the patient's own bone marrow into the damaged site. Suggest why this treatment would have limited success.

FIGURE 3 A surgeon performing a stem cell transplant

33 In Australia, the only stem cell treatment that is approved by health officials is haematopoietic stem cell transplantation (using stem cells from umbilical cord blood or bone marrow). This can be used to treat blood or immune disorders such as leukaemia.

There are other stem cell treatments, but these are considered 'unproven' in Australia. Unproven treatments have not been approved by health officials because they may pose risks to health, including infection, allergic reactions, or even the development of cancer.

a Explain why it would be important for stem cell treatments to go through an approval process by health officials.

b Discuss the ethical implications of approving some stem cell treatments and not others.

Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to link the cause and effect of a situation. This means you will need to identify the starting point, describe what causes the change, describe what changes and identify the final effect.

'Cause and effect' questions

One of the most common reasons for losing marks in these questions is not linking changes to the final effect.

One way to make sure that you link the cause to the effect is to write down the starting point and the finishing point with one or two lines between them. Once you have identified the cause and the effect, you can write a statement that links them together.

Cause: _____

Therefore: _____

Effect: _____

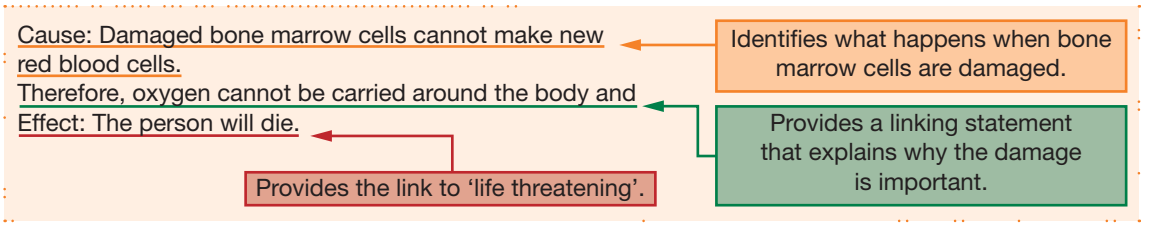
QUESTION 8a (2009 Biology Written Examination 1)

Cancer is a disease characterised by the rapid multiplication of cells. It is often treated with the use of chemicals; however, damage may occur to non-cancer cells.

a Explain how damaging bone marrow cells could be life threatening. 2 marks

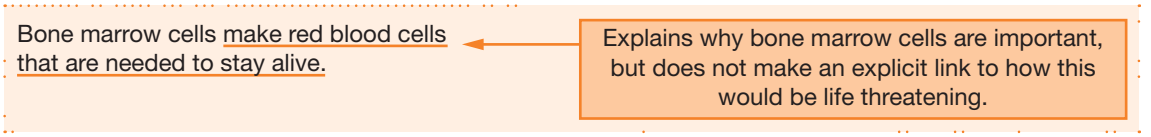
Source: 2009 Biology Written Examination 1, Question 8a, Short answer, reproduced by permission © VCAA

Response 1



This response would receive full marks because it identifies both the cause and the effect.

Response 2



This answer would only receive 1 mark because it does not say why red blood cells are important to keeping someone alive.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 4b (2012 Biology Written Examination)

e Briefly describe how the process of binary fission varies from that of mitosis. 2 marks

Prokaryotes use binary fission to replicate.
Eukaryotes use mitosis to replicate.

Source: 2012 Biology Written Examination, Question 4b, Short answer, reproduced by permission © VCAA

Marking guide

4e	1 mark for listing features of binary fission that are different from mitosis (two of the following). • The chromosome does not line up on the equator. • The chromosome does not separate at the centromere. • There are no spindle fibres. • There are no phases. • It is quicker.

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 an examiner.

Check your Student obook pro for the following digital resources and more:

Video
Cause and effect questions

Weblink
Past examinations and examiners' reports

CHAPTER 4

Biological systems

Vascular plants have specialised vascular tissue called xylem and phloem that enables the transport of water, minerals and organic substances around the plant. Vascular plants have two systems: the root and shoot systems. The two systems have different organs, tissues and specialised cells.

Multicellular organisms have specialised cells that carry out particular functions. As multicellular organisms get more complex, there is an increasing differentiation of cell types within the organism. This allows for the arrangement of tissues, organs and complex systems.

Mammals have the most complex systems of all multicellular organisms. The mammalian systems studied in this chapter include the digestive, endocrine and excretory systems. Each body system has different specialised cells, tissues and organs that are necessary for it to function.

KEY KNOWLEDGE

→ specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water

→ specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

FIGURE 1 A microscopic cross-section of the small intestine. The small intestine is a key organ in the human digestive system, which digests food from the stomach. Cells form tissue that combines to form the small intestine.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

4A Identify what all living things need to survive.

4A Groundwork resource
Requirements of life

4B Describe how cells transport water across the plasma membrane.

4B Groundwork resource
Osmosis

PRACTICALS

PRACTICAL	**4.2** Specialised cells, tissues, organs and systems

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your Student obook pro.

4.1 Organisation and specialisation of vascular plants

KEY IDEAS

In this topic, you will learn that:

- vascular plants have specialised cells, tissues, organs and systems for specific functions
- xylem is a type of vascular tissue needed for transpiration – the transport of water and mineral ions
- phloem is a type of vascular tissue needed for translocation – the transport of sugars.

vascular plant
a plant with vascular tissues (xylem and phloem)

Vascular plants are a large group of land plants, also known as tracheophytes. Like other multicellular organisms, they have systems made up of organs, tissues and specialised cells. All plants are autotrophs, which means they can produce their own chemical energy by photosynthesis. Photosynthesis occurs in the leaves of vascular plants and requires water, carbon dioxide and sunlight. Water is absorbed through the roots and moves against gravity through a type of vascular tissue called xylem (Figure 1) to get to the leaves. Carbon dioxide diffuses into the leaf via specialised structures called stomata. Photosynthesis produces sugars that need to be transported throughout the plant via a type of vascular tissue called phloem.

The structural difference between vascular plants and other plant types is the presence of vascular tissues as well as true roots, leaves and stems. Examples of vascular plants are flowering plants, conifers and ferns.

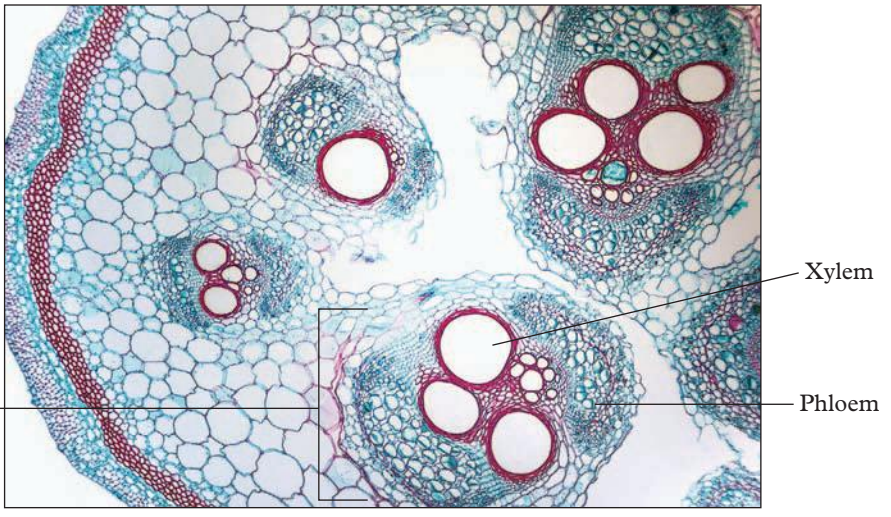


FIGURE 1 A cross-section of a stem of a pumpkin plant showing the vascular tissue

Organisation and specialisation of vascular plants

specialised cell
a cell that has certain structures and carries out particular functions

Cells are the structural and functional units that make up all living organisms. In multicellular organisms, **specialised cells** can be organised into tissues that form organs. Organs that function together to carry out an overall function are called a system.

Specialised plant cells include:

- root hair cells in plants – they have a large surface area to allow water absorption
- xylem and phloem cells, which enable the transport of water and organic substances through the plants.

Plant tissues

A **tissue** is a group of the same type of cells specialised to perform a specific function. In plants, these tissues include the:

tissue
a group of specialised cells functioning together for a particular purpose

- vascular tissue (xylem and phloem), which controls the flow of water and nutrients around a plant
- epidermal tissue, which covers the external parts of the plant
- parenchyma tissue in the leaves where photosynthesis occurs.

Plant organs

An **organ** is made of more than one tissue, forming a structural and functional unit. Plant organs are made up of more than one type of plant tissue. The different organs in a flowering plant are illustrated in Figure 2. Plant organs include:

organ
a group of tissues working together for a specific function

- roots for water and mineral absorption
- leaves, which are the main site of photosynthesis to produce organic substances for the plant and consist of different layers, as shown in Figure 3.
- stems, which transport water and mineral ions in the xylem, and organic substances in the phloem
- flowers, which are necessary for sexual reproduction in some plants
- fruits, which protect and disperse seeds.

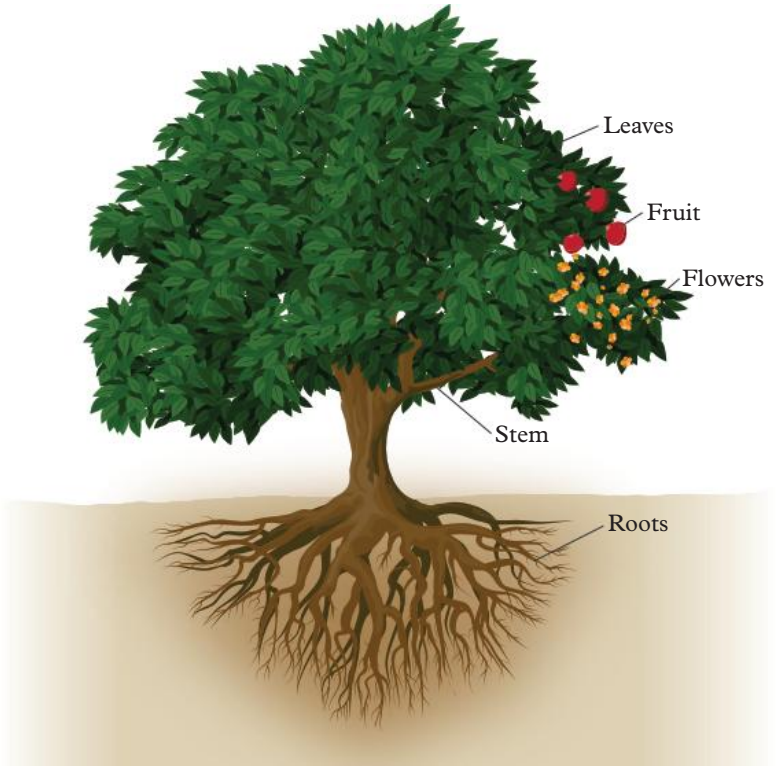


FIGURE 2 The different organs in a flowering plant

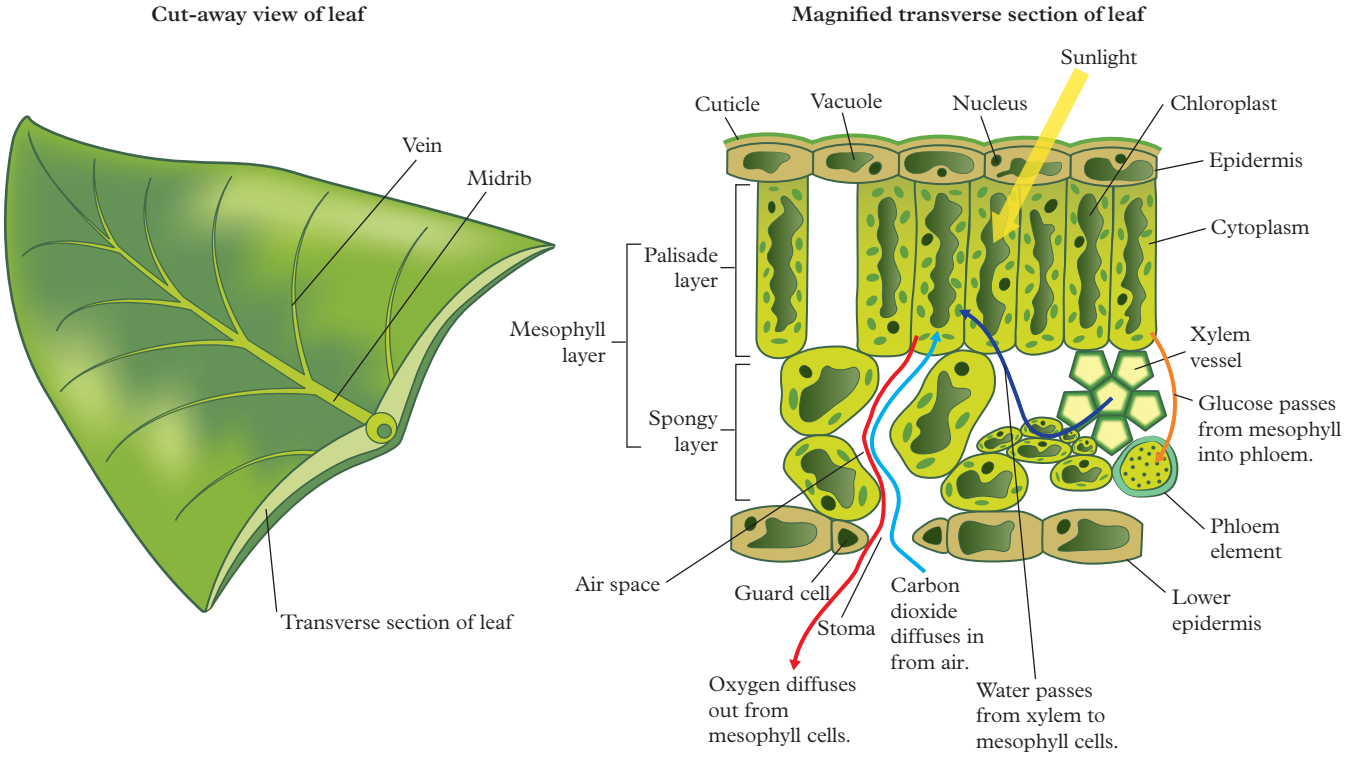


FIGURE 3 A transverse image of a leaf showing the different layers: cuticle, upper epidermis, mesophyll and lower epidermis. Leaves also have a lower cuticle.

Plant systems

system
a group of organs that function together for a particular purpose

shoot system
the plant system that develops above ground

root system
the plant system that develops below ground

A **system** is composed of different organs working together for one main function. There are two systems in plants: the shoot system and the root system. The **shoot system** consists of all the tissues above the ground, and the **root system** controls the function of the tissues mostly found below the ground (Figure 4). The shoot system is made up of a series of organs, including the leaf, shoots and reproductive flowers (in flowering plants). The root system is made up of the roots, tubers (storage organs) and rhizomes (modified underground stems).

Xylem function

xylem
the vascular tissue of plants that transports water and mineral ions

root hair
cells of the root that absorb water and minerals from the soil

The **xylem** transports water and dissolved mineral ions from the roots to the leaves in the process of transpiration.

Intake of water

Water is absorbed through **root hair** cells (Figure 5). The root hairs absorb water from the soil by osmosis. There is a higher ion concentration in the vascular tissue of land plants than in the soil. This creates a large concentration gradient, resulting in a large volume of water diffusing into the root hair cells along the concentration gradient. The root hairs have a large surface area to volume ratio, which increases the rate of water absorption.

Root hair cells also contain many mitochondria that produce energy so that they can also absorb mineral ions from the soil by active transport. This makes sure the concentration of ions in the plant cells is higher than in the soil, maintaining the concentration gradient so that water can diffuse into the root hair cells.

The water and mineral ions absorbed by the root hair cells are transported through the root and to the rest of the plant through the xylem.

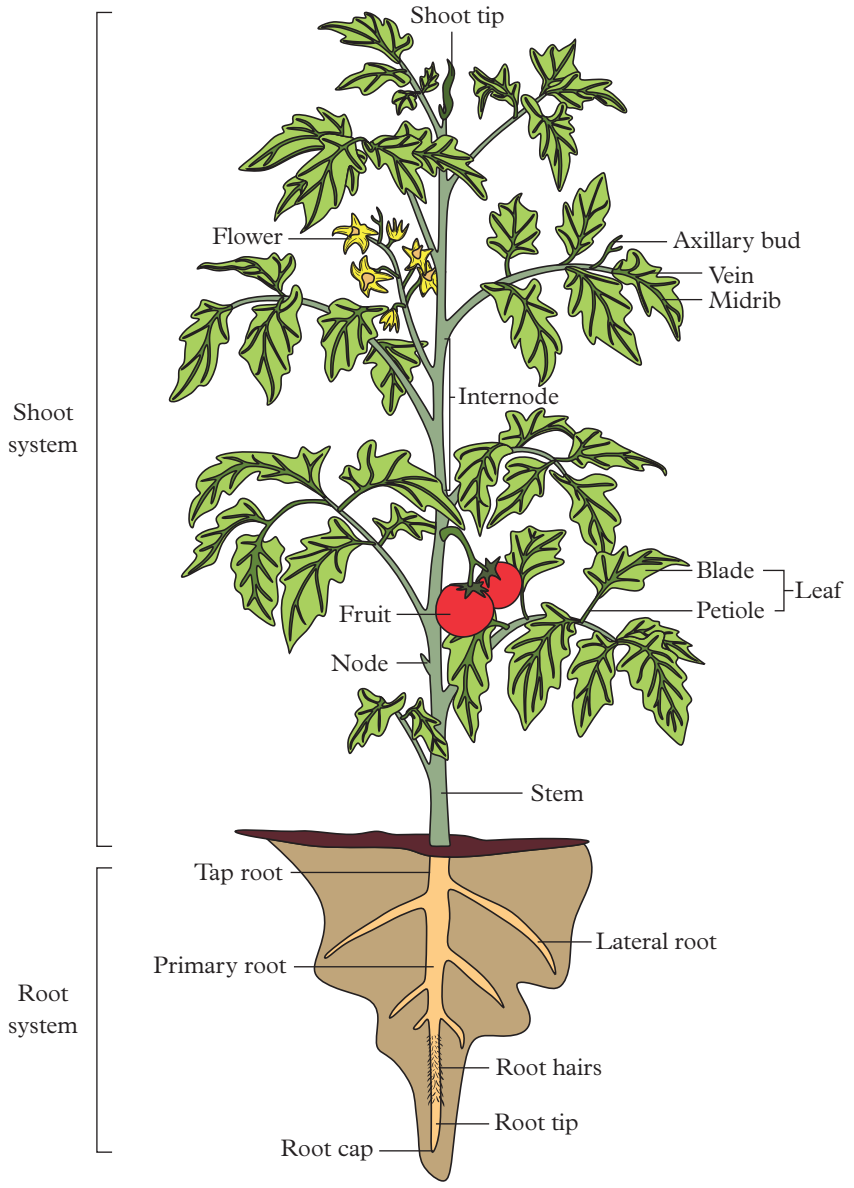


FIGURE 4 Plants have two systems: the root system is mostly below the ground and the shoot system is above the ground.

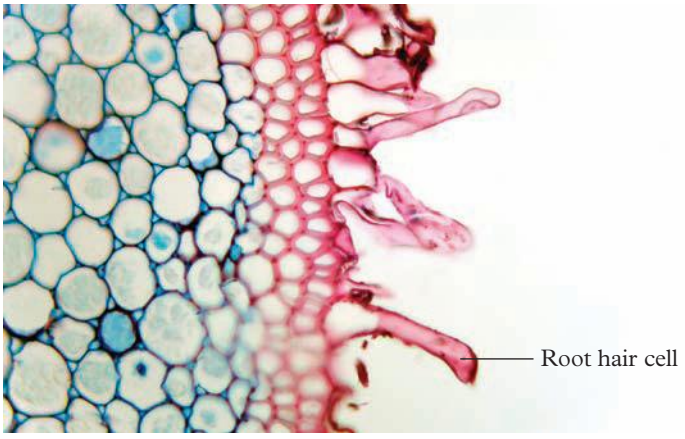


FIGURE 5 A microscope image of a plant root, showing the root hair cells with a large surface area to volume ratio

Movement of water through the plant

transpiration
the process of water movement through the xylem and evaporation at the leaves

The movement of water and dissolved minerals through the xylem of the plant and its evaporation at the leaves is known as **transpiration**. The water travels up through the plant, from the root to the leaves, against gravity. This passive (does not use energy) process relies on the cohesive (sticky) nature of water molecules. Water molecules have a strong tendency to stick together. So when water evaporates from the leaves, more water molecules in the xylem are pulled upwards to replace the water lost from those leaves. The constant loss of water through evaporation creates enough pressure in the xylem for the entire plant to constantly circulate water against gravity from the roots to the leaves.

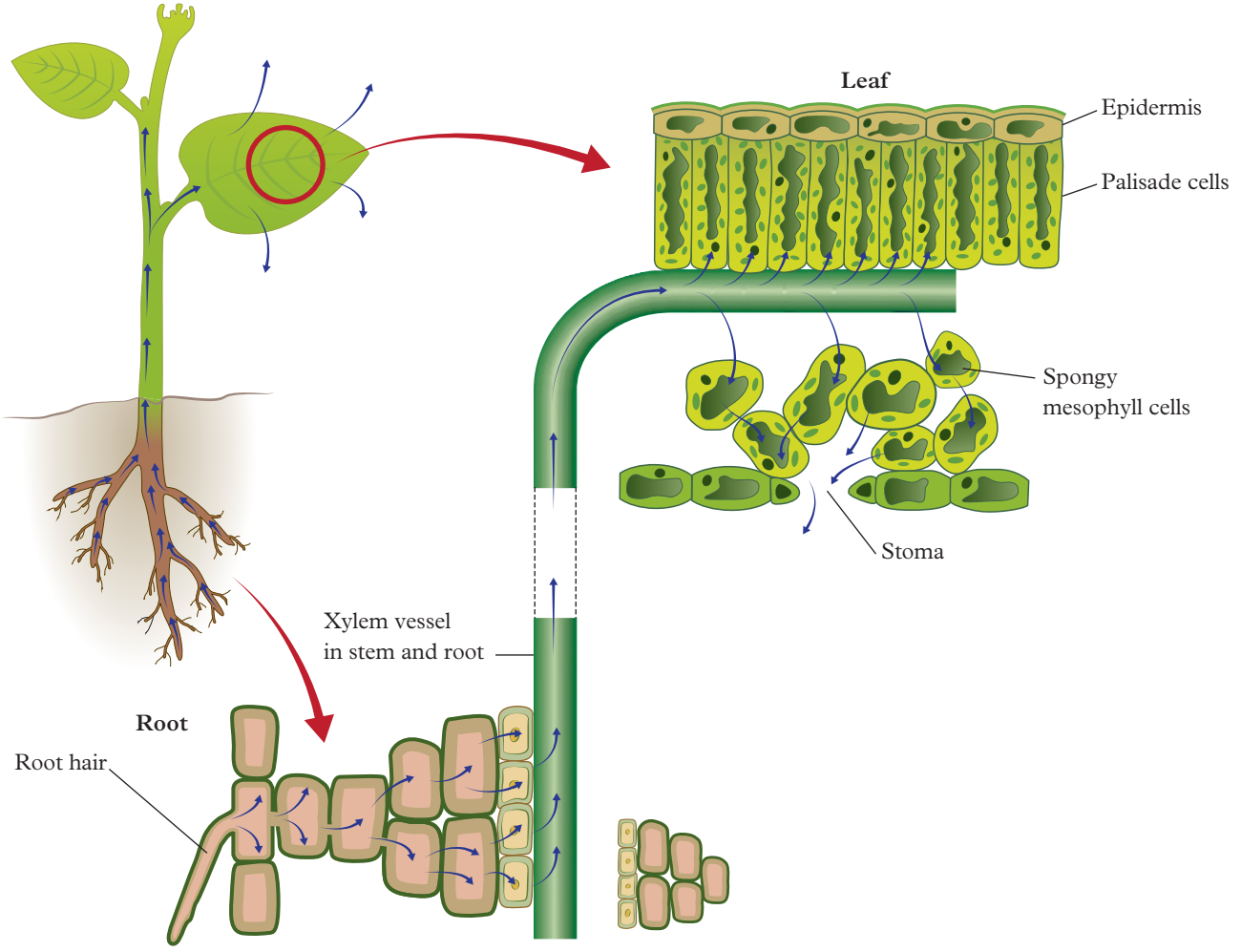


FIGURE 6 During transpiration, water moves upwards against gravity from the roots through the xylem tissue and evaporates from the stomata at the leaves.

Transpiration is essential for providing water for photosynthesis. It also helps cool the plant if it becomes overheated, helps the plant maintain turgor pressure so that it stays upright, can maximise its exposure to light for photosynthesis and allows the leaves and fruit to receive minerals from the soil. Transpiration is responsible for most of a plant's water loss.

The xylem tissue is composed of specialised cells called tracheary elements, which can hold water. There are two kinds of tracheary cells: tracheids and vessel members (Figure 7).

vessel member
a specialised cell of the xylem

- The **vessel members** are elongated cells that are joined together to form a long tube called a xylem vessel. These cells also have a thick (lignified) cell wall for strength.

When they mature, vessel members lose their nucleus and cytoplasm and are considered dead. There are perforations in the sides of these cells so that substances can move between neighbouring cells in the vascular bundle. Vessel member cells are only found in flowering plants.

- **Tracheids** are also non-living long, thin cells with thick (lignified) cell walls that provide structural support for the xylem. They are present in all vascular plants and are similar to vessel members except they have bordered pits instead of perforations and do not join together.

tracheid
a specialised cell of the xylem

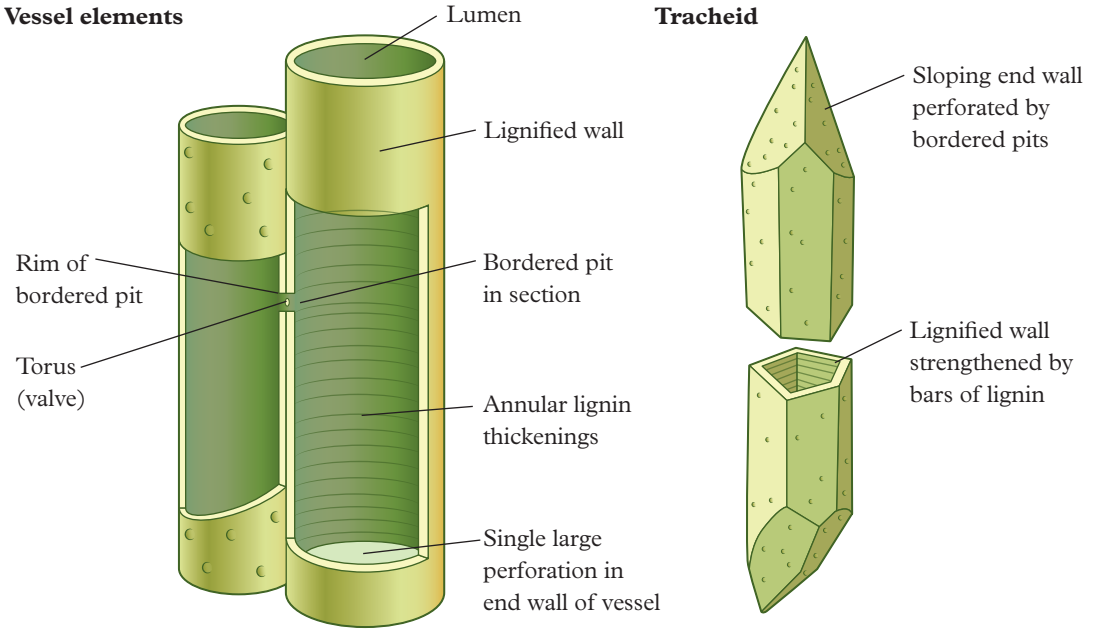


FIGURE 7 The water-carrying components of the xylem: vessel elements and tracheids

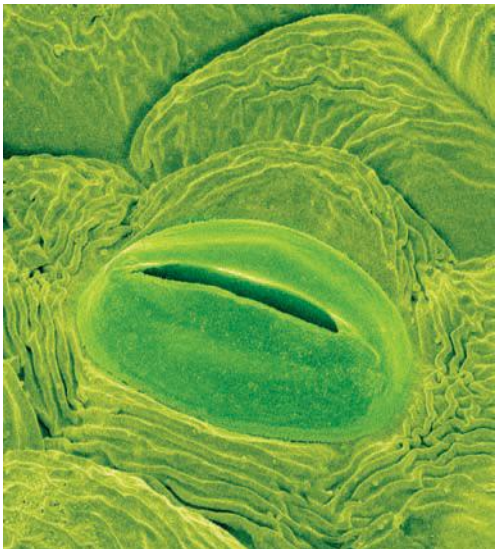


FIGURE 8 A close-up of a stoma and its guard cells

Loss of water at the leaves

Leaves have openings on their surfaces called stomata (singular: **stoma**), where carbon dioxide and oxygen diffuse in and out. Water can evaporate through stomata. There are two cells on either side of the stomata called **guard cells** (Figure 8).

The stoma is opened and closed by changes in the water content of the guard cells. When the guard cells are swollen and filled with water, as shown in Figure 9, they stretch and curve away from one another. When this occurs, the stoma opens. If the guard cells have little water, then they hold the stoma closed.

stoma
a small pore in the leaf of a plant, which allows gases to move in and out

guard cell
one of two cells surrounding a stoma in a leaf, which cause the stoma to open and close

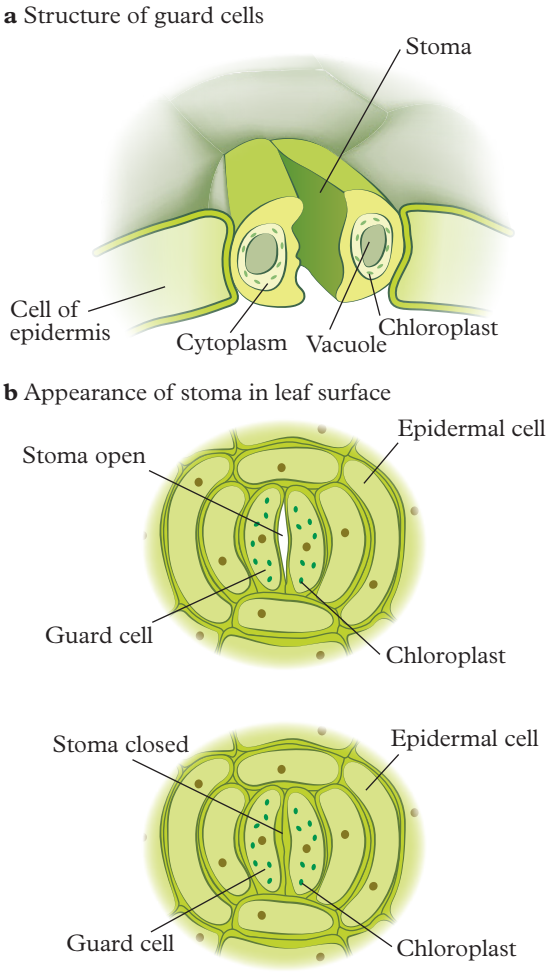


FIGURE 9 **a** Transverse view of a leaf, showing guard cells filled with water. **b** Top: The stoma is open when the guard cells are swollen and filled with water. Bottom: The stoma is closed when the guard cells have little water.

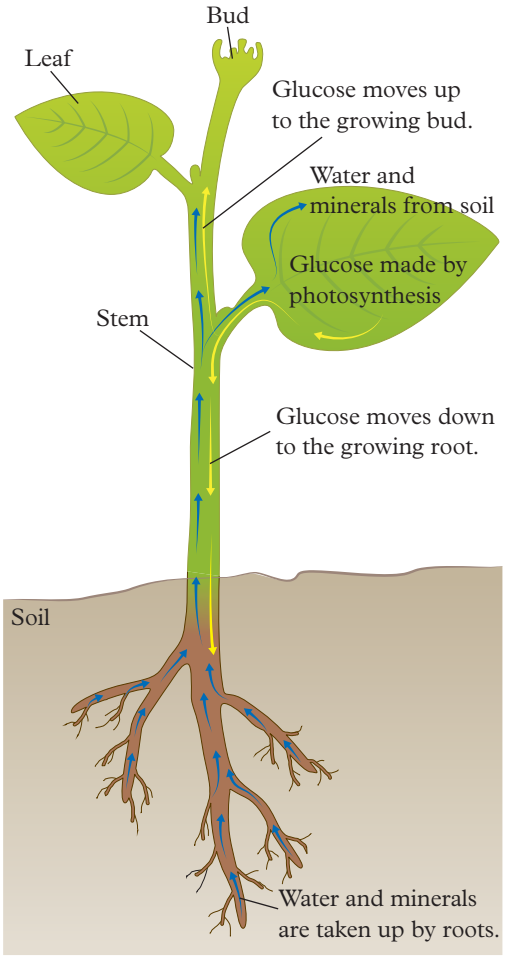


FIGURE 10 Organic molecules such as glucose can move in any direction in a plant through the phloem, unlike water, which moves upwards in the xylem.

Phloem function

phloem
the vascular tissue of plants that transports sugars (organic substances)

translocation
the process of sugar movement through the phloem

sieve tube element
a specialised cell of the phloem that helps in the translocation of sugars

The other type of vascular tissue is the **phloem**. The function of the phloem is to transport sugars (organic substances) from the leaves to other plant tissues in the process of **translocation**.

The leaf tissues produce organic substances by photosynthesis. Other plant tissues that don't photosynthesise also require organic substances. Sugars are transported from the leaves to other plant tissues through the phloem. The sugars are then broken down in the process of cellular respiration, which releases energy (ATP).

The fluid moving through the phloem tissue is called phloem sap. The sap has a high sugar content. Sugars produced in the leaves are pumped into companion cells that line the phloem tissue (Figure 11). From the companion cells, the sugars move into the **sieve tube elements**, which are one of the main specialised cells of the phloem tissue. In between the sieve tube elements are sieve plates, which prevent the backflow of the phloem sap.

Transport in each sieve tube element occurs in only one direction, but when sieve tube elements bundle together, they can transport the phloem sap in different directions (Figure 12).

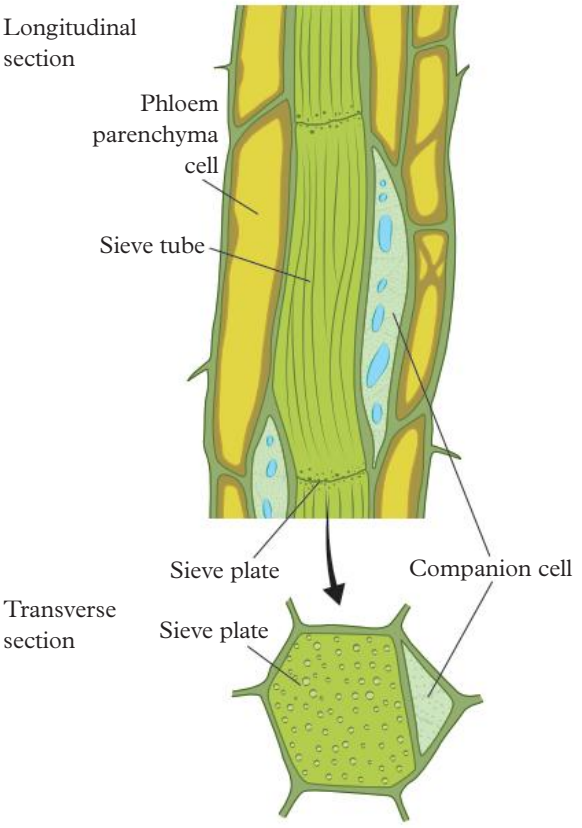


FIGURE 11 The different compartments of the phloem that transport organic molecules around a plant

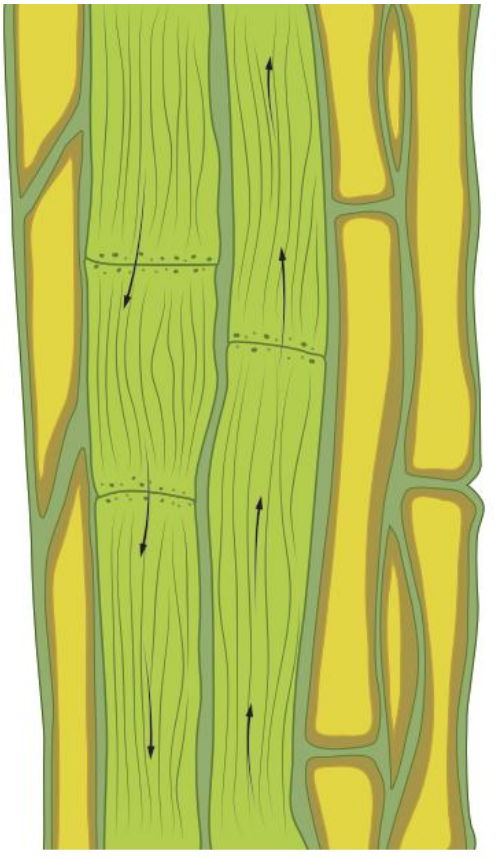


FIGURE 12 The phloem bundle can move sugars in both directions by the process of translocation.

CHECK YOUR LEARNING 4.1

Describe and explain

1. List the structural components of vascular plants.
2. Identify and describe the role of the different parts of the vascular system of plants.
3. Name the cells that control the evaporation of water from the leaves of plants.
4. Explain the transport of water and minerals from the soil into root hair cells.
5. Explain what is required for nutrients to move in both directions through sieve tube elements.
6. Define 'guard cell'.

Apply, analyse and compare

7. Use a comparison table to describe three differences between xylem and phloem tissue.
8. Apply your knowledge of surface area to volume ratio from Chapter 2 to explain why root hairs are important for plants.
9. Explain how water is able to travel upwards against gravity in a plant. Use the following terms in your response: roots, cohesive, evaporation, stomata.

Design and discuss

10. Discuss why transpiration is necessary for the survival of vascular plants.

4.2 Specialisation and organisation of animals

KEY IDEAS

In this topic, you will learn that:

+ complex multicellular organisms have levels of organisation from cells to tissues to organs to systems.

Cells are the structural and functional units that make up all living organisms. As you learnt in Chapter 2, cells can be either eukaryotic or prokaryotic. Prokaryotic cells are unicellular organisms (consisting of only one cell). These organisms need to produce energy and remove wastes in order to survive. Other organisms are composed of eukaryotic cells and can be multicellular.

The cells of all multicellular organisms need to extract nutrients from their environment, exchange respiratory gases and eliminate wastes. As multicellular organisms get bigger, their internal cells are further away from the surface where these exchanges take place. For this reason, cells in multicellular organisms become specialised to perform different functions. Specialised cells can be organised into tissues to form organs. When organs function together to carry out an overall function, this is known as a system.

Structural organisation of organisms

As multicellular organisms increase in complexity, there is an increasing differentiation of cell types within the organisms. This allows for the arrangement of tissues, organs and systems. Not every multicellular organism requires tissues, organs or systems.

In complex multicellular organisms, the following levels describe the organisation of cells in increasing order: specialised cells, tissues, organs and systems.

Specialised cells

Cells that have a certain function (specialised cells) can perform their specific role because of structural features that distinguish them from other cell types (Figure 1). For example, red blood cells are specialised cells with the role of carrying oxygen around the body. Red blood cells have the following structures to assist this role. They:

- contain haemoglobin, which carries oxygen
- have no nucleus, which enables them to carry oxygen and squeeze through capillaries
- are disc shaped so they have a large surface area to volume ratio, which allows for efficient gas exchange (oxygen and carbon dioxide).

Other specialised cells are:

- muscle cells, which are involved in the energy-requiring activities of movement
- cells that produce enzymes – they have a large number of mitochondria, rough and smooth endoplasmic reticulum and ribosomes. The enzymes are passed to the Golgi bodies and are modified and packaged for export from the cell or for use within the cell (e.g. as lysosomes).

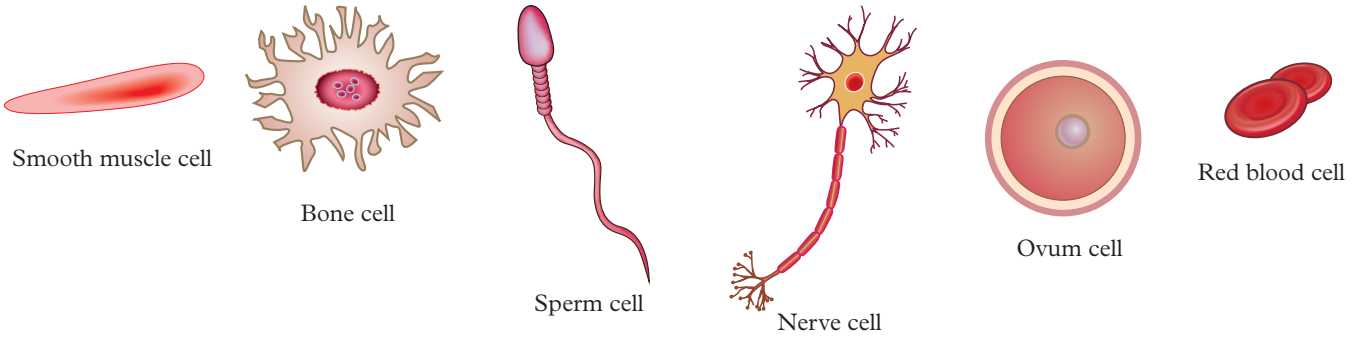


FIGURE 1 Cells in multicellular organisms are specialised for different functions.

Tissues

In complex multicellular organisms, cells are arranged in tissues (a group of the same type of specialised cells). In mammals, there are four main types of tissues.

- **Epithelial tissue** (or epithelium) covers the surface of an animal or organs; for example, the outer surface of organs, blood vessels, and the digestive and respiratory tracts. Most epithelial tissues are made up of many layers of closely packed cells that can rapidly divide to replace damaged or dead cells.
- **Connective tissue** mainly functions to support and connect tissues and organs to one another. This type of tissue also transports nutrients, wastes and chemical messengers around the body using blood and lymph or even bone. It can also store energy in the form of fat.
- **Muscle tissue** enables movement for an organism. There are three types of muscle tissue: skeletal, cardiac and smooth. Each type of muscle tissue is made of specialised cells with particular structures that allow different types of movement. In humans, skeletal muscles are located in the biceps (Figure 3), cardiac muscles are in the heart and smooth muscles are in hollow organs such as the intestines.
- **Nervous tissue** makes up the central and peripheral nervous systems. It functions by conducting nerve pulses in response to stimuli. Nervous tissue is located in the brain, spinal cord and nerves.

epithelial tissue
tissue made of tightly packed cells that lines surfaces

connective tissue
tissue that binds and supports other tissues or organs

muscle tissue
tissue that makes up muscles, which allow for movement

nervous tissue
tissue of the nervous system, which regulates and controls bodily functions

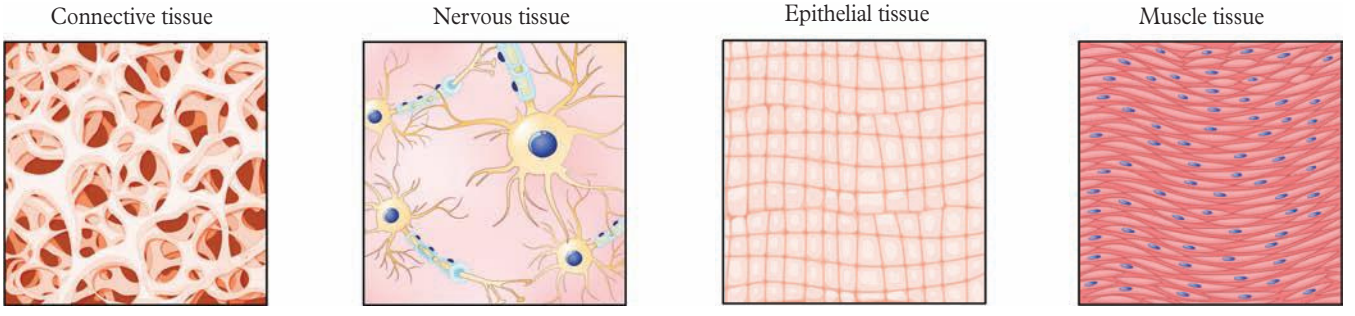


FIGURE 2 In multicellular organisms, cells are arranged as different types of tissues.

FIGURE 3 The muscles we use to lift weights and hold ourselves up only make up one-third of the muscle tissue in the human body. The remaining muscle works to pump blood through the body and digest nutrients.

Organs

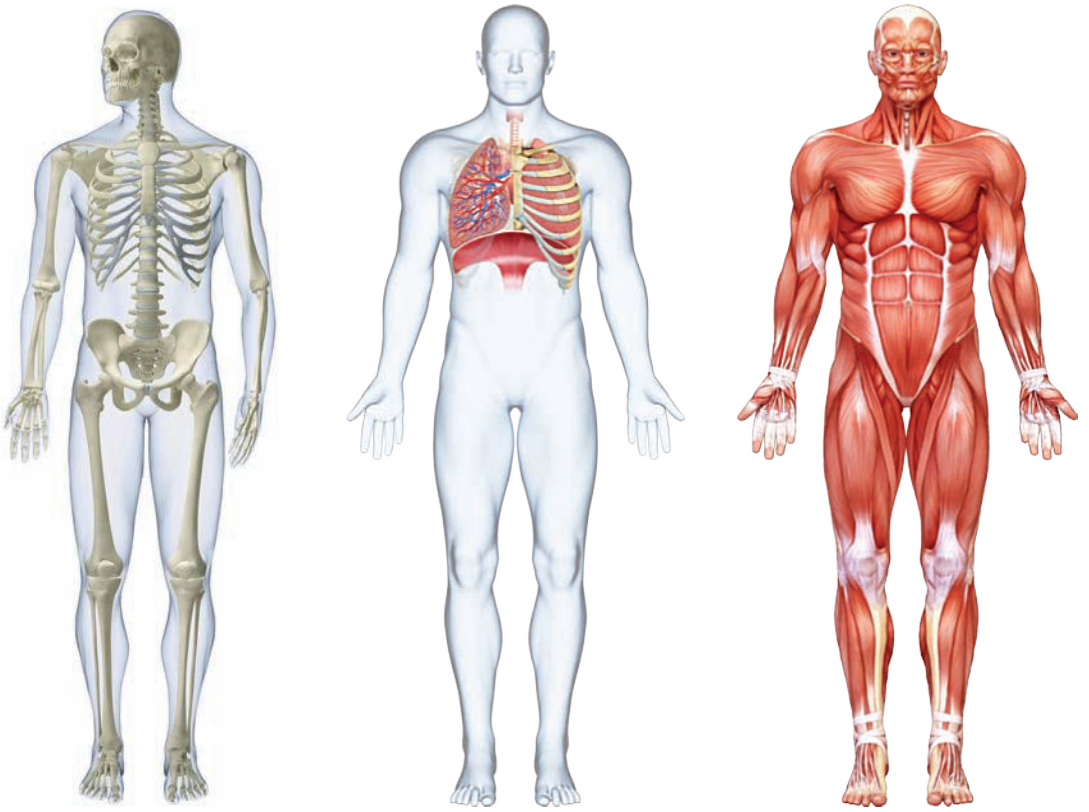
In animals, organs include the heart, stomach and liver. Since organs are made up of more than one tissue, they consist of several types of cells. For example, the human eye contains muscle cells to control the size of the pupil, clear epithelial cells of the lens and cornea to refract light, and nerve cells to send messages to the brain.

Systems

Systems (e.g. the excretory system) are coordinated so that they facilitate the supply of nutrients to, and production and removal of materials from, all cells of the organism.

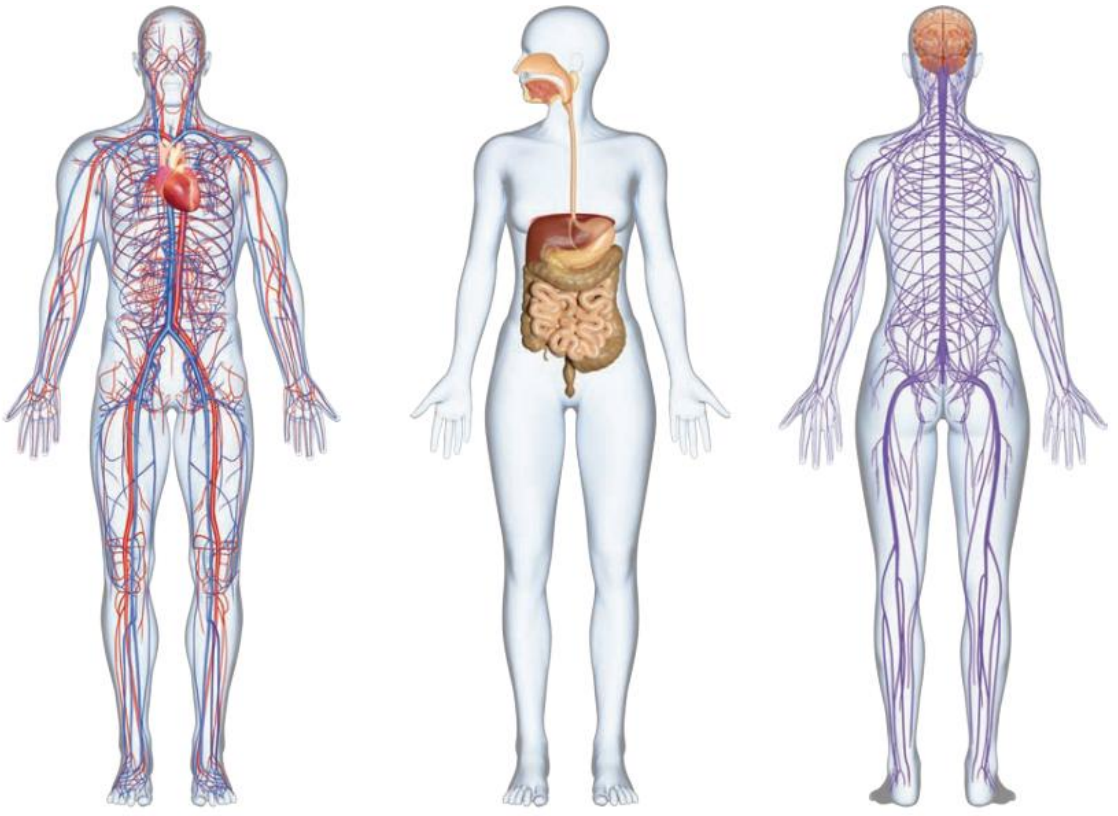
Mammalian body systems

Most vertebrates have similar body systems, although their precise structure and function can vary according to the environment in which they live. In mammals, these systems are more uniform. Although some systems are regarded as more important than others, almost every system is needed for survival. If one organ within a system is damaged or malfunctions, this can have large-scale consequences for other systems, which may result in the death of the organism. You will learn about three different human body systems (Figures 4 and 5) later in the chapter.



Skeletal system | Respiratory system | Muscular system

FIGURE 4 The skeletal, respiratory and muscular systems perform specific functions that work together to keep us alive.



Circulatory system | Digestive system | Nervous system

FIGURE 5 The circulatory, digestive and nervous systems are human body systems that perform specific functions but work together to keep us alive.

CHECK YOUR LEARNING 4.2

Describe and explain

1 Define 'specialised cell'.
2 Explain the structure of red blood cells that allows for their function of carrying oxygen around the body.
3 Describe where epithelial tissue is found.
4 Describe what is mean by the term 'system' in mammalian biology.

Apply, analyse and compare

5 Compare tissues and organs.
6 Explain why prokaryotic organisms (unicellular) do not require levels of organisation.

Design and discuss

7 Investigate the human heart and describe the types of tissues in this organ and their function.
8 Discuss why it is necessary for complex multicellular life to be organised into cells, tissue, organs and systems.
9 Examine the eye in Figure 6 and discuss how cell specialisation contributes to the structure and function of this organ and its different tissues.

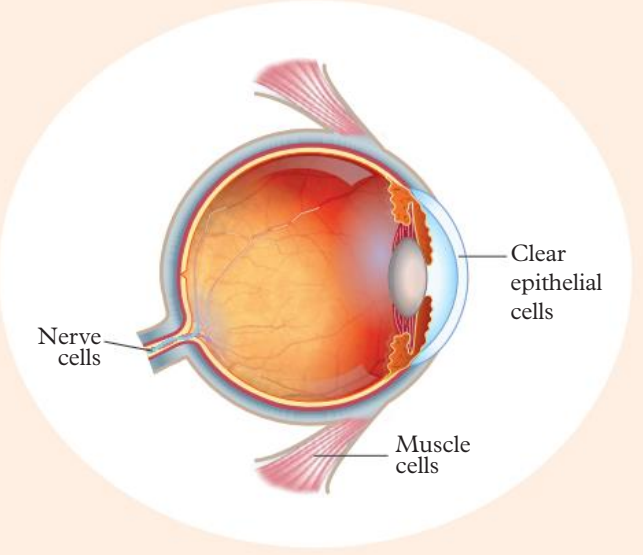


FIGURE 6 The human eye contains many different tissues and specialised cells.

4.3 Digestive system

KEY IDEAS

In this topic, you will learn that:

- the human digestive system is made up of an alimentary canal and associated organs that break down food physically and chemically
- the digestive system functions so the body can obtain the required nutrients and remove the rest from the body.

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 by an organism, because it cannot be synthesised

heterotroph
an organism that derives its nutrients from other living organisms

digestive system
the system in which ingested food is broken down, nutrients are absorbed and waste products are egested

All living organisms need to absorb different substances into their cells for maintenance, growth, repair and reproduction. A **nutrient** is any substance used as food by an organism. **Non-essential nutrients** are those that can be produced by the organism. **Essential nutrients** are those that cannot be produced by the organism and must be eaten or ingested.

Unlike plants, mammals are **heterotrophs**. This means mammals cannot make the organic compounds or nutrients they need to survive, but instead need to source them from other organisms by eating them. For example, humans feed on large chunks of solid organic material that comes from plants and animals. So humans 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
- eliminate undigested food.

This is achieved by the **digestive system** (Figure 1).

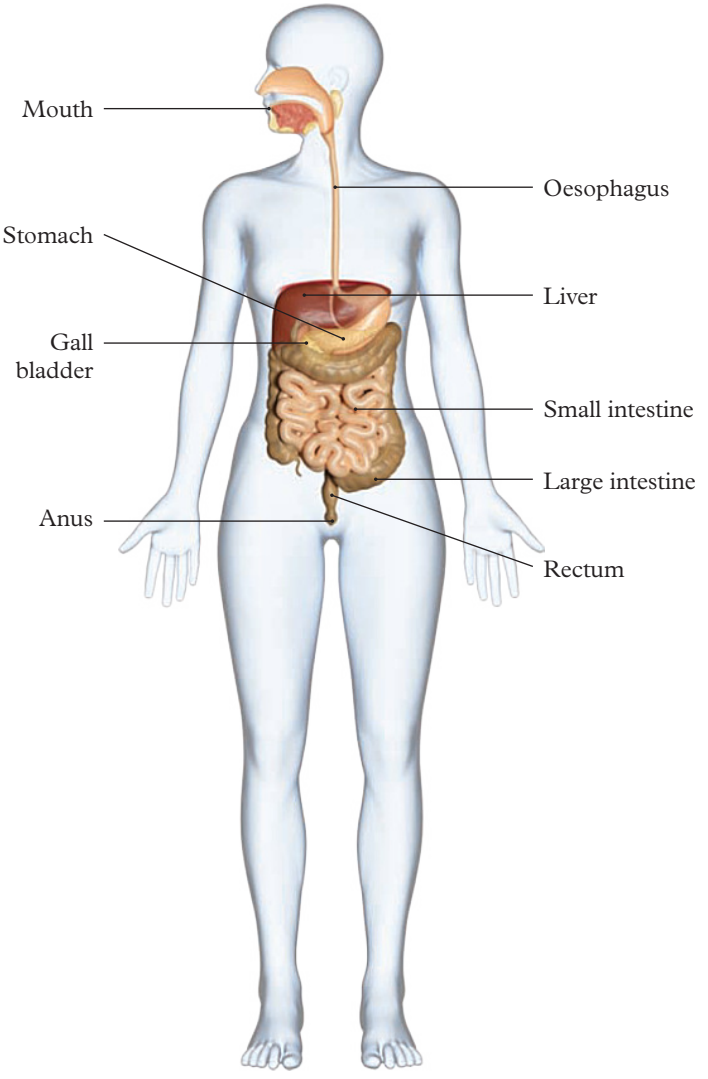


FIGURE 1 The components of the human digestive system

Structure of the human digestive system

As you have learnt in Topic 4.2, systems are composed of associated organs, organs are composed of different tissues and tissues are composed of cells. The digestive system is one of many human body systems. This system consists of an **alimentary canal**, also known as the digestive tract, and associated organs. Throughout the length of the alimentary canal, each part is specialised for a specific function.

alimentary canal the passage from mouth to anus in which food passes during digestion

The human digestive system consists of four basic layers.

- The outer layer is made of connective tissue and a thin supporting membrane tissue.
- Inside the connective tissue is a muscle layer, usually consisting of an outer layer and inner layer of smooth muscle cells. The muscles are not consciously controlled and are responsible for **peristalsis**. Peristalsis involves moving food in the alimentary canal by muscle contractions, as shown in Figure 2.
- The third layer contains the major blood and lymphatic vessels (both types of tissue), 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 epithelial tissue.

peristalsis the waves of contraction and relaxation in muscular walls of the alimentary canal, aiding in physical digestion and moving food forward through its length

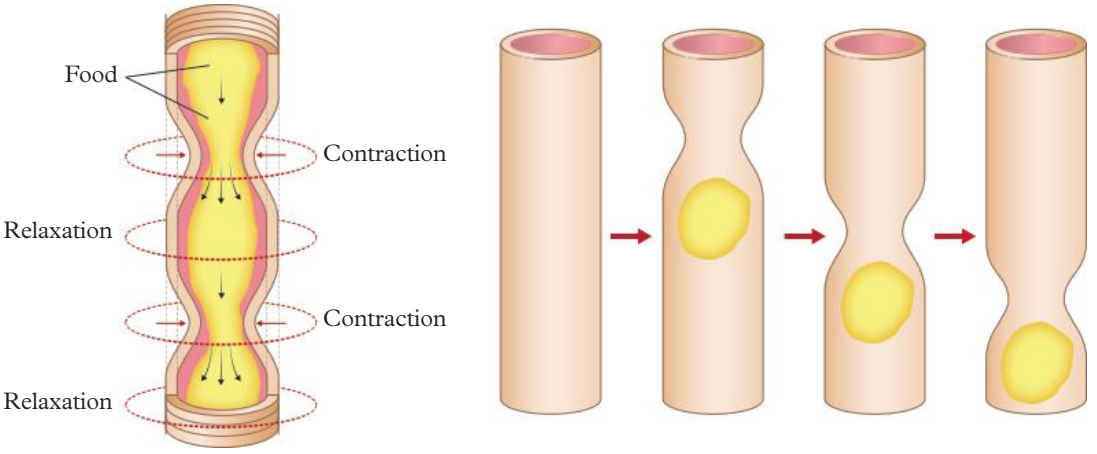


FIGURE 2 The process of peristalsis squashes and moves food through the alimentary canal.

Digestion

When we eat food, the food molecules are too large to be absorbed into the body straight away. Only very small molecules can cross the plasma membranes and enter cells lining the alimentary canal. There are two types of digestion: physical (or mechanical) and chemical. It is essential that physical digestion begins before chemical digestion can be effective.

Physical digestion

During **physical digestion**, large pieces of food are broken down into smaller pieces to increase the surface area to volume ratio. Chewing helps this process, but muscle movement in the alimentary canal does most of the work.

physical digestion the mechanical breakdown of food into small units

Chemical digestion

Organic molecules can be broken down by breaking the chemical bonds between their basic units (monomers). This is known as **chemical digestion**.

chemical digestion
the breakdown of complex molecules into subunits that are small enough to be absorbed

- Complex carbohydrates are broken down into monosaccharides (such as glucose).
- Proteins are broken down into amino acids.
- Lipids are broken down into subunits called fatty acids and glycerol.
- Nucleic acids are broken down into nucleotides.

A different enzyme assists the chemical digestion of each type of carbohydrate, protein, lipid or nucleic acid (Table 1).

Study tip

The term 'lipid' includes all fats and oils. Fats are solid at room temperature and oils are liquids at room temperature.

TABLE 1 Key enzymes involved in digestion and their function

Enzyme	Function
Amylase	Digests amylose in complex carbohydrates to the disaccharide (a double sugar made up of two monosaccharides joined) maltose (a simple sugar)
Carbohydrases	Digest disaccharides to monosaccharides (simple sugars)
Proteases	Digest proteins to polypeptide chains and amino acids
Lipases	Digest lipids to fatty acids and glycerol
Nucleases	Digest nucleic acids to nucleotides and then to pentose sugars, phosphate groups and organic bases

amylase
the general term for an enzyme that breaks down polysaccharides to disaccharides

carbohydrase
the general term for an enzyme that breaks down carbohydrate

protease
the general term for an enzyme involved in the breakdown of proteins

lipase
the general term for an enzyme that breaks down lipids

salivary glands
glands in the mouth that discharge saliva, which helps move food down the alimentary canal and starts chemically digesting the food

nuclease
the general term for an enzyme that breaks down nucleic acids

pH and chemical digestion

The digestive enzymes are affected by the level of acid (low pH) or base (high pH) present. Each enzyme has an optional pH at which it works best. If the system's pH is too low or too high, then the enzyme won't be able to catalyse the reaction. For this reason, different parts of the alimentary canal control the pH levels of their environment. The process of chemical digestion involves the following three steps:

- In the mouth, where the pH is about 7.5, chemical digestion of complex carbohydrates begins. The **salivary glands** secrete saliva, which contains mucus and the salivary amylase enzymes (Figure 3). The mucus moistens the food and the salivary amylase starts the digestion of starch to maltose.

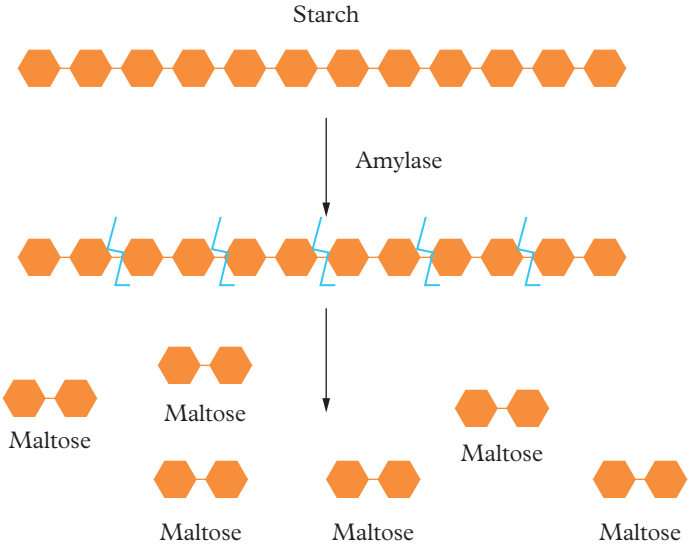


FIGURE 3 The chemical digestion of starch to maltose by the enzyme salivary amylase

Video
Digestion and enzymes

- Once the food reaches the **stomach**, **gastric juice** is secreted by glands in the stomach wall (Figure 4). This very acidic solution (pH 2) immediately stops the action of salivary amylase. In gastric juice, the **pepsin** enzymes breaks complex proteins into smaller polypeptide chains and dipeptides. Some glands in the stomach lining secrete mucus that protects the stomach wall from being digested. If this protective mucus is not produced in sufficient amounts, the stomach wall may become damaged by the acid and ulcers may form.
- In the first part of the **small intestine**, secretions from both the liver (via the **gall bladder**) and the **pancreas** are introduced. **Bile** (pH 7–8) is a liquid made in the liver and stored in the gall bladder. It contains mostly water, cholesterol, bile acids (also called bile salts) and bilirubin (a breakdown product or red blood cells). **Pancreatic juice** (pH 7–8.8) contains amylase, proteases, lipases and nucleases, which chemically digest complex carbohydrates, proteins, lipids and nucleic acids, respectively. The secretions from the liver and pancreas neutralise the stomach acid to provide optimal pH for the pancreatic enzymes to act in the small intestine.

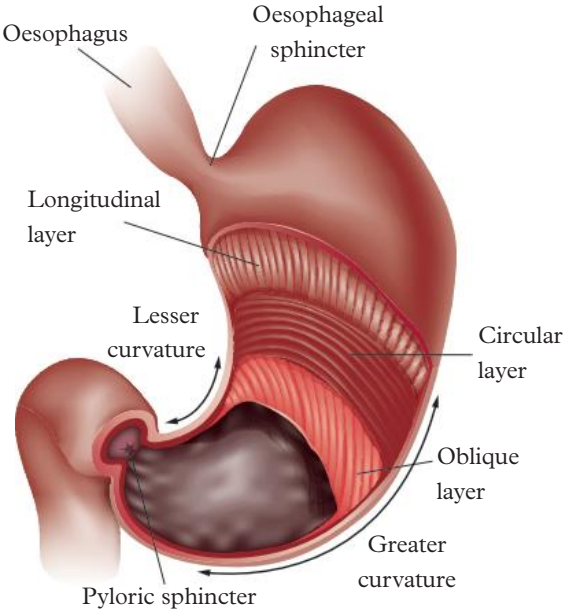


FIGURE 4 The structure of the stomach, where chemical digestion occurs

stomach
an organ of the digestive system that has a major role in the physical and chemical digestion of food

gastric juice
an acidic fluid secreted by glands in the stomach that aids in digestion

pepsin
a protease in the stomach that breaks down proteins into polypeptides

small intestine
the part of the alimentary canal between the stomach and the large intestine, mainly involved in absorption

gall bladder
an organ beneath the liver that stores bile and releases it into the intestine

pancreas
a gland behind the stomach that secretes digestive enzymes into the small intestine

bile
a fluid secreted by the liver, stored in the gall bladder and secreted in the stomach that is essential for digestion

pancreatic juice
a digestive fluid secreted by the pancreas into the small intestine

Absorption

Absorption of nutrients into the body involves different processes, such as osmosis, simple diffusion, facilitated diffusion and active transport. You learnt about the different types of transport across the plasma membrane in Chapter 2.

Most nutrients produced by digestion are small enough to pass through the membranes of specialised cells. Other molecules, such as glucose, are transported into a cell by facilitated diffusion, using specific receptor sites. Both of these are forms of passive transport.

Active transport is used when a substance is absorbed across the plasma membrane against a concentration gradient. In larger animals, these substances generally pass from the alimentary canal to a circulatory system, which transports them to the appropriate cells.

Small intestine

Most absorption of the small molecules produced during chemical digestion occurs in the very long, coiled, second part of the small intestine – the ileum. On the inner surface of the ileum are folds with small finger-like villi projecting from them. The folds help to slow the passage of food and the villi increase the surface area for digestion and absorption of the nutrients. The villi also move the contents around by circulating and swaying. The surface area is further increased by specialised cells called microvilli, which are hair-like extensions of the epithelial cells of the villi (Figure 5). Monosaccharides, nucleotides and amino acids are absorbed into the bloodstream by the villi.

Large intestine

large intestine
part of the alimentary canal that is found after the small intestine and functions to absorb water and move faeces to the anus for egestion

The main function of the **large intestine** is the absorption of water. About 7 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 called **faeces**. If the lining of the colon is irritated from an infection, then the faeces move through too quickly, and less water is reabsorbed into the body, resulting in diarrhoea. If the faeces pass through the colon too slowly, most of the water is absorbed. The result is a faecal blockage called constipation

faeces
a compacted, undigested food mass that is eliminated from the body

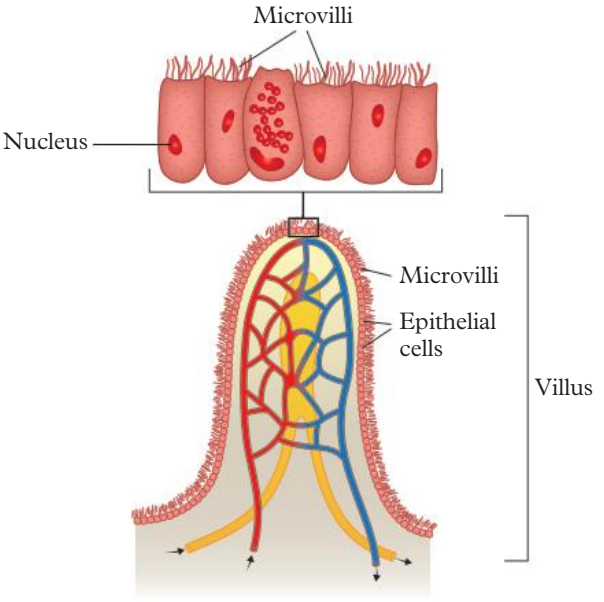


FIGURE 5 The structure of the villi on the inner surface of the second part of the small intestines increases the surface area for digestion and absorption of nutrients.

Elimination

Only the digested components of food will cross the epithelial lining to enter the bloodstream. Any undigested food is eliminated from the gut as faeces in the process of **egestion**. Egestion is the process of removing food that was never part of the organism. This is different from excretion, which is the removal of the waste products of cellular reactions. You will learn more about the excretory system in Topic 4.4.

egestion
the process of removing food that was never part of the organism

CASE STUDY 4.3

Alcoholic beverages

Ethanol is small molecule that is an active component of alcoholic drinks and can be absorbed by both the stomach and the small intestine. The process of absorption is increased if there is no food present, particularly fats and protein, which slow the absorption of the alcohol. Absorption increases if the alcohol is mixed with carbonated fluids because carbon dioxide stimulates movement of alcohol through the stomach into the intestines and then absorption into the bloodstream.

FIGURE 6 Alcohol consumption has a wide range of negative effects on the human body.

Ten per cent of alcohol is removed through urine, breath and sweat. The remaining 90% is processed through chemical digestion. The first stage of chemical digestion takes place in the liver, where alcohol is converted to acetaldehyde. The second and third stages occur in the liver and other organs. Acetaldehyde is converted into acetic acid and then into carbon dioxide, water and energy.

One of the effects of alcohol is depressing the brain. As the concentration of the alcohol rises from 0.05 to 0.1% in the blood, centres of the brain that control judgement, self-criticism and inhibitions stop working properly. Anxiety decreases and the person may have a sense of well-being and excitement. As the concentration increases to 0.1–0.5%, depression of the brain causes the person to become less alert, have a hazy awareness of their surroundings, lose muscular coordination and become sleepy. Above 0.5%, the body becomes significantly impaired, with complications such as respiratory failure and shock from the resulting low blood pressure. At approximately 0.55%, a person can enter a coma and die.

People who suffer from alcoholism have an addiction to alcohol. The body can assume that alcohol is food. Once this happens, cells become so adapted to the alcohol that they cannot operate well without it. Continued drinking of alcohol leads to inflammation of the stomach lining and poor digestion of food. This can lead to nausea while eating and overall leads to a decrease in the body's supply of essential nutrients. Nerves, particularly in the legs, begin to degenerate and the individuals can experience pain and weakness in these areas. The liver starts to degenerate as cells start to change. This is collectively called cirrhosis and eventually leads to death.

CHECK YOUR LEARNING 4.3

Describe and explain

1 Explain the difference between essential and non-essential nutrients.
2 List the components of the digestive system in order from entry of food to excretion of faeces.
3 Identify two tissues that are essential in the digestive system and describe their role.
4 Identify the type of tissue that connects the alimentary canal to the body wall.
5 Explain the role of the villi in the small intestine.

Apply, analyse and compare

6 Using the levels of organisation, identify the tissue, organ and system that begin with the specialised cell microvilli.

Cell: microvilli → tissue: _____ → organ: _____ → system: _____

7 Compare physical and chemical digestion.
8 Describe the features of the small intestine that enable it to function as the main site of absorption.

Design and discuss

9 Discuss why physical digestion is essential before chemical digestion can occur.

4.4 Excretory system

KEY IDEAS

In this topic, you will learn that:

- the excretory system removes waste from the body in the form of urea
- the human excretory system is made up of the kidneys, ureters, bladder and urethra.

All organisms produce wastes that need to be removed from the body. For example, carbon dioxide and water vapour are removed through the respiratory system; salts, urea and water are removed through the skin. In mammals, the **excretory system**, also known as the urinary system, includes a pair of kidneys that filter blood and remove wastes. Therefore, the excretory system is closely linked with the circulatory system. In mammals, these wastes leave the body mainly as **urine**, but also as sweat (Figure 1).

excretory system the system that removes wastes from the body

urine a fluid containing urea and other waste substances released from the kidneys, stored in the bladder and excreted via the urethra

Wastes form in the body during digestion. It is not healthy for the body to retain waste. After nutrients are absorbed into the body, the remaining indigestible solid matter, faeces, is egested through the colon.

FIGURE 1 Sweat is a feature of the excretory system.

Throughout the chemical digestion process, the body produces chemical waste. For example, during the digestion of proteins, bacteria in the intestines produce **ammonia** (NH_3) as a waste product. Ammonia is highly toxic and dissolves in water to form a corrosive base, which can directly damage animal cells. So, it must be removed from the body or converted to a less toxic compound, such as **urea**, to avoid cellular damage. Urea can be retained in the body for limited periods before removal. Mammals excrete urea in their urine.

ammonia a toxic waste produced by the body; NH_3

urea the main nitrogenous waste excreted in urine

Structure of the human excretory system

The organs for the urinary excretory system include the **kidneys**, **ureters**, **bladder** and **urethra**, as shown in Figure 2.

Structure and function of the human kidney

The kidneys are the primary organ of the excretory system. The kidneys remove excretory products from the blood plasma. The urine formed in the kidneys consists of waste materials dissolved in water. 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.

The kidneys are bean-shaped organs, as seen in Figure 3. Each kidney is enclosed by a capsule of connective tissue and consists of two layers of tissue: an outer, darker-coloured **renal cortex** and an inner, lighter-coloured **medulla** surrounding a central cavity. The two kidneys are located at either side of the spine in the abdominal cavity between the lowest rib and the top of the hip bone. They are connected to the circulatory system via the **renal arteries** (which carry the blood to the kidneys) and the **renal veins** (which return the 'cleaned' blood to the heart) and to the bladder via the ureters.

kidney an organ of the excretory system that filters blood and produces urine

ureter the duct that moves urine from the kidney to the bladder

bladder a membranous sac that stores urine from the kidneys

urethra the duct that moves urine out of the body from the bladder

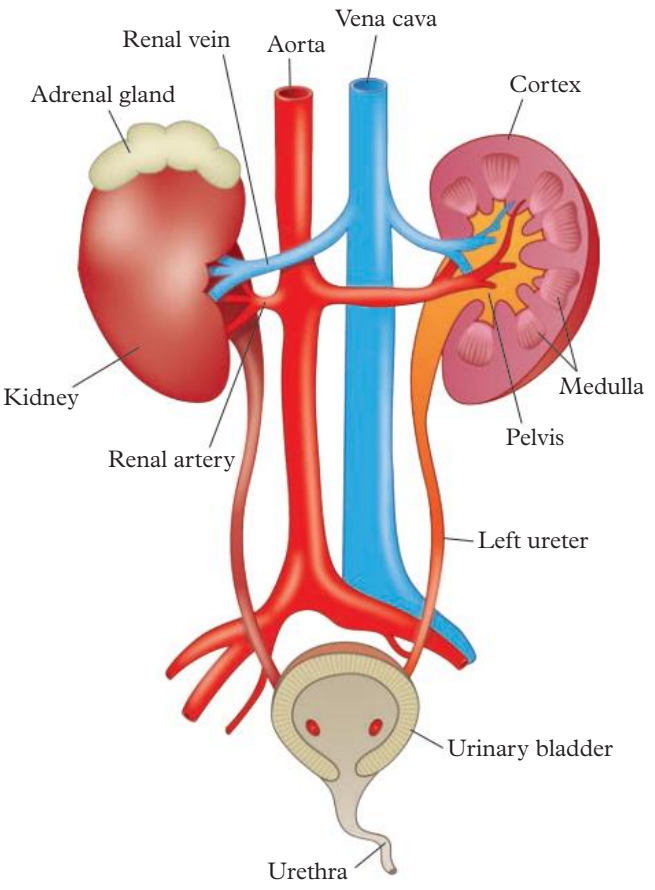


FIGURE 2 The human urinary excretory system

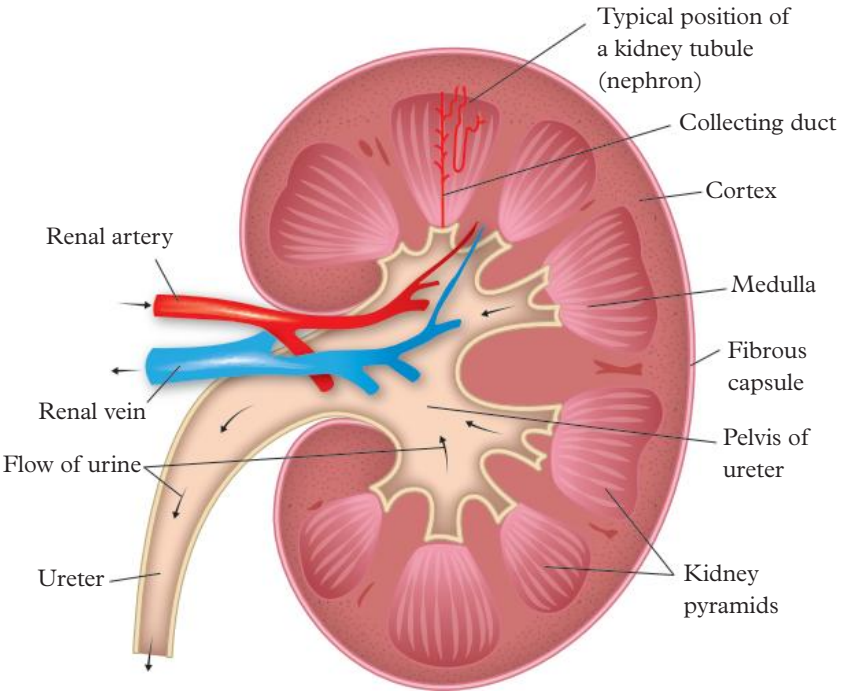


FIGURE 3 The internal structure of a kidney

Study tip

The kidney medulla is in the middle of the kidney. The cortex is just under the capsule of the kidney.

renal cortex
the outer part of the vertebrate kidney in which are found the Bowman's capsule, glomerulus and convoluted tubules of the nephron

medulla
the inner layer of the vertebrate kidney in which are found the loop of Henle and collecting tubules

renal artery
the blood vessel entering the kidney

renal vein
the blood vessel leaving the kidney

glomerulus
a capillary network in the Bowman's capsule where filtration occurs

Bowman's capsule
a cup-like sac at the beginning of the nephron that collects the filtrate from the capillary network (glomerulus)

collecting duct
the last part of the nephron that collects urine from many nephrons and moves the urine into the renal pelvis and ureters

proximal convoluted tubule
the part of the nephron between the Bowman's capsule and the loop of Henle that is involved in the process of reabsorption

loop of Henle
the part of the nephron in the medulla region of the kidney mainly involved in water and salt reabsorption

distal convoluted tubule
the part of the nephron between the loop of Henle and the collecting duct, which functions to concentrate the urine

Nephron

The nephron is the functional unit of the kidney. The nephron is made up of many cells and so is considered tissue. Each kidney contains between one million and two million nephrons embedded in loose connective tissue that are richly supplied with blood. Each nephron consists of an elongated tubule closely associated at one end with a group of blood capillaries (the **glomerulus**) via a cup-shaped **Bowman's capsule**. At the other end it opens into a **collecting duct**. Many nephrons open into one collecting duct, which then drains as urine out through the ureter (Figure 4).

The nephron tubule has distinct portions. The Bowman's capsule, wrapping around the glomerulus, opens into the **proximal convoluted tubule**, which is highly coiled. This leads to the U-shaped **loop of Henle** and on to the coiled **distal convoluted tubule**, which opens into the collecting duct.

The rest of the nephron is contained within the cortex of the kidney. Blood enters the capillaries of the glomerulus from a branch of the renal artery. It leaves in an arteriole that leads into a capillary bed surrounding the nephron tubules. This way, blood passing through the renal tissues passes through two sets of capillaries before leaving the kidney.

The three main functions of the nephron are:

- filtration of the blood
- reabsorption of required molecules and water
- secretion of unwanted waste molecules.

