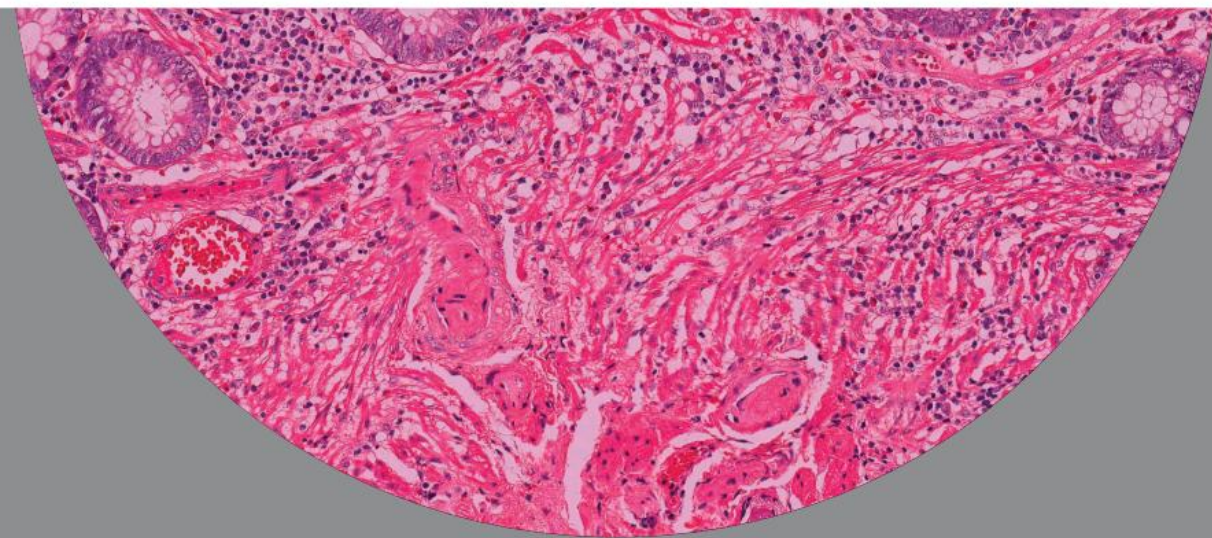


BIOLOGY IN FOCUS



YEAR

11

Glenda Chidrawi

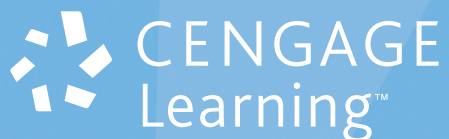
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2ND EDITION





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BIOLOGY IN FOCUS

YEAR

11

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2ND EDITION

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2nd Edition

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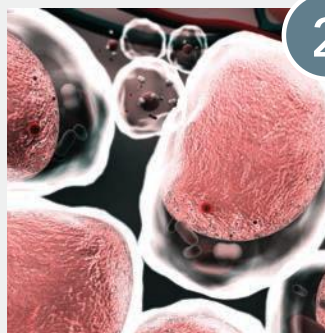
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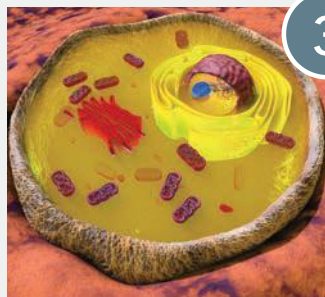


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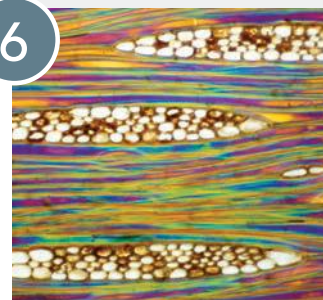


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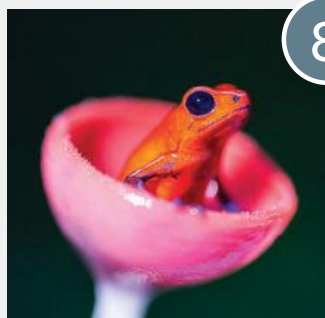


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PREFACE

Biology in Focus 2nd edition (Year 11) has been written to the specifications of the NSW Syllabus for the Australian Curriculum, Stage 6 Biology. The team of authors are academic and classroom teaching experts, chosen for their comprehensive knowledge of the biology discipline and best teaching practice in biology education at secondary and tertiary levels. They have written the text to make it accessible, readable and appealing to students, covering contexts that ensure students gain a wide perspective on the breadth and depth of current biology. The rigorous and methodological approach enables students to reach the highest possible standard. The level of depth and interest are aimed at giving students the necessary understanding to pursue tertiary studies in biology, health sciences, medicine, conservation science, genetics, biotechnology, bioinformatics and other STEM-related courses.

Each chapter of *Biology in Focus* follows a consistent pattern. Learning outcomes from the syllabus appear on the opening page. The text is then broken into manageable sections under headings and sub-headings. All chapters have been structured around the syllabus-identified inquiry questions, and focus within the chapter is on students asking and refining their own questions for investigation. Relevant diagrams that are easy to interpret and illustrate important concepts support the text. New terms are **bolded** and defined in a glossary at the end of the book. Important concepts are summarised to assist students to take notes. Question sets are found at the end of each section within the chapter, and a comprehensive set of review questions at the end of each chapter expands on the questions sets for further revision and practice. Questions have been set to accommodate the abilities of all students. Complete worked answers appear on the student website.

Worked examples, written to connect important ideas and solution strategies, are included throughout the text. Solutions

are written in full, including step-by-step instructions on how to perform mathematical calculations. The logic behind each step is explained and mathematical relationships are shown in their biological context. In order to consolidate learning, students are challenged to try similar questions on their own.

The broad range of investigations demonstrates the high level of importance the authors attach to exploring and discovering the living world through practical activities and research. Investigations are presented in a manner that provides opportunities for students to develop skills in designing experiments as well as in planning and conducting valid and reliable procedures, taking into account safety and conducting risk assessments. The hands-on activities introduce, reinforce and enable students to practise first-hand the Working Scientifically strand of investigation skills of the NSW syllabus, especially experimental design, data collection, analysis and conclusions. There are more than enough investigations to meet the 35 hour minimum requirement of the syllabus. Chapter 1 explores the concepts of reliability, validity and the nature of scientific investigation using the scientific method, and provides valuable information for performing and analysing investigations and carrying out depth studies. Detailed information is provided that is designed to enhance students' experiences and to provide them with information that will maximise their marks in this fundamental area, which is reinforced throughout the course.

Students are encouraged to evaluate experimental design and consider ideas for improvement, taking into account accuracy, precision, uncertainty and error – concepts that are introduced in Chapter 1. This invaluable tool supports student learning through chapter questions and investigations.

Biology in Focus 2nd edition (Year 11) provides students with a comprehensive study of modern biology that will fully prepare them for exams and any future studies in the area.

Glenda Chidrawi (lead author)

AUTHOR AND REVIEWER TEAMS

Glenda Chidrawi – lead author

Glenda Chidrawi (BSc Hons, HDipEd (PG)), with an Honours degree in molecular biology, has been involved in biology education for more than 30 years. She has lectured and taught biology at universities and schools in both South Africa and Australia (Brigidine College 2000–2014 and Knox Grammar School 2015–2016). Glenda is currently an education consultant with the Association of Independent Schools of NSW. Glenda has co-authored senior Biology textbooks, including *Biology Options – Communication*, part of an award-winning series. Glenda has also co-authored the *Biology in Focus Preliminary* and *Biology in Focus HSC* textbooks and the Student Resource CDs and Teachers' Resource CDs that support these publications. Glenda has had articles published in educational journals and has written programs for the AISNSW and material for the NSW QTP Science Program *Teaching the Stage 6 Syllabus*. More recently, Glenda co-authored the *Nelson iScience 10* textbook for the NSW Australian syllabus. Glenda is a familiar figure at education conferences in Australia and currently works in the area of teacher accreditation at AISNSW.

Sarah Bradstock

Sarah grew up in Sydney and graduated from the University of Sydney with a Bachelor of Veterinary Science in 1990. She practised as a small animal veterinarian for eight years. After completing a Graduate Diploma of Education in 1997 she worked as a full-time Science teacher in Sydney for 20 years. She is currently undertaking a Master of Education in Digital Literacy and Knowledge Networks at Charles Sturt University

because she has a special interest in the use of digital technology to enhance student engagement and learning in the Biology classroom. Sarah's special biological interest is in animal and human physiology and disease processes.

Margaret Robson

Margaret Robson has been a Science teacher with the NSW Department of Education for the last 37 years, teaching both Biology and Chemistry. She is currently Head Teacher of Science at Brisbane Water Secondary College. Margaret was one of the co-authors of the very successful *Biology in Focus HSC* textbook. Her work for this textbook included writing for the Student Resource CD and the Teachers' Resource CD. Margaret has been an HSC marker for Biology since 1996, including nine years as a Senior Marker. She has also served as a member of the committee responsible for preparing the Catholic Trial paper in Biology for the last seven years.

Elizabeth Thrum

Elizabeth has been teaching biology for 27 years in a variety of different contexts and schools. She has developed a reputation among her peers as an experienced Biology teacher at the HSC level in both marking and writing of trial papers. She is currently the Head of Science at Knox Grammar School, where she works with a passionate team of educators. She has a passion for teaching Biology and helping students reach their potential. She also likes to work with Biology teachers to ensure that they can teach engaging lessons. Above all she would like students to see how biology is relevant in their daily lives.

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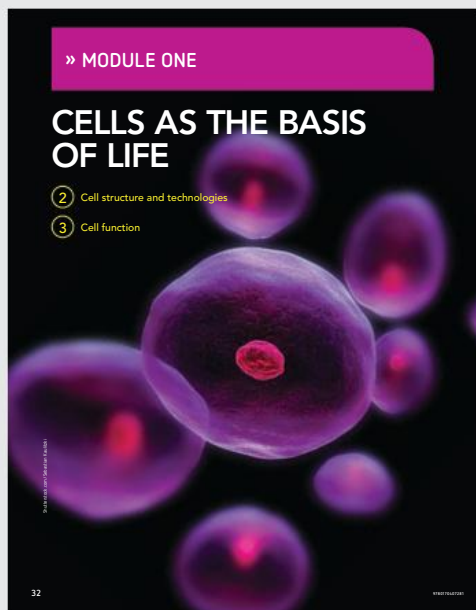
Lead Author Glenda would like to acknowledge **Mrs Joyce Austoker-Smith**, who encouraged her to put pen to paper and mentored her through the early years of writing textbooks. The authors would like to thank their families and colleagues for their support and encouragement, their publisher **Eleanor Gregory** for her guidance, and the many students they have taught over the years whose interest in Biology and desire to learn has been their inspiration.

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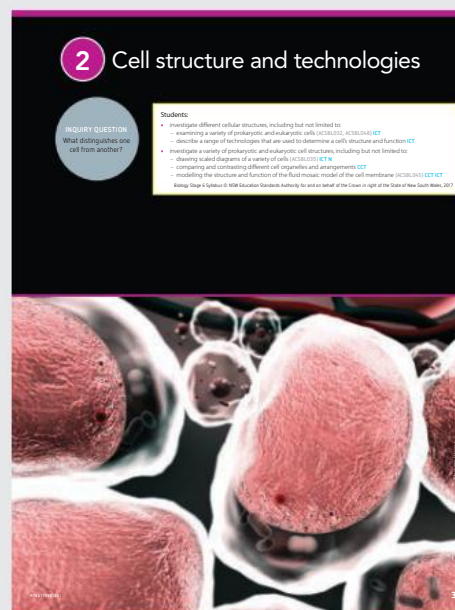
Eleanor Gregory sincerely thanks **Glenda, Marg, Sarah** and **Liz** for their perseverance and dedication in writing this manuscript. She also thanks **Pam Borger** and **Dr Stephen Bird** for reviewing the manuscript to ensure that it was of the highest quality. Also thanks to **Dr Stephen Bird, Pam Borger, Gillian Dewar** and **Evan Roberts** for creating NelsonNet material.

USING *BIOLOGY IN FOCUS*

Biology in Focus Year 11 has been purposely crafted to enable you, the student, to achieve maximum understanding and success in this subject. The text has been authored and reviewed by experienced Biology educators, academics and researchers to ensure up-to-date scientific accuracy for users. Each page has been carefully considered to provide you with all the information you need without appearing cluttered or overwhelming. You will find it easy to navigate through each chapter and see connections between chapters through the use of margin notes. Practical investigations have been integrated within the text so you can see the importance of the interconnectedness between the conceptual and practical aspects of Biology.



The content is organised under four modules, as set out in the NESA Stage 6 Biology syllabus. Each module begins with a **module opening page**.



Each chapter begins with a **chapter opening page**. This presents the learning outcomes from the NESA Stage 6 Biology syllabus that will be covered in the chapter and also gives you the opportunity to monitor your own progress and learning.

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

Throughout the text, important ideas, concepts and theories are summarised in **key concept boxes**. This provides repetition and summary for improved assimilation of new ideas.

KEY CONCEPTS

- Endocytosis moves large molecules that cannot cross the cell membrane into a cell. It requires the expenditure of energy.
- In endocytosis, the cell membrane changes shape and surrounds and engulfs the particle so that it enters the cell.
- Phagocytosis is the process whereby solid particles are engulfed by the cell membrane.
- Pinocytosis is the engulfing of fluid substances by the cell membrane.

Learning across the curriculum content has been identified by NESA as important learning for all students. This content provides you with the opportunity to develop general capabilities beyond the Biology course, as well as links into areas that are important to Australia and beyond. This content has been identified by a margin icon.



Mathematical relationships are presented in context. Step-by-step instructions on how to perform mathematical calculations are shown in the **worked examples**. The logic behind each step is explained and you can practise these steps by attempting the related problems presented at the end of each worked example.

WORKED EXAMPLE 13.1

A grassland area contains an initial population of 20 female kangaroos. The females give birth to 12 joeys in the next 12 months but four kangaroos die in that year due to drought and disease. If the growth rate is geometric, what will the kangaroo population be in:

- 2 years?
- 8 years?

ANSWER	LOGIC
a $M(t+1) = 20 + 12 - 4 = 28$ $\lambda = \frac{M(t+1)}{M(t)} = \frac{28}{20} = 1.4$ $M(t) = M(0)\lambda^t$ $M(2) = 20 \times (1.4)^2$ $M(2) = 39.2$ Therefore there will be 39 kangaroos in 2 years' time. b $M(t) = M(0)\lambda^t$ $M(8) = 20 \times (1.4)^8$ $M(8) = 20 \times (14.7)$ $M(8) = 295.2$ Therefore there will be 295 kangaroos in 8 years' time.	- Calculate the size of the population after year 1. - Rearrange the above equation to make λ the subject and then apply the equation. - Calculate the population in 2 years' time. - Use the same logic to calculate the kangaroo population in 8 years' time.

Biology is a science and you need to be given the opportunity to explore and discover the living world through practical investigations. **Investigations** introduce and reinforce the Working scientifically skills listed in the NESA Stage 6 Biology syllabus. In some cases, the investigations are open-ended. These provide you the opportunity to design and carry out your own scientific investigation, either individually or in a group. At times you are prompted to consider ideas for improvement or further investigation to illustrate that science is an ongoing and improving process. At other times, investigations are secondary-sourced, meaning that you need to research the subject using data and information gained by other people. Further information on how to conduct a scientific investigation can be found in the Working scientifically and depth study chapter on page 1.

INVESTIGATION 3.2

An investigation to model the process of osmosis

In this model of osmosis, the semipermeable dialysis tubing represents the selectively permeable cell membrane. The sucrose solution represents the cytoplasm of the cell and the distilled water represents the extracellular fluid.

AIM
To model the process of osmosis

MATERIALS

- 3 × 600 mL beakers
- Distilled water
- Sucrose solution
- Fine string
- 2 × glass rods
- 2 × 20 cm strips dialysis tubing
- 25 mL measuring cylinder
- 100 mL measuring cylinder
- Filter funnel
- Marking pen
- Plastic clingwrap
- Digital camera (optional)

RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THE RISK?
Broken glass	Injury to body	Take care at all times when using glassware.

METHOD

- Cut two pieces of dialysis tubing to 20 cm lengths and soak in a beaker of water for about 5 minutes.
- Tie one end of each piece of tubing securely with a piece of string, leaving the other end untied.
- Run the untied end of the tubing under water and rub it between your fingers to open it.
- Using a filter funnel and a measuring cylinder, pour a measured volume (about 30–35 mL) of sugar solution into the tubing so that the tubing is two-thirds full. (Record the exact volume of sugar solution used.)
- Tie the top of the tubing with string. Attach it to a glass rod as shown in Figure 3.12. This is your experimental apparatus.
- Repeat the previous two steps, this time filling the tubing with distilled water instead of sugar solution. This is your control apparatus.
- Using a measuring cylinder, fill each beaker about half-full and record an accurate measurement of the volume of water in each.
- Suspend the experimental and the control apparatus each in a beaker of distilled water as shown in Figure 3.12. Ensure that the tied ends of the dialysis tubing are just above the distilled water in the beaker to prevent leakage. Do not have the tubing too far out of the water because evaporation may occur and this will interfere with the accuracy of your results.



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



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

You will learn more about fluid transport in Chapter 6.

margin notes.

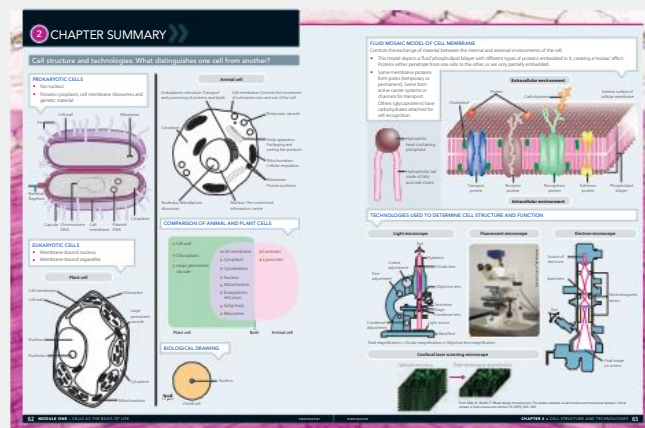
Regular opportunities to recall new terms and review recent concepts are provided as short **check your understanding** question sets throughout each chapter.

CHECK YOUR UNDERSTANDING 3.1b

- Define the process of active transport and provide an example of where this occurs.
- Distinguish between the processes of active transport and simple diffusion.
- Describe the process of endocytosis and provide an example of where it is used.
- Describe how the cell membrane is involved in each process listed below and provide an example of the use of each:
 - exocytosis
 - endocytosis
- Identify three types of substances that are removed from cells.

The **chapter review** section, which appears at the end of each chapter, provides the following:

- a visual **chapter summary** that shows how the important concepts are linked. This will be a valuable tool when you are revising for tests and exams



SYLLABUS MAPPING

Working scientifically mapping

Content statements from the NESA Stage 6 Biology syllabus are shown in full on the chapter opening pages of the chapters where they are dealt with. A full mapping of chapters and content statements can be found on the NelsonNet Teacher website. Below is a mapping of the outcome statements for Working scientifically across all the chapters of *Biology in Focus: Year 11*.

OUTCOME STATEMENTS A STUDENT:		CHAPTER												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	BIO11/12-1 develops and evaluates questions and hypotheses for scientific investigation	✓		✓			✓	✓			✓			✓
2	BIO11/12-2 designs and evaluates investigations in order to obtain primary and secondary data and information	✓		✓				✓		✓	✓			✓
3	BIO11/12-3 conducts investigations to collect valid and reliable primary and secondary data and information	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
4	BIO11/12-4 selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
5	BIO11/12-5 analyses and evaluates primary and secondary data and information	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
6	BIO11/12-6 solves scientific problems using primary and secondary data, critical thinking skills and scientific processes	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓
7	BIO11/12-7 communicates scientific understanding using suitable language and terminology for a specific audience or purpose	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓

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1

Working scientifically and depth studies

A student:

- Questioning and predicting
 - BIO-1 develops and evaluates questions and hypotheses for scientific investigation
- Planning investigations
 - BIO-2 designs and evaluates investigations in order to obtain primary and secondary data and information
- Conducting investigations
 - BIO-3 conducts investigations to collect valid and reliable primary and secondary data and information
- Processing data and information
 - BIO-4 selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media
- Analysing data and information
 - BIO-5 analyses and evaluates primary and secondary data and information
- Problem solving
 - BIO-6 solves scientific problems using primary and secondary data, critical thinking skills and scientific processes
- Communicating
 - BIO-7 communicates scientific understanding using suitable language and terminology for a specific audience or purpose

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Science is the systematic study, by observation and experiment, of the natural and physical world (Fig. 1.1). Science is characterised by a way of thinking and working, and, most fundamentally, by questioning. The knowledge and understanding that arise from this questioning are not in themselves science. They are the products of science, as is the technology that arises from this knowledge and understanding. Science is **empirical**, which means that when scientists ask questions, they seek to answer them by using evidence, in particular observational and experimental evidence.



FIGURE 1.1 Investigating in biology

Biology as a field of study was named in the 19th century and arose from the studies of medicine and natural history, both of which date back to ancient times. The term 'biology' comes from the Greek words *bios* (life) and *logos* (word or discourse). Biology asks questions about all living things, including plants, animals and micro-organisms. It asks questions about their structure and functioning, how and why they have changed over time and continue to change, about their interactions with each other and the environment, and about biodiversity and the continuity of life – looking at heredity and variation. These fields of interest in biology are grouped into subdivisions such as botany, zoology, microbiology, evolutionary biology, ecology and genetics. Given that all living things are interdependent, biology is a fascinating science!

1.1 The nature of biology

Questions lead to investigations and these in turn lead to scientific theories that are testable and falsifiable. This applies to all sciences, including biology. That means that, for a theory to be considered scientific, it must be possible to test it and, most importantly, to test whether it is not true. This is what **falsifiable** means: 'able to be disproved'. This sets science apart from many other disciplines in which there are theories that cannot be tested or disproved. Such theories are not scientific.

This is why scientists never talk about proving a theory, but rather about providing evidence to support a theory. When a large enough amount of evidence has been gathered that supports a theory, then that theory is accepted by the scientific community. Examples of theories in biology that have so much evidence supporting them that they are generally accepted are the cell theory and the Theory of Evolution by Natural Selection.

However, no matter how much evidence you gather supporting a theory, it takes only one experiment that disagrees to disprove a theory. As Einstein said: 'No amount of experimentation can ever prove me right; a single experiment can prove me wrong.'