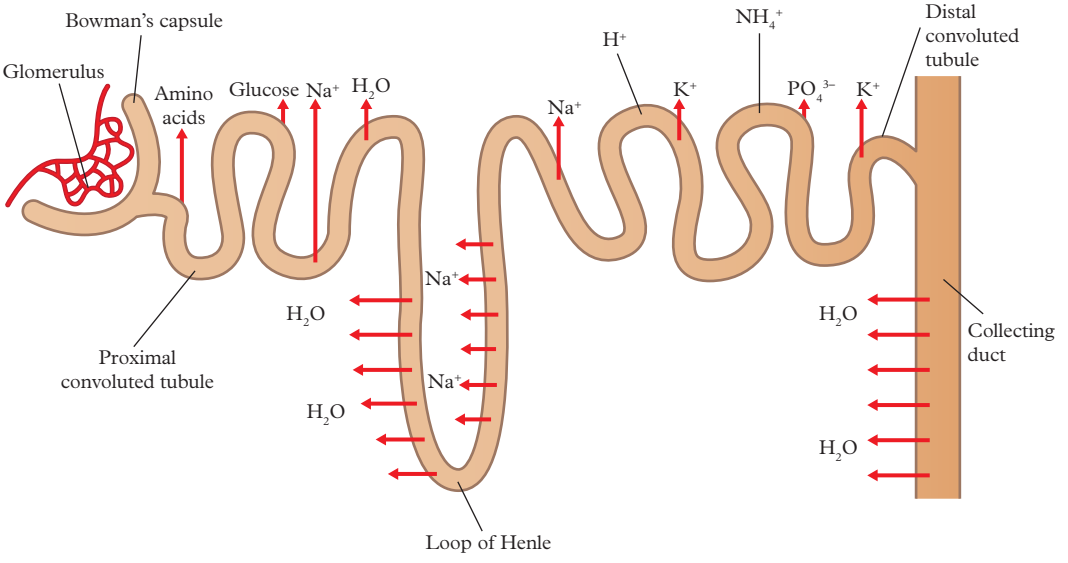


FIGURE 4 Reabsorption and secretion in the nephron

filtration
the first stage of urine production that produces filtrate in the Bowman's capsule

filtrate
the fluid filtered from the blood passing through the nephron

Filtration

Filtration is the first step of urine formation. Blood enters the glomerulus in the Bowman's capsule under high pressure. Water, ions and small molecules such as glucose, amino acids and urea are forced from the capillary into the Bowman's capsule. This fluid in the nephron is now called **filtrate** and has a similar composition to that of plasma, but without the larger protein molecules. Blood cells normally do not leave the blood vessels because they are too large to cross the capillary wall. The filtrate then moves through the nephron.

Reabsorption

As the filtrate leaves the Bowman's capsule, it passes into the proximal convoluted tubule where many of the useful substances are reabsorbed into the surrounding capillaries. This process is called **reabsorption**. Glucose and amino acids are absorbed by active transport against the concentration gradient. The surface of the specialised tubule cells is covered in many microvilli, which increases surface area for absorption, and are heavily loaded with mitochondria for energy production.

Salts such as sodium chloride are also absorbed by active transport in the proximal tubule. This produces an osmotic gradient along the nephron.

Water is then reabsorbed from the filtrate in the loop of Henle by osmosis, following the osmotic gradient generated by the reabsorption of salt. The walls of the descending loop are permeable to water, but impermeable to sodium ions, chloride ions and urea. The walls of the ascending loop are impermeable to water and urea, but actively pump sodium ions into the surrounding kidney tissue. When sodium ions actively move into the tissue, chloride ions follow passively because of the ionic gradient. This means the filtrate that travels down the descending loop of Henle is surrounded by a highly concentrated tissue fluid. The concentration of filtrate increases towards the base of the loop. A large concentration gradient is maintained, enabling water to diffuse out of the descending limb. 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.

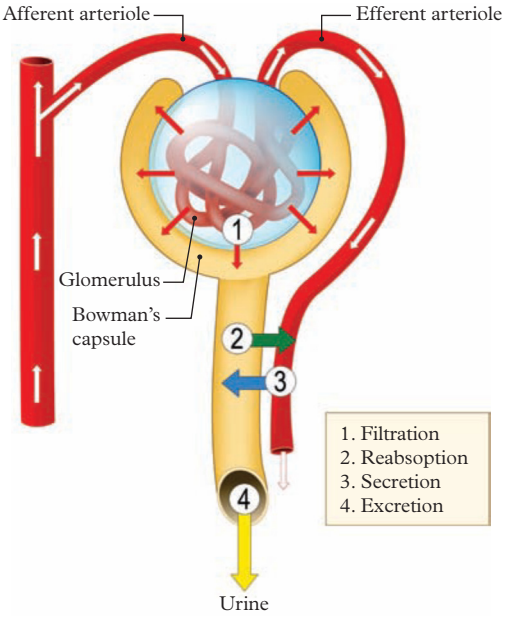


FIGURE 5 Urine formation involves filtration, reabsorption and secretion.

reabsorption
the second stage of urine production in which substances are reabsorbed from the filtrate into the surrounding capillary network

Secretion

Secretion involves the movement of waste products from the cells of the tubule walls into the filtrate. Ammonium (NH_4^+), potassium ions (K^+), hydrogen ions (H^+) and various dyes and drugs (such as penicillin) are actively secreted into the convoluted tubule alongside reabsorption. As these substances are added, the filtrate continues to become more concentrated as it passes through the nephron.

secretion
the final stage of urine production in which wastes are moved into the urine

The rate of excretion of urine from the collecting duct can be considered by the following equation:

Urinary excretion rate = filtration rate – reabsorption rate + secretion rate

Video
The nephron

CHECK YOUR LEARNING 4.4

Describe and explain

1 Identify the wastes that are removed by the excretory system.
2 Name the main components of the excretory system.
3 Describe the tissues that make up the kidneys.
4 Explain why the nephron is considered a tissue.

Apply, analyse and compare

5 Compare the functions of the ureter and urethra.
6 Explain how water is passively reabsorbed into the capillaries in the nephron.
7 Compare the functions of the loop of Henle and the villi.

Design and discuss

8 Research and describe how the excretory system interacts with the endocrine (hormonal) system.

4.5 Endocrine system

KEY IDEAS

In this topic, you will learn that:

- the endocrine system is made up of glands that produce and secrete hormones, which have various functions.

hormone
a chemical messenger that is released by endocrine glands and moves around the body in the bloodstream

endocrine system
a series of glands that secrete hormones that travel through the bloodstream to regulate body functions

nervous system
a complex network of nerves that transmit signals between the body and the brain and spinal cord to coordinate responses to stimuli

homeostasis
the regulation of an internal environment within a narrow range, despite changes to the external environment

stimulus
an internal or external change that causes a response

receptor
a structure that detects a stimulus

endocrine gland
an organ that produces and releases hormones directly into the bloodstream

target cell
a cell that responds to a hormone because it has specific receptors for that hormone

All large multicellular organisms need to pass messages between the cells and tissues so that they can keep functioning when the external environment changes. One way messages are passed on is through the chemical messengers called **hormones**. Hormones transfer information from one cell to another to regulate the body's growth, development, metabolism and a variety of other body functions. The **endocrine system** is a series of glands that produce and secrete hormones.

The endocrine and **nervous systems** work together in a coordinated fashion to maintain **homeostasis** (a stable internal environment). Homeostasis is important to regulate levels of nutrients, water, temperature and other factors in the body. **Stimuli** (singular: stimulus) are detected by the **receptors** of the endocrine and nervous systems and these body systems respond to maintain homeostasis.

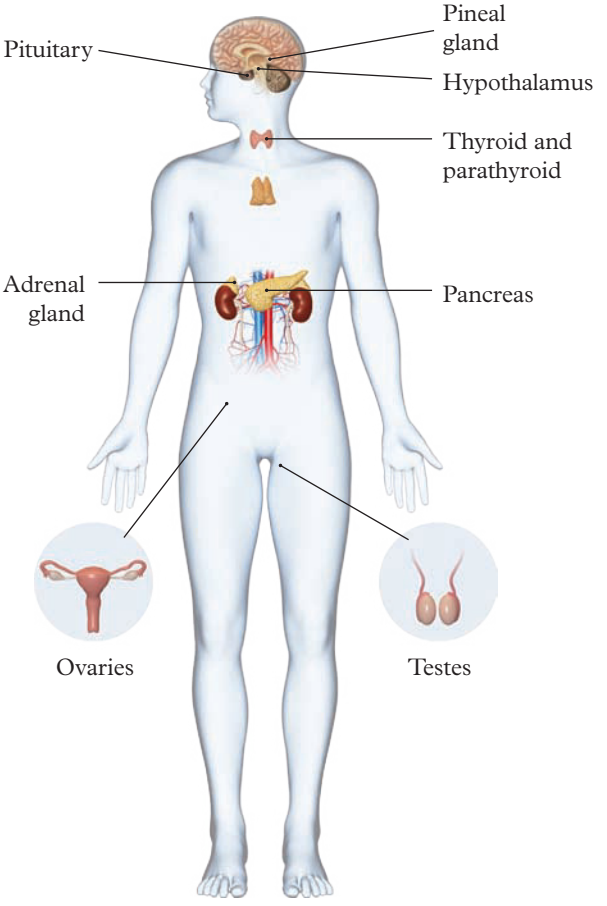


FIGURE 1 The positions of the main human endocrine organs. Females have ovaries and males have testes as part of their endocrine system.

Structure of the human endocrine system

Hormones are produced in the **endocrine glands**. The hormones then pass directly into the bloodstream and travel around the body in the blood until they reach their **target cells**.

Endocrine glands

The major glands (organs) of the endocrine system are the hypothalamus, pituitary, thyroid, parathyroids, adrenals, pineal, pancreas and reproductive organs (ovaries and testes). Figure 1 shows the location of the main human endocrine glands. In spite of their physical separation from one another, endocrine organs work together.

TABLE 1 The major human endocrine glands (organs), hormones, target tissue and functions

Organ	Hormone	Target tissue	Major function
Hypothalamus	Wide range of neurohormones	Pituitary gland	Links nervous and endocrine system via pituitary gland Controls homeostatic functions
Pituitary gland	Thyroid-stimulating hormone	Thyroid	Regulates thyroxine release from the thyroid
	Antidiuretic hormone	Kidneys	Increases the amount of water reabsorption in the kidneys
	Pituitary growth hormone	Bones and muscle	Regulates muscle growth and size of bones
Thyroid gland	Thyroxine	Body cells	Affects metabolic rate and plays an important role in growth, tissue development and differentiation
	Calcitonin	Blood	Decreases amount of calcium in the blood
Parathyroid glands	Parathyroid hormone	Blood	Acts in opposition to calcitonin – brings about removal of calcium from bone; and increases reabsorption of calcium in the kidney, so raising blood calcium levels
Adrenal glands	Adrenalin	Body cells	Increases metabolic rate
	Progesterone	Body cells	Regulates calcium in bones
	Oestrogen	Body cells	Development of certain sexual traits
Pineal gland	Melatonin	Skin cells	Regulation of skin pigment and biological rhythms
Pancreas	Glucagon	Liver	Increases blood glucose levels by converting glycogen to glucose
	Insulin	Liver and most cells	Decreases blood glucose levels by stimulating formation of glycogen
Ovaries	Oestrogen	Body cells	Initiates and maintains female secondary sexual characteristics
	Progesterone	Uterus	Maintains thickening of uterus lining
Testes	Testosterone	Male reproductive system and body cells	Initiates and maintains male secondary sexual characteristics

Hormones

Hormones are chemical messengers that are produced and released by the cells of endocrine glands, in response to particular stimuli. When they are released, hormones travel through the bloodstream until they reach a specific receptor attached to a target cell. Each hormone only affects specific body cells. The target cells have recognition sites (receptors) for specific hormones. Once the chemical messenger is bound to the receptor, the cell responds.

Stimuli that control the release of particular hormones include:

- the presence of a metabolic products in the blood
- the presence of another hormone in the blood
- stimulation by the autonomic nervous system.

Hormones influence target cells by:

- changing the permeability of the membrane to particular substances
- affecting enzymes located in the membrane
- affecting cell organelles
- activating genes to bring about specific protein production.

It takes time for a stimulus to cause the release of a specific hormone, for the hormone to reach the target cells and for these to respond. Similarly, once further release of a hormone is blocked or inhibited, it takes time for all the circulating hormone to be attached to target cells. Therefore, hormonal control is slow-acting, but long-lasting.

Hypothalamus

hypothalamus
a small region of the brain that has a vital role in regulating many body functions; referred to as the control centre

control centre
the hypothalamus of the endocrine system with the primary function of maintaining homeostasis

The **hypothalamus** is a section of the forebrain of vertebrates as shown in Figure 2. It plays a major role by releasing hormones to stimulate or suppress the release of hormones from the pituitary gland. Therefore, it is known as the **control centre** of the endocrine system.

The hypothalamus collects information from other parts of the brain, as well as monitoring levels of hormones and other chemicals in the blood vessels passing through it. Information generated by the hypothalamus is passed to the pituitary gland, which is directly below and adjoining it.

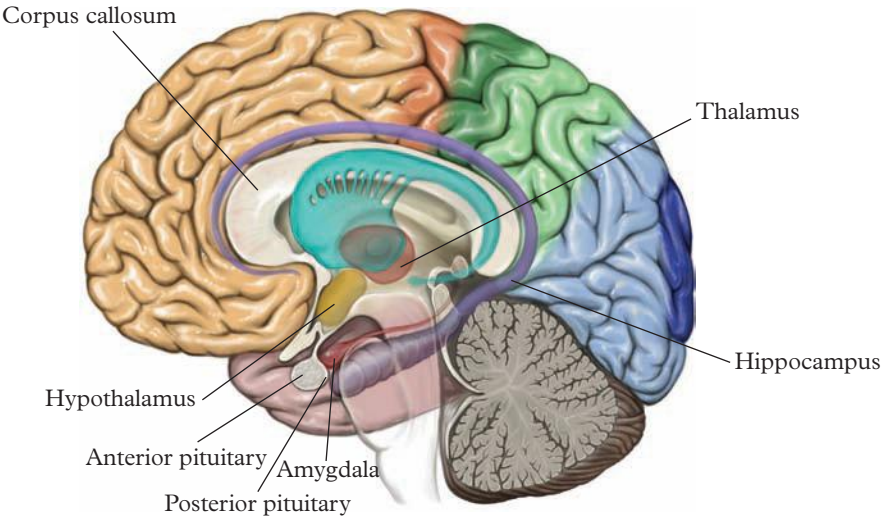


FIGURE 2 The human brain, showing the structure and relationship of the hypothalamus and pituitary gland

Pituitary gland

pituitary gland
an important gland that controls the activity of most other glands; referred to as the master gland

master gland
the pituitary gland of the endocrine system, which controls other glands

The **pituitary gland** is known as the **master gland** because it produces many different hormones that control the functions of other endocrine glands. It is located at the base of the brain, underneath the hypothalamus (Figure 2). The pituitary gland is divided into two parts: the anterior lobe and the posterior lobe. The two lobes produce and release different hormones:

The anterior lobe produces the following hormones (which are regulated by the hypothalamus).

- Growth hormone stimulates bone and tissue growth.
- Thyroid-stimulating hormone (TSH) stimulates the production of thyroid hormone from the thyroid gland.

- Adrenocorticotropin hormone (ACTH) stimulates the adrenal gland to produce several different hormones.
- Luteinising hormone (LH) and follicle-stimulating hormone (FSH) regulate and control sexual production and function.
- Prolactin stimulates milk production in females after childbirth.

The posterior lobe produces the following hormones (which are not regulated by the hypothalamus).

- Antidiuretic hormone (ADH) regulates water balance in the kidneys.
- Oxytocin controls uterus contractions during childbirth.

Not all endocrine glands are under the sole control of the hypothalamus and pituitary gland. Some are self-regulating because they respond directly to changes of metabolic products in the blood. For example, the secretion of insulin and glucagon from the pancreas is a response to blood sugar levels. Other organs, such as the adrenal cortex, are under direct nervous control.

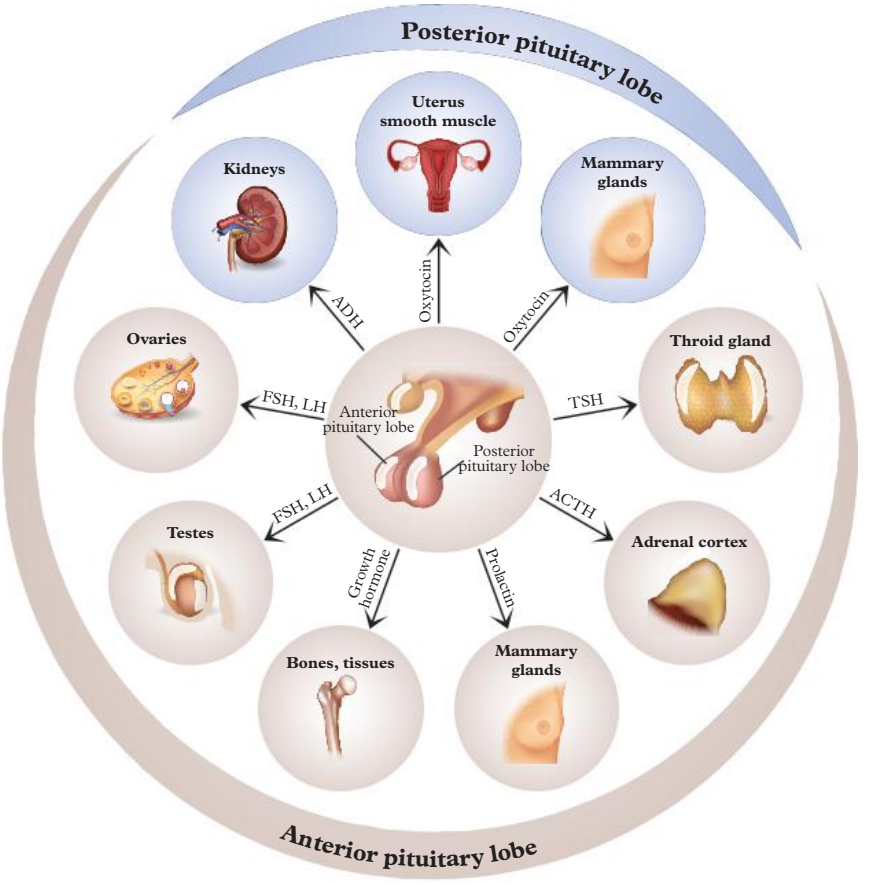


FIGURE 3 The hormones released from the anterior and posterior lobes of the pituitary glands

CHECK YOUR LEARNING 4.5

Describe and explain

1 Describe the function of the endocrine system.
2 Explain how endocrine glands can be very important even though they are small.
3 Explain how the anterior and posterior lobes of the pituitary gland differ.
4 Explain why the hypothalamus is referred to as the 'control centre' and the pituitary as the 'master gland'.
5 Name the hormones that are secreted by the thyroid gland. Describe how each one acts.

Apply, analyse and interpret

6 Explain why the responses of the endocrine system are considered slow-acting but long-lasting.
7 'All hormones affect all cells.' Use your knowledge of hormones and target cells to discuss the errors in this statement.

Design and discuss

8 Using an example, discuss how the pituitary gland can act to control the production and/or secretion of another hormone.

CHAPTER 4

Review

Chapter summary

4.1
- Vascular plants have specialised cells, tissues, organs and systems.
- The xylem is a type of vascular tissue that transports water and nutrients from the roots to the leaves for transpiration.
- The phloem is a type of vascular tissue that transports sugars from the leaves to the rest of the plant.

4.2
- There are four levels of organisation in complex multicellular life: cell, tissue, organ and system.

4.3
- The digestive system consists of an alimentary canal and associated organs that break down food physically and chemically so the body can obtain the required nutrients and remove the rest from the body.

4.4
- The excretory system removes waste from the body in the form of urea. The main components involved in this system are the kidneys, ureters, bladder and urethra.
- The kidney has many components that process waste, including the nephron, which manages reabsorption and secretion.

4.5
- The endocrine system includes endocrine glands that produce and secrete hormones, which have various functions.

Revision questions

Multiple choice

1 Identify which of the following is the correct order of organisation in both plants and animals.
- **A** Cell → tissue → organ → system
- **B** Tissue → organ → cell → system
- **C** Organ → tissue → cell → system
- **D** Cell → organ → tissue → system

2 Identify the role of the plant organ, the stem.
- **A** The main site of photosynthesis to produce organic matter
- **B** Necessary for sexual reproduction in plants
- **C** Necessary for the absorption of ground water and minerals
- **D** Transports water, mineral and organic substances

3 Identify the main molecule that moves around a plant in the phloem.
- **A** Water
- **B** Ions
- **C** Sugars
- **D** Oxygen

4 Identify which of the following are plant systems.
- **A** Shoot system and root system
- **B** Xylem and phloem
- **C** Flowers, leaves, stem and roots
- **D** Transpiration and translocation

5 Identify the function of connective tissue.
- **A** Forms the outer surface of organs and blood vessels as well as the lining of the digestive and respiratory tracts
- **B** Enables movement for the organism
- **C** Conducts nerve impulses to respond to stimuli
- **D** Supports and connects tissues and organs to one another

6 Identify the correct function for the digestive enzyme amylase.
- **A** Digest disaccharides to monosaccharides
- **B** Digest proteins to polypeptide chains and amino acids
- **C** Digest lipids to fatty acids and glycerol
- **D** Digest amylose in complex carbohydrates to the disaccharide maltose

7 Identify the role of the pancreas as an endocrine gland.
- **A** Regulates metabolic rate through the production and release of thyroxine
- **B** Regulates blood glucose levels by releasing glucagon or insulin
- **C** Initiates and maintains female secondary sexual characteristics
- **D** Regulates calcium levels in the blood

8 Identify which of the following are all organs of the excretory system.
- **A** Stomach, oesophagus, pancreas
- **B** Hypothalamus, pituitary, thyroid
- **C** Kidneys, bladder, urethra
- **D** Liver, gall bladder, ileum

9 Identify the part of the nephron that is needed to absorb large quantities of water from the filtrate.
- **A** Loop of Henle
- **B** Proximal convoluted tubule
- **C** Bowman's capsule
- **D** Distal convoluted tubule

10 Identify which of the following is not able to enter the Bowman's capsule from the glomerulus.
- **A** Amino acids
- **B** Large protein molecules
- **C** Water
- **D** Ions

Short answer

Describe and explain

11 Identify two examples of plant organs and describe how they maintain a plant's survival.

12 Explain the function of phloem and xylem. Construct a labelled diagram to support your explanation.

13 Examine Figure 1.

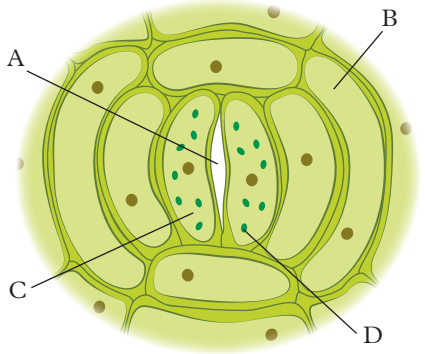


FIGURE 1 Stoma in leaf structure

a Match the following terms to the labels on the diagram of a stoma in Figure 1:
- chloroplast
- guard cell
- open stoma
- epidermal cell.

b Describe the function of the stoma in vascular plants.

14 Explain how water moves through a vascular plant.

15 Describe the cells or structures that control the loss of water in the leaves of a plant.

16 Explain why the digestive system must be located close to the circulatory system.

17 Describe the structure and function of the human:

a digestive system

b excretory system

c endocrine system.

18 Explain the importance of microvilli on the inner surface of the small intestine.

19 Create a flow chart to outline the process of physical and chemical digestion.

20 Chewing and enzymes both function to break down food. Contrast physical digestion and chemical digestion.

21 Define 'hormone'.

22 List three ways a hormone can influence a target cell.

23 Name and describe the main functions of a nephron during urine formation.

Apply, analyse and compare

24 Compare the two main specialised cells that make up xylem tissue.

25 Contrast the root and shoot systems of plants.

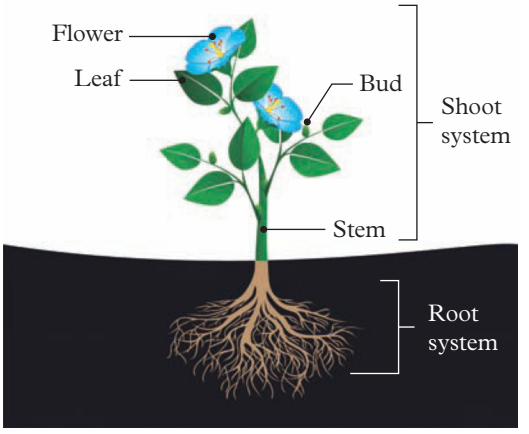


FIGURE 2 Root and shoot systems

26 Contrast the terms 'egestion' and 'excretion'.

27 Examine Figure 2. Salivary amylase is an enzyme produced by the salivary glands, which aids the breakdown of starch in chemical digestion.

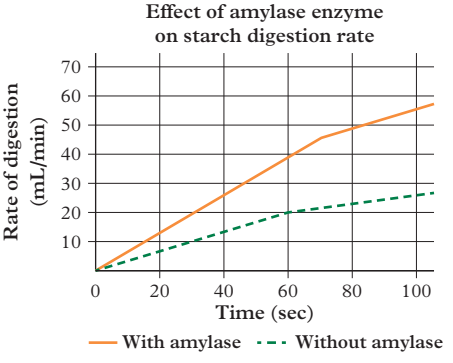


FIGURE 3 The effect of amylase enzyme on rate of starch digestion

a Identify the independent and dependent variables on the graph.

b Use the graph to compare the overall rates of digestion with and without salivary amylase.

c 'Digestion cannot occur without salivary amylase.' Use the information provided in the graph to support or refute this statement.

28 The hypothalamus and the pituitary gland are considered to be the control centre and master gland of the endocrine system, respectively. Produce a comparison table that compares the structure, location, hormones and functions of these glands.

29 Describe how the filtrate forms in the process of filtration in the nephron.

30 Discuss why it is important for hormones to act only on specific cells.

Design and discuss

31 By referring to structure and function, discuss how the microvilli are specialised for absorption in the small intestine. Predict what would happen to the functioning of the digestive system if the surface of the small intestine was smooth and had no microvilli.

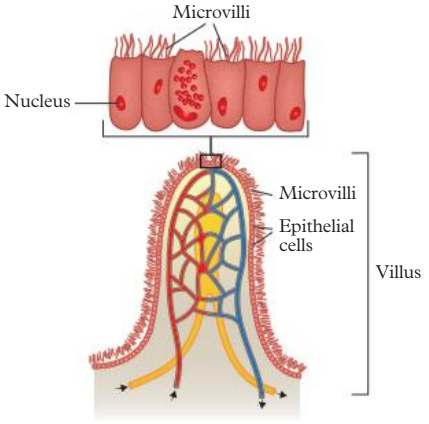


FIGURE 4 Microvilli

32 A common misconception is that urination is a process of the digestive system. Explain why this is incorrect.

33 Discuss how the endocrine system and excretory system work together to maintain water levels in the body.

34 Design an experiment to compare water loss in two different species of plants. In your experiment, make sure you identify:

a the independent and dependent variables

b at least two controlled variables

c how you intend to collect valid, accurate and reproducible data.

(Tip: You can find information on validity, accuracy and reproducibility in Chapter 1 Biology toolkit.)

Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to explain an answer. This means you will need to provide new information that shows that you understand the reason that something occurs. To do this, you should read a question three times.

Explaining in a response

The first time you read a question, you should identify the key idea or topic being described or asked about. The second time you read the question, you should underline or highlight the key words. This will make it easier for you to check that everything has been included. You can then start writing the answer. You should describe the process to show that you understand the connections between each step. When you finish writing your answer, read the question a final time to make sure that you have included everything that is needed.

QUESTION 1e (2002 Biology Written Examination 1)

Animal cells placed in distilled water swell and burst. Plant cells placed in distilled water do not burst.

e Explain why plant cells do not burst in this situation. 1 mark

Source: 2002 Biology Written Examination 1, Question 1e, Short answer, reproduced by permission © VCAA

Response 1

When cells are placed in distilled water, water goes into the cell, making them swell.
Plant cells have cell walls that stop the membrane from swelling too much or bursting.

This describes what happens to cells in distilled water.

This describes why the cell wall prevents the cells from bursting.

This response will receive the 1 mark.

Response 2

Plant cells do not burst because they have cell walls.

This answer does not explain the 'why' that is asked in the question, or refer to 'this situation'.

This response will not receive a mark because it does not provide all the information required by the question.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 6d,e (2005 Biology Written Examination 1)

There are many different types of endocrine cells in complex multicellular animals. Each type of endocrine cell secretes a different chemical.

d Explain how each type of endocrine cell influences the functioning of only specific cell types within the body. 1 mark

The hormone will only bind to a target cell. Not all cells are target cells.

e A tissue may, over time, lose its response to a particular hormone, even though the hormone concentration remains unchanged. Based on your understanding of how a hormone controls the functioning of other cells, suggest a reason for this decrease in responsiveness. 2 marks

Less hormone will be produced as a person gets older.

Source: 2005 Biology Written Examination 1, Question 6d,e, Short answer, reproduced by permission © VCAA

Marking guide

6d	1 mark for identifying that hormones will only act on cells that have particular receptors for that hormone.
6e	2 marks for one of the following responses. • As a cell ages, the receptor may become damaged (1 mark) and become less effective in binding to the hormone (1 mark). • The number of receptors on a cell may decrease with age (1 mark) and therefore the hormone will not change the function of these cells (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 an examiner.

Check your Student obook pro for the following digital resources and more:

Video
Explaining in a response

Weblink
Past examinations and examiners' reports

CHAPTER 5

System regulation

All living organisms need to regulate their internal environments in order to survive. Plants have processes to maintain water balance, including transpiration and osmosis. The waxy cuticle, stomata and root hairs are features of plants that help to control water regulation.

Animals maintain constant internal environments, within narrow limits, by homeostasis. Changes to the internal or external environment are detected by receptors and the body responds to the change (stimulus). A stimulus–response pathway is used to model this process. The response can be the reverse of the stimulus, known as negative feedback, or it can amplify the stimulus, known as positive feedback. Body temperature, blood glucose concentration and water balance are all regulated by negative feedback loops via homeostatic mechanisms.

It is important that homeostatic mechanisms are maintained because malfunction can cause diseases such as type 1 diabetes, hypoglycaemia and hyperthyroidism.

KEY KNOWLEDGE

- → regulation of water balance in vascular plants
- → regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops and associated organ structures
- → malfunctions in homeostatic mechanisms: type 1 diabetes, hypoglycaemia, hyperthyroidism

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

FIGURE 1 A transverse section from the middle of a leaf, showing the layers of cells. The surface (epidermis) of the leaf is covered by a waxy cuticle (top) to help prevent water loss. In the centre of the leaf is the xylem (brown) and phloem (red) tissue.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

5A Name two organs in the human body.

5A Groundwork resource
Human body systems

5B Explain how water moves in and out of plants.

5B Groundwork resource
Water transport in plants

5C Describe the structure and function of the endocrine system.

5C Groundwork resource
The endocrine system

PRACTICALS

PRACTICAL	**5.1** Movement of water through plants

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your Student obook pro.

5.1 Regulation of water in plants

KEY IDEAS

In this topic, you will learn that:

- plants maintain water balance by the processes of transpiration and osmosis
- key features of plants are involved in water balance, including the waxy cuticle, stomata and root hair cells.

Controlling water balance

epidermis
the outer layer of tissue in a plant

cuticle
the superficial, non-cellular layer covering a plant or an animal

Plants require water for essential reactions, including photosynthesis and cellular respiration. Chapter 4 introduced you to the different parts of a plant and their functions. Water is absorbed from the roots by osmosis and moves through the xylem vascular tissue by transpiration. During transpiration, water is lost from the leaves when the stomata are open.

Plants need to regulate water balance by controlling water loss and water absorption. Controlling how much water a plant has is vital to its survival. The two main processes associated with water regulation in plants are:

- transpiration (water evaporation from stomata)
- osmosis (water entering root cells).

FIGURE 1 The waxy cuticle of a leaf helps to prevent water loss.

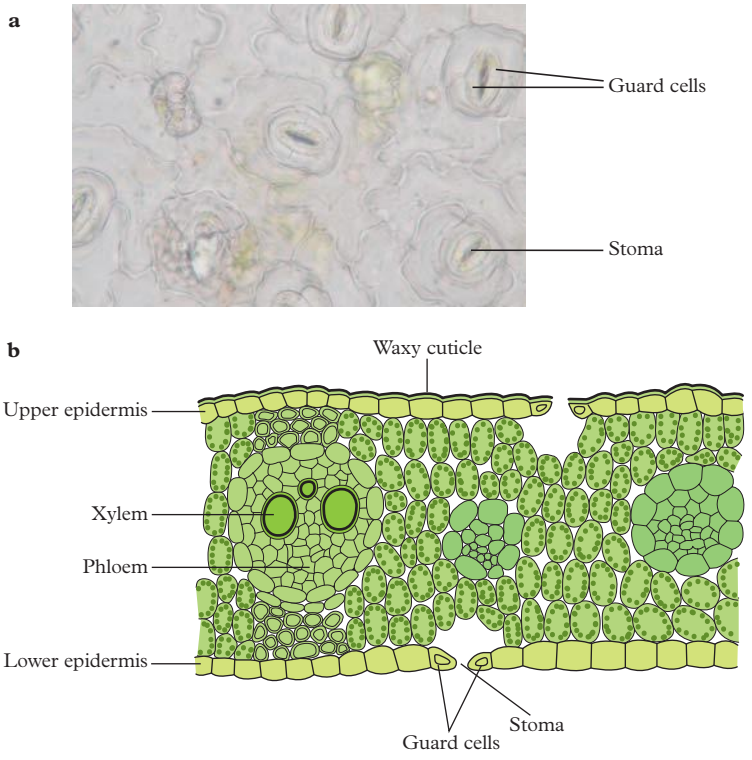


FIGURE 2 **a** A microscope image of the surface of a leaf, showing multiple stomata. **b** A transverse section of a leaf, showing stomata (openings) in the epidermal layer.

Key plant features for water balance

Vascular plants have several features to prevent excessive water loss and maintain water balance in cells to allow for important reactions such as photosynthesis.

Waxy cuticle

The outer layer of cells of the leaf is called the **epidermis**. The epidermis has a waxy **cuticle**, which is nearly waterproof and airproof (Figure 1). This waxy cuticle doesn't regulate water loss, but helps to prevent water loss from the leaf cells.

Stomata

Stomata (singular: stoma) are located on the surface of leaves and allow gas exchange (Figure 2). The carbon dioxide needed for photosynthesis enters through open stomata and diffuses into the cells from the air spaces in the middle layers of the leaf. During this

process, water is lost through the stomata during transpiration. The balance between transpiration and photosynthesis is a compromise for plants; stomata need to be open to allow photosynthesis to occur, but at the same time the plant risks water loss and dehydration.

Stomata open and close depending on the amount of water in the guard cells (Figure 3). Guard cell walls are thicker next to the pore than next to the surrounding epidermal cells. When the guard cells are full of water (turgid), the thin part of the wall stretches more than the thick part. This makes the two guard cells curve away from each other and the pore opens. As the guard cells lose water and their turgor pressure decreases, they become straighter and the pore closes.

If water is lost, the guard cells on either side of the stoma collapse and lose turgid pressure. This causes the stoma to close and gas exchange can no longer occur. Closing the stomata restricts the supply of carbon dioxide and the rate of photosynthesis reduces. Plants must continually take in water through their root system to compensate for water lost through transpiration.

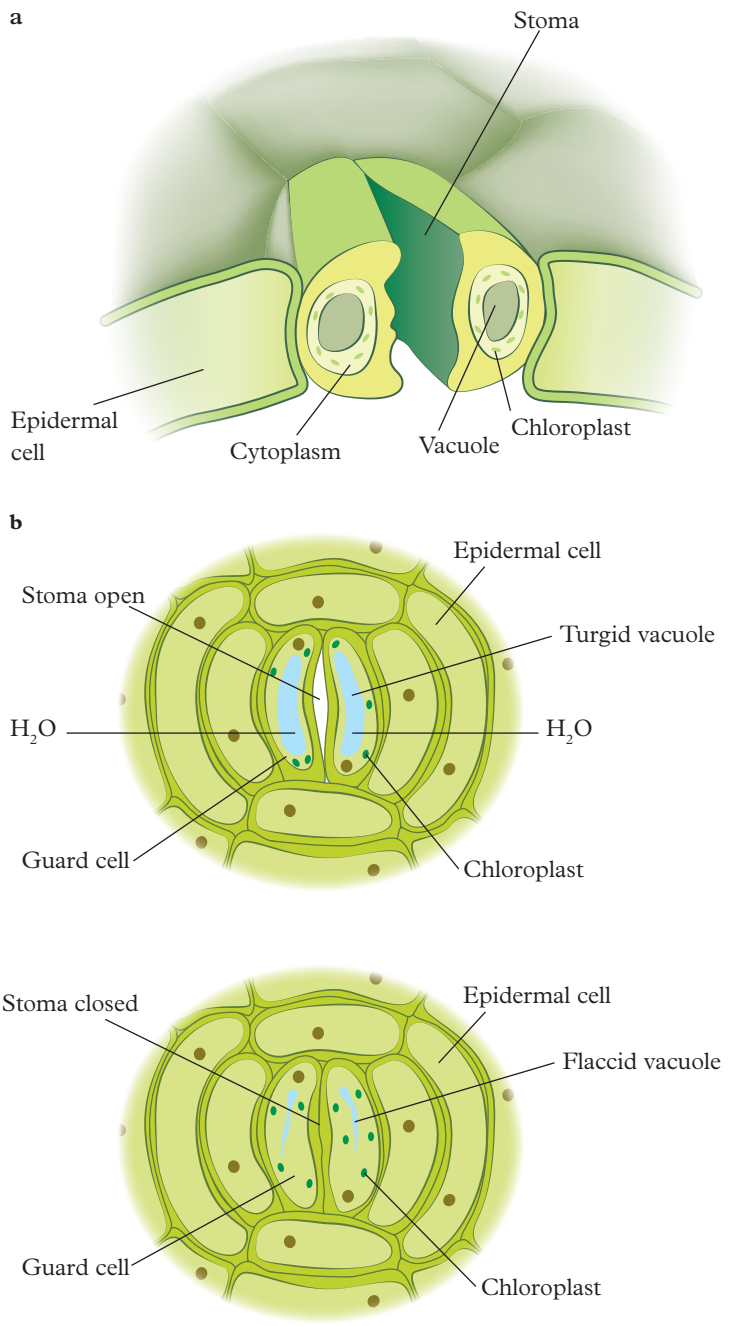


FIGURE 3 **a** The structure of guard cells. **b** The appearance of open and closed stomata on leaf surface. The stoma opens when the guard cells are filled with water and turgid. The stoma closes when the guard cells do not contain much water and are flaccid.

Factors that affect rate of water loss

The rate of water loss from leaves by transpiration is affected by a number of factors.

- **Number of stomata:** as the number of stomata increases, transpiration rate increases; the longer stomata remain open, the more transpiration can occur.
- **Position of stomata:** in curved leaves, stomata can be located in the curves, which traps transpired water so that it stays close to the leaf surface. The air surrounding the stomata contains large amounts of water vapour, which reduces water loss by transpiration.
- **Surface area of the leaf:** the larger the surface area, the more surface is exposed to UV radiation and generally the more stomata there are on the surface, both of which increase transpiration rate.
- **Humidity:** as humidity increases, transpiration rate decreases. At high humidity, there is a large amount of water vapour in the air, and a reduced concentration gradient between the air and the spaces in the leaf. Therefore, less water evaporates into the air, reducing transpiration rate.

- **Temperature:** as temperature increase, evaporation increases, and hence transpiration rate increases.
- **Wind speed:** as wind speed increases, the movement of water vapour away from the leaves increases. This movement of water vapour helps to maintain a high concentration gradient between the air and the leaf, resulting in an increased transpiration rate.

Factors that affect water loss from plants are summarised in Figure 4.

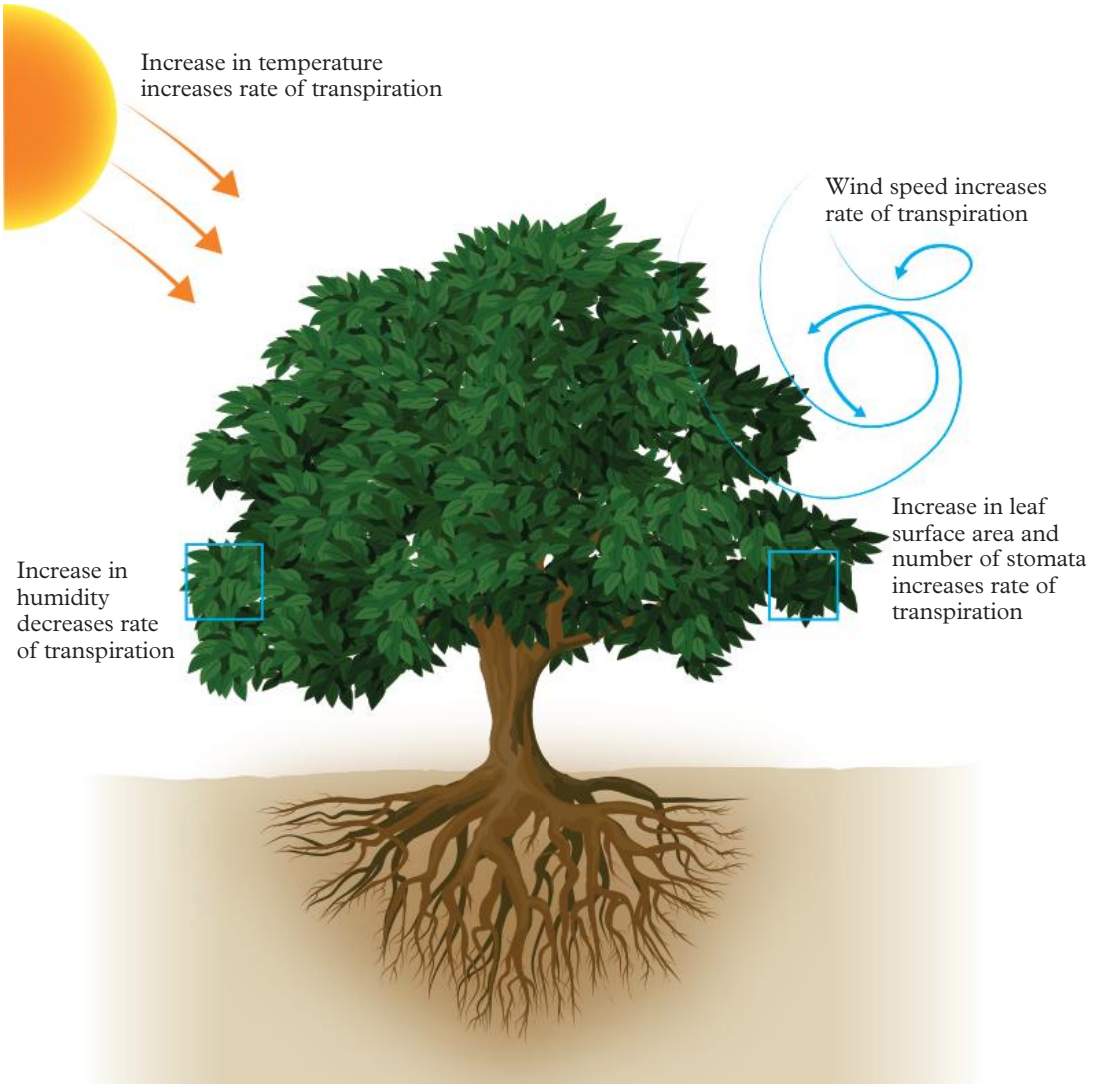


FIGURE 4 Wind speed, humidity, temperature, number of stomata and surface area affect the rate of transpiration in vascular plants.

Roots

All of the water used by land plants is absorbed from the soil through the root system. Water enters the roots by osmosis when the concentration of solutes in the cell is higher than in the surrounding soil.

concentration gradient
the unequal distribution of solute across a membrane

Plants increase the rate of water absorption by using a solute **concentration gradient**. As you learnt in Chapter 4, root hair cells actively transport mineral ions from the soil, against a concentration gradient. This produces a higher concentration of solutes inside the root cells than in the surrounding soil. Water moves into the root hair cells passively by osmosis, following the osmotic gradient (Figure 5).

Root hair cells have large vacuoles to store water. Water then diffuses to nearby root cells until it reaches the xylem tissue. In the xylem, water moves by transpiration towards the leaves of the plant. Most of the water that a root takes up from soil moves from the epidermis to the vascular cylinder by diffusing through cell walls, one cell to the next. This is unlike mineral ions, which are actively transported into root hairs by diffusing through plasmodesmata (narrow threads of cytoplasm between plant cell walls) to the vascular cylinder. This process allows plants to regulate water balance.

The absorption of water at the roots depends on several factors, including the:

- availability of water in the soil
- mineral ion concentration of the soil
- energy available in the root hair cells for active transport of mineral ions.

In plant roots, the Casparian strip is a diffusion barrier that directs water and solutes to the vascular tissues. Once inside the Casparian strip, most of the water moves from the epidermis to the vascular cylinder by diffusing through endodermal cell walls. To enter the vascular cylinder, water and dissolved minerals must enter cytoplasm by passing through the plasma membrane of a root cell.

Study tip

Osmosis is always a passive (no energy) process; however, the active transport of solutes into the cell can increase the rate of osmosis.

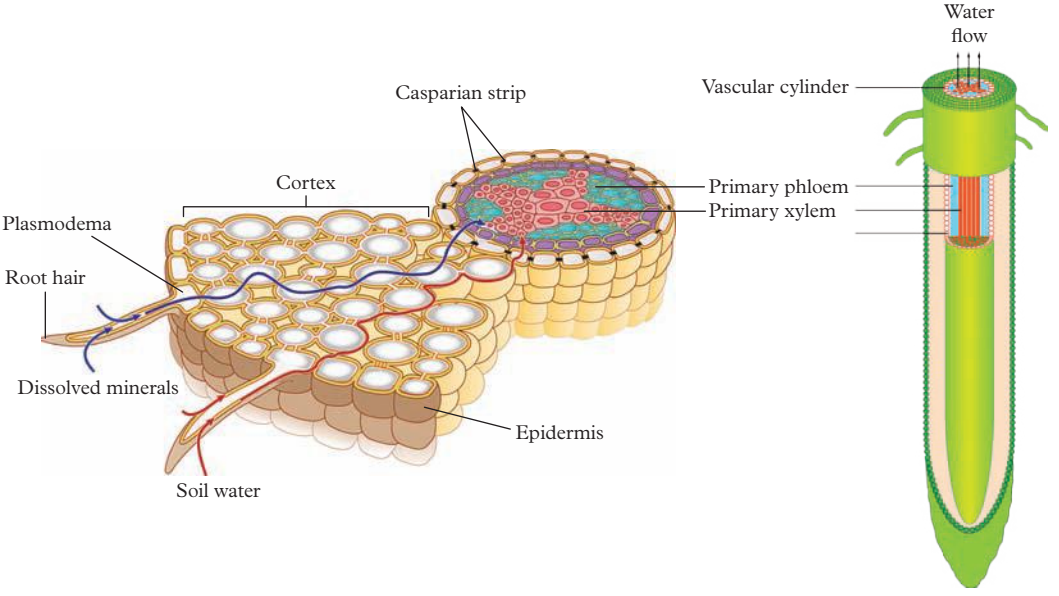


FIGURE 5 Mineral ions are actively transported into root cells so that water can follow passively. The water and mineral ions are transported through the xylem tissue from the roots to the shoots of the plant.

CHECK YOUR LEARNING 5.1

Describe and explain

1 Describe the process by which plants absorb water.
2 Name and describe three factors that increase the rate of transpiration.
3 Explain where stomata are located on a plant.

Apply, analyse and compare

4 Draw an image to represent stomata when the guard cells have lost water to the surrounding epidermis.
5 Explain why the waxy cuticle can prevent but not regulate water loss.

Design and discuss

6 Discuss why a solute concentration gradient needs to be formed before water can move into root hair cells.

5.2 Animal regulation mechanisms

KEY IDEAS

In this topic, you will learn that:

- homeostasis maintains a stable internal environment and stimulus–response models can be used to demonstrate how homeostasis is maintained
- negative feedback occurs when the homeostatic response is the reverse of the stimulus
- examples of homeostatic mechanisms in animals include the regulation of body temperature, blood glucose concentration and water balance.

Animals need to regulate their internal environments by the process of homeostasis. This includes the regulation of body temperature, blood glucose levels and water balance. In this topic, you will learn how the different body systems work together to maintain these factors within a narrow range.

Homeostasis

tolerance range the range of conditions in which an organism can survive

Homeostasis is the maintenance of a constant, stable internal environment within a **tolerance range**. This includes maintaining a constant internal body temperature, blood glucose levels and water balance. Animals must be able to detect changes in the internal environment caused by diet, exercise and other changes in the external environment. Once a change is detected, the body needs to respond to ensure that these factors return to the levels required to stay healthy.

Stimulus–response model

stimulus–response model the homeostatic pathway from stimulus to response

Stimulus–response models are a way of representing the pathway needed to maintain homeostasis.

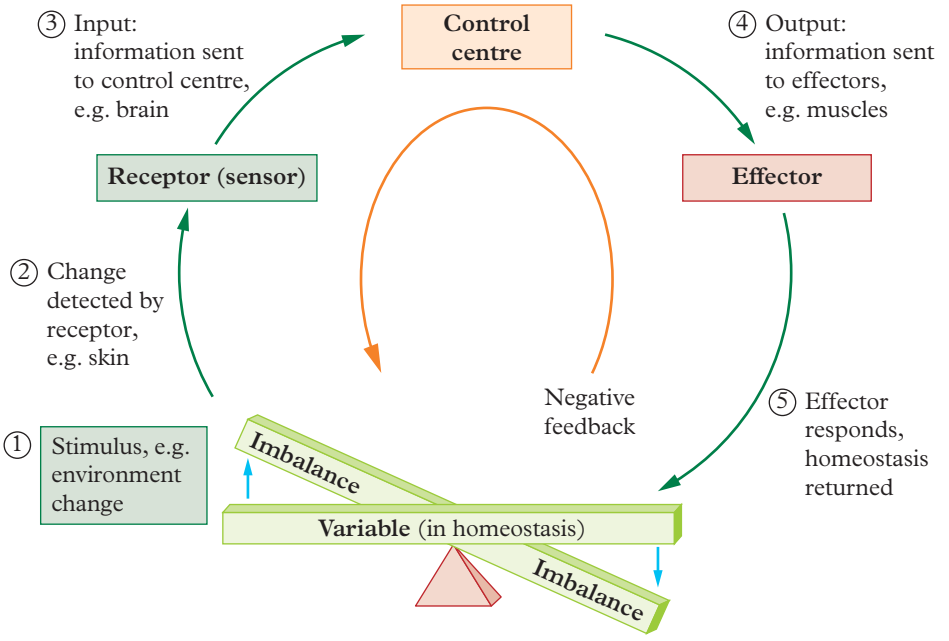


FIGURE 1 The stimulus–response model: a stimulus is detected by a receptor, which passes the information to a control centre, which sends a message to an effector, which responds.

Stimulus–response pathways begin with a change in the environment that acts as a stimulus. This change is detected by receptors (e.g. skin and eyes). Once detected, this information is passed to a control centre (e.g. brain and pancreas). The control centre interprets the information and sends a message to **effectors** (e.g. muscles and glands) that bring about a specific **response** (Figure 1).

effector
a muscle or gland that gives a response

response
a change in an organism resulting from a stimulus

Feedback loops

Homeostatic processes are maintained by two feedback loops – positive feedback and negative feedback.

Negative feedback

Negative feedback occurs when the response is the reverse of the stimulus (Figure 1). The system functions to reduce the detected change and return the level to the appropriate range. Most homeostatic mechanisms in animals, including body temperature, blood glucose and water balance, involve negative feedback loops.

negative feedback
when the homeostatic response is the reverse of the stimulus

For example, if body temperature increases, the homeostatic response is to reduce body temperature (Figure 2). The response is the reverse of the stimulus, so it is considered negative feedback.

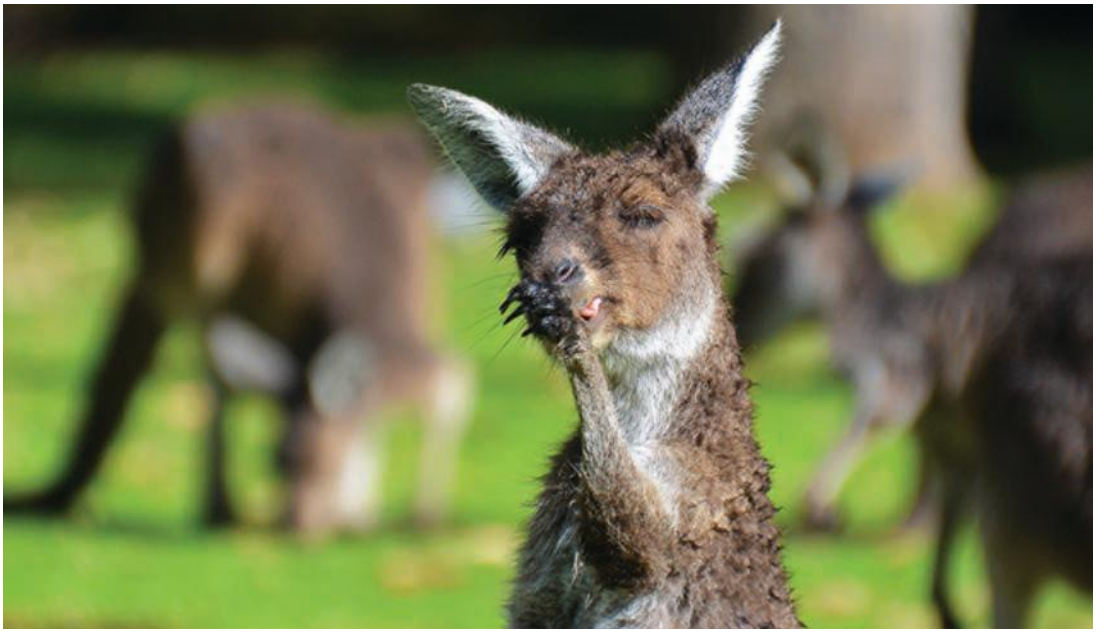


FIGURE 2 The behaviour of this kangaroo is part of a negative feedback loop. The kangaroo is too hot and is trying to reverse the stimulus.

Positive feedback

Positive feedback occurs when the response reinforces the stimulus, therefore functioning to increase the detected change. There are only a few examples of positive feedback in animals.

- During childbirth, the walls of the uterus stretch. This causes contractions to further stretch the walls. This positive feedback continues to become stronger until the baby is born (Figure 3).
- During lactation, the action of the baby sucking on the nipple stimulates increased milk production. The production of milk continues until the baby stops breastfeeding.
- When blood leaks from blood vessels after an injury, blood cells called platelets release clotting factors, which cause more platelets to come to the site of injury.

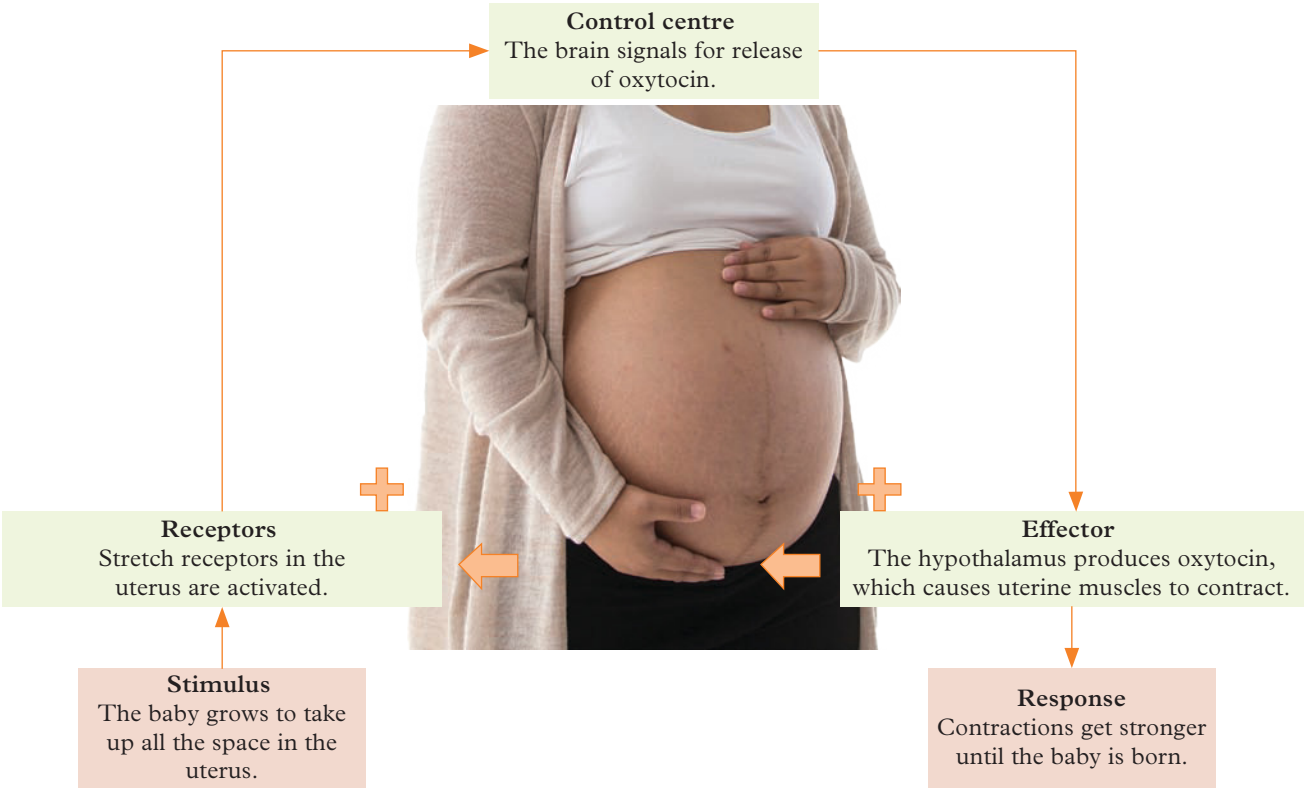


FIGURE 3 Childbirth is an example of positive feedback. Stretching of the uterus causes the hypothalamus to release the hormone oxytocin, which causes further stretching of the uterus until the baby is born.

Homeostatic mechanisms in animals

Animals have different mechanisms to regulate their internal environments and maintain optimum body temperature, blood glucose levels and water balance.

Thermoregulation

thermoregulation regulation of internal body temperature

Thermoregulation is the regulation of internal body temperature. Animals' internal body temperatures vary greatly; however, most mammals have a body temperature of between 36°C and 40°C. For example, humans have a body temperature of 36.3–37.3°C. The human body uses a range of mechanisms to keep the internal body temperature as close to this optimal level as possible. Thermoregulation involves a negative feedback pathway that includes receptors in the skin (Figure 4) and is controlled by the hypothalamus in the brain.

Heat is produced by cellular respiration that occurs in cells in the body. Some organs, such as the brain and muscles, produce more energy, creating an imbalance as they get hotter. Usually, heat is spread evenly around the body through the blood. So when one part of the body works harder than the rest, the body needs to find balance again and regulate its average temperature.

Table 1 shows how the stimulus–response model can be used to demonstrate thermoregulation.

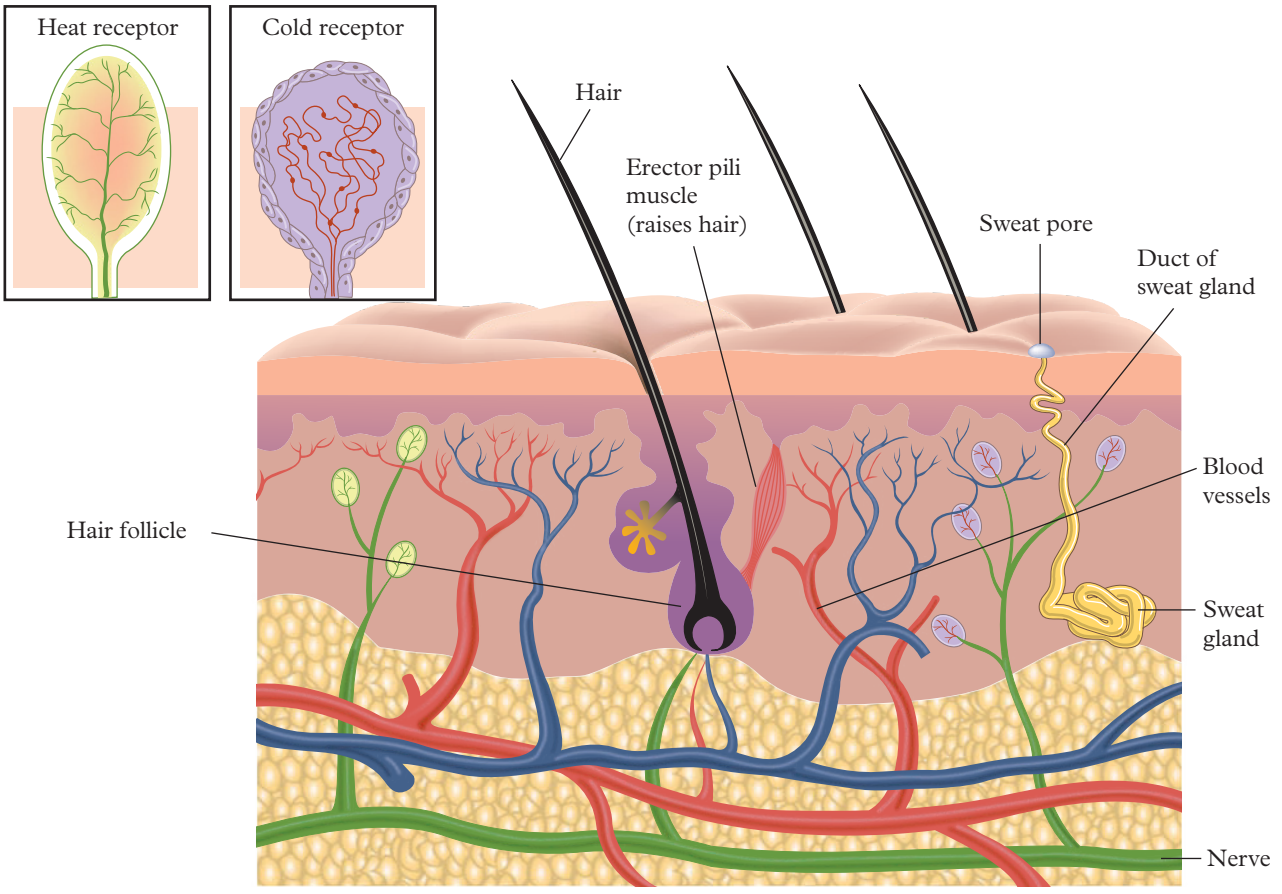


FIGURE 4 Thermoreceptors in the skin detect heat and cold.

TABLE 1 A stimulus–response model for thermoregulation

Stimulus	A change in the internal body temperature or a change in blood temperature occurs.
Receptors	**Thermoreceptors** in the skin and brain detect changes in the body temperature.
Control centre	The hypothalamus receives messages from the receptors.
Effectors	Blood vessels, muscles and/or sweat glands receive a message from the hypothalamus to initiate a response.
Response	Body temperature is increased or decreased to reverse the stimulus (negative feedback).

thermoreceptor a receptor that detects changes in temperature, either hot or cold

Response when body temperature increases

If body temperature is too high, the hypothalamus sends signals to the sweat glands to produce sweat, which evaporates from the skin. This evaporative cooling lowers the temperature. Blood vessels in the skin also receive a message to dilate, which facilitates heat loss from the skin (Figure 5). Hairs on the skin will also lie flat to prevent heat from being trapped between hairs.

Response when body temperature decreases

If body temperature is too low, the hypothalamus sends signals to the muscles to start shivering, which generates heat. Blood vessels also receive a message to constrict, which reduces blood flow to the surface of the skin. This reduces heat loss via radiation. In addition, hairs on the skin will stand erect to trap still air close to the skin, which acts as an insulating layer.

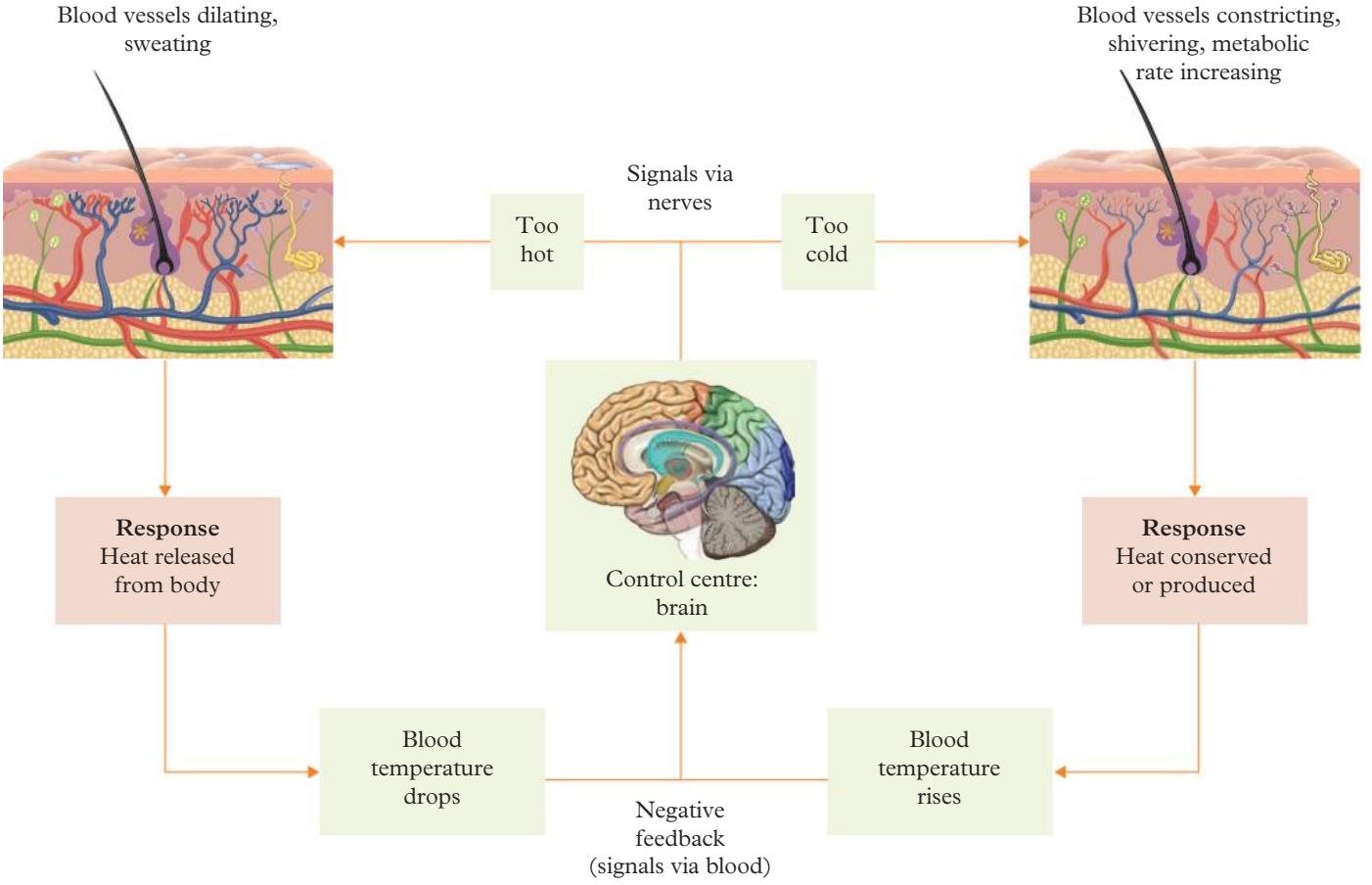


FIGURE 5 Thermoregulation maintains internal body temperature.

Blood glucose regulation

The control of blood glucose also involves a negative feedback mechanism. Optimal levels of glucose within the blood are about 90 mg/100 mL. Animals obtain glucose from their diet; after a carbohydrate-rich meal, blood glucose levels rise and must be returned to optimal level. Between meals, blood glucose concentrations drop because the cells are using the glucose for cellular respiration to produce energy. The blood glucose levels then drop below optimum levels and must be raised again.

Table 2 shows how the stimulus–response model can be used to demonstrate blood glucose regulation.

TABLE 2 A stimulus–response model for blood glucose regulation

Stimulus	Blood glucose concentration increases or decreases outside the optimal range.
Receptors	Blood glucose receptors detect a change in the blood glucose concentration.
Control centre	The hypothalamus receives messages from the receptors.
Effectors	The pancreas receives a message from the hypothalamus to initiate a response. The pancreas secretes the hormones insulin or glucagon, which act on the liver and other body cells to store or release glucose.
Response	Blood glucose concentration is increased or decreased to reverse the stimulus (negative feedback).

Response when blood glucose levels increase

When glucose levels increase above the optimal level, glucose receptors within the body detect this change. Beta cells of the pancreas respond by secreting the hormone **insulin**. Insulin travels through the blood to the target cells in the liver and muscles where it binds to the receptors. This causes the muscle and liver cells to absorb the blood glucose and store it as glycogen. Once glucose levels in the blood reach the optimal level, the pancreas stops secreting insulin (Figure 6).

Response when blood glucose levels decrease

When glucose levels decrease below the optimal level, glucose receptors within the body detect this change. Alpha cells of the pancreas respond by secreting the hormone **glucagon**. This increases the amount of glucose in the blood (reversing the stimulus) by triggering the liver to convert glycogen into glucose, which is then released into the blood. Once glucose levels in the blood reach the optimal level, the pancreas stops secreting glucagon.

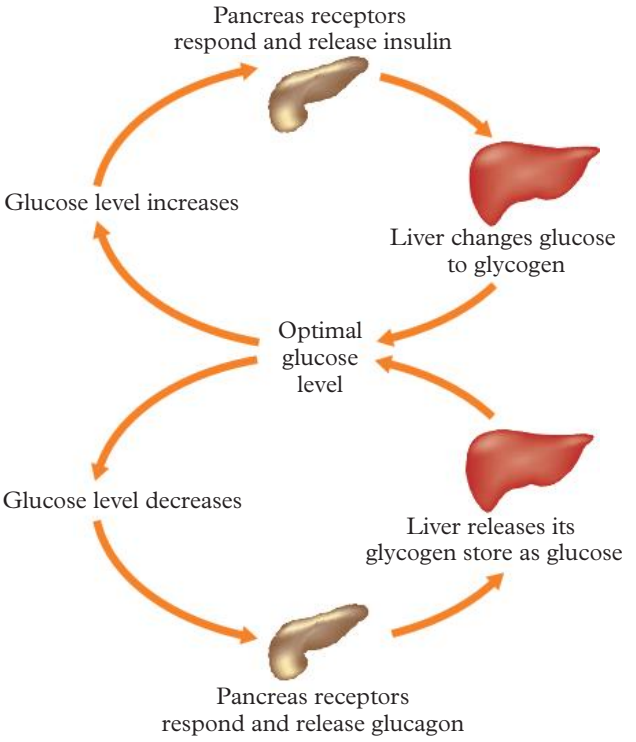


FIGURE 6 The pancreas and liver work together to maintain healthy glucose levels in the body.

Water balance

Water balance in animals is also controlled by a negative feedback pathway that involves many organs communicating with one another to regulate water levels and maintain homeostasis. The optimal blood water concentration, also known as osmolarity, of an adult human is 285–295 mOsm/kg (milliosmoles per kilogram). The kidneys and brain are the primary organs involved in maintaining water balance.

Water can enter the body through ingested food or drink, and is also produced (in small amounts) as a by-product of aerobic cellular respiration. A constant supply of water is essential for many reasons, including:

- as a solvent for many metabolic reactions in the body
- as the main component of cytosol (internal fluid of cells) and blood plasma
- to maintain body temperature
- for the production of urine and faeces to remove wastes from the body
- to lubricate joints and moisten tissues such as mouth, eyes and nose.

Table 3 shows how the stimulus–response model can be used to demonstrate water balance.

insulin
a hormone released by the pancreas that lowers blood glucose concentration

glucagon
a hormone released by the pancreas that raises blood glucose concentration

TABLE 3 A stimulus–response model for water balance

Stimulus	Osmolarity increases or decreases outside the optimal range.
Receptors	**Osmoreceptors** in the hypothalamus detect osmolarity levels outside the optimal range.
Control centre	The hypothalamus receives messages from the receptors. The pituitary gland receives a message from the hypothalamus to initiate a response. The pituitary gland changes the amount of anti-diuretic hormone it secretes.
Effectors	The kidneys respond by reabsorbing water from the collecting duct of the nephron or by removing excess water via the urine. The hypothalamus can also trigger a thirst response to increase water uptake by drinking if osmolarity is low.
Response	Osmolarity is increased or decreased to reverse the stimulus (negative feedback).

osmoreceptor
a receptor that detects changes in blood osmolarity

Response when water concentration decreases

anti-diuretic hormone (ADH) a hormone released by the pituitary gland that prevents the production of dilute urine in the kidneys

If a person is dehydrated, osmolarity is high. This triggers the pituitary gland to release **anti-diuretic hormone (ADH)** (Figure 7). ADH circulates in the blood and triggers the collecting ducts of the nephron in the kidney to increase water absorption. When osmolarity is low, the hypothalamus also activates a thirst response, to encourage an increased uptake of fluid through drinking. Together, these two responses maintain water balance.

Response when water concentration increases

When a person has consumed a lot of water, osmolarity is low. This triggers the pituitary gland to reduce or stop the release of ADH. This causes less water to be reabsorbed in the nephron and more water to be released in the urine. Therefore, the kidneys produce more dilute urine, excreting the excess water via the excretory system.

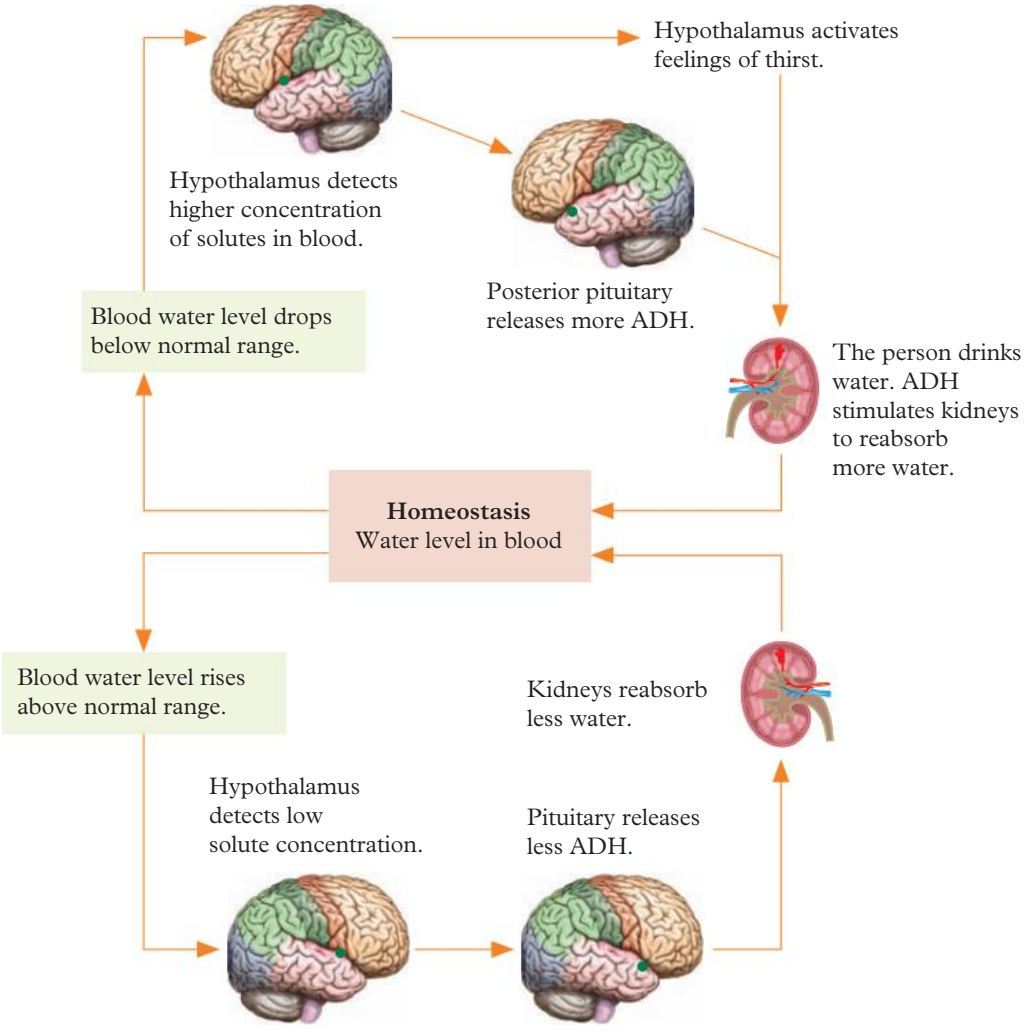


FIGURE 7 Anti-diuretic hormone (ADH) is responsible for regulating water balance in the blood.

CASE STUDY 5.2

Water balance in desert animals

In hot deserts, it can be very difficult for mammals to regularly find drinking water. This can have a significant effect on thermoregulation, which requires water to lower body temperature. Therefore, maintaining water balance is challenging in this environment and desert mammals have physiological adaptations to minimise water loss.

Desert mammals generally have a longer digestive tract, which increases the area for reabsorption of water from the developing faeces. Small desert mammals survive periods of drought by producing very small amounts of highly concentrated urine. They have a longer than usual loop of Henle in the nephron, which enables large amounts of water to be absorbed back into the body. Some desert mammals, particularly rodents, can produce a significant amount of water through metabolic reactions.

The spinifex hopping mouse (*Notomys alexis*) (also known by its traditional Aboriginal name *tarkawara*) has adapted to the harsh Australian desert (Figure 8). During periods of water deprivation, the small mouse produces very concentrated urine, more concentrated than that of any other mammal. The structure and function of its kidneys enables the mouse to produce almost solid urine. In this way, the mouse conserves water.

FIGURE 8 The spinifex hopping mouse conserves water by producing almost solid urine.

CHECK YOUR LEARNING 5.2

Describe and explain

1 Describe the difference between positive and negative feedback loops.
2 Define 'homeostasis'.
3 Explain what is meant by thermoregulation.

Apply, analyse and compare

4 Explain how receptors in the skin can initiate sweating when the internal body temperature exceeds 37°C.
5 Apply your understanding of negative feedback to explain how water is reabsorbed when water levels in the blood are low.

Design and discuss

6 Draw a flow chart showing a stimulus–response pathway for a decrease in water concentration.
7 Refer to Case study 5.2 to discuss how desert animals have adapted to limited water availability.

5.3 Malfunctions in homeostatic mechanisms

KEY IDEAS

In this topic, you will learn that:

- homeostatic mechanisms can malfunction, which can result in type 1 diabetes, hypoglycaemia or hyperthyroidism.

disease
a failure of regular physiological function

Disease is a failure of regular physiological function that leads to negative effects in the body. Some diseases are caused by infection or injury; others are caused by the body's failure to maintain a constant internal environment. This can stop feedback loops functioning effectively, which are known as malfunctions in homeostatic mechanisms.

Type 1 diabetes

Diabetes is a disease caused by the body's inability to regulate blood glucose levels. Normally, the body regulates blood glucose levels with the hormones insulin and glucagon. In people with diabetes, the homeostatic mechanisms do not work efficiently, which can lead to permanent organ damage or even death without medical treatment.

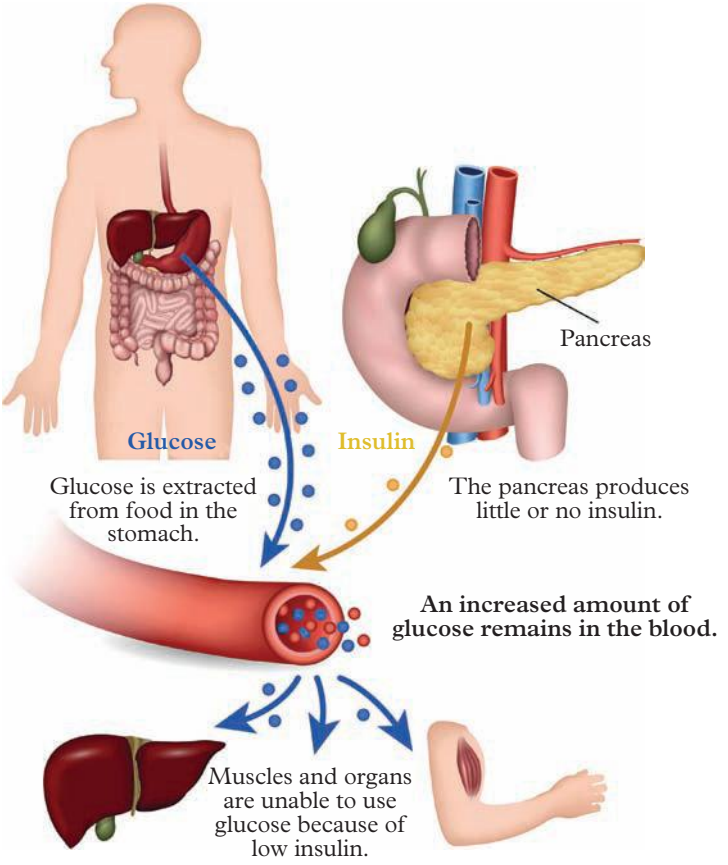


FIGURE 1 People with type 1 diabetes do not produce enough insulin, so they need to take in insulin by injection.

There are two main types of diabetes.

- **Type 1 diabetes** occurs when the pancreas cannot produce insulin because of an auto-immune disorder in which pancreas beta cells are destroyed. It is a common chronic childhood condition that represents about 10% of diabetes cases.
- Type 2 diabetes is characterised by consistently high blood glucose levels, which results in insulin resistance and blood sugar levels that never return to normal. Type 2 diabetes is a progressive disease, more common than type 1, and tends to be diagnosed in adults.

Insulin is secreted by the beta cells of the pancreas. Insulin moves around the body in the blood to its target cells in the liver, skeletal muscle and fat tissue. The various cellular responses of insulin act to lower blood glucose concentration.

People with type 1 diabetes produce immune cells that attack and destroy healthy beta cells. This means that little or no insulin is produced by the pancreas to reduce blood glucose levels (Figure 1). Patients cannot maintain blood glucose concentrations within the tolerance levels. This causes metabolic changes that result in weakened blood vessels and frequent urination, and over time causes serious damage to organs. Patients can be treated with insulin injections (Figure 2); however, if left untreated, the disease causes fatal damage to organs. Currently there is no cure, or prevention, for type 1 diabetes, only treatment.

FIGURE 2 Type 1 diabetes can be treated with insulin injections.

type 1 diabetes an autoimmune disease in which the person doesn't produce enough insulin to maintain blood glucose concentration

hypoglycaemia a condition in which blood glucose concentration drops too low

Hypoglycaemia

Hypoglycaemia is a condition in which blood glucose concentration drops below the tolerance range, below 72 mg/mL (Figure 3). This condition is a malfunction of blood glucose homeostasis. If hypoglycaemia is left untreated, blood glucose concentration continues to drop and the brain may not receive enough glucose. This can lead to unconsciousness or seizures. Hypoglycaemia is more common in people with diabetes; however, it can also occur in non-diabetic patients.

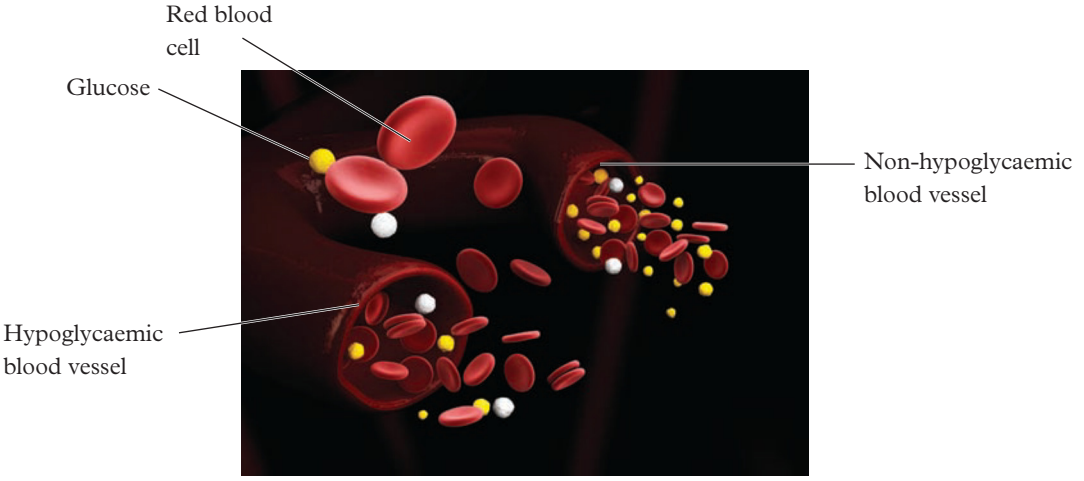


FIGURE 3 People with hypoglycaemia have low blood glucose concentrations.

FIGURE 4 People can check their blood glucose levels by pricking a finger with a lancet.

Hypoglycaemia can be caused by:

- a person with diabetes taking too much insulin
- fasting or missing a meal
- a diet that is too low in carbohydrates
- strenuous activity
- drinking alcohol.

People can check their blood glucose levels by a finger prick test (Figure 4). Early signs of hypoglycaemia are shaking, sweating, hunger, light-headedness, dizziness and weakness. Mild hypoglycaemia can be treated with 15 grams of fast-acting carbohydrates such as several jellybeans or a glass of soft drink. If blood glucose levels continue to drop, more severe symptoms include confusion, slurred speech, loss of consciousness, fitting and seizures. At this point, the patient cannot treat their own hypoglycaemia with fast-acting carbohydrates and instead requires an injection of the hormone glucagon. Glucagon raises the blood glucose levels and reverses severe hypoglycaemia.

hyperthyroidism a condition in which the thyroid is overactive and produces too many thyroid hormones

Hyperthyroidism

Hyperthyroidism is a malfunction of the endocrine system, when thyroid hormone levels are not maintained at an optimal level. It occurs when an overactive thyroid gland produces more thyroid hormones than needed. This increases the rate of metabolic reactions, and the body works harder and faster.

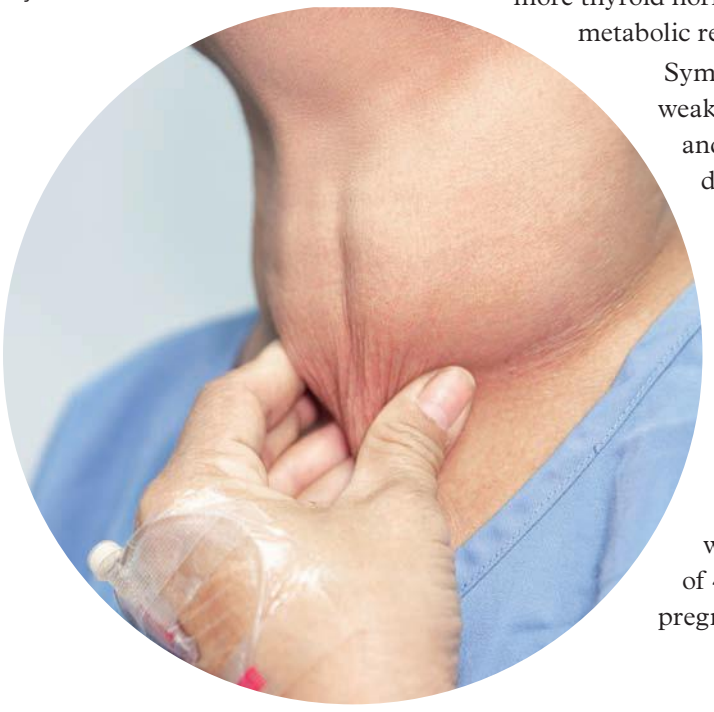


FIGURE 5 In hyperthyroidism, a goitre can develop as the thyroid gland enlarges.

Symptoms of hyperthyroidism include fatigue, muscle weakness, nervousness, rapid heartbeat, trouble sleeping and weight loss. People with hyperthyroidism may also develop a goitre if the condition is not managed or caught early. A goitre is an enlarged thyroid gland that appears as swelling of the neck (Figure 5).

Hyperthyroidism can be treated with medications that inhibit the production of thyroid hormones. This medication is called anti-thyroid medication. The most common cause of a malfunctioning thyroid is Graves' disease, which is caused by the body's immune system attacking the thyroid. Graves' disease is more common in women than in men, particularly women under the age of 40. Some women develop hyperthyroidism during pregnancy or after childbirth.

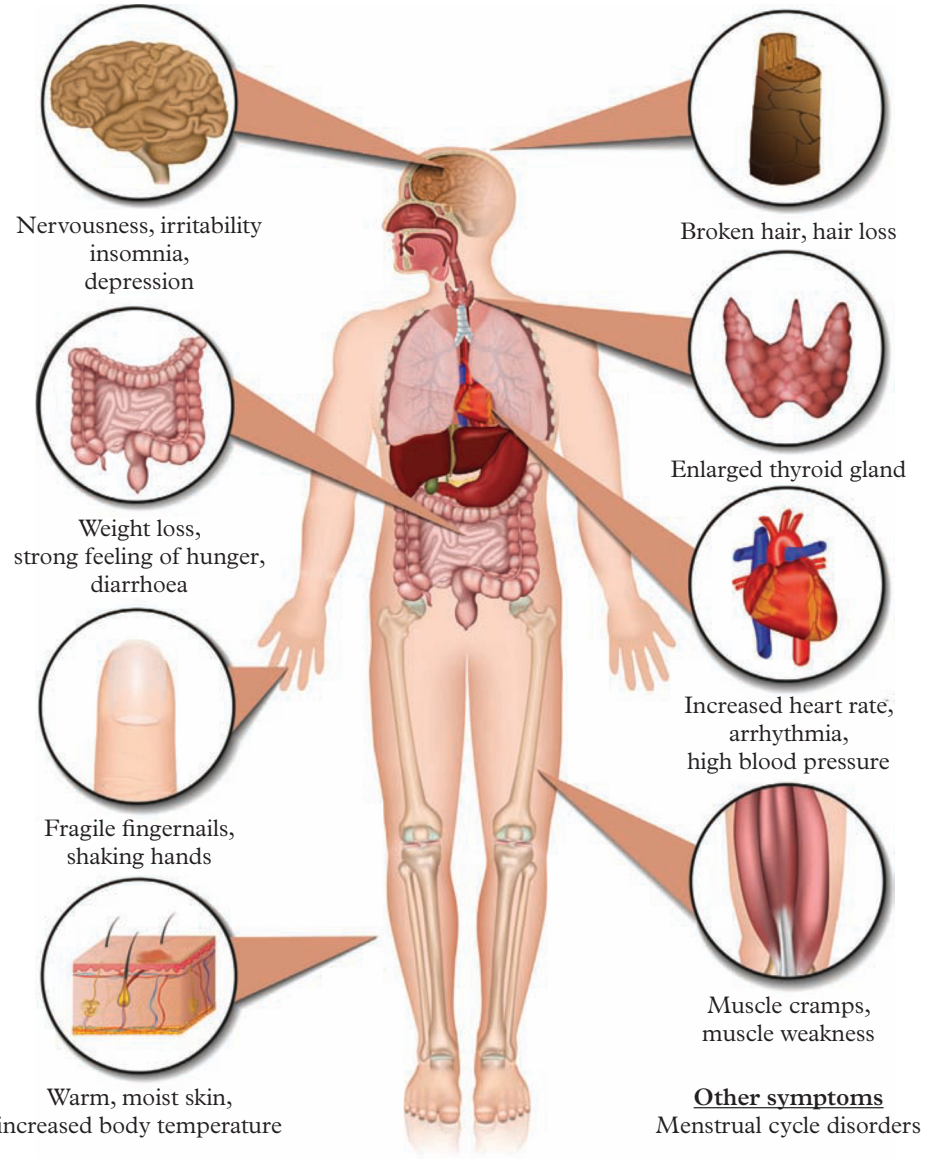


FIGURE 6 Symptoms of hyperthyroidism

CHECK YOUR LEARNING 5.3

Describe and explain

1 Describe the difference between type 1 and type 2 diabetes.
2 Name the homeostatic mechanism that is malfunctioning when type 1 diabetes develops.
3 Describe the symptoms of hyperthyroidism.
4 Identify the most likely cause of hyperthyroidism.

Apply, analyse and compare

5 Explain why type 1 diabetes is the most common cause of hypoglycaemia.
6 Explain how a source of fast-acting carbohydrate such as jellybeans works to return blood glucose to optimal levels in a patient suffering from hypoglycaemia.

Design and discuss

7 Discuss why homeostatic mechanisms are important for the survival of the organism, by referring to malfunction of homeostasis.

CHAPTER 5

Review

Chapter summary

5.1
- The balance of water in plants is maintained by the processes of transpiration and osmosis.
- Features of plants that are important in maintaining water balance are the waxy cuticle, stomata and roots.

5.2
- Homeostasis is the balance of an organism's internal environment and can be demonstrated by the stimulus–response model.
- Positive and negative feedback loops ensure that the body's internal environment returns to optimal levels when it is not balanced.
- Thermoregulation, blood glucose levels and water balance in humans are examples of how the stimulus–response model works.

5.3
- When the homeostatic mechanism malfunctions, diseases such as type 1 diabetes, hypoglycaemia and hyperthyroidism can result.

Revision questions

Multiple choice

1 Identify which of the following describes the movement of water and the stomata.
- **A** Water moves from guard cells to surrounding cells along a concentration gradient. Guard cells increase in turgor and the stomata open.
- **B** Water moves from the surrounding cells to the guard cells, which causes the guard cells to increase in size and close the stomata.
- **C** The guard cells become filled with water from surrounding epithelial tissue, becoming turgid. This causes them to curve away from each other and open the stomata.
- **D** The guard cells lose water to surrounding cells when there is limited water in the epithelial tissue. In response, the guard cells pull away from each other and the stomata open.

2 Identify which of the following would increase the rate of water loss from land plants.
- **A** Reduced number of stomata on the leaves of the plant
- **B** High humidity
- **C** Increased wind speed
- **D** Decreased temperature

3 Identify which of the following best describes homeostasis.
- **A** Altering the external environment to control the internal environment of an organism within narrow limits
- **B** Maintaining a constant internal environment of an organism within its tolerance range, despite changes to the external environment
- **C** Changing both the internal and external environments of an organism so that particular factors are maintained at optimal levels for survival and reproduction
- **D** Keeping the organism's internal environment in a fixed and unchanging state to ensure survival

4 Identify the homeostatic response that occurs when body temperature rises above 37.5°C.
- **A** Dilation of capillaries
- **B** Shivering of muscles
- **C** Constriction of capillaries
- **D** Reduced blood flow to capillaries

5 Identify which receptor only detects changes in temperature.
- **A** Thermoregulation
- **B** Osmoreceptor
- **C** Thermoreceptor
- **D** Skin receptor

6 Identify the control centre for most homeostatic mechanisms.
- **A** Pituitary gland
- **B** Pancreas
- **C** Hypothalamus
- **D** Spinal cord

7 A hormone is needed to raise blood glucose levels when they drop below the optimal level. The hormone is:
- **A** insulin, which is produced by beta cells of the pancreas
- **B** insulin, which is produced by alpha cells of the pancreas
- **C** glucagon, which is produced by beta cells of the pancreas
- **D** glucagon, which is produced by alpha cells of the pancreas.

8 ADH is produced in the:
- **A** pancreas
- **B** pituitary gland
- **C** hypothalamus
- **D** liver.

9 Identify what can be done to raise blood glucose levels in a person with severe hypoglycaemia.

A Give the person a glass of soft drink or a fast-acting carbohydrate.

B Inject the person with insulin.

C Give the person medication to inhibit the production of thyroid hormones.

D Inject the person with glucagon.

10 Identify which of the following are symptoms of hyperthyroidism.

A Weight loss and muscle weakness

B Hunger and sweating

C Unconsciousness and seizures

D Frequent urination and weakened blood vessels

Short answer

Describe and explain

11 Explain how water balance is regulated by the root systems of land plants.

12 Explain how the waxy cuticle prevents water loss in plants.

13 Describe three factors that affect the rate of water loss in vascular plants.

14 For the factors you identified in Question 13, describe how a vascular plant might counteract the effects of those factors to regulate water balance.

15 Explain how the roots of vascular plants use a solute concentration gradient to regulate water balance.

16 Describe negative feedback and give an example.

17 Explain why negative feedback is important for maintaining homeostasis.

18 Identify and describe the effector in the stimulus–response model for water balance in animals.

Apply, analyse and compare

19 Compare the two processes that control water regulation in plants.

20 Outline the role of blood vessels in the control of body temperature.

21 Produce a diagram that outlines how temperature is regulated in humans by negative feedback.

22 Aneta stands in the hot sun for hours on Athletics Day at her school. After competing in several events, her body needs to cool itself down.

a Identify the stimulus, receptors and control centre in this stimulus–response.

b Describe three possible effectors that Aneta's body might respond with to maintain homeostasis.

23 Eight-year old Kenny has just returned from a birthday party where he ate a lot of sugary treats. His blood glucose levels are very high.

a Identify the stimulus, receptors and control centre in this stimulus–response.

b Describe three possible effectors that Kenny's body might respond with to maintain homeostasis.

24 Describe what happens to urine produced by the kidney when osmolality is below the optimal level. Explain how this happens.

Design and discuss

25 Jenny is a marathon runner training for the Commonwealth Games. She lives in Melbourne and runs at least 100 km every week in preparation. The Commonwealth Games will be in Queensland and she is concerned about the humidity, which will be higher than in Victoria.

FIGURE 1 Jenny training for her marathon

a Explain how Jenny's body maintains thermoregulation when she is running and producing lots of heat through cellular respiration.

b Sweating is an important response to cool the body so that it doesn't overheat. Explain why this response would be less effective in a humid climate.

26 Type 1 diabetes is a malfunction of a homeostatic mechanism.

a Explain why people with type 1 diabetes are not able to regulate their blood glucose concentration.

b The graph in Figure 2 shows the blood glucose concentration (mg/mL) over a day with three meals.

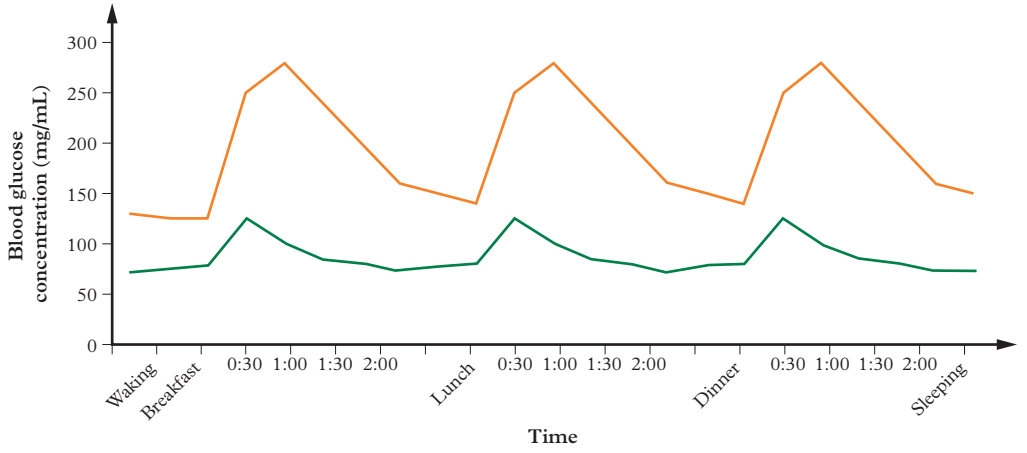


FIGURE 2 Blood glucose concentrations over a day for two people

i Identify the line in the graph that represents a person who has diabetes and the line that represents a person who does not have diabetes. Explain your answer.

ii Refer to Figure 2 to explain at which time(s) of the day insulin would be produced by the person who does not have diabetes.

c Draw a stimulus–response pathway for when the stimulus is an increase in blood glucose concentration in a person who does not have diabetes.

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Check understanding of this chapter.

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Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to read graphs and interpret data. You may need to describe the shape of the graph. This means you will need to use the information that you are given to show that you understand the data.

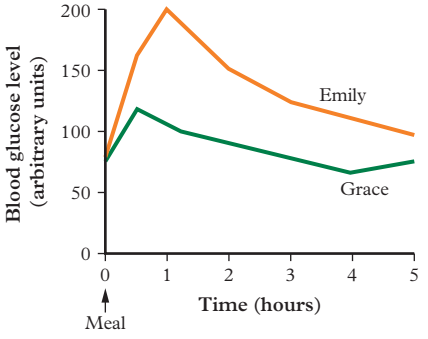
'Use the data to ...'

When you are asked to 'use the data' from a graph, it means you need to provide numbers or values from the graph and relate them to the titles on the axes.

To do this, you can create different sections on the graph. If the line of the graph slopes upwards, this may become section 1. If the graph then becomes flat, this may become a different section. Each section can be described individually to show that you understand what the data means.

QUESTION 1bi (2010 Biology Written Examination 1)

Blood glucose levels are controlled by a homeostatic mechanism. Two females of the same age and similar body structure were each given an identical meal. The following graph shows the level of blood glucose in each female for the five-hour period after eating the meal.



b i Explain whether Emily or Grace had a defect in the blood-glucose homeostatic mechanism. Refer to at least two parts of the graph to support your answer. 2 marks

Source: 2010 Biology Written Examination 1, Question 1bi, Short answer, reproduced by permission © VCAA

Response 1

Both Emily and Grace's blood glucose levels increase in the first hour after eating and then decrease over the next five hours. Emily's blood glucose levels go higher (200 units) compared to Grace's (130 units). Emily's take more than 5 hours to return to normal, while Grace's return to normal in 4 hours. Therefore, Emily has the defect in blood-glucose homeostatic mechanism.

Data from the two graphs is described and compared. This is the explanation.

This is the answer from the data.

This response would receive full marks. It uses the data in the graph to provide all information required by the question.

Response 2

Emily's blood sugar level started high and returned to normal.

This comment could describe both graphs and does not provide the numbers or data from the graph.

This response does not refer to the graph as required by the question and would not receive any marks.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 8a (2008 Biology Written Examination 1)

a Name a homeostatic system you have studied this year. Draw a labelled diagram outlining how the system operates. 3 marks

Blood glucose levels. When they are high, the body acts to return the glucose levels back to normal again.

Source: 2008 Biology Written Examination 1, Question 8a, Short answer, reproduced by permission © VCAA

Marking guide

8a	1 mark for the name of a stimulus of the example. 1 mark for the description of the effector and the way it responds. 1 mark for the indication of negative feedback in the response

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 an examiner.

Check your Student obook pro for the following digital resources and more:

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Past examinations and examiners' reports

UNIT 1

Practice exam questions

Multiple choice **(Total = 10 marks, 1 mark per question)**

1 All cells contain:
- **A** a nucleus, cytoplasm and genetic material
- **B** genetic material, cytosol and a cell membrane
- **C** cytoplasm, genetic material and organelles
- **D** organelles, a cell wall and genetic material.

2 A prokaryote:
- **A** has a large surface area to volume ratio
- **B** has a small surface area to volume ratio
- **C** does not need to consider surface area to volume ratios
- **D** has a smaller surface area to volume ratio than that of eukaryotes.

3 Identify the organelles labelled M, N and O in Figure 1.

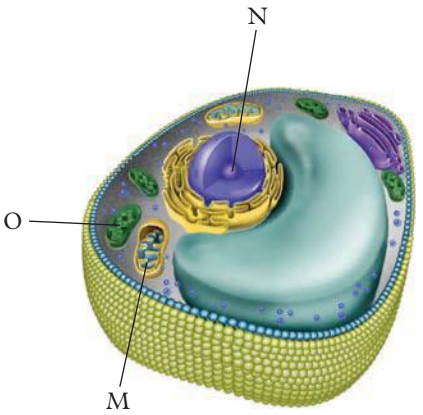


FIGURE 1 Identify M, N and O.

	M	N	O
A	Golgi apparatus	mitochondrion	nucleus
B	mitochondrion	nucleus	chloroplast
C	nucleus	chloroplast	mitochondrion
D	vacuole	nucleus	endoplasmic reticulum

4 Prokaryotic cells reproduce through:
- **A** mitosis
- **B** cytokinesis
- **C** binary fission
- **D** apoptosis.

5 The correct order of the sub-phases of mitosis is:
- **A** interphase, prophase, metaphase, anaphase and telophase
- **B** prophase, interphase, telophase and metaphase
- **C** anaphase, metaphase, prophase and interphase
- **D** prophase, metaphase, anaphase and telophase.

6 A stem cell that can develop into any cell in an organism is called:
- **A** pluripotent
- **B** totipotent
- **C** differentiated
- **D** specialised.

7 Identify which of the following describes the organisation of the body from smallest to largest unit.
- **A** System, organ, tissue, cell
- **B** Cell, tissue, system, organ
- **C** Organ, system, tissue, cell
- **D** Cell, tissue, organ, system

8 The role of the excretory system is to:
- **A** collect and eliminate wastes from the body
- **B** produce hormones that regulate the body
- **C** digest and absorb nutrients from food
- **D** store waste products from food.

9 Identify which of the following prevents water loss in a plant.

A Closing the guard cells in a leaf

B Increasing the amount of water absorbed by the roots

C Locating stomata on the top surface of a leaf

D Increasing the movement of water in the xylem

10 Which of the following is an example of negative feedback at high temperatures?

A Shivering

B Constriction of blood vessels

C Release of insulin

D Sweating

Short answer (Total = 20 marks)

QUESTION 11 (6 marks)

A student set up an experiment to determine the effect of sprinkling sugar over the surface of strawberries. The student washed 12 small strawberries in tap water, patted them dry and then weighed them. Four of the strawberries were coated with a teaspoon of sugar, four strawberries were placed in distilled water, and four strawberries were left on a plate at room temperature. After 30 minutes, all the strawberries were washed in tap water again, patted dry and weighed. The results of the experiment are shown in Table 1.

a Name the independent variable for the experiment. 1 mark

b Name the dependent variable for the experiment. 1 mark

c Explain why the average mass of four strawberries was used instead of the mass of a single strawberry. 2 marks

d Explain the change in mass of the sugar-coated strawberries. 2 marks

QUESTION 12 (6 marks)

An anatomical pathologist was using a microscope to examine a sample of tissue taken from a patient with suspected cancer.

a Identify whether the pathologist would expect to see many cells undergoing apoptosis if the tissue contained cancer cells. Justify your answer. 3 marks

b Identify whether the pathologist would expect to see many cells undergoing mitosis if the tissue contained cancer cells. Justify your answer. 3 marks

QUESTION 13 (4 marks)

The roots of two groups of pea plants were placed in radiolabelled water for 15 minutes. Small amounts of the radiolabelled water were found in the plants' leaves.

a Explain how the radiolabelled water was able to reach the leaves of the plant. 2 marks

b Over the next three days, the radiolabelled hydrogen in the water was found in the cell walls of the plant. Explain how the radiolabelled hydrogen was able to move to the cell walls. 2 marks

QUESTION 14 (4 marks)

In the human body, the concentration of glucose is kept within a narrow range. All cells in the body need a continuous supply of glucose for the production of ATP. The uptake of glucose occurs by facilitated diffusion.

a Define 'facilitated diffusion', using glucose as an example. 2 marks

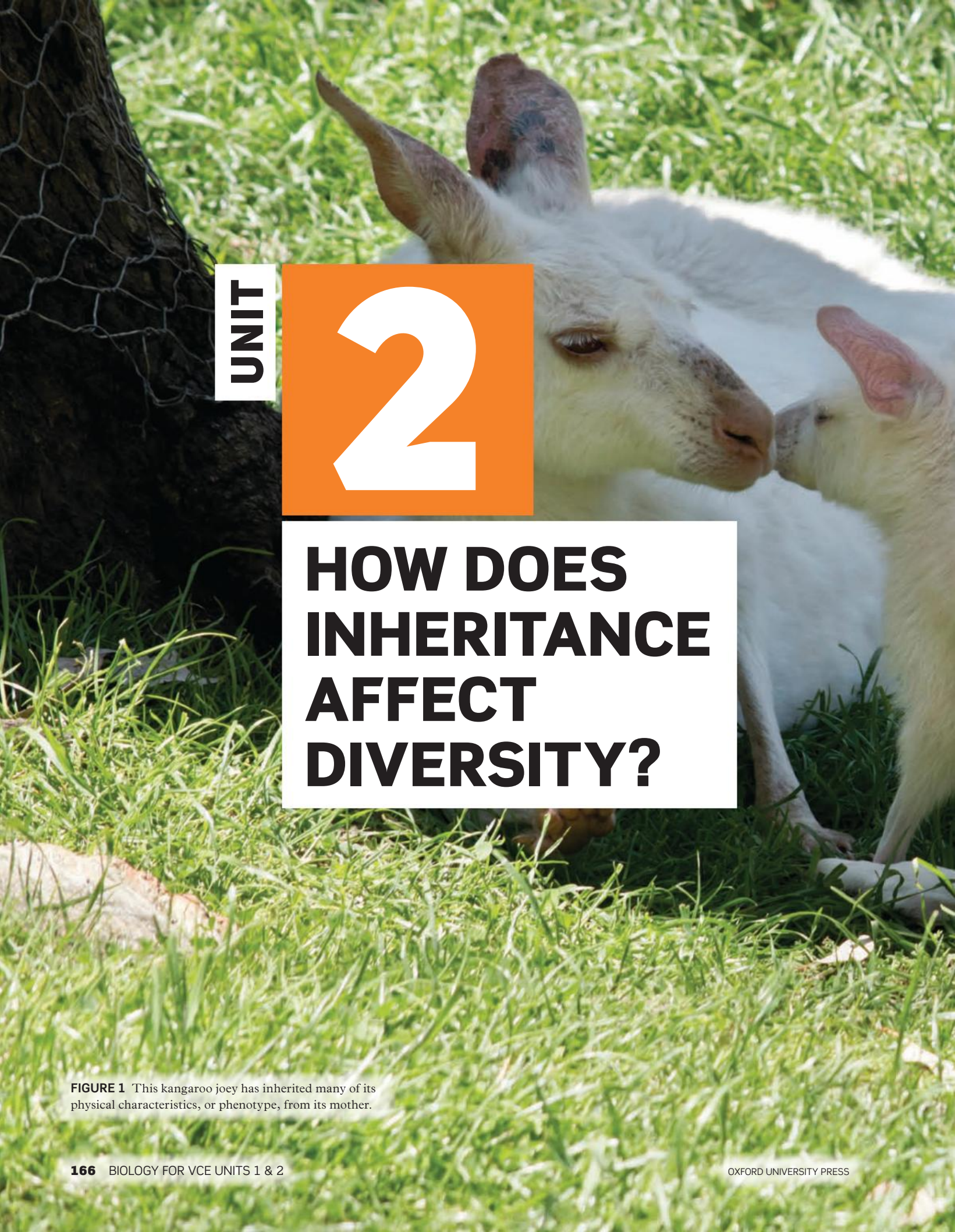
b To prevent the concentration of blood glucose becoming too low, the pancreas releases a hormone.

i Name this hormone. 1 mark

ii Identify the target organ for this hormone. 1 mark

TABLE 1 Results of the effect of sugar on strawberries

Treatment of strawberries	Average starting mass (g)	Average mass after 30 min (g)	Average difference in mass (g)
Sugar coated	7.23	6.80	−0.43
Distilled water	6.91	7.42	+0.51
Left on plate	7.30	7.25	−0.05



UNIT 2

HOW DOES INHERITANCE AFFECT DIVERSITY?

FIGURE 1 This kangaroo joey has inherited many of its physical characteristics, or phenotype, from its mother.

DNA is the molecule that transfers genetic information from parents to offspring. Each molecule is made up of a series of genes that control the structure and function of the organism. Pedigree charts and genetic crosses can be used to examine the inheritance of these physical characteristics. The environment can also affect how the organism grows and survives.

The characteristics of organisms include adaptations that help them to survive in an interdependent environment. The way organisms reproduce can affect the diversity and rate at which a population can increase its size or density. Aboriginal and Torres Strait Islander Peoples' knowledge and perspectives have contributed to understanding the diverse roles, interdependencies and survival of organisms in the Australian environment.

Outcomes

On completion of this unit, students should be able to:

→ explain how sexual reproduction influences the inheritance of genes and analyse pedigree charts to predict the outcome of genetic crosses

→ explain how genetic diversity and adaptations of top predators and keystone species affect the interdependence of populations

→ apply their genetic knowledge to a bioethical issue.

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Area of Study 1	How is inheritance explained?	Chapters 6–8, pages 168–241
Area of Study 2	How do inherited adaptations impact on diversity?	Chapters 9 and 10, pages 242–295

CHAPTER 6

Chromosomes and genomes

Chromosomes are located in the nuclei of cells and are made of DNA and protein. Human cells have 23 pairs of chromosome, including one pair of sex chromosomes. The Human Genome Project identified 20 000–25 000 operational genes in humans. Between those functional genes there are also many non-functional genes that belong to our evolutionary path through time. Variations of these genes are passed down to offspring via gametes. Gametes (egg and sperm) are genetically different from one another, which ensures variation in offspring.

You have two sets of chromosomes in your body cells: one set from your mother and one set from your father. For this reason, there are two copies of every gene in your somatic (body) cells. The alternative versions of a gene are referred to as alleles.

The chromosomes of different organisms are different in size and number, which can be seen in an organism's karyotype. Karyotypes can also be used to identify chromosome abnormalities, such as Down syndrome and Edwards syndrome.

The total DNA in the cell of an organism is known as the genome. It is important to identify the genes and determine their function to make advances in medical diagnosis and treatment.

KEY KNOWLEDGE

- → the distinction between genes, alleles and a genome
- → the nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- → variability of chromosomes in terms of size and number in different organisms
- → karyotypes as a visual representation that can be used to identify chromosome abnormalities
- → the production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity

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FIGURE 1 Chromosomes are structures in cells that package DNA.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

6A Describe the structure of a DNA molecule.

6A Groundwork resource
DNA

6B Define 'gene' and 'protein'.

6B Groundwork resource
Genes

6C Compare prokaryotic and eukaryotic cells.

6C Groundwork resource
Prokaryotes and eukaryotes

6D Explain what occurs during interphase of the cell cycle.

6D Groundwork resource
The cell cycle

PRACTICALS

NO-TECH PRACTICAL	**6.4** Modelling the movement of alleles in meiosis

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your Student obook pro.

6.1 Genes, alleles and genomes

KEY IDEAS

In this topic, you will learn that:

+ genes are the basic unit of heredity and carry instructions for a trait
+ alleles are the different forms of a gene
+ the genome is the complete set of genetic information within a cell.

All organisms pass on their genetic material through DNA. When a cell is functioning normally (producing protein from genes), the DNA that makes up the genes is loosely wound around proteins to form a complex called chromatin. When a cell is about to replicate itself, it needs to package the DNA by winding it more tightly around the proteins so that it does not become tangled. These tightly wound strands of DNA and protein are called chromosomes.

Genes

gene
a section of DNA that has a functional purpose, such as coding for a protein that determines a trait

gene expression
the process of converting the instructions in a gene to a product, which is usually a protein

enzyme
a protein that speeds up biochemical reactions

allele
an alternative form of a gene

Genes are small sections of deoxyribonucleic acid (DNA) and are the unit of heredity. They carry the instructions of an organism and are passed on to offspring through sexual reproduction. Genes vary in length from approximately 200 DNA base pairs to more than 2 000 000 base pairs. Long strands of DNA with many genes make up chromosomes.

Genes have a unique DNA sequence with instructions that allow the cell to produce a specific product, usually a protein, which gives rise to a characteristic or trait. The process of reading the instructions of a gene and producing a protein is known as **gene expression**. Genes affect many factors, such as a person's hair colour or the diseases they might develop.

Proteins are the key molecules that allow cells to function and interact with each other. Each organism has a set of unique proteins that have a variety of functions.

- **Enzymes** speed up chemical reactions within the body.
- Carrier proteins assist with transport of small molecules either through cell membranes or throughout the body (e.g. haemoglobin in red blood cells carries oxygen).
- Structural proteins provide support for cells.
- Antibody proteins assist in the immune response.
- Hormones and other protein messengers transmit signals around the body.

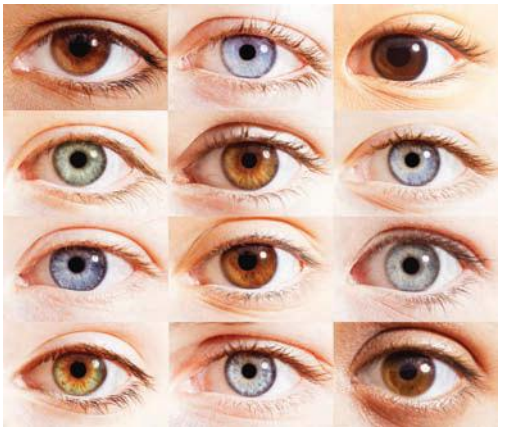


FIGURE 1 There are many alleles for eye colour.

Alleles

Each person has two copies of every gene, one inherited from each parent. These two copies may be the same as or different from each other and are known as **alleles**. Alleles are the different variations of a gene. Although there may be a variety of alleles for a gene, an individual carries two alleles for each gene, one on each matching chromosome. For every gene (e.g. eye colour, fur colour) there are two alleles and these can be the same or different. For example, an individual may have an allele for brown eyes and an allele for blue eyes, as well as two alleles for orange fur. The combination of different alleles for a single gene is responsible for an organism's unique physical traits.

Genome

The **genome** is all the DNA in one complete set of chromosomes in an organism. This includes all the base pairs contained in the set of chromosomes in the organism's **somatic cells** (non-reproductive cells). This is measured by the number of base pairs contained in one set of chromosomes.

Genomics is the study of genomes, particularly how genomes differ between species. The entire human genome was sequenced in 2003 by the Human Genome Project – an international collaboration of scientists. This project has revealed a DNA sequence for the human genome that makes up 3 billion base pairs. You can access this sequence freely from an online database. From this data, scientists have estimated that there are about 20 000 genes in the human genome (Figure 2). The next goal for geneticists is to identify all of the human genes and determine their function. Identifying the DNA sequence, genes and their function opens the door for research into new strategies for diagnosis, treatment and prevention of diseases and disorders.

genome
the complete set of genetic material in a cell of an organism

somatic cell
a cell in an organism other than the reproductive cells

genomics
a branch of biology that investigates genomes

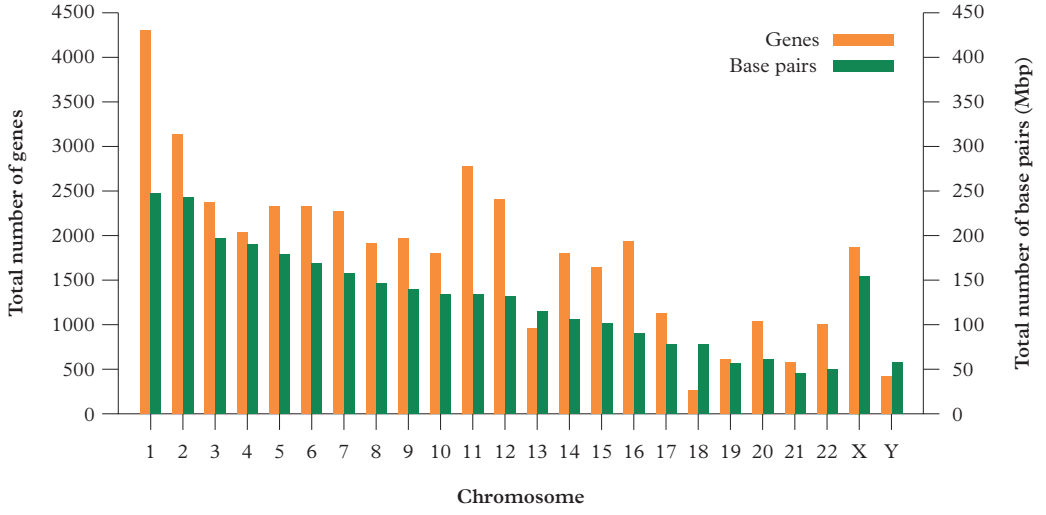


FIGURE 2 There are 20 000 genes in the human genome spread over the 24 different chromosomes (22 non-sex chromosomes and two sex chromosomes) (Mbp = mega-base pairs, 1 Mbp = 1 000 000 base pairs).

Study tip

Do not confuse the terms 'gene' and 'allele'. The gene is the trait and the alleles are the alternative forms.

CHECK YOUR LEARNING 6.1

Describe and explain

1 Explain why there are two alleles for each gene.

2 Define 'genome'.

Apply, analyse and compare

3 Use Figure 2 to determine approximately how many:

a genes are located on chromosome 7

b base pairs make up chromosome 13.

4 Explain why it was important to sequence the entire human genome.

5 Use a diagram to compare genes and alleles.

Design and discuss

6 Discuss three reasons why protein production is essential for the survival of a living organism.

6.2 Variability of chromosomes

KEY IDEAS

In this topic, you will learn that:

- chromosomes contain DNA and proteins, and occur in both prokaryotic and eukaryotic cells
- homologous chromosomes are pairs of chromosomes, one from the mother and one from the father, with the same gene loci
- chromosomes are either autosomes or sex chromosomes
- the structure, size, shape and number of chromosomes vary in different species.

Chromosomes

Chromosomes vary in size, structure and number across different organisms. Chromosomes are organised structures that contain the genetic material deoxyribonucleic acid (DNA) and associated proteins.

Prokaryotic cells (e.g. bacterial cells) have a single circular chromosome. Eukaryotic cells have linear chromosomes, which are located in the nucleus, as shown in Figure 1.

Prokaryotic chromosomes

Prokaryotic cells do not contain a nucleus, so the circular chromosome is not located in a membrane-bound structure but instead is found in a distinct region known as the nucleoid

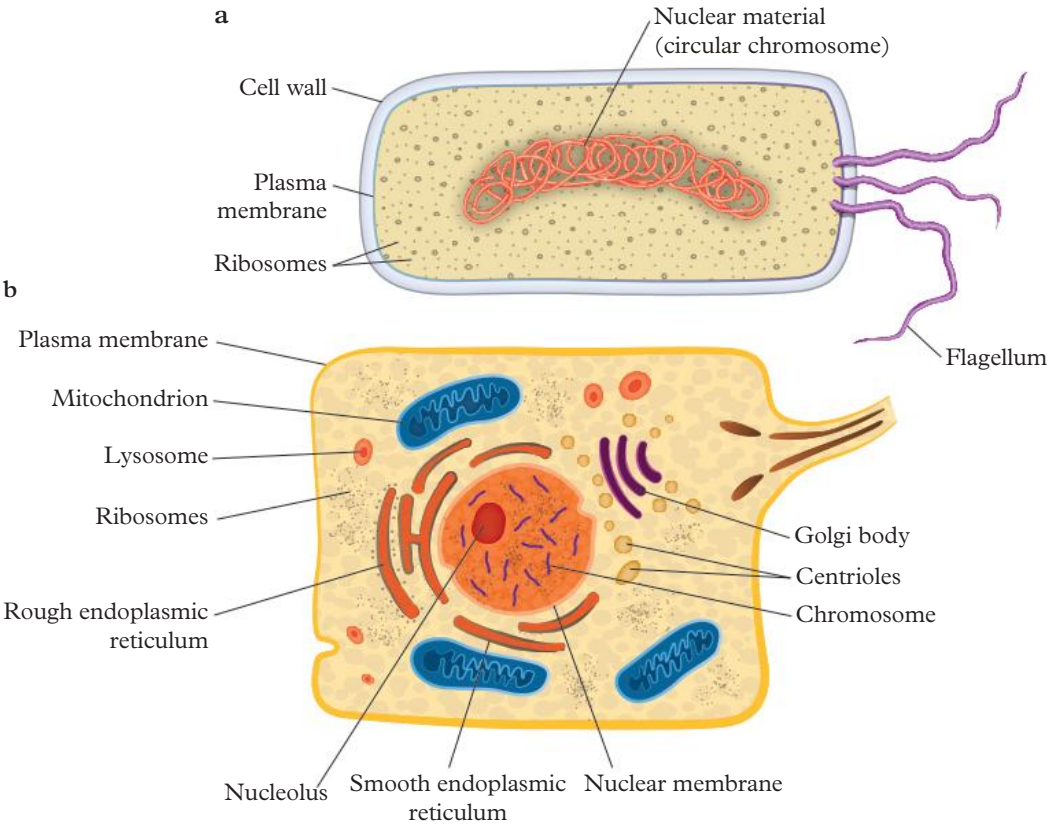


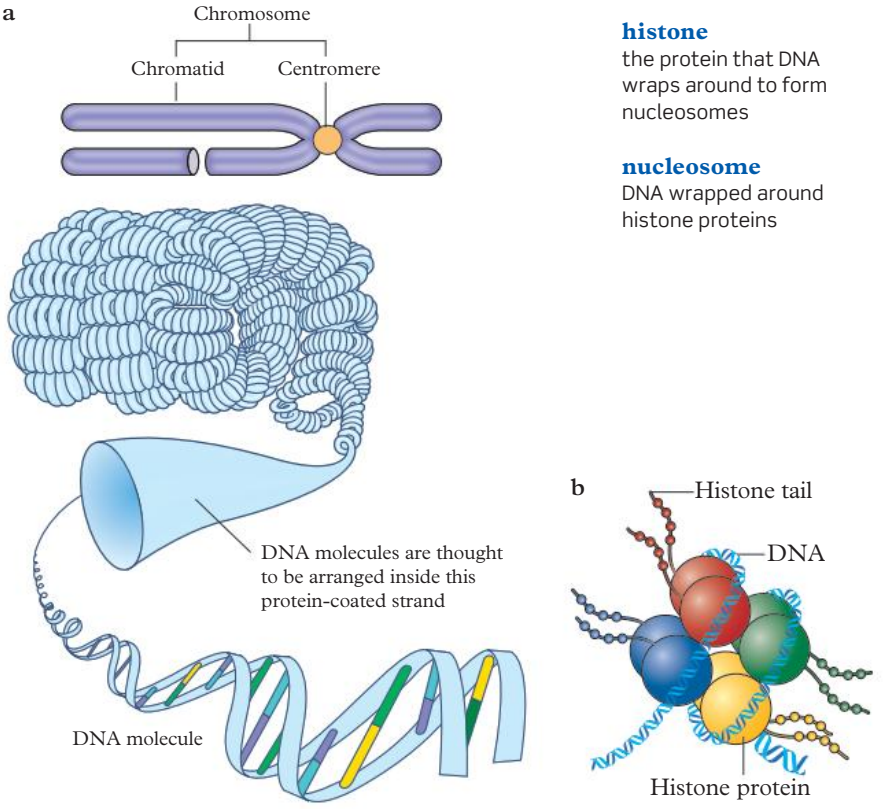
FIGURE 1 **a** Prokaryotic cells contain a single circular chromosome (shown here coiled up). **b** Eukaryotic cells contain sets of linear chromosomes located in the nucleus.

(see Chapter 2). Prokaryotic cells also contain additional genetic material in plasmids, which are small rings of DNA. Plasmids mostly contain non-essential genes and replicate independently of the single circular chromosome. They are also used in genetic engineering, which is explained in detail in Unit 3.

Eukaryotic chromosomes

In eukaryotic organisms, chromosomes contain DNA coiled around small proteins called **histones** to form a DNA–histone complex known as a **nucleosome**. The coiled DNA is about 2 metres long and the chromosomes package the DNA within the nucleus and protect the DNA from being broken down by enzymes.

When the cell is preparing to divide, the chromosomes condense and become visible in the cell. Chromosomes can be viewed under a light microscope at high magnification if the cell is stained. When the cell is not preparing to divide, the chromosomes are not condensed and DNA is only visible as a grainy substance without any detail (Figure 3). Uncondensed DNA is known as chromatin and is located in the nucleus of eukaryotic cells and consists of DNA coiled around histone proteins.



histone
the protein that DNA wraps around to form nucleosomes

nucleosome
DNA wrapped around histone proteins

FIGURE 2 **a** Chromosomes contain DNA that is coiled around histone proteins, forming **b** nucleosomes.

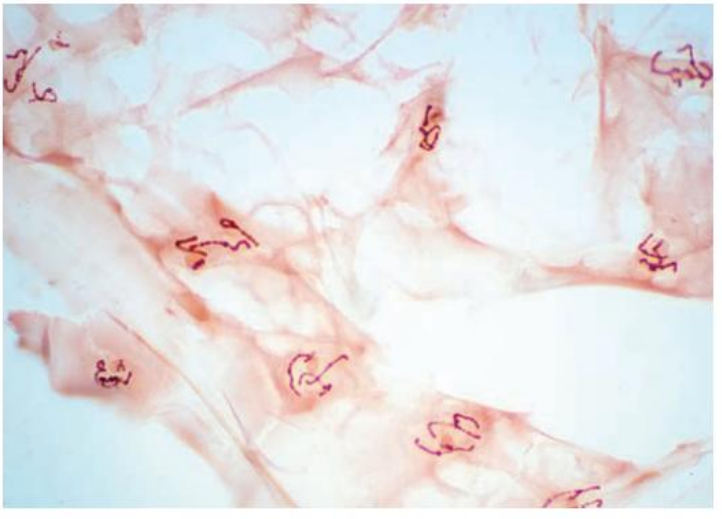


FIGURE 3 Dyed DNA found in saliva (in buccal epithelial and white blood cells) under a light microscope

Study tip

Chromosomes consist of tightly wound chromatin, which contains DNA wrapped around histone proteins.

Structure of chromosomes

Linear eukaryotic chromosomes consist of condensed DNA and histone proteins. Each chromosome has a centromere, a protein that denotes the joining of the two arms or two sister chromatids. This constriction point is not always at the centre of the chromosomes. The regions either side of the centromere are called the chromosome arms. The shorter arm is known as the p arm and the longer arm is known as the q arm (Figure 4).

Chromosomes are either unduplicated (singular) or bivalent where they contain two sister chromatids in a form ready for cell division.

Study tip

Bivalent chromosomes contain two chromatids; unduplicated chromosomes do not contain chromatids.

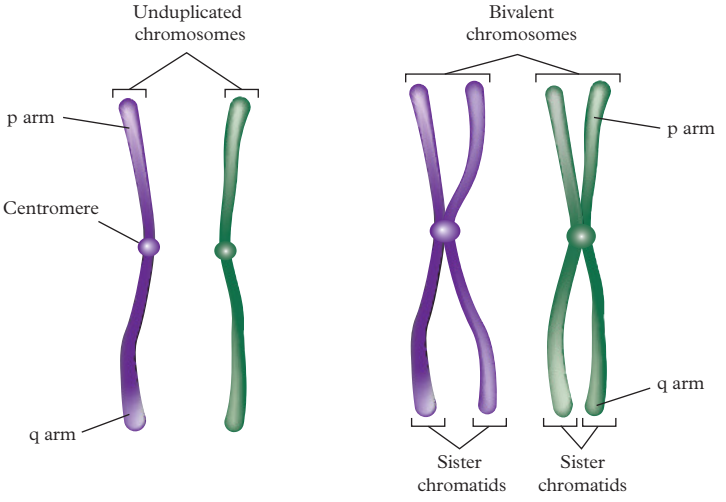


FIGURE 4 An unduplicated chromosome and a bivalent chromosome with two sister chromatids, both containing a centromere and p and q arms.

Chromosomes can be named according to the position of the centromere. There are four major types of chromosomes: metacentric, submetacentric, acrocentric and telocentric. These are shown in Figure 5.

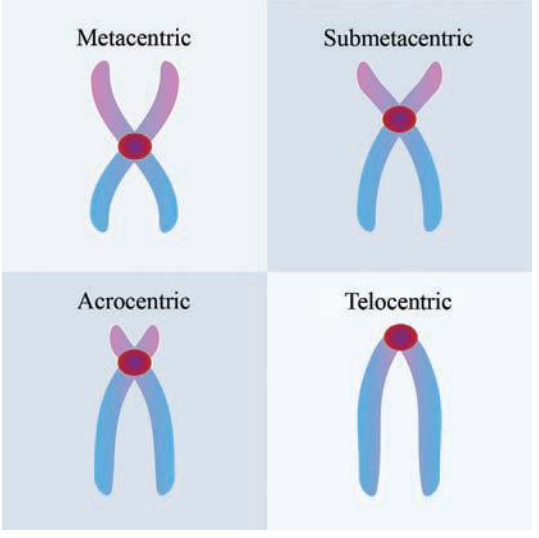


FIGURE 5 There are four main types of chromosomes based on the location of the centromere and hence the length of the chromosome arms.

FIGURE 6 A 3D rendering of chromosome structure.

Homologous chromosomes

Chromosomes vary in size, structure and number across different organisms. Humans have 46 chromosomes found as 23 pairs. Of those chromosomes, 23 chromosomes are inherited from the mother, and 23 are inherited from the father. Since there are two copies of each chromosome (one from the mother and one from the father), they form matching pairs. These matching pairs of chromosomes that are the same length and have centromeres and genes in identical positions are known as **homologous chromosomes**.

homologous chromosomes
a pair of chromosomes, one maternal and one paternal, that have the same number and position of genes

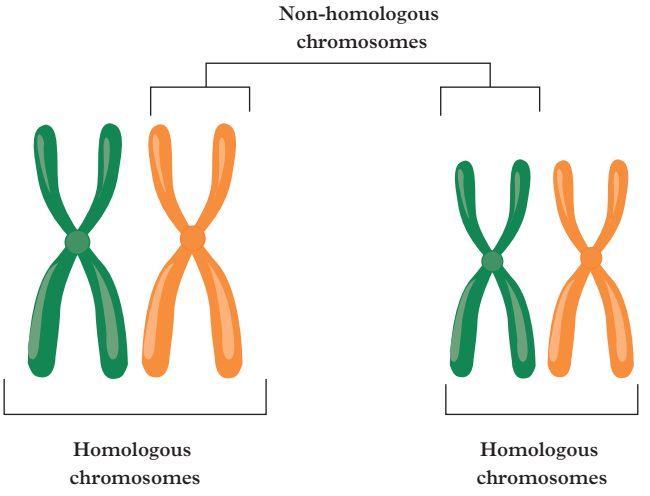


FIGURE 7 Two pairs of homologous chromosomes in their bivalent form (green are from the mother and orange are from the father). One chromosome from each pair is considered non-homologous.

Homologous chromosomes are the same size and structure. They carry the same genes at the same **locus** (plural: loci), the position of a gene, as shown in Figure 8.

locus
the location of a gene on a chromosome

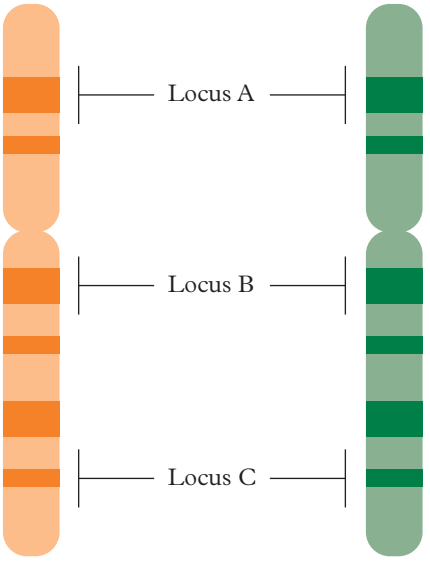


FIGURE 8 Homologous chromosomes have the same gene loci.

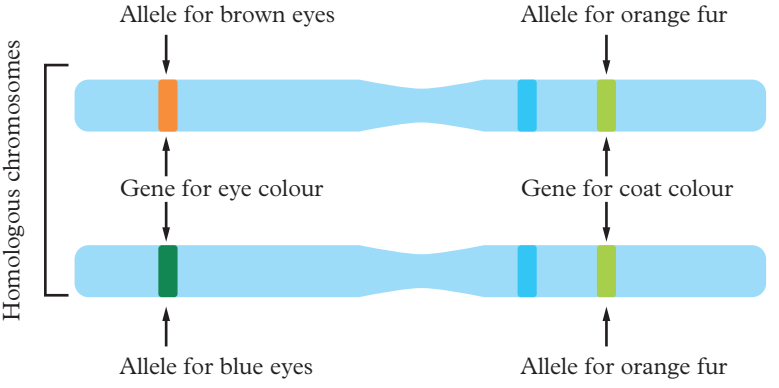


FIGURE 9 Each of these homologous chromosomes has an allele for a gene.

Autosomes and sex chromosomes

sex chromosome
a chromosome that determines the sex of an organism

autosome
a chromosome that is not involved in sex determination

There are 23 pairs of chromosomes in humans. Of these, one pair consists of two **sex chromosomes**, which determine the sex of the person. The other 22 pairs are known as **autosomes**, which are not involved in determining sex. In a cell containing two sets of chromosomes, each autosome has a homologous pair. Autosomes are numbered from 1 to 22 according to size, where chromosome 1 is the largest and chromosome 22 is the smallest.

In humans and other mammals, the two sex chromosomes are called the X and Y chromosomes (Figure 10). The X chromosome is much larger than the Y chromosome and contains approximately 1400 genes. Few, if any, of those genes are directly involved in sex determination. The Y chromosome contains approximately 200 genes. The presence or absence of the Y chromosomes determines the sex of the individual. In humans, the Y chromosome carries the *SRY* gene, which triggers male development, as well as other genes that enable sperm production. These traits, inherited via the Y chromosome, are referred to as Y-linked traits.

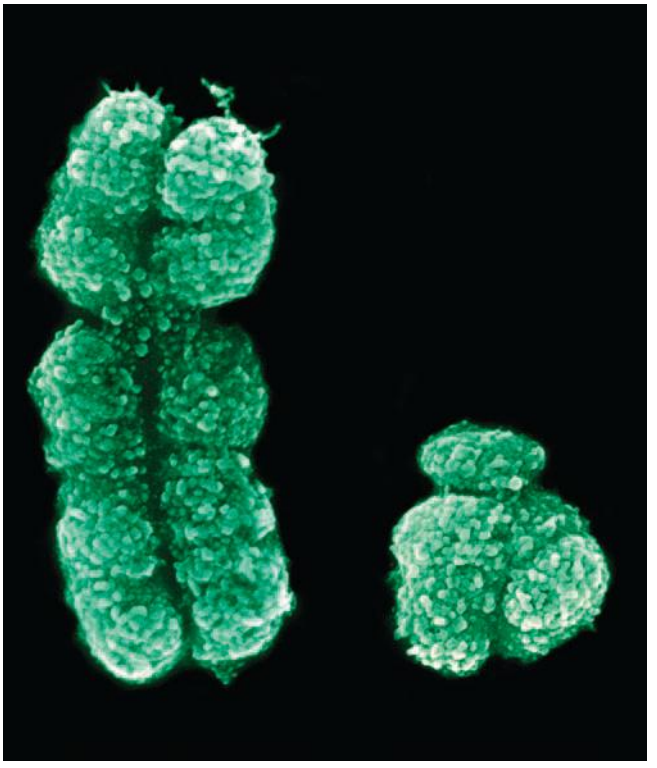


FIGURE 10 A scanning electron microscope image of X and Y chromosomes: the X chromosome (left) is submetacentric and the Y chromosome (right) is acrocentric.

Sex determination

homogametic
an organism that has two of the same sex chromosomes, e.g. XX

heterogametic
an organism that has two different sex chromosomes, e.g. XY

In humans, females have two X chromosomes (XX). Males have one X and one Y chromosome (XY) (Figure 11). If individuals have two sex chromosomes the same, they are considered **homogametic**. If an individual has two different sex chromosomes, they are considered **heterogametic**. Homogametic individuals produce only one kind of gamete, whereas heterogametic individuals produce two kinds of gametes. Both human males and females retain one of their mother's X chromosomes. Females receive their second X chromosome from their father and males receive their Y chromosome from their father.

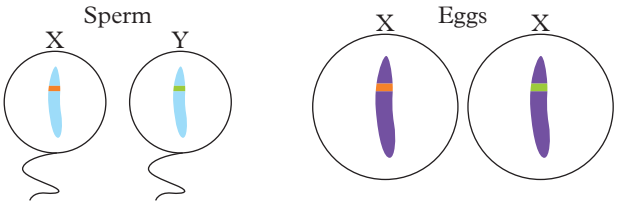


FIGURE 11 The sex of offspring is determined by the sex chromosome carried by the father's sperm cell. The sperm can have either the X or the Y chromosome when it enters the ovum. The mother's ovum always carries an X chromosome.

Sex determination systems

Other organisms have different types of sex chromosomes, and some organisms do not have any sex chromosomes; for example, fungi and algae. Birds, butterflies and strawberries have a Z and a W sex chromosome, where females have two different sex chromosomes (ZW), and males have two of the same (ZZ) (Table 1).

TABLE 1 Different sex chromosomes of different species

Organisms	Sex chromosomes	Female	Male
Humans, mammals, fruit flies and plants	X and Y	XX	XY
Grasshoppers and some other insects	X and O	XX	XO
Birds, butterflies, strawberries	Z and W	ZW	ZZ

CASE STUDY 6.2

X-inactivation

During early embryonic development, one of the X chromosomes in each female cell is randomly inactivated. This is known as **X-inactivation** (or lyonisation) after the English geneticist, Mary F. Lyon, who discovered it.

It is important that one of the X chromosomes inactivates because one X chromosome contains the correct amount of genes that need to be expressed. If this process didn't occur, then females would have too many X-linked genes being expressed.

Randomly, one of the X chromosomes makes a small dense ball-like structure called a **Barr body**. Because the Barr body is so condensed and compacted, it is unlikely that the genes are expressed and so it is considered inactive. The X chromosome that becomes

FIGURE 12 Geneticist Mary F. Lyon

X-inactivation
the process by which one X chromosome in females is inactivated

Barr body
a small dense structure containing an inactivated X chromosome

inactive is random and this occurs in the individual cells of the developing embryo. All the cells that descend from these original cells will maintain the same inactivated X chromosome.

An example of X-inactivation is seen in tortoiseshell cats. In cats, one of the genes that controls fur colour is located on the X chromosome and can be either orange or black. Female cats that have one X chromosome with the orange and one with the black will have a tortoiseshell appearance as seen in Figure 13.

FIGURE 13 The orange and black fur colour of tortoiseshell cats provides a visual representation of X-inactivation.

This is because during embryonic development, when X-inactivation occurs, different X chromosomes are inactivated in different cells. In some cells, the X chromosome with the orange fur colour is inactivated, and in other cells, the X chromosome with the black fur colour is inactivated. This means that skin tissue that arises from the cells will be either black or orange. This is known as mosaic expression.

Variability of chromosomes

There are 23 pairs of chromosomes in most human somatic cells and they vary greatly in size and shape. Chromosome 1 is the largest human chromosome and has about 3000 genes. There are approximately 20 000 genes across all of the chromosomes. Two genes located close together on the same chromosome are said to be **linked genes**.

linked genes
genes located close together on the same chromosome that are generally inherited together

Different species have different numbers of chromosomes. The number of chromosomes in the nucleus of a somatic cell is characteristic of the species. As shown in Table 2, there is a wide variety of chromosome numbers in eukaryotic organisms.

TABLE 2 The chromosome numbers of different species

	Scientific name	Common name	Chromosome number (somatic cell)	Estimated number of genes
Animals	*Parascaris equorum*	Horse nematode worm	2	14 000
	Musca domestica	House fly	12	14 000
	Felis domesticus	Cat	38	20 000
	Rattus norvegicus	Rat	42	23 000
	Homo sapiens	Human	46	22 000
	Capra hircus	Goat	60	21 000
Plants	*Daucus carota*	Carrot	20	32 000
	Oryza sativa	Rice	24	36 000
	Ophioglossum reticulatum	Coconut palm	1260	28 000

Mitochondrial and chloroplast chromosomes

Mitochondria and chloroplasts are membrane-bound organelles found in eukaryotic cells. Both of these organelles contain their own chromosomes, which are singular and circular, resembling those found in prokaryotic cells.

Plant cells that have chloroplasts contain chloroplast DNA (cpDNA), which consists of about 100 genes that code for proteins involved in photosynthesis. Mitochondria are found in most eukaryotic cells and contain mitochondrial DNA (mtDNA). Some of the genes on this chromosome code for proteins that make up the mitochondrion. mtDNA is commonly used by scientists to track the maternal ancestors of animals because the mtDNA is inherited through the mother's egg cell. Sperm mitochondria do not become part of the developing embryo because the mitochondria are mainly separate from the sperm's DNA.

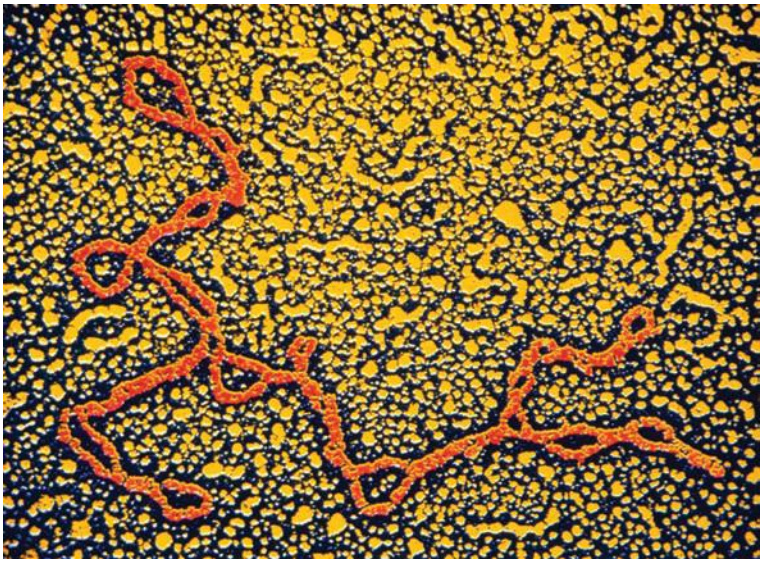


FIGURE 14 A transmission electron microscope image of a mitochondrial chromosome. The mitochondrial chromosome resembles a prokaryotic DNA loop, not a linear DNA strand.

CHECK YOUR LEARNING 6.2

Describe and explain

1 Describe the difference between homologous and non-homologous chromosomes.
2 Draw a bivalent metacentric chromosome and label the chromatids, centromere, p arm and q arm.
3 Name the organelles that contain DNA in the cells of eukaryotic organisms.
4 State how many autosomes and sex chromosomes there are in human somatic cells.
5 Explain the process that determines the sex of human offspring.

Apply, analyse and compare

6 Compare the structure and function of X and Y chromosomes in humans.
7 Compare homogametic and heterogametic sex in different species.
8 Compare the terms 'DNA', 'chromosome' and 'chromatin'.

Design and discuss

9 Referring to Case study 9.2, discuss the importance of X-inactivation in females.
10 Referring to Table 2, discuss whether chromosome number is related to the complexity of an organism.

6.3 Karyotypes

KEY IDEAS

In this topic, you will learn that:

- diploid cells have two sets of matching chromosomes and haploid cells have one set of chromosomes
- karyotypes are used to visualise all of the chromosomes from a nucleus to determine sex and identify chromosomal abnormalities.

Diploid and haploid

diploid
a nucleus or cell that contains two sets of chromosomes, one from each parent (2*n*)

haploid
a nucleus or a cell (usually an ovum or a sperm) that contains one set of chromosomes, so the chromosomes are not in pairs (*n*)

Pairs of matching chromosomes (that carry the same genes) are called homologous chromosomes. Cells that carry homologous chromosomes are said to be **diploid** (two complete sets of each chromosome) and are represented as $2n$, where 'n' is the number of chromosomes. Each diploid cell has one set of chromosomes from the male parent (father) and one set from the female parent (mother). Somatic cells are diploid cells.

The sex cells from each parent (the ovum and sperm cells) contain only one of each type of chromosome, or one set of chromosomes. These cells are described as **haploid** cells (n) and are produced by the process of meiosis.

Karyotypes

karyotype
the visual representation of the chromosomes from a cell nuclei of an individual

A **karyotype** is a visual display (photograph) of the full set of a species' chromosomes. To make a karyotype, scientists examine chromosomes when they are visible, from prophase to metaphase of cell division. The chromosomes are stained so that banding patterns of different chromosomes are visible. These banding patterns are very specific and reflect regions of the DNA that have different amounts of adenine and thymine compared to guanine and cytosine.

The chromosomes are photographed and the photos are rearranged so that the autosomal chromosomes are in order from largest to smallest and the sex chromosomes are placed at the end. The homologous pairs are identified by the length of the chromosomes, banding patterns and positions of the centromere.

A karyotype can also be prepared for the haploid sperm and ovum as seen in Figures 1 and 2.

Study tip

The term 'ploidy' refers to the number of sets of chromosomes in a cell. The prefix 'di' means two. Therefore, 'diploid' refers to two sets of chromosomes.

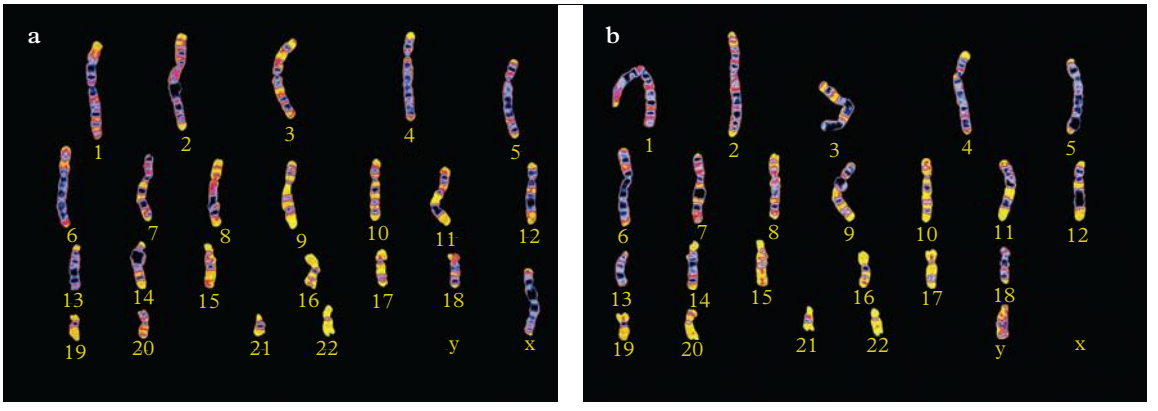


FIGURE 1 Colour-enhanced karyotypes for normal human male sperm cells that are haploid and either carrying **a** an X sex chromosome or **b** a Y sex chromosome

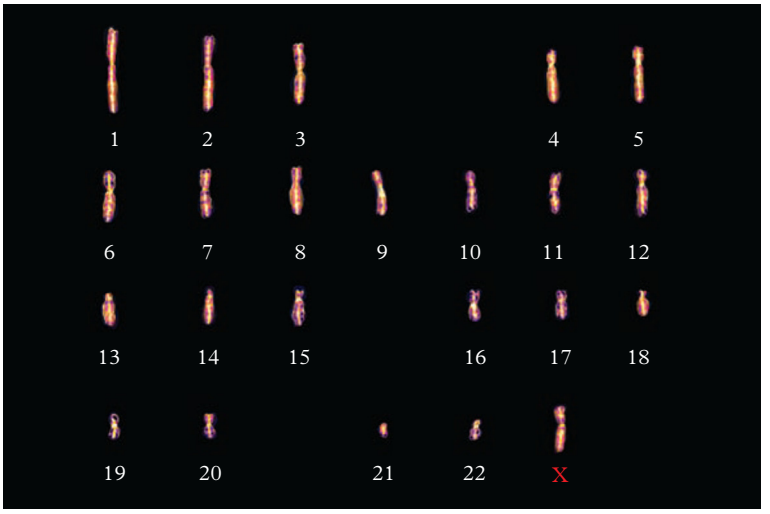


FIGURE 2 A colour-enhanced karyotype for a normal human female ovum, which is haploid and always carries the X sex chromosome

Human karyotypes

Human somatic cells have a diploid number of chromosomes (*2n*), and therefore a total of 46 chromosomes are shown on a human karyotype. A female has 22 pairs of autosomes and two X chromosomes, whereas a male karyotype has 22 pairs of autosomes and one X and one Y chromosome, as seen in Figure 3. The autosomes are numbered 1–22 from largest to smallest.

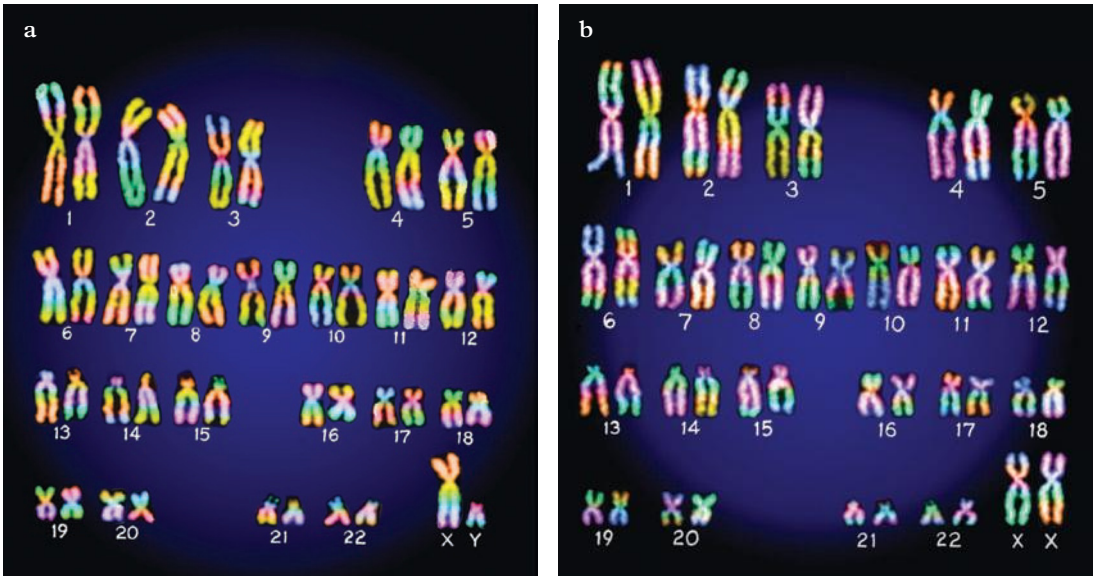


FIGURE 3 Colour-enhanced karyotypes of a **a** normal human male and **b** normal human female

What can be identified from a karyotype

Karyotypes can be used to:

- determine the sex of an individual
- identify different species by the number of chromosomes
- detect certain genetic anomalies, such as changes in chromosome number (extra or missing chromosomes) or chromosome structure (such as a duplication, an inversion or a deletion of a part of a chromosome).

aneuploidy
a genetic abnormality in which an individual has an abnormal number of chromosomes

trisomy
a genetic abnormality in which an individual has an extra copy of a chromosome

monosomy
a genetic abnormality in which one chromosome of a pair of homologous chromosome is missing

A number of genetic syndromes result from an increase or a decrease in chromosome numbers. When there is a missing or an extra chromosome, this is known an **aneuploidy**. There are two types of aneuploidy. An extra copy of one of the chromosomes is known as a **trisomy**. Down syndrome is an example of trisomy, with an extra copy of chromosome 21. This can be seen in the karyotype in Figure 4. If a chromosome is missing and there is only one chromosome from the normal pair, this is referred to as **monosomy**. An example of monosomy is Turner syndrome. A person with Turner syndrome lacks all or part of one of the X chromosomes, which is called monosomy X. Females with Turner syndrome are infertile because their ovaries do not fully develop.

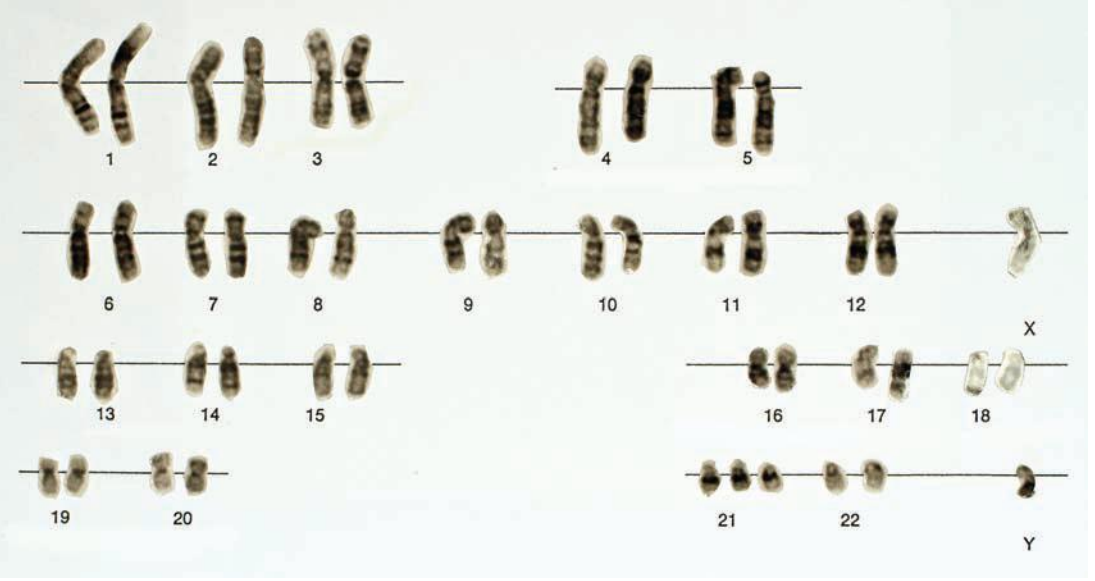


FIGURE 4 Down syndrome is caused by trisomy 21, as seen in this karyotype.

TABLE 1 Syndromes caused by changes to chromosome numbers

	Syndrome	Chromosomal change	Effects on the individual
Autosome abnormality	Down syndrome	Three copies of chromosome 21 (trisomy 21)	Intellectual disability, may be infertile, low muscle tone, short stature and a flat nasal bridge
	Patau syndrome	Three copies of chromosome 13 (trisomy 13)	Intellectual disability and physical abnormalities
	Edwards syndrome	Three copies of chromosome 18 (trisomy 18)	Intellectual disability, small head and jaw and clenched fists
Sex chromosome abnormality	Klinefelter syndrome	Additional X chromosome (47 chromosomes)	Male but underdeveloped sex organs; some intellectual disability, sterile with female secondary traits
	Turner syndrome	Only one full X chromosome (45 complete chromosomes)	Female with non-functioning ovaries; infertile, short stature, heart and kidney issues, some learning difficulties

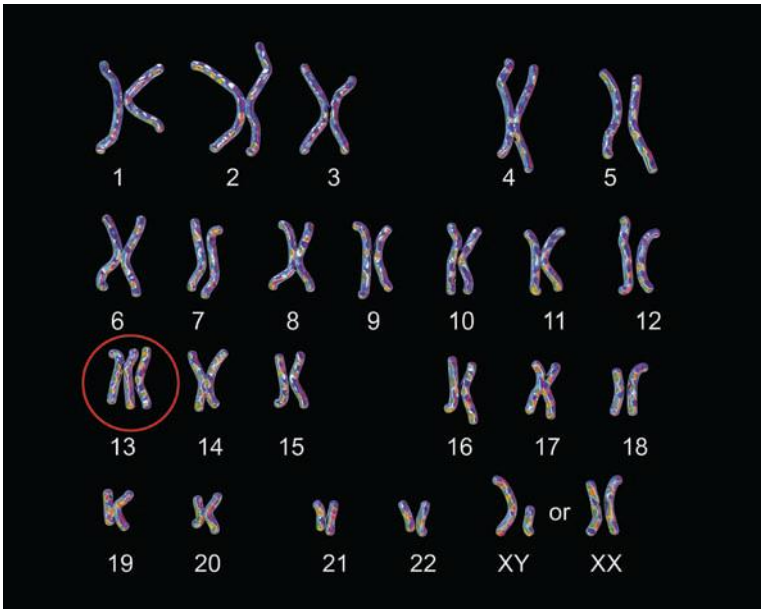


FIGURE 5 Patau syndrome is caused by trisomy 13, as seen in this karyotype.

CHECK YOUR LEARNING 6.3

Describe and explain

1 Define 'karyotype'.

2 Explain how a karyotype can be used to identify chromosome abnormalities.

3 Distinguish between the terms 'monosomy', 'trisomy' and 'aneuploidy'.

Apply, analyse and compare

4 Contrast the karyotypes shown in Figures 4 and 5.

5 Chromosome 1 contains about 3000 genes, whereas chromosome 21 contains about 400 genes. Using this information, discuss why an embryo with a trisomy 1 will not develop whereas one with a trisomy 21 will often survive.

6 Complete the following table. The first row has been done for you.

Organism	Number of chromosomes	
	Diploid ($2n$)	Haploid (n)
Human	46	23
Rabbit		22
Elephant	56	
Monkey	48	
Chili pepper plant		12
Dog		39

Design and discuss

7 Research another genetic disorder due to chromosomal abnormality. Describe the chromosomal change and the effect on the individual.

8 Research and explain how aneuploidy arises.

6.4 Meiosis

KEY IDEAS

In this topic, you will learn that:

- meiosis produces gametes (ovum and sperm) and occurs in two stages, meiosis I and meiosis II
- spermatogenesis and oogenesis occur in animals to produce gametes
- meiosis occurs in animals and plants
- crossing over of chromatids and independent assortment produces genetic diversity in gametes.

meiosis
a type of cell division that produces gametes

germline cell
a diploid cell in ovaries or testes that undergoes meiosis to form gametes

Gametes (e.g. ovum and sperm cells) are produced by the type of cell division known as **meiosis**. Meiosis begins with a diploid **germline cell** in animals; in the ovary in females and the testes in males. In meiosis, there are two separate divisions: meiosis I and meiosis II. Before meiosis can begin, interphase occurs to prepare the germline cell for gamete production.

As described in Chapter 3, there are three stages of interphase: G1, S and G2.

- G1 is the longest phase of the cell; the cell grows and produces protein and organelles. The germline cell is diploid, containing two copies of each chromosome.
- During S phase, a germline cell replicates its genetic material. In humans, all 46 chromosomes are replicated. The chromosomes are now in their bivalent form, and the two sister chromatids remain attached to each other at the centromere.
- During G2 phase, the cell starts rapidly growing and synthesising protein.

Meiosis I

Video
Meiosis

The first meiotic division (meiosis I) involves each pair of bivalent homologous chromosomes separating into separate cells. At the end of meiosis I, cytokinesis occurs to produce two intermediate haploid cells, each with a single set of bivalent chromosomes.