There are many examples of theories and hypotheses in biology that were proposed and later rejected or changed when new evidence came to light. For example, the theory of spontaneous generation is now obsolete, and a theory proposed as the one-gene-one-enzyme theory was later changed when it was realised that a single gene may code for a number of different polypeptides. There are also examples of theories that were based on hoaxes, such as that of Piltdown man. Some hypotheses have been rejected because the scientific method used could not be repeated and was later shown to be invalid (for example, the hypothesis that proposed that autism could be caused by a certain vaccination).

KEY CONCEPTS

- Scientific theories are falsifiable; they can be disproved, but they cannot be proved. For a theory to be accepted it must be supported by a great deal of evidence.
- A good hypothesis is falsifiable and it takes only one instance of results that disagree with the hypothesis to disprove it.
- No amount of success in testing a hypothesis can prove it is right. Each confirming instance only increases one's confidence in one's idea.

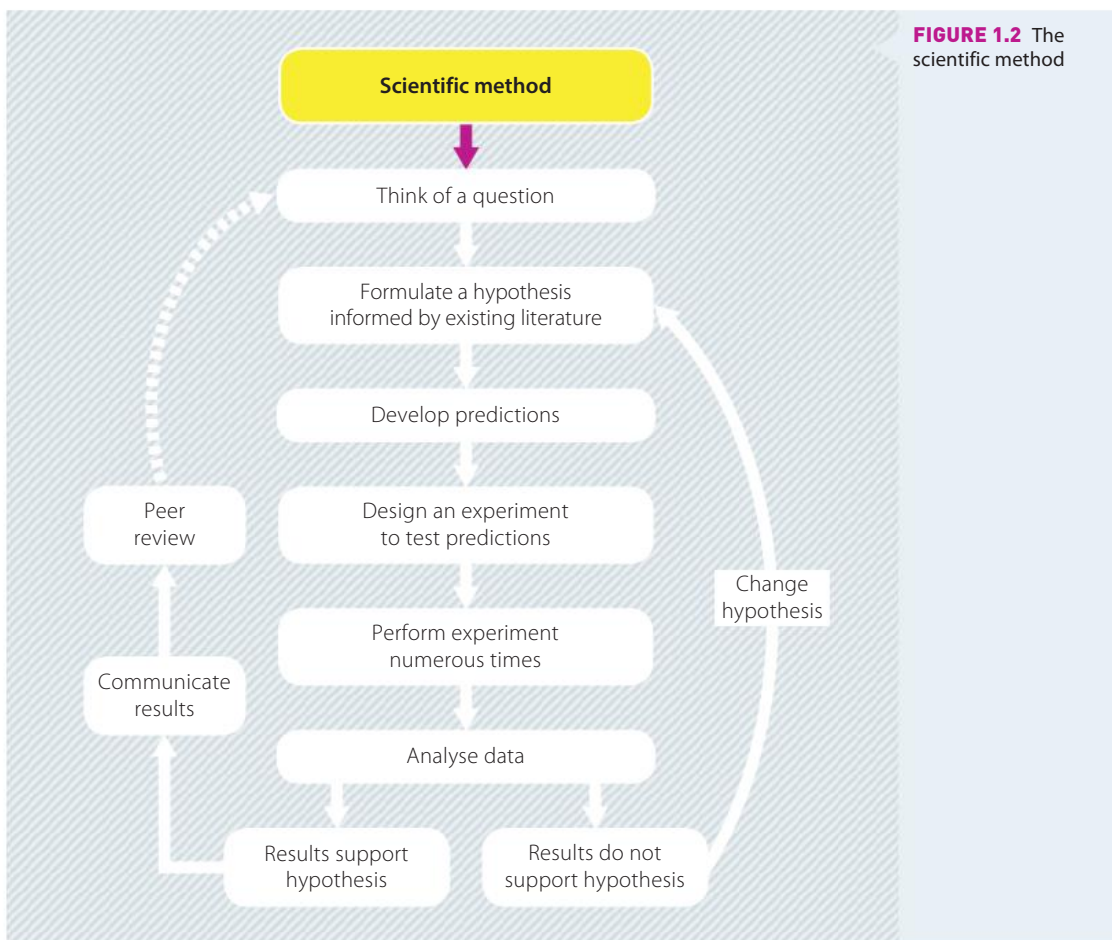


Laboratory
rules

The scientific method – an overview

The **scientific method** is the process of systematically gathering information and data by observation and measurement, and using the information and data to formulate and test hypotheses. It is from such investigations that the body of scientific knowledge that we accept today has been accumulated.

The scientific method is summarised in Figure 1.2.



Hypotheses

The scientific method begins with asking questions (sometimes called research questions). Based on these questions, you formulate a **hypothesis**, which is a tentative answer to your question. This usually involves reading the literature to see if anyone has already answered your question or investigated a similar question. For example, we might hypothesise that if we use a particular fertiliser on a certain species of seedling, then the seedlings will grow taller. We could test this hypothesis by performing experiments where we measure the height of a particular species of seedling subjected to different fertilisers.

In scientific investigations, progress is often not a straight line, from one point to the next, but a series of progressions that sometimes veer off the original path. Often the result of your initial experiments will make you reassess the direction you intend taking, and may lead you to change your hypothesis and refine your experimental design.

Experiment design and validity of results

An experiment is designed and performed to test the prediction, and the results are then analysed. If the results of the experiment agree with the prediction, then the hypothesis is supported. Note that it is not proved, only supported. There may be other explanations that would also be supported by the results. If the results do not agree with the prediction, then the hypothesis is not supported and the scientist needs to come up with another explanation.

Experiments are considered **valid** when scientists test the hypothesis that they intended to test and give consistent results when repeated. A valid experiment involves setting up controls and making sure that the only thing that changes in the experiment is the variable being tested. All other conditions must be **controlled** to remain the same. Experiments are considered **reliable** when they can be repeated to give the same results and random error is eliminated or minimised. An experiment is considered **accurate** when its measurements are close to the true value – for this to be achieved, the risk of error in measurement must be kept to a minimum. For an experiment to be valid, it must be both reliable and accurate. This will be dealt with in more detail in a later section (see page 16).

Communication and peer review

Reproducibility and peer review are important aspects of science. If an experiment cannot be repeated to give the same results, then there is a good chance that a mistake was made and the experiment is not valid. For example, if experiments cannot be repeated to give the same results because of uncertainties in the measurements, the result is that the hypothesis is clearly disproved.

Scientists communicate their work to each other to share new ideas and information and as a way of contributing to the ongoing development of science. They usually communicate new findings to each other in seminars and conferences, as well as writing articles for scientific journals. When you conduct an experiment and write a report on it, the report is very much like a scientific paper.

Before a scientific paper is published, it is reviewed by other scientists – experts in the particular area – who evaluate it. They try to determine whether:

- the experiments conducted were appropriate
- the conclusions drawn were valid
- the hypothesis is clearly supported or not.

If the paper is considered to make a useful contribution to science, and the experiments and analysis are valid, then it will be published. Other scientists can then read the paper and use it to inform their own work. Scientists also communicate their work in other ways to the public and to students.

Descriptions of the scientific method are somewhat idealised. In practice, the scientific method may be a bit messy and not follow the steps in order. Sometimes scientists have only questions but no hypothesis to answer them. In these cases, experiments are done or observations are made to try to form a hypothesis that can then be tested. Sometimes in trying to answer one question a new and more interesting question arises, so a scientist will change the selected experiments to work on the new question instead. However, once a scientific discovery is made, and even when a new and exciting discovery is made by accident, the scientific method will be used to formulate and test hypotheses that arise to explain it.



Science and pseudoscience

Read this article about the scientific method and come up with your own explanation of the difference between science and pseudoscience.

KEY CONCEPTS

- A hypothesis is a predictive statement about the relationship between the variables in an investigation and is an 'expected' answer to a question.
- The scientific method consists of questioning and formulating hypotheses, making measurements to test the hypotheses, analysing the results, and communicating them for peer review. It is the process by which science proceeds.

Biology as a scientific discipline

Disciplines within science can be characterised by the sorts of questions that they ask. Biology asks questions about the organisation and grouping of living organisms, how living things change over time, why some species survive and others do not, and how living things interact with their environments and with each other.

Biologists find that these questions may be answered by looking at the morphology and functioning of living organisms, how they reproduce and are adapted for survival, their origin, distribution and interactions, as well as inheritance patterns and increases in diversity. Biological studies ask questions at various levels – macroscopic, microscopic and molecular. Developments in technology and advances in knowledge and understanding in biology progress hand in hand, with each one assisting the other.

The more we find out in biology, the more questions are generated. There are many questions we have not answered yet. As current and future biologists investigate and answer these questions, yet more questions will arise that no one has thought of yet. Will all the possible questions about living organisms ever be answered?

Models in science

Over the generations, scientists have asked questions and sought and, at times, found answers to those questions. From their answers we have constructed **models** of how living things may be related and how and why they change over time. These models in themselves are always changing, as we get more evidence and better answers to existing questions, or as we seek answers to new questions. Models are representations of biological reality – they are not the reality itself any more than a model aeroplane is a real aeroplane. Models can be physical models, some are mathematical models made up of equations and data, and yet others are conceptual models consisting of principles, laws and theories. Biologists use all sorts of models as they ask and seek to answer questions. At times they combine models and switch between models.

Models in biology have two important purposes – to explain how things work, and to predict what will happen. A model that does not accurately predict the results of an experiment will generally be revised or replaced. Two models may give similar results in some situations but different results in others. Model selection is important to get valid and reliable results. For example, to estimate the abundance of animals in a population, several models may be used, including a mark–recapture model, transect model and direct count model. Each model relies on its own set of assumptions. If animals are relatively fast moving, a closed population mark–recapture model may be used. This model makes assumptions that there is no birth, death or emigration within the population, all animals have the same probability of being caught, and the marks or tags are not lost. For animals that are slow moving and occur in relatively large numbers, a distance sampling model (line transect with point counts) would be preferable. For fast-moving animals where migration does occur, an open population mark–recapture model is preferable. This does not mean that one model is always ‘right’ or ‘true’, just that the closed population mark–recapture model is better for certain types of animals. Choosing the right model for a situation is an important skill in solving problems in biology.

KEY CONCEPTS

- Biology uses models such as physical, mathematical and conceptual models to describe biological systems and to make and test predictions. Models are constantly being refined as we learn more.

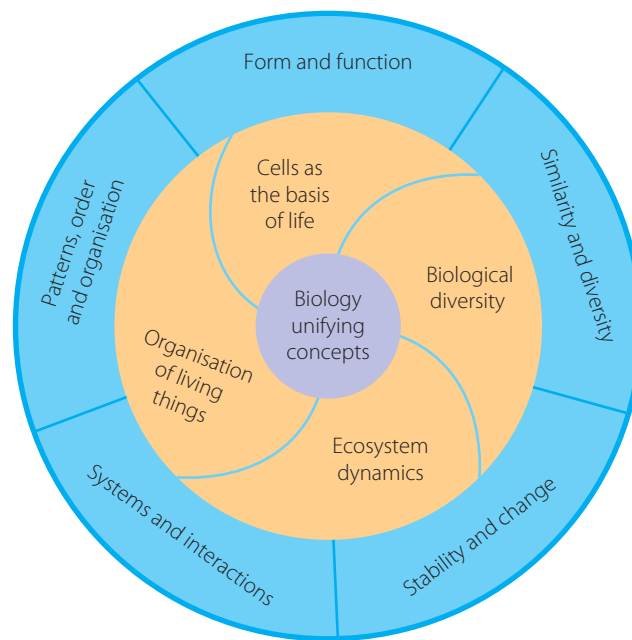
Biology – knowledge and understanding

As you progress through your Biology course, you will learn a lot of useful skills, and practise working scientifically by performing investigations and depth studies. You will also gain some knowledge and develop a deeper understanding of biology.

The knowledge that has arisen from answering questions asked by biologists can be broadly categorised into five major concepts: form and function; similarity and diversity; stability and change; systems and interactions; and patterns, order and organisms. Figure 1.3 shows how the five concepts in the Year 11 Biology course fit into unifying themes.

As you learn more of the content knowledge of biology, you need to create your own mental models to help you understand it. Concept maps are a useful way of representing your mental models. They help to remind you that biology is not simply a collection of facts. Every idea in biology is connected to other ideas. For each module in biology, you should create a concept map both to record the content that you learn and to make connections between different content areas and modules.

FIGURE 1.3 Unifying concepts in biology



1.2

Solving scientific problems: depth studies

Depth studies are your opportunity to work scientifically and solve scientific problems. When performing a depth study, you will pose questions, develop hypotheses to answer your questions, and then seek evidence to support or disprove your hypotheses. The evidence may come from the existing scientific literature, or from your own experiments. You will need to analyse data to determine whether your hypotheses are supported. Analysing data usually requires you to represent it in some way, often mathematically or graphically. Finally, as scientists do, you need to communicate your findings to others. There are many ways that you can do this, and you need to choose the method most appropriate to the audience you wish to communicate with.

Types of depth studies

There are two broad types of depth study:

- 1 first-hand or practical investigations, where you design and perform experiments to gather primary data, or to test a claim or device
- 2 investigations based on secondary sources, where you research and review information and data collected by other people.

First-hand investigations to gather primary data may be:

- work undertaken in a laboratory
- field work, where observations are undertaken at home, school or elsewhere (for example, on excursions or by engaging with community experts)
- the creation and testing of a model or device.

Secondary-source depth studies may include:

- undertaking a **literature review**
- investigating emerging technologies and their applications in biology
- analysing a science fiction movie or novel
- developing an evidence-based argument or a historical or theoretical account.

Depth studies may be presented in different forms, some of which include:

- written texts (experiment reports, field work reports, media reports, journal articles, essays and management plans)
- visual presentations (diagrams, flow charts, keys, posters and portfolios)
- multimedia presentations
- physical models
- a blend of the above.

All depth studies will involve the analysis of data, either from **primary data** that you collect yourself or **secondary data** that you collect from analysing research such as longitudinal data or resource management data. Looking for patterns and trends in data will involve analysing and constructing graphs, tables, flow charts, diagrams, keys, spreadsheets and tables and/or databases. This will be dealt with in more detail in the section Designing your investigation (see page 15). You may also wish to refer to the NSW Stage 6 Biology syllabus document for more information.

Why undertake a depth study?

Depth studies encourage us to identify areas of interest and enable us to deepen our understanding in a chosen area, taking responsibility for our own learning. Although a field of study may be identified by the teacher, students may pursue their own area of interest within this field, be it technology, current research, biologists working in the field, or other areas.

Depth studies provide students with time and an opportunity to:

- use the research methods that scientists use
- analyse works for scientific relevance and validity
- broaden their range of reading in a field of interest
- extend their depth of thinking and understanding
- ask questions and investigate areas that do not have definite answers
- investigate contentious issues and use critical thinking skills to consider the validity of views expressed in a variety of sources

- use inquiry-based learning and develop their creative thinking in an area of their own choosing, at their own level.

Stages in a depth study

The summary below outlines four main stages of conducting a depth study, as well as the *Working scientifically* skills (see the NESA Stage 6 Biology syllabus) that you will need to develop and apply at each stage.

1 *Initiating and planning* involves:

Questioning and predicting

(BIO-1): develops and evaluates questions and hypotheses for scientific investigation

Planning investigations

(BIO-2): designs and evaluates investigations in order to obtain primary and secondary data and information

2 *Implementation and recording* involves:

Conducting investigations

(BIO-3): conducts investigations to collect valid and reliable primary and secondary data and information

Processing data and information

(BIO-4): selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media

3 *Analysing and interpreting* involves:

Analysing data and information

(BIO-5): analyses and evaluates primary and secondary data and information

Problem solving

(BIO-6): solves scientific problems using primary and secondary data, critical thinking skills and scientific processes

4 *Communicating* involves:

(BIO-7): communicates scientific understanding using suitable language and terminology for a specific audience or purpose

Biology Stage 6 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2017

Working Scientifically
Skills Outcome:
BIO11/12-1

Posing questions and formulating hypotheses



FIGURE 1.4 Brainstorm as many ideas as you can in your group.

The first step to beginning any investigation or depth study is deciding on a question. A good research question is one that can be answered by conducting an experiment, making observations or conducting a secondary-source investigation.

Obviously, it is a good idea to investigate something that you find interesting. If you are working in a group, try to find something that is interesting to everyone in the group.

A good way to start is by 'brainstorming' for ideas (Fig. 1.4). This applies whether you are working on your own or in a group. Write down as many ideas as you can think of. Avoid being critical at this stage. Get everyone in the group to contribute, and accept all contributions uncritically. Write every idea down.

After you have run out of ideas, it is time to start being critical. Decide which questions or ideas are the most interesting. Think about which of these it is actually possible to investigate given the time and resources available. Remember that the most important resources you have are the skills of the people in the group. Make a shortlist of questions, but keep the long list, too, for the moment. Once you have your shortlist, it is time to start refining your ideas.

A good **research question** should define the investigation, set boundaries and provide some direction to the investigation. The difference between developing a research question and formulating a hypothesis can be summed up as 'known versus unknown'. You need to do some research of known results in your area of interest (research questions) before deciding what you think the expected outcome of an experiment may be (hypothesis).



Personal and social capability



Critical and creative thinking



Six methods of data collection and analysis

Writing a literature review – refining your question

Your depth study will be from one of the areas described in Figure 1.3, based on the NSW Stage 6 Biology syllabus document. These areas are described in the remaining chapters. However, you will need to go beyond the basic syllabus content because the purpose of a depth study is to extend your knowledge while at the same time building your skills at working scientifically.

The next step is therefore to find out what is already known about the ideas on your list. You need to do a literature review. If your depth study is a secondary-source investigation, then the literature review may be the investigation itself. A formal written literature review includes the information you have found and complete references to the sources of information. It also includes interpretation and critique of what you have read. This is particularly important for a secondary investigation.



Literacy



Information and communication technology capability



Critical and creative thinking

Why are literature reviews important?

Literature reviews are important because they help you to:

- increase your breadth of knowledge and identify what is and is not known about an area of research
- learn from others and think of new ideas that may be relevant to a research project
- identify gaps in current knowledge that you may wish to research or recommend be researched by scientists in the future
- identify methods that could be relevant to your project (avoid reinventing the wheel and/or making the same mistakes as others)
- identify the variety of views (sometimes opposing views) in an area of research and consider how these fit in with your own views.

Your literature review

A literature review is a search and evaluation of available literature in a particular subject area. It has a particular focus and so it is always defined by your research question or hypothesis.

The process of conducting a literature review involves researching, analysing and evaluating the literature. It is not merely a descriptive list of the information gathered on a topic, or a summary of one piece of literature after another. It outlines any opposing points of view in the research and also expresses the writer's perspective of the strengths and weaknesses of the research being reviewed. A literature review brings together results of different studies, pointing out areas where researchers or studies agree, where they disagree, and where significant questions remain. By identifying gaps in research, literature reviews often indicate the direction for future research.

When planning an investigation, you will find using a literature review will give you an idea of past findings and procedures, techniques and research designs that have already been used. This will help you to decide which methods are worth copying, which need modifying and which to avoid (those that have been inconclusive or invalid). You may plan your investigation to target a gap in research or try to replicate an investigation to test and validate claims and ideas.

The length of your literature review will depend on its purpose. If it is a depth study in itself, it will need to be more detailed and draw conclusions about the research. If it is used as an introduction to inform your research, it will be shorter and more focused. Discuss this with your teacher.

Reasons to write a literature review

- To extract information from sources
- To consider the validity of views expressed in each source
- To consider how existing views fit in with a research project, to place it in context and demonstrate how the research is linked to a body of scientific knowledge
- As an end in itself (for example, as a secondary source research assignment to use the findings to support a concluding judgement)
- As a starting point to begin planning a primary investigation, identifying both what is known and where there are current gaps in research

Characteristics of a good literature review

- Helps the reader know what knowledge and ideas have been established on a topic and the areas of strength and weakness in the research
- Organises the information gathered into sections that present themes
- Does not attempt to list all published material, but rather brings together and evaluates the literature according to a question, hypothesis or guiding concept

How to write a literature review

- 1 Getting started: define the topic or research questions (key concepts) and formulate a literature review question (you may have to do some wide reading before finalising this step). Write a list of key words.
- 2 Find articles: use library catalogues, databases and the Internet. Refine your search technique, using specific words that narrow your search to the focus question. Interpret and evaluate your search results. Record search words that are successful and, if necessary, modify your search strategy.
- 3 Structure and write your literature review:
 - i Introduction: define the topic, establish your reasons for reviewing the literature, state the specific focus of the review and explain the organisation or sequence of your review.
 - ii Body: group the literature according to common themes, provide an explanation of the relationship between the research question and the literature reviewed, and proceed from the general, wider view of the research to the specific area you are targeting.

Include information about the usefulness, recency and major authors or sources of the literature.
 - iii Conclusion: summarise important contributions of the literature, point out important flaws or gaps in research if appropriate, and explain the link between your focus question and the literature reviewed (if the literature review is your depth study) or why you have chosen your area of investigation (if the literature review was conducted to refine your investigation).

Evaluating sources

Always be critical of what you read. Be wary of pseudoscience, and any material that has not been peer reviewed. Apply the CRAAP (currency, relevance, authority, accuracy, purpose) test to websites that you find. The most reliable sites are from educational institutions, particularly universities, and government



How to successfully
evaluate and use
websites



Literature reviews

More detail on how to
write a good literature
review



The CRAAP test

Apply the CRAAP test
to any websites that
you find.



Critical and
creative thinking

and scientific organisations such as the CSIRO and WHO, and professional journals such as the *Medical Journal of Australia* and international equivalents. You can narrow your search to particular types of sites by including in your search terms 'site:edu' or 'site:gov' so that you find sites only from educational or government sources.

Make sure you keep a record of the information that you find as well as the sources, so that you can correctly reference them later (Fig. 1.5). It would be a good idea to start a logbook at this stage. You can write in references or attach printouts to your logbook. This can save you a lot of time later on! Your logbook may be hard copy or electronic but, either way, begin keeping it now.

Finally, talk to your teacher about your ideas. They will be able to tell you whether your ideas are likely to be possible for investigation given the equipment available. They may have had students with similar ideas in the past and can make suggestions about what worked well and what did not.

After you have researched your questions and ideas, you will ideally be able to narrow the shortlist down to the one question that you want to tackle. If none of the questions or ideas looks possible (or interesting), then you need to go back to the long list.

Proposing a research question or hypothesis

If you are doing a primary-source investigation, then you need to define a research question and/or hypothesis.