Prophase I

There are many similarities between prophase in mitosis and prophase I in meiosis. In both, the nuclear membrane breaks down, the chromosomes condense and become visible and the spindle fibres form.

Crossing over

crossing over
the process during prophase I of meiosis when homologous chromosomes exchange genetic material

recombinant chromosome
a chromosome formed after the crossing over of genetic material between the homologous chromosomes

Occasionally the matching homologous chromosomes sit so close to each other they become tangled. When this occurs, small parts of the genetic material can be exchanged between the homologous chromosomes. This process is called **crossing over** and allows for more possible combinations of genetic material to be passed on to the offspring (Figure 1). The product of crossing over is a chromosome that is part maternal and part paternal, known as a **recombinant chromosome**.

Metaphase I

disjunction
the organised separation of chromosomes during meiosis

During metaphase I, the homologous chromosomes move to the middle or equator of the cell. Each bivalent chromosome attaches to a spindle fibre at the centromere. The homologous chromosomes prepare to move to opposite ends of the cell. This means one bivalent chromosome 1 will attach to a spindle connected to one pole of the cell, while the other bivalent chromosome 1 will connect to the other cell pole. This separation between the homologous chromosomes is called **disjunction**.

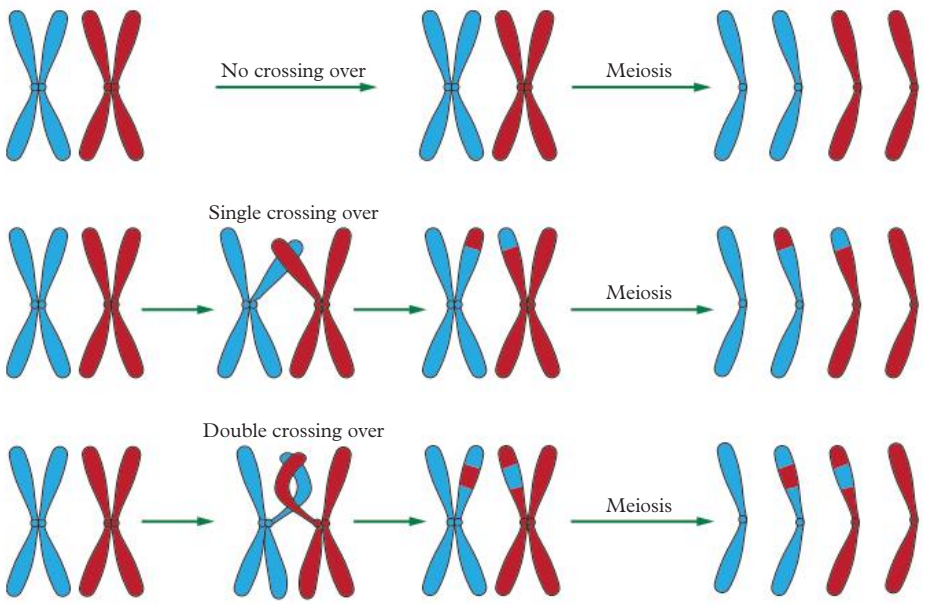


FIGURE 1 The difference in genetic make-up of gametes produced with no crossing over, as single crossing over and double crossing over.

Law of independent assortment

During metaphase I, the homologous chromosomes orient themselves independently along the middle of the cell. This is known as the **law of independent assortment** and it produces further variation in the genetic material of the gametes. For example, if the two homologous chromosomes of chromosomes 1 were labelled 'a' and 'b', then they may arrange themselves as a-b or b-a (red and blue in Figure 2). This is the case for all of the other 22 pairs of homologous chromosomes.

law of independent assortment a law that states that homologous chromosomes orient themselves randomly along the middle of the cell during metaphase I

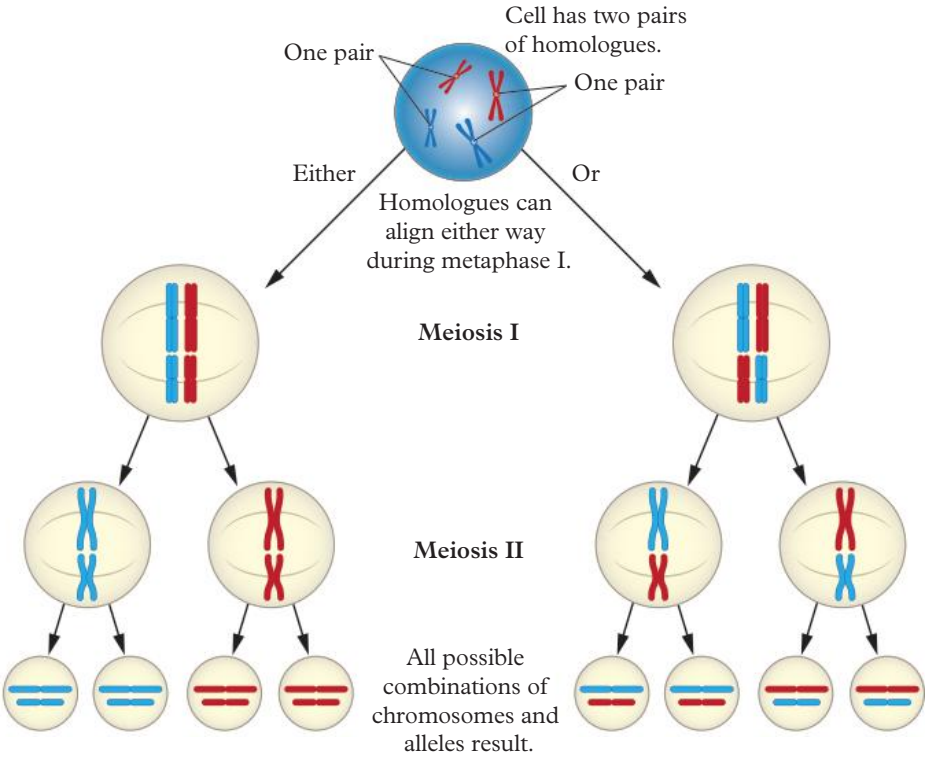


FIGURE 2 Independent assortment occurs during metaphase I, producing variation in the chromosomes of the gametes produced by meiosis.

Study tip

One of the key differences between mitosis and meiosis occurs in anaphase I. In mitosis anaphase, the bivalent chromosomes separate at the centromere, whereas in anaphase I of meiosis, the centromere remains attached and the whole bivalent chromosome moves to the cell pole.

Anaphase I

When the spindle fibres contract, the homologous chromosomes separate and go to opposite poles of the cell. This means each pole of the cell contains a single bivalent copy of each chromosome.

Telophase I and cytokinesis I

During telophase I, the spindle fibres break down and the chromosomes gather together, and may become surrounded by a nuclear membrane. Cytokinesis 1 occurs when the cell divides into two daughter cells. The nuclear membrane does not always form around the chromosomes at this stage as the cells can move directly into meiosis II.

Meiosis II

The second division (meiosis II) involves the centromere splitting and the sister chromatids of each chromosome moving to a new cell. Following cytokinesis, potentially four haploid gametes are formed that are genetically different from the original germline cell.

Prophase II

During prophase II, a new spindle is formed that is perpendicular (at right angles) to that of the original cell.

Metaphase II

In metaphase II, all of the individual bivalent chromosomes migrate to the middle of the cell. Once there, each of the chromatids that make up the bivalent chromosome attaches to a new spindle fibre though the centromere.

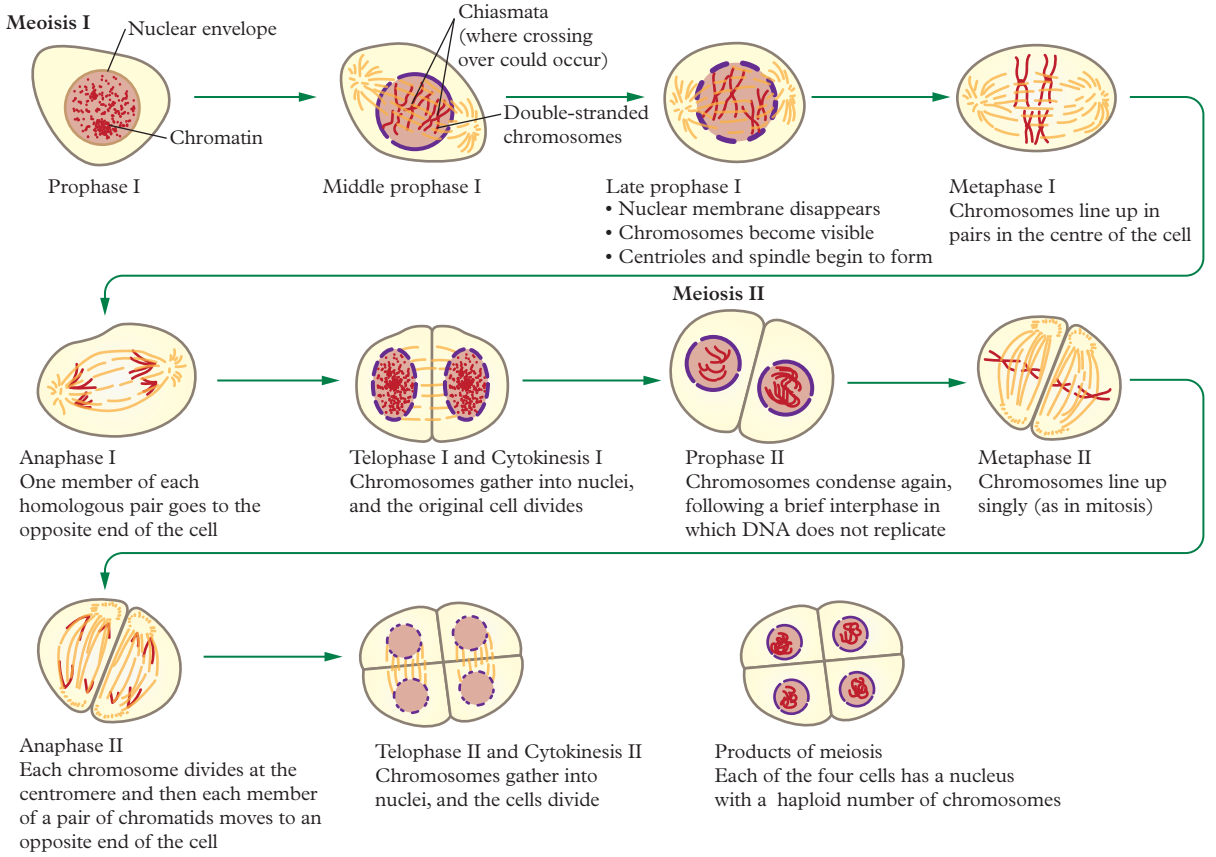


FIGURE 3 The stages of meiosis

Anaphase II

Each of the chromatids separate at the centromere when the spindle fibres contract. Each sister chromatid (now renamed as separate chromosomes) are pulled away from each other to the separate poles of the cell.

Telophase II and cytokinesis II

Once the new chromosomes have assembled at the ends of the cell, a new nuclear membrane forms around the genetic material and the cell divides along the equator to form individual cells.

Meiosis in animals

Meiosis in animals can result in the production of a sperm or the production of an egg (**ovum**). There are slight differences between these two processes.

ovum
a female gamete

Spermatogenesis

Spermatogenesis (the production of sperm) occurs in the testes of a male organism. During puberty, germline cells in the testes start undergoing meiosis to produce four haploid sperm cells (Figure 4).

spermatogenesis
the meiotic process of sperm production in the testes

During the process of anaphase I, the X and Y chromosomes in the diploid germline cell are pulled by spindle fibres to opposite poles of the cell. After the stages that make up meiosis II are completed, there are two sperm that carry a single copy of the X chromosome (and the other 22 autosomes) and two sperm that carry a single copy of the Y chromosome (and 22 autosomes). The four sperm produced by spermatogenesis carry their genetic material in the sperm head, while the tail is used to provide movement towards the ovum.

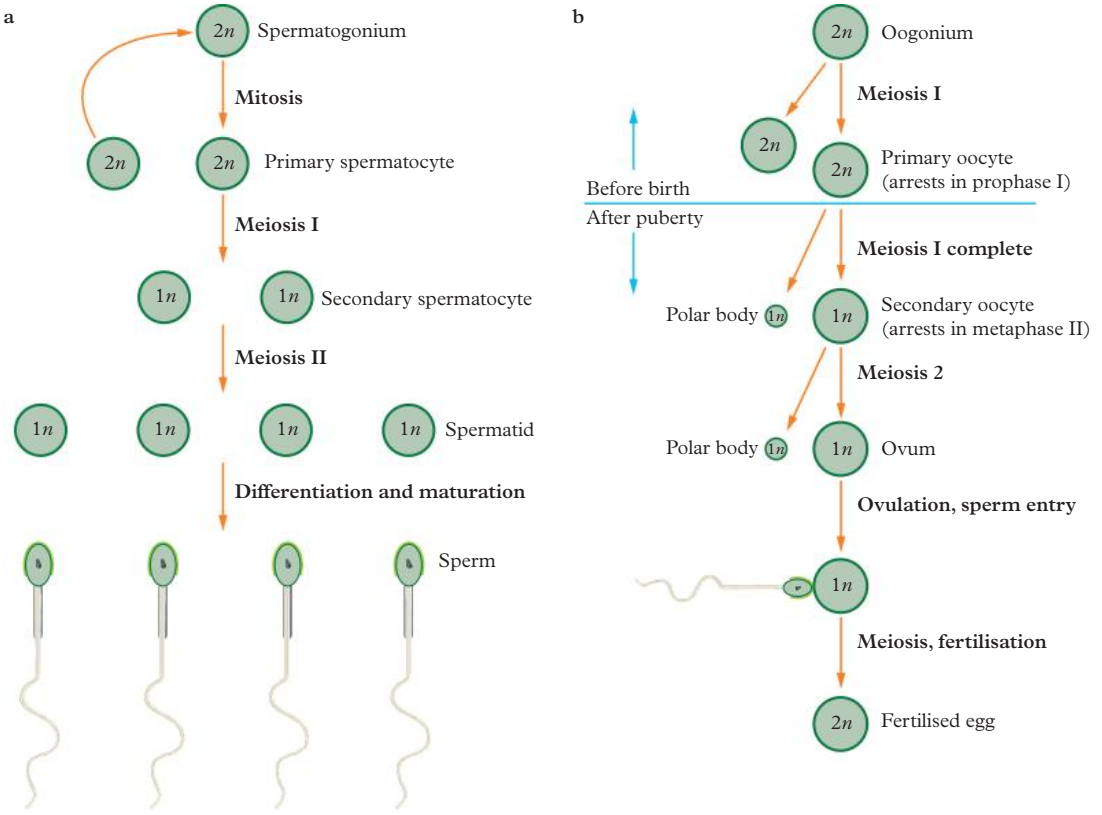


FIGURE 4 **a** Spermatogenesis occurs in the testes and produces four haploid sperm. **b** During oogenesis, meiosis is halted at different stages. The final result is a single ovum.

Oogenesis

oogenesis
the meiotic process of ovum production in the ovaries

Oogenesis (the production of a female gamete (ovum)) occurs in the ovaries of all female animals. Before a female is born, the germline cells in the foetus start undergoing meiosis I, but this halts before it is complete. At birth, each female has a finite number of germline cells with a suspended cell cycle.

In humans, the meiosis process is started again when the girl reaches puberty. One germline cell each month continues with meiosis to metaphase II, where it will again be halted. At each stage, the division of the cytoplasm during cytokinesis is uneven, producing one large cell and one smaller **polar body**. The haploid polar body usually breaks down whereas the larger cell continues through to produce the final gamete. This means that oogenesis only produces a single ovum (Figure 4).

polar body
a small cell that buds off a developing ovum during oogenesis and does not develop into ova

Meiosis in plants

The process of meiosis in plants is similar to that in humans and it produces equal-sized ova (eggs) and male gametes. Ova are usually produced in the base of flowering plants, whereas the male gametes are packaged into pollen grains and released from the tips of the anther. Pollen grains may travel from the anther to the stigma (Figure 5) with the help of wind and organisms such as insects or birds. Once pollen lands on a compatible stigma, the pollen grain germinates and grows a long tube down the style to the ovum in the ovule. The male gamete combines with the female gamete and fertilisation occurs.

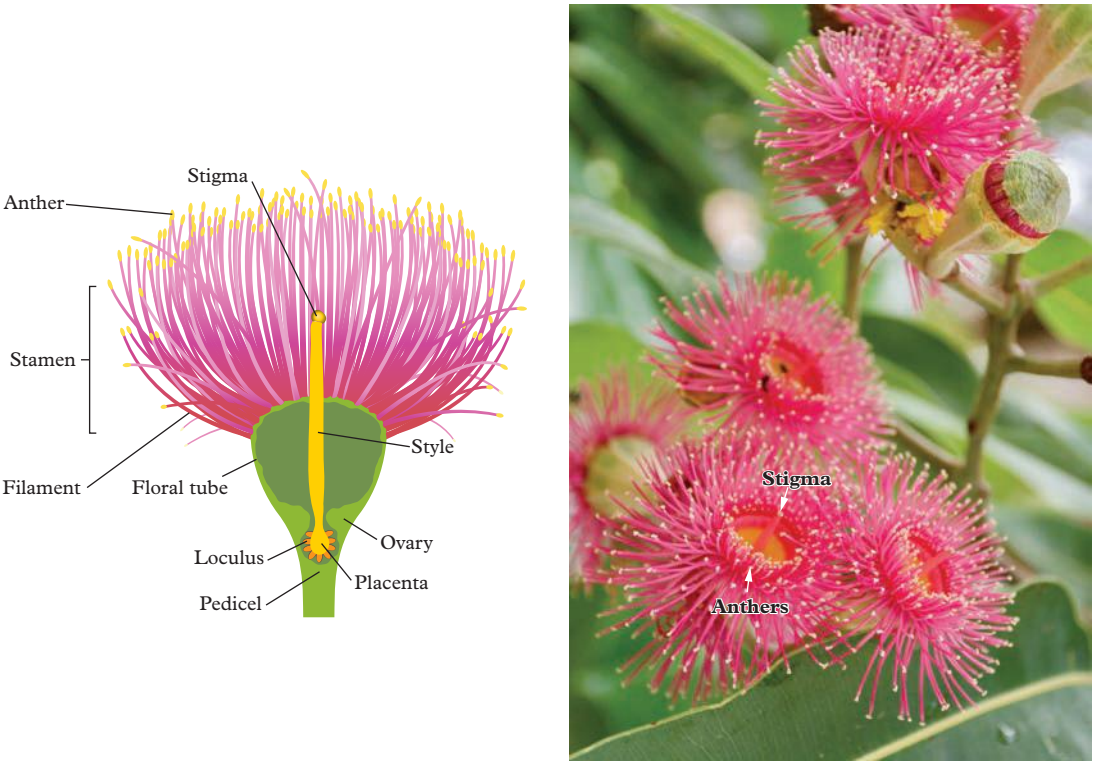


FIGURE 5 The internal reproductive parts of a flower

CASE STUDY 6.4

Abnormal chromosome numbers

Occasionally during anaphase I, the orderly separation of the homologous chromosomes does not occur. One of the bivalent chromosomes may attach to the wrong spindle so that both copies of the chromosome are linked to the same end of the cell. This is known as non-disjunction, and when it occurs, both chromosomes move to the same end during anaphase I. Non-disjunction results in an extra chromosome in one pair of gametes and one less chromosome in the other gamete pair. When the gamete is eventually fertilised, it can result in a cell with an extra chromosome (trisomy) or one less chromosome (aneuploidy).

An example of this is Down syndrome, in which there are three copies of chromosome 21 (Figure 6).

It can result in a group of symptoms that consistently occur in a syndrome.

Non-disjunction can also result in the gamete having one less chromosome. An example of this is Turner syndrome, where a girl is born with a single X chromosome instead of the usual two sex chromosomes (Figure 7). The group of symptoms resulting from Turner syndrome includes a webbed neck, short stature and possible heart defects.

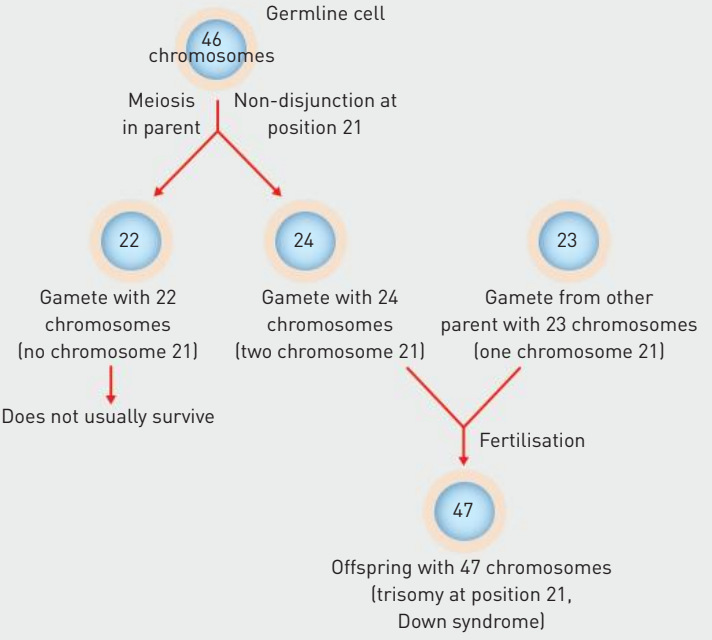


FIGURE 6 In Down syndrome, non-disjunction results in a person having three copies of chromosome 21.

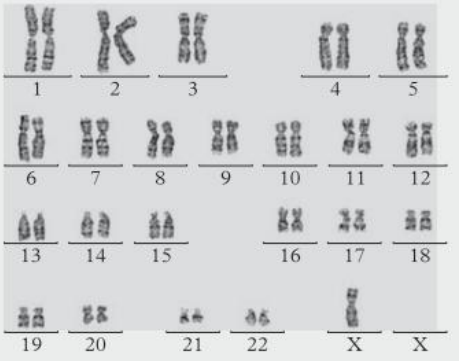


FIGURE 7 In Turner syndrome, non-disjunction of the sex chromosomes means a girl is born with one X chromosome instead of two.

CHECK YOUR LEARNING 6.4

Describe and explain

1 Describe the difference between diploid and haploid cells.

2 Explain how homologous chromosomes are similar to each other.

3 Explain how recombinant chromosomes form, and when during meiosis this occurs.

Apply, analyse and compare

4 Explain the advantage of chromosomes being independently assorted during meiosis.

5 Compare spermatogenesis and oogenesis.

6 Refer to Case study 6.4 to explain how gametes form with one more or one less chromosome.

Design and discuss

7 Discuss how you could have characteristics of both your maternal and paternal grandparents.

8 Design a poster that shows the process of meiosis.

CHAPTER 6

Review

Chapter summary

6.1
- Genes are sections of DNA found on chromosomes and contain genetic material required for the expression of different traits.
- Multiple alleles can come from one gene and they determine the trait the gene expresses, such as eye colour.
- The genome is the complete set of genetic information within an organism and can be sequenced by genomics.

6.2
- Chromosomes are made of DNA coiled around histone proteins and occur in both prokaryotic and eukaryotic cells.
- Homologous chromosomes have the same size and structure and contain one set of genes from the mother and one set from the father.
- Chromosomes are either autosomes, of which there are 22 pairs in humans, or sex chromosomes, of which there is one pair.
- The structure, size, shape and number of chromosomes varies greatly between species.

6.3
- Diploid cells have two sets of matching chromosomes and haploid cells have one set of chromosomes.
- Karyotypes are a visual display of chromosomes from an organism and can be used to identify sex, species and any chromosomal abnormalities.

6.4
- Meiosis is a type of cellular division that produces gametes (ovum and sperm) and occurs in two stages: meiosis I and meiosis II.
- Meiosis in animals occurs through spermatogenesis and oogenesis.
- Meiosis occurs in plants to produce male gametes packaged into pollen and female ovum.
- Crossing over of chromatids and independent assortment result in genetic diversity in offspring.

Revision questions

Multiple choice

1 During which stage of meiosis do the homologous chromosomes line up along the middle of the cell?
- **A** Prophase I
- **B** Metaphase I
- **C** Anaphase I
- **D** Telophase I

2 Crossing over occurs during:
- **A** prophase I
- **B** metaphase I
- **C** anaphase I
- **D** telophase I.

3 Identify the type of chromosome that has the centromere very near one end and a very short p arm.
- **A** Metacentric
- **B** Submetacentric
- **C** Acrocentric
- **D** Telocentric

4 Diploid cells contain two copies of each chromosome, which carry the same genes in the same loci. Identify the name of these two chromosomes.
- **A** Bivalent chromosomes
- **B** Non-homologous chromosomes
- **C** Homologous chromosomes
- **D** Sister chromatids

5 Consider the following comparisons between the cells at the end of meiosis and the germline cells at the beginning. Identify which statement is correct.
- **A** The cells at the end of meiosis have half the number of chromosomes and therefore half the amount of DNA.
- **B** The cells at the end of meiosis have half the number of chromosomes but only a quarter of the amount of DNA.
- **C** The cells at the end of meiosis have a quarter of the amount of chromosomes because there are two divisions.
- **D** The cells at the end of meiosis have the same amount of chromosomes but half the amount of DNA.

6 In a normal human ovum (egg cell), there are:
- **A** 23 autosomes and a pair of sex chromosomes, XX
- **B** 22 autosomes and one X chromosome
- **C** 22 pairs of autosomes and a single X chromosome
- **D** 23 pairs of chromosomes.

7 Identify which of the following statements is true about alleles.
- **A** Each gene only has two alleles.
- **B** An individual can only carry a maximum of two alleles for a gene.
- **C** An allele represents all the genes of an individual organism.
- **D** An individual has 23 alleles for each gene.

8 Cells that carry homologous chromosomes are:
- **A** complete
- **B** haploid
- **C** diploid
- **D** abnormal.

9 Identify the genetic abnormality in the karyotype shown in Figure 1.

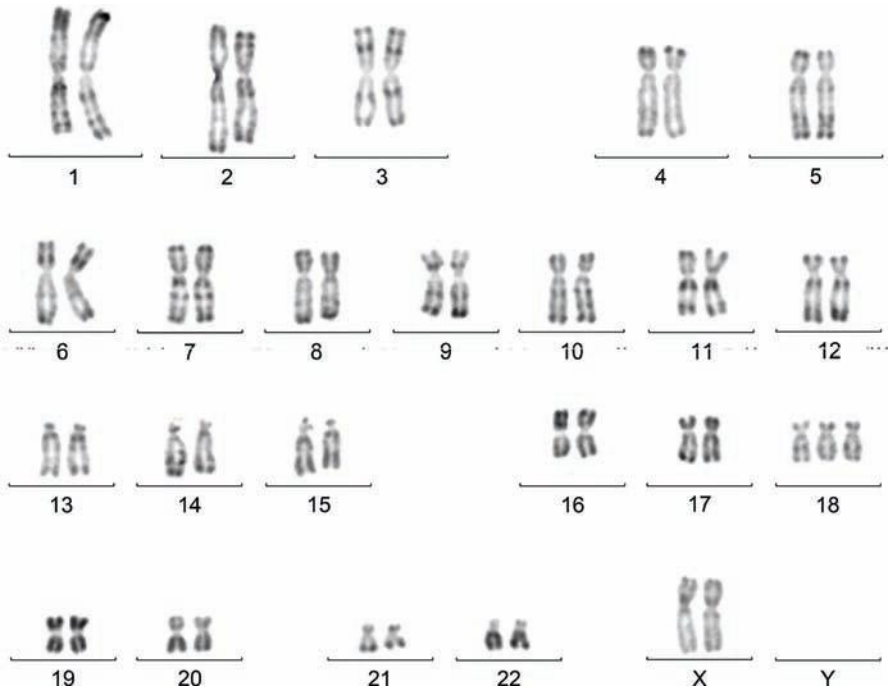


FIGURE 1 A karyotype

A Turner syndrome
B Down syndrome
C Patau syndrome
D Edwards syndrome

10 The alleles that determine the characteristics of an individual come from:
A the father only
B the mother only
C neither parent
D both parents.

Short answer

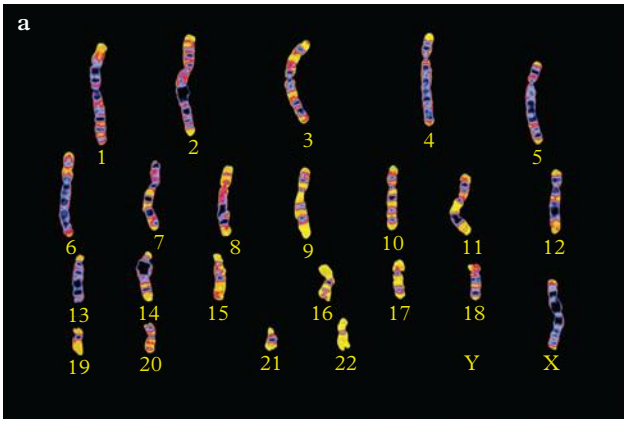
Describe and explain

11 Identify how many divisions occur during meiosis.
12 Describe the process of meiosis.
13 Explain why it is important for crossing over and independent assortment to occur.
14 Explain the importance of the centromere.
15 Draw a diagram to show what it is meant by homologous chromosomes.
16 Describe the difference in appearance between the two sex chromosomes, X and Y.
17 Define 'allele'.
18 Explain how studying the human genome and understanding the function of genes can improve detection and diagnosis of human diseases and disorders.

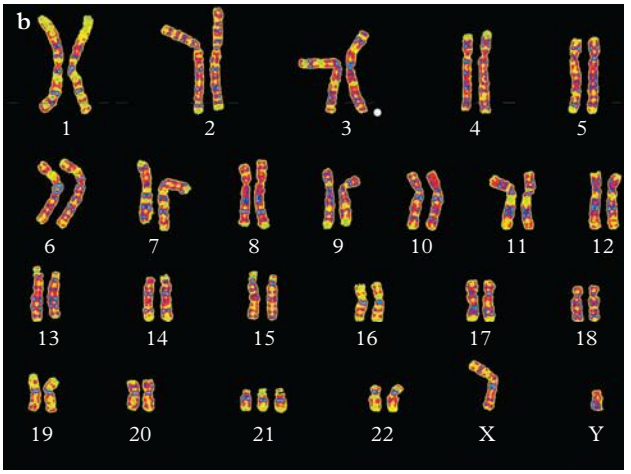
Apply, analyse and compare

19 Distinguish between genes and alleles.
20 Contrast autosomes and sex chromosomes.
21 Produce a table to compare cpDNA, mtDNA, DNA found in the nucleus of eukaryotic cells and prokaryotic DNA.
22 Identify the location and function of the *SRY* gene in humans.
23 Is a pair of sex chromosomes considered homologous? Explain.

24 Compare the karyotypes in Figure 2 and list the similarities and differences.



Karyotype a



Karyotype b

FIGURE 2

25 A honeybee has 32 chromosomes in each of its somatic cells.

- **a** How many sets of chromosomes would a haploid honeybee cell contain?
- **b** How many chromosomes would the honeybee have in a gamete cell?
- **c** How many sets of chromosomes would a fertilised honeybee egg have? Explain your answer.

26 Can the terms 'gene' and 'genome' be used interchangeably? Discuss.

Design and discuss

27 Chromosome numbers differ among species. For example, humans have 46 chromosomes in their somatic cells, whereas goats have 60 chromosomes. Discuss why chromosomes differ between species.

28 Discuss an example of a species in which the sex of an individual is not determined by the X/Y system.

29 Concept maps are great tools for revising. Design a concept map that compares mitosis and meiosis.

Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to use the mark allocation and space provided as a guide for how much to write in your response.

Use the mark allocation as a guide

It is important to avoid writing too much because sometimes a single word is enough to answer a question. The assessor does not want to read everything you know about a topic; they are looking for a direct answer to the question. You should be able to keep all your responses within the spaces provided in the assessment.

QUESTION 1d (2008 Biology Written Examination 2)

Meiosis is another form of cell division. A student claimed that there was no significant difference between mitosis and meiosis.

d Identify one significant feature of meiosis and explain how it indicates that it is a different process from mitosis. 2 marks

Source: 2008 Biology Written Examination 2, Question 1d, Short answer, reproduced by permission © VCAA

Response 1

Meiosis produces sex cells.
This is different from mitosis, which produces somatic cells.

The term 'gametes' can also be used.

Succinctly explains the difference

This response would receive full marks. The response is a clear statement that compares just one feature between mitosis and meiosis.

Response 2

Meiosis and mitosis are both forms of cell division but have some differences. Meiosis produces cells that are genetically different, and mitosis produces cells that are genetically identical. In meiosis, there are only two cells produced but mitosis can produce up to 4 cells.

This wastes time rephrasing the question.

Meiosis produces up to 4 cells and mitosis produces 2 cells.

This response would receive no marks. The first comparison about the cells produced from the two types of cell division is correct; however, the student contradicts themselves by giving another comparison that is incorrect. Do not write down everything you know about a topic, because you may find that you contradict your own work and receive no marks.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

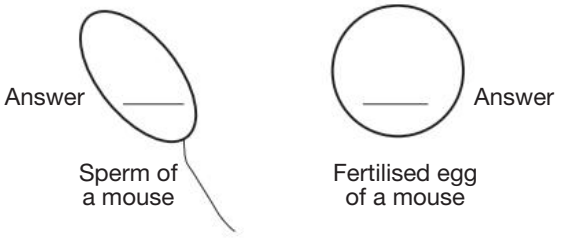
Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 8 (2013 Biology Written Examination)

Mice have a diploid number of 40.

a How many chromosomes are there in each of the following cells? 1 mark



Sperm of a mouse: 23
Fertilised egg of a mouse: 46

b Briefly state the biological significance of the process of meiosis. 2 marks

Meiosis produces gametes that have genetic variation, enabling individuals to be genetically different from one another.

Source: 2013 Biology Written Examination, Question 8, Short answer, reproduced by permission © VCAA

Marking guide

8a	1 mark for identifying the correct number of chromosomes in the mouse cells. Sperm of a mouse: 20; fertilised egg of a mouse: 40.
8b	1 mark for each correct biological significance (two of the following). • Crossing over and recombination provide variation in offspring. • Independent assortment during meiosis provides variation in offspring. • Fertilisation results in increased variation through the joining of gametes. • With increased variation in a population, there is an increased chance of species survival if selective pressures change. • Meiosis ensures that gametes are haploid.

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 an examiner.

Check your Student obook pro for the following digital resources and more:

Video
Use the mark allocation as a guide

Weblink
Past examinations and examiners' reports

CHAPTER 7

Genotypes and phenotypes

Allele symbols are used to represent the different variations of a gene. Symbols for alleles located on autosomes are capital letters (e.g. A) and lower-case letters (e.g. a) to represent the dominant and recessive traits, respectively. Alleles located on sex chromosomes are represented by an 'X' or a 'Y' followed by a superscript to represent the allele; for example, X^C. The combination of alleles for a trait is known as the genotype, and this is one of the factors that determines the phenotype. The phenotype is the physical appearance of the trait.

There are different types of genotypes, including heterozygous and homozygous. Dominant traits are those expressed in the heterozygous genotype and recessive traits are only expressed in homozygous recessive individuals. Traits can be completely dominant, codominant or incompletely dominant.

Lifestyle and environmental factors can affect the phenotype of the individual. Modifications can occur to the DNA without changing the DNA 'blueprint', but can still determine which genes are expressed and which are blocked or repressed. These modifications are known as epigenetics. The phenotype is a combination of the genetic material, environmental and epigenetic factors.

KEY KNOWLEDGE

- → the use of symbols in the writing of genotypes for the alleles present at a particular gene locus
- → the expression of dominant and recessive phenotypes, including codominance and incomplete dominance
- → proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

FIGURE 1 Pea plants have many phenotype variations; for example, flower colour where the purple phenotype is dominant to the white phenotype.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

7A What is the purpose of DNA?

7A Groundwork resource
DNA

7B Describe how offspring inherit genetic material from both their parents.

7B Groundwork resource
Genetic inheritance

7C Compare the terms 'gene' and 'allele'.

7C Groundwork resource
Alleles

PRACTICALS

NO-TECH PRACTICAL	**7.3** Factors that affect phenotypes

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your Student obook pro.

7.1 Using symbols for genotypes

KEY IDEAS

In this topic, you will learn that:

+ genotype refers to the alleles of a gene and phenotype refers to the expression of a gene
+ different genotypes depend on the combinations of alleles.

genotype
the combination of alleles for a gene

phenotype
the physical expression of the genotype and its environment

homozygous
a genotype in which the two alleles for the gene are the same

heterozygous
a genotype in which the two alleles for the gene are different

dominant trait
the trait that is expressed in the phenotype of a heterozygous individual

recessive trait
the trait that is only expressed in the phenotype of a homozygous individual

Video
Using symbols to write genotypes

Every cell in your body (apart from gametes and cells without a nucleus) are diploid. Diploid cells have one set of chromosomes from your mother and one set from your father. Genes are found on chromosomes and have different variations (alleles). The alleles of a gene are found at the same location (locus) on the chromosome. Every gene has a combination of two alleles and this is known as the **genotype**. The **phenotype** of a gene is the physical expression of the gene, which is determined by the genotype and environmental factors.

Genotypes

Genotypes can be either **homozygous** (two of the same allele) or **heterozygous** (two different alleles). In a heterozygous individual, usually only one of the two alleles is expressed in the phenotype. This is called the **dominant trait**. A dominant trait only requires one copy of the allele to be expressed. Other traits are called **recessive traits**. For a recessive trait to be shown in the phenotype, there needs to be two alleles present.

For example, earlobes can be either attached or detached (Figure 1). A person may have one of the following genotypes:

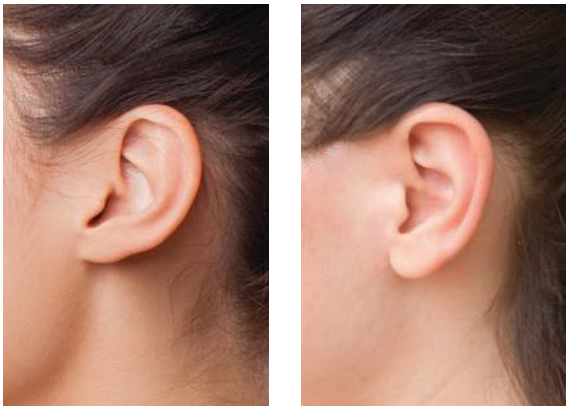
- two alleles for detached earlobes (homozygous)
- two alleles for attached earlobes (homozygous)
- one allele for detached earlobes and one allele for attached earlobes (heterozygous). Detached earlobes is a dominant trait. Attached earlobes is a recessive trait.

Genotypes are represented by letters

Traits can be represented by lower-case and capital letters.

- Dominant traits are represented by a capital letter. For example, detached earlobes would be given the symbol D.
- Recessive traits are represented by a lower-case letter. For example, attached earlobes would be given the symbol d.

Therefore, a person with the recessive trait of attached earlobes would have the genotype dd, and a person with detached earlobes (dominant trait) would have the genotype DD or Dd. There are two kinds of homozygous genotypes – homozygous recessive (dd) and homozygous dominant (DD). The heterozygous genotype in this example is Dd.



Attached earlobe | Detached earlobe

FIGURE 1 Earlobes can be attached or detached. Detached is dominant to attached. A person with detached earlobes has the genotype DD or Dd, whereas a person with attached earlobes has the genotype dd.

If a heterozygous individual carries the allele for the rec
trait, it will not show or be expressed in the phenotype of
individual. In this case, the individual is known as a **carı**

Sometimes you will have to assign an appropriate lett
for the allele symbols. For example, the dominant fur colou
in guinea pigs is black and the recessive trait is white fur.
Therefore, you would choose 'B' to represent the allele for black fur, and 'b' to represent the allele for white fur.

FIGURE 2 Black fur is a dominant trait in guinea pigs.

'rier
ɛterozygous
ıvidual with
.ıe allele for the recessive trait but who shows the dominant trait

There is another kind of genotype that is known as **hemizygous**. This refers to a gene with only one copy (allele) present in diploid cells; for example, the genes located on the sex chromosomes of males, who only have one X and one Y chromosome. Other examples of hemizygous genotypes arise when a gene is deleted or a chromosome is missing (i.e. mutations).

hemizygous
a genotype in which there is only one copy of the gene

Genotype types

Genotypes can be:

- homozygous recessive – two alleles for the recessive trait (lower-case letters, e.g. aa)
- homozygous dominant – two alleles for the dominant trait (capital letters, e.g. AA)
- heterozygous – two different alleles (e.g. Aa) (Figure 3)
- hemizygous – only one allele (e.g. A or a).

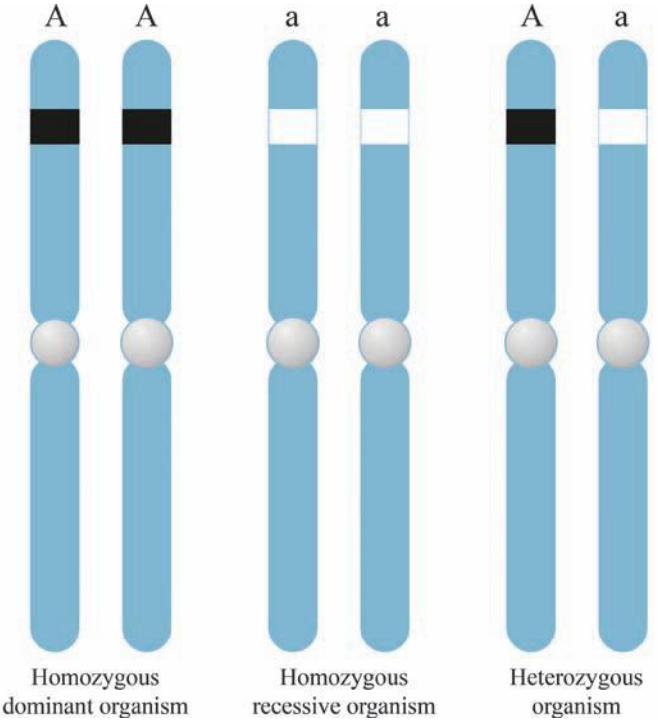


FIGURE 3 The genotypes of a particular trait can be homozygous dominant (AA), homozygous recessive (aa) or heterozygous (Aa).

Study tip

In 'homozygous', the prefix *homo* means the 'same'. In 'heterozygous' the prefix *hetero* means 'different'. In 'hemizygous', the prefix *hemi* means 'half'.

Study tip

When you are writing genotypes, you can make it clearer by underlining lower-case letters that are similar to their capital forms (e.g. 'Cc' and 'Ww'). These letters include c, k, m, o, s, v, w, x and z.

Allele symbols for sex-linked traits

Some genes are located on sex chromosomes (X and Y). Different allele symbols are used to identify these traits. Genes on the X chromosomes are known as X-linked genes and genes on the Y chromosomes are known as Y-linked genes.

The gene for red-green colour blindness is found on the X chromosome. The allele for the recessive trait (colour blindness) is X^c and the allele for the dominant trait (normal vision) is X^C. The 'X' shows that the gene is on the X chromosome and 'C/c' is the allele symbol. Females have two copies of the X chromosome, so they can be homozygous (X^CX^C or X^cX^c) or heterozygous (X^CX^c). Males only have one copy of the X chromosome, so they are hemizygous (X^CY or X^cY). The Ishihara test is used to test for red-green colour blindness (Figure 4).

The same rules apply for Y-linked genes, but females do not possess a Y chromosome, so we would only be concerned with the genotypes of males.

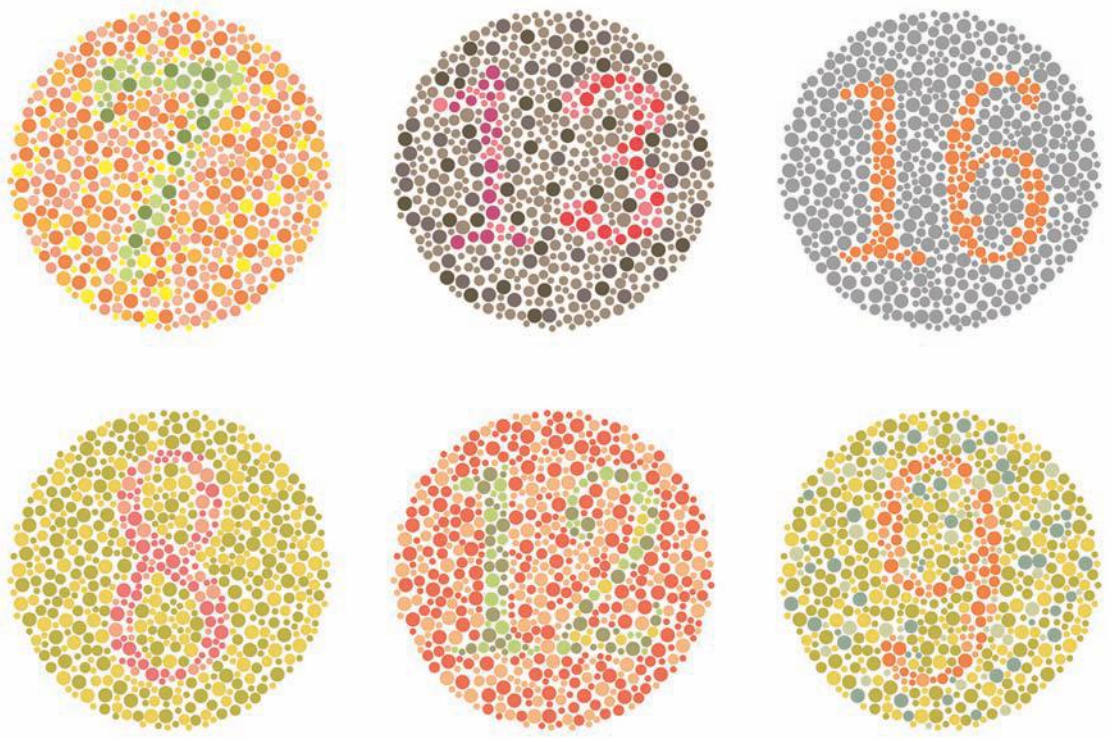


FIGURE 4 Red-green colour blindness can be tested for by the Ishihara test where two commonly confused colours are placed in the same image. If you are X^cX^c or X^cY, you may have difficulty reading a number in some or all of the circles. If you are X^CX^C, X^CX^c or X^CY, you will be able to read a number in each circle.

CHECK YOUR LEARNING 7.1

Describe and explain

1 Identify the allele symbols that are used to represent a recessive trait.

2 Identify the term used to describe the genotype of an individual who has two different alleles for a particular trait.

3 Describe a hemizygous genotype.

Apply, analyse and compare

4 Compare genotype and phenotype.

5 The gene for flower colour in peas has two alleles: purple (P) and white (p).

a Identify the dominant trait.

b Identify the possible combinations of these alleles. State whether each is homozygous or heterozygous.

6 Compare the allele symbols used for autosomal traits and sex-linked traits.

Design and discuss

7 Investigate a genetic disorder that could result in a hemizygous genotype.

7.2 Dominant and recessive phenotypes

KEY IDEAS

In this topic, you will learn that:

+ there are three patterns of dominance: complete dominance, codominance and incomplete dominance

Video
Patterns of dominance

dominance
refers to the relationship between the alleles of a gene and the observable phenotype

complete dominance
a pattern of dominance in which the recessive trait is completely masked by the dominant trait in a heterozygous genotype

dominant phenotype
the phenotype that is seen in a homozygous individual and a heterozygous individual

recessive phenotype
the phenotype that is observed from a homozygous recessive genotype

The genotype for a trait refers to a particular allele combination. The phenotype is the expression of the gene and how this is expressed as an observable characteristic. The phenotype depends on the genotype and different environmental factors.

The **dominance** of a trait determines the phenotype. Dominance (also known as patterns of inheritance) has three main types: complete dominance, codominance and incomplete dominance.

Complete dominance

Complete dominance describes the phenotype that always appears when there is at least one allele for that trait. This means the phenotypic trait appears in homozygous dominant or heterozygous genotypes. The recessive trait in these genes will only appear in homozygous recessive genotypes.

Complete dominance occurs in the seed colour (interior) of pea plants (Figure 1). The green phenotype is dominant and the yellow phenotype is recessive. Therefore, the allele notation of green is G, and yellow is g. Homozygous dominant (GG) and heterozygous (Gg) individuals have green seeds, which is the **dominant phenotype**. Homozygous recessive (gg) individuals have yellow seeds, which is the **recessive phenotype**. Because there is a distinct dominance pattern, it is considered complete dominance.

FIGURE 1 Pea plants can have green peas, the dominant trait, or yellow peas, the recessive trait.

Codominance

Some traits do not dominate other traits; instead, the traits are equally expressed in the phenotype and are known as codominant traits. This results in a third phenotype displayed by heterozygous individuals.

codominance
a pattern of dominance in which two traits are equally dominant and the heterozygous individual displays both traits

Codominance occurs in Andalusian chickens, who have a codominant trait for their feather colour. Black feathers and white feathers are equally dominant traits (Figure 2). The allele notation varies slightly for codominant traits. Since both traits are equally dominant, we assign a letter to signify the gene (F) and add a superscript to represent the alleles. As the traits are codominant, the superscripts are both capital letters. This means the allele for black feathers is F^B and the allele for white feathers is F^W. When both alleles are present (F^BF^W), both are equally expressed. The phenotypes of this trait are shown in Table 1.

TABLE 1 The different feather colour phenotypes and genotypes of Andalusian chickens

Phenotype	Genotype
Black feathers	F^BF^B
White feathers	F^WF^W
Black and white feathers	F^BF^W

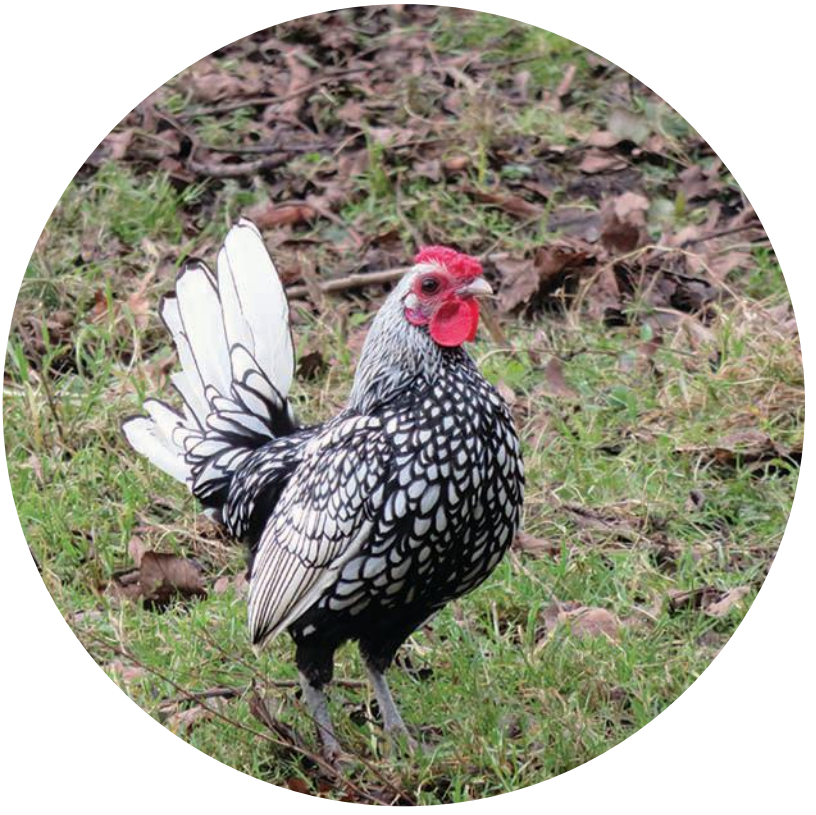


FIGURE 2 The genotype of this young Andalusian rooster with the black and white feathers would be F^BF^W.

CASE STUDY 7.2

Blood types – ABO system

Codominance is seen in the human ABO blood typing system (Figure 3). There are proteins on the surface of red blood cells that determine a person's blood type, and these proteins are inherited. If you have only the A protein, you are blood type A; if you have only the B protein, you are blood type B. If you have both the A and B protein markers, you are blood type AB. This is because the A and B phenotypes are equally dominant, following a codominant pattern.

There are three common alleles in the ABO system, making up four different phenotypes, as seen in Table 2. This gene demonstrates both codominance and complete dominance in the case of the recessive trait, blood type O. If an individual is blood type O, they have no A or B markers on their red blood cells.

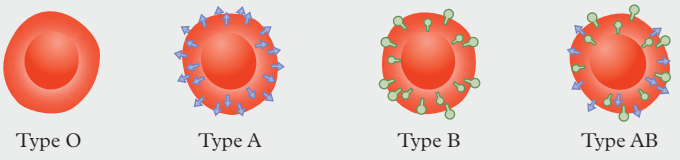


FIGURE 3 The four blood types of the ABO system showing the various surface protein markers.

TABLE 2 The ABO human blood typing system: the blood types and their corresponding genotypes

Blood type (phenotype)	Genotype(s)
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

Incomplete dominance

In **incomplete dominance**, one allele for a particular trait is not completely expressed over the other allele in a heterozygous individual. The heterozygous individual can have a blend of the two phenotypes. Incomplete dominance results in a third phenotype, which is a combination of the physical traits of the two alleles. Like codominance, the gene is indicated with a single letter, while the allele is indicated with a superscript.

Incomplete dominance can be seen in the flower colour of snapdragons. Red petal colour is not completely dominant to white petal colour, so heterozygous individuals exhibit a blend of both colours, pink (Figure 4).

incomplete dominance a pattern of dominance in which a heterozygous individual displays an intermediate phenotype that is a combination of the two alleles.

Study tip

Codominance allows both phenotypes to appear equally, whereas incomplete dominance provides a third phenotype that is a blend.

FIGURE 4 Snapdragons can have red, white or pink (blended phenotype) petals.

TABLE 3 The different petal colour phenotypes and genotypes of snapdragons

Phenotype	Genotype
Red petals	C^RC^R
White petals	C^WC^r
Pink petals	C^RC^W

Incomplete dominance has slightly different effects depending on whether it is controlled by one gene (such as petal colour in snapdragons) or multiple genes, as in the case of polygenic traits. Traits such as eye colour, skin colour and height are controlled by multiple genes. Each of the genes contributing to these traits can influence the phenotype so that individuals can have many different heights or shades of colour.

polygenic trait
a trait controlled by multiple genes

For example, skin colour is a **polygenic trait** controlled by multiple genes that influence the production of melanin. Melanin is the pigment in skin that is responsible for darker skin in humans. Some of those genes have incomplete dominance and contribute to a combination of factors affecting melanin production in the skin.

Phenotypes may also be affected by other genes that are completely separate from the encoded gene or other factors such as the environment. This will be discussed in Topic 7.3.

CHECK YOUR LEARNING 7.2

Describe and explain

1 Explain the meaning of 'dominance'.
2 Use an example to explain the difference between dominant phenotype and recessive phenotype.
3 Define 'incomplete dominance'.

Apply, analyse and compare

4 Compare the different types of dominance – complete dominance, codominance and incomplete dominance.
5 Read Case study 7.2 and explain why the ABO blood types are considered both codominant and completely dominant.
6 Explain how human skin colour is an example of incomplete dominance.
7 Examine the cow in Figure 5. Its hide is two colours: black and white.
   a Assign a symbol to represent the black and white hair alleles.
   b Use the symbols you identified in the last question to write a genotype for the cow that reflects its phenotype.
   c Name the type of dominance seen in this cow's phenotype.
   d Suggest a genotype for a cow of the same breed that only has black fur. Explain your response.

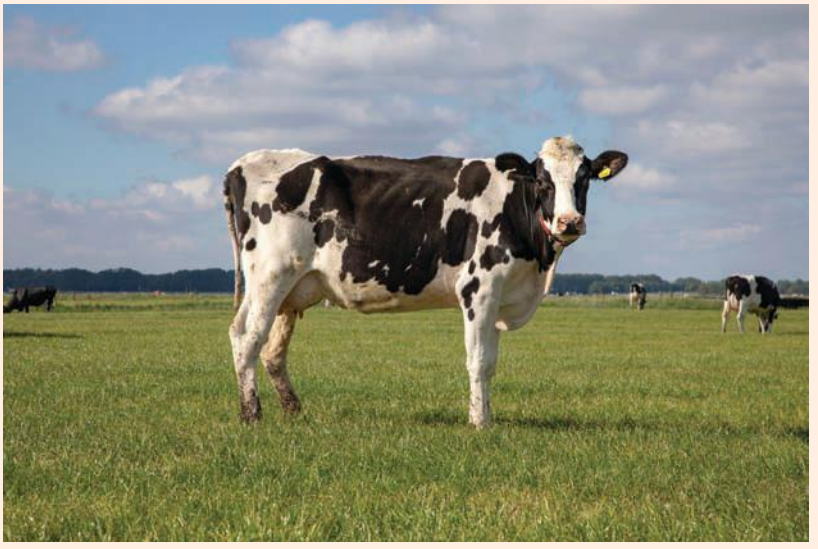


FIGURE 5 A holstein friesian cow has a black and white hide.

7.3 Environmental and epigenetic factors

KEY IDEAS

In this topic, you will learn that:

- environmental factors affect the phenotype of an individual
- epigenetic markers can attach to DNA and control the expression of genes
- genotype, environmental and epigenetic factors have a proportionate influence on phenotypes.

So far, we have discussed phenotypes that are determined almost solely by the genotype; however, the environment can play an important role in determining or influencing the phenotype. Identical twins, who have identical genotypes for all traits, can still show minor differences in their appearance as they age. This is due to environmental factors, such as variations in both the internal and external environments, as well as the way in which the genes are controlled (epigenetics). Therefore, phenotype is a combination of the genotype, environmental factors and epigenetic factors:

Phenotype = genotype + environmental factors + epigenetic factors

FIGURE 1 Identical twins have identical genotypes but can look different due to environmental or epigenetic factors.

Most of the time, the genotype will have the most influence on the phenotype. It is too difficult to determine the proportions of each factor on the phenotype for different traits, but estimates have been made for some traits.

Environmental factors

During times of frequent exposure to UV radiation, generally during the summer months, most skin types darken due to a higher production of melanin. This is an example of an environmental factor (UV radiation) affecting observable characteristics (skin colour).

Other environmental factors that can affect phenotypes are:

- the physical environment
- nutrition
- exposure to chemicals and toxins
- exposure to harmful radiation
- predators and pathogens
- competition for resources.

Phenylketonuria

phenylketonuria (PKU)
a genetic disorder that causes a build-up of phenylalanine, which can lead to problems with brain development

Phenylketonuria (PKU) is an inherited disease in which phenylalanine (one of the 21 amino acids) builds up, leading to problems with brain development. Although our bodies produce small amounts of phenylalanine, this amino acid is mainly obtained from our diet. Individuals with PKU have a mutation in an enzyme-producing gene that is responsible for breaking down phenylalanine in the diet. People with PKU do not have this enzyme, and cannot break down the phenylalanine. Instead, phenylalanine builds up to toxic levels in the body. Symptoms can include seizures, tremors and stunted growth. If PKU is not treated, it can result in irreversible brain damage.

PKU is a recessive trait. Therefore, a person with PKU is homozygous recessive and has inherited the trait from both parents. In Australia, newborn babies are tested for this genetic disorder. Fortunately, symptoms can be prevented by modifying the diet of a baby who is positive for this disorder. If people with the condition remove or reduce food containing phenylalanine from their diets (Figure 2), they have normal brain development. Because this trait is influenced by diet (environment), the phenotype is not solely determined by the genotype.

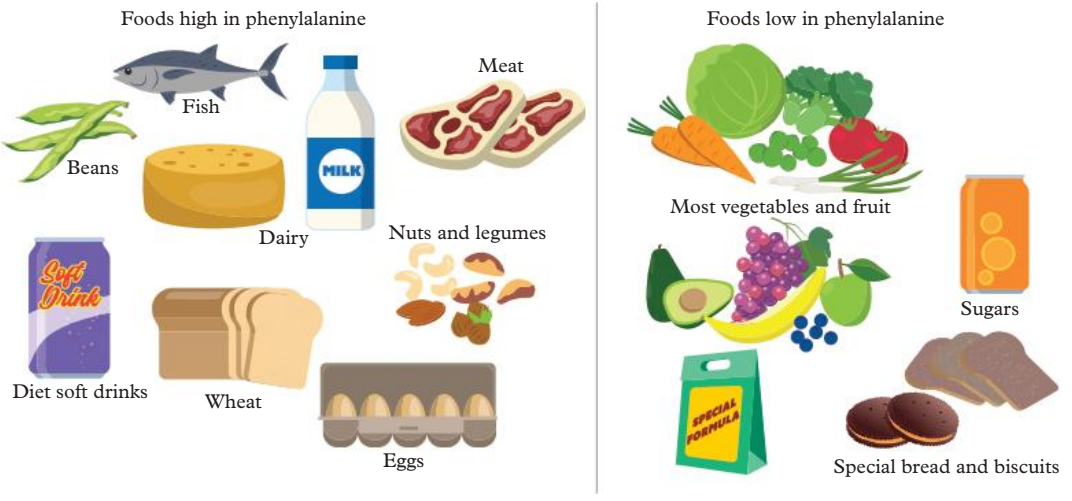


FIGURE 2 People with PKU must avoid foods containing phenylalanine.

Flower colour in hydrangeas

Hydrangea flower colour is a trait that is influenced by environment. Hydrangeas have large clustered flowers that are either pink or blue, depending on the pH of the soil (Figure 3). Cuttings from the same plant (having the same genotype) would have blue flowers in acidic soil (pH < 5.5) and pink flowers in slightly alkaline soil (pH > 6.5).

In acidic soil, more aluminium is available to be taken up by the plant. In hydrangeas, the pigment anthocyanine is normally red. However, it can bind with aluminium and form a blue pigment called metalloanthocyanine. Therefore, in acidic soil, the flower colour is blue. In alkaline soil, where aluminium is less readily available and the anthocyanine pigment stays red, the flowers are pink.

FIGURE 3 The flowers of hydrangeas are blue when grown in acidic soil and pink in alkaline soil.

CASE STUDY 7.3

Human height: genetics or nutrition?

Human height shows continuous variation with a large range of measurements, determined by many genes and environmental influences such as nutrition. On average, 60–80% of height is determined by genetics and 20–40% is influenced by environmental factors.

These estimates are based on studying the heights of relatives. It is not possible to determine the exact degree of genetics and environmental influence because environmental influence can vary greatly between individuals, even from the same household. Height heritability will vary between populations with different genetic backgrounds and different environments and diets.

The most important nutrient for individuals to reach their potential height is the protein consumed during childhood. Other minerals such as vitamins A and D and calcium also influence height. Malnutrition before puberty can affect height development. Children who have good nutrition, such as in developed countries, have the best chance of maximising their genetic potential for height.

Disease is another environmental factor that influences height. Where disease has resulted in growth defects, people can be treated with human growth hormone. If an individual is being treated with growth hormone, their final height is no longer determined by genetic heritability.

FIGURE 4 Human height is influenced by genetics, nutrition or a combination of both.

Epigenetics

epigenetics
the study of changes in gene expression caused by modification of the DNA without changing the sequence

Phenotypes can also be affected by factors within the body that control gene expression. **Epigenetics** is the study of factors that modify gene expression but do not alter the DNA sequence, resulting in variations to the phenotype. Epigenetics can be thought of as an extra layer of instructions controlling how genes are expressed.

DNA methylation
the process of adding methyl groups to the cytosine bases of DNA, which can change the expression of a gene

There are different types of epigenetic modifications or tags that can influence the expression of DNA. The most common is **DNA methylation**, which is the addition of a methyl group (CH_3) to the DNA base cytosine (Figure 5). When methyl groups attach, they can prevent the expression of the gene.

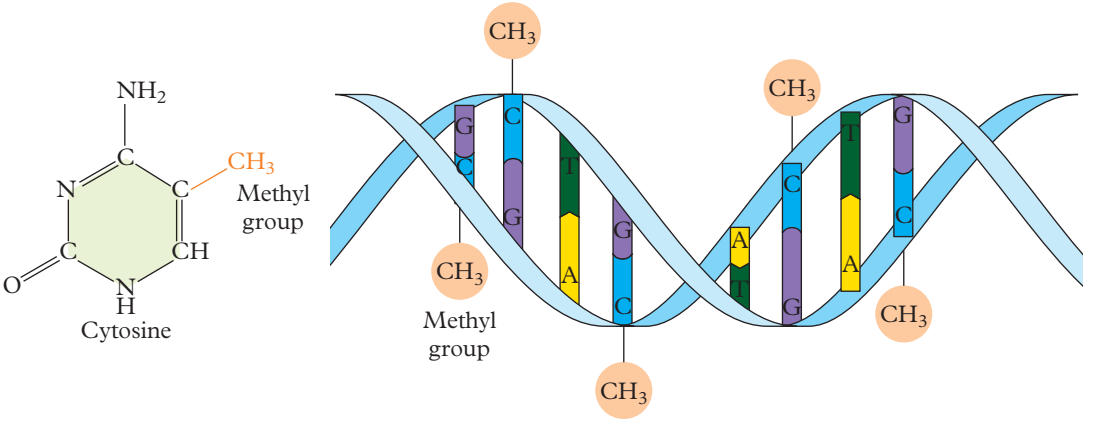


FIGURE 5 A methyl group (CH_3) can attach to the DNA base cytosine, preventing the expression of genes.

histone modification
the addition of chemical groups to histone proteins, which affects the spacing between nucleosomes and therefore gene expression

Another type of epigenetic modification is **histone modification**. DNA is coiled around small proteins called histones to form nucleosomes (Figure 6). Different chemical groups attached to the histone proteins determine the spacing between nucleosomes. One such chemical group is the methyl group, which makes the spaces between the nucleosomes tighter, and difficult for the cell to access the DNA. For this reason, the genes contained in these sections of the DNA are not expressed and can be considered inactive.

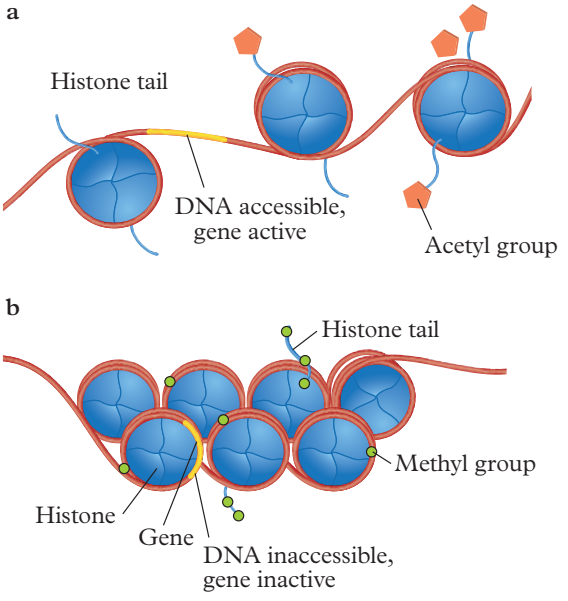


FIGURE 6 **a** DNA is coiled around histone proteins, forming nucleosomes. **b** If the nucleosomes are tightly packed, the DNA cannot be read and the genes become inactive.

When gametes are formed by meiosis, such epigenetic modifications are normally erased. However, some epigenetic tags can persist and are inherited. This sort of inheritance does not follow the genetic patterns already discussed, making it difficult to predict epigenetic outcomes.

Epigenomes

Epigenetic modifications are also affected by environmental factors such as diet, stress and exposure to chemicals and toxins. This leads to an epigenetic imprint, or DNA methylation pattern, on an individual's DNA caused by their lifestyle and other environmental factors. DNA methylation patterns are mostly determined early in development. Hence, the environment and diet of a pregnant woman may affect the DNA methylation pattern of her developing embryo. An individual's DNA methylation patterns and other epigenetic tags are known as their **epigenome**.

epigenome the epigenetic modifications to the DNA and histone proteins of an individual

Epigenetics and disease

An epigenetic marker can control the expression of a gene, which is essentially the same as the effect of a genetic mutation. Cancer is the result of uncontrolled cell replication caused by mutations in the DNA. Cancer is recognised as both a genetic and an epigenetic disease.

The DNA in cancerous cells often has a different methylation pattern from that of normal healthy cells. This is evidence that epigenetics is linked to the formation of cancerous cells. The methylation pattern contributes to the abnormal replication of cancer cells.

CHECK YOUR LEARNING 7.3

Describe and explain

1 Explain how hydrangea flowers from the same plant can produce different-coloured flowers.
2 Explain what phenylketonuria is and how environmental conditions can decrease the effects of this disease.
3 List some environmental factors that can affect phenotypes.

Apply, analyse and compare

4 Plants with the same genotype can have reduced growth at higher altitudes. Identify an environmental factor affecting the phenotype in this situation and explain how this is an example of phenotype being affected by factors other than genotype.
5 By referring to Case study 7.3, analyse why we cannot determine the different proportions of influence of genotype and nutrition on human height.
6 Describe how cancer can be caused by epigenetic modifications.

Design and discuss

7 Discuss the following statement. 'Our epigenome is mainly determined during embryonic development. Therefore, our mother's and grandmother's lifestyles affect our own epigenetic tags.'

CHAPTER 7

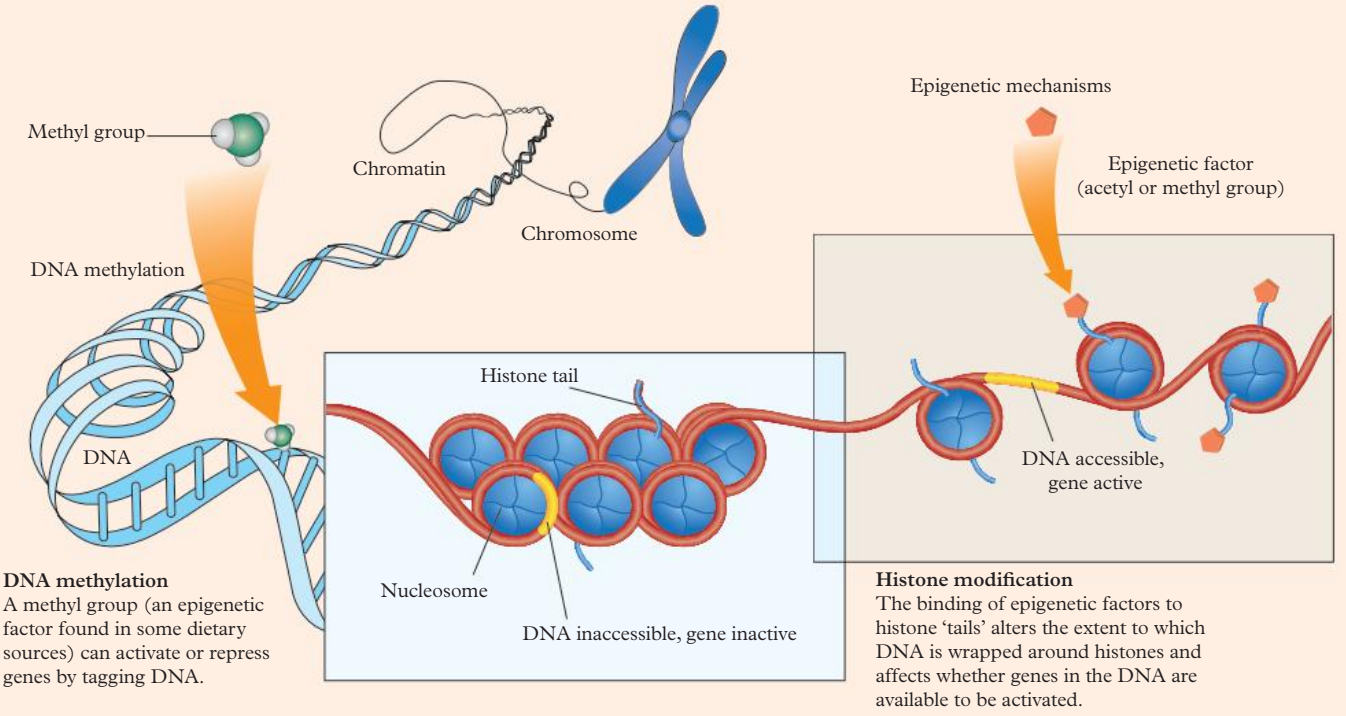
Review

Chapter summary

7.1
- The combination of alleles for a gene is called a genotype.
- The phenotype is the physical expression of a genotype that is affected by the environment and epigenetic factors.

7.2
- The three types of dominance are complete dominance, codominance and incomplete dominance

7.3
- Phenotypes are affected by genotypes and environmental factors.
- Epigenetic markers can attach to DNA and control the expression of genes.
- Genotype, environmental and epigenetic factors have a proportionate influence on phenotypes.



DNA methylation
A methyl group (an epigenetic factor found in some dietary sources) can activate or repress genes by tagging DNA.

Histone modification
The binding of epigenetic factors to histone 'tails' alters the extent to which DNA is wrapped around histones and affects whether genes in the DNA are available to be activated.

Key formula

Phenotype = genotype + environmental factors + epigenetic factors

Revision questions

Multiple choice

1 Identify which genotype refers to a gene with only one copy of the allele present in diploid cells.
- **A** Heterozygous
- **B** Hemizygous
- **C** Homozygous dominant
- **D** Homozygous recessive

2 Identify which of the following genotypes shows alleles for a homozygous recessive trait.
- **A** AB
- **B** AA
- **C** Aa
- **D** aa

3 Identify which of the following is true.
- **A** Incomplete dominance refers to a monogenic trait with two different phenotypes.
- **B** Incomplete dominance is a trait with three possible phenotypes: the dominant phenotype, the recessive phenotype and a phenotype where the dominant and recessive traits are equally expressed.
- **C** The dominant trait is discrete and observed in all heterozygous individuals.
- **D** The heterozygous individual of an incomplete dominant trait displays a blend of two alleles because one allele is not completely expressed over the other allele.

4 Identify which of the following correctly describes the relationship between genes and alleles.
- **A** A gene codes for a trait and alleles are the different variations of the trait.
- **B** Different alleles code for genes.
- **C** Genes are found at the same location on chromosomes; alleles are found at different locations.
- **D** Genes are found on autosomes and alleles are found on sex chromosomes

5 Identify which genotype can be considered a carrier for a recessive trait.
- **A** aa
- **B** AB
- **C** Aa
- **D** AA

6 Red-green colour blindness is an X-linked recessive trait. Identify the genotype of a phenotypically normal male.
- **A** X^CX^C
- **B** X^cX^c
- **C** X^CY
- **D** X^cY

7 An individual with the genotype I^Ai for blood type would have which of the following phenotypes?
- **A** Type A
- **B** Type O
- **C** Type AB
- **D** Type AO

8 If nucleosomes are spaced close together because of histone modifications, then the gene will be:
- **A** inactive
- **B** activated
- **C** switched on
- **D** removed.

9 Hydrangea flowers in acidic soil are blue because:
- **A** aluminium from the soil contains a blue pigment that is absorbed by the plant
- **B** anthocyanine is normally red but converts to blue at pH > 6.5
- **C** acidic soils usually have a higher temperature, leading to changes in coloured pigments
- **D** anthocyanine binds to aluminium from the soil and changes to a blue pigment.

Short answer

Describe and explain

10 Name the term that involves the study of heritable phenotypic changes that do not involve alterations of the DNA sequence.

11 Suggest one factor, other than DNA sequences, that can affect the final biological height of a person.

12 Define:

- **a** heterozygous
- **b** homozygous dominant
- **c** homozygous recessive.

13 Identify the allele symbols that should be used for a dominant trait and a recessive trait.

14 Describe how the allele symbols for sex-linked traits and codominant traits are different from symbols for complete dominant traits.

15 Describe the different types of epigenetic modification.

Apply, analyse and compare

16 Compare dominant and recessive phenotypes.

17 Is it correct to say that genotype = phenotype? Explain your reasoning.

18 Dimples are a dominant trait.

- **a** Suggest symbols to represent the alleles for dimples and no dimples.
- **b** Using the symbols you have identified for part a, identify two genotypes that could result in the expression of dimples.

FIGURE 1 Dimples are a dominant trait.

19 Use an example to explain the effect of the environment on phenotype.

20 Many scientists use twin studies to identify non-genetic factors that affect phenotypes. Suggest why comparing identical twins is useful for such studies.

21 Some cat breeds (e.g. Siamese) contain an enzyme that converts tyrosine (dark pigment) to melanin. The dark pigment is only seen in the cooler areas of the body (face, ears, feet and tail) where the enzyme is less active. In the cooler months, these cats appear darker and this dark pigment fades a little during the warmer months.

Explain how this is an example of an environmental factor affecting the phenotype.

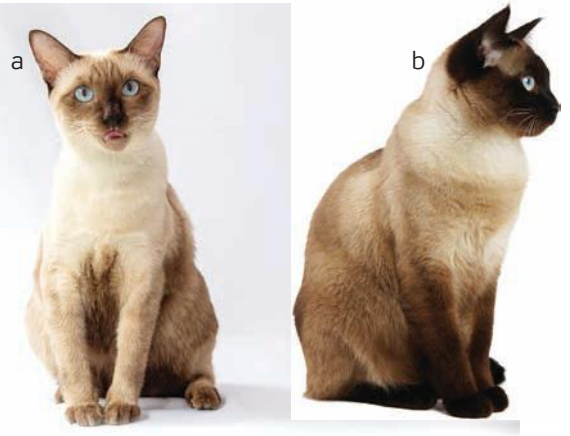


FIGURE 2 A Siamese cat in **a** a warm environment with less melanin production and **b** a cool environment with more melanin production

22 Explain why genetically identical twins are not always phenotypically the same.

23 Some organisms respond to predators by changing parts of their body. *Daphnia* is a water flea that is able to develop a helmet to protect itself against a predator. Chemicals produced by the predator enable this helmeted formation.

FIGURE 3 The helmeted form (left) and non-helmeted form of *Daphnia*

a Explain how helmet development is an example of environmental influence on phenotype.

b Explain how this phenotypic change provides an advantage to *Daphnia*.

Design and discuss

24 Haemophilia is an X-linked recessive trait. Individuals with haemophilia do not have enough clotting factors in their blood and therefore can suffer from frequent bleeding, both internal and external. Boys can inherit the allele for the recessive trait from their mothers, which causes the haemophilia phenotype.

a Explain the term 'X-linked allele'.

b Identify the genotype of a male affected with haemophilia.

c Identify the genotype of a female affected with haemophilia.

d Explain why it is it more common for males than females to have X-linked recessive traits.

e For a female to have haemophilia, her father must have the condition. Discuss this statement.

25 Researchers sometimes use twins to study the impact of genetic and environmental factors on phenotype, such as height or weight.

a Discuss why researchers would prefer to use identical twins to study the impact of environmental factors, as opposed to two random test participants.

b Outline one ethical implication of using twins in biological studies.

Check your Student obook pro for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to format your response based on the directional word in the question.

Respond to the directional word

You need to identify the directional word in a question – this is the key word telling you how to respond.

Memory-type directional words include define, describe, list, outline, name and state. Your responses to these key words should present your knowledge on the topic.

Analysis-type directional words include explain, justify, compare and discuss. Your responses to these key words should demonstrate your analytical skills and application of knowledge.

QUESTION 1a (2003 Biology Written Examination 2)

The back of the leopard frog (*Rana pipiens*) can be either patterned or non-patterned. Several patterned frogs were allowed to breed and they produced 75 patterned offspring and 25 non-patterned offspring.

a **i** Which of the phenotypes, patterned or non-patterned, is dominant.

ii Explain your answer to **i**. 1 + 1 = 2 marks

Source: 2003 Biology Written Examination 2, Question 1a, Short answer, reproduced by permission © VCAA

Response 1

i patterned

ii When two patterned frogs mated, 25% of the offspring were non-patterned. This means the non-patterned allele was being carried by the parents and must be recessive. If the patterned phenotype was recessive, no non-patterned offspring would be produced.

This provides enough information to answer the question. They key word asks you to 'identify' only.

Using data from the question helps to demonstrate your understanding.

This response would receive full marks. The answer to part i is a one-word answer because this is all the question asked for. The second part of the question is the explanation, which requires an application of knowledge. This response clearly justifies why the patterned phenotype is dominant.

Response 2

i The patterned phenotype is dominant.

ii The patterned phenotype is dominant because it occurs at a higher frequency, and phenotypes that are more common are dominant.

This does not 'explain'. Explanations require you to provide more detailed information that shows you understand why or how things occur.

The second part of the response would not receive a mark. The explanation is unclear and dominant phenotypes are not always the most common (e.g. Huntington disease).

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 3 (adapted from 2008 Biology Written Examination 2)

Many gene loci are involved in determining blood groups. One gene, the ABO gene, is responsible for the ABO blood groups.

This gene locus has the alleles:

I^A: A protein produced

I^B: B protein produced

i: no protein produced

There are four phenotypes, called blood groups, in this system. They are A, B, AB and O.

a Complete the following table using the allele symbols given above. 2 marks

Blood group	Possible genotypes
B	I^BI^B
AB	I^AI^B

Source: 2008 Biology Written Examination 2, Question 3, Short answer, reproduced by permission © VCAA

b Explain why the ABO blood groups are an example of codominance. 1 mark

The blood groups show codominance because they are all equally dominant to one another.

Marking guide

3a	1 mark for identifying the correct genotypes for each blood group: • Blood group B: I^BI^B and I^Bi • Blood group AB: I^AI^B
3b	1 mark for explaining that both the A and B protein markers are present in the heterozygote genotype I^AI^B; therefore, the two traits (A and B) are equally dominant. (Note: Blood group O is recessive and is an example of complete dominance when compared with either blood group A or blood group B.)

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 an examiner.

Check your Student obook pro for the following digital resources and more:

Video
Responding to directional words

Weblink
Past examinations and examiners' reports

CHAPTER 8

Inheritance

Have you ever realised you share a trait with your mother or father? Or do you have a trait, such as a particular hair colour, that neither your mother nor your father has? Traits are inherited by the combination of maternal and paternal alleles. There are different patterns of inheritance, including autosomal dominant (e.g. Huntington disease), autosomal recessive (e.g. albinism) and sex-linked (e.g. red-green colour blindness). A pedigree shows the inheritance of a trait over two or more generations and can be used to predict the pattern of inheritance.

Monohybrid crosses are used to observe the relationship between two alleles and determine the dominant and recessive phenotypes. Punnett squares can determine the probability of particular genotypes and phenotypes in the offspring. When two genes are linked or assorted independently, we can use dihybrid crosses to predict the genetic outcomes of the offspring.

KEY KNOWLEDGE

- → pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance
- → predicted genetic outcomes for a monohybrid cross and a monohybrid test cross
- → predicted genetic outcomes for two genes that are either linked or assort independently.

Source: *VCE Biology Study Design (2022-2026)* reproduced by permission © VCAA.

FIGURE 1 Each generation inherits traits from the previous generation.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

8A How does meiosis produce genetically different gametes?

8A Groundwork resource
Meiosis

8B What is the purpose of the X and Y chromosomes?

8B Groundwork resource
X and Y chromosomes

8C What are the different allele notations used for dominant and recessive traits (autosomal) and X-linked traits?

8C Groundwork resource
Representing alleles

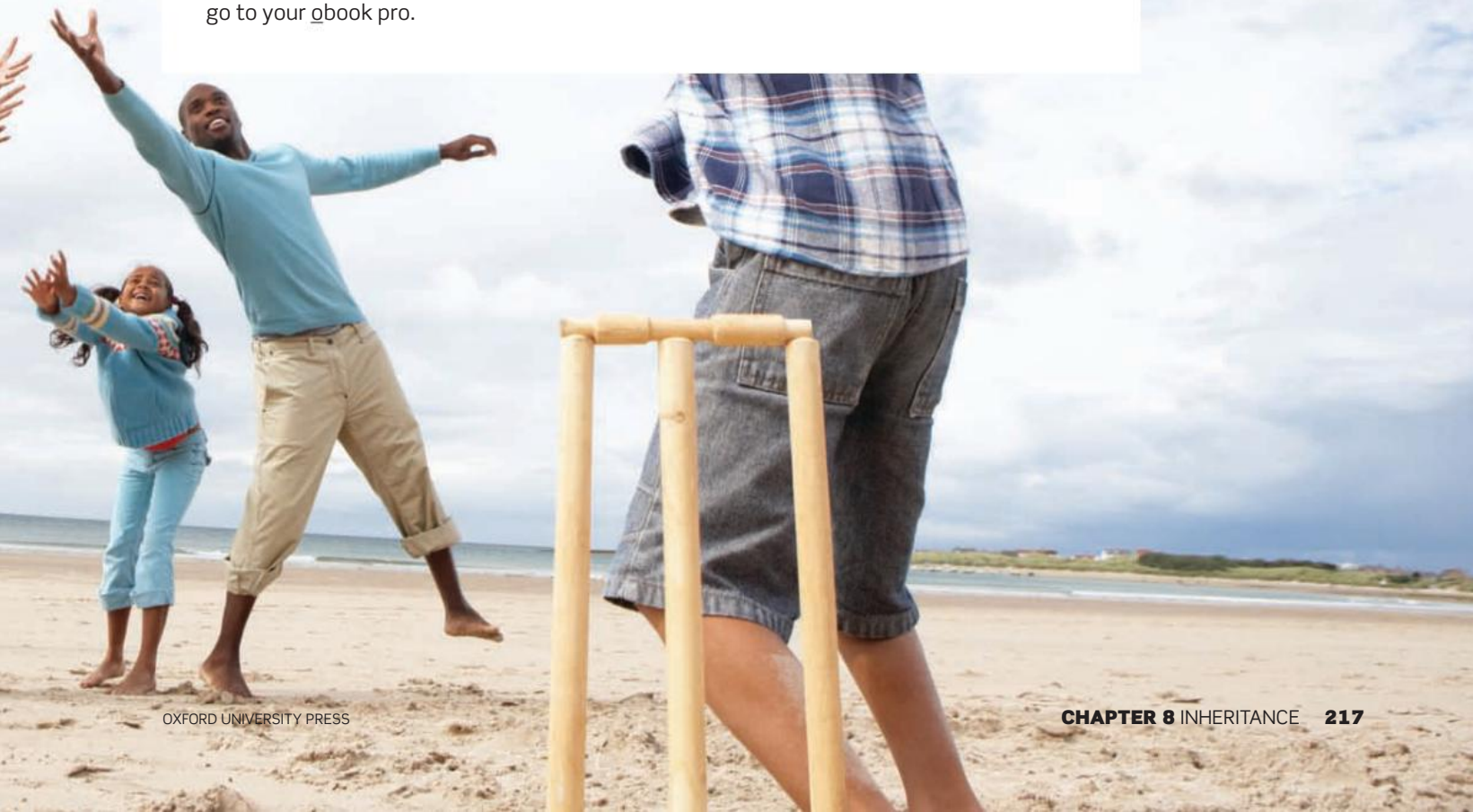
8D What is the difference between a genotype and a phenotype?

8D Groundwork resource
Genotypes and phenotypes

PRACTICALS

NO-TECH PRACTICAL 8.1 Sex-linked inheritance

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.



8.1 Pedigree charts and inheritance patterns

KEY IDEAS

In this topic, you will learn that:

- autosomal inheritance refers to patterns of inheritance that are related to genes located on autosomes
- sex-linked inheritance refers to patterns of inheritance that are related to genes located on the X or Y chromosome
- pedigree charts can be analysed to determine the presence of a genetic trait, patterns of inheritance and the genotypes of individuals.

Patterns of inheritance

Video Patterns of inheritance

Gregor Mendel (1822–1884) was a botanist and monk who lived and worked in a monastery in what is now the Czech Republic. Mendel is referred to as the 'father of genetics' for his research into patterns of inheritance from breeding pea plants in the monastery gardens. His discoveries formed the foundation of the study of heredity and are referred to as the Mendelian laws of inheritance.

Mendel worked with several different traits in pea plants, including plant height, pod shape and colour, seed shape and colour, and flower position and colour. He was able to show that when two plants with different traits are crossed, the resulting offspring follow a predicted trend. Mendel found that the offspring do not always have the phenotypes of their parents, but instead display the phenotypes of those traits that are dominant.

law of segregation the law that states that during gametes formation (meiosis), each gamete randomly receives one allele of each gene

One of the laws of Mendelian inheritance is the **law of segregation**. Mendel found that each parent contributes one allele to their offspring and these alleles combine to produce the genotype. We now have better technology that has given us a more advanced understanding of the law of segregation. We know that during meiosis, the gametes (egg and sperm) only obtain half of the chromosomes from the original parent cell. The law of segregation states that alleles from homologous chromosomes separate during meiosis, and then during fertilisation allele pairs randomly unite. The alleles then form the genotype and help to determine the phenotype of the offspring.

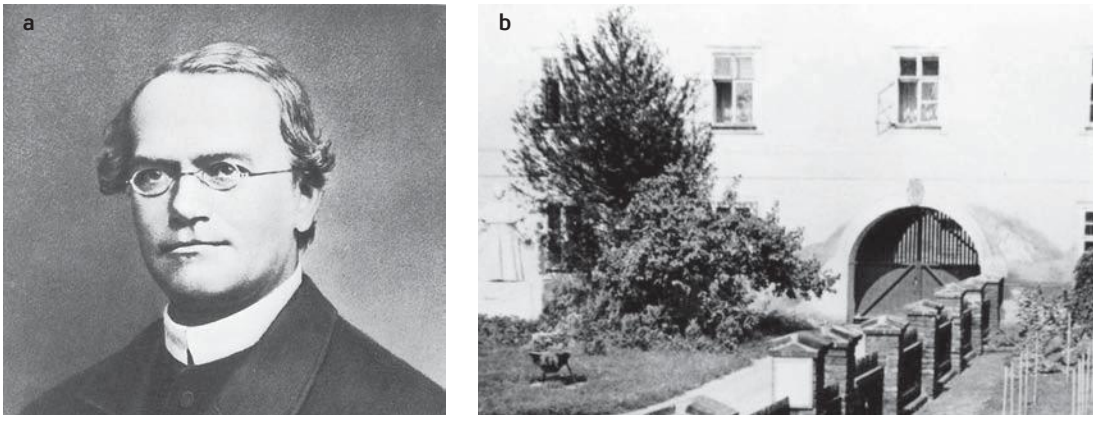


FIGURE 1 **a** Gregor Mendel, a botanist and monk, is referred to as the 'father of genetics'; **b** the garden at the monastery where Mendel conducted his experiments with pea plants.

Autosomal dominant and autosomal recessive inheritance

Inheritance of a single gene on an autosome (non-sex chromosome) can be dominant or recessive. This kind of inheritance is known as complete dominance. An **autosomal dominant** trait requires only one copy of the allele for the dominant trait to express the dominant phenotype. When one allele of a gene completely masks the effect of the allele for the trait that is recessive, it is also called complete dominance. An **autosomal recessive** trait requires two copies of the same allele for the recessive trait to express the recessive phenotype.

autosomal dominant
a pattern of inheritance where affected individuals have at least one allele (located on an autosome) for the trait

autosomal recessive
a pattern of inheritance where two copies of the same allele (located on homologous autosomes) must be present for the trait to show in the phenotype

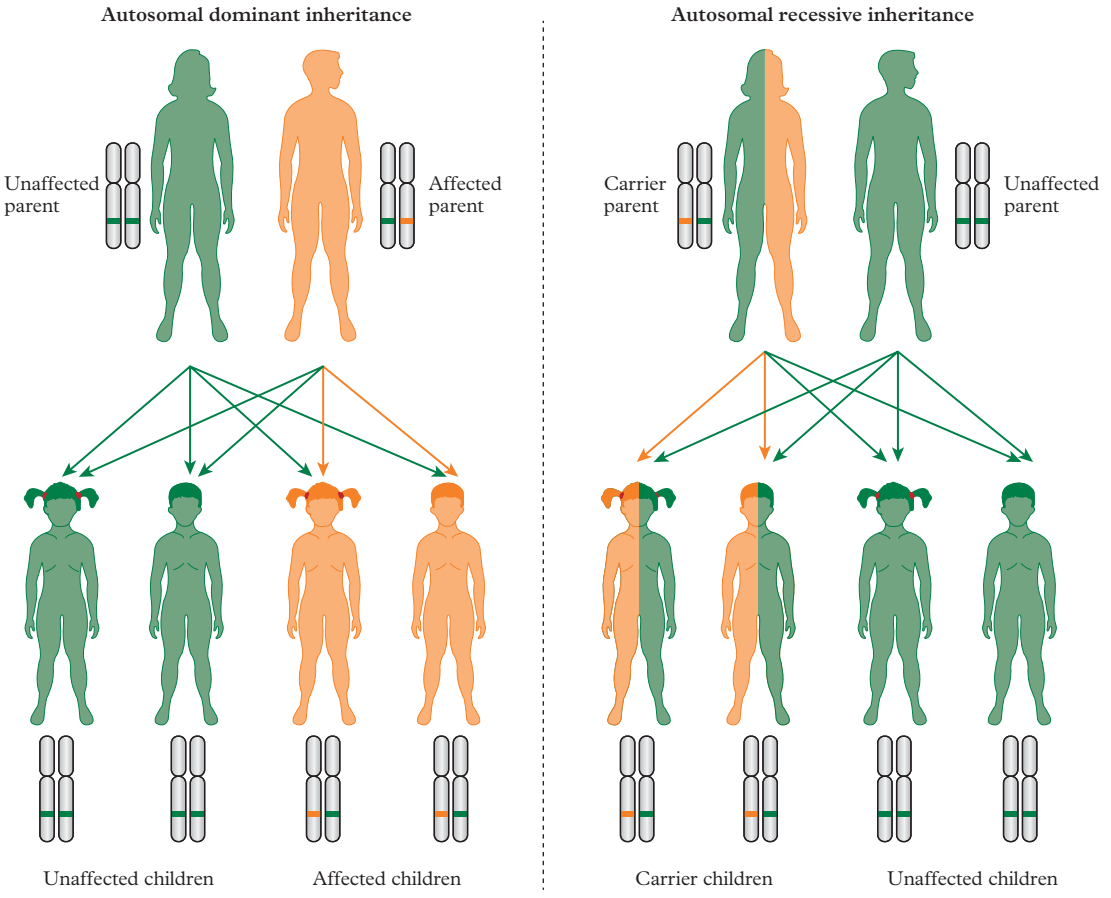


FIGURE 2 Autosomal dominant and autosomal recessive inheritance

Sex-linked inheritance

Genes are also found on the sex chromosomes (X and Y in humans). **Sex-linked** inheritance refers to the passing on of genes located on the X or Y chromosome.

sex-linked
refers to genes that are found on the X or Y chromosome

Human females have 44 autosomes and two X chromosomes. They will always pass on an X chromosome to their offspring via the egg. Males have 44 autosomes and an X and a Y chromosome. A male can pass on an X or a Y chromosome to the offspring via the sperm. Therefore, it is the male's sperm that determines the sex of the offspring (see Chapter 9).

There are three patterns of sex-linked inheritance: Y-linked, X-linked recessive and X-linked dominant inheritance.

Y-linked
a pattern of inheritance where the gene for the trait is located on the Y chromosome

- **Y-linked** inheritance refers to genes located on the Y chromosome. Traits on the Y chromosome will be neither dominant nor recessive because there is only one Y chromosome in males (and none in females). The Y chromosome is much smaller than the X chromosome and contains about 72 protein-coding genes (compared with about 900 on the X chromosome). These traits are only observed in males, and are passed from father to son. An example of Y-linked inheritance is mutations in the *SRY* gene, which affects male sexual development.

X-linked recessive
a pattern of inheritance where the gene for a recessive trait is located on the X chromosome

- **X-linked recessive** inheritance refers to genes for a recessive trait located on the X chromosome (Figure 3). Females can be carriers (heterozygotes) of X-linked recessive traits because they have two X chromosomes. Males only have one X chromosome (hemizygous) so either they have the trait by carrying the allele for the recessive trait on their X chromosome, or they are unaffected by carrying the allele for the dominant trait on their X chromosome. This pattern of inheritance is seen more frequently in males than in females. An example of an X-linked recessive condition is haemophilia, a bleeding disorder in which the blood does not clot properly.

X-linked dominant
a pattern of inheritance where the gene for a dominant trait is located on the X chromosome

- **X-linked dominant** inheritance refers to genes for a dominant trait located on the X chromosome (Figure 4). This pattern of inheritance is seen more frequently

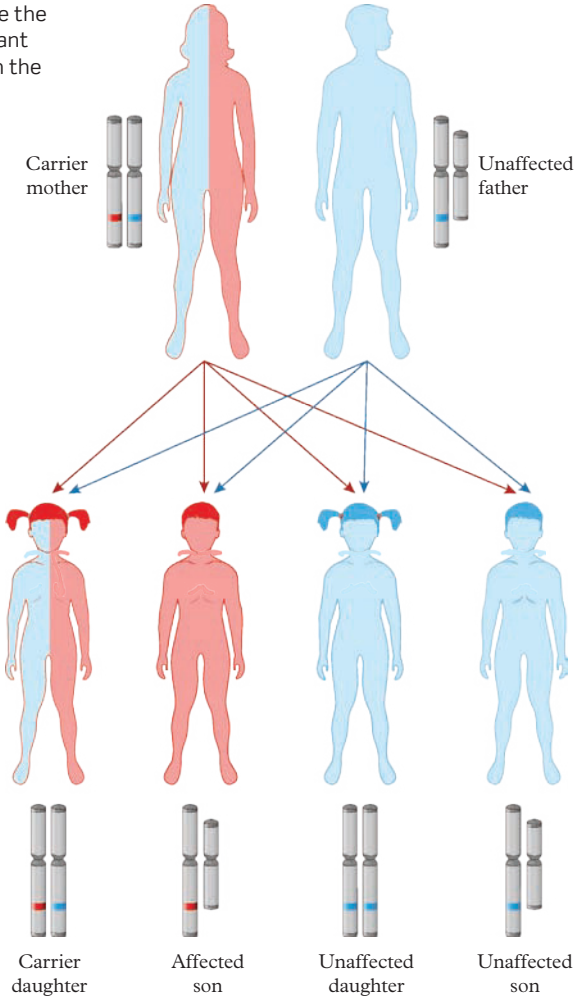


FIGURE 3 In X-linked recessive inheritance, females can be carriers of X-linked recessive traits.

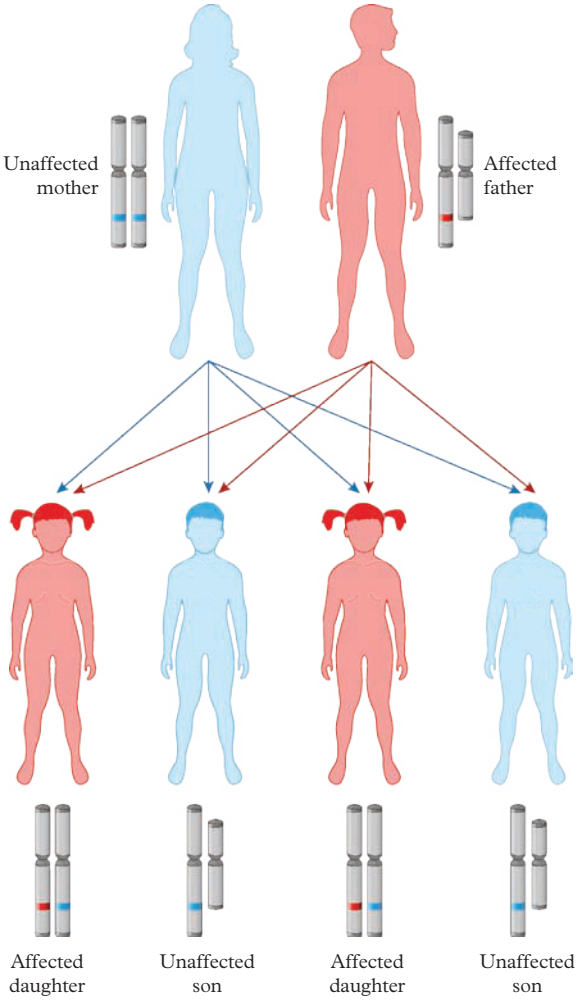


FIGURE 4 In X-linked dominant inheritance, if the trait is present, then the individual will be affected (male or female).

in females than in males. Sometimes affected males do not survive because they are so severely affected with only one X chromosome compared with heterozygous females. Rett syndrome is an X-linked dominant condition – it is a brain disorder in which individuals have slower growth, coordination issues and learning difficulties.

Pedigree charts

Pedigrees show the inheritance of traits over two or more generations. If you have enough data, you can determine the mode of inheritance from a pedigree. You can also determine the probability of an allele occurring in potential offspring.

pedigree
a diagram that shows the inheritance of a trait in a family for at least two generations

Specific symbols are used to construct pedigrees. These are shown in Figures 5 and 6.

- Males are represented by squares. Females are represented by circles. A square or circle with a line through it indicates a deceased individual.
- The trait shown is represented by a shaded circle or square. These individuals are known as 'affected' individuals.
- Non-shaded individuals are considered 'unaffected' but may be carriers for recessive traits.
- A mating line is denoted by a horizontal line between two individuals. A vertical line leads to their offspring.
- Roman numerals on the left-hand side represent generation numbers. Individuals are identified by Arabic numbers underneath each symbol, running from left to right.

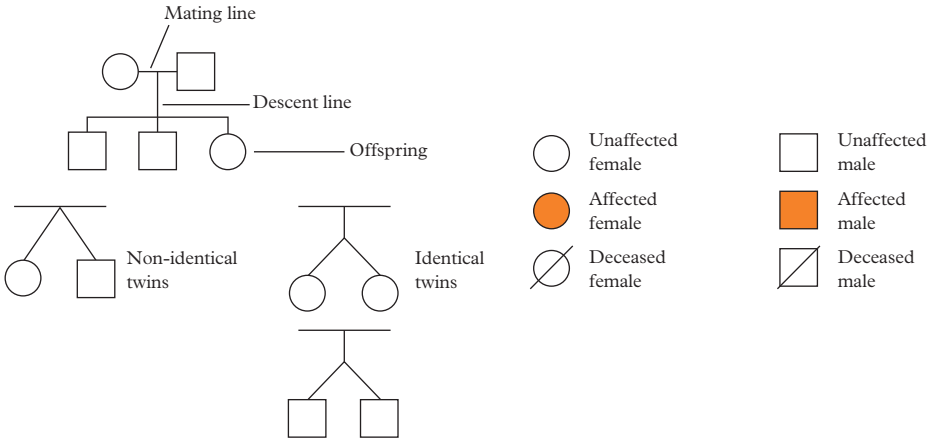


FIGURE 5 The different symbols used to construct a pedigree chart. Circles are used for females and squares are used for males.

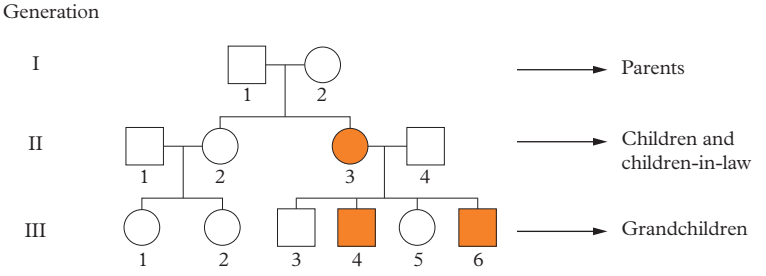


FIGURE 6 The numbering systems used to construct pedigree charts. Generations are labelled with Roman numerals vertically down the charts and individuals are numbered with Arabic numbers from left to right across the chart.

Analysing pedigrees

Pedigrees can be analysed to determine the pattern of inheritance. As you have learnt, there are several patterns of inheritance and there are rules and questions that you can ask to determine which type of inheritance is shown in a pedigree.

Autosomal inheritance in pedigree charts

If the inheritance is autosomal (dominant or recessive), then generally equal numbers of males and females are affected.

- If parents do not display the trait but offspring are affected, then this is autosomal recessive inheritance (Figure 7). This means the parents must be carriers of the recessive trait. Another indicator of autosomal recessive inheritance is that the trait skips a generation. Although not considered strong evidence of the pattern of inheritance, it can help make a first prediction of which pattern of inheritance the pedigree most likely shows.
- Autosomal dominance means every affected individual must have an affected parent (Figure 8). If both parents are affected, and some of their children do not have the trait, then the trait is dominant.

Study tip

You can identify individuals in pedigree charts, by using numbers. For example, the individual in the second generation and third across is called II-3.

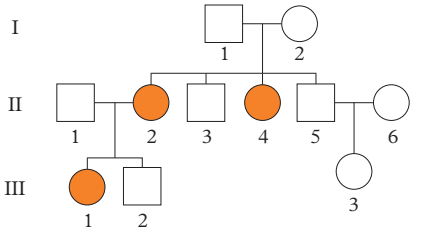


FIGURE 7 Albinism is an autosomal recessive trait in which people have reduced amounts of melanin pigment in their skin, hair and/or eyes. This pattern of inheritance can be determined with two unaffected parents (I-1 and I-2) having an affected child (e.g. II-2 and II-4).

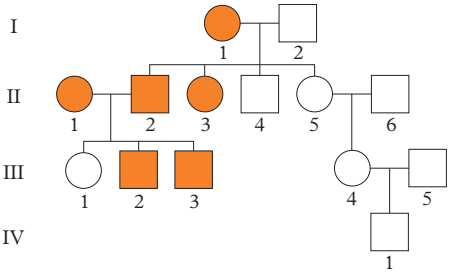


FIGURE 8 Huntington disease is an autosomal dominant trait. Neurons in the brain break down, which affects the person's movement and thinking. This pattern of inheritance can be shown when every affected individual has an affected parent and if two affected parents (II-1 and II-2) have some unaffected children (III-1).

Sex-linked inheritance in pedigree charts

Sometimes a trait may follow a sex-linked pattern of inheritance.

- Y-linked inheritance: Male offspring inherit the Y chromosome from their fathers. If all affected fathers have affected sons, then it is most likely Y-linked. Females are never affected by Y-linked traits. The trait is observed in each generation (if there are males) (Figure 9).

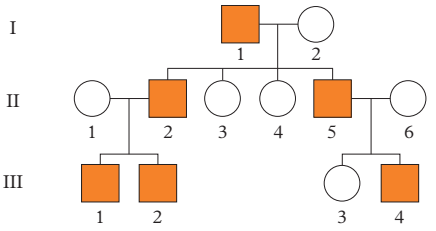


FIGURE 9 Hairy ears are a Y-linked trait. This pattern of inheritance can be determined by observing all affected fathers with affected sons. For example, father I-1 has two sons who are both affected (II-2 and II-5), and no females are affected.

- X-linked recessive inheritance generally affects males more than females (Figure 10). If affected mothers have affected sons, then it may be X-linked recessive. Affected fathers will pass the X chromosome to their daughters. The daughters will be carriers (if they didn't receive an allele for the X-linked recessive trait from their mother). Females can be carriers and pass the trait onto their sons.

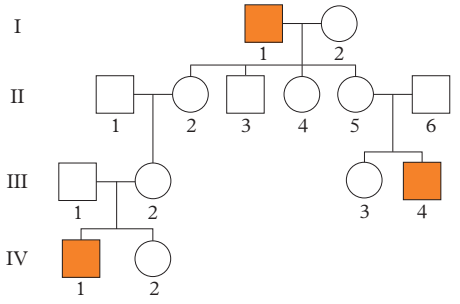


FIGURE 10 Red-green colour blindness is an X-linked recessive trait, which affects more males than females. This pattern of inheritance can be determined when an affected father (I-1) passes the allele for the trait to his daughters (II-5) and his daughter then has an affected son (III-4).

- X-linked dominant inheritance is rarer than X-linked recessive inheritance and generally affects more females than males (Figure 11). If all of the daughters and none of the sons of affected males have the trait, then it is most likely X-linked dominant. In this pattern of inheritance, all affected sons have an affected mother and all affected daughters have an affected father.

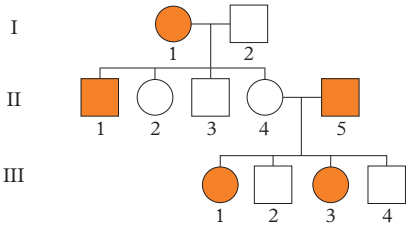


FIGURE 11 Rett syndrome is an X-linked dominant disorder. It is a neurological disorder that mostly affects females. This pattern of inheritance can be determined when affected fathers (II-5) have affected daughters (III-1 and III-3), as well as if all affected sons (II-1) have affected mothers (I-1).

Steps to analyse a pedigree

Analysing a pedigree can be challenging. It is best to follow a series of steps to determine the pattern of inheritance, such as the one shown in Figure 12 on the next page.

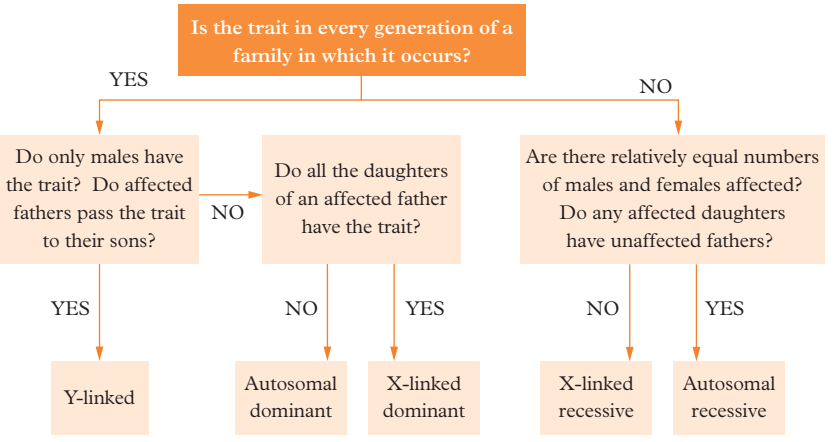


FIGURE 12 Steps to analysing the pattern of inheritance for a pedigree

Video
Worked example 8.1: Analysing a pedigree

WORKED EXAMPLE 8.1

ANALYSING A PEDIGREE

1 Determine the pattern of inheritance for the pedigree chart in Figure 13 and provide evidence to support your response.

2 Assign genotypes for individuals I-1, I-2 and II-1.

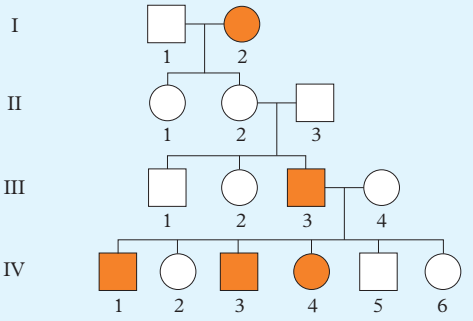


FIGURE 13 A pedigree chart

SOLUTION

1 Determine whether the trait appears in every generation of the family.

The trait skips generation II. Therefore, it is recessive.

Next, determine whether relatively even numbers of males and females are affected. Do any affected females have unaffected fathers?

No. The trait is X-linked recessive. This is because individual IV-4 is affected and she would have received an allele for the recessive trait from her affected father (III-3) as well as her mother (III-4), who must be a carrier.

2 Now that you have determined the pattern of inheritance, assign allele symbols and determine genotypes.

Since it is X-linked recessive, the allele symbols can be X^T (unaffected) and X^t (affected).

Genotypes:

I-1: X^TY (unaffected male)

I-2: X^tX (affected female)

II-1: X^TX^t (unaffected female but with affected mother; therefore, a carrier)

CHECK YOUR LEARNING 8.1

Describe and explain

1 Explain why Mendel is considered the 'father of genetics'.

2 Identify where the genes for autosomal traits are located.

3 Draw pedigree symbols to represent:
- **a** an affected female
- **b** identical twin boys
- **c** a couple who are both unaffected with an affected son.

4 Explain why Y-linked traits are:
- **a** neither dominant nor recessive
- **b** rare.

5 Describe the evidence from a pedigree that supports X-linked dominant traits.

Apply, analyse and compare

6 Explain why males are more likely to inherit X-linked recessive traits and females are more likely to inherit X-linked dominant traits.

7 Consider the pedigree in Figure 14.

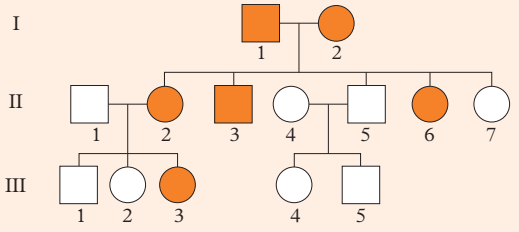


FIGURE 14 A pedigree chart

- **a** Which members of the family are affected by the trait?
- **b** How many children do individuals I-1 and I-2 have?
- **c** What is the pattern of inheritance? How do you know?
- **d** Assign genotypes to the following individuals:
  - **i** I-1
  - **ii** II-2
  - **iii** III-5

8 Examine the pedigree for red hair in Figure 15.
- **a** Identify the following features in the pedigree:
  - **i** the number of generations shown
  - **ii** the number of twins
  - **iii** the number of people with red hair in generations II and IV.
- **b** Determine the pattern of inheritance.
- **c** Assign genotypes to the following individuals:
  - **i** II-1
  - **ii** III-3
  - **iii** II-3

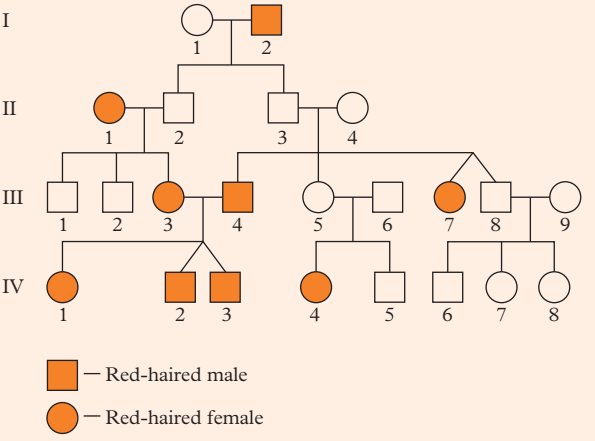


FIGURE 15 A pedigree for red hair

9 Consider the pedigree in Figure 16.

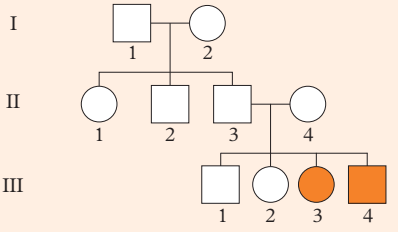


FIGURE 16 A pedigree chart

- **a** What is the pattern of inheritance? Explain your answer.
- **b** Which individuals can you confirm have the genotype:
  - **i** homozygous recessive?
  - **ii** heterozygous?
- **c** Can you determine whether any individuals are homozygous dominant? Why or why not?

8.2 Predicting outcomes using different crosses

KEY IDEAS

In this topic, you will learn that:

- Punnett squares can be used to predict the genotypes and phenotypes of offspring from a genetic cross
- a test cross can be used to determine the genotype of an individual with a dominant phenotype.

Mendel discovered that traits are passed from parents to their offspring in a predictable pattern. He achieved this by crossing pea plants with different phenotypes and observing the traits of the offspring. Today, you can predict the inheritance of a single gene (monohybrid) by using a **Punnett square**. A Punnett square is a table used to determine the probability of particular genotypes and phenotypes in the offspring for one trait controlled by a single gene, such as hair colour.

Punnett square
a table that predicts the genotypes of a particular cross

Monohybrid cross

A **monohybrid cross** describes the inheritance of traits that are controlled by only one gene; for example, cheek dimples (Figure 1). The single gene for cheek dimples has two alleles: dimples (the dominant trait, D) and no dimples (the recessive trait, d). We can use a Punnett square to examine how this trait is passed on to offspring.

monohybrid cross
a cross between two individuals differing in one trait

To make a Punnett square, put the alleles (for the genotype) of the parents along the top and down the side of the table. Fill the remaining boxes by combining the alleles (letters) of each parent (Figure 2).

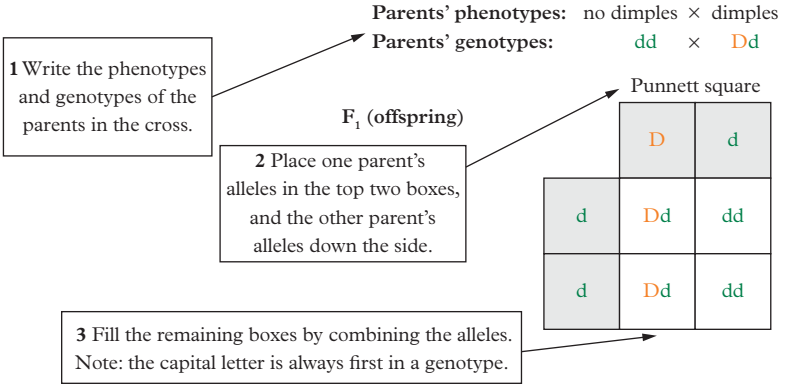


FIGURE 2 The layout of a Punnett square

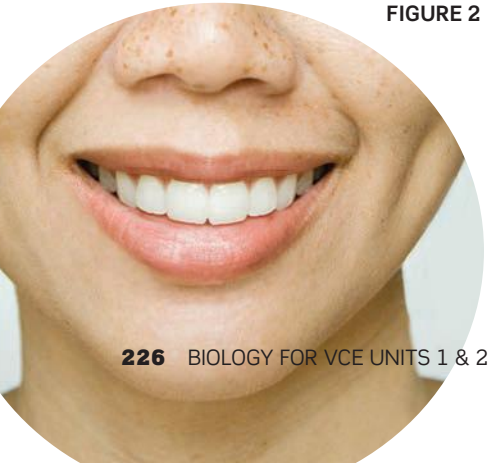


FIGURE 1 Dimples is a dominant trait controlled by one gene.

Then you can write the genotype and phenotype ratios of the offspring (Figure 3). The first generation of offspring is called the F_1 generation. If two individuals of this F_1 generation are bred with each other, the offspring are called the F_2 generation.

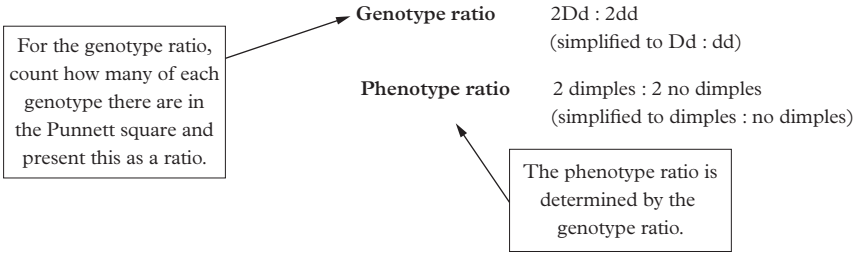


FIGURE 3 Genotype and phenotype ratios

Steps for constructing a Punnett square

1. Determine the possible phenotypes and genotypes of each parent.
2. Draw a Punnett square containing the parental alleles and determine the possible genotypes of the offspring by combining the parental alleles in each box.
3. Address the question, which may involve determining the ratio or the probability of genotypes or phenotypes of the offspring (F_1) (Figure 2).

Study tip

You can use a highlighter to easily identify the phenotypes of the offspring. Use different colours to represent the dominant and recessive traits.

WORKED EXAMPLE 8.2A

MAKING A PREDICTION USING A PUNNETT SQUARE

Fur colour in rabbits is controlled by a single gene, with two alleles, white (W) and black (w). A heterozygous white rabbit is crossed with a homozygous black rabbit. Predict the percentage of offspring from this cross that will be white.

FIGURE 4 Fur colour in rabbits is controlled by a single gene with two alleles, white (W) and black (w).

Video
Worked example 8.2A: Making a prediction using a Punnett square

SOLUTION

1. Determine the phenotypes of the parents.

   Parents' phenotype: white rabbit × black rabbit

   Then determine the genotypes of the parents. The dominant trait has not been identified in the question. In Chapter 7, you learnt that the heterozygous individual displays the dominant trait. Therefore:

   Parents' genotype: Ww × ww

2. Draw the Punnett square with the parental alleles. Then combine the alleles to determine the genotypes of the offspring.

	W	w
w	Ww	ww
w	Ww	ww

3. Refer back to the question.

   The percentage of white offspring (Ww) will be 50% (2 out of 4).

Study tip

Remember that when you write genotypes, if a letter looks similar as lower case and upper case, it can help if you underline the lower-case letter (e.g. 'C<u>c</u>' and 'W<u>w</u>'). These letters include c, k, m, o, s, v, w, x and z.

FIGURE 5 The gene for pod colour is controlled by two alleles, green (G) and yellow (g).

true-breeding individuals that when crossed together produce offspring with the same genotype and phenotype as the parents for a particular trait

When individuals who are homozygous for the same gene are crossed, the offspring will also be homozygous for that gene. These offspring are referred to as **true-breeding** individuals. For example, pod colour in pea plants is controlled by two alleles: green (G) and yellow (g). Green pods are the dominant trait. If two yellow-pod plants (gg) are crossed, all the offspring will be yellow (gg) and are considered true-breeding.

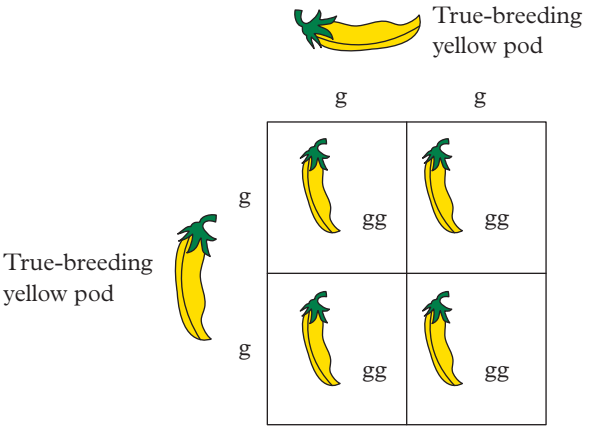


FIGURE 6 A Punnett square showing true-breeding

hybrid an individual that was produced by phenotypically different parents

When two true-breeding individuals with different traits are crossed, the offspring will be **hybrids** and will show the dominant trait. For example, if a plant with green pods (GG) and a plant with yellow pods (gg) are crossed, all the offspring will have green pods with genotype Gg. These offspring are considered hybrids for pod colour because they have the heterozygous genotype.

Study tip

A Punnett square can also be used for sex-linked traits. The same rules apply, but you need to use different allelic symbols with X and Y to represent the chromosomes, and use the alleles as superscripts (e.g. if the gene was on the X chromosome then the genotypes may be: X^HX^h and X^hY).

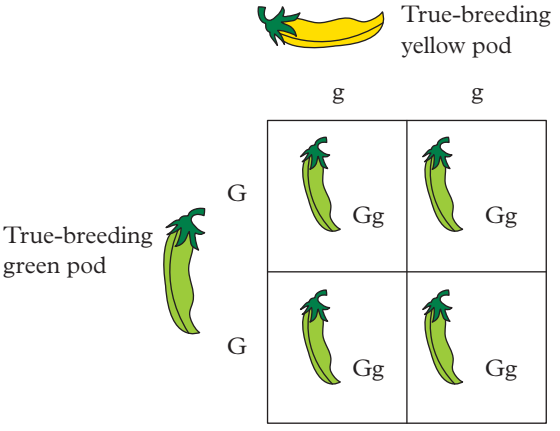


FIGURE 7 A Punnett square showing hybrids

Monohybrid test cross

monohybrid test cross a cross between an individual with the dominant phenotype and an individual with the recessive phenotype to determine the genotype of the dominant individual

It can sometimes be difficult to determine the genotype of an individual with a dominant phenotype. This is because the genotype could be heterozygous (Bb) or homozygous (BB) for the dominant trait. In animal and plant breeding, if there is a short time between generations and a large number of offspring in each generation, you can conduct a **monohybrid test cross** (or test cross) to determine the genotype of an individual.

Test crosses involve crossing the individual that has the unknown genotype with an individual known to be homozygous (bb) for the recessive trait. If a large number of offspring (at least 16) are produced, there are two possible outcomes.

1 All the offspring have the dominant phenotype – the unknown parent is most likely homozygous (BB) for the dominant trait.
2 There is at least one offspring with the recessive trait – the unknown parent must be heterozygous (Bb).

For example, purple flowers (P) in pea plants are dominant to white flowers (p). A plant with purple flowers has an unknown genotype. This plant is crossed with a plant that has white flowers (pp). The cross produces 16 offspring. Two have white flowers, and the rest have purple flowers. This means that, to produce white flowers in the offspring, the original purple-flowered plant must be heterozygous for the gene (Pp), as shown in the Punnett square in Figure 8.

Parents' phenotype: purple flowers × white flowers

Parents' genotype: P? × pp

F_1 (offspring)

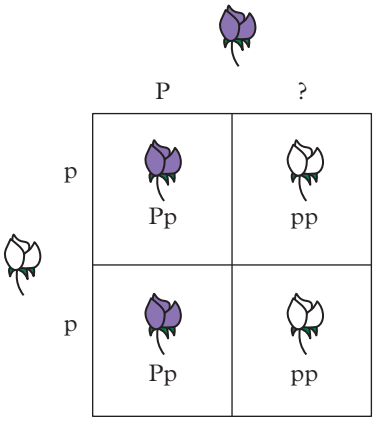


FIGURE 8 A Punnett square showing the monohybrid test cross

FIGURE 9 The purple flower of the pea plant is dominant to the white flower.

Because some offspring have the recessive phenotype, they must have inherited one allele (p) for the recessive trait from each parent. Therefore, the parent with the unknown genotype must be heterozygous (Pp). Even though this doesn't follow the predicted 1:1 phenotype ratio, what is shown in real life doesn't always followed the expected probability. If more offspring are bred (larger sample size) from this cross, then it would be expected that the ratio would be closer to the predicted probability.

WORKED EXAMPLE 8.2B

EXPLAINING INHERITANCE

In Persian cats, long hair (H) is dominant to short hair (h). The owners of a cat with the dominant phenotype wanted to determine its genotype. Explain how they might achieve this.

SOLUTION

1 The unknown cat must have at least one allele for the dominant trait (H); the other is unknown. So it could be HH or Hh. If the owner used a test cross with a short-haired cat (hh), there are two possible outcomes. If the unknown allele is for the dominant long-haired trait, no offspring will have the recessive short hair phenotype. If the unknown allele is for the recessive short-haired trait, some offspring with this phenotype will be produced.

Video Worked example 8.2B: Explaining inheritance

FIGURE 10 In Persian cats, long hair is dominant to short hair.

2 Draw Punnett squares from the information provided.

	H	H
h	Hh	Hh
h	Hh	Hh

	H	h
h	Hh	hh
h	Hh	hh

FIGURE 11 Punnett squares for the dominant Persian long-haired cat and recessive short-haired cat

CHECK YOUR LEARNING 8.2

Describe and explain

1 Explain how you would use a monohybrid test cross to determine the genotype of an individual displaying the dominant phenotype.

2 What is a Punnett square used for?

Apply, analyse and compare

3 Distinguish between true-breeding and hybrid individuals.

4 If long eyelashes are dominant to short eyelashes, determine the genotype and phenotype ratios of the offspring between two individuals who are both heterozygous for this trait.

5 The pedigree in Figure 12 shows the coat colour of mice over four generations.

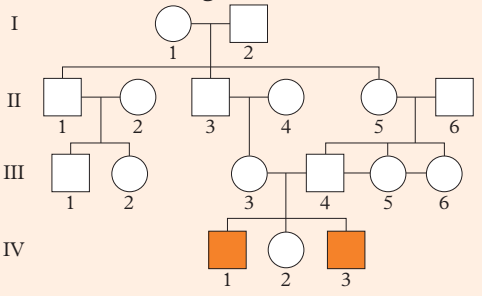


FIGURE 12 A Pedigree chart showing coat colour of mice over four generations

a How many offspring did individuals II-3 and II-4 have?

b How are individuals III-3 and III-4 related?

c Is this trait dominant or recessive? Provide evidence to support your answer.

d What would be the genotypes of individuals III-3 and III-4?

e Construct a Punnett square to determine the phenotype ratio of offspring for individuals III-3 and III-4.

f If individuals III-3 and III-4 have another child, who is unaffected, what is the probability III-3 and III-4 are heterozygous for coat colour?

6 Amanda has blue eyes, her mother has blue eyes and her father has brown eyes. Amanda drew a Punnett square to determine the chance that she could have been born with brown eyes (Figure 13).

a Explain why Amanda's Punnett square is incorrect.

b Redraw Amanda's Punnett square correctly.

Father (brown eyes)

Mother (blue eyes)

	B	B
B	BB	BB
b	Bb	Bb

FIGURE 13 Amanda's Punnett square

Design and discuss

7 Create a Punnett square to identify whether one of your traits is dominant or recessive.

8.3 Predicting outcomes for linked and independently assorted genes

KEY IDEAS

In this topic, you will learn that:

- dihybrid crosses are used to predict the phenotype ratios for both X-linked and Y-linked individuals.

Dihybrid cross

dihybrid cross
a cross between two individuals to observe the inheritance of two different traits

law of independent assortment
a law that states that alleles of different genes separate independently from one another during meiosis

unlinked genes
genes on different chromosomes that assort independently from one another

linked genes
genes on the same chromosome that are likely to be inherited together

So far, we have considered the inheritance of single genes with two alleles. You can also analyse the inheritance of two different genes controlling different phenotypes. A **dihybrid cross** is a cross involving two different genes to determine the relationship between the alleles for each gene, as well as the relationship between those genes.

Mendel's second law of inheritance is known as the **law of independent assortment**. This explains that if alleles for one gene assort independently of alleles for another gene, the two traits will be inherited independently. Therefore, those genes must be located on separate chromosomes and are considered to assort independently (or be **unlinked genes**). However, sometimes two different genes may be located on the same chromosome and are most likely inherited together. These genes are considered **linked genes**. In Figure 1, the gene for eye colour and coat colour are shown as linked because they are located close to each other on the same chromosome.

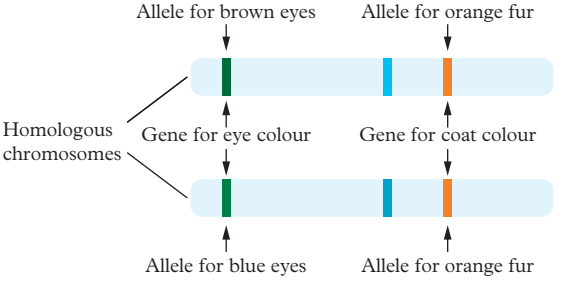


FIGURE 1 Two different genes near each other on the same chromosome are said to be linked. Here, the gene for eye colour and the gene for coat colour are linked.

Dihybrid cross (genes assorted independently)

If genes assort independently (unlinked and located on separate chromosomes), you can analyse the inheritance pattern of two genes by using a dihybrid cross.

Steps for constructing a dihybrid cross

1. Determine the allele combinations for the parental genotypes.
2. Draw the dihybrid cross, with the parental allele combinations on the top and down the side. Then combine the alleles in the boxes to determine the potential genotypes of the offspring.
3. Determine the phenotypes of the offspring.
4. Address the question, which may involve determining the phenotypic ratio of the offspring or probability of certain phenotypes.

If two heterozygous individuals are crossed in an unlinked dihybrid cross, then you will get a 9:3:3:1 phenotypic ratio. Worked example 8.3A takes you through these steps.

Video
Worked example 8.3A: Constructing a dihybrid cross

FIGURE 2 Genetics determine whether you have dimples and can roll your tongue.

WORKED EXAMPLE 8.3A

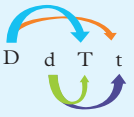
CONSTRUCTING A DIHYBRID CROSS

The gene for dimples has two alleles: dimples (D) and no dimples (d). The trait for the ability to roll the tongue is also controlled by one gene with two alleles: tongue rolling (T) and no tongue rolling (t). The genes for dimples and tongue rolling are located on different chromosomes. If two individuals who are heterozygous for both traits (DdTt) are crossed, determine the probability that offspring will not have dimples and will not be able to roll their tongue.

SOLUTION

1 Determine the allele combinations for the parental genotypes by referring to the following diagram.

Parental genotypes:



Allele combinations: DT, Dt, dT, dt

2 Draw the dihybrid cross, with the parental allele combinations on the top and side. Then combine the alleles in the boxes to determine the potential genotypes of the offspring.

Parental allele combinations

	DT	Dt	dT	dt
DT	DDTT	DDTt	DdTT	DdTt
Dt	DDTt	DDtt	DdTt	Ddtt
dT	DdTT	DdTt	ddTT	ddTt
dt	DdTt	Ddtt	ddTt	ddtt

Combine parental alleles to determine genotypes of offspring

3 Determine the phenotypes of the offspring:

Possible types of female gametes

Possible types of male gametes	DT	Dt	dT	dt
DT	DDTT Dimples and can roll tongue	DDTt Dimples and can roll tongue	DdTT Dimples and can roll tongue	DdTt Dimples and can roll tongue
Dt	DDTt Dimples and can roll tongue	DDtt Dimples and cannot roll tongue	DdTt Dimples and can roll tongue	Ddtt Dimples and cannot roll tongue
dT	DdTT Dimples and can roll tongue	DdTt Dimples and can roll tongue	ddTT No dimples but can roll tongue	ddTt No dimples but can roll tongue
dt	DdTt Dimples and can roll tongue	Ddtt Dimples and cannot roll tongue	ddTt No dimples but can roll tongue	ddtt No dimples and cannot roll tongue

Possible offspring genotypes and phenotypes

4 Address the question, which may involve determining the phenotype ratio or probability.
Phenotype ratio:

Dimples and can roll tongue	:	Dimples and cannot roll tongue	:	No dimples but can roll tongue	:	No dimples and cannot roll tongue
9	:	3	:	3	:	1

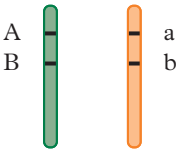
Probability that offspring will not have dimples and will not be able to roll their tongue = $\frac{1}{16}$

Dihybrid cross (linked genes)

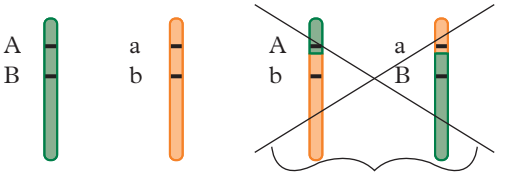
Linked genes for two different traits are found on the same chromosome. Linked genes tend to be inherited together because they do not sort independently during meiosis. Crossing over can occur between genes on the same chromosome, but this is unlikely, particularly if they are close together. Therefore, the closer the genes are to one another on the same chromosome, the more likely it is that they will be inherited together.

You know that when two heterozygote individuals are crossed in a normal dihybrid cross, the expected phenotypic ratio is 9:3:3:1. However, if those genes are linked and inherited together, then the phenotypic ratio produced is 3:1 because no recombinant genotypes are observed.

Genes close together on the same chromosome are linked.



The gametes are formed.



It is unlikely that these gametes will form, unless crossing over occurs between the two genes.

When writing linked genes in allelic notation, we use a horizontal line to represent the chromosome:

$$\frac{A\ \ B}{a\ \ b}$$

And the gametes formed are:

$$\frac{A\ \ B} \quad \text{and} \quad \frac{a\ \ b}$$

FIGURE 3 Linked genes for two different traits are located on the same chromosome.

Linkage reduces genetic variation in offspring because fewer phenotypes are produced. Linkage can be identified when more offspring than expected have the phenotype of the parents. When representing dihybrid crosses with linked genes, the alleles are shown as vertical pairs. This is known as linkage notation and is explained in Worked example 8.3B.

Video
Worked example 8.3B: Determining genotypes and phenotypes for linked genes

WORKED EXAMPLE 8.3B

DETERMINING GENOTYPES AND PHENOTYPES FOR LINKED GENES

Fruit flies (*Drosophila melanogaster*) have two genes that are on the same chromosome: wing length and eye colour. Long wings (L) are dominant to short wings (l) and red eyes (R) are dominant to white eyes (r). A homozygous long-winged red-eyed male was crossed with a short-winged white-eyed female. Determine the possible genotypes and phenotypes of both the F_1 and F_2 generations.

FIGURE 4 Fruit fly (*Drosophila melanogaster*)

SOLUTION

1 Determine the parents' phenotypes and genotypes:

long wings, red eyes × short wings, white eyes

LLRR × llrr

Then use linkage notation to write the genotypes (underline the alleles of a genotype to show the genes are linked):

$$\frac{L\ R}{L\ R} \qquad \frac{l\ r}{l\ r}$$

2 Work out the allele combinations of the parents (no crossing over occurs):

$$\underline{L\ R} \qquad \underline{l\ r}$$

3 Determine the offspring (F_1 generation)

$$\frac{L\ R}{l\ r}$$ (all long winged, red eyed)

4 Cross two of the F_1 individuals together to determine the F_2 generation:

$$\frac{L\ R}{l\ r} \times \frac{L\ R}{l\ r}$$

5 Determine the allele combinations:

Parent 1: $\underline{L\ R}$ and $\underline{l\ r}$

Parent 2: $\underline{L\ R}$ and $\underline{l\ r}$

6 Set up a Punnett square to work out the possible F_2 genotypes:

	$\underline{L\ R}$	$\underline{l\ r}$
$\underline{L\ R}$	$\frac{L\ R}{L\ R}$	$\frac{L\ R}{l\ r}$
$\underline{l\ r}$	$\frac{L\ R}{l\ r}$	$\frac{l\ r}{l\ r}$

Therefore, the genotype ratio:

$$1\ \frac{L\ R}{L\ R} : 2\ \frac{L\ R}{l\ r} : 1\ \frac{l\ r}{l\ r}$$

Phenotype ratio: 3 long-winged, red-eyed: 1 short-winged, white-eyed

CHALLENGE 8.3

Trihybrid cross

You now know how to complete a cross for two linked and unlinked genes. When there are three unlinked genes, it is called a trihybrid cross. An individual with a heterozygous genotype for three unlinked genes will have eight possible allele combinations for the gametes. For example, if the genotype is AaBbCc, then the allele combinations are ABC, ABc, AbC, Abc, aBC, aBc, abC and abc. For the following question, follow the same steps as for a dihybrid cross but in an 8 × 8 square.

1 Two heterozygous pea plants (YyTtSs) for three unlinked traits were crossed. The three traits were yellow (Y) or green (y) seeds, tall (T) or short (t) plant, and smooth (S) or wrinkled (s) seeds. What is the probability of offspring being tall plants with smooth yellow seeds?

CHECK YOUR LEARNING 8.3

Describe and explain

1 Describe the law of independent assortment.

2 Explain the difference between linked genes and genes assorted independently.

3 What would be the expected phenotype ratio for a linked dihybrid cross between two heterozygous individuals?

4 Define 'dihybrid cross'.

5 What are the possible allele combinations for the genotype TTGg?

Apply, analyse and compare

6 Summarise the steps for producing a dihybrid cross and consider ways of remembering it for your exam.

7 In dogs, the genes for coat colour and coat length always sort independently during meiosis.

a Are the two genes linked? Justify your answer.

b If black coat is dominant to white coat and long hair is dominant to short hair, complete a dihybrid cross to determine the genotypes and phenotypes of the F_1 generation when two heterozygous individuals are crossed.

Design and discuss

8 Design an experiment to determine whether two genes (pea colour and plant height) in pea plants are linked. In your experiment, identify the genotypes and phenotypes of the parents, and predict the outcome for the offspring if the genes are:

a unlinked

b linked.

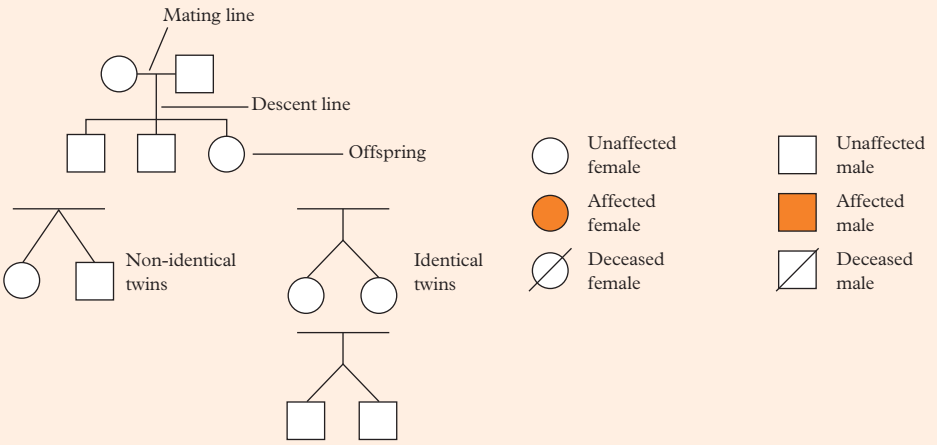
CHAPTER 8

Review

Chapter summary

8.1

- There are two patterns of autosomal inheritance (autosomal dominant and autosomal recessive) and three patterns of sex-linked inheritance (Y-linked, X-linked recessive and X-linked dominant).
- Pedigree charts are used to determine the pattern of inheritance and genotype of individuals. There are rules for constructing a pedigree chart, as provided below.

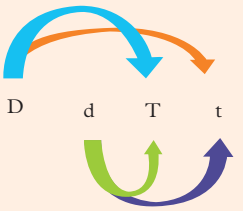


8.2

- Punnett squares are used to predict the genotypes and phenotypes of offspring.
- Test crosses can be used to determine the genotype of individuals with a dominant phenotype.

8.3

- Dihybrid crosses are used to predict the phenotype ratios for two different genes, whether independently assorted or linked. The following diagram can be used to determine the possible allele combinations for the parental genotypes.



Revision questions

Multiple choice

1 Which type of trait is found on an autosome and requires two copies of the same allele to be expressed in the phenotype?

A Autosomal recessive
B Autosomal dominant
C X-linked recessive
D X-linked dominant

2 Consider Figure 1.

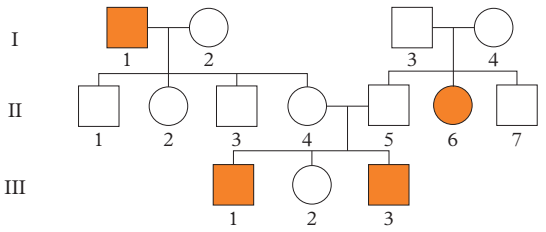


FIGURE 1 A pedigree chart

Which of the following is true?

A Individual I-1 is a female.
B Individuals II-3 and II-4 are cousins.
C Individuals III-1 and II-5 are son and father.
D The trait shows a dominant pattern.

3 Which of the following symbols represents an affected female in a pedigree chart?

A Shaded square
B Unshaded square
C Shaded circle
D Unshaded circle

4 Red-green colour blindness is inherited as an X-linked recessive trait. A couple were surprised to discover that one of their sons had red-green colour blindness, when both parents had normal vision.

Which of the following is the most likely genetic explanation for the occurrence of the trait in their son?

A The father is a carrier for red-green colour blindness.
B The mother is a carrier for red-green colour blindness.
C The mother is homozygous dominant for red-green colour blindness.
D The father is heterozygous for red-green colour blindness.

5 Tongue rolling is an autosomal dominant trait. Two tongue rollers had a family of four children. Three of the four children could roll their tongues, but one could not. Which of the following is true?

A Both parents must be heterozygous.
B One parent could be homozygous and the other heterozygous.
C All the tongue-rolling children must be heterozygous.
D The child who could not roll their tongue is the only possible homozygous genotype in the family.

6 Red hair is recessive to black hair. The first child of two parents with black hair has red hair. Which of the following statements is correct?

A The mother is homozygous dominant.
B The father is homozygous recessive.
C Both parents are heterozygous.
D Only the father is heterozygous and the mother is homozygous recessive.

FIGURE 2 Red hair is recessive to black hair.

7 Detached earlobes (E) is dominant to attached earlobes (e). A couple both heterozygous for detached earlobes are considering having children. What is the chance that this couple will have a child with detached earlobes?

A 0%
B 25%
C 50%
D 75%

8 What phenotypic ratio would you expect for a cross between two heterozygous individuals for two linked genes?

A 9:3:3:1

B 1:1:1:1

C 3:1

D 1:1

9 Dimples (D) is dominant to no dimples (d) and brown hair (B) is dominant to blonde hair (b). What are the possible genotypes of the potential offspring of a male with genotype DdBb and a female with genotype DDBB?

A DDBB, DDBb, DdBB, DdBb

B DDBB

C DdBb, ddbb

D DDBB, DdBb

10 Worms have two genes on the same chromosome: the number of body segments and the presence of light-sensing organs. The possible alleles for these genes include two body segments (B) or three body segments (b), and light-sensing organs (L) or no light-sensing organs (l). What are the possible parental allele combinations for the cross between two individuals with genotypes BBLL and bbll?

A BL and bl

B Bl only

C Bb and Ll

D BbLl and bbll

Short answer

Describe and explain

11 What evidence provided from a pedigree chart supports X-linked recessive traits?

12 Explain the law of segregation.

13 Why is it more common for males to have sex-linked traits?

14 Describe the difference between a pedigree chart, Punnett square, monohybrid cross and dihybrid cross.

15 Explain the steps involved in producing a monohybrid cross.

16 Explain the steps involved in producing a dihybrid cross.

Apply, analyse and compare

17 Compare the two Mendelian laws: the law of independent assortment and the law of segregation.

18 Haemophilia is an X-linked recessive trait, where X^h is affected by haemophilia and X^H is unaffected by haemophilia.

a Draw a Punnett square to show the cross between a man with haemophilia and a woman who is a carrier.

b What are the genotype and phenotype ratios of their offspring?

c What percentage of the offspring will have haemophilia?

19 Fur colour in mice is controlled by a single gene. A heterozygous white male and a black female had four offspring who were all white with the genotype Ww.

a Identify the genotype(s) of the father.

b Identify the genotype(s) of the mother.

c What should the phenotype ratio of the offspring be?

d Draw a Punnett square to show a cross between two of the white offspring (F_1 generation). Include the genotype and phenotype ratios of their offspring (F_2 generation).

20 Consider Figure 3.

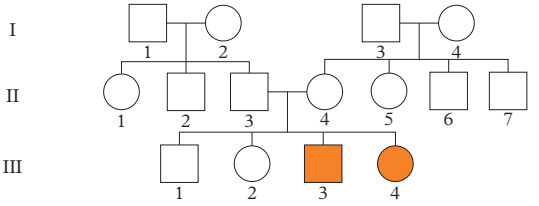


FIGURE 3 A pedigree chart

a Is the trait dominant or recessive? Explain your answer.

b Identify which individuals have the trait.

c Using appropriate allele symbols, identify the possible genotype(s) of individual II-4.

d Using appropriate allele symbols, identify the possible genotype(s) of individual III-4.

21 The gene for eye colour in humans is carried on chromosome 19. Brown eyes are dominant to blue eyes. If a heterozygous female and a male who is homozygous for brown eyes have children, what are the potential eye colours of their offspring?

FIGURE 4 Blue eyes are recessive to brown eyes

22 In pea plants, tall plants (T) are dominant to short plants (t) and round pods (R) are dominant to wrinkled pods (r).

a A homozygous tall, round-pod pea plant was crossed with a homozygous short, wrinkled-pod pea plant. What is the phenotype ratio of the F_1 generation?

b Two heterozygous tall, round-pod pea plants were crossed. What is the probability of their offspring being short with wrinkled pea pods?

23 In mice, coloured fur (C) is dominant to white fur (c). Normal behaviour (N) is dominant to circling behaviour (n). The two genes are on different autosomes. Pairs of mice were crossed and the following offspring were produced. Predict the probable genotypes of the parents in each cross.

a A coloured normal mouse was crossed with a white normal mouse. The offspring produced were 29 coloured normal and 10 coloured circlers.

b A coloured normal mouse was crossed with a white circling mouse. The offspring produced were 7 coloured circlers, 9 white normal and 6 white circlers.

24 In guinea pigs, black (B) is dominant to white (b) and rough coat (R) is dominant to smooth coat (r). A black, rough-coated male guinea pig was crossed with a white, smooth-coated female. Several litters from the pair resulted in offspring, ¼ of which had black smooth coats, ¼ white smooth, ¼ white rough and ¼ black rough. Predict the probable genotypes of the parents.

25 Haemophilia is a sex-linked recessive gene in humans. If a father and son both have haemophilia, but the mother does not, explain what the genotype of the mother could be.

Design and discuss

26 Discuss how the results of a monohybrid test cross can determine whether the phenotypically dominant individual is homozygous dominant or heterozygous.

27 Discuss how the results of a dihybrid cross can indicate whether two traits are linked or assorted independently.

28 Jeff is given a true-breeding female guinea pig with rough, black fur and a male with smooth, white fur.

a Explain how Jeff could produce a strain of true-breeding smooth, white-furred guinea pigs.

b Consider whether it is possible to produce a strain of true-breeding rough, black-furred guinea pigs. Explain your method.

Exam essentials

Responding to questions

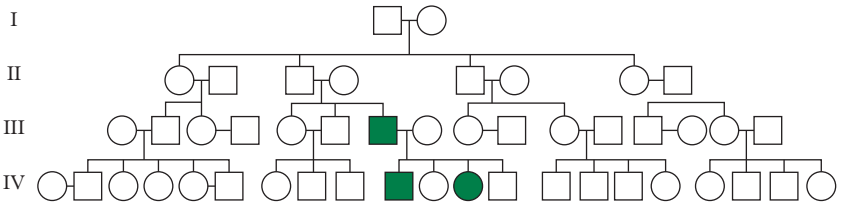
In Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to use data from the question in your response.

Refer to data in your response

When a question provides data in a table, graph or image, you should embed the appropriate data in your response. By doing so you are demonstrating your understanding of the question and ability to analyse the information provided.

QUESTION 8b (2015 Biology Written Examination)

Hereditary retinoblastoma is a rare autosomal dominant trait. The pedigree below shows the trait appearing in a family with no prior history of the condition before generation III.



Explain the appearance of this trait in generations III and IV.

2 marks

Source: 2015 Biology Written Examination Question 8b, Short answer, reproduced by permission © VCAA

Response 1

Dominant traits require only one allele for the dominant trait to show in the phenotype. Individual III-7 must have inherited a random mutation in the retinoblastoma gene, since neither of his parents have the trait. He has passed on the allele for the trait to two of his offspring (IV-10 and IV-12), which explains the appearance of the trait in generation IV.

- The definition of the dominant trait helps to explain the appearance of the trait.
- Referring to specific individuals from the pedigree makes the explanation clear.
- Refer to specific information in the question where possible and appropriate.

This response would receive full marks because there is an explanation for the appearance of the trait in both generation III and generation IV.

Response 2

The male in generation III has the trait because he inherited it from his parents who must be carriers for the condition. This person has then given it to his children.

- Not specially referring to an individual from the pedigree makes the response unclear.
- Use information from the question where possible instead of being vague.

This response wouldn't receive any marks. There cannot be carriers of dominant traits since a dominant trait only requires one allele to show in the phenotype. The response is also unclear because it doesn't specifically refer to individuals from the pedigree. It also doesn't directly refer to the question.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 4a (2005 Biology Written Examination 2)

In corn the colour of the stem can be either wild type, which is dark green, or virescent, which is pale green.

Cross	Phenotype of parents	Temperature at which raised	Offspring
1	virescent X virescent	20°C	virescent
2	virescent X virescent	37°C	wild type
3	wild type X wild type	20°C	3 wild type : 1 virescent
4	wild type X wild type	37°C	wild type

The parents in crosses 1 and 2 had the same genotype. The parents of crosses 3 and 4 had the same genotype.

a What conclusions can you draw:

i by comparing crosses 1 and 2?

The colour of the stem can change from dark green (wild type) to virescent (pale green) when the temperature is high.

ii from the results of cross 3 only?

Two wild type parents can produce virescent offspring in the right conditions.

1 + 1 = 2 marks

Source: 2005 Biology Written Examination 2 Question 4a, Short answer, reproduced by permission © VCAA

Marking guide

4ai	- 1 mark for comparing crosses 1 & 2 by stating that 37°C produces wild type and 20°C produces virescent.
4aii	- 1 mark for any of: Determining that virescent is a recessive trait Identifying that the parents from cross 3 must be heterozygous Determining that wild type is a dominant trait.

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 an examiner.

Check your Student obook pro for these digital resources and more:


Video tutorial
Referring to data


Weblink
Past examinations and examiners' reports

CHAPTER 9

Reproduction

The ability of an organism to produce many offspring quickly is an advantage in a competitive environment, expecially if the organism is suited to the environment. Instead of expending energy by looking for a mate, a single organism may be able to rapidly populate the environment by producing cloned offspring. Scientists have harnessed this approach in developing technologies that allow the desired characteristics to be selected for in the next generation.

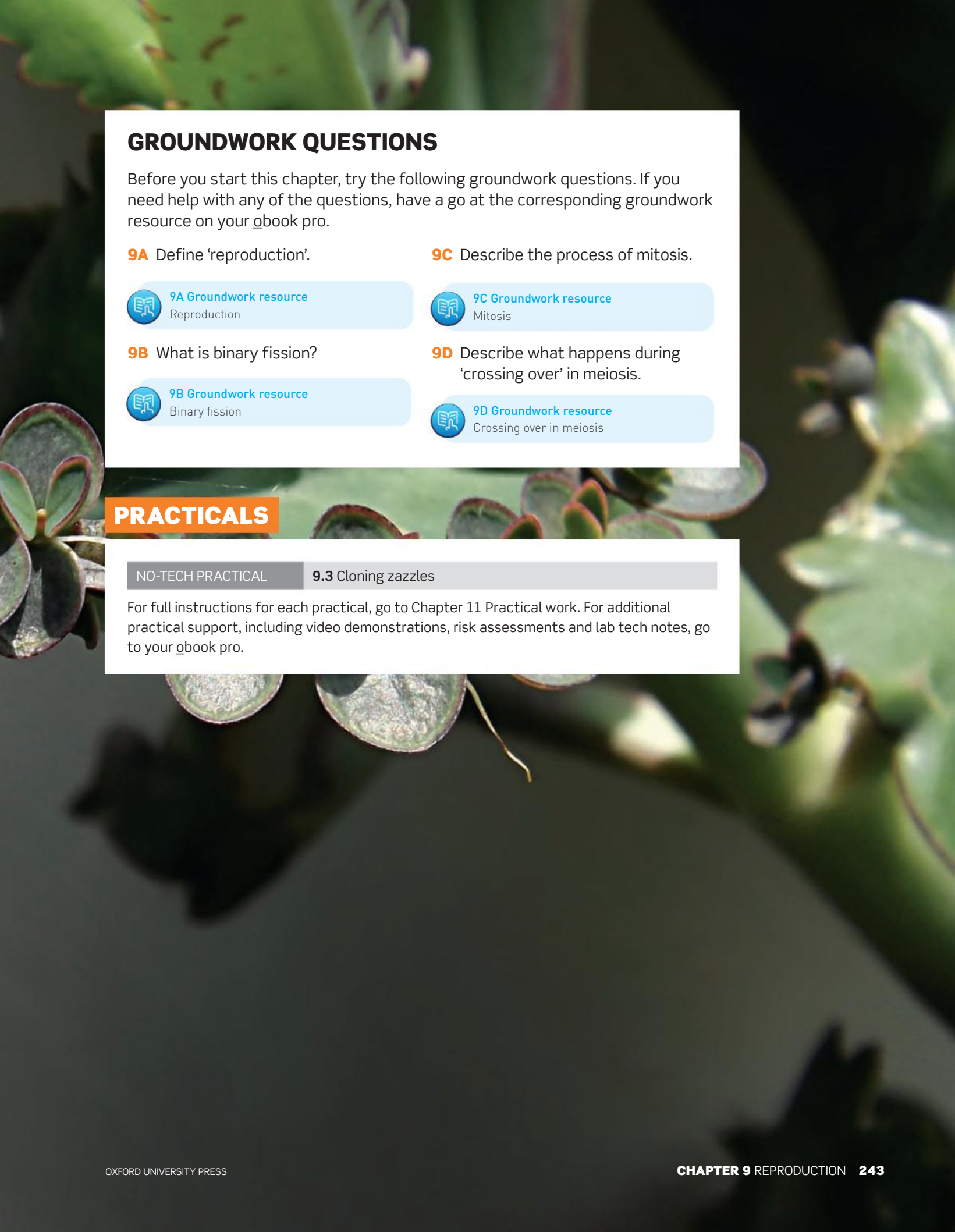
If the environment changes, then the physical characteristics that were adapted for the previous conditions may no longer offer an advantage. Survival in this new environment may require the unique mix of characteristics that comes from combining the genetic material of two parents in sexual reproduction.

KEY KNOWLEDGE

- → biological advantages and disadvantages of asexual reproduction
- → biological advantages of sexual reproduction in terms of genetic diversity of offspring
- → the process and application of reproductive cloning technologies

Source: *VCE Biology Study Design (2022–2026)* reproduced by permission © VCAA

FIGURE 1 *Kalanchoe blossfeldiana* is a plant that can produce many cloned offspring in a very short time, allowing it to quickly populate an area.



GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

9A Define 'reproduction'.

9A Groundwork resource
Reproduction

9B What is binary fission?

9B Groundwork resource
Binary fission

9C Describe the process of mitosis.

9C Groundwork resource
Mitosis

9D Describe what happens during 'crossing over' in meiosis.

9D Groundwork resource
Crossing over in meiosis

PRACTICALS

NO-TECH PRACTICAL	**9.3** Cloning zazzles

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.

9.1 Asexual reproduction

KEY IDEAS

In this topic, you will learn that:

- asexual reproduction occurs when a single parent produces genetically identical offspring quickly
- types of asexual reproduction include fission, budding, vegetative propagation, spore formation and parthenogenesis
- advantages of asexual reproduction include not requiring a partner to reproduce, producing more offspring, and reproducing quickly
- offspring produced asexually are disadvantaged if environmental conditions change.

The ability of a single parent to reproduce without the fusion of egg and sperm is called **asexual reproduction**.

asexual reproduction
a mode of reproduction in which a single parent reproduces without the fusion of egg or sperm

Advantages of asexual reproduction

There are distinct advantages to being able to reproduce as a single parent. Sexual reproduction requires two parents who each contribute half the genetic material. Asexual reproduction removes the need for an individual to search for a partner or to undergo a courting ritual to display their health and vitality. This then leaves more energy to produce a greater number of offspring.

Favourable environmental conditions also allow a single parent to quickly produce many offspring. Organisms that reproduce asexually tend to mature rapidly, passing on their physical characteristics to the next generation, dominating the environment and preventing other species from sharing the resources. This is especially important in plants, who cannot easily move to a new environment if competition moves in. These factors make asexual reproduction an important survival advantage for a species.

There are several types of asexual reproduction.

Study tip

Only refer to asexaully produced offspring as 'identical' when referring to their genetic material. The daughter cells may have identical genetic material to the parent cell, but the number or arrangement of other organelles may not be identical.

Fission

The division of a parent cell into two or more cells is called **fission**. There are two types of fission – binary fission (Chapter 6) and multiple fission.

fission
a form of asexual reproduction in which a parent cell divides into two or more genetically identical daughter cells

In binary fission, the parent cell replicates its genetic material, then divides into two (equal sized) genetically identical daughter cells. Prokaryotic cells reproduce by binary fission. Eukaryotic organisms such as amoeba and euglena also undergo binary fission (Figure 1).

In multiple fission, the parent cell divides into many genetically identical daughter cells. Organisms such as algae undergo multiple fission (Figure 2).

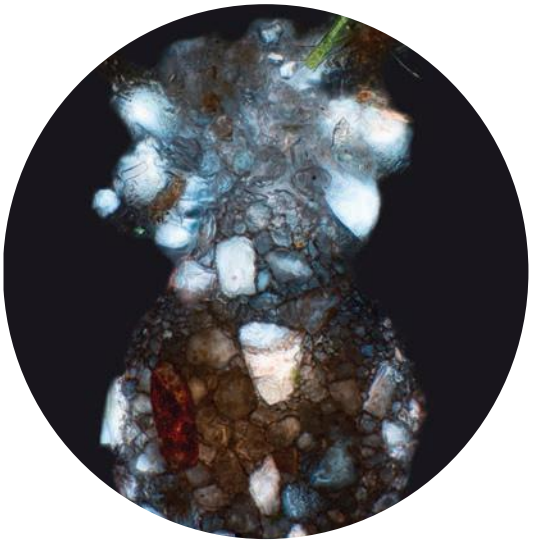


FIGURE 1 Some eukaryotes such as amoebas reproduce by binary fission.

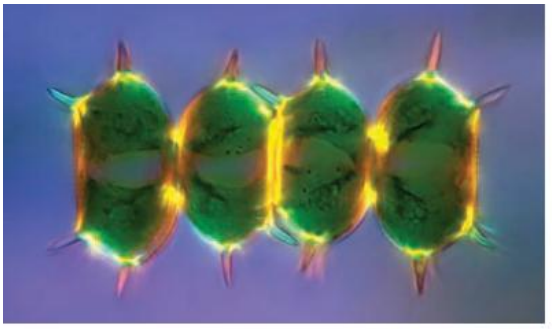


FIGURE 2 Algae can reproduce rapidly by multiple fission.

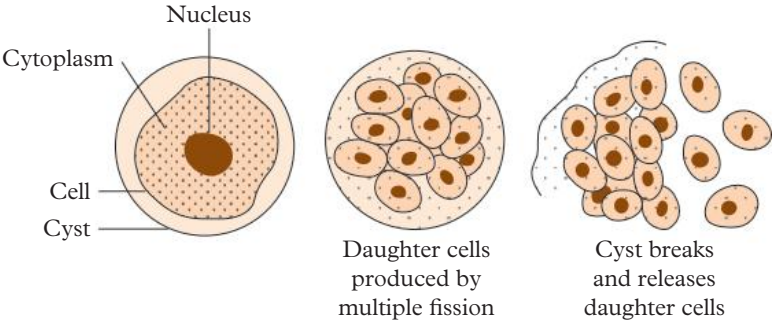


FIGURE 3 The process of multiple fission involves the parent cell producing many genetically identical daughter cells.

Budding

Some single-celled organisms develop small growths or buds off the side of the parent cell. These buds develop into new, genetically identical daughter cells. This process is called **budding** (Figure 4). Yeast uses this process to quickly produce multiple offspring when conditions are suitable.