For example, you may begin by thinking: 'I wonder if a new fertiliser will affect plant growth.' This idea is too general, so you need to turn it into a more specific research question. The research question may be: 'What effect does a new fertiliser have on root and stem growth in a plant?' The question needs to be specific enough to guide the design of your experiment. It needs to include what you will be varying (for example, type of fertiliser) and what result you will expect (root and/or stem growth). Once you have decided on your research question, further reading will guide you to design a suitable experiment (Fig. 1.6). You would read up about the chemical components of different fertilisers, ways of measuring root and stem growth, and what types of plants have and have not had growth benefits from fertilisers in the past. You need to decide on what specifically you will be changing (for example, you may decide to select a new fertiliser with twice as much nitrogen as the old fertiliser) and exactly what you will measure (shoot height, root length and root mass in a seedling). The research question can then be turned into a hypothesis: *If a fertiliser that contains more nitrogen is introduced, then a particular seedling's shoot height, root length and root mass will increase.*



FIGURE 1.5 Start researching your topic and make sure you keep a record of all your references. Good record keeping is important in scientific research, and it begins at this stage of the investigation.



FIGURE 1.6 You need to frame your research question carefully. This student is investigating plant growth with different fertilisers.

KEY CONCEPTS

- Frame your research question carefully by making it specific enough to guide the design of the investigation.
- Poor research question: 'How can we make a seedling grow the best?' 'Best' is a vague term. What you mean by 'best' may not be what someone else means.
- Good research question: 'Which one of two fertilisers gives the maximum growth of roots and stem in a seedling?' This question is not vague. It tells you what you will be varying and what you will be measuring. It also gives a criterion for judging whether you have answered the question.

Formulating a hypothesis

A hypothesis is a predictive statement about the relationship between the variables and is an 'expected' answer to your question. It is often written as an 'If ... then ...' statement, to explain an expected relationship, such as: 'If x is introduced/increased/decreased, then y will increase/decrease/stay the same.'

An example of a hypothesis is:

If the amount of nitrogen in fertiliser provided to a seedling in the soil is increased, then the height of the stem and/or length of the roots of the seedling will increase.

Your hypothesis should give a prediction that you can test, ideally quantitatively (that is, by taking measurements).

A hypothesis is usually based on some existing model or theory. It is a prediction of what will happen in a specific situation based on that model. For example, investigators may use a model such as one that describes how, in the nitrogen cycle, nitrates from the soil are assimilated into proteins for plant growth. A hypothesis based on an increased nitrate model may predict that, with plants that normally grow in nitrogen-poor soils, introducing additional nitrogen in a fertiliser may increase growth.

A good research question or hypothesis identifies the variables that will be investigated. Usually you will have one dependent variable and one independent variable. For a depth study you may have two or more independent variables that you control (for example, you may test two different fertilisers if time and resources allow). You should only change one variable at a time in any investigation.

If your experiments agree with predictions based on your hypothesis, then you can claim that they support your hypothesis. This increases your confidence in your model, but it does not prove that it is true. Hence, an aim for an experiment should never start 'To prove ...', because it is not possible to actually prove a hypothesis, only to disprove it.

If your experimental results disagree with your hypothesis, then you may have disproved it. This is not a bad thing! Often the most interesting discoveries in science start when a hypothesis based on an existing model is disproved, because this raises more questions.

Even if your question or hypothesis meets these criteria, do not be surprised if you change or modify it during the course of your investigation or depth study. In scientific research, the question you set out to answer is often only a starting point for more questions.

KEY CONCEPTS

- Investigations begin with a question, which is used to formulate a hypothesis.
- A literature review helps you refine your question or hypothesis. It helps you know what knowledge and ideas have been established on a topic and the areas of strength and weakness in the research.
- A good hypothesis is a statement that predicts the results of an experiment, states the expected relationship between the variables and can be tested using quantitative measurements.

1.3 Planning your depth study



Critical and
creative thinking

There are many things to consider when planning and designing an investigation. You need to think about how much time you will have, what space and equipment you will need, and where you will go if you want to make measurements or observations outside. If you are doing a secondary-source investigation or some other type of depth study, such as a creative work (like building a physical model), you still need to plan ahead to make sure you have the resources you need.

You may be working in a group or on your own. Most scientists work in groups. If you can choose who you work with, think about it carefully. It is not always best to work with friends. Think about working with people who have skills that are different from your own.

Having a plan allows you to ensure that you collect the data, whether from a primary or secondary source, that is needed to test your hypothesis. The longer the investigation, the more important it is that you have a clear plan. Table 1.1 lists several things to consider.



Work and
enterprise

TABLE 1.1 Planning your depth study

PRIMARY-SOURCE INVESTIGATION	SECONDARY-SOURCE INVESTIGATION
What data will you need to collect?	What information will you need to gather?
What materials and equipment will you need?	What sources will you use?
When and where will you collect the data?	When and where will you gather the information?
If you are working in a group, what tasks are assigned to which people?	If you are working in a group, what tasks are assigned to which people?
Who will collect the data?	Who will collect what information?
Who will be responsible for record keeping?	How will record keeping be done to avoid plagiarism?
How will the data be analysed?	How will the information be analysed?
How will sources be referenced?	How will sources be referenced?

Devising a plan for your investigation

The most common problem that students have is time management. It is important to plan to have enough time to perform the experiments, including repeat measurements, and to analyse them and to report on them.

A good plan will help you keep on track. Your teacher may ask you to hand in a plan of your depth study before you begin the implementation stage. Table 1.2 gives an idea of the types of things you should think about.

Working Scientifically
Skills Outcome:
BI011/12-2



Personal and
social capability

TABLE 1.2 Depth study plan

INTRODUCTION TO DEPTH STUDY PLAN	
Title <i>What?</i>	Choose a title for your depth study.
Rationale <i>Why?</i>	Explain why you have chosen this area of research. Describe what you are hoping to achieve through this investigation. Include any ways you think your investigation may benefit yourself, your class and possibly your family, friends and the school/wider community (if applicable).
Type of depth study and research model (if applicable) <i>Which?</i>	State the type of depth study you intend conducting (e.g. literature review, practical investigation). Where applicable, describe any theoretical models that you will use for your depth study. Include references to your reading and explain why you chose this model.
Timeline	
Action and time frame <i>When?</i>	Working scientifically skills <i>How?</i>
1 Initiating and planning <i>When?</i> (For example, weeks 1–2)	<i>Questioning and predicting:</i> formulate questions and/or a hypothesis; make predictions about ideas, issues or problems. <i>Planning:</i> wide reading – research background information; assess risks and ethical issues; plan valid, reliable and accurate methods; select appropriate materials and technologies; identify variables; plan experimental controls and how to measure them.
2 Implementation and recording <i>When?</i> (For example, weeks 2–4)	<i>Conducting investigations:</i> safely carry out valid investigations; make observations and/or accurate measurements; use appropriate technology and measuring instruments. <i>Processing and recording data and information:</i> collect, organise, record and process information and/or data as you go.
3 Analysing and interpreting <i>When?</i> (For example, week 4–mid week 5)	<i>Analysing data and information:</i> reduce large amounts of data by summarising or coding it; begin looking for trends, patterns or mathematical relationships. <i>Problem-solving:</i> evaluate the adequacy of data (relevance, accuracy, validity and reliability) from primary and/or secondary sources.





INTRODUCTION TO DEPTH STUDY PLAN

4 Communicating When? (For example, weeks 5–mid week 6).	Presenting your depth study: use appropriate language, scientific terminology, calculations, diagrams, graphing and other models of representation; acknowledge your sources.	
Final presentation	Due date: end of week 6	
Data collection		
Note that what you submit in your final depth study may be different from your initial planning list.		
a Action: independent variable Describe what you will change in your investigation.	b Outcome: dependent variable What will you measure and how will you measure it? (Quantitative/qualitative data?)	c Validity: controlled variables What will you need to keep constant to make this a fair test? What control(s) will you use (if applicable)?
Data analysis and problem solving		
d Data analysis What method(s) will you use to analyse the data, and how will you represent the trends and patterns?	e Conclusion How will you judge whether the experiment was valid? How will your data allow you to test your hypothesis or answer your question?	

Working Scientifically
Skills Outcome:
BI011/12-3



Selecting equipment

A well-framed question or hypothesis will help you choose the equipment that you need. For example, if your hypothesis predicts a temperature change of 0.5°C, then you will need a thermometer that can measure to at least this precision (precision and accuracy are discussed on page 18). You also need to know how to use the equipment correctly. Always ask if you are unsure. The user manual will usually specify the precision of the device and let you know of any potential safety risks, so read it.

You need to think about how you can minimise uncertainties and errors. Minimising uncertainty is not just about using the most precise equipment you can find; it is also about clever experimental technique.

Working safely: risk assessment

You may be required to complete a risk assessment before you begin your investigation. You need to think about three things:

- 1 What are the possible risks to you, to other people, and to the environment or property?
- 2 How likely is it that there will be an injury or damage?
- 3 If there is an injury or damage to property or environment, how serious are the consequences likely to be?

A 'risk matrix' can be used to assess the severity of a risk associated with an investigation. 'Negligible' may be getting clothes dirty. 'Marginal' might be a bruise from falling off a bike, or from a broken branch in a tree. 'Severe' could be a more substantial injury or a broken window. 'Catastrophic' would be a death or the release of a toxin into the environment. You need to ensure that your investigation is low risk.

Once you have considered what the possible risks are, you need to think about what you will do about them. What will you do to minimise them, and what will you do to deal with the consequences if something does happen? You can use a risk assessment table like the one shown in Table 1.3.

Consider where you will perform your experiments or observations. Will you need to consider the convenience or safety of others? Talk to your teacher about what space is available.

TABLE 1.3 Example risk assessment table for managing risks

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THE RISK?
Potassium permanganate	Eye irritant	Wear safety glasses. If the solution comes in contact with the eyes, use an eyewash.
Glassware	Broken glass may cut the skin	Handle all glassware with care. If glass breaks, sweep it up with a brush and dustpan.



Ethical considerations

There are ethical frameworks for biological investigations, protecting the lives of animals and humans. You need to take into consideration ethical principles before you begin your research. You need to think about basic human values, animal rights, the rights of children, and whether the use of some technologies has ethical repercussions. Ethical principles in biology could be a whole depth study of its own.

Include in your research for your literature review information about ethical codes of conduct related to your investigation.

In a secondary-source investigation, take precautions with cyber safety and remember to keep your personal information private.



KEY CONCEPTS

- In primary-source investigations, you collect and analyse your own data. In secondary-source investigations, you analyse someone else's data.
- Investigations need to be planned carefully so that they answer your research question. You also need to consider safety, ethical issues and the possible environmental impacts of your investigation.



Use of live organisms in schools

Designing your investigation

Data: reliability, accuracy, validity and relevance

When designing your investigation, think about how you can minimise uncertainties and overcome failure. For example, root growth will be affected if plant roots are attacked by fungus (mould). Try to think of all the things that could go wrong in your experiment and put preventative measures in place. You may also need to come up with a backup plan, so start early in case things go wrong and you need to re-do your experiment.

If you are conducting a secondary-source investigation, then your literature review will be the basis of your investigation. Remember that a literature review is not simply a summary of what you have read – you need to add meaning. This may come from comparing and contrasting competing models and constructing an argument, or by analysing and presenting secondary-source data. When using secondary sources, remember to make comparisons between data and claims in a number of reputable sources, including science texts, scientific journals and reputable Internet sites, and to reference these appropriately.

If you are doing a primary-source investigation, a brief literature review will form the background information and then you will be performing measurements to gather data yourself. You can collect data by performing experiments or making observations in the field. You will gain practice at making measurements if you do some of the investigations in the following chapters. These investigations can form a basis for your depth study.

Working Scientifically Skills Outcome: BI011/12-3



Variables

When doing experiments, you need to decide which variable you will change, what you will measure and which variables you will control. Consider which variables you can control, and which you cannot. Typically, an experiment will have three types of variable:

- 1 an **independent variable**, which we are testing and we therefore purposefully change
- 2 a **dependent variable**, which is the result that we measure – this changes as a result of changing the independent variable. We assume that the dependent variable is in some way dependent on the independent variable.
- 3 **controlled variables**, which are kept constant so that they do not interfere with our results.

Reliability

Whenever possible you should make repeat measurements. This allows you to check that your measurements are reliable. Your results are reliable if repeat measurements give the same results within experimental uncertainty. If a result is not **reproducible**, it is not a reliable result. The cause may be that a variable other than the one you are controlling may be affecting the value of the dependent variable. If this is the case, you need to determine what this other variable is, and control it if possible. Results may also be unreliable if random errors occur in the method. A reliable experiment is one which, if repeated multiple times, gives the same result (within an acceptable margin of error). Reliable sources, such as scientific journals and texts, are sources whose information is trustworthy because it is written by qualified professionals and is consistent across multiple sources.



Accuracy

Accuracy may refer to a result or to an experimental procedure. Accuracy of a result (data) is a measure of how close it is to an expected value given in scientific literature (for example, scientific journals). Secondary-source information is accurate when it is found to be similar to information presented in peer-reviewed scientific journals.

To improve accuracy in experiments, we use the most precise measuring instruments available, avoid human error (for example, measuring errors), carry out repeat trials, and find an average to smooth out random errors so that the value we obtain approaches the expected value more closely.

Accuracy is also linked to any uncertainty in measurement. For example, we can determine the size of red blood cells by estimating their number in a field of view and dividing by the size of that field of view. Alternatively, we can measure their size with less uncertainty using a mini grid slide or a calibrated digital microscope.

Plausible accuracy is accuracy that is estimated, taking into consideration the evident sources of error and the limitations of the instruments used in making the measurements.

Validity

To ensure that results are valid, in a primary investigation you must carry out a fair test:

- Identify variables that need to be kept constant
- Develop and use strategies to ensure these variables are kept constant
- Demonstrate the use of a control
- Use appropriate data collection techniques
- Trial procedures and repeat them, checking the results are the same each time.

In a control, you remove the factor being tested in the experiment to see whether, without that factor, a negative result is obtained.

These steps ensure that the process used and the resultant data measure what was intended. Results need to be valid if you are going to be able to draw a conclusion from them.



An investigation is valid if factors that may vary within an experiment are deliberately held constant to ensure a fair test. These ‘controlled variables’ are kept the same so that the only factor that is allowed to change in the experiment is the independent variable.

Evaluating your investigation

Some good questions to ask to assess reliability, validity, accuracy and precision are shown in Table 1.4.

TABLE 1.4 Assessing reliability, accuracy and validity in investigations

	PRIMARY INFORMATION AND DATA	SECONDARY INFORMATION AND DATA
Reliability	Have I tested with repetition? Have I done multiple trials and found an average to eliminate random errors?	How consistent is the information with information from other reputable sources? Are the data presented based on repeatable processes?
Accuracy	Do the results of the investigation agree with the scientifically accepted value? Have I used the best measuring equipment available?	Is this information similar to information presented in peer-reviewed scientific journals?
Validity	Does my experiment measure the variable of interest? Does it actually test the hypothesis that I want it to? Have all variables apart from those being tested been kept constant? Have errors been kept to a minimum? Are my results accurate and reliable?	Do the findings relate to the hypothesis or problem? Are the findings accurate and the sources reliable?

KEY CONCEPTS

- An experiment will have three types of variable: dependent, independent and controlled.
- Reliability of first-hand data is the degree with which repeated observation and/or measurements taken under identical circumstances will yield the same results.
 - To assess reliability, compare results from repeat experiments to see if they are the same.
 - To improve reliability, control all variables other than those being tested, repeat and average results to reduce random errors, and use precise measuring equipment so that the same result can be obtained each time the experiment is repeated.
- To assess accuracy, examine how close a measurement is to its true value or how similar the information is to that in peer-reviewed scientific literature.
 - To improve accuracy, minimise uncertainty, reduce systematic errors and use the most precise measuring equipment available. Use peer-reviewed secondary sources.
- To assess validity in a primary investigation, evaluate how closely the processes and resultant data measure what was intended.
 - In a secondary investigation, assess whether the information is relevant to the topic and if it is from reliable sources.
 - To improve validity, refine the experiment design to reduce complex variables that cannot be kept constant, as well as reducing random and systematic errors.

Gathering data

You also need to consider how many data points to collect. In general, it is better to have more data than less. However, you will have limited time to collect your data, and you need to allow time for analysis and communicating your results. A minimum of 6–10 data points is usually required to establish a relationship between variables, if the relationship is linear. A linear relationship is one where if you plot one variable against the other you get a straight line. If you think the relationship might not be linear, then take more data points and think carefully about how they will be spaced. You should try to collect more data in the range where you expect the dependent variable to be changing more quickly. For example, if you are measuring temperature of a hot object as it cools as a function of time, then you should collect more data early, when cooling is more rapid.



You will need to keep a record of what you do during your investigation. You do this in a hard copy or electronic logbook.

Keeping a logbook

Scientists keep a logbook for each project that they work on. A **logbook** is a legal document for a working scientist. If the work is called into question, then the logbook acts as important evidence. Logbooks are sometimes even provided as evidence in court cases (for example, in patent disputes). Every entry in a scientist's logbook is dated, records are kept in indelible form (pen, not pencil), and entries may even be signed. Never record data onto bits of scrap paper instead of your logbook!

Your logbook will include:

- notes taken during the planning of your investigation
- a record of when, where and how you carried out each experiment
- diagrams showing the experimental set-ups, biological drawings, and other relevant information
- all your raw results
- all your derived results, analysis and graphs
- all the ideas you had while planning and carrying out experiments, and analysing data
- printouts, file names and locations of any data not recorded directly in the logbook.

It is not a neat record, but it is a complete record (Fig. 1.7). Your teacher may check your logbook at various intervals to assess your progress.



FIGURE 1.7 Make sure you keep an accurate record of what you do as you do it.

Your logbook

Always write down what you do as you do it. It is easy to forget what you did if you do not write it down immediately. Your logbook may be hard copy or electronic. Either way, your logbook is a detailed record of what you did and what you found out during your investigation. Make an entry in the logbook every time you work on your depth study.

Logbooks are important working documents for scientists. All your data should be recorded in a logbook, along with all records of your investigations.

Recording data and creating scientific tables

If you are going to be collecting multiple data points, then it is a good idea to draw a table to record them in. Scientific tables are always drawn with a ruler, and they are fully enclosed tables with appropriate headings. Label the columns in the table with the name and units of the variables. If you know that the uncertainty in all your measurements is the same, then you can record this at the top of the column as well. Otherwise, each data entry should have its uncertainty recorded in the cell with it. When constructing a results table, put units in the headings and not in the body of the table. It is best practice to put the independent variable in the first column and the dependent variable in the second, if you are drawing a vertical table. For a horizontal table, the independent variable is placed in the top horizontal row and the dependent variable in the first vertical column.

It is a good idea to start your analysis while you are collecting your data. If you spot an outlier and you are still making measurements, then you have the opportunity to repeat that measurement. If you made a mistake, then put a line through the mistake and write in the new data.

Plotting and analysing data as you go is sometimes beneficial because it allows you to spot something that may be of interest early on in your investigation. You then have a choice between revising your hypothesis or question to follow this new discovery, or continuing with your plan. Many investigations start with one question and end up answering a completely different one. These are often the most fun, because they involve something new and exciting. Some of the most significant finds (for example, penicillin) have come from unexpected results of experiments or serendipity.



Literacy



Personal and social capability



Literacy

Working Scientifically Skills
Outcome: BI011/12-4

Accuracy, precision and errors in measurement

When making measurements, your aim is to be as precise and accurate as possible.

An accurately measured result is one that represents the 'true value' of the measured quantity as closely as possible. When we take repeated measurements, we assume that the mean (average) of the measurements will be close to the 'true value' of the variable. However, this may not always be the case. For example, if you have ever been a passenger in a car with an analogue speedometer and tried to read it, your reading will be consistently different from what the driver reads. This is because of parallax error. The needle sits above the scale, and when viewed from the side does not line up correctly with the true speed. Beware of parallax error with any equipment using a needle. This is an example of a **systematic error**, in which measurements differ from the true value by a consistent amount. Note that often we do not know what the 'true value' is.

Scientists should be aware of the possibility of error in all stages of an investigation. Notes on possible sources of error should be kept in the logbook:

- Planning stage: errors may arise as a result of limitations of time and/or materials. Assess the possibility and adjust the method so that errors are minimised.
- Data collection and processing stages: remember to assess the degree of uncertainty and to keep note of the accuracy of measuring devices.
- Concluding stage: evaluate the validity of the investigation and discuss any sources of error, as well as possible ways of reducing error in future investigations.

Sometimes it is difficult to remember the difference between accuracy and precision. For example, on a dart board, think of accuracy as how close to the centre your dart hits, and your measurement of precision as how closely you can group your shots (Fig. 1.8).

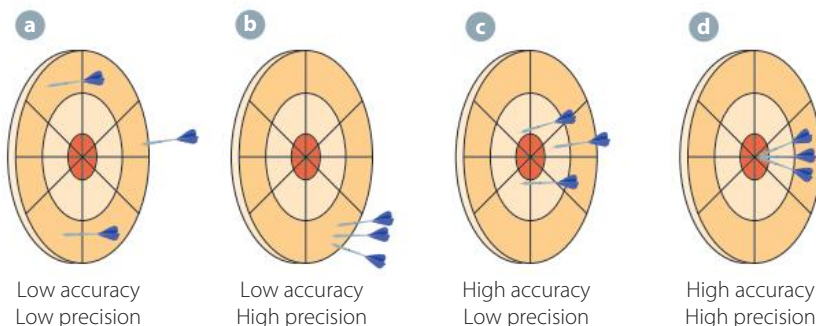


FIGURE 1.8 On a dart board, accuracy is determined by how close to the centre (bullseye) your dart lands. Precision is how closely you can group your darts.

When looking at precision and accuracy in scientific measurements, measurements that are close to the known value are said to be accurate, whereas measurements that are close to each other are said to be **precise**. Therefore, for measurements to be accurate *and* precise, they must be close to the mean value and the measurements need to be close to each other.

A graph may also be used to show the relationship between accuracy and precision (Fig. 1.9).

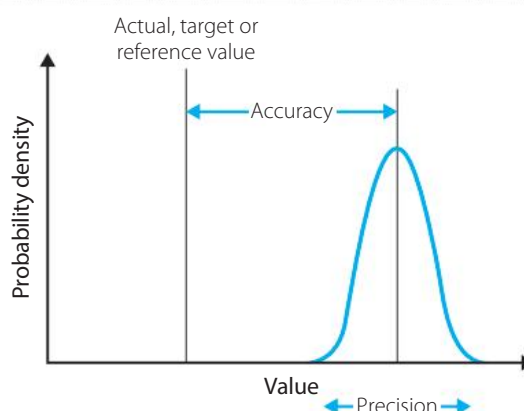
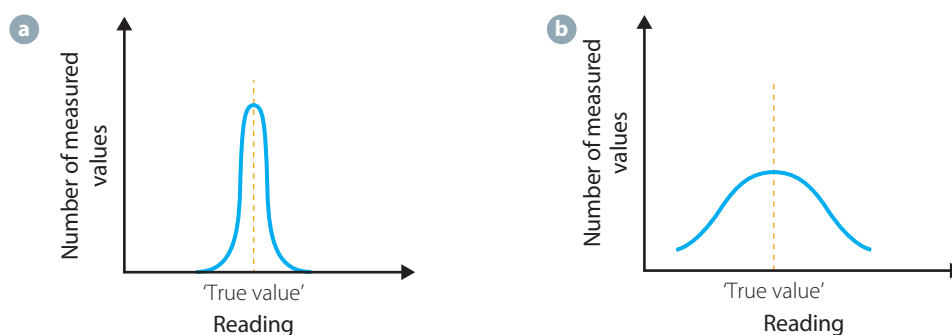


FIGURE 1.9 Graph distinguishing between accuracy and precision

In the scientific definition, precision is described as a measure of the variability of the measurements, so it affects the spread of the repeated measurements about the mean value. The smaller the spread, the greater the precision. This is shown in Figure 1.10. Figure 1.10a shows precise measurements, and Figure 1.10b shows less precise measurements. Note that both data sets are centred about the same average, so they have the same accuracy.

FIGURE 1.10 In a plot of number of measured values versus reading, the results in **a** have a small spread about the mean and are therefore more precise. The results in **b** have a larger spread about the mean and are less precise.



There is always the risk that errors in measurement may arise when actually doing the measuring, but some errors also arise when we are calculating derived data. We need to keep both types of error to a minimum if our results are to be reliable, accurate and valid.

Visit the weblink *Accuracy and precision* to increase your understanding of minimising error and to clarify some concepts about processing of raw data that may seem complex at first. This weblink deals with precision and accuracy, and gives an easy but realistic example of how and why it is necessary to process raw data and to calculate percentage, mean and standard deviation.

Estimating uncertainties

When you perform experiments, there are typically several sources of uncertainty in your data. Sources of **uncertainty** that you need to consider are the:

- limit of reading of measuring devices
- precision of measuring devices
- variation of the **measurand** (the variable being measured).

For all devices there is an uncertainty due to the limit of reading of the device. The limit of reading is different for analogue and digital devices.

People often confuse precision with the resolution of a measuring device. The resolution tells us about the 'degree to which an instrument can be read'. Precision is the 'degree to which an instrument can be read repeatably and reliably'.

Analogue devices have continuous scales and include swinging needle multimeters and liquid in glass thermometers. For an analogue device, the **limit of reading**, sometimes called the resolution, is half the smallest division on the scale. We take it as half the smallest division because you will generally be able to see which division mark the indicator (needle, fluid level, etc.) is closest to. So, for a liquid in a glass thermometer with a scale marked in degrees Celsius (Fig. 1.11a), the limit of reading is 0.5°C .

Digital devices such as digital multimeters and digital thermometers have a scale that gives you a number. A digital device has a limit of reading uncertainty of a whole division. So a digital thermometer that reads to whole degrees (Figure 1.11b) has an uncertainty of 1°C . For a digital device the limit of reading is always a whole division, not a half, because you do not know whether it rounds up or down, or at what point it rounds. The digital device (c) has a greater resolution than (a) or (b) because it measures to one decimal place. The limit of reading is 0.1°C .

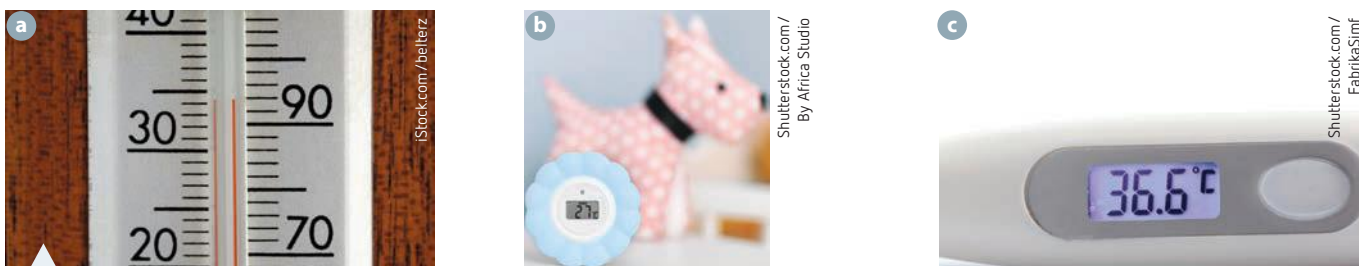


FIGURE 1.11 Digital and analogue thermometers with different resolutions (reading limits)

The resolution or limit of reading is the minimum uncertainty in any measurement. Usually the uncertainty is greater than this minimum.

Measuring devices such as data loggers usually have their precision given in the user manual.

Many students think that digital devices are more precise than analogue devices. This is often not the case. A digital device may be easier for you to read, but this does not mean it is more precise. The uncertainty due to the limited precision of the device is generally greater than the limit of reading. (See Figs 1.11a, 1.11b.)

KEY CONCEPTS

- Systematic error is due to the measuring device (for example, if it is not calibrated correctly) or technique (for example, parallax error or through incorrect positioning of the instrument).
- Random error is due to unavoidable variations in reading a measurement.
- Accuracy refers to the closeness of a measured value to a standard or known value.
- Precision refers to the closeness of two or more measurements to each other.
- The uncertainty in any measurement depends upon the limit of reading of the measuring device, and the precision of the device.

Analysing data

When you have collected all your data, you will need to analyse it. Record all your analyses in your logbook. If you have more than a few data points, it is a good idea to display them in a table. Tables of data need to have headings with units for each column, and a caption telling you what the data means or how it was collected (see how to construct a table on page 18). Tables are used for recording raw data and also for organising derived data.

Calculating derived data from raw data

Raw data is what you actually measured (with units and uncertainties). **Derived data** is data that you have calculated using your raw data. For example, your raw data may be the length of roots and height of shoots in each plant. From this data you may choose to derive average length and height of roots and shoots and/or you may wish to calculate the overall percentage growth.

Drawing and using graphs

If you look at any science journal, you will see that almost every article contains graphs. Graphs are not only a useful way of representing data, but they are also commonly used to analyse relationships between variables. You should have lots of graphs in your logbook as part of your exploration of the data. It is often useful to plot your data in different ways, especially if you are unsure what relationship to expect between your dependent and independent variables.

Graphs should be large and clear. The axes should be labelled with the names of the variables and their units. The independent variable is placed on the x -axis and the dependent variable on the y -axis. Choose a scale so that your data takes up most of the plot area. This will often mean that the origin is not shown in your graph. Usually there is no reason why it should be. The scale is plotted in equal increments.

Working Scientifically
Skills Outcome:
BI011/12-5



Critical and
creative
thinking



Numeracy



Literacy



Data points

Some helpful advice on deciding the number of data points

To determine a relationship you need to have enough data points and the range of your data points should be as large as possible. A minimum of six data points is generally considered adequate if the relationship is expected to be linear (give a straight line), but always collect as many as you reasonably can, given the available time.

For non-linear relationships, you need more data points.

Types of graphs

There are different types of graphs so you need to know which type to use. Your choice will depend on what you have measured.

Scatter plots are plotted when you are looking for a relationship between variables. A scatter plot is a graph showing your data as points (Fig. 1.12a). Do not join them up as in a dot-to-dot picture. Use a line of best fit if they appear to fall in a straight line.

Line graphs are used to find a relationship between the variables. When both the independent and dependent variables are continuous, a line graph is drawn to show how one variable will affect the other. For example, the independent variable may be the number of hours seedlings were exposed to light and the dependent variable may be the average height of the shoots (see Table 1.5).

TABLE 1.5 Height of shoots in seedlings exposed to variable periods of light

TIME EXPOSED TO LIGHT PER DAY FOR 2 WEEKS (hours)	HEIGHT OF SHOOTS (mm)
0	24
2	18
4	17
6	15
8	13
10	11
12	9
14	7

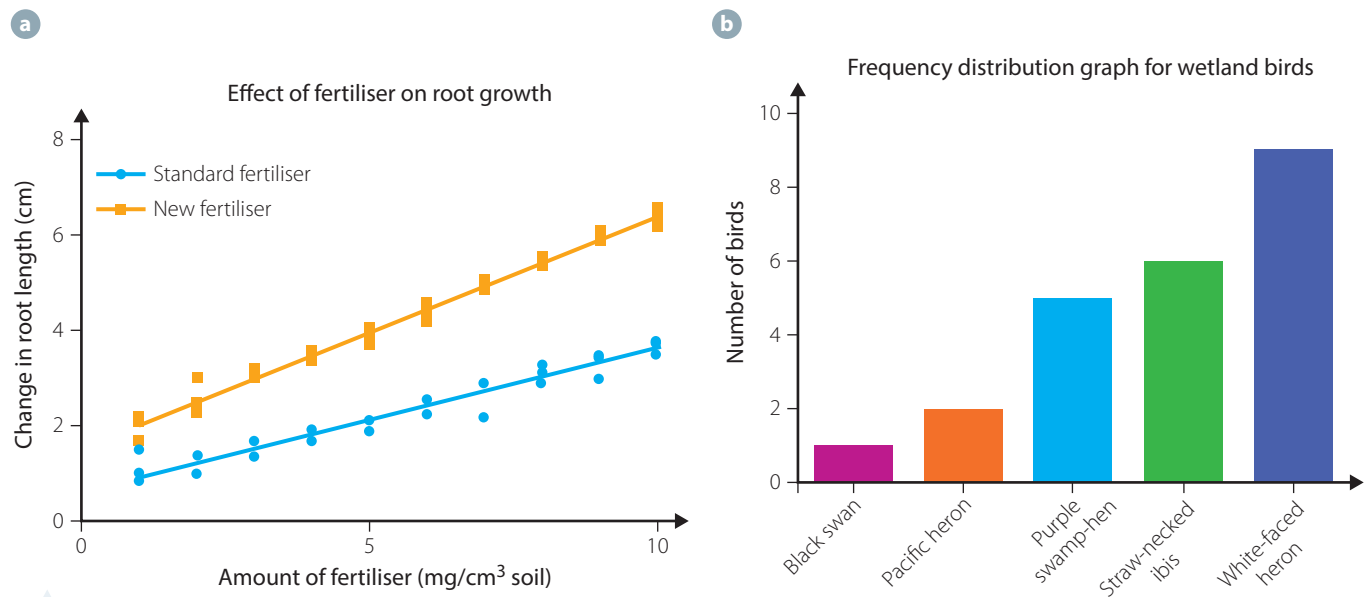


FIGURE 1.12 **a** A scatter plot demonstrating a mathematical relationship; **b** a column graph displaying results from counting categories

Column or bar graphs are used if groups of things have been counted and measured. An example is the heart rates of different types of animals. A bar graph has categories on the y -axis and numbers on the x -axis. A column graph has numbers on the y -axis and categories on the x -axis (Fig. 1.12b). The columns or bars have a gap between them and do not touch.

A **histogram** is similar to a column graph, but the columns touch each other. These are used for data where the categories each contain the same type of data. An example is the average monthly rainfall in Sydney during autumn and winter in 2016 (Table 1.6).

TABLE 1.6 Average rainfall in Sydney during autumn and winter, 2016

MONTH	AVERAGE RAINFALL (mm)
March	130
April	129
May	120
June	133
July	97
August	81

A **sector or pie graph** is used to compare parts of a whole. An example is the composition of a predator's diet (Table 1.7 and Fig. 1.13). A protractor must be used when drawing a pie chart.

TABLE 1.7 Components of diet of red fox (*Vulpes vulpes*)

FOOD	DIETARY CONTRIBUTION (%)
Rabbits	30
Lambs	20
Small marsupials	10
Frogs	10
Lizards	10
Birds	5
Carrion	5
Fruit	5
Other	5

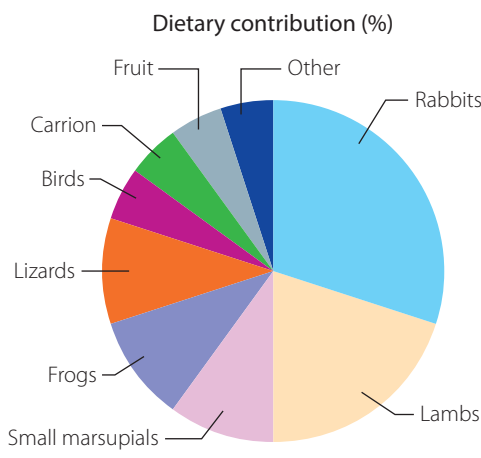


FIGURE 1.13 Data in Table 1.7 shown as a pie graph

Linear lines of best fit

A good graph to start with is simply a graph of the raw data. You will usually be able to tell by looking whether the graph is linear. If it is, then fit a straight line (**line of best fit**).

Removing outliers

When you plot your raw data, you may find that one or two points are **outliers**. These are points that do not fit the pattern of the rest of the data. These points may be mistakes. For example, they may have been incorrectly recorded or a mistake may have been made during measurement. They may also be telling you something important. For example, if they occur at extreme values of the independent variable, then it might be that the behaviour of the system is linear in a certain range only. You may choose to remove or ignore outliers when fitting a line to your data, but you should be able to justify why.



Non-linear lines of best fit

Relationships between variables are often not linear. If you plot your raw data and it is a curve, then do not draw a straight line through it. In this case you need to think a little harder. If your hypothesis predicts the shape of the curve, then try fitting a theoretical curve to your data. If it fits well, then your hypothesis is supported.

Note that a line of best fit is not the same as joining the dots. It is rarely useful or appropriate to join the dots, even though this is often the default setting in spreadsheet software.

KEY CONCEPTS

- Data is usually recorded in tables.
- Graphs are used to represent and analyse data.
- Linear graphs are useful for analysing data.

Interpreting your results

Once you have analysed your results, you need to interpret them. This means being able to either answer your research question or state whether your results support your hypothesis.

You need to take into account the uncertainties in your results when you decide whether they support your hypothesis. For example, suppose you have hypothesised that the maximum range in which the enzyme pepsin will function is between 35°C and 40°C, yet your results show that the maximum activity occurs at 42°C. You may think that this result does not support your hypothesis. To say whether the result agrees with the prediction, you need to consider the uncertainty. If the uncertainty is 1°, then the results disagree with the hypothesis. If the uncertainty is 2° or more, then the results do agree and the hypothesis is supported.

If your hypothesis is not supported, it is not enough to simply say 'our hypothesis is wrong'. If the hypothesis is wrong, what is wrong with it?

It may be that you have used a model that is too simple. For example, when designing an experiment using catalase, you may base your hypothesis on the model that enzymes in the human body work best at around human body temperature (37°C), like many digestive enzymes. In your experiment, you then find that the optimum temperature for catalase is 10°C. This may be because you were not aware of the model that proposes that, in order to function in cells lining the digestive tract, catalase needs to avoid being digested. To do this, it changes shape to its functional form and works best at a low optimum temperature between 0 and 10°C. At body temperature it is indigestible but not the optimum shape for peak performance. Therefore, your hypothesis may be better described by a model that takes into account the idea that catalase must avoid being digested and achieves this by functioning best at temperatures lower than body temperature. Before you decide that the model is at fault, however, it is a good idea to check carefully that you have not made any mistakes.

It is never good enough to conclude that 'the experiment didn't work'. Either a mistake was made or the model used was not appropriate for the situation. It is your job to work out which. In doing so, you will come up with more questions.

Experiments that do not support predictions based on existing models are crucial in the progress of science. It is these experiments that tell us that there is more to find out, and inspire our curiosity as scientists.

KEY CONCEPTS

- You must know the uncertainty in your results to be able to test your hypothesis.
- If your hypothesis is disproved, you need to be able to explain why.

Working Scientifically
Skills Outcome:
BIO11/12-6



Numeracy



Enzyme model

Effect of
temperature on
catalase activity

1.4 Communicating your understanding

Working Scientifically
Skills Outcome:
BI011/12-7

If research is not reported on, then no one can learn from it. An investigation is not complete until the results have been communicated. Most commonly a report is written. Scientists also use other means to communicate their research to each other, such as posters and talks. To communicate their work to the public, scientists may use science shows and demonstrations, public lectures, websites, videos and blogs. All of these are useful ways of communicating your understanding, and you need to select the mode that best suits the content you wish to communicate and the audience to whom you wish to communicate.



Literacy



Information and
communication
technology
capability

Writing reports

A report is a formal and carefully structured account of your investigation or depth study. It is based on the data and analysis in your logbook. However, the report is a summary. It contains only a small fraction of the information that you collected.

A report consists of several distinct sections, each with a particular purpose. When writing a report for a science journal, you will need to provide an abstract and an introduction, but for secondary school purposes the following headings are suggested:

- Background information
- Aim
- Hypothesis
- Risk assessment
- Materials
- Method
- Results and analysis
- Discussion of results
- Conclusion
- Acknowledgements
- References
- Appendix.

Reports in scientific journals are always written in the past tense, because they describe what you have done. They start with an abstract – a very short summary of the entire report, typically between 50 and 200 words. It appears at the start of the report but is always the last thing that you write. Try writing just one sentence to summarise each part of your report.

At school level, your report may be written in the present or past tense. Start with a clearly stated aim, making sure it includes variables and the change you will be measuring.

Background information

The background information tells the reader why you did this investigation or depth study and how you developed your research question or hypothesis. This is the place to explain why this research is interesting. The introduction also includes the literature review, which gives the background information needed to be able to understand the rest of the report. The introduction for secondary-source report is similar to that for a primary-source investigation. In both cases, it is important to reference all your sources correctly.

Aim

In any experiment, the aim describes what you intend to do. For example, you may aim to investigate, to measure, to model, to compare, to verify or to calculate. The aim should be brief and it should link with the hypothesis that predicts what you expect to find.

Hypothesis

The hypothesis is written as a predictive 'If ... then ...' statement stating your expected result, and it must be falsifiable (that is, it must be able to be disproved). It does not give a reason why you expect that result.

Risk assessment

Risk assessment is discussed on pages 14–5.

Materials

A listing of all the materials and equipment (including quantities and concentrations, if applicable) that you used during the experiment is provided.

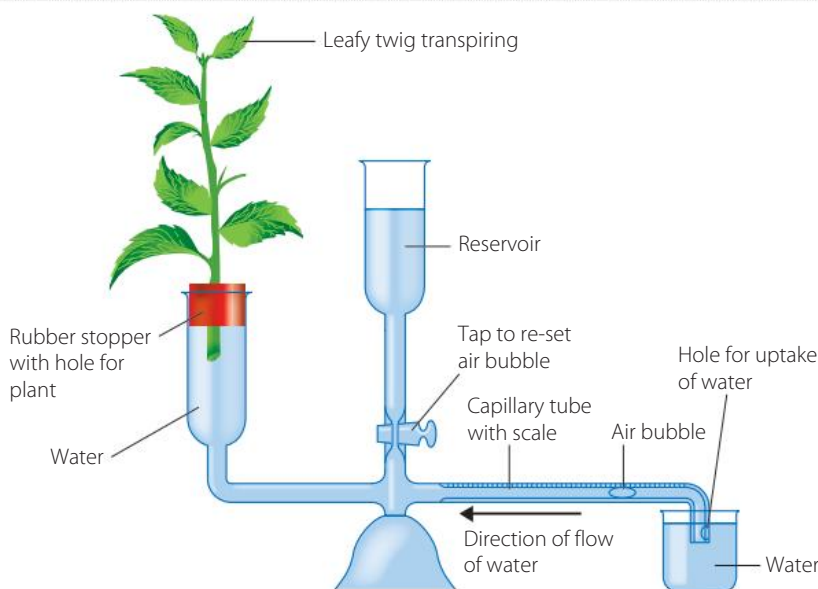
Method

The method summarises what you did. It says what you measured and how you measured it. It is not a recipe for someone else to follow. It also explains, briefly, why you chose a particular method or technique. The method is written in point form. If in the present tense, each sentence usually starts with a verb. The method also describes how you measured your results and recorded your information.

For a primary-source investigation, the method describes how you carried out your experiments or observations in enough detail that someone with a similar knowledge level could repeat your experiments. It should include large, clear diagrams of equipment set-up, such as water baths in enzyme experiments. You should have diagrams in your logbook, but these are generally rough sketches. Diagrams should be redrawn neatly for a report, as in Figure 1.14.

The method section for a secondary-source investigation is generally shorter. If you are doing a review of the current literature on a topic, then your method will say what literature searches you carried out and how you decided which sources to use.

FIGURE 1.14 A potometer is used to measure the rate of absorption in relation to transpiration.



Results

The results section is a summary of your results. It is usually combined with the analysis section, although they may be kept separate.

Tables comparing the results of different experiments or secondary sources are useful. Avoid including long tables of raw data in your report. Wherever possible, use a graph instead of a table. If you need to include a lot of raw data, then put it in an appendix attached to the end of the report.

Think about what sort of graph is appropriate. If you want to show a relationship between two variables, then use a scatter plot. Display your data as points with uncertainty bars and clearly label any lines you have fitted to the data. Column and bar graphs are used for comparing different data sets. Do not use a column or bar graph to try to show a mathematical relationship between variables.

Any data and derived results should be given in correct SI units with their uncertainties. If you performed calculations, then show the equations you used. You might want to show one example calculation, but do not show more than one if the procedure used is repeated.

Discussion

The discussion should summarise what your results mean. If you began with a research question, give the answer to the question here. If you began with a hypothesis, state whether or not your results supported your hypothesis. If not, explain why. If your investigation led you to more questions, as is often the case, say what further work could be done to answer those questions.

Conclusion

The conclusion is a very brief summary of the results and their implications. Say what you found. A conclusion should be only a few sentences long and should not contain any inferences. Make sure your conclusion relates back to your aim and hypothesis. This is where you state whether or not your hypothesis is supported.

Acknowledgements and references

Scientific reports often include acknowledgements thanking people and organisations that helped with the investigation. This includes people who supplied equipment or funding, as well as people who gave you good ideas or helped with the analysis. In science, as in other aspects of your life, it is always polite to say 'thank you'.

The final section of a report is the reference list. It details the sources of all information that were actually used to write the report. This will generally be longer for a secondary-source investigation. Wherever a piece of information or quotation is used in your report it must be referenced at that point. This is typically done either by placing a number in brackets at the point (for example, [2]), or the author and year of publication (for example, (Smith, 2016)). The reference list is then provided in either a footnote at the end of each page or a single complete list at the end of the report. There are different formats for referencing, so check with your teacher what format they prefer. There are several good online guides to referencing.