Some multicellular organisms can also reproduce by producing a genetically identical bud that then breaks off to form a new organism. Hydras are freshwater organisms that live in warm environments and reproduce asexually by budding. These multicellular organisms can form a new bud every two days when there is plenty of food available (Figure 5).

budding
a form of asexual reproduction in which single-celled and some multicellular organisms develop small growths or buds that develop into new, genetically identical organisms

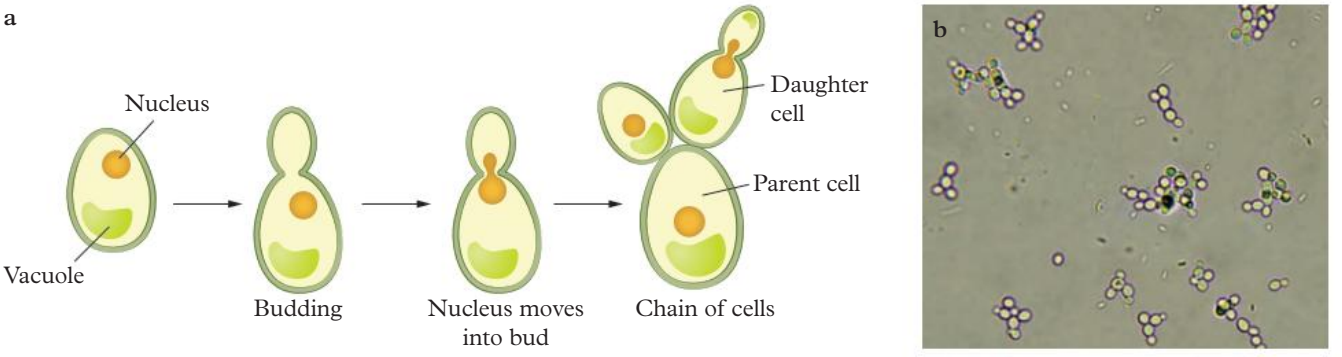


FIGURE 4 Yeast cells can reproduce asexually by budding. **a** The yeast life cycle. **b** Budding yeast cells.

FIGURE 5 Hydra are able to produce smaller, genetically identical daughter organisms by budding.

Fragmentation

fragmentation
a form of asexual reproduction in which the body of a multicellular organism divides into many parts containing genetically identical cells

Fragmentation occurs when the body of a multicellular organism divides into multiple parts. These parts are able to heal at the site of the wound and new, genetically identical organisms can grow from each fragment. Some worms and seastars can reproduce in this manner (Figure 6).

FIGURE 6 Some seastars can grow a new organism from the fragment of a detatched leg.

Vegetative reproduction

vegetative reproduction
a form of asexual reproduction in which a plant undergoes fragmentation to form another genetically identical plant

Fragmentation in plants is called **vegetative reproduction**. Many plants can reproduce when small vegetative parts break off and form new, genetically identical organisms. Gardeners take advantage of this when they intentionally break the soft tissue from a stem or root (called a cutting) and plant it in new soil. The cutting grows new roots and leaves, and eventually becomes a cloned copy of the parent plant. For example, when the eyes of potato tubers are removed and replanted in the soil, each one grows into a new plant (Figure 7).

Some plants (e.g. *Kalanchoe blossfeldiana*) produce small plantlets on their leaves that drop off and form independent daughter plants (Figure 8a). Other plants such as *Fragaria* × *ananassa* (strawberry plants) produce specialised roots called stolons (Figure 8b). These can form new genetically identical offspring.

FIGURE 7 Potatoes are able to grow new plants from the eyes in their tubers.

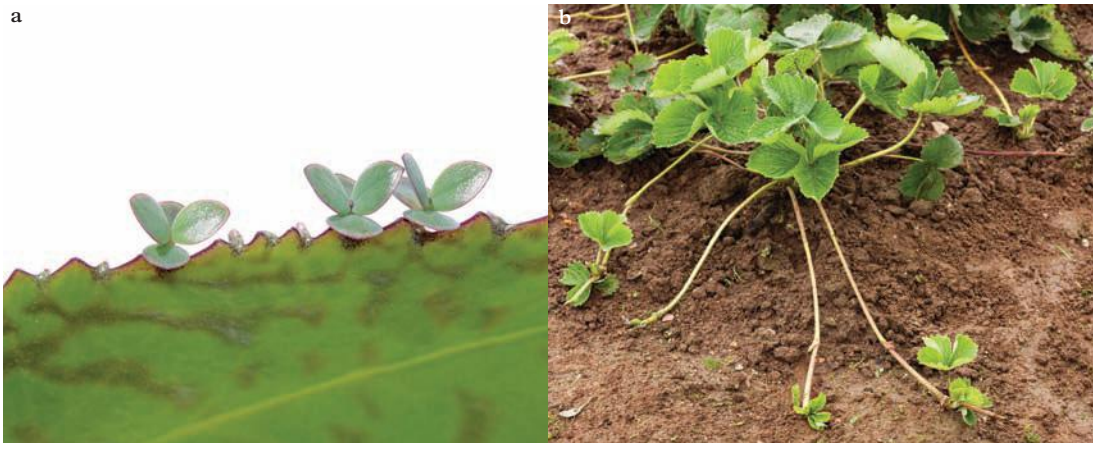


FIGURE 8 **a** *Kalanchoe blossfeldiana* and **b** *Fragaria* × *ananassa* (strawberry plants) reproduce through a type of fragmentation called vegetative reproduction.

Spore formation

A **spore** is a reproductive cell that can develop into a new organism without fusing with another reproductive cell. Unlike multicellular seeds, spores are single cells that can only be seen under a microscope. Spore formation only occurs in non-flowering plants and microscopic organisms. Ferns, fungi and mosses can reproduce through spores located on the underside of their leaves.

Fungi can form spores for both sexual and asexual reproduction. Some fungi, such as *Rhizopus nigricans* commonly found on bread, have spores arranged in small circular structures called sporangia (Figure 9). Eventually, the wall surrounding the spores breaks apart and the spores are carried away by wind or water.

FIGURE 9 *Rhizopus nigricans* (bread mould) is a common fungus that reproduces asexually by forming spores.

spore
a reproductive cell produced by bacteria, fungi, mosses and ferns, capable of developing into a new organism without fusing with another reproductive cell

Bacteria can also form spores. This occurs when a bacterial cell places a protective coating around its daughter cells to enable them to survive under extreme conditions.

Parthenogenesis

Some female animals can reproduce without involving a male animal. This is called **parthenogenesis** and occurs when an embryo develops from an unfertilised egg cell. There are two types of parthenogenesis.

- Mature egg cells produced by mitosis can directly develop into new organisms. Two egg cells with half the mother's genetic material fuse and produce offspring that have different mixes of the mother's genetic material.
- A normal egg cell develops with half the genetic material of the parent cell. Some organisms such as ants or bees will then produce mature male animals with less genetic material in each cell than in the mother's cells.

Some species can switch between sexual reproduction and parthenogenesis, depending on the availability of resources and mates (Figure 10).

parthenogenesis
a form of asexual reproduction in which a female animal reproduces without fertilisation of an egg by a male

FIGURE 10 *Heteronotia binoei* (Bynoe's gecko) is one of the few Australian native animals that can reproduce by parthenogenesis.

Disadvantages of asexual reproduction

clone
a cell or an organism that is genetically identical to the parent

Although the ability to reproduce asexually allows a rapid increase in numbers when environmental conditions are favourable, there are disadvantages. When there is only one parent, the diversity of the offspring is very limited. Often the offspring are **clones**, genetically identical to the parent. A change in environmental conditions affects all organisms equally. For example, if a disease starts spreading through a genetically identical population, all the organisms will be equally vulnerable. If one organism dies from the disease, their cloned siblings will probably die too.

Organisms that reproduce asexually are also unable to produce genetically different individuals that may be more suited to an altered environment when conditions change. Asexual reproduction results in little variability in the phenotype of the organism. Therefore, no members of the population will be better suited to the changing conditions. If one member of the population is vulnerable in different environmental conditions, then all members are all equally vulnerable.

The rapid nature of asexual reproduction can also result in overpopulation. This can lead to a shortage of food and shelter for individual organisms, ultimately limiting the survival of the species.

CHECK YOUR LEARNING 9.1

Describe and explain

1 Define 'asexual reproduction'.
2 Explain the difference between a seed and a spore.
3 Define 'parthenogenesis'.

Apply, analyse and compare

4 Compare fission and fragmentation.
5 Compare the advantages and disadvantages of asexual reproduction.
6 Scientists in Townsville, Queensland, studied a female zebra shark (*Stegostoma fasciatum*) called Leonie. Leonie had a male partner at the aquarium and together they produced more than two dozen offspring. In 2012, the male shark was moved to another tank. Leonie did not have any male contact again, but in 2016, she had three more offspring. Genetic testing showed the three offspring carried only genetic material from their mother.

FIGURE 11 Leonie was a zebra shark.

a Identify the kind of asexual reproduction that would have occurred in this case.
b Outline the advantages and disadvantages of reproducing in this way.

Design and discuss

7 Discuss ways you could generate a new garden without buying any new plants.
8 In baking, a starter is a culture of yeast and bacteria that converts starch molecules into sugars. When baking sourdough bread, part of the starter is used, while the remainder of the starter culture is fed sugar or flour and saved until the next time. Discuss the type of reproduction that occurs in the starter culture.

9.2 Sexual reproduction

KEY IDEAS

In this topic, you will learn that:

- sexual reproduction produces genetic diversity in gametes and offspring
- genetic diversity provides a survival advantage in changing environmental conditions.

gamete
a haploid cell, egg and sperm

Asexual reproduction has many advantages, but the production of genetically identical offspring can be a disadvantage. Instead, many organisms reproduce sexually, which increases the genetic variation in their offspring. This is done by producing specialised sex cells called **gametes** (egg and sperm in animals) from specialised germline cells in the ovaries (female animals) and testes (male animals). In flowering plants, the female gamete is called the ovum and is produced in an ovary, and the male gamete is contained in a pollen grain produced in the anther.

Genetic diversity in gametes

Gametes are produced through meiosis. Meiosis involves the duplication of all the genetic material before an organised division of the chromosomes produces four gamete cells. During this process, homologous chromosomes pair up in prophase I. Occasionally, the homologous (matching) chromosomes (each of the same length and with the same centromere) become tangled and exchange genetic material in a process called crossing over.

When your mother produced an egg by meiosis, the two chromosomes 1 (one from your maternal grandmother and one from your maternal grandfather) became paired and the chromosome arms may have become tangled. For example, some of the genes from your maternal grandfather ended up on the chromosome from your maternal grandmother. The same matching genes from your maternal grandmother relocated to the chromosome from your maternal grandfather. Each chromosome is now a mix of both grandparents' genetic material. This process of genes crossing over can occur to any of the 23 chromosomes inherited from your mother (Figure 1).

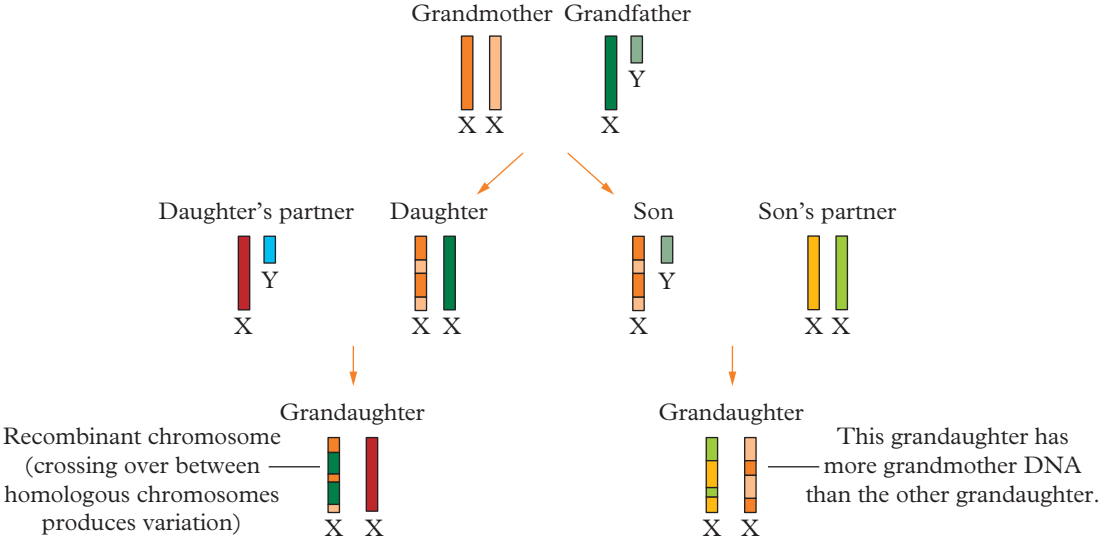


FIGURE 1 Crossing over provides genetic diversity in the gametes.

The 23 chromosomes you inherited from your mother can also become reassorted. This means they do not travel in a single group. During meiosis, the chromosomes that move to each end of the cell may be a mixture of both your maternal grandmother's and grandfather's chromosomes. For example, at one pole of the cell, chromosomes 1–3, 7, 9 and 11–15 may be from your mother's mother and the remaining chromosomes 4–6, 10 and 16–22 may be from your mother's father. As a result, the egg from which you inherited your mother's genetic material would have had some characteristics of both maternal grandparents. This is the consequence of the law of independent assortment (Chapter 6).

Both crossing over and the law of independent assortment result in gametes with uniquely diverse sets of genetic material.

Genetic diversity in offspring

sexual reproduction a mode of reproduction that involves a haploid female gamete (egg) fusing with a haploid male gamete (sperm)

During **sexual reproduction**, the gametes combine; the egg from the mother combines with the sperm from the father. Each gamete cell contains half of the genetic material of each parent. Every egg and sperm cell contains a unique combination of the parents' genetic material.

When the egg and sperm cells fuse, the fertilised cell has two copies of the chromosomes (diploid). If each gamete contains a unique mix of chromosomes, the resulting offspring that grows from the fertilised cell also has a unique set of characteristics. This is why siblings are unique despite sharing the same biological parents. One family can end up with a diverse range of characteristics in the children (Figure 5). Only identical twins who originated from the same fertilised egg start life with the same set of characteristics.

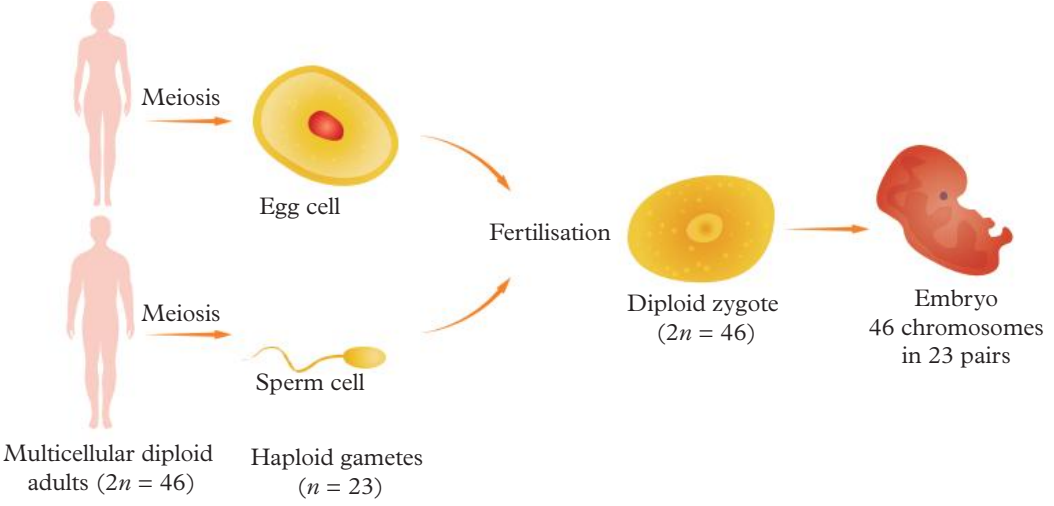


FIGURE 2 Each gamete contains a unique haploid set of the genetic material of each parent.

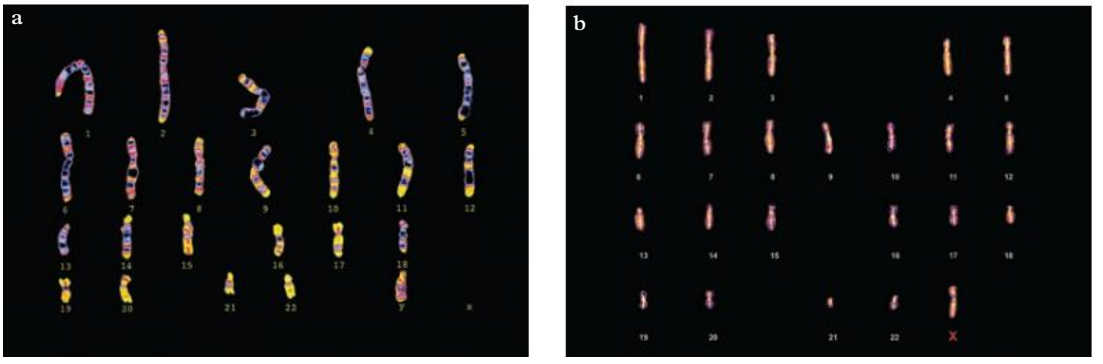


FIGURE 3 The karyotypes of **a** a sperm cell and **b** an egg cell. Each gamete contains a single copy of each chromosome (haploid).

FIGURE 4 When the gametes combine, the final cell has two copies of each chromosome (diploid).

Advantages of sexual reproduction

Our environment is often changing. From year to year, the climate, amount of food or water and the presence of predators changes. Organisms that are suited to the environment one year may not survive the following year. Having a high genetic diversity between siblings means there are differences in their physical characteristics. A variety of skin colours ensures that at least one sibling will be able to camouflage and hide from a predator, allowing it to survive and pass on its genes to the next generation. If a new disease emerges, greater genetic diversity in the immune systems within a population increases the chances of at least one member of the species being able to survive the infection and produce the next generation.

Sexual reproduction can also help to eliminate any mutations that might have occurred. Asexual reproduction leads to genetically identical offspring and this might include passing on any harmful mutations that may have occurred in the parent. In sexual reproduction, any mutation in germline cells only has a 50% chance of being passed on.

FIGURE 5 Siblings in the same family will have many different combinations of their parents' genes.

CHALLENGE 9.2

Reproducing coral

Many corals can reproduce both sexually and asexually. When small pieces of coral break off from a colony as a result of wave action or storms, they sometimes attach to a solid surface and develop into a new colony. This genetically identical clone of the parent coral will only develop when conditions are favourable.

FIGURE 6 Brain coral produces both male and female gametes.

Most coral species are also hermaphrodites – they can produce both male and female gametes. Some species (e.g. brain and star corals) produce both eggs and sperm at the same time. Other corals (e.g. elkhorn coral) produce only one type of gamete (either male or female), while their neighbour produces the other type of gamete. To maximise the chances of reproducing, they release their gametes at the same time in a process called spawning. This means every coral in an area must receive the signal at the same time.

In the Great Barrier Reef in Queensland, when the water temperature rises above a minimum value, the gametes of corals mature. Spawning then begins on the inner reef 1–6 days after the next full moon (typically October); corals on the outer reef typically spawn during November or December.

1 Although brain corals can produce male and female gametes at the same time, this does not mean the offspring are clones. Explain why.
2 Describe the advantage of neighbouring elkhorn coral producing different types of gametes (one produces male while the other produces female).
3 Explain the difference in timing between coral spawning on the inner reef and on the outer reef.

CHECK YOUR LEARNING 9.2

Describe and explain

1 Define 'diversity'.
2 Explain how homologous chromosomes are similar to each other.

Apply, analyse and compare

3 State the advantages and disadvantages of sexual reproduction.
4 Summarise how crossing over and independent assortment can lead to genetic diversity in gametes.
5 Explain how sexual reproduction can lead to genetic diversity of offspring.

Design and discuss

6 Discuss how you could have characteristics of both your maternal and paternal grandparents.
7 Occasionally two sisters who are not twins can look very much alike. Describe why it would be impossible for them to be genetically identical.

9.3 Cloning technologies

KEY IDEAS

In this topic, you will learn that:

- reproductive cloning technologies include somatic cell nuclear transfer and embryo splitting
- reproductive technologies are used in agriculture and horticulture.

Clones are relatively common in plants and microorganisms. Cloning through asexual reproduction can produce many offspring that are suited to the current environmental conditions. Scientists have harnessed this approach to develop technology that produces cloned organisms with desirable characteristics. This approach is faster and more exact than selecting parents with the desirable characteristics in the hope that their breeding will result in offspring with the same characteristics.

Somatic cell nuclear transfer

enucleate
to remove the nucleus from a cell

Somatic cell nuclear transfer involves taking the nucleus from a somatic cell, such as a skin cell, and transferring it into an **enucleated** (the nucleus removed) egg cell. The first example of this procedure occurred when mammary gland cells from the udder of a sheep (genetic donor) were used to produce Dolly the sheep in 1996 (Figure 1).

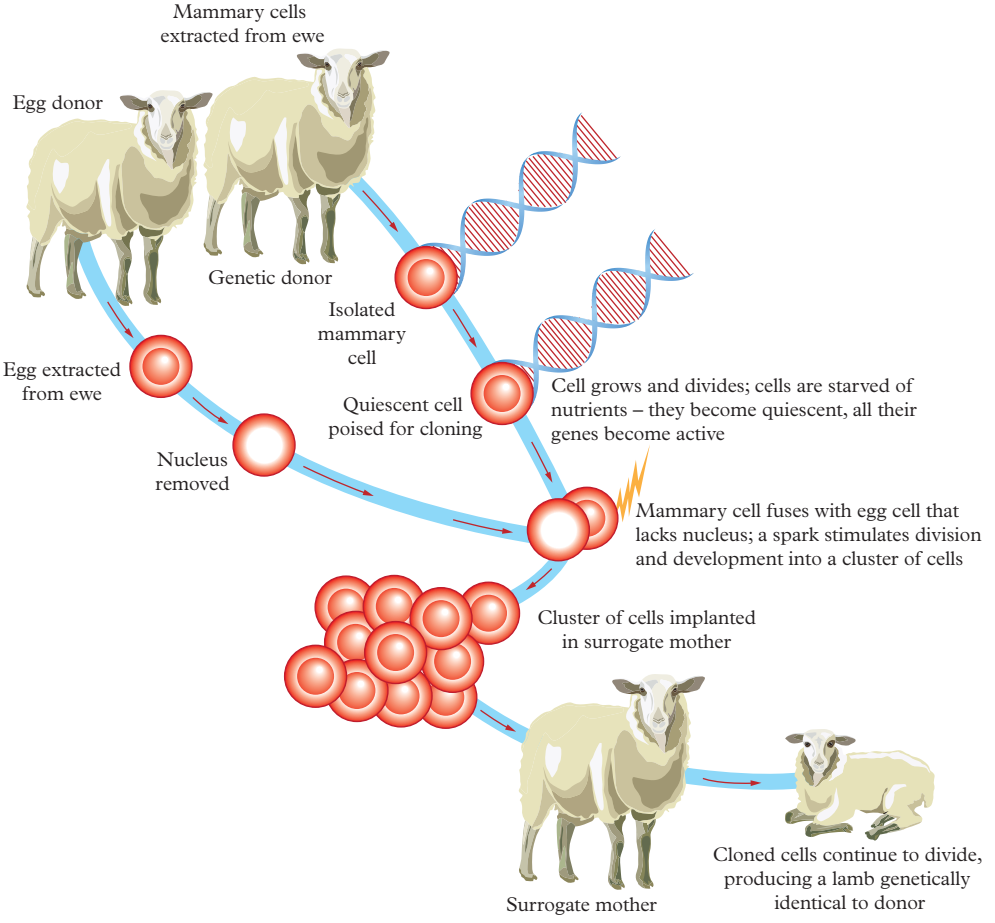


FIGURE 1 Dolly the sheep had three mothers – the genetic donor, the egg donor and the surrogate ewe.

FIGURE 2 Dolly the sheep, who died in 2003 after developing lung disease and arthritis.

The mammary gland cell containing genetic material was fused with the enucleated egg cell of another sheep (egg donor). This transferred the nucleus from the genetic donor into the cell of the egg donor. A small electric shock stimulated the egg to start dividing into more cells, before it was implanted into a surrogate mother sheep.

Although Dolly had three mothers (genetic donor, egg donor and surrogate mother) the genetic material in the nucleus of Dolly was identical to the genetic donor and was therefore a clone of the genetic donor. Dolly did not look and behave exactly like her genetic donor because she would have received different nutrients during her lifetime and experienced different stimuli and life events. All of these would have affected the neuroplasticity of her brain (the way that the brain cells are connected) and the way her muscles and behaviours developed over time.

Although early reports indicated that Dolly may have aged faster than a normal sheep, these reports were discounted after her cloned sisters lived normal lifespans with no evidence of ill effects from the cloning procedure.

The first primate clones

In China, after 10 years of trying, a team of researchers at the Institute of Neuroscience in Shanghai successfully cloned two identical long-tailed macaque monkeys. Zhong Zhong was born two weeks before Hua Hua in December 2017 (Figure 3).

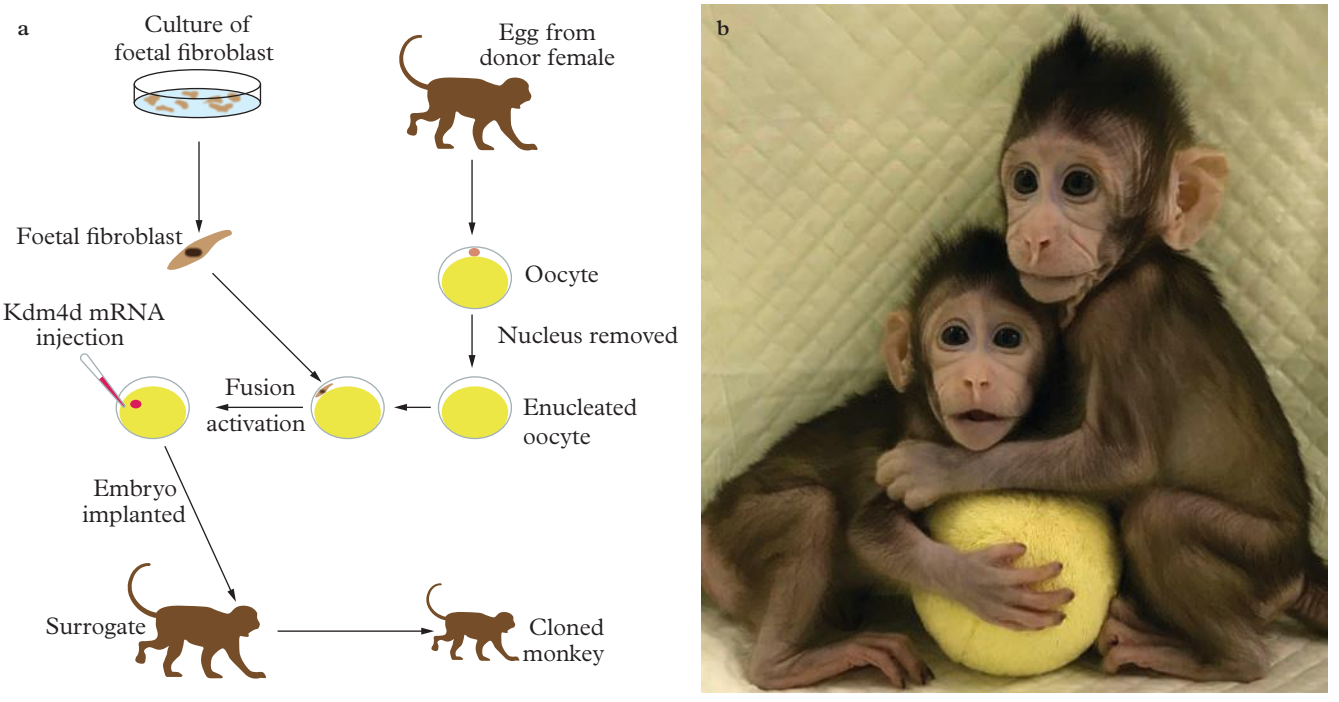


FIGURE 3 **a** Cloning of macaque monkeys through somatic cell nuclear transfer. **b** The two resulting live births, Zhong Zhong and Hua Hua.

These two monkeys were cloned from a non-embryonic cell. The donor nucleus came from an aborted foetus. It is possible to genetically modify monkey cells in a dish and then grow these cells in large numbers. The final step involved taking DNA out of these genetically modified cells and putting it into enucleated monkey egg cells. The researchers produced 127 genetically modified egg cells by this process. A total of 109 diploid egg cells developed into embryos, and 79 were transferred into 21 surrogate monkey mothers. This resulted in six pregnancies and finally two live births.

Embryo splitting

Identical twins are produced when a single fertilised egg undergoes mitosis to produce two, then four, then eight cells. The genetically identical group of cells splits into two separate groups of cells, and the two groups develop into two genetically identical individuals.

This process can be replicated in the laboratory. It is called embryo splitting. Early in the process of growing an embryo, all of the cells have the ability to develop into any cell in the body. When these cells are separated into smaller groups, the cells continue to divide and grow into identical embryos. These embryos can be implanted into different surrogate mothers and be genetically identical 'twin' siblings when born (Figure 4).

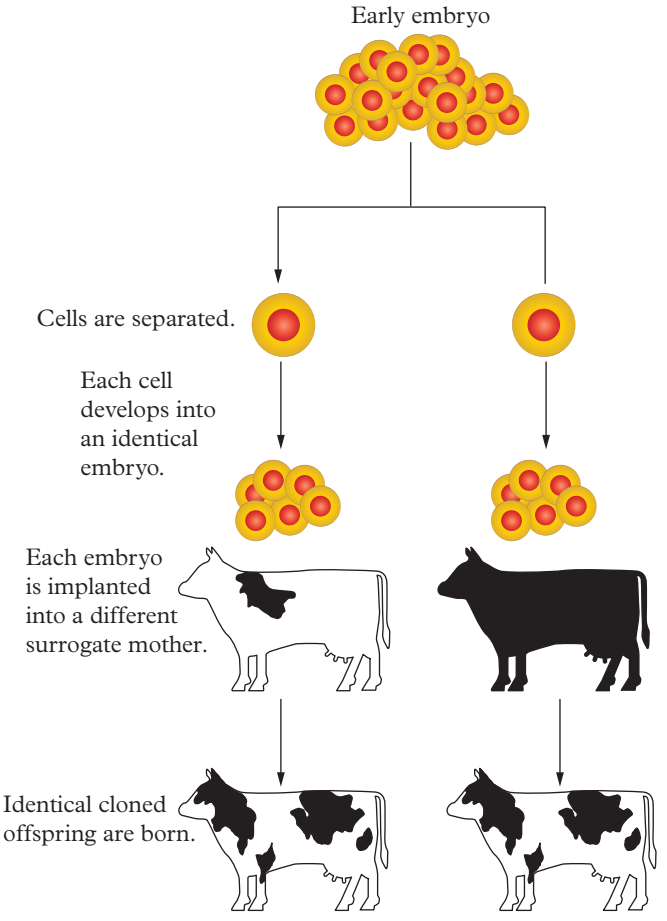


FIGURE 4 Embryo splitting or artificial twinning can be used to produce genetical identical cloned siblings.

Applications of reproductive cloning technologies

Reproductive cloning has potential benefits in medicine and agriculture. In medicine, researchers often require genetically identical organisms to test the variety of drugs used for cancer treatments or to test vaccines. Sheep like Dolly are modified so that their milk produces a particular protein needed for blood clotting in humans. Cloning these sheep allows scientists to produce larger quantities of the life-saving milk. The special blood-clotting protein can be separated from the milk and used by people who need it to survive.

Other animals with desirable agricultural characteristics, such as an ability to produce more milk or lean meat, can also be cloned. Although this process is more expensive than traditional breeding, it ensures that the characteristics are passed on to the next generation of animals.

Another reason cloning is desirable is the possibility of rebuilding populations of endangered or even extinct species of animals. Since 2001, the endangered guar (Asian ox), banteg (ox) and three African wildcats have been successfully cloned.

CASE STUDY 9.3A

Cloning for genetic diversity

Population numbers of black-footed ferrets are so low that they were once thought to be extinct. But there are still seven individuals in the wild in North America.

At the end of 2020, US scientists cloned the black-footed ferret, as part of conservation efforts to protect the endangered species. The clone, Elizabeth Ann, was created from the frozen cells of Willa, a black-footed ferret that lived more than 30 years ago.

Currently, all black-footed ferrets in the wild are descended from seven individuals, which concerns conservationists. Limited genetic diversity makes it difficult to recover an endangered species. For example, the lack of genetic diversity can be dangerous for disease resistance

Luckily for the species, scientists in the 1980s sent tissue samples from Willa to San Diego Zoo Global's Frozen Zoo. The Frozen Zoo established a cell culture and kept the frozen cells.

A genomic study showed that Willa's genome had three times more unique genetic variations than the living population. So if Elizabeth Ann successfully mates and reproduces, she could provide much needed genetic diversity to the species.

FIGURE 5 The black-footed ferret is an endandered species.

CASE STUDY 9.3B

Saving the banana

FIGURE 6 Altering the genetic material of young banana plants may allow them to withstand a fungus.

Despite the many species of bananas that grow naturally around the world, more than 90% of the commercially grown bananas in Australia are clones of a particular species of Cavendish banana. This is because a fungal disease, *Fusarium wilt* (Tropical Race 1 (TR1) or Panama disease), devastated all other commercially grown bananas in the 1950s. The *Fusarium* fungus cannot be killed by fungicides and can spread around the world on contaminated equipment or in the soil. As a result, farmers quickly discovered that Cavendish bananas were the only species resistant to the fungus. Farmers used vegetative propagation to increase the numbers of banana plants and therefore increase their production of bananas. This means most of the bananas that are available on the market today are cloned copies of each other.

There is a downside to this use of cloned plants. A new subspecies of the fungus that causes Panama disease has evolved. In 2019, the Tropical Race 4 (TR4) strain was found in a banana plantation in the Americas. This fungus can infect Cavendish banana plants, destroying whole plantations. This time, there are no other species of bananas that are resistant to the fungus.

Genetic engineering may be the only way to save the banana, according to the science journal *Nature*. Australian scientists are trying to alter the genetic material of the Cavendish banana plants so that they can resist the disease. Instead of inserting foreign DNA from another plant, the scientists are trying to activate a dormant section of DNA that gives resistance to the TR4 fungus. Before the genetically modified plants can be marketed, they must receive approval from Australian regulators.

CHECK YOUR LEARNING 9.3

Describe and explain

1 Describe an enucleated egg.
2 Identify which of Dolly the sheep's mothers were genetically identical to her. Provide evidence to support your answer.
3 Explain why cloning an animal might have disadvantages.

Apply, analyse and compare

4 Explain why embryo splitting is also called twinning.
5 Compare somatic cell transfer and embryo splitting.
6 Read Case study 9.3A.
   a Explain how, in this case, cloning is able to increase the genetic diversity of the species
   b Explain why Elizabeth Ann's genes could not be cloned from a living black-footed ferret.
7 Read Case study 9.3B. Describe the process of cloning involved in producing the Cavendish species of banana.

Design and discuss

8 Some people pay commercial companies to produce a clone of their favourite pet. Discuss the likelihood of these pets being identical to their predecessors.
9 Discuss two ethical reasons why the scientific community has banned the cloning of humans.

CHAPTER 9

Review

Chapter summary

9.1
- Asexual reproduction is a form of reproduction in which one parent produces genetically identical offspring. Asexual reproduction has some disadvantages.
- Types of asexual reproduction include fission, budding, vegetative propagation, parthenogenesis and spore formation.
- Offspring produced asexually are disadvantaged if environmental conditions change.

9.2
- Sexual reproduction is a mode of reproduction in which two parents produce genetically diverse offspring.
- Offspring that are genetically diverse have a higher chance of surviving if environmental conditions change.

9.3
- Two methods of reproduction by cloning are somatic cell nuclear transfer and embryo splitting.
- Reproductive technologies can be used in agriculture and horticulture.

Revision questions

Multiple choice

1 In asexual reproduction, all of the offspring are:
- **A** physically identical
- **B** genetically identical
- **C** physically and genetically identical
- **D** genetically different.

2 Identify which type of asexual reproduction occurs when a single female animal gives birth to offspring.
- **A** Fission
- **B** Budding
- **C** Vegetative propagation
- **D** Parthenogenesis

3 Identify the type of asexual reproduction that is occuring in the yeast shown in Figure 1.
- **A** Fission
- **B** Budding
- **C** Vegetative propagation
- **D** Parthenogenesis

FIGURE 1 Yeast reproduces asexually

4 Fragmentation occurs when:
- **A** a bacterial cell divides into two genetically identical daughter cells
- **B** the body of a multicellular organism breaks into smaller pieces, which become new organisms
- **C** a queen ant produces genetically identical male worker ants
- **D** a hydra produces a smaller genetically identical daughter organism.

5 Onion plants can reproduce by growing a smaller bulb from the side of the parent bulb. This is an example of:
- **A** fission
- **B** budding
- **C** vegetative propagation
- **D** parthenogenesis.

6 Asexual reproduction has occurred when an embryo:
- **A** develops from an egg and a sperm
- **B** is genetically identical to its twin
- **C** is genetically identical to its parent
- **D** develops through in vitro fertilisation (IVF).

7 Clones are:
- **A** physically identical
- **B** genetically identical
- **C** physically and genetically identical
- **D** genetically different.

8 In sexual reproduction, offspring are usually:
- **A** physically identical
- **B** genetically identical
- **C** physically and genetically identical
- **D** genetically different.

9 Somatic cell nuclear transfer involves:
- **A** sexual reproduction
- **B** a form of twinning
- **C** an enucleated egg
- **D** a natural form of asexual reproduction.

10 The amount of genetic material passed from parent to offspring in asexual reproduction is:
- **A** 25%
- **B** 50%
- **C** 75%
- **D** 100%.

Short answer

Describe and explain

11 Define 'asexual reproduction'.

12 Describe two processes for asexual reproduction in plants.

13 Identify two advantages of asexual reproduction.

14 Define 'sexual reproduction'.

15 Describe the characteristics of a clone.

16 Explain why the ability to produce a large number of genetically identical offspring quickly can be an advantage.

17 Explain why genetic diversity between offspring might be an advantage in a changing environment.

18 Explain how crossing over provides genetic diversity in gametes.

19 Reproductive cloning technologies include somatic cell nuclear transfer and embryo splitting. Outline the process for each of these cloning techniques.

20 Identify and describe two examples of how genetic cloning technologies can be applied.

Apply, analyse and compare

21 Compare vegetative reproduction and fragmentation.

22 Tissue culture involves taking tiny fragments of a plant and growing them in a medium containing growth hormones. Name and describe this type of reproduction.

FIGURE 2 Regrowing parts of a plant in a laboratory

23 Create a table to compare the advantages and disadvantages of sexual and asexual reproduction.

24 Seastars can affect the 'farming' of shellfish such as clams and oysters by drilling into the shells and eating the organisms living inside. Commercial growers of the shellfish throw the seastars into their boats, cut them up and then throw the pieces overboard. Explain why this may not be the best way to protect the shellfish.

25 Explain how Thelma the python could live alone in a zoo for more four years, and yet lay more than 60 eggs, producing six healthy babies.

Design and discuss

26 Currently, there are only two female northern white rhinoceros alive in the world. Discuss how somatic nuclear transfer could be used to increase the population of northern white rhinoceros.

FIGURE 3 The northern white rhinoceros (*Ceratotherium simum cottoni*) is critically endangered.

27 A student claimed that a plant grown from a cutting would be identical to the parent plant. Discuss the accuracy of this claim.

28 'Parthenogenesis is a form of cloning.' Discuss why this statement is incorrect.

29 Consider the monkeys that were cloned by scientists in China (described on page 254 of topic 9.3). Genetically identical monkeys could provide a useful research tool when studying human diseases. But some people believe this raises a number of ethical concerns. Evaluate the use of cloning in this case in terms of a:

- **a** consequences-based approach to ethics
- **b** duty-based approach to ethics
- **c** virtues-based approach to ethics.

30 Strawberries can reproduce by vegetative propagation. They produce horizontal shoots above the ground, called stolons but more commonly known as runners. These runners can produce their own roots and grow into the ground to become their own plant.

A group of students were asked to investigate the impact of sunlight availability on the rate at which a strawberry plant can produce runners. Design this experiment by answering the following questions.

- **a** Suggest an aim for this experiment.
- **b** Identify the dependent and independent variables.
- **c** Identify three variables that will need to be controlled.
- **d** Suggest a method for this experiment, including how you would collect accurate and reliable data.
- **e** Outline any potential safety risks in the method, and safety precautions that should be taken.

FIGURE 4 Strawberry stolons plant their own roots into the ground surrounding the mother strawberry plant.

Check your Student obook pro for these digital resources and more:

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Compete in teams to test your knowledge.

Chapter quiz
Check your understanding of this chapter.

Check your Teacher obook pro for these resources and more:

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Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to write a definition when explaining a process.

Define terms

Defining a term means that you need to show a clear understanding of the term and how it is applied in biology. It is important to understand why some words are included in a definition. For example, when defining 'prokaryotes', you need to specify that they contain 'no nucleus' or 'no membrane-bound organelles'.

QUESTION 1

Some organisms can reproduce asexually to produce genetically identical daughter cells. Budding is a method of reproduction in yeast and hydra.

a Define 'budding'. 1 mark

b Describe two disadvantages of asexual reproduction. 2 marks

Response 1

a A form of asexual reproduction where small growths develop on the parent organism that develop into genetically identical organisms.

b Due to limited diversity, a disease may affect all organisms in the population and the population is less likely to be able to adapt to a changing environment.

This definition is specific.

Refers to genetically identical organisms.

This response would receive full marks because the definition accurately describes budding with reference to 'genetically identical organisms'. In part b, two distinct disadvantages are described and linked to reduced diversity in asexual reproducing populations.

Response 2

a Budding is a type of asexual reproduction where identical daughter organisms are produced.

b Asexual reproduction has several disadvantages, including the fact that offspring are clones of the original parent organisms. Another disadvantage is that there is only one parent organism reproducing.

This is not accurate; it must say 'genetically identical daughter organisms'.

This is a description of asexual reproduction, not a disadvantage.

This is an advantage, not a disadvantage

There is not enough information in the definition to be awarded the mark. To say 'identical daughter organisms' is not correct for budding because the daughter organisms are smaller than the original parent organism. In part b, neither of the disadvantages is accurate and no marks would be awarded for this response.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

QUESTION 8b (2016 Biology Written Examination)

Two species of *Cryptasterina* sea stars are found in coastal Queensland. *Cryptasterina pentagona* is found in warmer water further north, while *Cryptasterina hystera* is found further south in cooler water.

b One of the phenotypic differences between these two species of sea stars is their method of reproduction. *C. pentagona* reproduces sexually and its sperm and eggs are free-floating in the ocean. *C. hystera* self-fertilises and its fertilised eggs are kept within the sea star until maturity. The researchers found that one species of *Cryptasterina* has a significantly higher diversity of alleles in its gene pool than the other species. Using this information about reproduction strategies, which species of *Cryptasterina* would you expect to have the highest diversity of alleles? Explain your answer. 2 marks

Both species have a high diversity of alleles because they reproduce sexually, which produces variation in the population.

Source: 2016 Biology Written Examination, Question 8b, Short answer, reproduced by permission © VCAA

Marking guide

8b	1 mark for identifying the correct species *C. pentagona* 1 mark for explaining that *C. pentagona* reproduces sexually where two individuals provide the genetic material to the offspring.

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 an examiner.

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CHAPTER 10

Adaptations and diversity

All organisms on Earth have characteristics that increase their chances of survival and allow them to carry out their life functions at optimal levels within their particular environments. These characteristics or *adaptations* have often evolved over long periods of time by the process of natural selection. Some characteristics are more obvious than others, such as the long neck of the giraffe or the horns of a rhinoceros. Others are more subtle, such as air pockets inside the leaves of many aquatic plants, which allow them to float and/or receive oxygen while submerged underwater. The purpose of some adaptations is still a mystery to scientists, such as the ability of scorpions to glow blue under ultraviolet light.

Another way species ensure survival in a changing environment is by having high genetic diversity. Captive breeding and isolated populations make it difficult for a species to adapt to big changes, such as a pandemic outbreak and climate change.

KEY KNOWLEDGE

- → the biological importance of genetic diversity within a species or population
- → structural, physiological and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments
- → survival through interdependencies between species, including impact of changes to keystone species and predators and their ecological roles in structuring and maintaining the distribution, density and size of a population in an ecosystem
- → the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems

FIGURE 1 Most Australian scorpion species glow in the dark under UV light. Scientists speculate this adaptation is used by the scorpions to know when they are exposed. If any part of the scorpion's body is exposed to sunlight (UV), they know they are exposed to predators and so move to hide.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. If you need help with any of the questions, have a go at the corresponding groundwork resource on your obook pro.

10A Explain why organisms that reproduce asexually are more vulnerable when climate changes.

10A Groundwork resource
Asexual reproduction

10B Briefly outline how sexual selection improves the survival of a species.

10B Groundwork resource
Sexual selection

10C Discuss one example of how an ecosystem can alter as a result of bushfire, drought or flooding.

10C Groundwork resource
Changing ecosystems

PRACTICALS

PRACTICAL	**10.2** Plant adaptations
PRACTICAL	**10.3** Field study of adaptation and distribution

For full instructions for each practical, go to Chapter 11 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.

10.1 Genetic diversity

KEY IDEAS

In this topic, you will learn that:

+ maintaining a large genetic diversity within a species or population improves survival.

In Chapter 9, you explored the advantages of sexual reproduction for producing offspring with a diverse range of genetically controlled characteristics. These characteristics can have a large effect on the survival of an individual organism, and ultimately on the survival of the species.

Species diversity

genetic diversity the total number of genetically controlled characteristics that appear in the phenotype of a species

species a taxonomic group, allocated two (genus and specific) names; only members of the same species can produce fertile offspring when mating under natural conditions

gene pool all the alleles that exist for all the genes within an interbreeding population

The characteristics that are important for an organism's survival are inherited equally from its mother and its father. During meiosis, the cells that produce the egg and sperm first pair their matching homologous chromosomes. This allows crossing over to occur before the chromosomes are randomly assorted into gametes. The formation of the gamete and the process of fertilisation (when the egg and sperm gametes combine) result in the **genetic diversity** that is important for survival.

Genetic diversity is a way to describe the genetic information that provides the variety of phenotypes that occur in a species.

Species

Organisms are considered to be the same **species** if they can produce living (viable) and fertile offspring under natural conditions. Some organisms of different species can combine their gametes to produce offspring but the offspring do not have homologous chromosomes that can form pairs during meiosis. For example, horses (64 chromosomes) and donkeys (62 chromosomes) are considered to be different species. If a female horse mates with a male donkey, they may produce a mule (63 chromosomes) (Figure 1). The mule is unable to produce offspring and is considered non-fertile.

Plants also exist as species that can reproduce to produce viable, fertile offspring under natural conditions. Occasionally, a pollen grain from one species may land on the female part of the flower of another species. But the pollen grain may not be able to transfer its genetic material to the egg. Even if the pollen fertilises the egg, the new plant will be unable to produce gametes of its own. For example, seedless watermelons are produced when the pollen of a diploid species fertilises a tetraploid egg of another species to produce a triploid species. The triploid species develops seedless fruit.

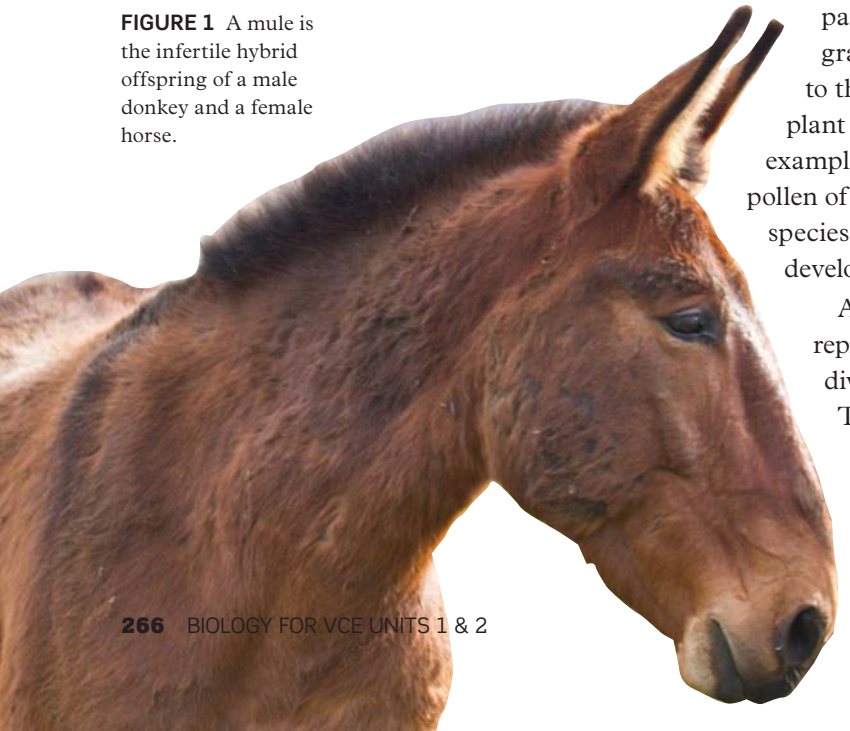


FIGURE 1 A mule is the infertile hybrid offspring of a male donkey and a female horse.

A **gene pool** is all the alleles for all genes in a sexually reproducing species. If a species has wide genetic diversity, it can adapt to changes in the environment. The greater the variety of physical characteristics (as determined by the genotype), the more likely it is that a single individual will have a sufficient set of characteristics that will allow it to survive. If the organism survives, then it will be able to mate and

pass on those successful characteristics to the next generation.

Members of the same species may spread out over a large area, a country or even the world. Despite being widespread, members of the same species will tend to group together. Groups of the same species, in the same place, at the same time, are called a **population**.

FIGURE 2 A group of the same species in one area, such as these *Homo sapiens*, is called a population.

population
the number of individuals of a species living in a particular place at a particular time

Genetic diversity in a population

The survival of a species is dependent on individual organisms surviving long enough to reproduce. Sexual reproduction increases genetic diversity, leading to greater variations in the physical characteristics of the population.

To survive, all organisms need to stay within a set range of conditions. If an environment becomes too hot or too cold, then individual organisms can struggle to survive. If there is too much or too little light, or too little food, then individual organisms may die. The range of conditions within which an individual organism can survive is known as the **tolerance range**. Within the tolerance range is the **optimum range**, where the organisms carry out life processes (e.g. living, hunting, mating and raising offspring) at an optimal level. Outside the tolerance range, organisms will not survive (Figure 3).

tolerance range
the range of conditions in which an organism can survive

optimum range
the range of a conditions in which an organism carries out life processes

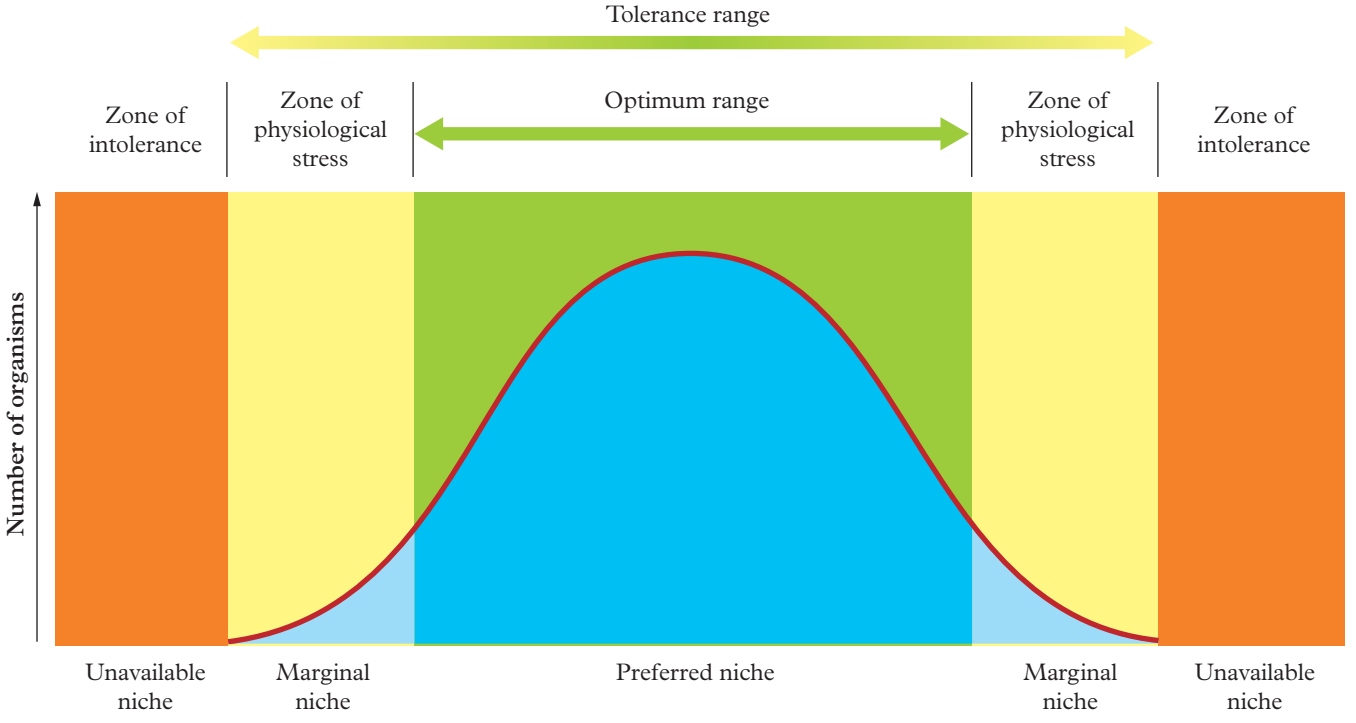


FIGURE 3 A graphical representation of the optimum and tolerance ranges for organisms

The advantage of genetic diversity

The advantage of genetic diversity within a species or population is that individual organisms have diversity in their tolerance range. For example, rabbits (*Oryctolagus cuniculus*) originated from the cooler wet climates of Europe (Figure 4). Their behavioural and physical characteristics allowed them to survive the often-freezing conditions. Rabbits were introduced to Australia by settlers from the First Fleet in 1788. These rabbits did not survive very well because they were house-bred animals with a low genetic diversity, meaning their physical characteristics were very similar to one another. It wasn't until several decades later that 24 wild rabbits were brought to Australia by Thomas Austin. These rabbits had greater genetic diversity than the house-bred variety. This variation resulted in some phenotypes that gave some individuals the physical characteristics that enabled them to survive and reproduce in the arid conditions of Australia. The mild winters (compared to England's) allowed the rabbits to breed all year round. As a result, the rabbit population grew and spread across Australia rapidly.

FIGURE 4 Wild rabbits have a greater genetic diversity than domesticated rabbits. In Australia, the variation in phenotypes gave some individuals an advantage for survival in the Australian environment.

Low genetic diversity

A large population does not necessarily mean a large genetic diversity. If a population started with a small number of genetically similar organisms (such as from a small family), then recombining the chromosomes or crossing over the genes will have a limited effect on the genetic diversity of the offspring. For example, low genetic diversity in potato crops can make them susceptible to fungal diseases such as potato blight (Figure 5). Another example is a family where both parents have the alleles for the trait of red hair. Because this is a recessive trait, all the children will also have red hair. The genetic diversity of hair colour is low. In contrast, if new individuals with a different set of alleles were introduced to a population, the genetic diversity would increase, potentially increasing the number of physical characteristics that would allow the organisms to survive should the environmental conditions change.

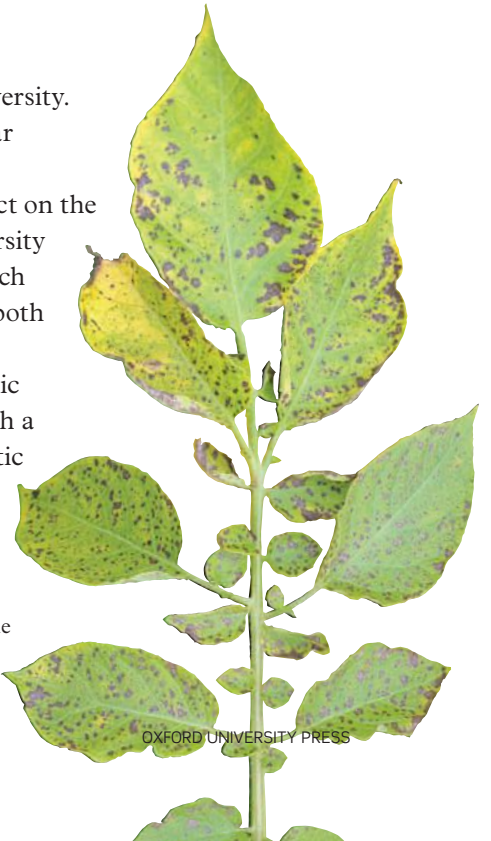


FIGURE 5 A low genetic diversity can make a population of potatoes vulnerable to new fungal diseases.

CASE STUDY 10.1

Genetic diversity in Tasmanian devils

The Tasmanian devil (*Sarcophilus harrisii*) was once common in Victoria and the other states of mainland Australia. It is thought that approximately 11 000 years ago, there was a change in the environment that resulted in only one family surviving. This small group of related devils had a very limited genetic diversity and are thought to be the ancestors of all current Tasmanian devils.

Over the next 10 000 years, the increasingly arid environment and hunting by the mainland dingos wiped out all the mainland devils. During the last 400 years, the Tasmanian devil was limited to the dingo-free, more temperate island of Tasmania. This meant that the surviving devils were only able to produce offspring with genetically similar mates. The high level of inbreeding on the east coast of Tasmania resulted in low genetic diversity and very similar physical characteristics. This meant that the devil population had the same genetic markers to fight diseases. So when one east coast Tasmanian devil developed a cancer on its face, the cancer was quickly passed to another devil via biting during mating. Because the genetic markers on the cells of both devils were the same, their immune systems could not recognise the foreign cancer cells and so the cancer spread quickly. The cancerous tumour on the devil's face makes it hard for the animal to eat and so, sadly, many devils died of starvation.

The cancer (called devil facial tumour disease) continued to spread among the east coast Tasmanian population, but devils on the west coast of Tasmania were more genetically diverse. This meant their immune systems could detect and attack the cancer, allowing the Tasmanian devil to continue to survive.

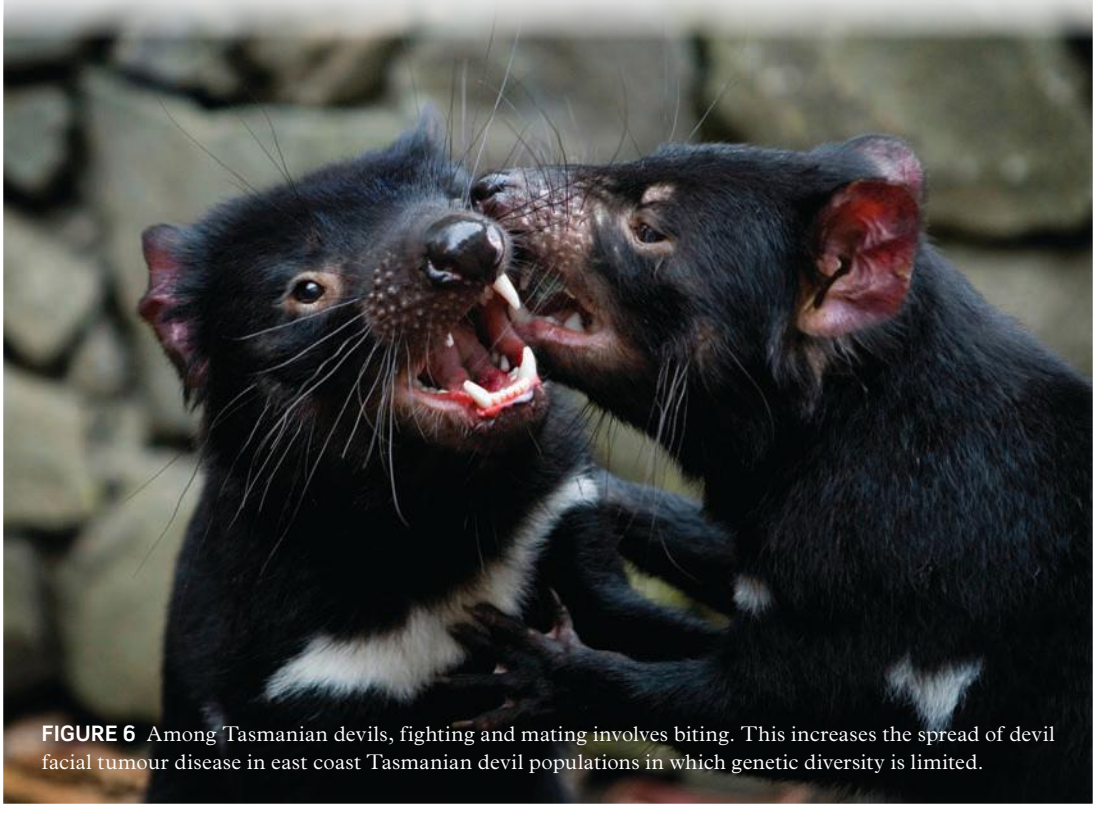


FIGURE 6 Among Tasmanian devils, fighting and mating involves biting. This increases the spread of devil facial tumour disease in east coast Tasmanian devil populations in which genetic diversity is limited.

CHECK YOUR LEARNING 10.1

Describe and explain

1 Define 'genetic diversity'.

2 Explain the difference between species and population.

3 Explain why a species needs individuals to have diversity in their tolerance ranges.

4 Define 'tolerance range'.

Apply, analyse and compare

5 Use an example to explain how a large population can have a low genetic diversity.

6 One way of roughly measuring genetic diversity in a species is to compare the number of DNA nucleotide differences between individuals of the same species. The greater the difference in nucleotides, the greater the genetic diversity.

A study researching the genetic diversity of cheetahs produced the graph shown in Figure 7.

a Examine the graph and compare the genetic diversity of cheetahs to that of Tasmanian devils.

b Compare the genetic diversity of cheetahs to those of humans and domestic cats.

c Draw a conclusion about the genetic diversity of cheetahs based on the data shown.

d Explain why this makes cheetahs a threatened species.

7 Analyse Case study 10.1 and explain why the east coast population of Tasmanian devils was severely damaged by a facial cancer and the west coast populations survived. Consider how you would protect the remaining east coast population from future diseases.

Design and discuss

8 Discuss how some populations of humans can tolerate the extremely high temperatures of central Australia, whereas other populations can tolerate the very low temperatures of Siberia.

9 In 1840, most people in Ireland relied on potatoes as their food source. They would grow new potatoes by cutting up the previous year's potatoes and replanting them. Use your knowledge of cloning from Chapter 9 and genetic diversity to explain why a fungus was able to cause a potato famine in 1845.

FIGURE 8 Potato blight makes potatoes inedible.

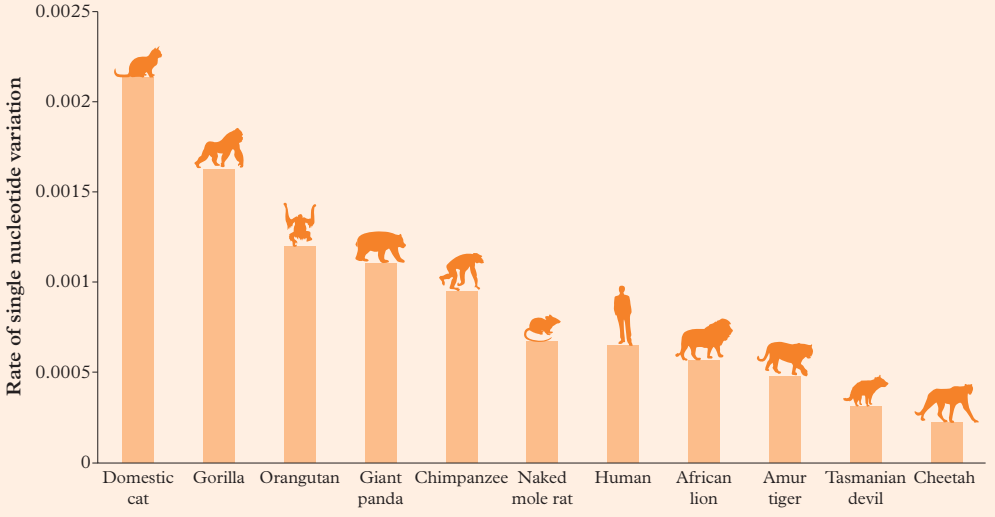


FIGURE 7 Estimates of diversity in the cheetah genome relative to other mammal genomes.

10.2 Adaptations to enhance survival

KEY IDEAS

In this topic, you will learn that:

- adaptations enhance the survival of plants and animals in their environments
- structural adaptations are physical features of an organism that provide a survival advantage
- behavioural adaptations are the ways animals act to respond to an environmental condition
- physiological adaptations are functional characteristics that regulate processes or produce products within an organism
- plant responses to changing environmental conditions involve moving parts of their body systems.

Australia has a wide range of environments, from sunburnt deserts to mountain ranges, rainforests and shorelines (Figure 1). This means that Australian native organisms must be able to tolerate many different environmental conditions to survive. Organisms that live in temperate forests must be able to survive drier conditions than organisms that live in rainforests. Grassland environments have lower temperatures and more shade than a desert environment. As an island, Australia has a long coastline where organisms are exposed to the drying effects of salt water and harsh sunlight.

In order to survive, organisms need a variety of adaptations that are specialised to their environment.

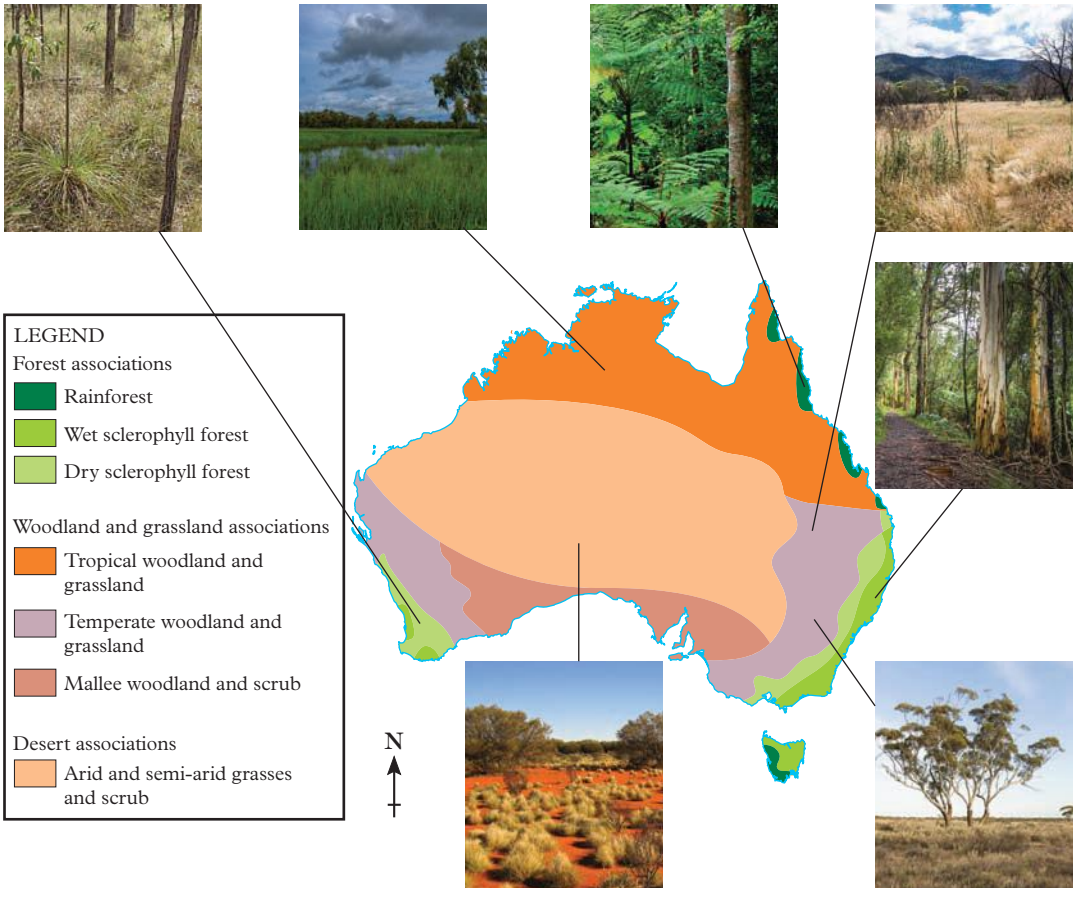


FIGURE 1 Australian organisms are adapted to many different types of environments.

Adaptations

adaptation
a characteristic that enhances an organism's survival within an environment

Adaptations are the phenotypic characteristics in a species that enhance an organism's survival within an environment. Every characteristic of an organism in a species is an adaptation that results from the genetic information contained within a cell.

Adaptations are the result of mutations or permanent changes in the DNA of an organism. A mutation can result in a small change in a physical characteristic of an organism and increase its chances of surviving. For example, a small mutation in the genes that control skin colour may result in a small change in the patterns of the skin that allow an animal to camouflage more effectively. This allows the animal to survive long enough to mate and have offspring. The mutation that causes the new skin patterns can be passed on to the next generation. As more and more members of the population inherit the mutation, the mutation becomes an identifying part of the species. This means the mutation has become an adaptation of the species rather than of an individual organism.

There are three types of adaptation: structural, behavioural and physiological.

Structural adaptations

structural adaptation
a physical characteristic of body size and shape that increases an organism's chances of survival and reproduction

Structural adaptations are physical characteristics of an organism's body size and shape that improve the survival and reproduction of the species. All structural adaptations are inherited from the previous generation.

Most structural adaptations of plants are related to photosynthesis. Because water and light are required for photosynthesis, plants need structures that regulate water levels while still being able to capture light. Plants in low light environments have very different adaptations from those growing in full sunlight. Some of these structural adaptations are:

- leaf shape, size and positioning to capture light for photosynthesis
- leaf structures that regulate water loss
- specialised root systems that maximise water and oxygen uptake (Figure 2)
- reproductive structures for efficient dispersal, pollination and germination.

FIGURE 2 The aerial (above ground) roots of this mangrove plant on the Queensland coastline allow for increased transportation of oxygen to the highly anoxic (depleted of oxygen) roots below ground.

Structural adaptations of animals relate to their ability to gather food, escape predators, control their body temperature and regulate water levels. These include:

- features to deter or avoid predators (spines, fangs)
- insulating features against low temperatures (fur, blubber)
- ear size to either reduce or increase heat loss
- surface area to volume ratio to conserve water or heat
- features for feeding (teeth and jaw structure)
- features for swimming (flippers or webbed feet) (Figure 3).

FIGURE 3 The watry treefrog (*Ecnomiohyla tuberculosa*) from Ecuador has webbed feet, which are an advantage when swimming.

Hot, dry Australian environments

Xerophytes are hardy, drought-tolerant plants that are well adapted for hot, dry environments. Beach spinifex (*Spinifex longifolius*) and mulga (*Acacia aneura*) are examples of xerophytic plants that live in Australian desert ecosystems.

xerophyte
a plant suited to living in hot, dry environments that is generally drought tolerant

Xerophytes such as eucalypts have silver-green coloured leaves that hang vertically to minimise their exposure to sunlight (Figure 4a). Mulga have needle-like leaves (Figure 4b). The leaves stand erect, which decreases the heat that is absorbed by the leaves, prevents water from evaporating and allows more water to be retained for photosynthesis.

FIGURE 4 **a** Eucalypts have leaves that hang down to minimise heat absorption and prevent water loss through evaporation. **b** The needle-like leaves of mulga help prevent water loss. They have a thick cuticle and sunken stomata and are covered in tiny hairs that reduce transpiration.

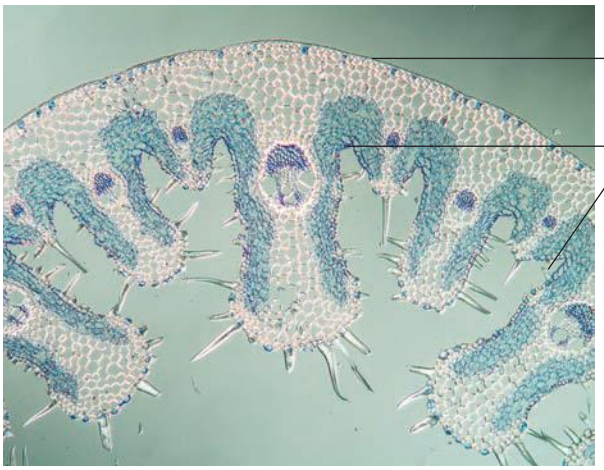


FIGURE 5 A light micrograph of a transverse section of a rolled leaf from marram grass (*Ammophila arenaria*), showing stomata deep within pits.

The leaves of xerophytic grasses are often rolled to form spikes that trap moisture and reduce water loss. The stomata are located on the inner surface of each rolled leaf (Figure 5). These stomata allow carbon dioxide to enter for photosynthesis. In xerophytes, the stomata are often sunken into pits and are surrounded by hairs that create a humid microclimate to trap water. The stomata are often closed during the day and open at night when the temperature is lower. This limits how much water evaporates during the hot day. The outer surface of each leaf has a thick, waxy cuticle to protect the leaf and reduce water loss.

Animals that live in Australia's desert environment have small bodies with large surface area to volume ratios. This means heat can enter or leave their bodies much more quickly than in larger animals. These animals can quickly warm up in the morning and cool down in the shade, which is essential for survival in hot, dry environments. These animals often have large ears and long tails that contain many blood vessels, which can quickly release body heat to the environment (Figure 6). Animals in these ecosystems often have claws and strong forelimbs that are suited for burrowing to shelter during the hottest part of the day and avoid predators.

FIGURE 6 The large ears and long tail of the nocturnal spinifex hopping mouse (*Notomys alexis*) allow it to live in a hot climate. The larger surface area to volume ratio increases the amount of heat radiating from the body.

Warm, wet Australian environments

Some plants are well adapted to cope with wet environments. Water lilies (*Nymphaea nouchali*) and water sprites (*Ceratopteris thalictroides*) are examples of hydrophytes that live in Australia's tropical ecosystems. Their adaptations include:

- thick waxy leaves with pointed ends that enable water to run off during high rainfall; this helps to prevent fungal growth in humid environments
- large leaves for maximising photosynthesis, especially in the darker, lower levels of a tropical rainforest where less light is available.

FIGURE 7 The water lily is a hydrophyte and has thick and large waxy leaves.

For example, the Australian water lily has large leaves that enable it to capture the maximum amount of light for photosynthesis (Figure 7). Water lilies don't need adaptations for preventing water loss because they are surrounded by a constant supply of water. However, they do have adaptations that allow them to survive in an aquatic habitat. For example, they have stomata on the upper surface of the leaf to allow for the exchange of oxygen and carbon dioxide. Water continually moves through the plant from the roots to the atmosphere, exiting the stomatal pores on the upper leaf surface. These plants also have large air-filled chambers in the leaves that lower the density of the leaves and allow them to float on top of the water (Figure 8).

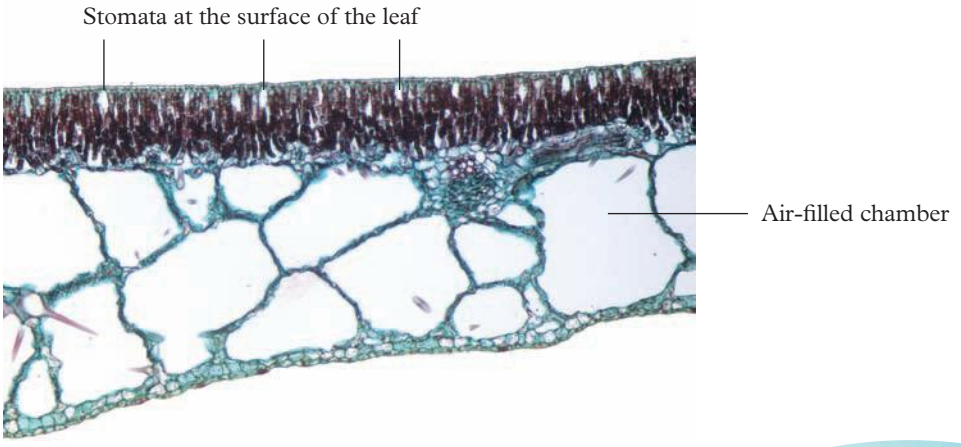


FIGURE 8 A transverse cross-section of a water lily leaf, showing the stomata on the surface and large air chambers in the leaf that allow it to float.

Animals that live in warm, wet environments often have structural adaptations that allow them to move effectively through the water. For example, the streamlined shape of fish is an inherited structural adaptation. The platypus (*Ornithorhynchus anatinus*) has webbed feet to help it swim through the water (Figure 9). On land, platypuses walk on their knuckles to protect the webbing. The male animals also have a poisonous spur on their hind feet to defend themselves from predators. Their bill is flexible and has many receptors that enable it to detect the movement of prey such as yabbies and small fish. These are all structural adaptations that make the platypus successful in inland freshwater creeks.

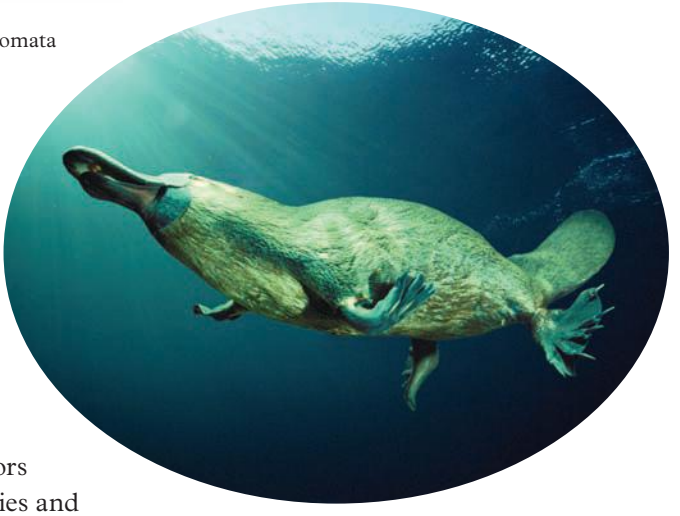


FIGURE 9 The platypus has a number of structural adaptations that are passed from one generation to another.

Behavioural adaptations

behavioural adaptation
a behaviour that increases an animal's chances of survival and reproduction

Behavioural adaptations are displays, movements and actions that provide communication to enhance the survival and reproduction of an animal. Behavioural adaptations include forms of communication (mating or aggression), migration and survival.

Some of these behaviours (such as a spider weaving a web) are inherited through genetics, whereas other behaviours are learnt through social means, including from parents or other members of the species.

Migration behaviour

A change in an animal's environment can be a signal for a change in behaviour. For example, a cooling environment, or reduction in daylight hours, can be a cue for an animal to migrate (a regular long-distance change in location) to a warmer environment. Some animals (turtles and pigeons) use Earth's magnetic field to change their location to a more optimal environment, while other animals (scorpions) use the light of the Sun or moon to modify their behaviour. Scorpions glow under ultraviolet light, although scientists still don't know why (Figure 10). One study found that scorpions were less active in UV light, most likely to avoid heat. During the full moon, the scorpions would also avoid moving around.

FIGURE 10 Many Australian scorpions are less active during the full moon. This behavioural adaptation increases their chance of surviving, possibly because more prey might be available during dark nights.

Communication behaviour

Animals communicate with each other in a variety of ways, including by sight, smell, touch and sound. The Australian fruit fly uses all of these signals in its courtship behaviour (Figure 11). The female fruit fly releases chemical signals to attract the male, who then uses vision to identify her. The male then touches the female's abdomen with a foreleg before vibrating his wings to produce a courtship song.

Many animals use signals to communicate their ownership of a particular territory. Dingoes (*Canis lupus dingo*) communicate with family members by howling, but when their territory is threatened, they bark as a warning.

FIGURE 11 Female Australian fruit flies (*Bactrocera tryoni*) use chemical signals as a way of communicating to their male mate.

Survival behaviour

nocturnal
most active at night

Many animals in hot, dry environments are **nocturnal**. They sleep in burrows or other shelters during the day to avoid high daytime temperatures. These animals are most active and feed during the coolest parts of the day.

Some animals cool themselves by evaporative cooling. This regulates internal body temperature by releasing heat into the external environment, which has a cooling effect. Animals carry out evaporative cooling by a variety of behaviours, including panting, rolling in mud, water spraying and mouth gaping (Figure 12).

Many small mammals display a huddling behaviour that helps them to maintain a constant internal temperature. Huddling in groups decreases the surface area of the animals exposed to the colder environment. This keeps the animals in the centre of the huddle warm. Each animal takes a turn at being on the outside of the group, so no one animal is constantly subjected to extremely cold or windy conditions.

Other animals bask in the sun to warm up. This behaviour is essential for ectotherms to maintain their body temperature. For example, lizards use the heat of their surroundings to stay warm enough to move and carry out other biological activities.

FIGURE 12 Crocodiles cool themselves by mouth gaping, which allows air to move across the mouth, reducing internal body temperature.