References versus bibliographies

Note that a reference list is not the same as a bibliography. A bibliography is a list of sources that are useful to understanding the research. They may or may not have actually been used in the report. You should have a bibliography in your logbook from the planning stage of your investigation. The references will be a subset of these sources. A primary-source investigation does not include a bibliography. A secondary-source investigation may include a bibliography as well as references, to demonstrate the scope of your literature search. For some secondary-source investigations, such as an annotated bibliography, the bibliography itself may be a major section of the report.

Working
Scientifically
Skills Outcome:
BI011/12-3



Referencing guide

This guide is designed to help you with referencing your sources.

Referencing i-tutorial

This tutorial will help you understand referencing and show you how to avoid plagiarism.



Information and
communication
technology
capability



Writing a
bibliography



A good practical report

Appendix

Appendices often contain information that it is not essential in explaining the findings of an investigation. For example, any lengthy and repetitive information that supports your finding, such as relevant raw data, is presented in an appendix.

KEY CONCEPTS

- A formal report has the same form as an article written by a scientist. It begins with an abstract (in a scientific journal) or an aim and, at school level, background information. It includes information from a literature review on both the scientific principles behind the research and the research method selected. It includes a risk assessment, materials, method, results and analysis, discussion and conclusion. All sources need to be referenced correctly.

Other ways of communicating your work

You may want to present the results of your investigation in some other way. Scientists communicate their work in many ways. Sometimes a poster is presented or a seminar is given. An article or blog may be written or a web page created. Scientists usually use more than one means, and sometimes several means, to communicate a really interesting investigation.

Look at examples of science investigations reported on websites, in the newspaper, on the TV and so on. This will give you an idea of the different styles used in the different modes. Think about the purpose. Is it to inform, to persuade, or both? What sort of language is used?

Think about your audience and purpose, and use appropriate language and style. A poster is not usually as formal as a report. A video or web page may be more or less formal, depending on your audience.

Posters and websites use a lot of images. Images are usually more appealing than words and numbers, but they need to be relevant. Make sure they communicate the information you want them to. An example of a poster is provided on pages 30–31.

Consider accessibility if you are creating a website. Fonts need to be large enough and clear on websites, and digital images should have tags. You can follow the weblink for more information on accessibility and web-page design.

If you make a video, then consider who your audience is and what will appeal to them. Think about how you will balance content with entertainment.

A formal report uses referencing to show where you found information. Other means of communicating about your depth study or investigation also need to acknowledge the sources of information you used. You also need to be very careful about using copyright content – for example, you cannot copy images from other people's websites without permission unless the site's owner gives that permission. Talk to your teacher about how they would like you to acknowledge your sources.

However you communicate your work, make sure you know what the message is and who the audience is. Once you have established that, you will be able to let other people know about the interesting things you have discovered in your investigation.

Ideas for depth studies

As you progress through this book, you will see investigations in each chapter. Some of these investigations are described in detail. They are designed to be useful as training exercises in learning how to perform primary investigations – how to set up equipment, make measurements, and analyse data. Even if your depth study is from secondary sources, it is important to gain some experience of doing experiments because biology is based on experiment.

At the end of each module, there is a short section called 'Depth study suggestions'. Here you will find ideas for primary- and secondary-source investigations, which build on the content of the preceding



Website accessibility

The Royal Society for the Blind has information on making websites accessible.

chapters. These suggestions are sourced from experienced teachers and university academics, and from biology education literature. Your own teacher will have ideas and suggestions. You can also generate your own ideas by reading about topics you are interested in. Consider what skills from other areas you might bring to a depth study, particularly if you are artistically creative or musical. Many biologists combine their love of science with creative pursuits.

By carrying out depth studies, you will extend your knowledge and understanding in biology but, more importantly, you will learn how to work scientifically – you will learn how to do biology.

KEY
CONCEPTS

- There are many ways of communicating your findings. Choose a method that is appropriate to your investigation and your intended audience.

Poster: A new fertiliser stimulates seedling growth of the newly discovered and rare *Eucalyptus pyreneae*

Arthur B. Ruse, Jacqueline Hammond, Rufus C. Smith, Karen Trace and Leigh B. Waters, Pyrenees State High School, Warrenmang, Victoria, Australia

Introduction

The recent identification of a new rare *Eucalyptus* species in the Pyrenees region of north west Victoria, *Eucalyptus pyreneae* (Figure 1), has prompted efforts to try to cultivate the species (1). This would allow for regeneration of local areas with the native tree, promoting conservation of this species and enriching the natural biodiversity of the area.

Growing *E. pyreneae* seedlings has proven difficult without the addition of a fertiliser, although the standard low-phosphorus fertiliser used for *Eucalyptus* species, Super Ready, has not stimulated the same enhanced growth that is usual in other species (2).

A new fertiliser, ExtraGro, has recently become available for native Australian plants. It contains identical levels of phosphorus, potassium and trace elements to those in Super Ready but has double the amount of nitrogen, which promotes foliage growth (3). The aim of this study was to determine whether ExtraGro, containing greater nitrogen, enhanced *E. pyreneae* growth above that stimulated by Super Ready.



FIGURE 1
Eucalyptus pyreneae

Method

Seedlings were obtained from a nursery at a length of $10\text{ cm} \pm 2\text{ cm}$ and grown in 300g of standard Australian native plant potting mixture (Figure 2). Plants were exposed to full sunlight and were watered every second day with 25mL tap water.

Fertiliser (2mg per seedling) was applied to the soil immediately prior to each watering.

After two weeks, seedlings were analysed for total length, shoot length, root length, total dry weight, shoot dry weight and root dry weight.

Six replicate seedlings were tested per condition.



FIGURE 2 Seedlings in their growing containers. Left pot, seedling treated with standard fertiliser and right pot, Super Ready.

Tng DYP, Janos DP, Jordan GJ, Weber E and Bowman DMJS (2014) Phosphorus limits *Eucalyptus grandis* seedling growth in an unburnt rain forest soil. *Front. Plant Sci.* 5:527. doi:10.3389/fpls.2014.00527 Licenced under CC BY 4.0 <http://creativecommons.org/licenses/by/4.0/>

Results: ExtraGro stimulates enhanced root growth

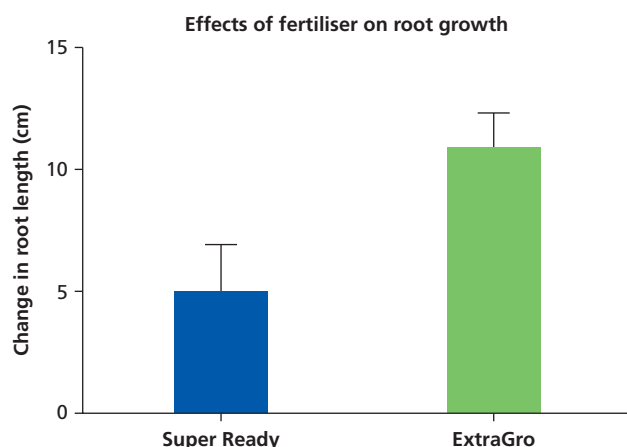


FIGURE 5 Change in root length of seedlings after two weeks of treatment, normalised to untreated seedlings (difference in treated seedling length divided by difference in untreated seedling length).

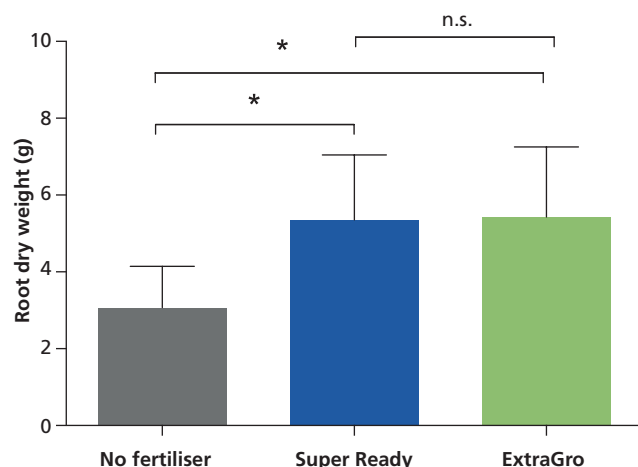


FIGURE 6 Root dry weight after two weeks of treatment. * $P < 0.05$, n.s. = not significant. Bars show mean $\pm$ standard deviation, $n = 6$.

Results: ExtraGro promotes greater shoot growth



FIGURE 3 Representative seedlings after two weeks of treatment. Left, untreated seedlings. Centre, seedlings treated with Super Ready and right, seedlings treated with ExtraGro.

Mullan, G. D. and White, P. J. 2001. Seedling Quality: Making informed choices. Bushcare and the Department of Conservation and Land Management. Photo by G. Mullan.

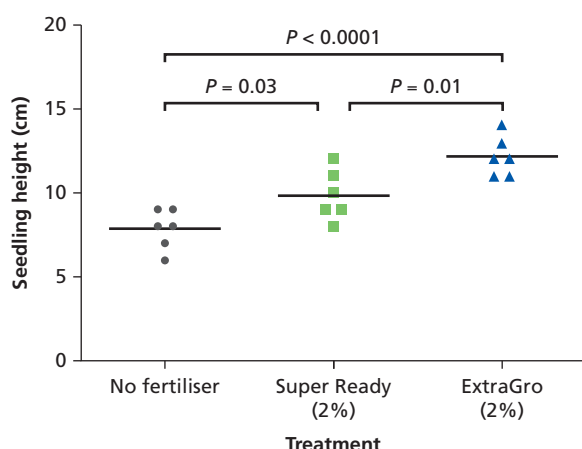


FIGURE 4 Effects of fertilisers on seedling height after two weeks of treatment

Treatment of *E. pyreneae* seedlings with the standard Australia native plant fertiliser, Super Ready, increased seedling height over a growing period of two weeks above the height reached by treatment with water alone. However, ExtraGro caused superior seedling shoot growth in terms of biomass (e.g. Figure 3) and height (Figure 4).

In addition to stimulating shoot elongation and biomass accumulation, we found ExtraGro to have superior root-enhancing properties over Super Ready. Root length increased significantly more over two weeks following treatment with ExtraGro than with Super Ready (Figure 5). However, root biomass was not increased by ExtraGro (Figure 6), suggesting that the increased nitrogen in this fertiliser stimulated the growth of longer but thinner roots.

Conclusions

We tested whether the ExtraGro fertiliser, containing twice as much nitrogen, stimulated enhanced *E. pyreneae* seedling growth over that stimulated by the standard Australian native plant fertiliser Super Ready.

ExtraGro promoted greater shoot elongation and biomass accumulation. In addition, it stimulated increased root elongation, although it did not alter root biomass gain over a two-week period.

Therefore, we have found that *E. pyreneae* seedlings respond better to a high-nitrogen fertiliser than standard fertiliser. This significant finding may inform future efforts to cultivate this species.

References

- Perugia E., et al. 'A new Eucalypt native to the Victorian Pyrenees State Park'. *Australian Journal of Native Flora*, Vol 3, pp.206–8, 2011.

Acknowledgements

We thank the Pyrenees Nursery for kind provision of the *E. pyreneae* seedlings. We also thank P. Whitely for contributions to plant maintenance, and we thank our teacher Ms M Marshall for valuable contributions to our study design and poster preparation.

» MODULE ONE

CELLS AS THE BASIS OF LIFE

- ② Cell structure and technologies
- ③ Cell function

Shutterstock.com/Sebastian Kaulitzki

2 Cell structure and technologies

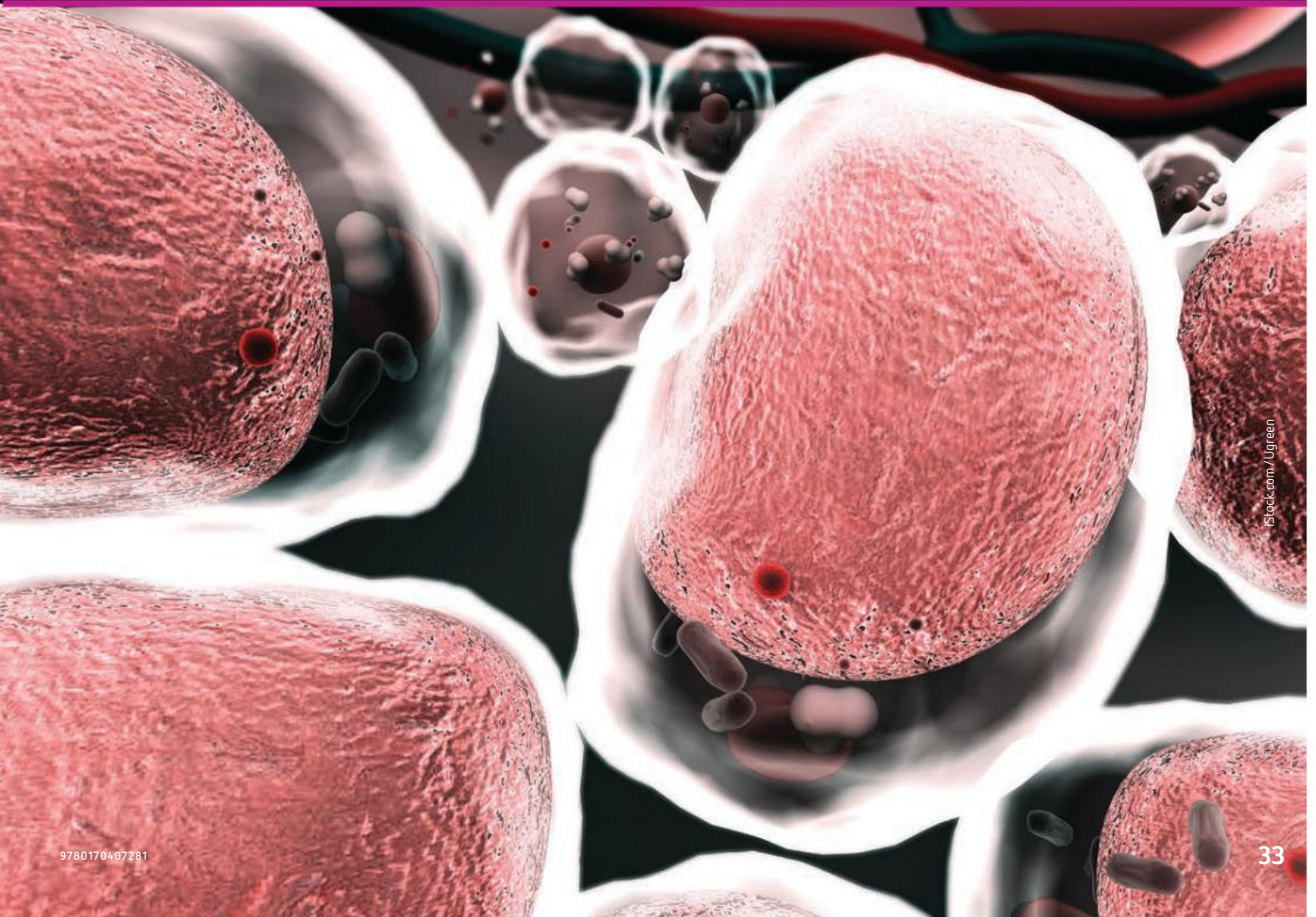
INQUIRY QUESTION

What distinguishes one cell from another?

Students:

- investigate different cellular structures, including but not limited to:
 - examining a variety of prokaryotic and eukaryotic cells (ACSBLO32, ACSBLO48) [ICT](#)
 - describe a range of technologies that are used to determine a cell's structure and function [ICT](#)
- investigate a variety of prokaryotic and eukaryotic cell structures, including but not limited to:
 - drawing scaled diagrams of a variety of cells (ACSBLO35) [ICT N](#)
 - comparing and contrasting different cell organelles and arrangements [CCT](#)
 - modelling the structure and function of the fluid mosaic model of the cell membrane (ACSBLO45) [CCT](#) [ICT](#)

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When you think about it, living organisms are amazing things. The secrets of their functioning have intrigued many generations of scientists over many hundreds of years. It has only been since the development of technology such as the microscope that the details of the structure and functioning of living things have been determined. This started with the discovery of the cell as the basic unit of all living things.

Since then, it has been found that even though cells share some similarities, not all cells are the same. They differ in their structure, function and organisation.

Some organisms consist of only one cell that has to perform all functions. Other organisms contain many different cells, each with a specific structure and function, organised to work together to ensure effective functioning.

2.1 Types of cells

Even though there are many different types of cells in organisms, they can be classified as either **prokaryotic** or **eukaryotic** cells. Prokaryotic cells are 'primitive' cells and have a much simpler structure than eukaryotic cells. There are many more prokaryotic cells on Earth than there are eukaryotic cells. Although these two types of cells have many differences, they share basic similarities, with each possessing a **cell membrane**, **cytoplasm** and **ribosomes** (structures that produce proteins in the cell).

Prokaryotic cells

With the word derived from the Greek *pro* (before) and *karyon* (nucleus), prokaryotic cells range in diameter from 0.1 to 5.0 μm (micrometres). The four main structures that all prokaryotic cells possess are the cell membrane, the cytoplasm, ribosomes and genetic material. The cell (plasma) membrane is responsible for controlling what goes into and out of the cell.

There is no membrane surrounding the genetic material and therefore no **nucleus**. Most of the genetic material forms a large loop called the bacterial chromosome, with the rest in small circular rings called **plasmids**. The structures inside prokaryotic cells are not surrounded by membranes – they simply float in the fluid-like cytoplasm, as does the genetic material. Structures that are present in some prokaryotic cells are a **cell wall**, **pili** (singular: pilus), **flagella** (singular: flagellum) and a **capsule**. Pili are hair-like structures on the surface of some cells that allow them to adhere to nearby substances. Flagella are whip-like tails that provide the cell with locomotion. The cell wall protects the cell and provides structural support. The substances it is composed of differ depending on the type of cell. The capsule is a layer composed of complex carbohydrates outside the cell wall and protects the cell.

Most organisms that are composed of prokaryotic cells are **unicellular** – a single cell. Some bacterial species clump together as a colony of prokaryotic cells that work together.



FIGURE 2.1 Cells are the basic structural and functional unit of the diverse range of all living things. **a** Amoeba; **b** roses; **c** animals of the Great Barrier Reef

Figure 2.2 shows a generalised three-dimensional diagram and a scientific two-dimensional line drawing of a typical prokaryotic cell.

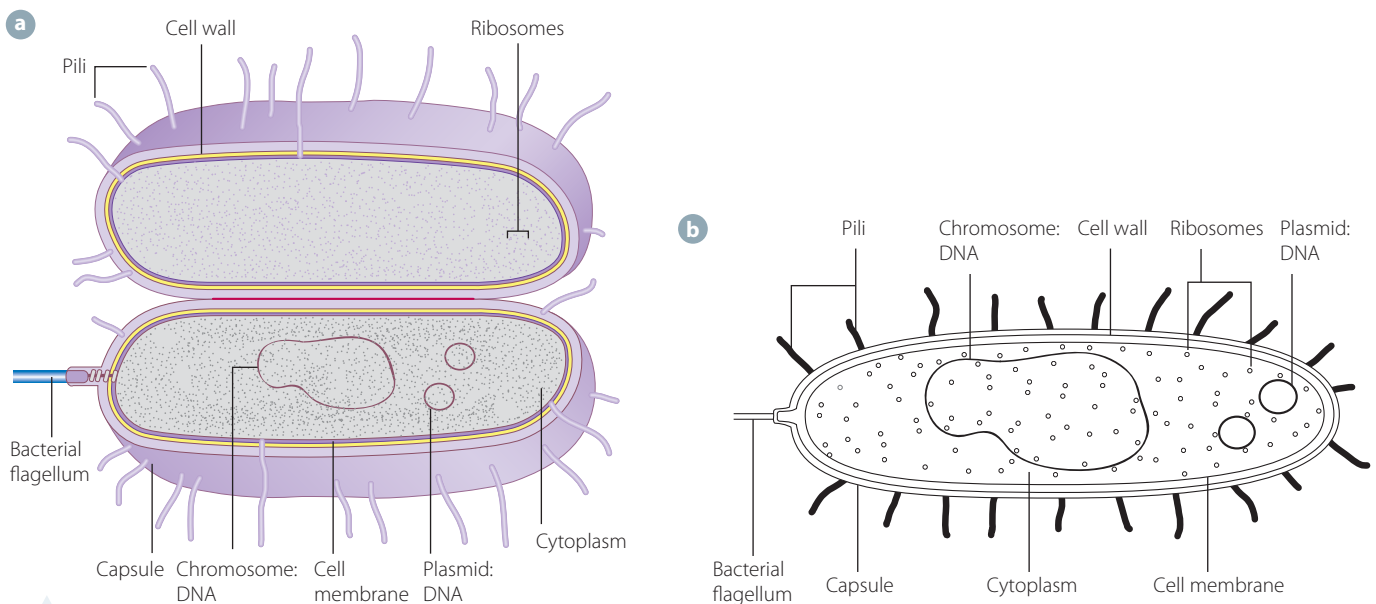


FIGURE 2.2 **a** A generalised diagram of bacteria – a prokaryotic cell; **b** a scientific line drawing of the cell

Prokaryotic organisms (or **prokaryotes**) can be divided into two main groups: bacteria and **archaea**. The cells in these groups are similar in both shape and size, but differ chemically in terms of their genetic material and proteins. Bacteria can be found in many different environments and can be either beneficial or harmful to living organisms (Fig. 2.3a). Archaea (Fig. 2.3b) are unicellular organisms that are found in extreme and harsh environments, such as hydrothermal vents and hot springs.

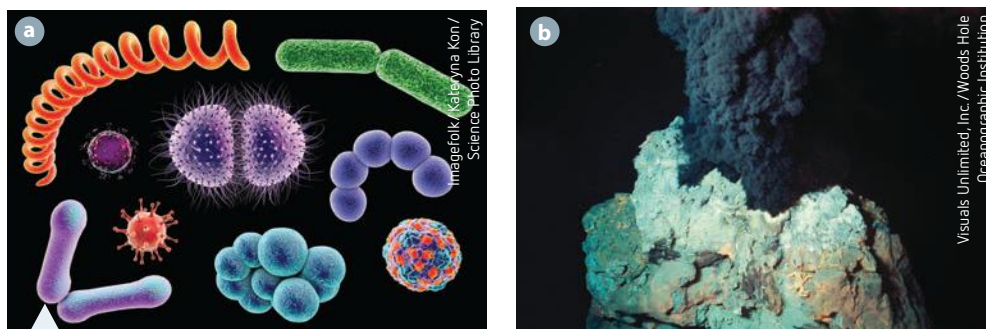


FIGURE 2.3 **a** Different types of bacteria; **b** Archaea are prokaryotes found in harsh environments such as hydrothermal vents as shown here. Archaea are found in the water where the hot fluid is escaping.