Plant responses

Although plants do not have behaviours, they can move in response to changes in their environments. These **plant responses** can be directional or non-directional responses. Although these responses are similar to behavioural adaptations in animals, they are physiologically controlled by hormones or regulated by osmosis.

plant response
a plant movement that increases its chances of survival

Tropisms are directional growth responses either towards (positive) or away from (negative) a physical environmental factor such as light, water or gravity. Tropisms are controlled by hormones such as auxin and ethene.

tropism
a directional movement of a plant towards or away from an environmental factor

The root tips of a plant have a positive hydrotropism response when they grow towards water. The growing stems of plants have a positive phototropism response when they grow towards light.

CASE STUDY 10.2

Auxins

The **auxins** are a group of hormones that are responsible for a shoot tip growing towards a light source. Auxin is produced by shoot tips and causes cells to become longer. If one side of the stem is exposed to more light, auxin accumulates on the shaded side. There is uneven cell growth as the cells on the dark side elongate faster than the cells on the side exposed to light. The shoot tip slowly bends towards the light source.

auxin
a hormone responsible for phototropism in plants

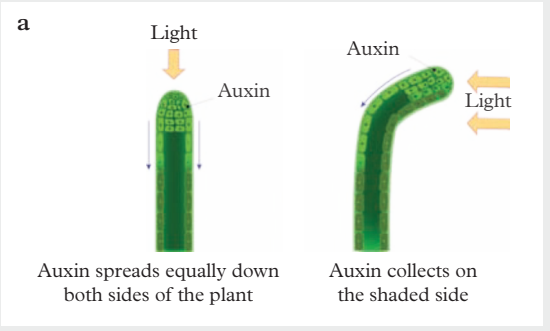


FIGURE 13 **a** Auxin hormones cause cells on the dark side of the stem to elongate. This results in the plants growing towards light. **b** These seedlings are showing positive phototropism.

nastic response
a non-directional movement of plants

Nastic responses are non-directional movements of specific plant tissues. These are in response to changes in the environment, such as touch, light or temperature. The Venus fly trap (*Dionaea muscipula*) uses a nastic response to close its leaves, trapping prey for extra nutrients. The mimosa plant (*Mimosa pudica*) is able to rapidly close its leaves, which makes it harder to see and prevents it being eaten by herbivores (Figure 14). These movements are controlled by the movement of water in and out of the cells that form the hinge of the plant tissues.

FIGURE 14 **a** An untouched mimosa leaf. **b** A mimosa leaf after being touched; the leaflets are reduced to appear as single spikes and be less appealing to herbivores.

Physiological adaptations

physiological adaptation
a functional adaptation that increases an organism's chances of survival

Physiological adaptation allow organisms to maintain and regulate internal functions. This occurs through the chemical reactions inside a cell, which ultimately affect the organ system function of an entire organism. These adaptations can occur within 30 minutes, and animals have no conscious control over the changes.

Physiological adaptations in plants

Australian plants have physiological adaptations that enable them to cope with the extreme Australian ecosystems, including too much or too little light, salt or extreme temperatures.

All plants carry out photosynthesis, converting light energy into chemical energy. This process requires water and carbon dioxide. For carbon dioxide to enter the leaves, the stomata must be open. In hot, dry ecosystems this is a disadvantage because water is also lost through the stomata every time they are open.

Some plants, such as cacti, use a modified photosynthetic pathway (called crassulacean acid metabolism (CAM)), which prevents water being lost during the day. The stomata of these plants are only open at night when temperatures are low and water loss is minimal. The carbon dioxide forms the four-carbon malic acid molecule, which is stored in the plant vacuoles until it is required. During the day, malic acid is released from the vacuoles and broken down to carbon dioxide, which is transported to the chloroplasts where it enters the photosynthesis pathway. In this way, the plant can obtain the carbon dioxide for photosynthesis without having to rely on stomata being open during the day (Figure 15).

FIGURE 15 At night, CAM plants such as cacti open their stomata to collect and modify carbon dioxide, storing it in vacuoles as malic acid. During the day, this modified carbon dioxide is used in the chloroplasts for photosynthesis. The stomata are closed during the day when temperatures are high, minimising water loss.

Plants living in high-saline ecosystems, such as salt lakes, intertidal zones and coastal sand dunes, have physiological adaptations to survive in a high-saline environment, where salt continually enters the plants in water through the roots. These adaptations include:

- transporting excess salt into old tissues and plant vacuoles
- increasing water uptake into tissues with high salt concentrations
- pumping excess salt from root systems
- excreting salt from salt glands
- shedding leaves that contain high salt concentrations.

Avicennia is a genus of mangrove that has glands on the surface of their leaves that excrete excess salt (Figure 16). These specialised glands enable the mangroves to regulate their internal salt concentration.

FIGURE 16 Salt water is excreted from the salt glands of mangrove leaves. The water evaporates, leaving salt crystals on the leaf surface.

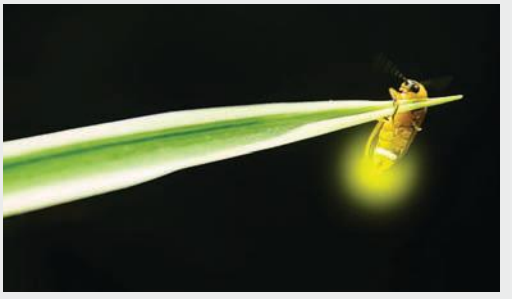
Physiological adaptations in animals

Animals have a wide range of physiological adaptations to ensure their survival in the environmental extremes of Australia.

In hot environments, animals need to cool their bodies and prevent excessive water loss. Many mammals, including humans, become flushed in a hot environment because the blood vessels dilate (become wider) and carry heat from the centre of the body to the skin. The evaporation of sweat from the skin helps remove heat energy. To compensate for the loss of water through sweating, the kidneys reabsorb water from urine, making the urine more concentrated.

In cold environments, animals limit the amount of heat lost to the environment by raising the feathers, fur or hair. This traps a layer of warm air close to the skin, keeping them warm. If the temperature drops further, mammals start shivering. The muscle movement generates heat that helps them to keep warm.

TABLE 1 Different forms of physiological adaptations in animals

Physiological adaptation	Description	Example
Camouflage	Camouflage allows animals to blend in with their environment to capture prey or avoid predation. Some animals produce pigments that can be moved between cells when required to blend in with the colours of their surroundings.	This lizard can change colour to match its environment. 
Antifreeze proteins	Some fish produce proteins that prevent their tissues from freezing. These antifreeze proteins prevent ice crystals forming in their blood.	Fish living in Antarctic waters produce antifreeze proteins. 
Bioluminescence	Some animals such as fireflies, anglerfish and jellyfish can release light energy to lure prey, attract mates or ward off predators. These organisms produce a pigment that reacts with oxygen, producing bioluminescence.	Each firefly has its own specific bioluminescent flash that attracts a mate. 

Study tip

Often, different adaptations are directly related. For example, a snake's fangs are a structural adaptation. Showing or using these fangs are behavioural adaptations. The venom production is a physiological adaptation.

CHECK YOUR LEARNING 10.2

Describe and explain

1 Define 'adaptation'.

2 Give an example of one behavioural and one physiological adaptation of an animal that lives in extremely cold environments.

3 After a long day outside in the heat, you notice your urine is a dark yellow/brown colour. Identify the type of adaptation and explain how it provides an advantage to survival.

4 Explain whether salt excretion in salt-lake grasses is a behavioural, structural or physiological adaptation.

Apply, analyse and compare

5 Compare the environmental conditions that might affect the survival of an organism at high tide and low tide.

6 Apply your understanding of structural adaptations to compare the leaf structures of rainforest plants and desert plants.

7 Compare xerophytes and hydrophytes.

Design and discuss

8 The great desert skink (*Egernia kintorei*) is found in hot, dry regions of Australia. It is a long, slender burrowing animal that is red-brown in colour (Figure 17). These skinks are nocturnal, mainly feeding on termites at night and basking at the entrance to their burrows at sunrise. They can hibernate together during winter in an interconnected series of underground burrows where they live with a large family, often made up of at least three generations. Their main predator is feral cats.

Discuss how different types of adaptations allow the great desert skink to survive in the hot, dry desert conditions.

9 Design a concept map of a plant that is well adapted to survive in an extreme Australian environment. List the environmental factors as well as the different adaptations your plant has that ensure its survival.

10 Discuss in small groups or as a class the adaptations humans have developed over time. Consider what adaptations we might develop in the next 50–100 years.

FIGURE 17 The great desert skink of Australia (*Egernia kintorei*)

10.3 Interdependence

KEY IDEAS

In this topic, you will learn that:

- the survival of a species depends on its interactions with other species in an ecosystem
- the structure, distribution, density and size of a population can change
- the loss of a keystone species can have a disproportionate effect on many other species in an ecosystem.

ecosystem a community of interacting organisms and the physical factors that surround them

The different environments in Australia consist of **ecosystems**, each containing a diverse range of species and their physical surroundings. No organism lives completely isolated from its surroundings. Instead, its survival depends on the temperature, availability of water and light, prey, competition and predators. All organisms rely on interactions with other organisms and species in order to survive. The interactive relationship between different species for survival is called interdependence.

Types of relationships

community all the species that occupy a specific place at a specific time

The relationships between all organisms can be indicated through a food web, which represents the feeding relationships within a **community**. Food webs define the flow of energy in an ecosystem as indicated by the direction of arrows. This type of diagram allows you to identify different species that compete for the same food source. For example, Figure 1 shows that termites, kangaroos, wombats and crickets all compete for the same grass in an ecosystem. The arrows show that the energy contained in the grass moves into the animals that eat it. The diagram also allows you to predict that these animals would be affected (their populations will decrease) during a drought if the population of grass plants decreased. All of the species in the food web are interdependent on one another.

Each species in an ecosystem has a role in maintaining the balance. If one population increases, then it affects (increases or decreases) the population structure of another species.

Population structure

A population structure describes the variety of genotypes and phenotypes within a population. It can include the number of individual organisms within an area, how they are distributed throughout the area, how close together they live and the genetic make-up of the individuals in the area that they occupy.

It is important that scientists can describe the structure of a population so that they can determine how populations change over time and predict how populations are likely to change in the future.

Size

The size of a population is the number of individual organisms of the same species, living in the same area at the same time. There are many ways of calculating the size of a population, including direct observation (counting each organism individually) and indirect observation (counting a small part of the population and extrapolating the numbers to predict the total number).

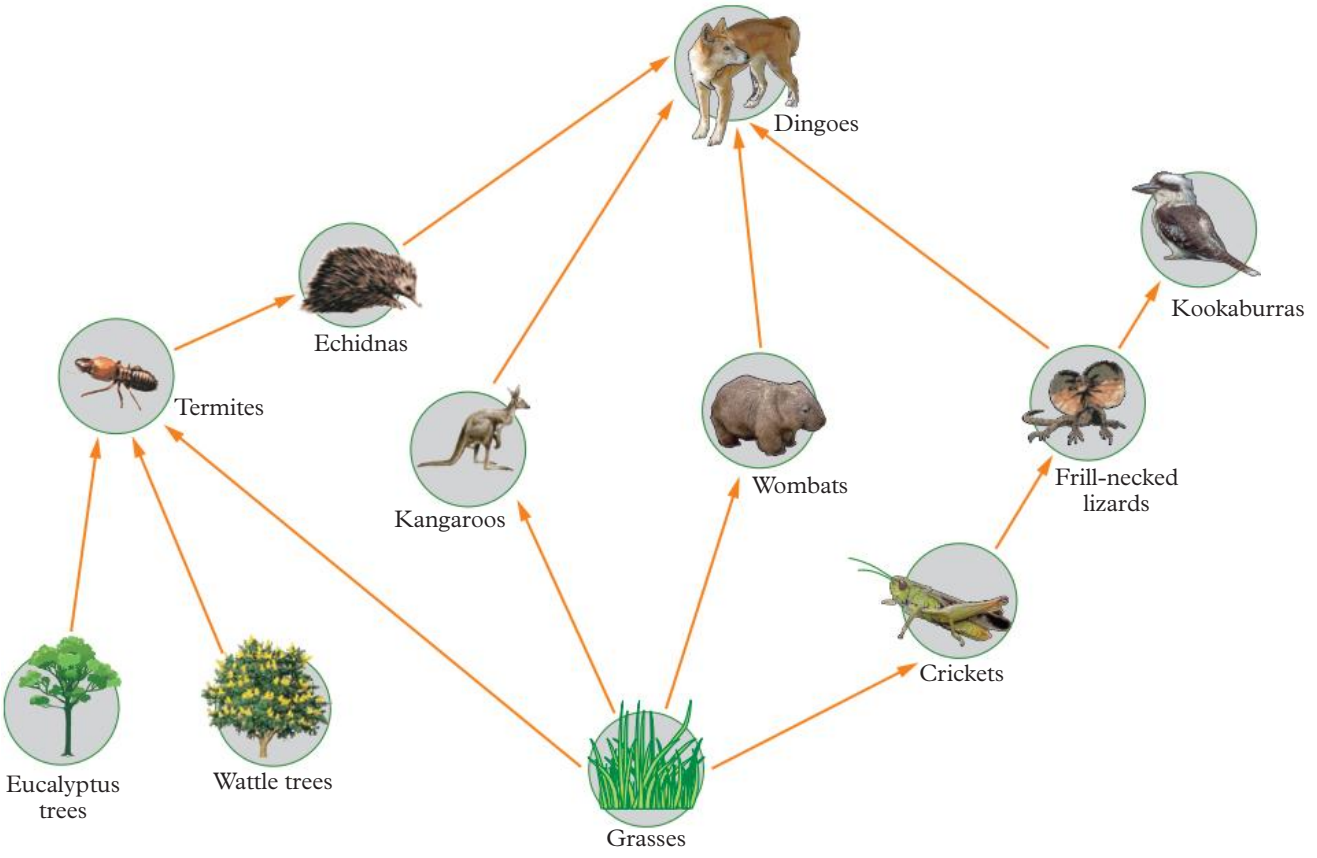


FIGURE 1 A food web shows the interdependence of organisms in an ecosystem.

Small populations are more vulnerable to changes in environmental factors. This is because small populations live close together and a single change in that area may affect all individual organisms. The International Union for Conservation of Nature regularly prepares a list of all the endangered species around the world. The Red List of Threatened Species classifies a species as endangered if there has been a 50–70% decrease in population over the last 10 years, the population lives in a geographical area less than 500 km^2 and the population contains fewer than 2500 adults.

Density

The **density** of a population is a measure of the average number of individual organisms living in a population in a given area. For example, a population of 100 Bogong moths (*Agrotis infusa*) living in an area of 10 metres by 10 metres (100 m^2) has a density of 1 moth per square metre. All populations have an optimum number of organisms that can live in an area before the amount of food, water and availability of shelter is affected. The maximum size or density of a population that is able to survive in an ecosystem is called the **carrying capacity**.

density
the average number of individual organisms living in a population in a given area

carrying capacity
the total population that can be supported by an environment

Distribution

There are many ways a population of organisms can be spread over an area. That population may be distributed evenly in a uniform manner (Figure 2), gathered together in random groups (Figure 3) or clumped together in patches (Figure 4).

distribution
the way in which members of a population are dispersed in a specific area

The **distribution** of a population may be a result of the physical surroundings in the ecosystem, such as the availability of water or nutrients. It may also be affected by the availability of shelter, food, mates or protection from predators. For example, the mountain pygmy-possum (*Burramys parvus*) is distributed in clusters at Mt Bogong to Mt Higginbotham and Mt Buller in Victoria, and Kosciuszko National Park in New South Wales. At these locations, the pygmy-possum can find food (the Bogong moth) and nesting sites, and there is enough snow cover to enable the pygmy-possum to hibernate for seven months of the year. Outside of these conditions, the pygmy-possum struggles to survive – it has reached the limit of its tolerance range.

FIGURE 2 When a population is uniformly distributed, individual organisms are evenly spaced throughout the ecosystem.

FIGURE 3 When a population is randomly distributed, an organism has an equal chance of being anywhere in an area. There is usually competition between organisms for resources.

FIGURE 4 When a population has a clumped distribution, individuals live in areas close to specific resources. These areas are separated by areas with low levels of resources.

Changes in populations

Many factors affect the structure, size, density and distribution of a species; for example, the presence of a predator. Predators are organisms that kill and eat other organisms (the prey) of another species. There are many types of predators, including dingoes, which kill and eat bush rats (Figure 5).

Predation can have a significant effect on prey populations and on the whole community of species living in the ecosystem. A predator can change the distribution of a population from uniform to clumped in sheltered areas. The introduction of a predator can also affect the size or density of more than one species in an ecosystem. This was illustrated when two dingoes hunted and killed seven foxes that were released in a 37 km^2 fenced area in the desert of South Australia. As a result, the number of small mammals in the fenced area increased significantly. This is because a higher-density fox population hunts and kills more prey than a smaller number of dingoes. Foxes also hunt smaller prey than that of dingoes. In one study of short-necked turtles (*Emydura macquarii*), a fox-controlled area lost 93% more turtle nests than a similar area controlled by dingoes. In general, a dingo-controlled area has a greater biodiversity of small mammals than a fox-controlled area (Figure 6).

FIGURE 5 The dingo is the top predator in many Australian ecosystems.

predation
when one organism kills and consumes another organism

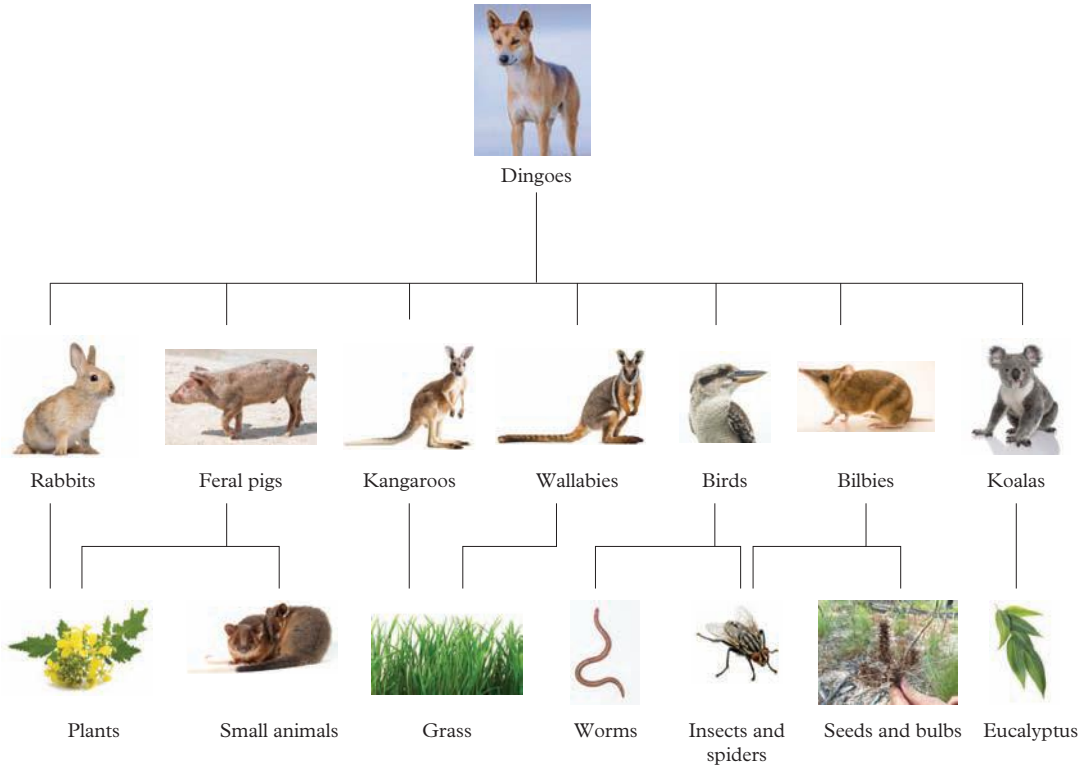


FIGURE 6 The dingo is the top predator in this food web.

When a predator moves into a new ecosystem, there is usually more than enough food for the predator. As a result, the predator has enough energy to breed and raise offspring. As the predator population increases, the size of the prey population decreases. Once the number of prey decreases, the predators start to starve and compete with each other for food. This causes the predator population to decrease. Once the prey are not being hunted by as many predators, their numbers start to increase again. This cyclic pattern of predator increase causing prey decrease, followed by predator decrease causing prey increase, is called the predator–prey interaction (Figure 7)

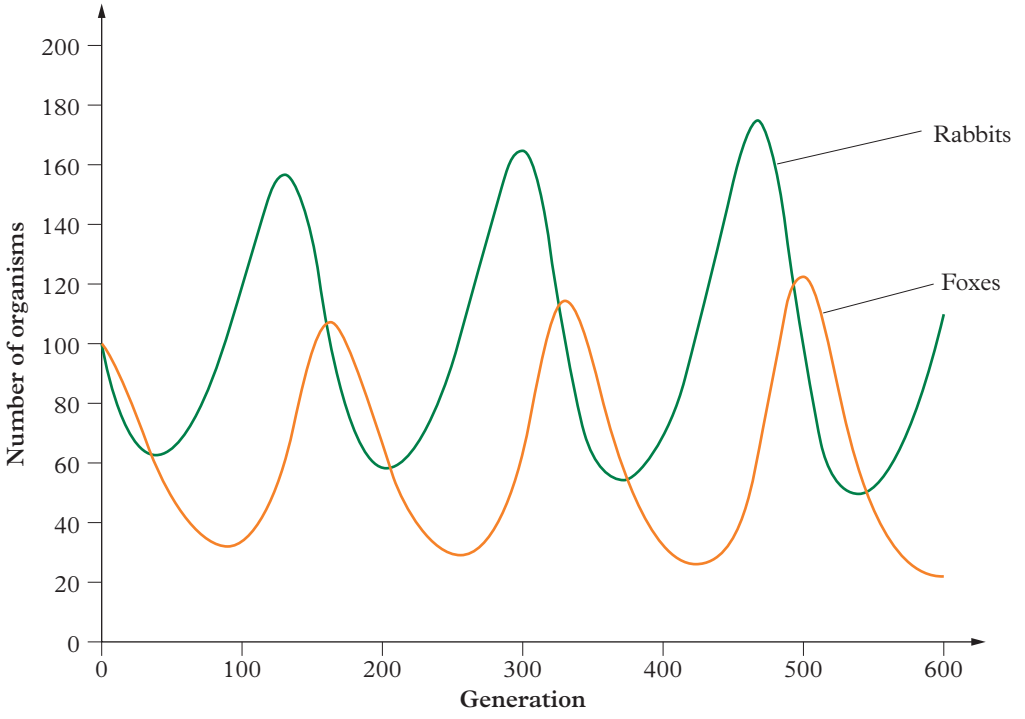


FIGURE 7 The predator–prey interaction suggests that prey numbers will always increase before predator numbers increase.

Keystone species

keystone species
a species that has a large effect on its environment and surrounding organisms

Some species, such as the dingo, have a greater effect on a food web than other species. These species are called **keystone species**. When some species are removed from a food web, other species may slightly increase or decrease in population size. When keystone species are removed from a population, it can affect the whole ecosystem. For example, if the dingoes in Figure 6 were removed, there would be a large increase in the numbers of rabbits, feral pigs, kangaroos, wallabies, birds, bilbies and koalas. This would then cause over-consumption of many insects, small animals and plant species. Therefore, the whole ecosystem would suffer from a lack of food, and many species would be lost from the area, and the biodiversity of the ecosystem would decrease.

CASE STUDY 10.3

Lights off for the Bogong moth

One of the key food sources of mountain pygmy-possums is Bogong moths (Figure 8). For 7000 years, the moths have migrated from their winter breeding grounds throughout Queensland, New South Wales and western Victoria, to the Victorian alpine region. This is especially important to the pygmy-possums because the arrival of the moths coincides with the pygmy-possums' last feed before they start hibernating for the winter. If the possums are unable to feed, they cannot hibernate effectively, meaning they use too much energy over winter when there are fewer food sources available to them.

During the spring seasons of 2017 and 2018, the number of Bogong moths making the annual migration to alpine areas decreased from approximately 4.4 billion to an almost undetectable number. This resulted in a large decline in the population of the mountain pygmy-possum. As a result, Zoos Victoria is running a campaign for Australians to turn off any unnecessary lights along the path of migrating moths each spring. Because the moths are attracted to artificial lighting, they are distracted from their migration, causing a decrease in their population size in alpine areas, resulting in the decline of the mountain pygmy-possum population.

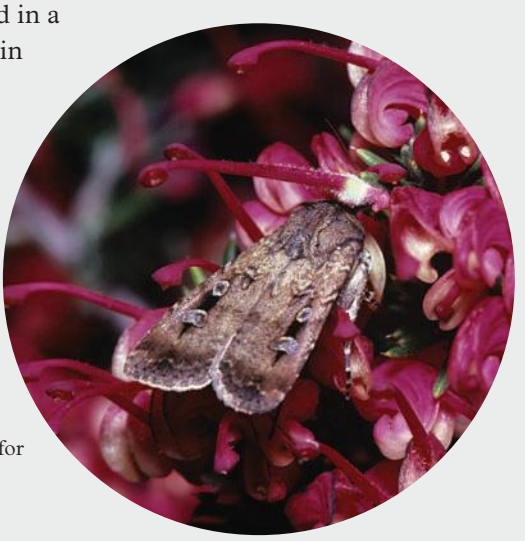


FIGURE 8 The migration of Bogong moths is essential for the survival of mountain pygmy-possums.

CHECK YOUR LEARNING 10.3

Describe and explain

1 Define 'ecosystem'.
2 Explain the difference between a population and a community.
3 Describe, using an example, what a keystone species is.

Apply, analyse and compare

4 Compare the effect of a fox and a dingo on an ecosystem.
5 In a rocky intertidal system, mussels, barnacles and seaweeds require a hard substrate to grow on. As a result, they compete for space on the rocks. Mussels are the dominant species and can out-compete all the other species within a few years. However, seastars prefer to eat mussels, which frees up space for the other organisms to grow. Identify the keystone species of this ecosystem. Use evidence to support your answer.

Design and discuss

6 Compare the population density, population size and population distribution of an animal or plant in your local area.
7 'Humans affect ecosystems by removing important predators.' Discuss this statement, providing evidence to justify whether you agree or disagree.

10.4 The first biologists

KEY IDEAS

In this topic, you will learn that:

- Aboriginal and Torres Strait Islander Peoples' knowledges and cultures involve a unique understanding of adaptations of species, and interdependencies between Australian ecosystems.

The Aboriginal and Torres Strait Islander Peoples' knowledge of the Australian landscape has developed over the last approximately 60 000 years. Much of the knowledge of the history, cultures and beliefs is passed down through the generations by oral storytelling. There are more than 700 different cultural groups in Aboriginal and Torres Strait Islander cultures that combine science and historical events to explain changes in the local landscape. Many of these stories correlate to events that occurred thousands of years ago, including the increase in sea level after the last ice age, animals that have since become extinct, floods, asteroid strikes and volcanic eruptions.

Some stories have commonalities among the different nations and others are unique to particular areas and peoples.

Stories of adaptations

Many of the creation stories that have permission to be told focus on explaining the features of the land and the adaptations of the native wildlife that lives in the area. One story of an animal adaptation is retold below.

The wallaby and the dugong

A traditional story from the Lockhart River region, on the eastern coast of Cape York, Queensland, describes how the flat-tailed wallaby and straight-tailed dugong were both unhappy with the way their tail prevented them moving effectively. As a result, they agreed to swap their tails for a short time. The dugong loved the way the flat tail allowed him to move smoothly through the water, while the strong straight tail helped the wallaby to jump high and fast across the land. They decided to keep their tails, and their children had the same tails as the parents.

This story illustrates the advantages of the structural adaptations of the two types of tails and how they were inherited across the generations.

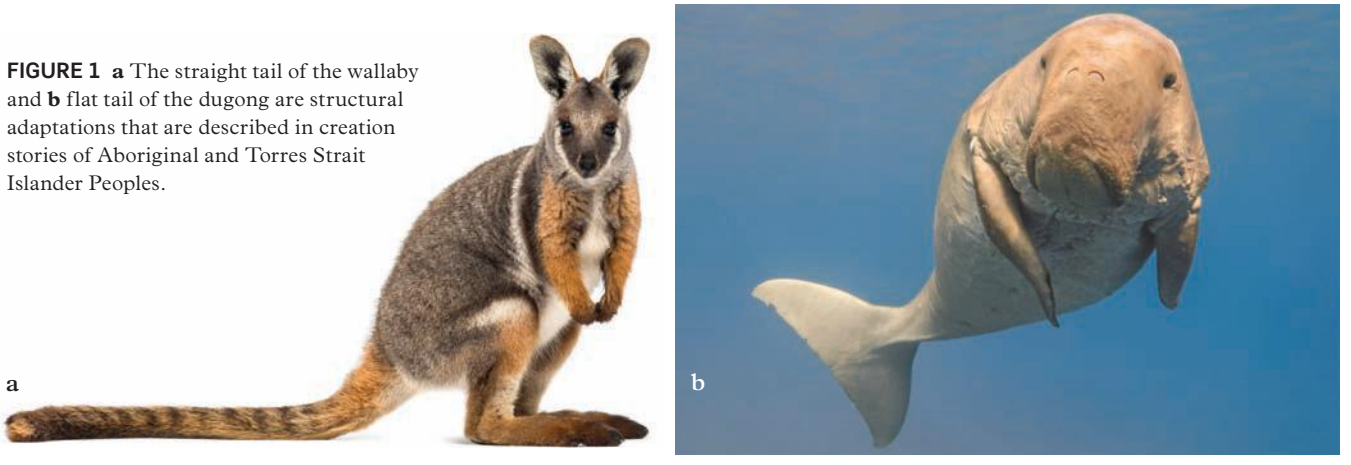


FIGURE 1 **a** The straight tail of the wallaby and **b** flat tail of the dugong are structural adaptations that are described in creation stories of Aboriginal and Torres Strait Islander Peoples.

Traditional interdependency

Aboriginal and Torres Strait Islander Peoples have long understood their interdependency with the local environment. Many practices centre on protection and sustainable harvesting, where an individual or a family only removes abundant items from the environment. Seasonal calendars are based on when and how many bird eggs can be collected, when is the best time to hunt lizards, and when and where plants can be collected.

Many local communities that live along the coast of Australia place their shells or fish remains into middens. These heaps of shells and bones allow the soil to aerate and the calcium protects the soil from salinity. The middens also provide a history of the foods that are gathered. If the remains of one type of organism dominate the top of the pile, then the group will farm another species for their next meal. These practices provide evidence of an understanding of the interconnectedness of land, plants and animals, where predation of a single population can upset the balance between all species. These middens have also been vital to providing evidence of how long Aboriginal and Torres Strait Islander Peoples have been living on this land.

Study tip

Make sure you have the permission of local Aboriginal and Torres Strait Islander Peoples before you start telling their stories.

Firestick farming

Aboriginal and Torres Strait Islander communities work with fire to help regenerate the local environment. The Martu are the Indigenous owners of land in Australia's Western Desert. They have been observing the effects of fire on plant and land populations for many generations. They claim that burning the local plants and woodlands in the cool, damp months helps to grow more food for the local animals, including the hopping mouse, emu, red kangaroo and hill kangaroo. This approach is called firestick farming because burning small areas during winter has been shown to remove established vegetation in some spaces while maintaining the mature plants in other areas. This produces a mosaic pattern of old established vegetation together with new greener grasses. The new growth is attractive to small foraging animals that are native to the area, while maintaining established shelters. The result is a clumping distribution of old and new growth containing a greater variety of species. The overall effect is an increase in biodiversity, which benefits all livings things that rely on the ecosystem to survive.

CHECK YOUR LEARNING 10.4

Describe and explain

1 Explain your understanding of 'interdependence'.
2 Describe the advantage of the structural adaptations in the story of the dugong and the wallaby.
3 Describe the location of the Torres Strait Islands.

Apply, analyse and compare

4 Compare a midden and a European rubbish tip.
5 Compare firestick farming and more modern burning-off methods.

Design and discuss

6 Discuss the impact of firestick farming on a bushland area near your school.

CHAPTER 10

Review

Chapter summary

10.1
- Genetic diversity is important for increasing a species' survival. For example, it allows a species to withstand diseases.
- There are many different ecosystems in Australia for which different species need adaptations to survive.

10.2
- The greater the variety of physical characteristics (as determined by the genotype) in a species, the more likely it is that a single individual will be able to respond to change and therefore survive and pass their genes on to the next generation.
- Structural adaptations are physical changes in a species that increase its chances of survival; for example, webbed feet for more effective swimming.
- Behavioural adaptations are ways of acting that increase an organism's chances of survival.
- Physiological adaptations are ways of regulating or producing products that increase an organism's chances of survival; for example, camouflage.
- Plants respond to changes in the environment, including through tropisms.

10.3
- Within an ecosystem, species can be predators or prey.
- A population's size, density and distribution can change.
- Keystone species are very important to an ecosystem. If they are lost, it can dramatically increase and decrease the populations of other species.

10.4
- Aboriginal and Torres Strait Islander Peoples' knowledge of the land has provided strong understandings of adaptations and interdependencies between different species in Australia.

Revision questions

Multiple choice

1 Venom production is a:
- **A** structural adaptation
- **B** behavioural adaptation
- **C** physiological adaptation
- **D** nastic response.

2 A plant with large, broad leaves with waxy cuticles would be found in:
- **A** tropical rainforests
- **B** sandy deserts
- **C** grasslands
- **D** none of the above.

3 Stomata are:
- **A** cells that control the entry and exit of gases into and out of a leaf
- **B** cells containing large numbers of chloroplasts for photosynthesis
- **C** pores that gases move through to enter and exit a leaf
- **D** found within chloroplasts and contain chlorophyll for photosynthesis.

4 Panting enables animals to:
- **A** remove excess water by transpiration
- **B** conserve heat by evaporative cooling
- **C** release heat by evaporative cooling
- **D** conserve water by transpiration.

5 Having a small body with a large surface area to volume ratio is essential for:
- **A** reducing heat loss in a cold, windy environment
- **B** conserving water in a hot, dry environment
- **C** increasing heat loss in a hot, dry environment
- **D** conserving water in a cold, windy environment.

6 Kangaroos often lie in the shade during the day. This is an example of a:
- **A** structural adaptation
- **B** behavioural adaptation
- **C** physiological adaptation
- **D** functional adaptation.

7 When kangaroos lie in the shade they:
- **A** increase heat loss by evaporation
- **B** increase heat loss from the wind
- **C** reduce heat gain from the Sun
- **D** increase heat gain from the ground.

8 The distribution of the camels in Figure 1 could be described as:

FIGURE 1 Distribution of the camels

- **A** uniform
- **B** clumping
- **C** random
- **D** organised.

9 A keystone species:
- **A** is always a predator
- **B** has a disproportionate effect on other species in an ecosystem
- **C** is a small organism that affects an ecosystem
- **D** supplies the energy for the rest of the ecosystem.

10 The Venus fly trap can close rapidly in order to trap prey. This is an example of a:
- **A** tropism
- **B** nastic response
- **C** plant behaviour
- **D** photosynthetic response.

Short answer

Describe and explain

11 Explain the importance of genetic diversity in a population.

12 Define the following terms and give an example of each.

- **a** Structural adaptation
- **b** Physiological adaptation
- **c** Behavioural adaptation

13 Explain why plant movements are described as responses rather than behavioural adaptations.

14 Explain why high genetic diversity within a species helps the survival of a population.

15 Explain what is meant by 'interdependencies between species'.

16 Define 'keystone species'.

17 Explain the importance of a keystone species to an ecosystem.

18 Describe one way in which an Aboriginal and Torres Strait Islander culture (or cultures) demonstrates an understanding of interdependencies in Australian ecosystems.

19 Contrast the terms 'distribution', 'density' and 'size' when describing a population.

Apply, analyse and compare

20 The frill-necked lizard (*Chlamydosaurus kingii*) has an extra flap of skin around its next to make it look larger when frightened (Figure 2). Explain the survival advantage of such an adaptation.

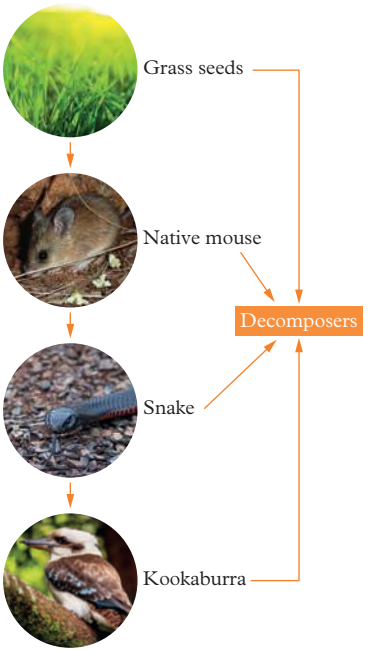
FIGURE 2 The frill-necked lizard (*Chlamydosaurus kingii*)

21 The Australian masked owl (*Tyto novaehollandiae*) lives in areas with trees and a shrub understorey. The owls are nocturnal and their prey includes rodents, possums, bandicoots, reptiles and insects. Most of their prey is caught on the ground or in trees. The population of the Australian masked owl is listed as threatened in Victoria. Use your understanding of food webs to explain how the population may be supported in the future.

22 The root systems of freshwater plants are often very small or even non-existent. Suggest a reason for this adaptation.

23 Being nocturnal is a common adaptation of animals in hot, dry environments. Create a table outlining the advantages and disadvantages of being active during the day compared with being active at night in the desert.

24 Use the food chain in Figure 3 to identify how the kookaburra will be affected during a drought.



Note: The direction of the arrows indicates 'eaten by' = direction of energy flow

FIGURE 3 A food chain

25 The graph in Figure 4 records the population size of a predator and its prey.
   - **a** Identify which species (A or B) is the predator and which is the prey.
   - **b** Use the data to explain trends in the increase and decrease in population numbers of both species over time.
   - **c** Predict what would happen if species A was removed from the ecosystem.

Design and discuss

26 Create a diagram that outlines three physiological adaptations of a human and their individual survival advantages.

27 Research Australian mangroves and discuss how different adaptations enable it to survive in a high salt environment.

28 Phototropism refers to the change in a plant's position in response to light. Design an experiment that could be used to test if a plant species has the ability to bend towards light.
   - **a** Identify an aim for the experiment.
   - **b** Identify the dependent and independent variables for the experiment.
   - **c** Identify at least two controlled variables.
   - **d** Write a hypothesis for the experiment.
   - **e** Outline a method for the experiment. (Remember to make sure that your method produces reliable data and can be reproduced).
   - **f** Identify two risks for your experiment and how you could mitigate or remove them to ensure participant safety.

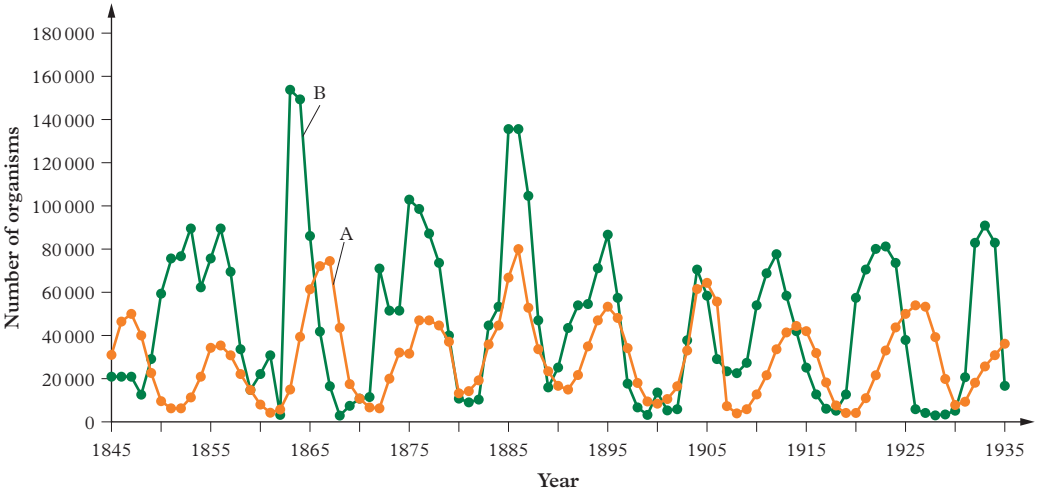


FIGURE 4 A graph of predator–prey interactions

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Exam essentials

Responding to questions

During Units 1 & 2 Biology, you can prepare yourself for success in Units 3 & 4 by learning how to respond to questions effectively. For example, in your assessments you may be expected to design experiments to test a hypothesis.

Describe the variables when designing experiments

For experiment design questions, you will most likely need to describe the independent and dependent variables. It is important to plan out your response before writing and use the mark allocation and answer space as a guide to the level of depth required.

QUESTION 4a (2009 Biology Written Examination 1)

The beet caterpillar is an insect pest of the tomato plant. When a beet caterpillar starts to eat a tomato plant, the plant responds by producing a chemical known as jasmonic acid. Jasmonic acid and its derivatives have a variety of odours. Some scientists have suggested that these odours attract wasps to the caterpillar-affected plants.

a i Outline an experiment you would carry out to test this hypothesis. 2 marks

Source: 2009 Biology Written Examination 1, Question 4a, Short answer, reproduced by permission © VCAA

Response 1

Set-up: get two large groups of tomato plants (three or more in each group) that are the same species, height and age and place them into two separate containers. In one of the containers, also place the beet caterpillar; the other tomato container is unaffected. Keep all other environmental factors the same (e.g. temperature, humidity, light availability). After 24 hours, release the wasps into the containers and observe their behaviour.
Independent variable: the presence of beet caterpillar
Dependent variable: the attraction of wasps to caterpillar-affected plants

Includes a control group for the experiment, and outlines controlled variables.

The variables are specified.

This response would receive full marks. It has been planned out and clearly states the experimental set-up and variables. The controlled variables are also included in the description of the set-up.

Response 2

Get two tomato plants and let the caterpillar eat one and not the other. Then observe the wasps to see if they are attracted to the plants.

This description is vague, and there is no mention of how variables will be controlled.

This response would not receive any marks for several reasons: the independent and dependent variables are not clear, the sample size (two plants) and no further trials means it is not a fair test, and controlled variables have not been considered.

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the response.

Question 9b (2013 Biology Written Examination)

Eighteen brush-tailed rock wallabies were released into the Grampians in late 2012. The wallabies had been bred in captivity in zoos and nature reserves in Victoria, South Australia, New South Wales and the Australian Capital Territory. Care was taken to ensure that the gene pool of the released wallabies was as diverse as possible.

b i What is a gene pool? 1 mark

The genes present in a species.

ii Using your knowledge of natural selection, explain why it is an advantage to have a diverse gene pool among the released wallabies. 1 mark

A diverse gene pool is necessary for the wallabies to be able to breed with each other.

Source: 2013 Biology Written Examination, Question 9b, Short answer, reproduced by permission © VCAA

Marking guide

9bi	1 mark for describing a gene pool being the complete set of alleles for a population.
9bii	1 mark for explaining that diversity produces a variety of phenotypes and if the environment changes, there is an increased chance of survival of the population.

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 an examiner.

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Area of Study 3

Student-designed scientific investigation

On completion of Units 1 & 2 of this course, your knowledge of the outcomes for each unit will be assessed. The types of assessments teachers can set are outlined in your toolkit. The final assessment for each unit includes a student-adapted or designed investigation. Below is a step-by-step approach to completing your own student investigation. This skill will help you complete your final internal Units 3 & 4 assessment, if you do this course next year.

A student-designed scientific investigation involves using science skills (stating an aim, formulating a hypothesis, and planning and carrying out a controlled experiment) to answer a science question based on your biological knowledge. Your investigation could involve extending an experiment from Unit 1 or 2 to examine new factors, or you could develop a new experiment for yourself.

Use a logbook to record the details and date of each step in your investigation.

Step 1: Ask a scientific question

Consider the topics and experiments that you have done throughout the year. Did you have any questions that remain unanswered? Could you modify a prior experiment to answer that question?

It is important to phrase your question carefully. For example, the question 'How does the phloem affect plant growth?' cannot be answered because you will not be able to examine all the tissues that help plants grow. A better question might be 'Does the size of the phloem cause an increase in the dispersal of sugar throughout the plant?' The second question will help in the design of the experiment.

Step 2: Develop a valid, reproducible test

Most experiments need a reliable, reproducible test as the basis. You will have used a variety of these tests during your Biology course. These may include:

- comparing surface area to volume ratios
- identifying different plant cells
- determining osmotic balance
- identifying the stages of mitosis
- demonstrating the movement of water in a plant
- modelling the process of meiosis
- modelling the effect of environmental factors on inheritance
- modelling the process of reproductive cloning
- observing the adaptation of germinating seeds.

There are many variables in these tests that can become a new independent variable. Changing this variable could affect the results (the dependent variable) of the test. For example, changing the direction of sunlight could affect the direction of plant growth, or changing the environmental factors of a human could affect the different types of alleles inherited. For each of these tests, you will need to check that they will answer the original question that you asked in step 1.

If you are using a new test, you will need to repeat the test (unchanged) three or more times to check that the results are reliable and reproducible.

Step 3: Form a hypothesis

Once you have a reliable test, and a variable you want to change (independent variable), you will need to form a hypothesis. A hypothesis is a statement that can be tested experimentally. There are two parts to the hypothesis:

- how the independent variable will change the dependent variable
- the scientific reason why this will occur.

This can be written as:

If the dependent variable is affected by the independent variable, then the dependent variable will increase/decrease when the independent variable is increased or decreased.

Step 4: Design a controlled experiment

When designing your experiment, you will need to consider all the factors that could affect the outcome. Using the reliable test from step 2 will limit these factors. Consider all the possible sources of error. How will you improve your accuracy? (i.e. What equipment will you need to calibrate?) How could you improve your precision? (i.e. How big will your sample size be? How many times will you repeat your experiment?) Copy the diagram in Figure 1 into your logbook and complete the details.

Step 5: Record the results of your experiment

Make sure you record any changes that you made to your original test. Record the amounts and concentrations of each material that you use, and the steps you took to minimise any errors. Include the results of every part of the experiment, both quantitative (numbers) and qualitative (descriptions) in your logbook. Your final poster might not include all these details, but it is useful to have them just in case. Draw up tables for your data. A sample results table is shown in Figure 2.

Identify any outliers (measurements that are very different from the other data points) and attempt to explain them.

Draw a graph to show the relationship between the independent variable and the dependent variable. Refer to your Biology Toolkit for graphing tips.

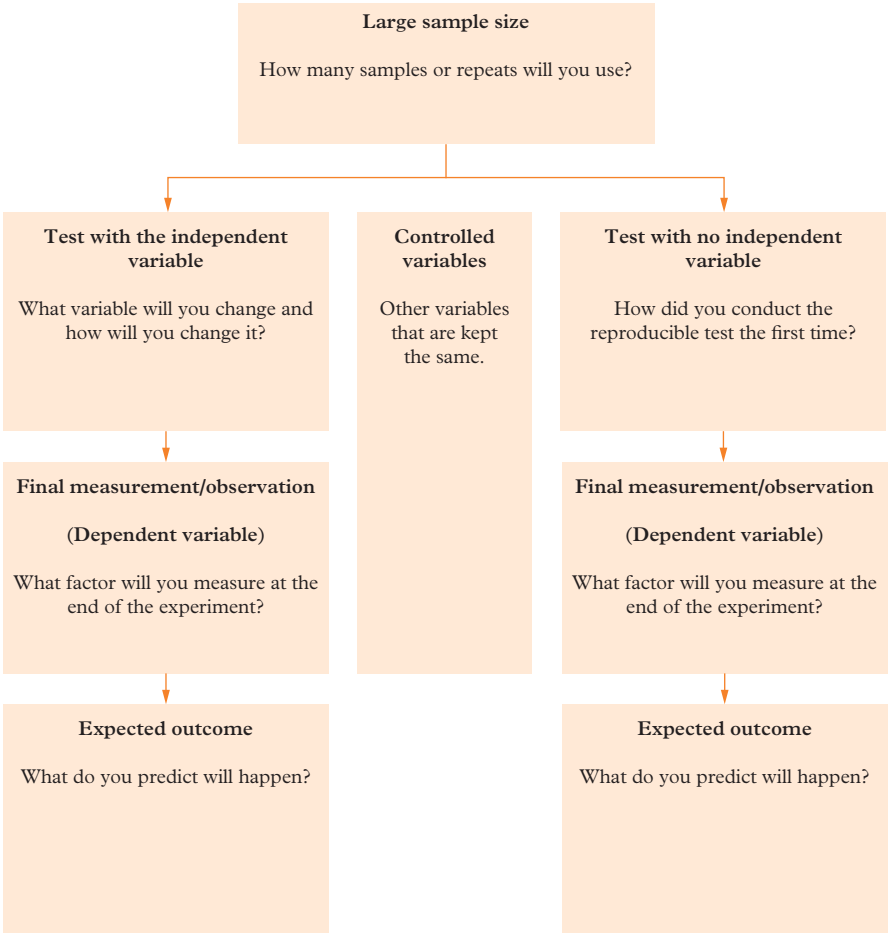

FIGURE 1 Complete this diagram when designing your experiment.

Table 1 Average change in temperature of test tube when placed in a water bath for 5 minutes

Consistent significant figures within each column

Headings given with units

Temperature ± 1 (°C)	Resistance heating (Ω)	Resistance cooling (Ω)	Mean resistance (Ω)	Absolute uncertainty (Ω)
10	4.89	5.05	4.97	0.08
20	5.12	5.24	5.18	0.06
30	5.26	5.34	5.30	0.04
40	5.40	5.60	5.50	0.10
50	5.62	5.80	5.71	0.09
60	5.80	6.00	5.90	0.10
70	5.97	6.13	6.05	0.08
80	6.19	6.31	6.25	0.06

Systematic presentation

All raw data to the resolution of the instruments used

Processed data to the same number of significant figures as the raw data

Uncertainty to a maximum of 1 or 2 significant figures

FIGURE 2 An example of a results table

Step 6: Discuss your results

This section is a chance to make a connection between your results, the biological concepts you have studied and the scientific question that you asked. In this section, you should answer the following questions.

- Do you have enough data to answer your question? Is this a limitation of your experiment?
- Is there any relationship between the independent variable and the dependent variable?
- Is there a conclusion to be made about the relationship between the independent variable and the dependent variable?
- Does the data support the hypothesis?
- How do your results compare with the biological concepts that you have learnt?
- How would your results apply in the real world?
- Have any further questions arisen as a result of your experiment?

Step 7: Present your work

Refer to your Biology Toolkit (Chapter 1) and *Biology for VCE Units 1 & 2 Student Workbook* for tips on how to present your investigation through a poster, report, multi-modal presentation, article or visual display.

TABLE 2 Assessment rubric

Component	Content requirement	Mark allocations (X/40)
Title	Question under investigation	
Introduction	Brief explanation or reason for undertaking the investigation, including a clear aim, a hypothesis and/or prediction and relevant background biological concepts	
Methodology and methods	Brief outline of the selected methodology used to address the investigation question	
	Summary of data generation method/s and data analysis method/s	
Results	Presentation of generated data/evidence in appropriate format to illustrate trends, patterns and/or relationships	
Discussion	Interpretation and evaluation of analysed primary data	
	Identification of limitations in data and methods, and suggested improvements	
	Cross-referencing of results to relevant biological concepts	
	Linking of results to investigation question and to the aim to explain whether or not the investigation data and findings support the hypothesis	
	Implications of the investigation and/or suggestions as to further investigations that may be undertaken	
Conclusion	Conclusion that provides a response to the investigation question	
	Identification of the extent to which the analysis has answered the investigation question, with no new information being introduced	
References and acknowledgements	Referencing and acknowledgement of all quotations and sourced content relevant to the investigation	
Logbook	Students record in their logbooks all elements of their investigation planning, comprising identification and management of relevant risks, recording of raw data, and preliminary analysis and evaluation of results, including identification of outliers and their subsequent treatment.	

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UNIT 2

Practice exam questions

Multiple choice **(Total = 10 marks, 1 mark per question)**

1 An example of symbols to represent alleles is:
- **A** AB and Tt
- **B** TT and Tt
- **C** T and t
- **D** X and Y.

2 Identify which of the following can be used to identify homologous chromosomes.
- **A** The loci of genes
- **B** The location of the chiasma
- **C** The number of chromosomes
- **D** Their connection at the centromere

3 The diploid number of chromosomes in a female mouse is 40. It is reasonable to suggest that in the mouse:
- **A** the chromosomes exist as homologous pairs
- **B** a skin cell will contain 20 chromosomes
- **C** at the end of meiosis, there would be 40 chromosomes in each cell
- **D** during mitosis, there would be 20 chromosomes.

4 In mice, the gene for hair colour could be black (B) or brown (b), and the gene for hair length could be short (L) or long (l). Both these genes assort independently.

When a mouse with short black hair was crossed with a mouse with long brown hair, 50% of the offspring had short hair and 50% of the offspring had black hair.

The genotype of the parent mouse with short black hair was:
- **A** LLBB
- **B** LLBb
- **C** LlBB
- **D** LlBb.

5 Human blood type is determined by co-dominant alleles. There are three alleles: I^A, I^B and i. The I^A and I^B alleles are co-dominant and the I allele is recessive. The possible blood types are A (either I^AI^A or I^Ai), B (either I^BI^B or I^Bi), AB (either I^AI^B) and O (ii).

A woman with type A blood and a man with type B blood could potentially have offspring with which of the following blood types?
- **A** Type A and type B
- **B** Type B only
- **C** Type AB only
- **D** Any blood type

6 Sex-linked genetically inherited traits:
- **A** can appear in both males and females
- **B** are only found in males
- **C** are only found in females
- **D** are only found on the X chromosome.

7 Consider the pedigree chart in Figure 1.

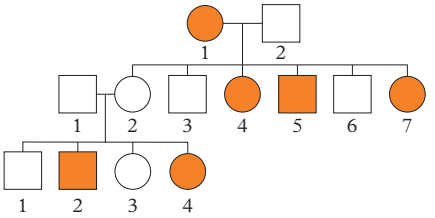


FIGURE 1 A pedigree chart

The type of inheritance shown in Figure 3 is:
- **A** autosomal dominant
- **B** autosomal recessive
- **C** X-linked dominant
- **D** X-linked recessive.

8 Identify which of the following genotypes you would not expect to find among the offspring of a Gg test cross.

A GG
B Gg
C gg
D GG and Gg

9 The gametes of a plant with the genotype DdBb should have the genotype:

A Dd and Bb
B DB and db
C Db, DB, db and dB
D Dd, Bb, DB and db.

10 A species that other species in an ecosystem largely depend on, and whose removal would negatively affect the whole ecosystem is called a:

A predator species
B keystone species
C prey species
D parasitic species.

Short answer (Total = 20 marks)

QUESTION 11 (5 marks)

The chromosomes were removed from a cell undergoing metaphase of mitosis before being collated and photographed (Figure 2).

a The arrangement of chromosomes was identified as atypical. Suggest a reason for this observation. 1 mark

b Explain how an error during meiosis could result in the arrangement of chromosomes found in this person. 4 marks

QUESTION 12 (7 marks)

Interphase is part of the cell cycle.

a Describe what occurs during the S phase of meiosis. 1 mark

b Name the phase in meiosis where crossing over occurs. 1 mark

c Name the phase in meiosis where the sister chromatids separate at the centromere. 1 mark

d Describe why crossing over and independent assortment are important for the survival of a species. 4 marks

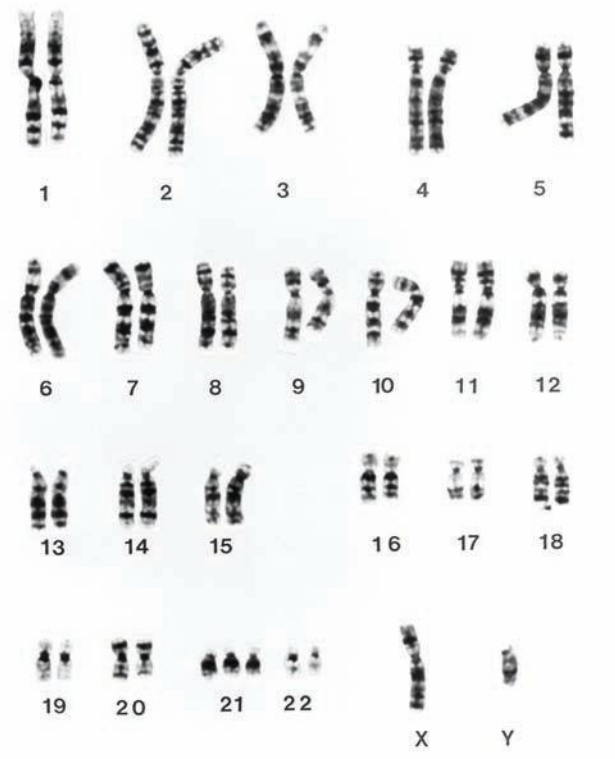


FIGURE 2 A karyotype

QUESTION 13 (4 marks)

Figure 3 illustrates the process of reproductive cloning that was used to produce the first cloned sheep (Matilda) in Australia in 2000.

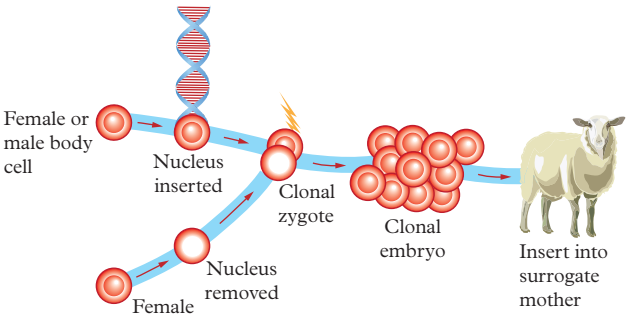


FIGURE 3 The cloning process that produced the first cloned sheep in Australia

a Define 'clone'. 1 mark

b Describe one advantage of reproductive cloning. 1 mark

c Describe one disadvantage of reproductive cloning. 1 mark

d Compare the expected reactions and behaviour of Matilda the sheep to that of her genetic parent. Justify your answer. 1 mark

QUESTION 14 (4 marks)

In the early 1920s, the US government encouraged the hunting and extermination of the grey wolf in Yellowstone National Park. A food web of the organisms living in the park is shown in Figure 4. Although the coyotes can eat the larger elk, this usually only occurs when an elk is sick or injured.

a Describe the expected impact on the size and density of the elk population as a result of the extermination of the grey wolf. 1 mark

b The elk like to eat the young aspen and willow trees in the park. These trees provide shelter for birds and prevent erosion of nearby streams and rivers.

Describe how the change in elk population would affect the: 3 marks

i fruit density

ii biodiversity of bird population

iii coyote population.

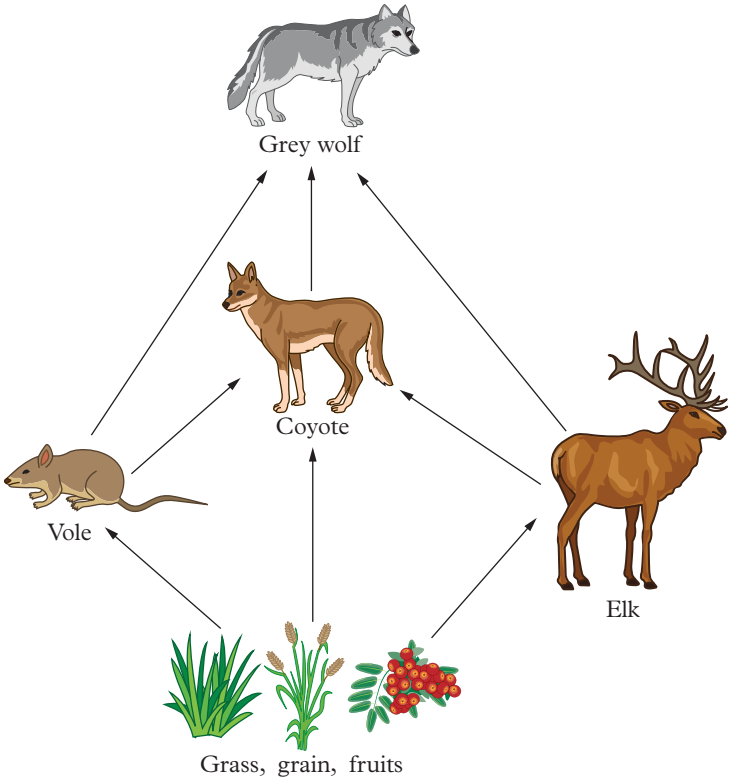


FIGURE 4 A Yellowstone National Park food web

UNITS 1 & 2

Practice exam questions

Multiple choice **(Total = 20 marks, 1 mark per question)**

1 A cell that does not contain a nucleus is most likely to be a:
- **A** fungal cell
- **B** bacterial cell
- **C** plant cell
- **D** animal cell.

2 Skeletal muscle cells use a lot of energy (ATP) to help the movement of bones. Identify which of the following statements about skeletal muscle cells is correct.
- **A** Muscle cells need many mitochondria for photosynthesis.
- **B** Muscle cells need a lot of glucose for cellular respiration.
- **C** Muscle cells need large vacuoles to store ATP.
- **D** Muscle cells need a cell wall to provide support for movement.

3 Glucose is a large molecule that requires a protein channel to move passively through a cell membrane. This is an example of:
- **A** osmosis
- **B** facilitated transport
- **C** active transport
- **D** diffusion.

4 Identify which of the images shown in Figure 1 represents a cell in metaphase.
- **A** Cell A
- **B** Cell B
- **C** Cell C
- **D** Cell D

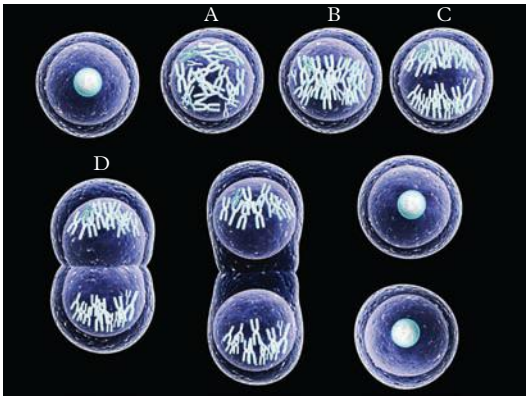


FIGURE 1 The different stages of mitosis

5 During which stage of mitosis do the centromeres split?
- **A** Prophase
- **B** Interphase
- **C** Anaphase
- **D** Metaphase

6 The loss of water from the leaves of a plant is called:
- **A** osmosis
- **B** translocation
- **C** condensation
- **D** transpiration.

7 The main function of xylem tissue is:
- **A** protecting a plant from disease
- **B** transporting water from the leaves to the roots
- **C** transporting water from the roots to the leaves
- **D** transporting glucose from the roots to the leaves.

8 Figure 2 illustrates the movement of water through a plant. Identify what is happening at each stage.

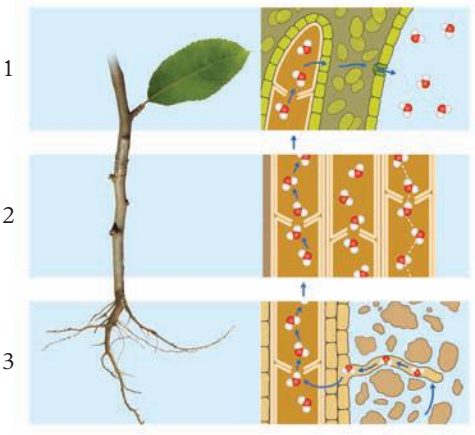


FIGURE 2 The movement of water through a plant

	Stage 1	Stage 2	Stage 3
A	Water molecules are sticking together	Osmosis causes water to move	Evaporation of water
B	Evaporation of water	Water molecules are sticking together	Osmosis causes water to move
C	Evaporation of water	Osmosis causes water to move	Water molecules are sticking together
D	Osmosis causes water to move	Evaporation of water	Water molecules are sticking together

9 Identify which of the following features helps absorption in the digestive system.

A The large surface area to volume ratio of the villi

B The nephron capsule in the kidney

C The beta cells in the pancreas

D Physical digestion by the teeth and tongue

10 A student decided to test their blood glucose levels after eating a slice of cake. They found that their blood glucose levels went up and then returned to normal. Identify the statement that best describes what had occurred.

A The student's pancreas released glucagon, which caused glucose to be released from the liver.

B The student's pancreas released insulin, which caused glucose to be absorbed into the liver.

C The glucose was excreted in the student's urine.

D The student's muscles released stored glycogen.

11 Hyperthyroidism can cause:

A a decrease in sweating

B weight gain

C increased blood sugar levels

D weight loss.

12 Identify the statement that gives information about the phenotype but not the genotype.

A XY

B TtHH

C A tall pea plant

D A female carrier for red-green colour blindness

13 Consider the karyotype in Figure 3.

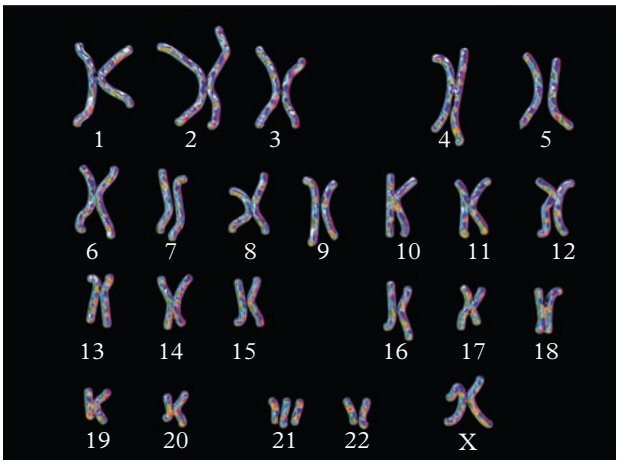


FIGURE 3 A karyotype of an individual

The karyotype shown is a:

A male with Down syndrome

B female with Down syndrome

C normal male

D normal female.

14 Identify when replication of DNA occurs in the formation of gametes.

A Interphase

B Prophase

C Metaphase

D Anaphase

15 An oak tree with 14 chromosomes undergoes meiosis to produce pollen and ova. Determine the number of chromosomes that are in the fertilised ova.

A 7

B 14

C 21

D 28

16 Identify the stage of meiosis where independent assortment occurs.

A Metaphase I

B Anaphase I

C Metaphase II

D Anaphase II

17 Asexual reproduction evolved before sexual reproduction. Over time, sexual reproduction has become the most common form of reproduction in animals. Identify which of the following is a plausible reason for this.

A Sexual reproduction produces novel genotypes through genetic recombination.

B Sexual reproduction prevents the transmission of genetic mutations.

C Sexual reproduction provides a way to have two parents to raise offspring.

D Sexual reproduction prevents overpopulation of an ecosystem by a single species.

18 Mendel noted the genetic traits of seeds as:

L = long, l = short

W = wrinkled, w = smooth

Y = yellow, y = white

R = ribbed, r = grooved

The genotype of a short, wrinkled, yellow, grooved seed is:

A llWwyyrr

B LLWWyYRr

C LlWwYYRr

D llWwYYrr.

19 In pea plants, a single gene determines the height of a plant. The allele for tall plants is an incompletely dominant trait. Calculate the result of crossing two plants that are heterozygous for this trait.

A 25% tall, 50% intermediate height, 25% short

B 50% tall, 25% intermediate height, 25% short

C 25% tall, 25% intermediate height, 50% short

D 100% intermediate height

20 Some mother rats are more attentive to their offspring than others. Rat pups that receive more attention (grooming) during their first week of life are more likely to grow up to be happy and calm than those pups who are ignored. Ignored pups are also more prone to disease. This is an example of:

A genetic inheritance

B epigenetic factors

C phenotypic changes

D genotypic changes.

Short answer **(Total = 40 marks)**

QUESTION 21 (10 marks)

a Define 'prokaryotic cell'. 1 mark

b Describe two similarities between a prokaryotic cell and a eukaryotic cell. 2 marks

c Describe the difference between the genetic material in a prokaryote and a eukaryote. 2 marks

d Use surface area to volume ratios to explain why a prokaryotic cell needs to be small. 2 marks

e **i** Name the process shown in Figure 4. 1 mark

ii Describe one advantage and one disadvantage of cell division in prokaryotes. 2 marks

FIGURE 4 What process is shown?

QUESTION 22 (5 marks)

A fertilised cell can take 5 days to develop into a blastocyst (Figure 5).

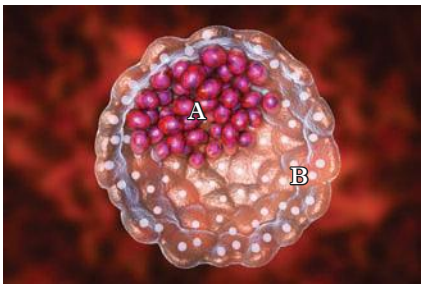


FIGURE 5 A blastocyst

a Identify which part of the labelled cell (A or B) would be pluripotent. 1 mark

b Define 'pluripotent'. 1 mark

c Induced pluripotent cells are adult stem cells that have been genetically reprogrammed so that they can become any cell in the body (except placental cells). Researchers are currently investigating whether these cells can be used to replace damaged cells in the brains of people with Parkinson's disease or skin burns.

i Describe how induced pluripotent stem cells are different from the pluripotent stem cells in the blastocyst. 1 mark

ii Suggest why some people might prefer induced pluripotent stem cells to be used than the cells from the blastocyst. 2 marks

QUESTION 23 (6 marks)

When the body needs to conserve water, the hypothalamus sends a message to the pituitary gland to release antidiuretic hormone (ADH) into the bloodstream. ADH binds to receptors in the kidney, causing the kidney to reabsorb more water. This causes the volume of the blood to increase again, which slows the release of ADH.

a Name this type of regulation. 1 mark

b Describe the stimulus for this regulation. 1 mark

c Alcohol can decrease the amount of ADH produced. Describe how the consumption of alcohol can result in dehydration. 4 marks

QUESTION 24 (4 marks)

The pedigree in Figure 6 represents the ancestry of a person with ocular albinism. This disorder causes a lack of pigmentation in the eye.

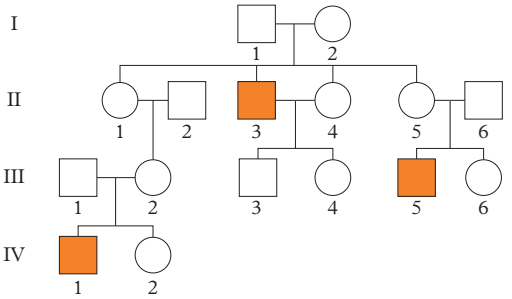


FIGURE 6 A pedigree chart

a Explain what the circles and squares represent in a pedigree chart. 2 marks

b With reference to Figure 6, explain why the trait for ocular albinism cannot be:

i dominant 1 mark

ii autosomal recessive. 1 mark

QUESTION 25 (6 marks)

Two unlinked genes affect the colour of mouse hair. CC or Cc mice are agouti (light and dark shades of colour on each hair), whereas mice with the genotype cc are albino because all the pigment production is blocked. At the second locus, the B allele (black agouti) is dominant to the b allele (brown agouti).

A mouse with a black agouti coat is mated with an albino mouse (bbcc). Half the offspring are albino, a quarter are black agouti and a quarter are brown agouti.

a Identify the genotype of the black agouti parent. 1 mark

b Identify the genotype of the black agouti offspring. 1 mark

c Identify the possible genotypes of the gametes of a mouse that was heterozygous for both traits. 4 marks

QUESTION 26 (3 marks)

A study compared how cattle, sheep and camels coped in a desert environment (42°C). The average amount of water lost from the animals' bodies each day was calculated (Table 1).

TABLE 1 Water loss from the bodies of different animals

Animal	Water lost from body each day (%)
Cattle	6–8
Sheep	4–5
Camel	1–2

a From the information provided, explain which animal will survive the longest at 42°C. 1 mark

b These animals are mammals and can sweat to cool down. Suggest one other physiological adaptation that would enable these animals to lower their body temperatures. 1 mark

c In another study of dogs in similar environments, it was found that panting was an effective way to increase evaporative cooling. Describe one advantage to the dogs of panting rather than sweating. 1 mark

QUESTION 27 (6 marks)

Southern cassowaries are large birds that live in the Daintree rainforest. They eat a diverse range of fruits, as well as small vertebrates (e.g. snails, frogs and eggs), invertebrates, fungi and carrion. They have been recorded as eating more than 238 species of plants. The cassowaries swallow the fruit whole, digest the pulp and pass the seeds in large piles of dung over a wide area.

Because of their widespread effect on the ecosystem, cassowaries are described as a keystone species.

a Describe a keystone species. 1 mark

b The size of the cassowary population is affected by their need for a wide territory. Each cassowary needs 300 square hectares of rainforest habitat to survive. Describe how population size is affected by the expanding farmland in the state. 3 marks

c Describe how the change in population size described in part b would affect the distribution of many of the plant species in the Daintree rainforest. 2 marks

CHAPTER 11

Practical work

One of the core parts of the VCE Biology course is the key science skills that accompany the learning of the content. These scientific investigations may be practical investigations that generate primary data, or research investigations that involve the collation of secondary data. Each unit of work will also require you to design your own experiment or research task. You should write all your investigations in a logbook that will be monitored and submitted to teachers. Before undertaking an investigation for the first time, you should consider ethical concerns, including the importance of sociocultural, economic, political and legal factors that may arise from science-related decision-making.

SAFETY IN THE LABORATORY

This chapter highlights key safety concerns for each practical. There are also some general safety concerns to consider before completing any practical work.

→ Tie back long hair.
→ Do not eat or drink in the laboratory.
→ Always be aware of your peers and act in a way that will not cause harm.
→ Wear a lab coat, safety glasses, closed-toed shoes and gloves.
→ Review the school's safety procedures and locations of eye wash, shower, spill kits and first aid kits.
→ Handle chemicals with care and consult your teacher and risk assessments for the hazards involved with each chemical.
→ Keep flammable materials away from open flames.
→ Handle hot material with appropriate equipment (i.e. heat-resistant gloves and tongs).
→ Before using any electrical equipment, check for damaged or exposed wires.
→ Fieldwork should be completed in groups, with a full risk assessment completed prior to the trip.
→ Consider the bioethical approaches and concepts before starting a practical.

It is each teacher's and school's responsibility to conduct a risk assessment prior to any practical covered in this book.

FIGURE 1 Understanding the biochemical reactions that occur in all living things is an essential part of the biology course.

UNIT 1 PRACTICALS

PRACTICAL	**2.2** Surface area to volume ratio matters
PRACTICAL	**2.3** Internal structure of plant cells
PRACTICAL	**2.4** Osmosis through potato plasma membrane
PRACTICAL	**3.2** Stages of mitosis
PRACTICAL	**4.2** Specialised cells, tissues, organs and systems
PRACTICAL	**5.1** Movement of water through plants

UNIT 2 PRACTICALS

NO-TECH PRACTICAL	**6.4** Modelling the movement of alleles in meiosis
NO-TECH PRACTICAL	**7.3** Factors that affect phenotypes
NO-TECH PRACTICAL	**8.1** Sex-linked inheritance
NO-TECH PRACTICAL	**9.3** Cloning zazzles
PRACTICAL	**10.2** Plant adaptations
PRACTICAL	**10.3** Field study of adaptation and distribution

2.2 PRACTICAL

Surface area to volume ratio matters

Practical worksheet
2.2 Surface area to volume ratio matters

Practical demonstration
2.2 Surface area to volume ratio matters

Lab tech notes
2.2 Surface area to volume ratio matters

Risk assessment
2.2 Surface area to volume ratio matters

CAUTION: Acid can cause chemical burns if left on the skin. Wear safety glasses, lab coat and gloves during this experiment. Wash with plenty of water if acid contacts skin.

Context

All cells need to move substances in and out. For example, animal cells need to move glucose and oxygen into the cell and move carbon dioxide and other wastes out. If this happens too slowly, the cell will not produce enough energy, or waste will build up inside the cell to toxic levels.

Molecules move randomly and not always to where they are needed. Long thin cells have a large membrane surface that allows molecules to easily reach the centre. Spherical cells have a long distance/diameter between the membrane and the centre of the cell, making it more difficult for the molecules to reach the centre. Because cells can be different shapes and sizes, the most effective way to compare movement of molecules in and out of the cell is by using the ratio of membrane surface area and cell volume.

Phenolphthalein is an indicator that is pink in basic solution and clear in acid solution.

Aim

To compare the rate of acid diffusion in phenolphthalein jelly with different surface area to volume ratios

Materials

- 100 mL of 0.1 M hydrochloric acid
- 250 mL beaker
- 0.01 M NaOH agar gel containing phenolphthalein indicator and sodium hydroxide solution
- Ruler (preferably plastic)
- Paper towel
- White tile
- Plastic spoon
- Sharp blade (slim-bladed knife or scalpel)
- Cutting board for gel
- Timer

Method

1. Pour 100 mL of 0.1 M hydrochloric acid into the 250 mL beaker.
2. Place the agar gel on the cutting board. Use the sharp blade and ruler to cut the gel into two cubes of 1 cm and 2 cm.
3. Use the plastic spoon to gently add the cubes into the beaker of acid. Start the timer.
4. Calculate the surface area (SA), volume (V) and SA:V ratio for each cube. Copy Table 1 into your logbook and use it to record your results.
5. After 10 minutes, use the spoon to gently remove the cubes from the acid and place them on the white tile.
6. Immediately cut the cubes in half and measure the depth (to the nearest millimetre) of the gel that stayed pink. Record the measurements in Table 1.
7. Dispose of the agar gel in the container provided.

TABLE 1 The measured values of the phenolphthalein gel

Dimensions of the phenolphthalein gel cube	A Surface area of cube	B Volume of cube	C SA:V $\left(\frac{A}{B}\right)$	D Dimension of gel staying pink	E Volume of pink portion	F Volume of clear gel portion (B – E)	G Percentage of block uncoloured $\left(\frac{F}{B}\right) \times 100\%$
1 cm × 1 cm × 1 cm							
2 cm × 2 cm × 2 cm							

Results

Produce a graph showing dimensions of the gel block against the percentage of uncoloured gel block.

Discussion

1 Identify the independent and dependent variables for this experiment.
2 Identify two other variables that needed to be controlled in this experiment. Describe how they were controlled.
3 Calculate how far into each block of gel the acid was able to diffuse.
4 Identify which block had the greatest percentage of uncoloured gel.
5 Identify which block (large or small SA:V) the acid was able to penetrate to the centre.
6 Use your answer to Question 3 to explain why cells need to remain small.
7 Compare your result to those of other groups in the class. Explain any variations that might have occurred.
8 Describe one random error and one systematic error for this experiment.
9 Explain how this experiment could be changed to improve the accuracy and precision of the results.

Conclusion

Explain how the surface area to volume ratio affects the effectiveness of molecular transport in and out of a cell.

2.3 PRACTICAL Internal structure of plant cells

Practical worksheet
2.3 Internal structure of plant cells

Practical demonstration
2.3 Internal structure of plant cells

Lab tech notes
2.3 Internal structure of plant cells

Risk assessment
2.3 Internal structure of plant cells

Context

All cells contain genetic material, ribosomes and cytoplasm surrounded by a membrane. There are two types of cell: eukaryotic and prokaryotic. Prokaryotic cells, including bacteria, are small and do not have membrane-bound organelles. Eukaryotic cells (including plant cells) contain membrane-bound organelles, including a nucleus, endoplasmic reticulum, Golgi apparatus and mitochondria. The photosynthetic cells in a plant also contain chloroplasts.

Aim

To identify and draw diagrams of different plant cells

Materials

- Onion
- Leaf from *Elodea canadensis* plant
- Methylene blue stain or iodine
- Water
- Light microscope
- 2 glass slides
- 2 coverslips
- Blotting paper
- Cutting board
- Knife
- Pipette
- Newspaper square (2 cm × 2 cm)

Method

Part A: Using a microscope

1. Connect the microscope to a power source and turn on the light.
2. Place the square of newspaper on the glass slide. Add one drop of water and then gently lower the coverslip onto the slide so that no air bubbles are trapped. This is called a 'wet mount'.
3. Place the glass slide on the stage of the microscope so that the letters and words are facing you. Make sure that you are using the ×4 (the shortest) objective lens.