Eukaryotic cells

‘Eukaryotic’ is derived from the Greek *eu* (‘true’ or ‘proper’) and *karyon* (‘nucleus’).

These cells range in size from 10 to 100µm and are much more complex than prokaryotic cells. Eukaryotic cells are characterised by a membrane-bound nucleus containing the genetic material of the cell. All of the internal structures of these cells are membrane bound and are known as **organelles**. Each organelle has a specific function within the cell. Together these organelles carry out all of the biochemical processes and reactions, such as respiration and photosynthesis, that are required for the successful functioning of a living cell.

The different types of organelles and their function are discussed later in this chapter.



Comparing
types of cells

Living organisms that contain eukaryotic cells are known as **eukaryotes**. These organisms can be either unicellular or **multicellular** (containing many cells). *Paramecium*, *Amoeba* and *Euglena* are examples of unicellular eukaryotes (Fig. 2.4).



FIGURE 2.4 Examples of unicellular eukaryotes: **a** *Paramecium*; **b** *Amoeba*; **c** *Euglena*



Different types of cells

Summarise the
similarities and
differences between
prokaryotic and
eukaryotic cells.

Multicellular plants and animals are composed of a variety of different types of eukaryotic cells.

KEY CONCEPTS

- There are two types of cells: prokaryotic and eukaryotic.
- Prokaryotic cells exist as single cells and have no membrane-bound nucleus or organelles.
- Bacteria and Archaea kingdoms contain prokaryotic cells.
- Eukaryotic cells have a membrane-bound nucleus and membrane-bound organelles.

INVESTIGATION 2.1

A practical investigation to examine prokaryotic and eukaryotic cells



Practical
introduction
to using a
microscope

Living cells, whether prokaryotic or eukaryotic, possess structures that allow them to carry out the biochemical processes required for them to function effectively. These structures are organised differently in different types of cells.

A variety of prokaryotic and eukaryotic cells can be examined using a light microscope. Only certain structures (such as the cell membrane, nucleus, cytoplasm and chloroplasts) are large enough to be viewed using the microscopes available in school laboratories. For more details of other structures in a cell, electron micrographs need to be used.

AIM

To examine and compare a variety of prokaryotic and eukaryotic cells using a light microscope

MATERIALS

- Light microscope
- Microscope slides
- Coverslips
- Onion
- Knife/scalpel
- Forceps or dissecting needles
- Eye dropper (optional)



- Methylene blue stain with eye dropper
- Paper towelling
- 500 mL beaker of water for used microscope slides and coverslips
- *Ambulia* plant (or an alternative freshwater-oxygenating plant available from the local aquarium or biological supplier)
- Plastic bag
- Disposable gloves
- Prepared slide of human cheek cells
- Prepared slide of bacteria
- Prepared slides of plant and animal tissues (for example root hairs, guard cells, frog blood cells, human blood cells, sperm cells or neurons)
- Immersion oil

RISK ASSESSMENT

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Knife/scalpel	Sharp edges can cause cuts	Use knife/scalpel with care, hold by the handle and keep fingers away from sharp edge of knife.
Microscope slides/coverslips	Sharp edges can cause injury if broken	Handle with care. Push gently on coverslip. Always focus by moving objective lens away from slide.

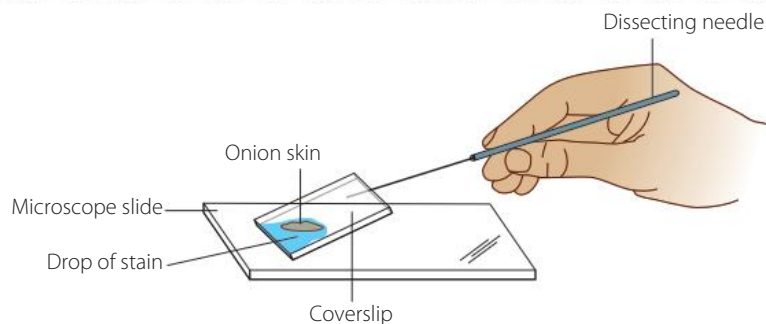


METHOD

A Plant cell: onion

- 1 Remove the onion skin, cut through the onion and separate the layers.
- 2 Carefully lift a thin section of onion tissue from the surface of one of the layers.
- 3 Prepare a wet mount of this tissue using the technique outlined in the following steps.
- 4 Cut a piece of onion tissue about 1 cm² in area and place this in a drop of methylene blue stain on the glass microscope slide. Be careful not to fold the tissue over on itself.
- 5 Using a dissecting needle, lower the coverslip carefully to avoid the formation of air bubbles (Fig. 2.5).
- 6 Place a piece of paper towel over the coverslip and microscope slide to dry any excess stain.

FIGURE 2.5 Diagram showing technique for lowering coverslip on to a wet mount



- 7 View under low power, then under high power.
- 8 Draw a scientific diagram of two or three cells. Use a sharp pencil and draw single, solid lines. Each diagram should be large enough (approximately 6–7 cm in size) to clearly show all structures visible inside the cells. Each diagram should have detailed and accurate labels. Label lines should be parallel if possible and should never cross over each other. They should have no arrowheads and should touch the actual structure being labelled.
- 9 Label the nucleus, cell membrane and cytoplasm.
- 10 Total magnification should also be recorded.

A worked example to calculate total magnification is shown on page 39.



» B Plant cell: *Ambulia* – pond weed

- 11 Prepare a wet mount using a leaf from the tip of the plant.
- 12 Place the leaf on to a drop of water and gently lower the coverslip (see step 5 above).
- 13 View under low power, then under high power. Note any streaming movement of the cytoplasm and chloroplasts.
- 14 Draw a diagram of one cell (see step 8 above). Label the cell wall, nucleus, chloroplasts and cytoplasm.
- 15 Record the total magnification.

C Animal cell: cheek cells

- 16 Observe a prepared slide of stained cheek cells under low power and then high power.
- 17 Draw a diagram of one of these cells and label the cell membrane, nucleus, cytoplasm and any other structures you can identify.
- 18 Record the total magnification.
- 19 View prepared slides of other animal and plant tissue supplied by your teacher.
- 20 Identify any different cell structures observed.

D Prokaryotic cell

- 21 Observe a prepared slide of bacterial cells.
- 22 Use an oil immersion objective to give a higher magnification (to observe the bacteria). Place a drop of oil on the coverslip above the specimen and centre the oil immersion objective lens over the oil. Use the fine focus adjustment to obtain a clear image.
- 23 Draw one bacterial cell and record the magnification. Note the size of a bacterial cell compared to a cheek cell.

RESULTS

- 1 Your results will include scientific diagrams including labels and total magnification of:
 - a an onion cell
 - b an *Ambulia* cell
 - c a cheek cell
 - d a bacterial cell
 - e two other cells you observed.
- 2 In a table, record the similarities and differences in size and structure between the cells you have observed and drawn in the previous question:
 - i two plant cells: **a** and **b**
 - ii a plant cell and an animal cell: **b** and **c**
 - iii a plant cell and a bacterial cell: **a** and **d**
- 3 List the cells in order of size from smallest to largest.

DISCUSSION

- 1 Describe why methylene blue stain was used when preparing the wet mount of the onion cell.
- 2 Compare the size of a bacterial cell to the plant and animal cells you have seen so far.
- 3 Outline any cell detail seen inside the bacterial cells.
- 4 Identify two limitations of using a light microscope.
- 5 Using your observations of the cells, suggest two differences between prokaryotic and eukaryotic cells.
- 6 Describe how the prepared slides that you used compare to the ones that you prepared yourself.
- 7 Describe how using oil immersion helped you to see the internal structure of the bacterial cell.

CONCLUSION

Write a summary statement that relates to the aim of this investigation. A brief summary of what you did (variable changed) and what you found (variables observed) is required.

Calculating total magnification

To calculate the total magnification when using a light microscope, the magnification of the ocular (eyepiece) lens is multiplied by the magnification of the objective lens being used:

$$\text{total magnification} = \text{magnification ocular lens} \times \text{magnification objective lens}$$



WORKED EXAMPLE 2.1

Calculate the total magnification of a microscope when the magnification of the ocular lens is $10\times$ and the magnification of the objective lens is $10\times$.

ANSWER	LOGIC
$= 10 \times 10$	▪ Multiply the magnification of ocular lens by the magnification of objective lens.
$= 100\times$	▪ Calculate the answer.

TRY THESE YOURSELF

Complete the following table.

OCULAR LENS MAGNIFICATION	OBJECTIVE LENS MAGNIFICATION	TOTAL MAGNIFICATION
$10\times$	$20\times$	
$10\times$	$40\times$	
$12\times$		$480\times$

KEY CONCEPTS

- You can use a light microscope to view cells.
- Total magnification is calculated by multiplying the magnification of the ocular lens by that of the objective lens.

- 1 State the two different types of cells, and list features of each.
- 2 What features do the two different types of cells share?
- 3 Complete the following table to compare the features of prokaryotic and eukaryotic cells.

CHARACTERISTIC	PROKARYOTIC CELLS	EUKARYOTIC CELLS
Membrane-bound nucleus		
Membrane-bound organelles		
Unicellular/multicellular		
Examples		

- 4 Draw a labelled scientific diagram of the following cells as seen through the light microscope:
 - an onion cell
 - a cheek cell.
- 5 Calculate the total magnification of a light microscope when a $12\times$ ocular lens and a $20\times$ objective lens are used to view a sample. Show your working.

CHECK YOUR UNDERSTANDING

2.1

2.2

Technologies used to determine cell structure



FIGURE 2.6 Hans and Zacharias Janssen invented the first compound microscope.

Scientists in the 1500s used handheld magnifying glasses to view objects of interest. In the quest to see greater detail, scientists invented the first compound microscope (Fig. 2.6). This microscope had two convex lenses placed at either end of a barrel and was the precursor to the light microscope. After much refining, this simple handheld device has transformed into the microscopes that are commonly used in the school laboratory.

After further developments were made to the structure of these compound microscopes, such as placing them on a stand, adding focus knobs and a light source, scientists were better able to determine the structure of organisms. Robert Hooke, in the 1660s, was able to view and draw the structure in cork that led to his use of the term 'cella', leading to our term 'cell' (Fig. 2.7).

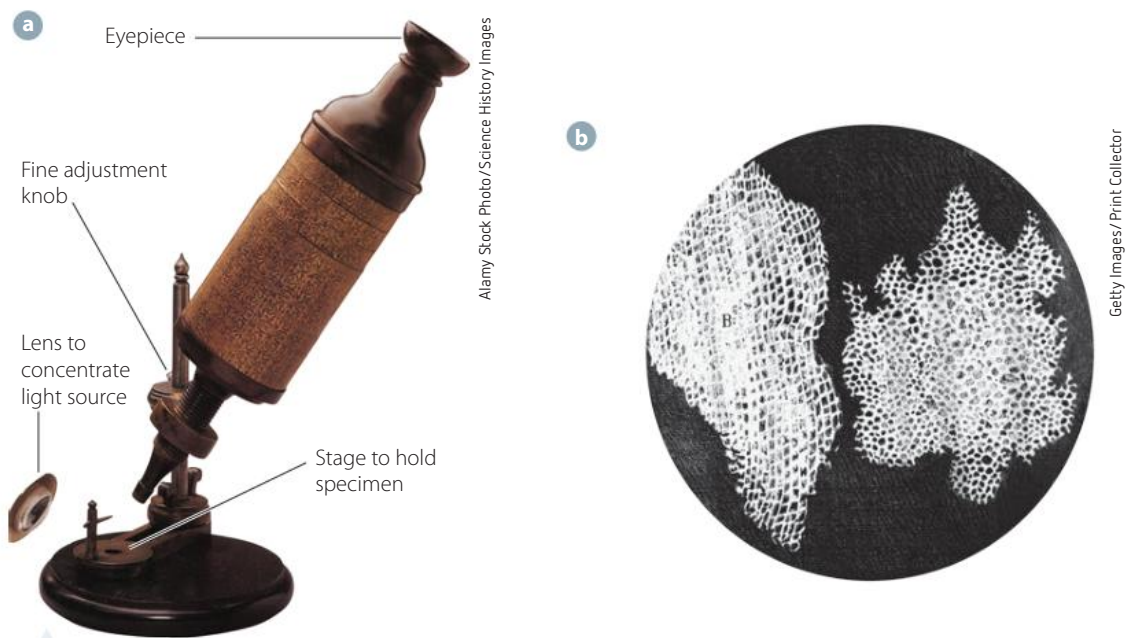


FIGURE 2.7 **a** Hooke's compound microscope; **b** Hooke's drawing of cork, showing the compartments he called 'cella'

Modern microscopes

Further refinements in the structure of compound microscopes continued over the succeeding years until we have those that are in use today.

Light microscopes

In the compound light microscope such as those you use in the school laboratory, a light source passes through a condenser lens and then through the thin specimen. This beam of light then passes through the convex objective lens, where the image is magnified and viewed through the ocular lens (Fig. 2.8).



Discovering
the principle of
a compound
microscope

Compound light microscopes can produce images with a **magnification** (increase in size of the image) up to $1500\times$ depending on the lenses used. In microscopy, as well as magnification, **resolution** (or resolving power) is also important in order to see the detail of structures. Resolution is the ability to distinguish between two separate objects. It is the *smallest distance* between two objects where each can be observed as separate. For a compound light microscope, the maximum resolution is 200 nm (nanometres). This means that the best light microscopes will only be able to distinguish two separate structures if the distance between them is 200 nm or more. If the distance between the objects is less than 200 nm, two distinct objects will be seen as one object.

Both living and non-living specimens can be viewed using a compound light microscope.

Fluorescence microscopes

The fluorescence microscope is similar to the light microscope. It has extra features that enable scientists to produce images of specific parts of cells. Structures beyond the limit of resolution of the light microscope can be seen using this microscope.

The sample to be viewed is labelled with a **fluorescent** substance that will attach to the structures that the scientist wants to specifically observe. The sample is illuminated with a high-intensity source of light that causes the fluorescent substance to emit light. This fluorescent light is directed through filters that separate it from surrounding light and the viewer is able to see only those areas of the sample that are fluorescing (Fig. 2.9).

See page 44 for conventions regarding units of measurement.

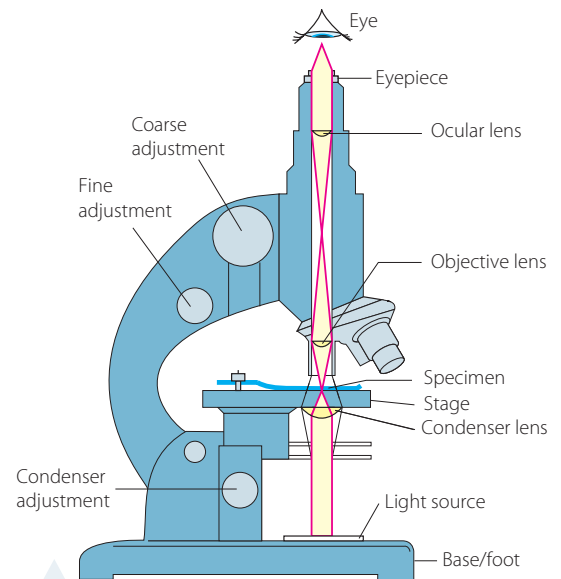


FIGURE 2.8 The compound light microscope

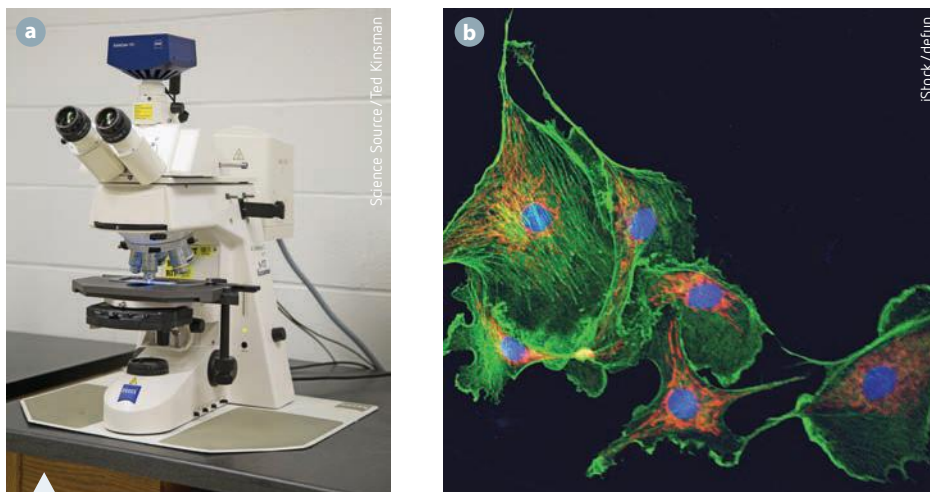


FIGURE 2.9 **a** A fluorescence microscope; **b** image of cells seen through a fluorescence microscope, showing different parts of the cell exhibiting different colours of fluorescence

Electron microscopes

Since the 1950s, studies of **microscopic** organisms have been revolutionised by the development of the electron microscope. This instrument uses an electron beam instead of light, and electromagnets instead of glass lenses. The interaction between the electrons and the object forms a viewable image on a screen (Fig. 2.10). The use of electrons instead of light gives much greater magnification. Electron microscopes also have a much higher resolving power than light microscopes because electrons have a much shorter wavelength than light.

The electron microscope reveals structures at not only the cellular level, but also at the subcellular level. Materials that were formerly believed to have little or no structure have been shown to have

elaborate internal organisation. Many parts of cells (organelles) were seen for the first time after the invention of the electron microscope. Other parts previously seen with the light microscope can be seen in far greater detail, providing increased knowledge of their internal structure. This has led to a greater understanding of their functions in cells. Features as small as one-tenth of a nanometre (one ten-billionth of a metre) can be seen, including individual atoms.

There are two main types of electron microscopes: the scanning electron microscope (SEM) and the transmission electron microscope (TEM).

The electron microscope shown in Figures 2.10 and 2.11 is called a transmission electron microscope (TEM) because the electrons are transmitted (pass through) the specimen. The TEM produces a two-dimensional image. It is the most common form of electron microscope. It can magnify up to 1 500 000 times and has a resolution of about 2 nm.

A scanning electron microscope (SEM) bombards solid specimens with a beam of electrons, which causes secondary electrons to be emitted from the surface layers of the specimen. The SEM has poorer resolution (about 10 nm) than a TEM, but gives excellent three-dimensional images of surfaces (Fig. 2.12).



Zoom into the micro world



Virtual scanning electron microscope

Try to get the best possible image for each specimen viewed in the virtual scanning microscope.



Information and communication technology capability

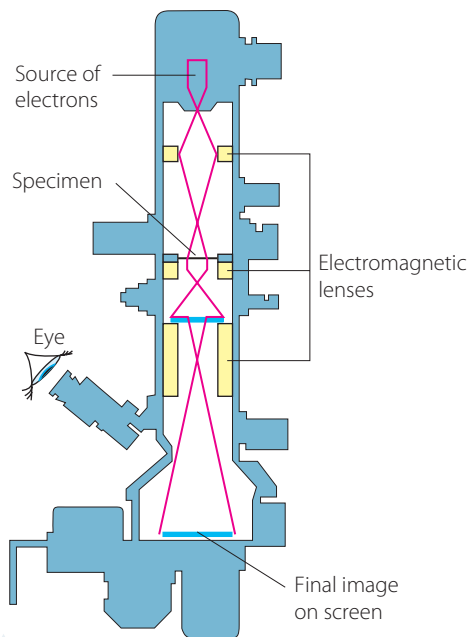


FIGURE 2.10 The electron microscope



FIGURE 2.11 A transmission electron microscope (TEM) currently used in biological research

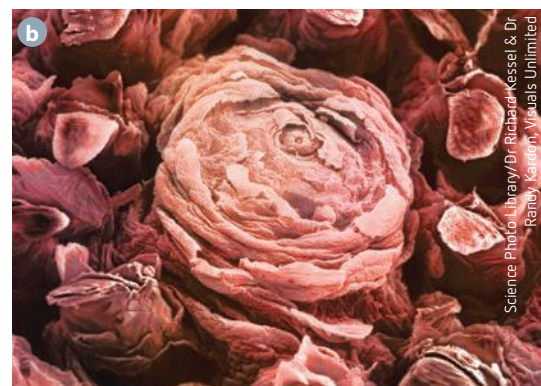
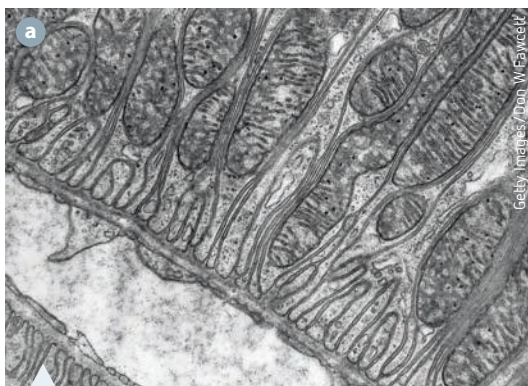


FIGURE 2.12 **a** TEM image of kidney cells; **b** SEM image of the surface of the tongue. The resolution of the microscope is high enough to show the individual taste buds.

Although there are many advantages in using an electron microscope, there are some disadvantages. For example, the specimen must be placed in a vacuum for viewing, because air would interfere with the flow of electrons. As a result, living tissue cannot be viewed.

The preparation of the specimen is very complicated and comes with a risk of introducing **artefacts** into the image. An artefact is something that is introduced into the image that wouldn't normally be there. Comparing samples prepared in different ways can identify whether artefacts are present.

The size, expense and maintenance costs are much larger in this type of microscope than in others.

Computer-enhanced technology to study cells

Digital processing of images produced by microscopes allows scientists to view cells in new ways. For example, cell scan software produces three-dimensional representations of cell structure, allowing a much greater understanding of cell structure and function. Our knowledge about cells has been helped by the development of advanced computer technologies to construct models that can be used to determine how molecules interact in cellular reactions.

Confocal laser scanning microscopy can be used to highlight the three-dimensional structure of samples being studied. A **laser** produces a narrow intense beam of light that is focused to a pinpoint on the sample while all the surrounding, out-of-focus areas are not included in the image. This focusing occurs many times through the specimen at different levels. An image reconstruction program puts together the data from the images taken at different levels and constructs a three-dimensional image (Fig. 2.13). These microscopes are often used to image the structural components of cells and have the advantage that the specimen remains intact.

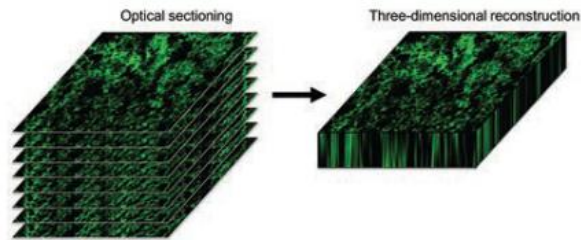


FIGURE 2.13 Confocal laser scanning microscope takes an image of the sample at many different levels. A computer program is then used to construct a three-dimensional image.



Technologies used to study cells

From Jekle, M., Becker, T.: Wheat dough micro-structure: The relation between visual structure and mechanical behavior. Critical reviews in food science and nutrition 55 (2015), 369–382

KEY CONCEPTS

- Early microscopes allowed scientists to see cells for the first time.
- Magnification indicates how much an image has been increased in size.
- The resolution indicates the minimum distance objects need to be apart to be able to be seen separately.
- Light microscopes pass light rays through thin specimens that are magnified by convex glass lenses.
- Magnification in light microscopes can be up to 2000×, maximum resolution 200 nm.
- Living and non-living specimens can be viewed using a light microscope.
- Fluorescence microscopy targets specific structures and uses labelling of these structures with fluorescent substances to see them.
- Electron microscopes use electron beams and electromagnets instead of light rays and lenses.
- Two types of electron microscopes are transmission electron microscopes (TEM) and scanning electron microscopes (SEM). No living specimens can be viewed with an electron microscope.
- In a TEM, beams of electrons pass through a specimen and produce a two-dimensional image. Very high magnification and resolution are possible (up to ten million times with some SEMs).
- In a SEM, electron beams bounce off surfaces and create a three-dimensional image.
- Confocal laser scanning microscopes use pinpoint laser beams to make images of many layers, which are then combined into a three-dimensional model.

CHECK YOUR UNDERSTANDING

2.2

- 1 Explain the difference between the terms 'magnification' and 'resolution'.
- 2 Outline how a light microscope works.
- 3 Identify two advantages and one disadvantage of using the light microscope to view specimens.
- 4 Outline the process used in fluorescence microscopy and provide one advantage over the use of a light microscope.
- 5 Explain how an image is created in an electron microscope.
- 6 Use a table to compare the TEM with the SEM. Features to use could be such things as the magnification, resolution, the type of image formed and the way it is produced.
- 7 Identify two advantages and two disadvantages of using the electron microscope to view specimens.
- 8 Describe how a three-dimensional image is produced when using a confocal laser scanning microscope.

2.3 Sizes of cells

Advances in biology over the last decades have pushed our view of the microscopic world to ever-decreasing sizes. Centimetres, millimetres and even micrometres or microns (μm) are often too large to measure some objects. We are now in the 'nano age'.

1 metre (m) = 10^2 centimetres (cm)

= 10^3 millimetres (mm)

= 10^6 micrometres or microns (μm)

= 10^9 nanometres (nm)

1 cm = $1/100$ m

1 mm = $1/1000$ m

1 μm = $1/1\,000\,000$ m

1 nm = $1/1\,000\,000\,000$ m

Figure 2.14 demonstrates the size of the objects seen by the naked eye, a light microscope and electron microscope.

How big?
Compare the size of a human hair to that of a red blood cell and an Ebola virus.

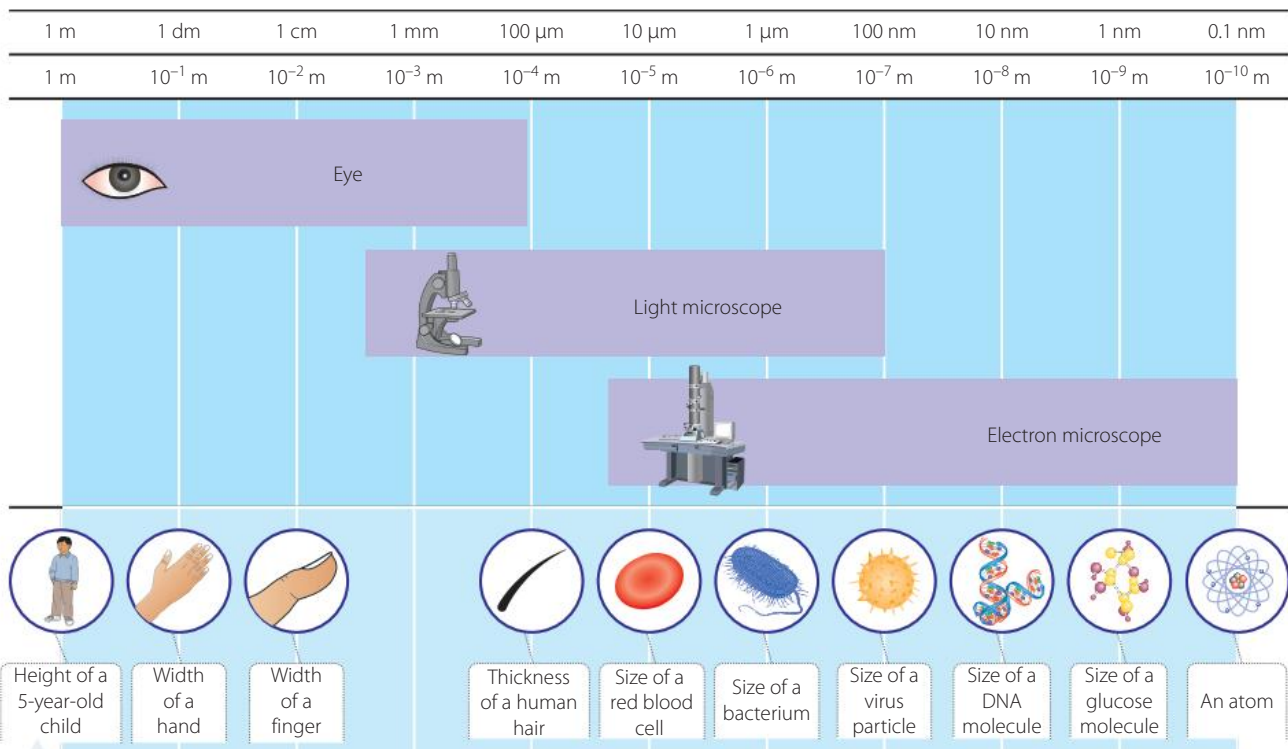


FIGURE 2.14 Size and comparison of images seen by the naked eye, light microscope and electron microscope

Drawing scaled diagrams

When drawing different types of cells, such as those viewed in Investigation 2.1, it is useful to draw these cells to scale. This allows a more accurate representation of the size of these cells.

Diagrams that are drawn to scale will always contain a 'scale bar', which indicates the scale to which the diagram is drawn.

The scale bar represents a specific whole number of μm and is often 1–5 cm in length. In order to draw the scale bar:

- 1 Determine the actual length of the object to be drawn.
- 2 When the actual length of the object determined above is divided by the length of the proposed drawing, a whole number should be obtained.

For example:

length of cell = $8\ \mu\text{m}$

length of drawing = 4 cm

$$\frac{\text{Actual length}}{\text{Length of drawing}} = \frac{8\ \mu\text{m}}{4\ \text{cm}}$$

$$\text{Scale} = \frac{2\ \mu\text{m}}{1\ \text{cm}}$$

Therefore, a scale bar 1 cm in length would represent $2\ \mu\text{m}$
or a scale bar 2 cm in length would represent $4\ \mu\text{m}$, and so on.



How to approach
drawings in
biology

WORKED EXAMPLE 2.2

A human cheek cell, as observed in Investigation 2.1 and shown in Figure 2.15, has a diameter of approximately $60\ \mu\text{m}$. Its nucleus has a diameter of $6\ \mu\text{m}$. Draw a scaled diagram of the human cheek cell and its nucleus.

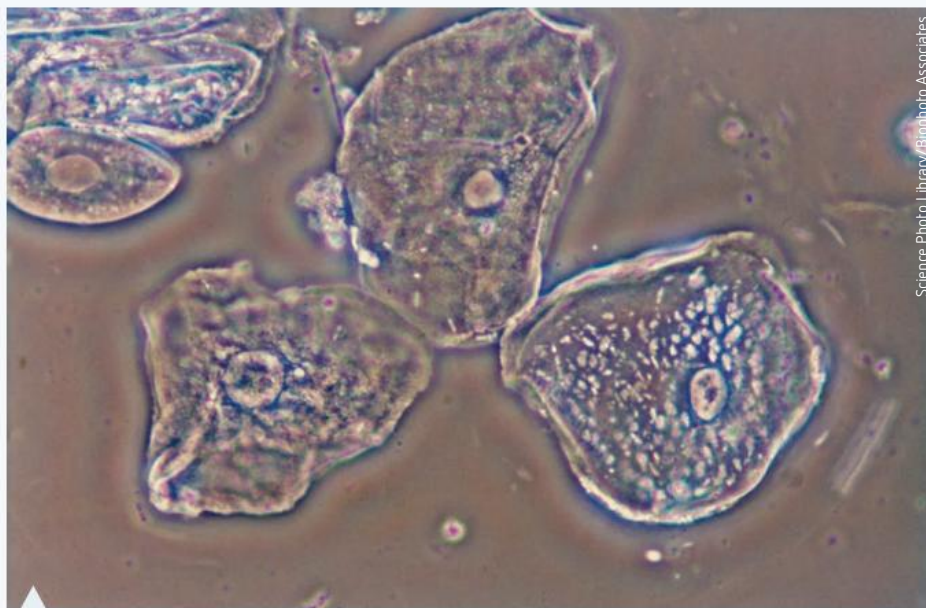


FIGURE 2.15 A human cheek cell with nucleus

ANSWER

Actual diameter of cell = $60\text{ }\mu\text{m}$

Diameter of cell to be drawn = 5 cm

$$\begin{aligned}\text{Scale} &= \frac{60\text{ }\mu\text{m}}{5\text{ cm}} \\ &= \frac{12\text{ }\mu\text{m}}{1\text{ cm}}\end{aligned}$$

A scale bar of 1 cm represents $12\text{ }\mu\text{m}$.

The nucleus is $6\text{ }\mu\text{m}$, which would be equivalent to 0.5 cm .

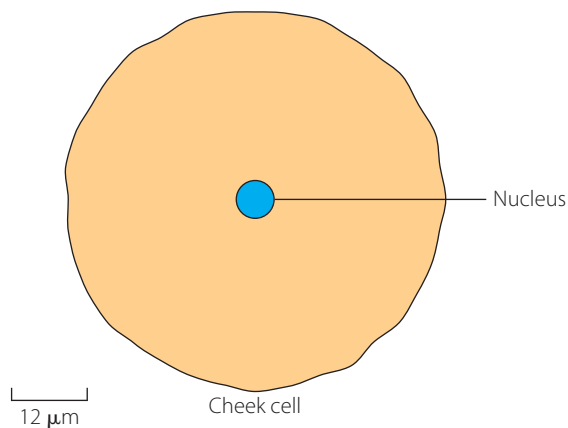


FIGURE 2.16 Scaled diagram of human cheek cell

LOGIC

- Extract data from question.

$$\frac{\text{Actual diameter}}{\text{Diameter of drawing}}$$

- Measure 5 cm both across and down the centre of the area where the diagram is to be drawn.
- Remembering the guidelines for biological drawings, draw one solid line in a roughly circular shape with the 5 cm diameter. (Note: the cheek cell is not perfectly circular)
- According to our scale 1 cm represents $12\text{ }\mu\text{m}$.
- Calculate the diameter to draw for the nucleus.
- Draw in the nucleus with a diameter of 0.5 cm (5 mm).
- Include the scale bar at the base of the drawing.

TRY THESE YOURSELF

Draw a scaled diagram of the following cells.

- Onion cell that is oblong in shape with a length of $30\text{ }\mu\text{m}$ and a width of $12\text{ }\mu\text{m}$.
- A red blood cell with a diameter of $8\text{ }\mu\text{m}$.

KEY CONCEPTS

- $1\text{ cm} = 10\text{ mm}$
- $1\text{ mm} = 1000\text{ }\mu\text{m}$
- $1\text{ }\mu\text{m} = 1000\text{ nm}$
- Scaled diagrams must always contain a scale bar.
- The scale to be used can be calculated by dividing the actual size of the cell by the length of the diagram to be drawn.

The size of different types of cells (not drawn to scale) are shown in Figure 2.17.

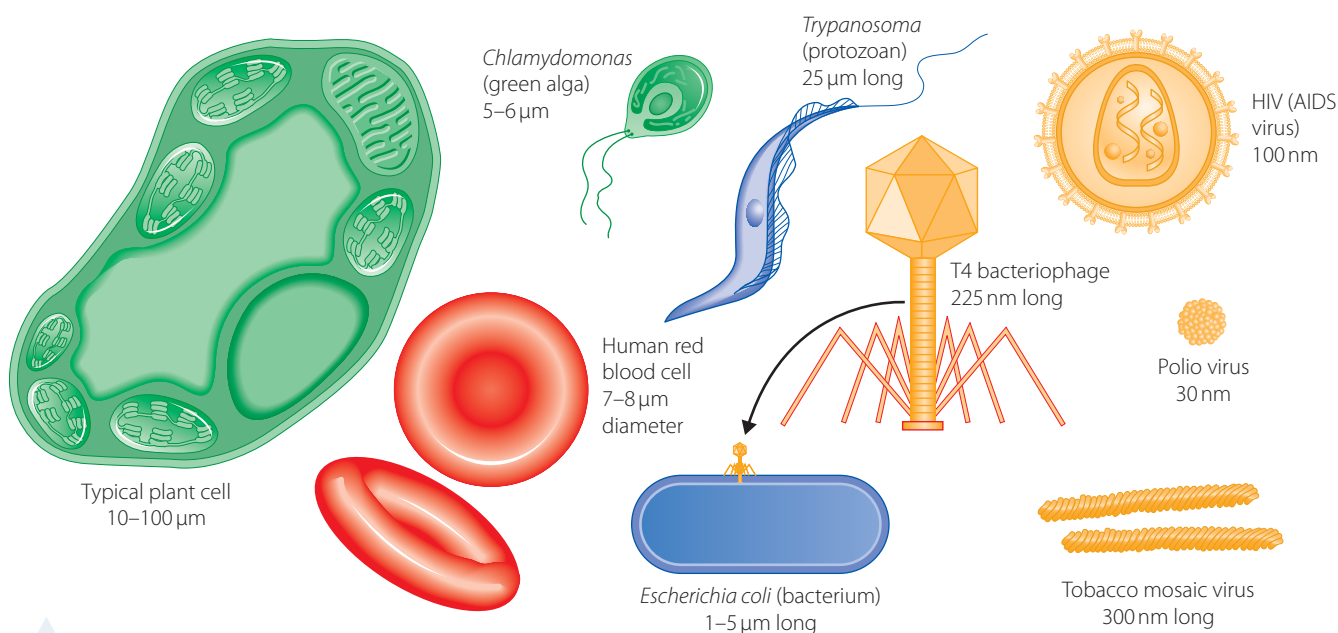


FIGURE 2.17 Measurements of biological specimens (not drawn to scale)

- Using the measurement given for each cell, list the cells in order from the smallest to the largest.
- State which of the cells are prokaryotes and which are eukaryotes.
- What does the statement 'not drawn to scale' mean?
- What is the size of the typical plant cell in mm?
- Which is larger, a T4 bacteriophage or an *E. coli* bacterium? Explain your answer.
- Convert the following measurements:
 - 2 cm to mm
 - 0.013 mm to μm
 - 4000 nm to μm
 - 0.080 μm to nm.
- Using a ruler and the scale provided, determine the actual size of the full cell shown in Figure 2.18. Show the formula you have used and all workings.

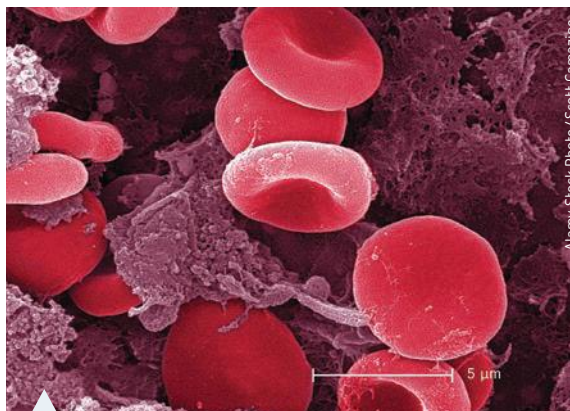


FIGURE 2.18 SEM image of a red blood cell with a scale bar

2.4 Organelles in cells

All eukaryotic cells contain membrane-bound internal structures called organelles, each with a specific structure and function. Different organelles share the common feature of having internal structures that are enclosed by their own membrane. The membrane may be either double or single in structure. Although each organelle has a different structure and function, they all work together to contribute to the effective functioning of a cell as a unit. Many organelles have maximised the amount of surface area they have available to carry out their particular functions.

One of the differences between organelles is their size. Some organelles, such as the nucleus, vacuoles and chloroplasts, can be seen with a light microscope. Details of other organelles, such as mitochondria and ribosomes, can be seen only by using an electron microscope (see Table 2.1).

TABLE 2.1 Comparison of the structures visible using light and electron microscopes

SCHOOL LIGHT MICROSCOPE (10–400×)	ADVANCED LIGHT MICROSCOPE (800–2000×)	ELECTRON MICROSCOPE (60–1 500 000×)
- cell wall - nucleus and nuclear membrane - chloroplast - vacuole: tonoplast and cell sap - cytoplasm	All structures in previous column as well as: - cell membrane - Golgi body - mitochondria - nucleolus. Special staining required for all	All structures in previous two columns as well as: - endoplasmic reticulum - ribosomes - lysosomes - centrosome - cytoskeleton (special staining is needed to see this).

The arrangement of organelles also varies depending on whether the cell is a plant or animal cell. A generalised diagram and line drawing of a eukaryotic animal cell is shown in Figure 2.19 and a plant cell in Figure 2.20.

Plant and animal cells contain many of the same organelles. The plant cell, however, possesses a cell wall, chloroplasts and a large vacuole that the animal cell does not.

Figure 2.21 summarises the organelles that are found in both plant and animal cells. It also shows the organelles specific to plant cells and those that are only present in animal cells.

Membranes – selective boundaries

The cell membrane (alternative names are *plasma membrane*, *cytoplasmic membrane* and *plasmalemma*) surrounds the cell contents in all cells and separates the cell contents from their surroundings. It controls the passage of water and other chemical substances into and out of cells. It is a selective barrier, permitting the passage of only certain molecules into or out of cells. This property gives the cell membrane the feature of being **selectively permeable** (sometimes referred to as semipermeable). Both plant and animal cells have a cell membrane. The membranes surrounding organelles are also selective in allowing only certain substances to pass between the cytoplasm and the organelle.

Protoplasm

It is in the **protoplasm** of cells that the functions essential to life, such as making cellular products and respiration, are carried out. The protoplasm is the living content of a cell that is surrounded by the cell membrane. The protoplasm is composed of the nucleus and the cytoplasm. The cytoplasm (that part of the protoplasm outside the nucleus) consists of a liquid called the **cytosol** in which there are dissolved chemical substances (for example, ions such as chloride ions), suspended organelles and insoluble granules. Approximately 90 per cent of the cytoplasm is water – the medium in which all cell chemicals are dissolved or suspended.