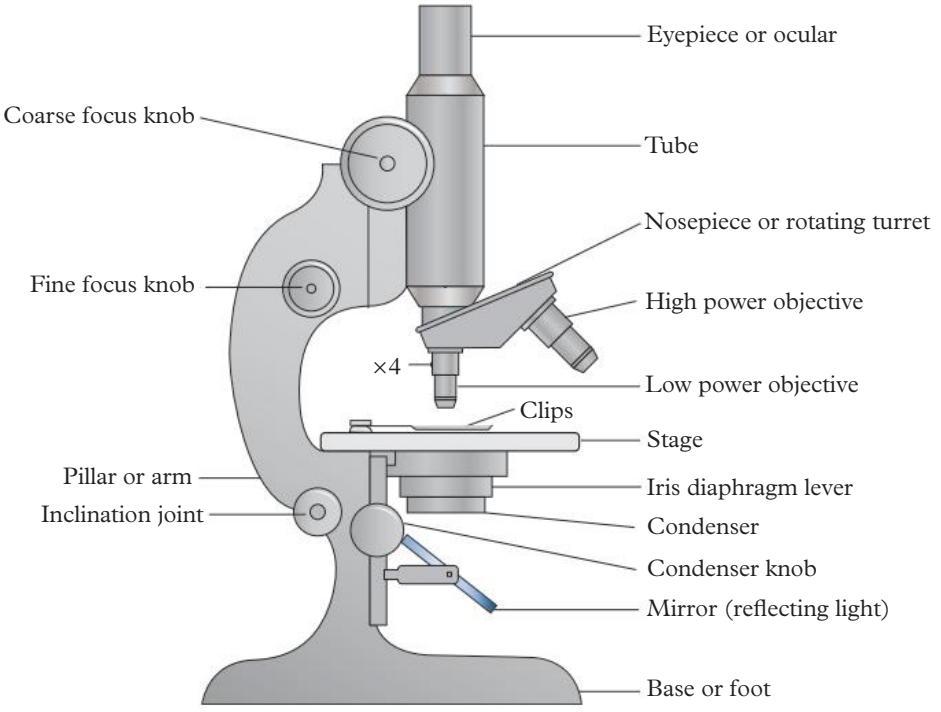


FIGURE 1 A microscope and its parts

4 Look from the side of the microscope and adjust the coarse focus knob so that the objective lens is *just above – and not touching –* the slide. Check which way you must turn the knob to move the objective lens away from the slide.
5 Look down the eyepiece lens and slowly move the coarse focus knob to bring the letters into view. Find one letter from the newspaper to focus on (an 'e' is a good letter to use). Draw the letter you observed in your logbook. Note the difference between observing the letter with and without a microscope.
6 Move the glass slide towards you and observe how the letter moves when looking down the microscope. Record your observation in your logbook.
7 Move the slide slightly to the left and repeat your observation. Record your observation in your logbook.
8 Increase the magnification by rotating the objective lens to ×10. Describe what has happened to the view down your microscope.

Part B: Unstained onion cell

1 Use the cutting board and the knife to slice the onion into small wedges.
2 Between the fleshy layers of an onion are some thin, transparent layers. These layers are one cell thick. Peel off a layer of this skin and place it on a glass slide.
3 Add one drop of water and then gently lower the coverslip onto the slide so that no air bubbles are trapped.
4 Place the glass slide on the microscope stage and examine it under low power. When the cells are in focus, change the objective lens to ×100 and use the fine focus knob if necessary.
5 Draw a labelled diagram of three onion cells. Remember to draw what you see, rather than what you expect to see.
6 Retain this slide for Part C.

Part C: Stained onion cell

1 Use the onion slide from Part B.
2 Add one drop of the methylene blue (or iodine) on one outer edge of the cover slip.
3 Place the blotting paper on the opposite side of the coverslip. This will draw out the water and stain under the coverslip and over the layer of onion skin.
4 Place the slide on the microscope stage and focus first on low power, before refocusing on high power (×100).
5 Draw a labelled diagram of three onion cells. Can you identify the cell wall, membrane, cytoplasm and nucleus?

Part D: *Elodea* cells

1 Place a single green *Elodea* leaf on a new glass slide.
2 Add one drop of water over the leaf, before gently lowering the coverslip so that no air bubbles are trapped.
3 Draw a labelled diagram of three *Elodea* cells. Can you identify the nucleus, green chloroplasts and cytoplasm?
4 Chloroplasts can sometimes be seen floating in a moving stream of cytoplasm. Observe the *Elodea* cells for evidence of this cytoplasmic streaming.

Results

Include your labelled diagrams in this section.

Discussion

1 Describe how the use of a stain changes the appearance of the onion cells.
2 Compare the onion (root) cell and the *Elodea* (leaf) cell. Describe any differences that you observed.
3 Describe the role of the chloroplasts that are usually present in *Elodea* leaf cells.
4 Explain why chloroplasts are not evident in the onion cells.

Conclusion

Describe the features of leaf and onion cells that can be seen under a light microscope.

2.4 PRACTICAL Osmosis through potato plasma membrane

Practical worksheet
2.4 Osmosis through potato plasma membrane

Practical demonstration
2.4 Osmosis through potato plasma membrane

Lab tech notes
2.4 Osmosis through potato plasma membrane

Risk assessment
2.4 Osmosis through potato plasma membrane

Context

Osmosis is the passive net movement of water through a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration. The solute concentration is the amount of solutes (including salt, NaCl) dissolved in the solution. If a plant cell is placed in a high solute solution (hypertonic solution), the cell will lose water. If the plant cell is placed in a low solute solution (hypotonic solution), the cell will gain water. If the plant cell is placed in a solute solution that is isotonic, there will be no net movement of water into or out of the cell. This process allows plants to take up water into root cells such as those found in potato plants.

Aim

To determine the osmotic balance in a potato cell

Materials

- 5% salt solution
- Large potato
- Water
- 6 test tubes and a test-tube rack
- 2 glass stirring rods
- 2 measuring cylinders (10 mL)
- Paper towel (or blotting paper)
- 1000 µL micropipette and tip
- Potato peeler
- Scales
- Knife
- Chopping board
- Ruler
- Permanent marker
- Timer

Method

1 Label the test tubes with concentration percentages: 0%, 0.1%, 0.5%, 1%, 2.5%, 5%.

2 Make up the solutions according to Table 1. Mix each solution thoroughly with a glass stirring rod. Carefully wash and dry the stirring rod after each solution. (If a micropipette is not available, extra 0.5% solution can be prepared and then diluted 1:5.)

TABLE 1 Concentration of solutions to be prepared

Concentration of salt (%)	Volume of distilled water (mL)	Volume of 5% salt solution (mL)
0	10	0
0.1	9.8	0.2 (200 µL)
0.5	9	1
1	8	2
2.5	5	5
5	0	10

3 Peel the potato and then cut it into six cuboids of 0.5 cm × 0.5 cm × 3 cm.

4 Gently blot each potato segment with the paper towel to remove excess water. Zero the balance. Weigh each section of potato. Copy Table 2 into your logbook and use it to record the masses.

5 Place each potato segment into each test tube until it is fully submerged. Start the timer.

6 After 15 minutes, remove each potato segment from the test tube and place it on the blotting paper.

7 Use the paper towel to blot each potato segment carefully.

8 Zero the balance. Record the mass of each potato segment in Table 2. Calculate the percentage change in mass of each segment.

$$\text{Percentage change in mass} = \frac{\text{Change in potato mass}}{\text{Initial mass of potato}} \times 100\%$$

TABLE 2 Measured change in mass or potato in different concentrations of salt solution

Salt concentration (%)	Potato mass before immersion (g)	Potato mass after immersion (g)	Change in mass (g)	Percentage change in mass (%)
0				
0.1				
0.5				
1				
2.5				
5				

Results

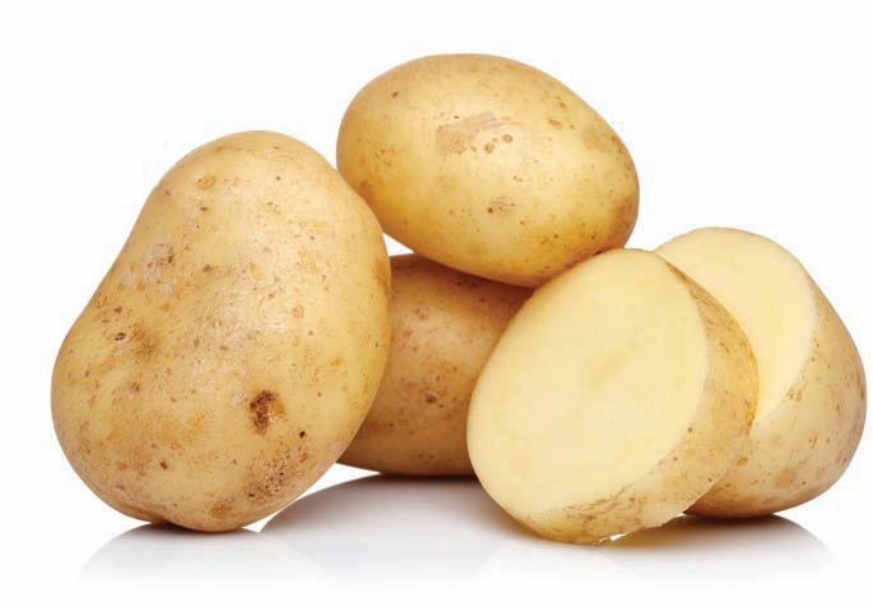
Draw a graph of the salt concentration against the percentage change in potato mass. Draw a line of best fit for your graph.

Discussion

1 Identify the independent variable and dependent variable for this experiment.
2 Explain why the potato was peeled before it was used.
3 Explain why the outside of the potato was patted dry before the experiment.
4 Explain why it was important to make sure each segment of the potato was equal in size.
5 Explain why some segments of the potato gained mass and others lost mass.
6 Use your graph to identify the percentage of salt concentration in the cells of the potato.
7 Identify at least one random error and one systematic error in this experiment.
8 Describe how you could improve the accuracy of your results.
9 Describe how you could improve the precision of your results.

Conclusion

Describe what you know about the osmotic balance of the potato.



3.2 PRACTICAL Stages of mitosis

Practical worksheet
3.2 Stages of mitosis

Practical demonstration
3.2 Stages of mitosis

Lab tech notes
3.2 Stages of mitosis

Risk assessment
3.2 Stages of mitosis

Context

One of the identifying factors for any living organism is its ability to grow. In Practical 2.2, you learnt that surface area to volume ratio limits a cell's ability to move substances in and out. This suggests that as a multicellular organism grows, the number of cells (rather than the size of the cells) must increase. Each cell must come from a parent cell and must be able to coordinate its actions with all other cells in the multicellular organism. As a result, the information contained in each parent cell must be passed on without any errors. The process of passing on important identical genetic information between parent cells and daughter cells occurs through mitosis.

Mitosis is a series of organised stages that must occur in the correct order to prevent any errors. If a cell makes an error during mitosis, the cell cannot pass the checkpoints. This would result in a cell undergoing organised cell death (apoptosis). Occasionally a cell can bypass the different checkpoints. When this occurs, the cell has the potential to become a cancer cell.

Aim

To identify the individual stages of mitosis and to determine the length of time a cell spends at each stage

Materials

- Prepared slides of stained onion or garlic root tips
- Microscope
- Logbook and pencil for drawings

Method

1 Connect the microscope to the power source and turn on the light.

2 Place the prepared slide of stained onion or garlic root on the stage of the microscope.

3 Locate the growth zone of the root and use the coarse focus knob to identify individual cells. Then rotate the objective lens to focus on medium or high power.

FIGURE 1 The cells of an onion root tip undergoing mitosis

4 Identify the four stages of mitosis (prophase, metaphase, anaphase and telophase (see Figure 2)) on your slide. Draw a picture of each stage in your logbook.

5 Select a single field of view of the root tip and do not move the glass slide from this view. Count the approximate number of cells in the field of view.

6 Count the number of cells in each stage of mitosis in the field of view. Copy Table 1 into your logbook and use it to record your numbers.

7 Determine the percentage of time each cell will spend in each stage of mitosis by using the formula below.

$$\text{Percentage of time in stage} = \frac{\text{Number of cells in stage}}{\text{Total number of cells in field of view}} \times 100\%$$

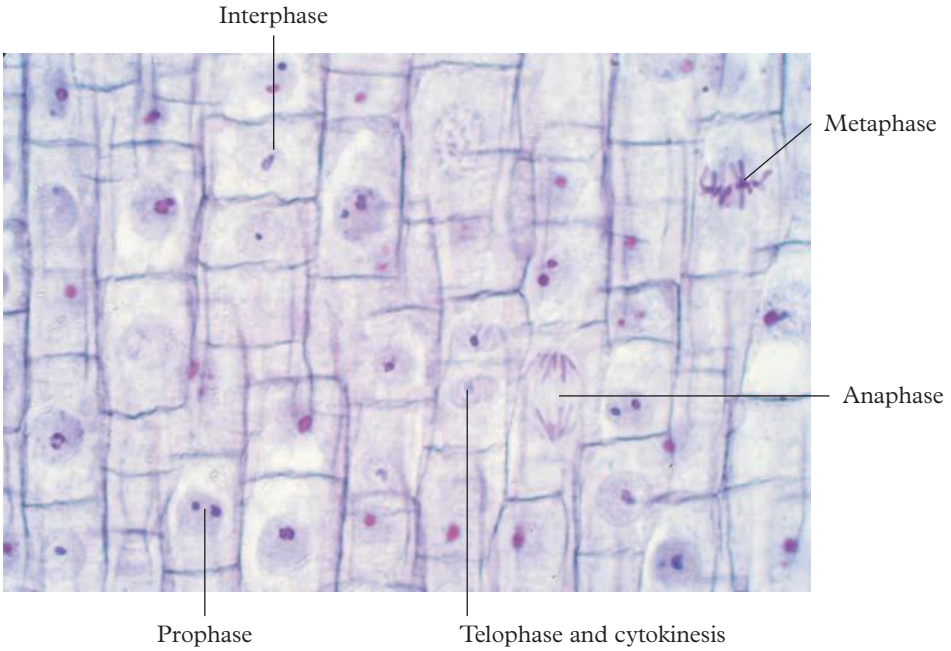


FIGURE 2 Cells at prophase, metaphase, anaphase and telophase

Results

TABLE 1 The number of cells in each stage of the cell cycle

Stage of cell cycle	Number of cells	Percentage of time in each stage (%)
Prophase (mitosis)		
Metaphase (mitosis)		
Anaphase (mitosis)		
Telophase (mitosis)		
Interphase (not mitosis)		
Total number of cells		100

Discussion

1 Identify which of the four stage takes the most time to complete. Explain how you reached this decision.

2 Identify which stage takes the shortest time to complete (least number of cells identified).

3 Explain what would happen if a cell missed the metaphase stage of mitosis.

4 Suggest why there are two checkpoints before prophase and before metaphase.

5 Explain why it is important that a cell undergoes apoptosis if it fails a checkpoint.

6 Anatomical pathologists are specialised doctors who examine suspected cancer tissue. Suggest why they may check for an increased number of cells undergoing mitosis.

Conclusion

Describe what you know about the different stages of mitosis and the length of time a cell spends at each stage.

4.2 PRACTICAL Specialised cells, tissues, organs and systems

Practical worksheet
4.2 Specialised cells, tissues, organs and systems

Practical demonstration
4.2 Specialised cells, tissues, organs and systems

Lab tech notes
4.2 Specialised cells, tissues, organs and systems

Risk assessment
4.2 Specialised cells, tissues, organs and systems

Context

Multicellular organisms are made up of many cells. In order to function effectively, the cells must be able to work together. This means cells can specialise to perform different functions. Some cells specialise to move the organism, while others specialise to transport water, gases or materials. When a number of cells specialise to perform the same function, they become a tissue. In some parts of the organism, different tissues work together to achieve a common outcome. This may include breaking food into nutrients that can be absorbed or removing waste. Different tissues organised for a particular role are an organ.

Smooth muscle cells of animals form tissues that can contract and relax without conscious thought. Smooth or involuntary muscle consists of cells with a single nucleus that are long and pointed at their ends.

The trachea is responsible for transporting gases between the external environment and the air sacs (alveoli) of the lungs. The trachea must remain open at all times, although it must be able to expand and contract when needed. To do this, it has a semicircular layer of almost clear cartilage in its wall. Because the air taken in may contain dust, pollen and bacteria, the lining of the trachea has ciliated epithelial cells mixed with mucus-secreting (goblet) cells. The mucus traps any particles in the air and the beating cilia pass the particles back to the mouth. The trachea forms part of the gas-exchange system whose role is to supply oxygen to and remove carbon dioxide from the blood.

Plant cells are also differentiated into tissues. Leaves are important plant organs. All leaves are covered in protective epidermal tissue. Photosynthesis occurs in the palisade mesophyll cells. To obtain sunlight, these cells need to be in the upper layers of the leaf. The palisade cells are rectangular with their short ends parallel to the leaf surface. Photosynthesis needs both carbon dioxide and water. Water is transported to these cells through the xylem via spongy mesophyll tissue. Carbon dioxide from the air enters the leaf at specific pores (stomata), usually on the bottom surface of the leaf (lower epidermis).

The leaf is part of the shoot system, which also includes the stem.

A zone diagram (Figure 1) is a plan of the specimen that clearly shows the distribution and relative amount of each tissue present. Zone diagrams are also known as line or map diagrams. They show no cell detail.

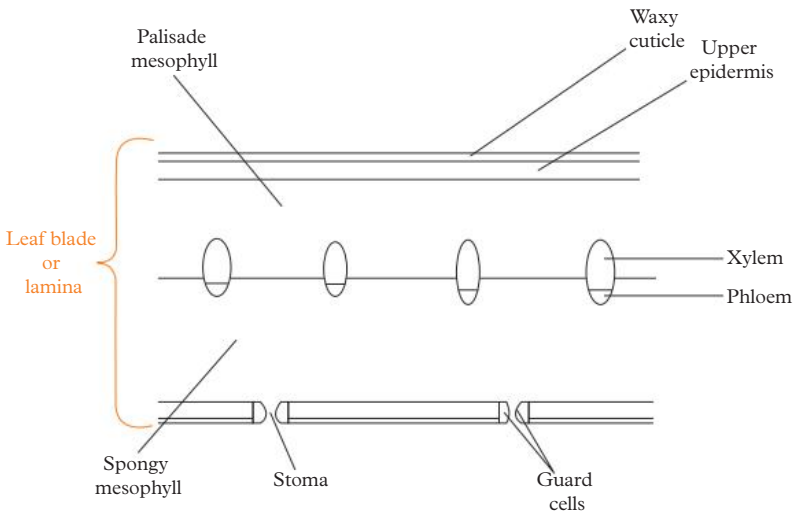


FIGURE 1 A zone diagram of the cross-section of a leaf

Aim

- To examine, draw and label cells observed in animal and plant tissue
- To relate the structure of the tissue cells to their functions
- To examine the relationship of the tissue in an organ
- To examine the interaction of the organ in a system

Materials

- Microscope
- Prepared slides of:
  - teased out smooth muscle cells
  - transverse section (TS) of trachea
  - palisade mesophyll cells
  - TS of leaf

Method

For each diagram, include a title of the cell type, the magnification and stains used, and labels for any organelles (e.g. nucleus) observed.

Part A: Animal tissues and organs

1. Examine the slide of smooth muscle cells. Identify and draw three adjoining cells.
2. Examine the slide of the TS of the trachea. Identify the smooth muscle tissue. Determine the orientation of each layer. (Does it run around the diameter of the trachea or along the length of the trachea?) Draw three cells to show how they are arranged in the tissue.
3. Identify any other tissues in the organ; for example, the clear cartilage, ciliated epithelial lining cells, or mucus-producing goblet cells. Draw a sample of two or three cells of each tissue type.
4. Draw the TS of the trachea as a zone diagram. Include layers of each tissue type without cell structure, labelling each tissue layer. Do not colour in the diagram.

Part B: Plant tissues and organs

1. Examine the slide of palisade mesophyll cells. Draw two adjoining photosynthesising cells. Include any chloroplasts you can see.
2. Examine the TS of the leaf. Identify the palisade mesophyll cells.
3. Identify other tissues (e.g. epithelial cells, stoma, xylem and phloem cells) in the organ. Draw and label a zone diagram of the TS of the leaf.

Discussion

1. Define:
   - **a** tissue
   - **b** organ
   - **c** system.
2. Explain why a multicellular organ might need to have cells specialised for different functions.
3. Explain which tissues in the trachea:
   - **a** produce mucus to protect the lungs from dust and pollen
   - **b** expand to allow more oxygen into and carbon dioxide out of the lungs.
4. The leaf is an organ of the plant. Explain how the xylem tissue must work with the palisade tissue so that the leaf can perform its specialist function of producing glucose for the whole plant.
5. The leaf and stem are part of the shoot system of a plant. Explain how the different organs (leaf and stem) must work together so that the whole plant survives.

Conclusion

Use an example to explain why a multicellular organism must have specialised tissues, organs and systems in order to survive.

5.1 PRACTICAL Movement of water through plants

Practical worksheet
5.1 Movement of water through plants

Practical demonstration
5.1 Movement of water through plants

Lab tech notes
5.1 Movement of water through plants

Risk assessment
5.1 Movement of water through plants

Context

The fine hairs on a root use osmosis to pass water from the soil, into the cell and to the root xylem. The constant movement of water into the root creates pressure, which forces water against gravity and up the xylem. This upward force of water is called root pressure.

The leaves of a plant constantly lose water through evaporation. This process is called transpiration. Water molecules are attracted to each other and the walls of small xylem tubes. This means as water is lost from the leaves, more water is pulled up the xylem vessels from the roots.

Aim

To demonstrate movement of water in a plant through root pressure and transpiration

Materials

Each group requires:

- Celery stalks
- Food colouring
- Large beakers
- Stirring rod
- Razor blade
- Distilled/deionised water
- Microscope slide
- Coverslip
- Marker pen
- Microscope
- Pencil and eraser
- Petroleum jelly
- Rubber band
- Toothpick
- Petri dish

Method and Results

Prepare Parts A and B together.

Part A: Passage of water through celery

1. Half-fill the beaker with distilled/deionised water and add drops of the food colouring until the solution is very dark in colour. Stir the solution so that the food colouring is evenly distributed.
2. Wash the celery with water and then place the base of the celery in the solution. Leave it for 24–48 hours.
3. Record your observations of the celery leaves.
4. Remove the celery stalk from the solution and wash it thoroughly with water. Cut a thin section from the centre of the celery stalk. Slice thin slices of the stem. Add a drop of water to the centre of a clean microscope slide and carefully place a slice onto the water. Add another drop of water and cover it with a coverslip.
5. Examine the slice under the microscope. Identify the xylem and draw a labelled diagram.

Part B: Passage of water through celery with petroleum jelly

1. Set up a beaker containing food colouring as in Part A.
2. Completely coat the celery stem and leaves with a thin, even smear of petroleum jelly and then place the plant with its base in the solution. Leave it for 24–48 hours.
3. Record your observations of the celery leaves.

4 Remove the celery stalk from the solution and wash it thoroughly with water. Cut a thin section from the centre of the celery stalk. Slice thin slices of the stem. Add a drop of water to the centre of a clean microscope slide and carefully place a slice onto the water. Add another drop of water and cover it with a coverslip.
5 Examine the slice under the microscope.
6 Copy Table 1 into your logbook and use it to compare your observations of the two plants.

Part C: Cohesion and adhesion in water

1 Take two clean microscope slides. Stand them together vertically.
2 Place the thin end of a toothpick between the two slides close to their tops.
3 Wind a rubber band around the top of the two slides to hold the two slides and the toothpick together.
4 Add some food colouring to a small amount of water and put it into the Petri dish.
5 Stand the slides vertically in the water.
6 Observe and record the level of coloured water between the slides.

Discussion

1 Describe the evidence you have from Part A that water was moving up the celery stalk to the leaves.
2 Explain why the celery stalk is coated in petroleum jelly in Part B.
3 Use data from Parts A and B to explain why transpiration is important for the movement of water through a plant.
4 Explain how the movement of water up the microscope slides is similar to root pressure.
5 Explain how water can move from the roots to the leaves of a 10-metre-tall tree.

Conclusion

Explain the mechanism of water movement from the roots to the leaves of a plant.

TABLE 1 Comparison of water movement in two experiments

	Turgor of leaves	Colour of leaves	Evidence of food colouring inside the plant
Plants at start of experiment			
Plant without petroleum jelly after 24 hours			
Plant coated in petroleum jelly after 24 hours			

6.4 NO-TECH PRACTICAL

Modelling the movement of alleles in meiosis

Practical worksheet
6.4 Modelling the movement of alleles in meiosis

Practical demonstration
6.4 Modelling the movement of alleles in meiosis

Lab tech notes
6.4 Modelling the movement of alleles in meiosis

Risk assessment
6.4 Modelling the movement of alleles in meiosis

Context

The DNA in each of your cells contains the genetic information (genes) that determines all of the characteristics in your body. The versions of the genes (alleles) determine the colour of your hair or eyes, your height, the position of all your facial features and the way you smile. You may share some, but not all, of these features with your siblings. How can brothers and sisters be different if they each inherit half of their DNA from their mother and half from their father?

Aim

To model the process of meiosis, including crossing over and independent assortment

Materials

Each group requires:

- Masking tape
- Permanent marker
- 6 pipe cleaners (4 of colour 1 and 2 of colour 2)
- A4 sheet of paper
- Pencil
- Eraser
- Scissors

Method

1. Cut both of the 'colour 2' pipe cleaners in half to form four short sections. These will represent short chromosomes. Remove two of the short chromosomes.
2. Place four small tags of masking tape on each of the two remaining short chromosomes, two tags near each end (Figure 1). These tags represent the alleles of genes on a chromosome.
3. Use the permanent marker to label the tags on one of the short chromosomes A, B, C and D. Label the tags on the other short chromosome a, b, c and d.
4. Select two of the longer pipe cleaners to become long chromosomes. Place two tags near each end of the long chromosomes.
5. Use the permanent marker to label the tagged alleles on one long chromosome E, F, G and H. Label the tagged alleles on the other long chromosome e, f, g and h.

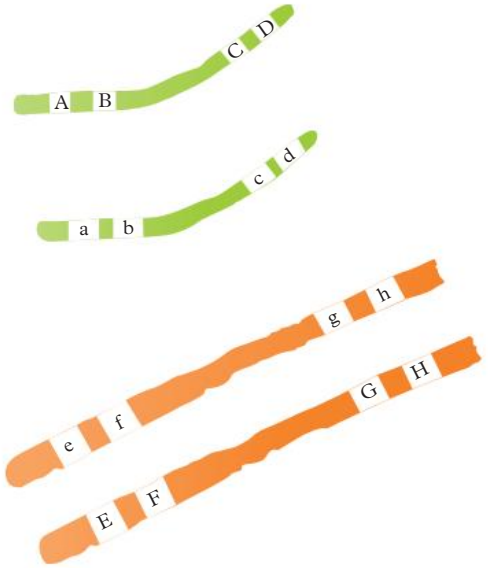


FIGURE 1 Labelled chromosomes

6. Place your labelled chromosomes in the centre of a sheet of A4 paper. This represents a germline cell about to undergo meiosis. Use a pencil to draw a circle around the chromosomes to represent the nucleus. Draw the model cell and chromosomes.
7. Before the cell can undergo meiosis, each of the chromosomes must replicate the DNA. Select the remaining pipe cleaners and join one to each of the tagged chromosomes by twisting them

around the centre (Figure 2). This represents the centromere of each bivalent chromosome. Place labelled tags around each of the new sections of DNA (chromatids). Draw the model cell and chromosomes.

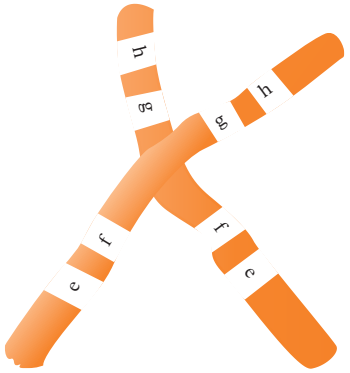


FIGURE 2 A chromosome with two chromatids

8 After checking that all chromosomes are correctly labelled, use the eraser to remove the line that represents the nuclear membrane.

9 Place the two long (homologous) chromosomes side by side, and the two short (homologous) chromosomes together. Demonstrate crossing over by swapping the 'd' tag from the end of one of the short chromosomes with the 'D' tag from the other short chromosome. You should now have chromosomes with A, B, C, d, and a, b, c, D. Draw the model cell and chromosomes.

10 Line the homologous pairs of chromosomes along the centre of the A4 paper cell. Draw the model cell and chromosomes.

11 Move one long chromosome and one short chromosome to each end of the A4 paper cell. Draw the model cell and chromosomes.

12 Use the scissors to cut the A4 paper in half. You should now have two smaller paper cells, each with one long chromosome and one shorter chromosome. Draw the model cells and chromosomes.

13 Place the chromosomes along the centre of each of the paper cells. Draw the model cells and chromosomes.

14 Unwind the centromeres of the pipe cleaners so that they are no longer bivalent chromosomes. Move one long and one short pipe cleaner to each end of the paper cells. Draw the model cells and chromosomes.

15 Use the scissors to cut each paper cell in half so that each new paper cell has one long and one short chromosome. Draw the model cells and chromosomes.

Results

Label the nine diagrams that you drew during the modelling of meiosis. Correctly label each stage.

Discussion

1 Identify the tag that represented another allele at the same gene locus as A.

2 Describe the two parts that exchanged genetic information during crossing over.

3 Use a diagram to explain what would happen if crossing over occurred between sister chromatids

4 Describe the allele combinations that occurred in the daughter cells from your modelling.

5 Describe other possible allele combinations that could be obtained if your modelling was repeated. Use an example to explain your answer.

6 Explain how meiosis can result in random assortment.

Conclusion

Explain how meiosis and crossing over contribute to genetic variation of a species.

7.3 NO-TECH PRACTICAL Factors that affect phenotypes

Practical worksheet
7.3 Factors that affect phenotypes

Practical demonstration
7.3 Factors that affect phenotypes

Lab tech notes
7.3 Factors that affect phenotypes

Risk assessment
7.3 Factors that affect phenotypes

Context

The physical characteristics, or phenotype, of an organism are determined by the alleles they inherit from their parents. Some alleles have a greater impact on the phenotype than other alleles. If a single allele determines a particular physical characteristic, then the phenotype is described as dominant. If a characteristic requires two copies of an allele to be present before the phenotype is present, then the characteristic is recessive.

In this activity, you will model the inheritance of a series of characteristics for small creatures called zazzles. These characteristics include the dominant traits of straight tail, long body and four eyes. The corresponding recessive characteristics are curly tail, short body and two eyes. The zazzles can have clear coats, or they can have a spotted back or have a large black patch on their back. The inheritance of these characteristics exhibits co-dominance.

The genotype of the zazzle is not the only factor that determines their physical characteristics. Many zazzles can inherit a single unicorn horn from their parent. Incomplete inheritance can result in a shorter horn. Zazzles with a horn are regularly hunted for tribal medicines. Hunted zazzles are less likely to survive, and therefore less likely to reproduce and pass on this allele to the next generation of zazzles.

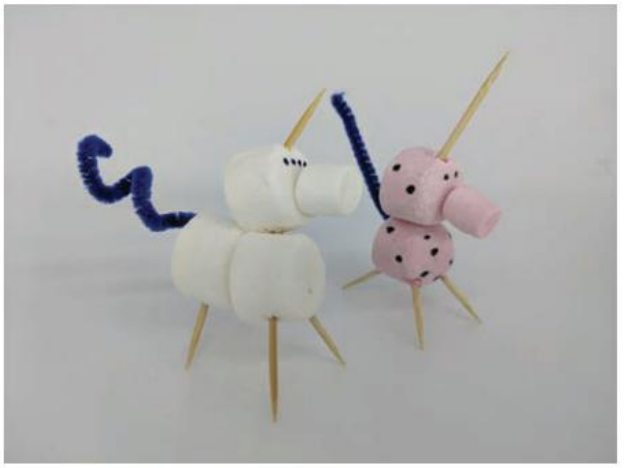


FIGURE 1 Zazzles

Aims

- To model the inheritance of dominant, recessive, co-dominant and incomplete dominant traits when there are no environmental factors affecting the organisms
- To model the effect that environmental factors have on the inheritance of alleles

Materials

- Bag containing 6 different coloured counters
- Permanent marker
- Toothpicks
- Pipe cleaners
- White and pink large marshmallows (or similarly coloured play dough)
- White and pink small marshmallows
- Blue and black felt-tipped markers
- Scissors
- Bag containing 20 dried red lentils and 20 dried green lentils
- 4 plastic cups
- Die

Part A: Inheritance of traits with no environmental factors

Method

1 Choose a counter from the bag. Use a permanent marker to draw a 'T' on one side and a 't' on the other side. This represents the inheritance of a long tail (T) or a short tail (t) from the parent.

2 Flip the counter to determine which allele (T or t) is passed on to your baby zazzle from the father. Copy Table 1 into your logbook and use it to record your results.

3 Use a second counter to represent the length of the body. Write an 'L' on one side to represent a long body and an 'l' on the other side to represent a short body.

4 Flip the counter to represent which allele (L or l) is passed on to your baby zazzle from the father. Write your results in Table 1.

5 Use a third counter to represent four eyes (E) or two eyes (e). Flip the counter to determine the allele that is passed on to your baby zazzle.

6 The pattern of coat on your baby zazzle can be clear (C^NC^N), spotted back (C^NC^P) or a single large black patch (C^PC^P). Both parents of your zazzle have spotted coats. This means the counter needs to have C^N on one side and C^P on the other side because either allele can be inherited. Write these symbols on the counter and flip the counter to determine which allele is passed on from the father. Write your results in Table 1.

7 The presence of a unicorn horn is a trait that shows incomplete dominance. A zazzle can have no horn (U^YU^Y), a short horn (U^YU^H) or a long horn (U^HU^H). The parents of your zazzle both have short horns. This means the counter needs to have U^Y on one side and U^H on the other side because either allele can be inherited. Write these symbols on the counter and flip the counter to determine which allele is passed on from the father. Write your results in Table 1.

8 The mother of your baby zazzle has the same traits as the father. Flip all five of the counters again to determine the alleles that have been passed on to your zazzle from the mother. Write your results in Table 1.

9 The final counter is used to determine the sex of your zazzle. The mother has two X chromosomes. This means she can only pass on an X chromosome to your zazzle baby. The father can pass on either an X or a Y chromosome. Write 'X' on one side of the final counter and a 'Y' on the other side. Flip the counter to determine which chromosome is passed on to your zazzle from the father. Write your results in Table 1. If your zazzle is a girl, use the large pink marshmallows. If your zazzle is a boy, use the large white marshmallows.

10 Determine the phenotype of your zazzle.

11 Use the materials provided to construct your baby zazzle.

Results

TABLE 1 Alleles inherited from parents

Chromosome/ counter	Trait and letter representing it	Allele inherited from father	Allele inherited from mother	Phenotype of baby zazzle
1	Tail: curly (T) or straight (t)			
2	Body length: long (L) or short (l)			
3	Four eyes (E) or two eyes (e)			
4	Coat colour: clear (C^NC^N), spotted back (C^NC^P) or single large patch (C^PC^P)			
5	No horn (U^YU^Y), short horn (U^YU^H) or long horn (U^HU^H)			
6	Sex (X or Y)			

Part B: Inheritance of horns when hunted

Method

1 Count the number of red and green lentils in your bag to make sure you have 20 of each. The red lentils represent the allele for the long horn (U^H) and the green lentils represent the allele for no horn (U^Y).

2 Replace the dried lentils in the bag and mix them thoroughly.

3 Use the permanent marker to label the four plastic cups: 'Dead', 'U^HU^H', 'U^HU^Y' and 'U^YU^Y'.

4 Without looking, randomly select two lentils from the bag. This represents the first offspring of the next generation.

- If you have selected two green lentils (U^YU^Y), then the offspring has no horn. This means they will not be hunted and will survive to have children.
- If you have selected a green and a red lentil U^HU^Y, then the offspring will have a short horn and may be hunted. Role the die. If there is an odd number, then the hunter is successful and the zazzle will die (place both lentils in the 'Dead' cup). If there is an even number, then the hunter will not be successful (place the lentils in the U^HU^Y cup).
- If you have selected two red lentils (U^HU^H), then the offspring will have a long horn. This means the horn will be prized by hunters. Role the die. If there is a 6, then the zazzle will escape (place the lentils in the U^HU^H cup). If a number from 1 to 5 is rolled, then the hunter will be successful and the zazzle will die (place both lentils in the 'Dead' cup).

5 Repeat step 4 for the remaining lentils. Copy Table 2 into your logbook and use it to record your results.

6 Place all the surviving lentils from the U^HU^H, U^HU^Y and U^YU^Y cups back in the bag.

7 Repeat step 4, this time recording the number of zazzles that have a long horn (U^HU^H), short horn (U^HU^Y) or no horn (U^YU^Y) in Table 3.

Results

TABLE 2 Surviving alleles inherited from parents

	Number of red lentils	Number of green lentils
Generation 1	20	20
Generation 2		

TABLE 3 Number of zazzles with and without horns.

	Long horn (U^HU^H)	Short horn (U^HU^Y)	No horn (U^YU^Y)
Number of zazzles			

Discussion

1 Calculate the number of chromosomes in each of the:
   - **a** mother's somatic cells
   - **b** father's gametes
   - **c** baby zazzle's cells.

2 Identify your baby zazzle's genotype.

3 Describe how your baby zazzle inherited its coat colour. Describe how this would be the same as or different from that of its brothers or sisters.

4 Describe the appearance of zazzles whose parents had:
   - **a** no horns
   - **b** long horns.

5 Describe how the presence of hunters affected the number of zazzles born with long horns in the next generation.

6 The length of the horn depends on the presence of the nutrient magnesium. If the zazzles were not able to access enough of this nutrient, describe how this would affect the length of the horn.

Conclusion

Describe the inheritance of dominant traits, recessive traits, co-dominant traits and incomplete dominant traits. Describe how environmental factors such as the presence of hunters can affect the proportion of individuals displaying certain traits within a population.

8.1 Sex-linked inheritance

NO-TECH PRACTICAL

Practical worksheet
8.1 Sex-linked inheritance

Practical demonstration
8.1 Sex-linked inheritance

Lab tech notes
8.1 Sex-linked inheritance

Risk assessment
8.1 Sex-linked inheritance

Context

Like humans, zazzles can inherit congenital a condition called congenital stationary night blindness (CSNB). CSNB is a rare non-progressive disorder where zazzles have difficulty seeing objects at night. This particular disorder can have detrimental effects on an organism, making them vulnerable to being hunted at night. As an X-linked disorder, it mainly affects male zazzles.

Aim

To examine the inheritance of the X-linked recessive condition, congenital stationary night blindness, in zazzles

Materials

- 2 different coloured counters
- Permanent marker

Method

1. One of the counters will represent the sex chromosomes of the mother zazzle. Use the permanent marker to write 'X^B' (normal night-sight) on one side and 'X^b' (CSNB) on the reverse side of the counter.
2. The second counter will represent the sex chromosomes of the father zazzle. Use the permanent marker to write 'Y' on one side of the counter, and 'X^b' (CSNB) on the reverse side of the counter.
3. Flip both counters to determine the sex and inheritance of CSNB by the first child. Copy Table 1 into your logbook and use it to record your results, adding more rows as required.
4. Continue to flip both counters until you have modelled 50 genetic crosses. Complete Table 1 to determine the genotype and phenotype of all offspring.

Results

TABLE 1 The genotype and phenotype of the cross X^BX^b and X^bY

Cross	Genotype	Male or female	CSNB (Yes/No)
1			
2			
3			
4			
5			

Discussion

1. Use a Punnett square to predict the proportion of males and females with CSNB.
2. Calculate the proportion of males and females from your experiment that have CSNB.
3. Compare the prediction of your Punnett square to the results of your modelling.
4. Describe the effect this disorder will have on the proportion of male and female zazzles being hunted for their horns.
5. Describe the effect this disorder will have on the proportion of male and female zazzles left in the population.

Conclusion

Describe what you know about the inheritance of X-linked disorders.

9.3 NO-TECH PRACTICAL Cloning zazzles

Practical worksheet
9.3 Cloning zazzles

Practical demonstration
9.3 Cloning zazzles

Lab tech notes
9.3 Cloning zazzles

Risk assessment
9.3 Cloning zazzles

Context

The population of uni-horned zazzles is rapidly decreasing as a result of hunting. This has led to calls for a new conservation program to increase their numbers, including reproductive cloning. This process would involve cloning a long-horned male zazzle by removing the nucleus from one of its skin cells and inserting the nucleus into an egg cell of a no-horned zazzle. After a small electric shock, the egg cell will start replicating into 100 cells. It will then be implanted into a no-horned surrogate mother.

Aim

To model the process of reproductive cloning technology

Materials

- White play dough
- Yellow play dough
- Red play dough
- Blue play dough
- 2 toothpicks
- Sticky tape
- Scissors
- Pen
- Camera
- 2 pieces of A4 paper (one for the play dough design and the other for labels)

Method

Part A: Preparation

1. Roll one small ball of yellow play dough to represent the nucleus of the genetic parent.
2. Flatten the blue play dough slightly before wrapping it around the yellow nucleus to form the somatic cell of the long-horned zazzle.
3. Roll one small ball of the red play dough to represent the nucleus of the non-genetic parent egg.
4. Flatten the white play dough slightly before wrapping it around the red nucleus of the non-genetic parent egg.
5. Place the blue/yellow somatic cell (genetic parent) next to the white/red egg cell (non-genetic parent).
6. Place a toothpick into each cell. Use the sticky tape to label the genetic parent and the non-genetic parent. Take a photo of the cells.

Part B: Modelling

1. Remove the red nucleus from the non-genetic parent cell and place it to one side. Take a photo of the cell.
2. Remove the yellow nucleus from the genetic parent cell and place it into the centre of the white cell of the non-genetic parent. Close the white play dough around the yellow nucleus. Place the correct label on the cell. Take a photo of the cell. The cell is now ready to start replicating.
3. Print out the photos and use the sticky tape to attach them to the A4 paper.
4. Write descriptions of the process on the A4 paper.

Results

Produce a poster or diagram of the cloning process.

Discussion

1 Explain the appearance (horn or no horn) of the zazzle baby once it is born.

2 Describe the influence the surrogate mother will have on the appearance of the baby. Consider any epigenetic factors in your answer.

3 Identify this process as sexual or asexual reproduction. Justify your answer.

4 Describe the advantages and disadvantages of this process.

5 Choose one of the following bioethical issues that may arise as a result of this process. Justify your answer to the question.

   a Should the zazzle be released into the rest of the wild zazzle population?

   b The reproductive cloning program costs $200 000 per zazzle born. Is this worth the cost?

   c Should this process be used to breed zazzles for commercial horn use?

   d If the genetic parent was owned by one person, and the surrogate zazzle was owned by a second person, who owns the baby zazzle?

   e Should the baby zazzle be used for scientific research?

Conclusion

Describe what you know about reproductive cloning.

10.2 PRACTICAL Plant adaptations

Practical worksheet
10.2 Plant adaptations

Practical demonstration
10.2 Plant adaptations

Lab tech notes
10.2 Plant adaptations

Risk assessment
10.2 Plant adaptations

Context

Like all cells, plant cells need a series of adaptations to increase their chances of surviving in an environment. These adaptations can be structural, behavioural or physiological. Stems and roots have adapted so that the cells in the tip of a stem extend towards the light, and cells in the root tip extend downwards.

Aim

To observe the response of a seed to gravity

Materials

- 6 pea seeds
- Protractor
- Cotton wool
- Petri dish
- 6 pins
- Cork
- 200 mL beaker
- Watch glass
- Paper towel (wet)

Method

1 Allow six pea seeds to germinate on damp cotton wool in a Petri dish for 5 days in the dark, or until the radicles (developing roots) are straight and 30 mm long.

2 Wrap damp cotton wool around the cork and use the pins to attach the six seedlings with straight radicles to the cork. Make sure three of the radicles are pointing upwards and three are pointing downwards. Attach just above the centre of the cork.

3 Put folded damp paper towel in the bottom of the 250 mL beaker. Seedlings need to be kept at a high level of humidity to grow.

4 Place the cork and seedlings in the base of the beaker. Cover with the watch glass.

5 Place the covered beaker containing seedlings in a dark cupboard for 1 week. Check each day that they are not drying out too much. Add a little water if they are.

6 After one week, remove the beaker with the seedlings from the cupboard and measure the degree of curvature of the radicles (see Figure 1) towards or away from the original position (i.e. vertical).

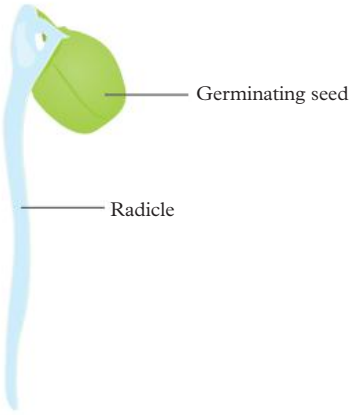


FIGURE 1 A germinating pea seed

7 Copy Table 1 into your logbook and use it to record your results.

Results

TABLE 1 Response of radicles to gravity

Radicle number	Radicle start position	Your results	Class results (Group)							Average
			A	B	C	D	E	E	F	
1	Up									
2	Up									
3	Up									
4	Down									
5	Down									
6	Down									

Discussion

1 Use the results table to explain why it is necessary to have a large number of plants for an experiment.

2 A radicle is the part of the plant that develops into the plant root. Describe the advantage of a root growing down as a result of gravity.

3 Identify this adaptation as physiological, structural or behavioural. Explain your reasoning.

Conclusion

Explain how a seed's adaptations improve its chances of survival.

10.3 PRACTICAL Field study of adaptation and distribution

Practical worksheet
10.3 Field study of adaptation and distribution

Practical demonstration
10.3 Field study of adaptation and distribution

Lab tech notes
10.3 Field study of adaptation and distribution

Risk assessment
10.3 Field study of adaptation and distribution

Background

Select a plant species from a local field guide to your area. Alternatively, visit a local nursery and select a plant.

1 What is the scientific name and common name of your plant?

2 Describe a structural and a physiological adaptation that enhances the survival of your plant. Describe how these adaptations increase the plant's chances of survival.

3 Identify how your plant may reproduce sexually or asexually.

4 Formulate a question about where your plant is likely to survive in a native environment in your area (*in situ*). Include any limitations you will need to make on area size or location.

Examples include:

- distribution of your species in a national park and/or a comparison between the national park and the non-national park
- population density of your plant at one area of a national park and/or a comparison between the national park and the non-national park
- competition between different species of plants for resources
- any other question you negotiate with your teacher.

5 Write a hypothesis (testable statement that includes a prediction) for your scientific question.

Aim

To observe the adaptation and distribution of a selected plant species in the field

Materials

- Quadrats (1 m × 1 m)
- Plastic spoon
- Small plastic container containing tap water and 5 drops of universal indicator
- Thermometer
- Light meter
- Universal indicator charts

Method (*in situ*)

1 Set up a transect line across the area you are visiting.

2 Place the quadrats at regular intervals across the transect line. Each quadrat should have a number for identification.

3 At each location, test the following factors. Copy Table 1 into your logbook and use it to record your results.

- Air temperature: use the thermometer to determine the temperature of the air 1 metre above ground level.
- Soil pH: use a plastic spoon to put a small amount of soil into the plastic container with water and universal indicator; swirl to mix the contents. Use a colour chart to record the pH of the soil.
- Soil temperature: carefully place the thermometer 5 cm into the soil. When the temperature remains stable, record the temperature.
- Light level: use the light meter to record the amount of light (lux) in the centre of the quadrat at ground level.
- Soil type: use the classification grid in Figure 1 to determine the type of soil in the quadrat.

4 Copy Table 2 into your logbook and use it to record each type of plant found inside the quadrat, and the approximate percentage of ground that it covers.

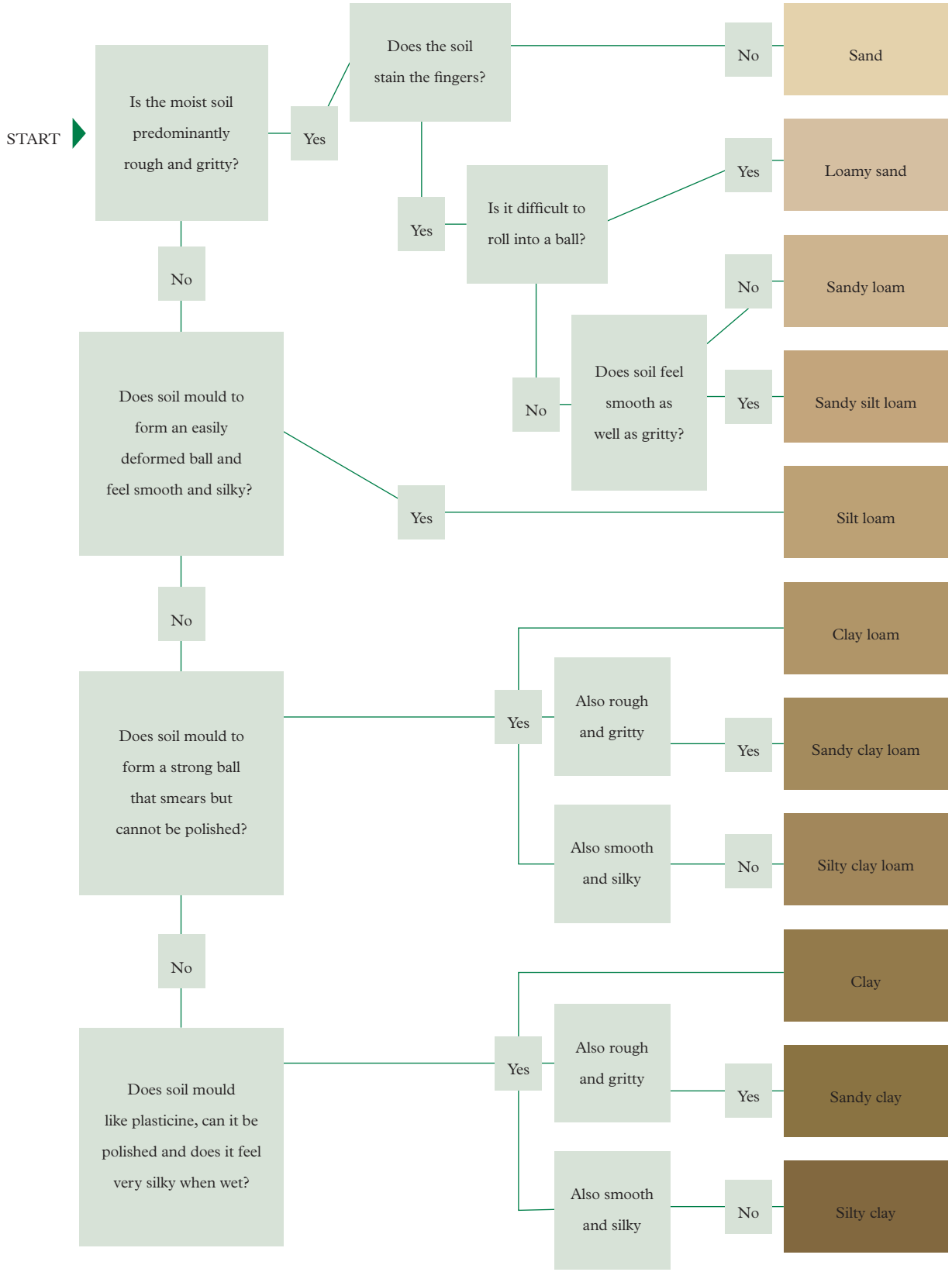


FIGURE 1 Classification grid for soils

5 Select two examples of your plant from different locations of the study area. Describe the structural appearance of both examples, including the height, width, amount/number of leaves exposed to sunlight or shade and the symmetry of the plant.

Results

Complete Tables 1 and 2 as a summary of class results.

TABLE 1 The physical factors *in situ* that affect plant survival

Factor	Quadrat					
	1	2	3	4	5	6
Air temperature (°C)						
Soil pH						
Soil temperature (°C)						
Light (lux)						
Soil type						

TABLE 2 The plants and percentage cover *in situ*

	Plant type	Percentage cover in quadrat					
		1	2	3	4	5	6
Plant A							
Plant B							
Plant C							
Plant D							
Plant E							

Discussion

1 Explain how the percentage cover of your chosen plant varied over the different quadrats. Was it more likely to be found in one quadrat than in any other quadrat?
2 Describe the distribution, density and size of your plant's population across the area.
3 Identify and describe any physical factors that had the same variation as your plant. Describe the variation.
4 Describe one adaptation of your chosen plant that enabled it to survive in the environment with that physical factor.
5 Compare two examples of your plant found in different locations. Explain how the plant may have adapted to survive in the different locations.
6 Could the differences in the plants described in Question 5 be due to sexual diversity? Explain your answer.
7 Research to determine whether local Indigenous peoples used your chosen plant for traditional food or medicines.
8 Suggest a way your plant could be genetically manipulated to improve its survival in the area in the future. Discuss the bioethical issues that could arise as a result of this manipulation.

Conclusion

Explain what you know about the adaptations, population distribution and local Indigenous people's knowledge and use of your chosen plant.

FIGURE 1 Quadrats are commonly used in the field to isolate a standard unit of area and to study the distribution of an item over a large area.

GLOSSARY

A

Aboriginal and Torres Strait Islander Peoples
the original inhabitants and custodians of the land now known as Australia, inhabiting this land for more than 65 000 years

accuracy
how close the experimental data is to the true value

adaptation
a characteristic that enhances an organism's survival within an environment

aim
the main purpose of the practical investigation

alimentary canal
the passage from mouth to anus in which food passes during digestion

allele
an alternative form of a gene

ammonia
a toxic waste produced by the body; NH_3

amylase
the general term for an enzyme that breaks down polysaccharides to disaccharides

anaphase
a stage of mitosis when the chromosomes separate at the centromere and move to opposite sides of the cell

aneuploidy
a genetic abnormality in which an individual has an abnormal number of chromosomes

anti-diuretic hormone (ADH)
a hormone released by the pituitary gland that prevents the production of dilute urine in the kidneys

apoptosis
programmed cell death

apoptotic body
a bleb that has separated from a cell but is still enclosed in membrane

asexual reproduction
a mode of reproduction in which a single parent reproduces without the fusion of egg or sperm

autosomal dominant
a pattern of inheritance where affected individuals have at least one allele (located on an autosome) for the trait

autosomal recessive
a pattern of inheritance where two copies of the same allele (located on homologous autosomes) must be present for the trait to show in the phenotype

autosome
a chromosome that is not involved in sex determination

auxin
a hormone responsible for phototropism in plants

B

Barr body
a small dense structure containing an inactivated X chromosome

behavioural adaptation
a behaviour that increases an animal's chances of survival and reproduction

beneficence
the ethical principle of a commitment to minimising risk and doing good

bilayer
a double layer

bile
a fluid secreted by the liver, stored in the gall bladder and secreted in the stomach that is essential for digestion

binary fission
a form of asexual reproduction in which the parent cell splits into two equal-sized daughter cells

biogenesis
the production of new living organisms from other living organisms

biology
the science of living things that is divided into different fields that cover the morphology, physiology, anatomy, behaviour, origin and distribution of organisms

bivalent chromosome
a pair of chromatids connected by a centromere

bladder
a membranous sac that stores urine from the kidneys

bleb
a bulge of cellular contents on the outside of an apoptotic cell

Bowman's capsule
a cup-like sac at the beginning of the nephron that collects the filtrate from the capillary network (glomerulus)

budding
a form of asexual reproduction in which single-celled and some multicellular organisms develop small growths or buds that develop into new, genetically identical organisms

C

carbohydrase
the general term for an enzyme that breaks down carbohydrate

carrier
a heterozygous individual with one allele for the recessive trait who shows the dominant trait

carrier protein
an integral protein that changes shape to transport molecules across the membrane

carrying capacity
the total population that can be supported by an environment

caspases
protease enzymes that are responsible for many steps in the apoptosis pathway

cell cycle
the process of a cell growing, dividing and dying

cell theory
the theory that describes cells as the basic component of all living organisms

cell wall
the outer protective and support structure of plant cells

cellular respiration
a process carried out by mitochondria in which glucose is converted into usable energy (ATP)

centriole
an organelle made up of microtubules that are involved in mitosis

centromere
the centre of a chromosome

centrosome
an organelle made up of two centrioles

channel protein
an integral protein that allows molecules to cross through the membrane

checkpoint M
the point in the cell cycle just before anaphase when all sister chromatids are checked that they are attached correctly to the spindle microtubules

chemical digestion
the breakdown of complex molecules into subunits that are small enough to be absorbed

chlorophyll
a pigment in chloroplasts that absorbs particular wavelengths of light for photosynthesis

chloroplast
an organelle of plant cells that carries out photosynthesis

cholesterol
a steroid molecule that regulates the fluidity of the membrane

chromatid
one strand of a bivalent chromosome

chromatin
the DNA and proteins that can be wound tightly to form a chromosome

chromosome
a coiled, condensed structure of DNA and associated histone proteins

cilia
hair-like extensions of the plasma membrane of some eukaryotic cells that require movement

cleavage
the process of splitting of a cell to form two daughter cells

clone
a cell or an organism that is genetically identical to the parent

codominance
a pattern of dominance in which two traits are equally dominant and the heterozygous individual displays both traits

collecting duct
the last part of the nephron that collects urine from many nephrons and moves the urine into the renal pelvis and ureters

community
all the species that occupy a specific place at a specific time

complete dominance
a pattern of dominance in which the recessive trait is completely masked by the dominant trait in a heterozygous genotype

concentration gradient
the unequal distribution of solute across a membrane

connective tissue
tissue that binds and supports other tissues or organs

contractile vacuole
a structure in some protists, which is involved in controlling the amount of water in a cell

control centre
the hypothalamus of the endocrine system with the primary function of maintaining homeostasis

controlled variable
a variable that is kept constant in an experiment

core skills
basic 'soft skills' required in most careers

Country
an area (not just geographical) that is traditionally owned and looked after by an Aboriginal (and sometimes Torres Strait Islander People) language group or community; a place of spiritual meaning with deep feelings of connection and attachment

cristae
projections of the mitochondrial inner membrane

crossing over
the process during prophase I of meiosis when homologous chromosomes exchange genetic material

cuticle
the superficial, non-cellular layer covering a plant or an animal

cytochrome c
a small protein on the inner membrane of mitochondria, which is involved in the electron transport chain of aerobic cellular respiration

cytokinesis
a stage in mitosis and meiosis when the cell divides into two daughter cells

cytoplasm
the contents of eukaryotic cells, excluding the nucleus

cytoskeleton
the internal skeleton of the cytoplasm – a support network of interconnected microscopic fibres and tubes

cytosol
the internal fluid component of a cell, excluding organelles

D

death receptor
a receptor on the surface of a cell that initiates the death of a cell

density
the average number of individual organisms living in a population in a given area

deoxyribonucleic acid (DNA)
the genetic material that carries cellular instructions

dependent variable
the variable being tested and measured in an experiment

diffusion
the random movement of substances across the plasma membrane from an area of high substance concentration to an area of low substance concentration

digestive system
the system in which ingested food is broken down, nutrients are absorbed and waste products are egested

dihybrid cross
a cross between two individuals to observe the inheritance of two different traits

diploid
a nucleus or cell that contains two sets of chromosomes, one from each parent ($2n$)

disease
a failure of regular physiological function

disjunction
the organised separation of chromosomes during meiosis

distal convoluted tubule
the part of the nephron between the loop of Henle and the collecting duct, which functions to concentrate the urine

distribution
the way in which members of a population are dispersed in a specific area

DNA methylation
the process of adding methyl groups to the cytosine bases of DNA, which can change the expression of a gene

dominance
refers to the relationship between the alleles of a gene and the observable phenotype

dominant phenotype
the phenotype that is seen in a homozygous individual and a heterozygous individual

dominant trait
the trait that is expressed in the phenotype of a heterozygous individual

E

ecosystem
a community of interacting organisms and the physical factors that surround them

effector
a muscle or gland that gives a response

egestion
the process of removing food that was never part of the organism

endocrine gland
an organ that produces and releases hormones directly into the bloodstream

endocrine system
a series of glands that secrete hormones that travel through the bloodstream to regulate body functions

endocytosis
active transport of macromolecules into the cell via vesicle formation from the plasma membrane

endoplasmic reticulum
an organelle involved in sorting, modifying and packaging proteins, lipids and steroids

enucleate
to remove the nucleus from a cell

enzyme
a protein that speeds up biochemical reactions

epidermis
the outer layer of tissue in a plant

epigenetics
the study of changes in gene expression caused by modification of the DNA without changing the sequence

epigenome
the epigenetic modifications to the DNA and histone proteins of an individual

epithelial tissue
tissue made of tightly packed cells that lines surfaces

equilibrium
when equal numbers of a specific molecule are either side of the plasma membrane

essential nutrient
a nutrient that must be ingested and absorbed by an organism, because it cannot be synthesised

eukaryote
an organism consisting of eukaryotic cells, such as animals, plants, fungi and protists

eukaryotic cell
a cell that contains a nucleus and other membrane-bound organelles

excretory system
the system that removes wastes from the body

exocytosis
active transport of substances out of the cell through the fusion of vesicles and the plasma membrane

external examination
an external test that assesses your knowledge of a subject

F

facilitated diffusion
passive movement of a substance through carrier or channel proteins from an area of high concentration to an area of low concentration

faeces
a compacted, undigested food mass that is eliminated from the body

filtrate
the fluid filtered from the blood passing through the nephron

filtration
the first stage of urine production that produces filtrate in the Bowman's capsule

fimbria
a fine extension of the bacterial plasma membrane that allows the cell to adhere to surfaces; plural *fimbriae*

fission
a form of asexual reproduction in which a parent cell divides into two or more genetically identical daughter cells

flaccid
limp

flagellum
a tail-like extension of the bacterial plasma membrane that allows movement; plural *flagella*

fragmentation
a form of asexual reproduction in which the body of a multicellular organism divides into many parts containing genetically identical cells

G

G1 checkpoint
the point in the cell cycle when a cell is assessed for the health of its organelles so it can proceed to the G2 phase

G2 checkpoint
the point in the cell cycle when a cell is assessed to see if the new DNA strands were made correctly

gall bladder
an organ beneath the liver that stores bile and releases it into the intestine

gamete
a haploid cell, egg and sperm

gastric juice
an acidic fluid secreted by glands in the stomach that aids in digestion

gene
a section of DNA that has a functional purpose, such as coding for a protein that determines a trait

gene expression
the process of converting the instructions in a gene to a product, which is usually a protein

gene pool
all the alleles that exist for all the genes within an interbreeding population

genetic diversity
the total number of genetically controlled characteristics that appear in the phenotype of a species

genome
the complete set of genetic material in a cell of an organism

genomics
a branch of biology that investigates genomes

genotype
the combination of alleles for a gene

germline cell
a diploid cell in human ovaries or testes that undergoes meiosis to form gametes

glomerulus
a capillary network in the Bowman's capsule where filtration occurs

glucagon
a hormone released by the pancreas that raises blood glucose concentration

glycolipid
a lipid of the plasma membrane with short carbohydrate chains attached

glycoprotein
a protein of the plasma membrane with short carbohydrate chains attached

Golgi apparatus
the combined Golgi body and associated vesicles

Golgi body
an organelle involved in modifying proteins into their final shapes and transporting them into vesicles

graph
a way of representing data to visually identify the relationship between the variables

guard cell
one of two cells surrounding a stoma in a leaf, which cause the stoma to open and close

H

haploid
a nucleus or a cell (usually an ovum or a sperm) that contains one set of chromosomes, so the chromosomes are not in pairs (*n*)

hemizygous
a genotype in which there is only one copy of the gene

heterogametic
an organism that has two different sex chromosomes, e.g. XY

heterotroph
an organism that derives its nutrients from other living organisms

heterozygous
a genotype in which the two alleles for the gene are different

histone
the protein that DNA wraps around to form nucleosomes

histone modification
the addition of chemical groups to histone proteins, which affects the spacing between nucleosomes and therefore gene expression

homeostasis
the regulation of an internal environment within a narrow range, despite changes to the external environment

homogametic
an organism that has two of the same sex chromosomes, e.g. XX

homologous chromosomes
a pair of chromosomes, one maternal and one paternal, that have the same number and position of genes

homozygous
a genotype in which the two alleles for the gene are the same

hormone
a chemical messenger that is released by endocrine glands and moves around the body in the bloodstream

Human Genome Project
an international program aiming to map the entire human genome

hybrid
an individual that was produced by phenotypically different parents

hydrophilic
'water loving'; a molecule that attracts water

hydrophobic
'water fearing'; a molecule that repels water

hyperthyroidism
a condition in which the thyroid is overactive and produces too many thyroid hormones

hypertonic solution
a solution that has a higher concentration of solutes than within the cell

hypoglycaemia
a condition in which blood glucose concentration drops too low

hypothalamus
a small region of the brain that has a vital role in regulating many body functions; referred to as the control centre

hypothesis
a prediction of the outcome of a practical investigation based on accurate scientific knowledge

hypotonic solution
a solution that has a lower concentration of solutes than within the cell

I

incomplete dominance
a pattern of dominance in which a heterozygous individual displays an intermediate phenotype that is a combination of the two alleles.

independent variable
the variable that is changed or controlled in an experiment

insulin
a hormone released by the pancreas that lowers blood glucose concentration

integral protein
a protein of the plasma membrane that spans from one side of the cell to the other

integrity
the ethical principle of a commitment to search for knowledge and be honest in approach

interphase
the phase cells undergo in their everyday lifecycles

intrinsic pathway
a biochemical pathway occurring completely within a cell that triggers apoptosis

isotonic solution
a solution that has the same solute concentration as within the cell

J

justice
the ethical principle of ensuring a fair and equal consideration of all factors

K

karyotype
the visual representation of the chromosomes from a cell nucleus of an individual

keystone species
a species that has a large effect on its environment and surrounding organisms

kidney
an organ of the excretory system that filters blood and produces urine

L

large intestine
part of the alimentary canal that is found after the small intestine and functions to absorb water and move faeces to the anus for egestion

law of independent assortment
a law that states that homologous chromosomes orient themselves randomly along the middle of the cell during metaphase I

law of segregation
the law that states that during gamete formation (meiosis), each gamete randomly receives one allele of each gene

linked genes
genes located on the same chromosome that are generally inherited together

lipase
the general term for an enzyme that breaks down lipids

locus
the location of a gene on a chromosome

loop of Henle
the part of the nephron in the medulla region of the kidney mainly involved in water and salt reabsorption

lyse
burst

lysosome
a specialised vacuole containing digestive enzymes to break down old, damaged organelles and cellular components as well as substances taken into the cell

M

master gland
the pituitary gland of the endocrine system, which controls other glands

matrix
the fluid-filled space within the inner mitochondrial membrane

medulla
the inner layer of the vertebrate kidney in which are found the loops of Henle and collecting tubules

meiosis
a type of cell division that produces gametes

metabolism
all the chemical processes occurring within a cell

metaphase
a stage of mitosis when chromosomes move to the centre of the cell

methodology
the approach used to plan and conduct a scientific investigation with justification

microfilaments
a component of the cytoskeleton made of actin

microtubules
a component of the cytoskeleton made of tubulin

mind map
a graphical way to represent key ideas and relationships between concepts

mitochondrion
an organelle that carries out cellular respiration in all eukaryotic cells

monohybrid cross
a cross between two individuals who are homozygous for a trait but with different alleles

monohybrid test cross
a cross between an individual with the dominant phenotype and an individual with the recessive phenotype to determine the genotype of the dominant individual

monosomy
a genetic abnormality in which one chromosome of a pair of homologous chromosomes is missing

multicellular
consisting of many cells

multiple-choice question
an examination question that requires you to select the most appropriate option from four possible alternatives

multipotent stem cell
a stem cell that can only differentiate into a limited number of closely related cell types

muscle tissue
tissue that makes up muscles, which allow for movement

mutagen
something that causes a mutation, either chemical, physical or biological

mutation
a permanent change to the DNA sequence

N

nastic response
a non-directional movement of plants

negative feedback
when the homeostatic response is the reverse of the stimulus

nervous system
a complex network of nerves that transmit signals between the body and the brain and spinal cord to coordinate responses to stimuli

nervous tissue
tissue of the nervous system, which regulates and controls bodily functions

nocturnal
most active at night

non-essential nutrient
a nutrient that can be synthesised by an organism

non-maleficence
the ethical principle of avoiding harm or minimising the amount of harm inflicted

nuclease
the general term for an enzyme that breaks down nucleic acids

nucleoid
a region of a prokaryotic cell where DNA is located

nucleolus
the region of the nucleus that produces ribosomes

nucleosome
DNA wrapped around histone proteins

nucleus
an organelle that stores genetic information within DNA; involved in protein synthesis and DNA replication

nutrient
any substance used as food by an organism

O

oogenesis
the meiotic process of ovum production in the ovaries

optimum range
the range of conditions in which an organism carries out life processes

organ
a group of tissues working together for a specific function

organelle
a compartment within the cytoplasm of a eukaryotic cell where specialised functions are carried out

osmoreceptor
a receptor that detects changes in blood osmolality

osmosis
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

outcome
the key knowledge and skills needed to demonstrate a satisfactory achievement in an Area of Study

outlier
any value that sits outside the data set

ovum
a female gamete

P

pancreas
a gland behind the stomach that secretes digestive enzymes into the small intestine

pancreatic juice
a digestive fluid secreted by the pancreas into the small intestine

parthenogenesis
a form of asexual reproduction in which a female animal reproduces without fertilisation of an egg by a male

pedigree
a diagram that shows the inheritance of a trait in a family for at least two generations

pepsin
a protease in the stomach that breaks down proteins into polypeptides

peripheral protein
a protein attached to one side of the plasma membrane, or to other proteins

peristalsis
the waves of contraction and relaxation in muscular walls of the alimentary canal, aiding in physical digestion and moving food forward through its length

phagocytosis
a form of endocytosis where solid macromolecules are transported into the cell

phenotype
the physical expression of the genotype and its environment

phenylketonuria (PKU)
a genetic disorder that causes a build-up of phenylalanine, which can lead to problems with brain development

phloem
the vascular tissue of plants that transports sugars (organic substances)

phospholipid
a molecule consisting of a phosphate head and a lipid tail; a key molecular component of the plasma membrane

photosynthesis
the process by which light energy is converted into chemical energy (glucose) in the chloroplasts of plant cells

physical digestion
the breakdown of food into small units

physiological adaptation
a functional adaptation that increases an organism's chances of survival

pilus
a small extension of the bacterial plasma membrane used to exchange genetic material (plasmids); plural *pili*

pinocytosis
a form of endocytosis where fluid is transported into the cell in a vesicle

pituitary gland
an important gland that controls the activity of most other glands; referred to as the master gland

Place
a space confined by physical or intangible boundaries occupied and regarded as belonging to individuals or groups of Torres Strait Islander Peoples (and sometimes Aboriginal Peoples); the spaces have varying spiritual meaning to the people

plant response
a plant movement that increases its chances of survival

plasma membrane
the boundary of all cells that separates the cytosol from the external environment and controls the entry and exit of substances

plasmid
a small circular piece of extra DNA found in bacterial cells

plasmodesmata
structures that join the cell walls of neighbouring plant cells together

plasmolysis
the process by which a plant cell membrane pulls away from the cell wall as water is lost from the cell via osmosis

plastid
an organelle in plant cells that produces and stores pigments and starch

pluripotent stem cell
a stem cell that can differentiate into any cell type within a broad group

polar body
a small cell that buds off a developing ovum during oogenesis and does not develop into ova

polygenic trait
a trait controlled by multiple genes

population
the number of individuals of a species living in a particular place at a particular time

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

predation
when one organism kills and consumes another organism

primary data
data collected by the investigator from first-hand sources

prokaryote
a single-cell organism made of a prokaryotic cell

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

prophase
a stage of mitosis when DNA coils into chromosomes

protease
the general term for an enzyme involved in the breakdown of proteins

protein pump
an integral protein that actively transports molecules across a membrane against a concentration gradient

proximal convoluted tubule
the part of the nephron between the Bowman's capsule and the loop of Henle that is involved in the process of reabsorption

Punnett square
a table that predicts the genotypes of a particular cross

Q

qualitative data
data that tends to be non-numerical and is subjective (e.g. hair colour, choice of clothing)

quantitative data
data expressed as a number (e.g. concentration of solutions, temperature)

quiescent
in a period of rest or dormancy

R

random error
an error that affects the precision of the data due to an unknown and unpredictable error in the experimental process

raw data
measurements or observations of the dependent variable

reabsorption
the second stage of urine production in which substances are reabsorbed from the filtrate into the surrounding capillary network

receptor
a structure that detects a stimulus

recessive phenotype
the phenotype that is observed from a homozygous recessive genotype

recessive trait
the trait that is only expressed in the phenotype of a homozygous individual

recombinant chromosome
a chromosome formed after the crossing over of genetic material between the homologous chromosomes

renal artery
the blood vessel entering the kidney

renal cortex
the outer part of the vertebrate kidney in which are found the Bowman's capsule, glomerulus and convoluted tubules of the nephron

renal vein
the blood vessel leaving the kidney

repeatability
a measure of achieving the same set of data if the experiment was repeated under the same conditions

reproducibility
a measure of achieving the same set of data if the experiment was repeated with a different experimenter in a different laboratory

respect
the ethical principle that accepts the value of living things and their ability to make their own decisions where possible

response
a change in an organism resulting from a stimulus

ribosome
an organelle in which proteins are made

risk assessment
a document that outlines the potential risks, hazards and subsequent control measures that should be taken to avoid harm

root hair
cells of the root that absorb water and minerals from the soil

root system
the plant system that develops below ground

rough endoplasmic reticulum
an organelle that produces, modifies and packages proteins synthesised on ribosomes

S

salivary glands
glands in the mouth that discharge saliva that helps move food down the alimentary canal and starts chemically digesting the food

secondary data
data collected by another person, not the investigator, which is relevant to the scientific investigation

secretion
the final stage of urine production in which wastes are moved into the urine

semi-conservative replication
a process where each strand of the previous DNA is used to form a complementary new strand

sex chromosome
a chromosome that determines the sex of an organism

sex-linked
refers to genes that are found on the X or Y chromosome

sexual reproduction
a mode of reproduction that involves a haploid female gamete (egg) fusing with a haploid male gamete (sperm)

shoot system
the plant system that develops above ground

short-answer question
an examination question that requires a written response

sieve tube element
a specialised cell of the phloem that helps in the translocation of sugars

small intestine
the part of the alimentary canal between the stomach and the large intestine, mainly involved in absorption

smooth endoplasmic reticulum
an organelle that produces, modifies and packages steroids, carbohydrates and lipids

somatic cell
a cell in an organism other than the reproductive cells

specialised cell
a cell that has certain structures and carries out particular functions

species
a taxonomic group, allocated two (genus and specific) names; only members of the same species can produce fertile offspring when mating under natural conditions

spermatogenesis
the meiotic process of sperm production in the testes

spindle
thread-like proteins that attach to the centromere of chromosomes in order to move them during mitosis

spore
a reproductive cell produced by bacteria, fungi, mosses and ferns, capable of developing into a new organism without fusing with another reproductive cell

stem cell
a cell that is capable of forming different cell types

stimulus
an internal or external change that causes a response

stimulus–response model
the homeostatic pathway from stimulus to response

stoma
a small pore in the leaf of a plant, which allows gases to move in and out

stomach
an organ of the digestive system that has a major role in the physical and chemical digestion of food

stroma
the fluid region of chloroplasts

structural adaptation
a physical characteristic of body size and shape that increases an organism's chances of survival and reproduction

surface area
the total area of the plasma membrane that diffusion occurs across

system
a group of organs that function together for a particular purpose

systematic error
an error that affects the accuracy of the data by causing the reading to differ from the true value

T

table
a form of organising data systematically into columns

target cell
a cell that responds to a hormone because it has specific receptors for that hormone

thermoreceptor
a receptor that detects changes in temperature, either hot or cold

thermoregulation
regulation of internal body temperature

thylakoid
a disc-shaped sac within chloroplasts where chlorophyll is produced

tissue
a group of specialised cells functioning together for a particular purpose

tolerance level
the range of conditions that an organism can survive

tonoplast
a membrane of the large central vacuole of plant cells

totipotent stem cell
an undifferentiated cell that can later differentiate into any type of cell

tracheid
a specialised cell of the xylem

translocation
the process of sugar movement through the phloem

transpiration
the process of water movement through the xylem and evaporation at the leaves

trisomy
a genetic abnormality in which an individual has an extra copy of a chromosome

tropism
a directional movement of a plant towards or away from an environmental factor

true-breeding
individuals that when crossed together produce offspring with the same genotype and phenotype as the parents for a particular trait

true value
the value that accurately represents the measurement had the experiment been conducted perfectly

tumour necrosis factor-α (TNF-α)
a signalling molecule that has roles in inflammation and apoptosis

turgid
swollen

type 1 diabetes
an autoimmune disease in which the person doesn't produce enough insulin to maintain blood glucose concentration

U

unicellular
consisting of a single cell

unipotent stem cell
a stem cell that can only form one cell type on division

unlinked genes
genes on different chromosomes that assort independently from one another

urea
the main nitrogenous waste excreted in urine

ureter
the duct that moves urine from the kidney to the bladder

urethra
the duct that moves urine out of the body from the bladder

urine
a fluid containing urea and other waste substances released from the kidneys, stored in the bladder and excreted via the urethra

V

vacuole
a membrane-bound, fluid-filled organelle used by plants as a fluid reservoir

validity
a measure of whether the investigation is sound

vascular plant
a plant with vascular tissues (xylem and phloem)

vegetative reproduction
a form of asexual reproduction in which a plant undergoes fragmentation to form another genetically identical plant

vesicle
a small fluid-filled organelle that transports substances throughout the cytoplasm, fusing with other cellular membranes to release their contents

vessel member
a specialised cell of the xylem

volume
the total amount of space in a contained area

X

xerophyte
a plant suited to living in hot, dry environments that is generally drought tolerant

X-inactivation
the process by which one X chromosome in females is inactivated

X-linked dominant
a pattern of inheritance where the gene for a dominant trait is located on the X chromosome

X-linked recessive
a pattern of inheritance where the gene for a recessive trait is located on the X chromosome

xylem
the vascular tissue of plants that transports water and mineral ions

Y

Y-linked
a pattern of inheritance where the gene for the trait is located on the Y chromosome

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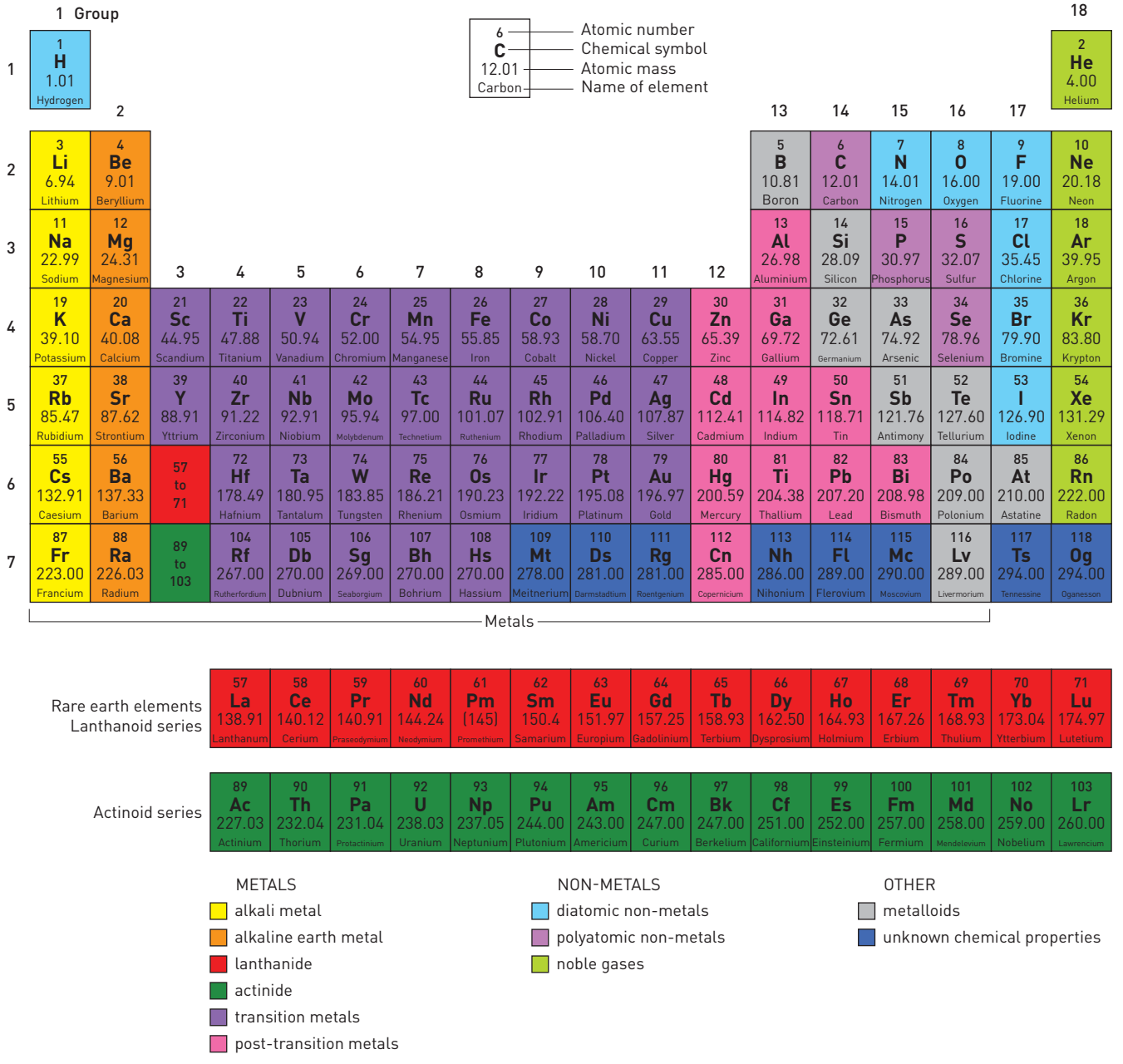

This front cover shows a salt lake in Victoria where tussock grass, known as *Poa sallacrustis*, has evolved to withstand high concentrations of salt by excreting crystals from its leaves. The large tree in the foreground cannot regulate salinity in the same way and so cannot survive.

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