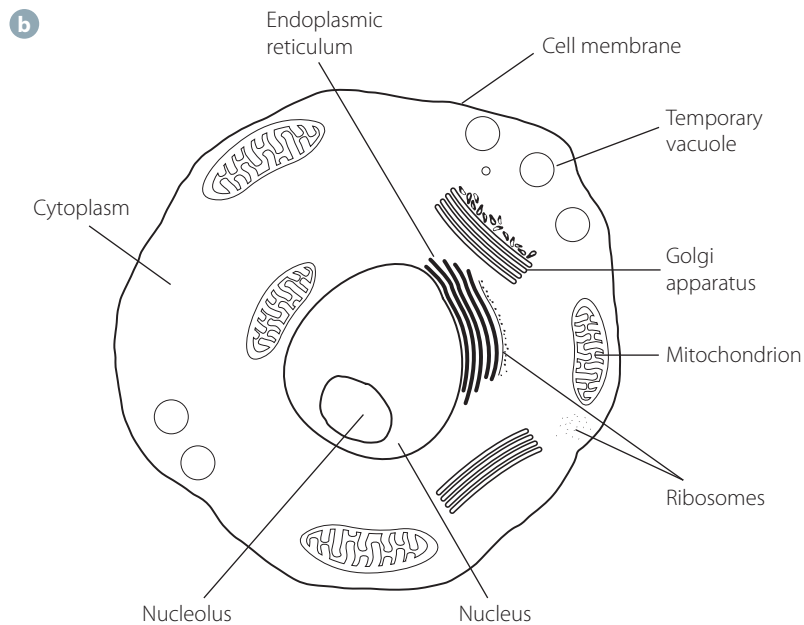
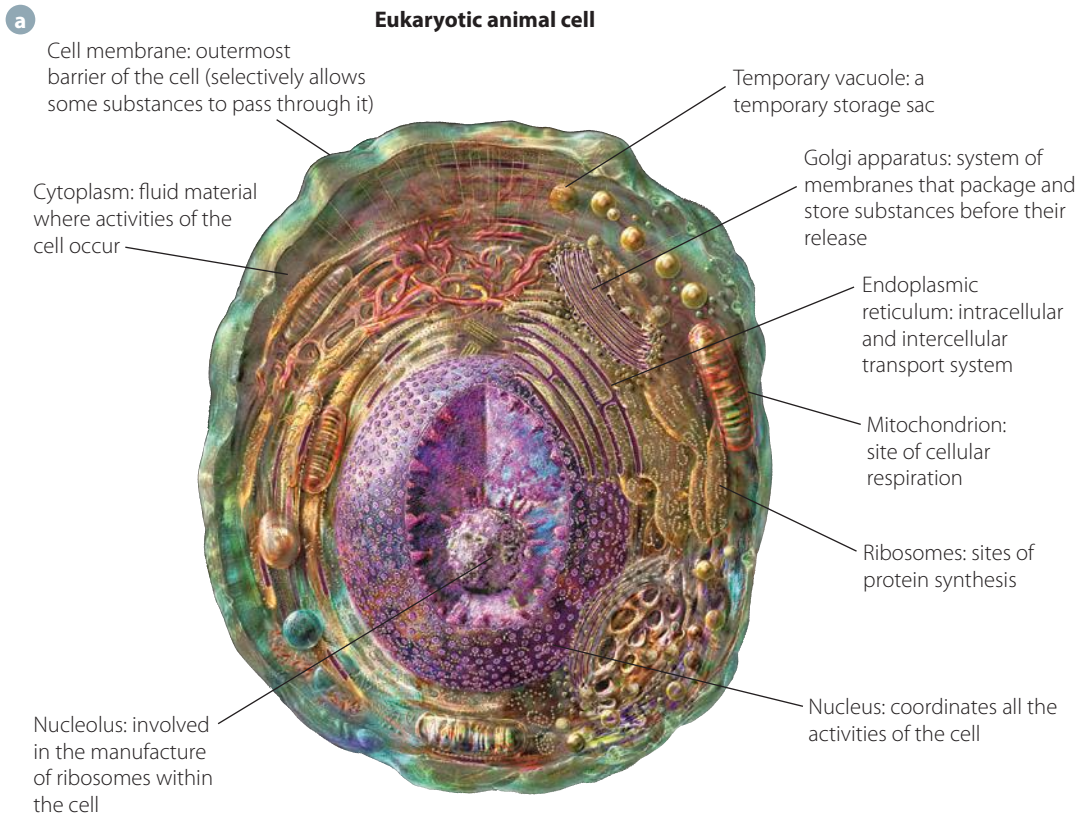
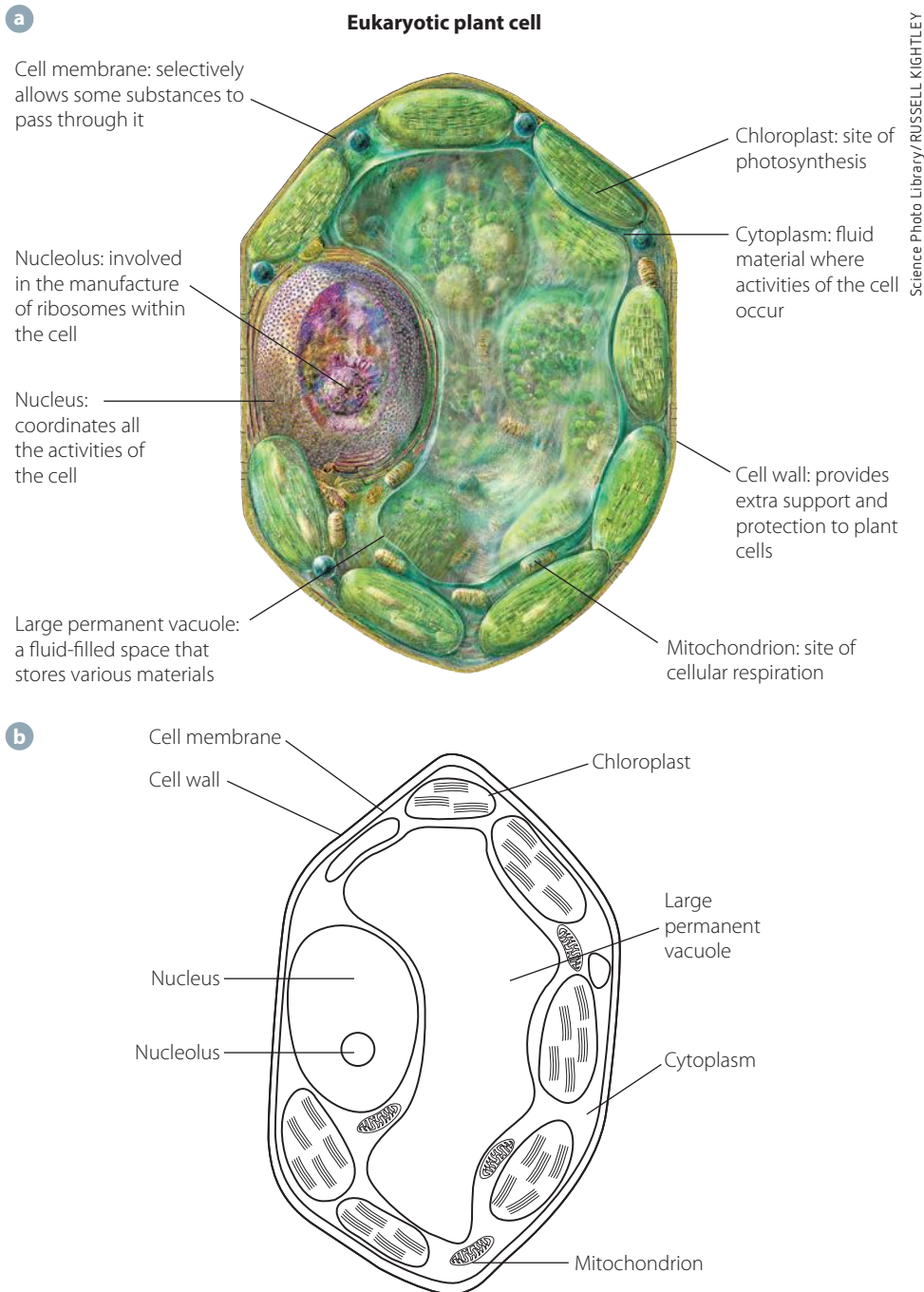


FIGURE 2.19 **a** a eukaryotic animal cell showing its nucleus and organelles; **b** a scientific line drawing of the cell



Science Photo Library/RUSSELL KIGHTLEY

FIGURE 2.20 **a** A eukaryotic plant cell showing its nucleus, cell wall and other organelles; **b** a scientific line drawing of the cell

Nucleus – the control and information centre

The nucleus (plural: nuclei) appears as a large, spherical or oval structure in the cytoplasm (Fig. 2.22). It is colourless, transparent and slightly more jelly-like than the rest of the cell. Most organisms have one nucleus per cell. The nucleus stores the information needed to control all cell activities. It is therefore essential for the nucleus to be able to communicate with the surrounding cytoplasm. Electron micrographs reveal that the nucleus is surrounded by a double **nuclear membrane** or nuclear envelope, pierced by tiny **pores**. These pores regulate the passage of substances between the nucleus and cytoplasm, allowing communication between them.

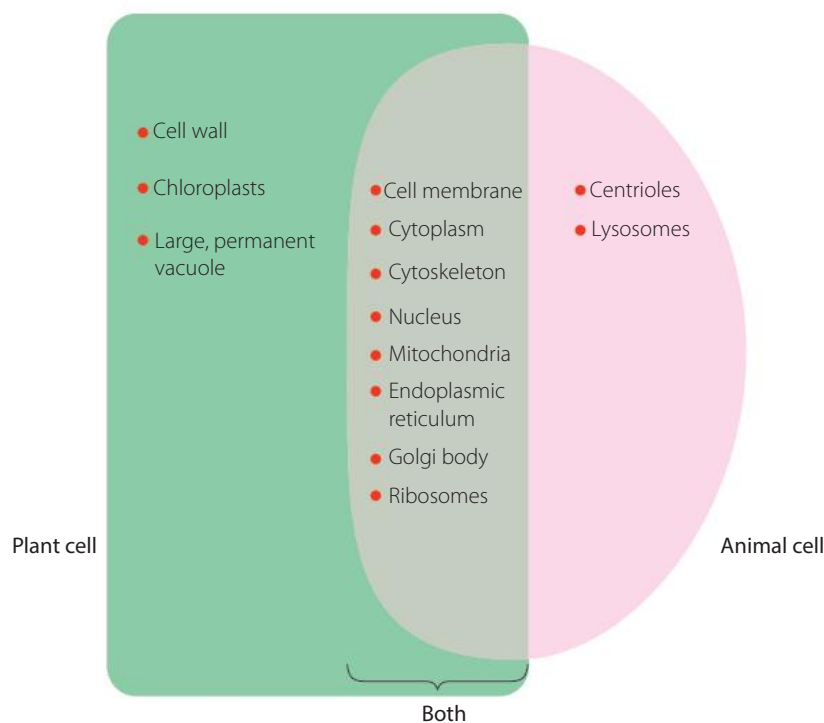


FIGURE 2.21
Summary of
structures found in
plant and animal cells

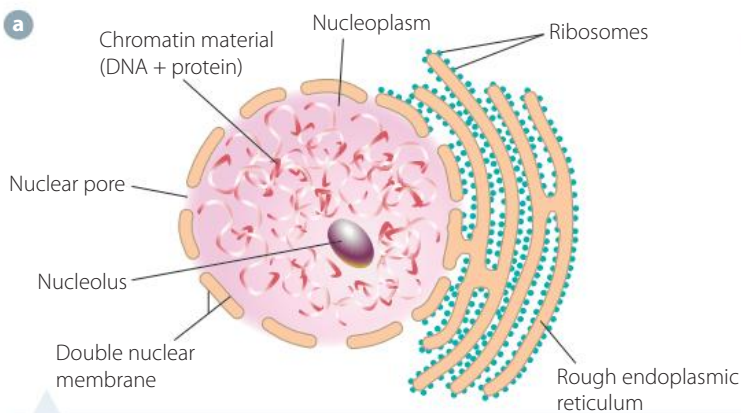


FIGURE 2.22 **a** Diagram of nucleus showing nucleolus, nuclear membrane, nucleoplasm, chromatin material and associated endoplasmic reticulum and ribosomes; **b** electron micrograph image of nucleus

Science Source / Alfred Pasieka

The **nucleoplasm** or nuclear sap is the liquid part of the nucleus in which the chromatin material is found. Chromatin is made up of protein and nucleic acid. The deoxyribonucleic acid, **DNA**, is stored in the nucleus. It is a very large chemical that holds, in a coded form, all the genetic information (the 'blueprint') necessary to control the cell's function. This DNA contains the hereditary information of an organism that gets passed from one generation to the next. Within one organism, the information stored in the DNA of each cell is the same. Before a cell divides, the information on the DNA must be copied so that it can be transmitted (passed on) to newly formed cells. The **chromatin** separates into short, thick separate rod-shaped structures called **chromosomes**, which become visible in dividing cells (from the Greek *chromo* (coloured) and *soma* (body), so named because chromosomes take up stains easily when being prepared for microscopy). Each species of organism has its own particular number of chromosomes; for example, humans have 46 chromosomes, a platypus has 52, a lettuce has 18 and a camel has 70.



FIGURE 2.23 Rough ER studded with ribosomes

The **nucleolus** is a dense, granular region commonly seen within the nucleoplasm. It contains a large amount of nucleic acid; some DNA, but mostly RNA. The nucleolus is responsible for the manufacture of organelles called ribosomes, the essential 'machinery' of the cell.

Endoplasmic reticulum – transport and processing of proteins and lipids

The outer nuclear membrane is usually continuous with a network of flattened, interconnected membranes – the **endoplasmic reticulum** (ER). The ER provides a connection of pathways between the nucleus and the cell's environment, allowing intracellular transport (transport within a cell). The immense folding of the sheets of membrane increases its surface area.

ER may have ribosomes attached (rough ER; Fig. 2.23) or may have no ribosomes (smooth ER).

The main function of ER is *transport*, but it also plays a role in *processing* cell products: rough ER folds and processes proteins made by the cell and it can also synthesise lipids. Smooth ER is the main site of lipid production, essential for membrane repair and manufacture. ER may also transport substances from one cell to another in plant cells, passing through channels called cell pits in the cell wall.

Ribosomes – protein synthesis

Ribosomes are small organelles that appear as dense, rounded granules in electron micrographs of cells. Their small size increases their surface area. Each is made of the chemicals RNA and protein, and they are the 'machinery' that carries out the genetically coded instructions of DNA to *produce* any *proteins* necessary for cell functioning and structure. Amino acids are joined in order to form polypeptides, the structural unit of proteins.

Ribosomes may be found free in the cytoplasm or scattered over the surface of ER. Newly synthesised proteins pass from the ribosomes into the ER, where the protein is folded.

Golgi bodies – packaging and sorting the products

The **Golgi body** (also known as Golgi apparatus) is also made of flat membranes, but it differs from ER in that it does not have ribosomes attached and its membranes are arranged in stacks of four to 10. The Golgi body (Fig. 2.24) is easily recognisable by its curved shape on one surface, where *vesicles* can be seen

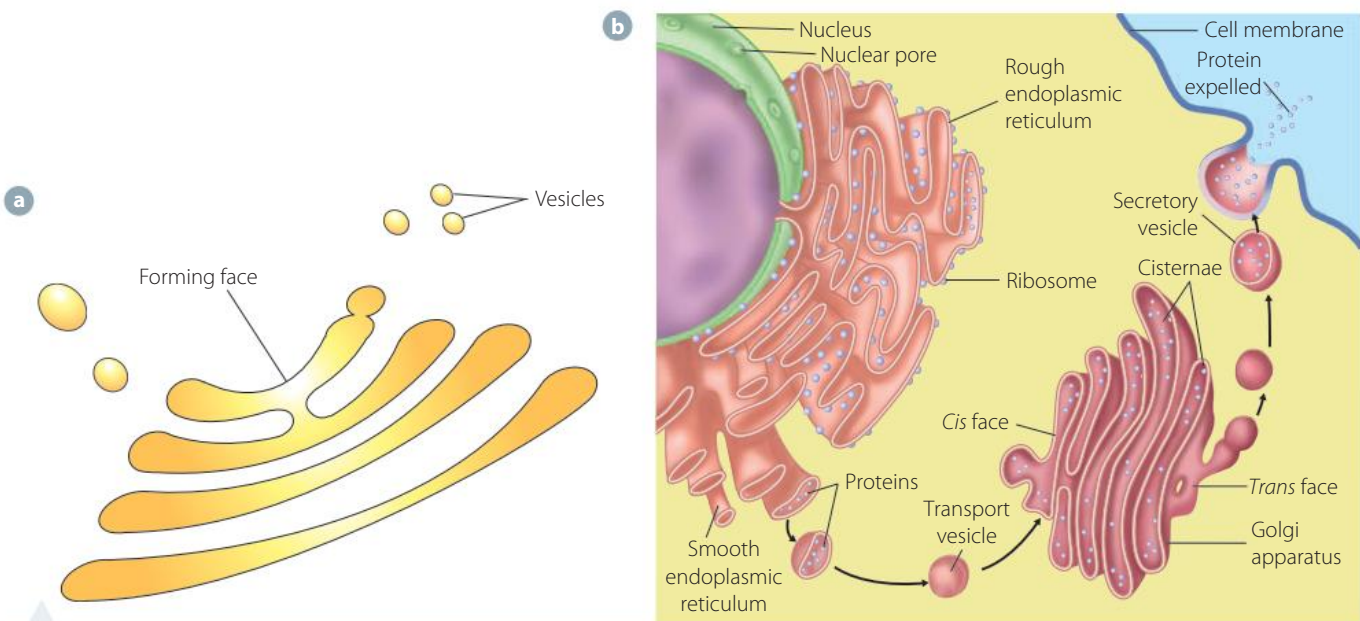


FIGURE 2.24 **a** Golgi body and vesicles; **b** diagram showing the relationship between the ER, Golgi body and the cell membrane

budding off. This surface is called the *forming face* and the vesicles are evidence of the secretory function of Golgi bodies. The opposite surface may be convex or flat.

Golgi bodies process, package and sort cell products. They are involved in adding proteins and carbohydrates to cell products and they also provide a membrane around the cell products to package them. The membranes provided by Golgi bodies vary and serve as a packaging 'label'. Features of the membrane are used to sort these products, determining where they will end up – they may be transported within the cell to wherever they are required or they may be secreted from the cell.

Lysosomes – digestion and destruction

Organelles within the cytoplasm of cells will eventually reach their 'use-by date' and wear out. Instead of wasting the raw materials that make up these organelles, the cell has a clever method of recycling and reuse. This is the job carried out by **lysosomes** ('lysis' = to break apart), special organelles found within the cytoplasm of animal cells.

Lysosomes (Fig. 2.25) are formed by the Golgi body. They contain digestive enzymes that are responsible for splitting complex chemical compounds into simpler ones, such as when proteins are broken down into amino acids. These simpler molecules can then be used as building blocks for new compounds and organelles. Sometimes lysosomes may destroy the entire cell. This process is known as **apoptosis** or programmed cell death. It is a deliberate action by the cell to destroy old and damaged cells. Under the direction of the cell, the lysosome membrane ruptures, releasing the enzymes, which then digest the contents of the cell, killing it in the process.

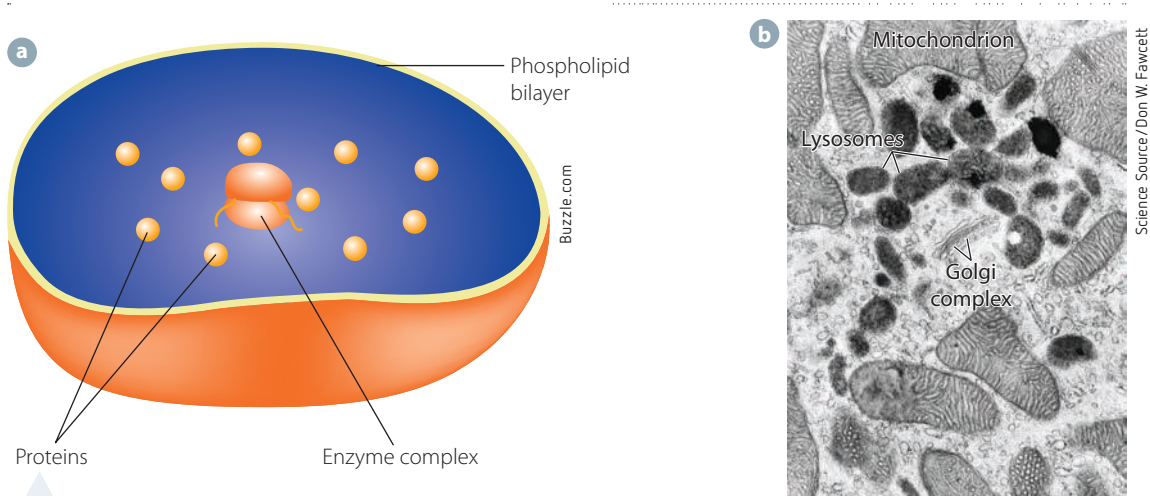
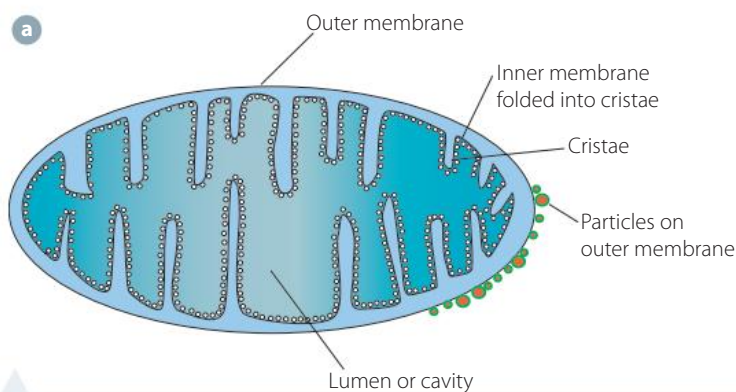


FIGURE 2.25 **a** Structure of a lysosome; **b** electron micrograph showing lysosomes and the Golgi body (apparatus)

Mitochondria – cellular respiration

Mitochondria (Fig. 2.26) are the 'powerhouses' of a cell, producing energy in the form of energy-rich molecules by the process of **cellular respiration**. Mitochondria (singular: mitochondrion) are usually rod-shaped but may be round; they vary in both shape and size. Mitochondria are smaller than the nucleus and chloroplasts but larger than ribosomes.

The number of mitochondria in a cell depends on how much energy the cell needs to carry out its functions. Less active cells contain few mitochondria, whereas very active cells have hundreds or even thousands of mitochondria. For example, active liver cells contain 1000 to 2000 mitochondria. Just as machines in a factory need electrical energy in order to work, so cells need energy, in the form of a chemical called ATP (adenosine triphosphate), to work. Mitochondria combine oxygen with sugars during the process of cellular respiration to release energy in a form (ATP) that the cell can use.



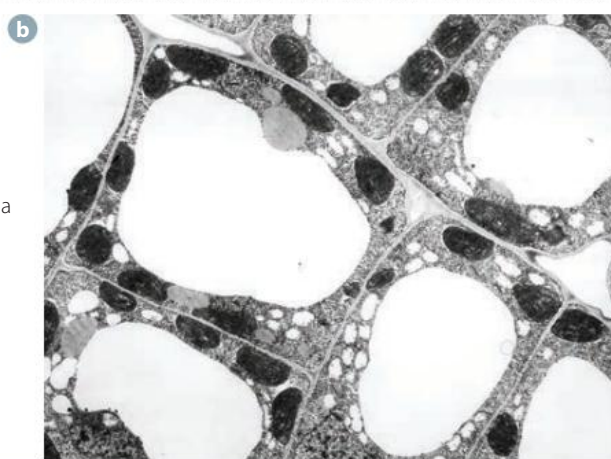
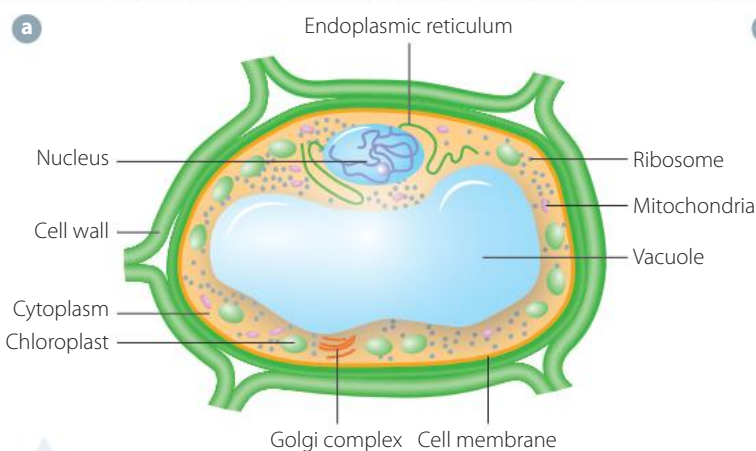
Alamy Stock Photo/Science History Images

FIGURE 2.26 **a** Simplified diagram of mitochondrion in longitudinal section; **b** electron micrograph of a mitochondrion

A double membrane surrounds each mitochondrion. The *outer membrane* gives the mitochondria their shape and allows the passage of small substances into and out of mitochondria. The *inner membrane* is folded into fine, finger-like ridges or **cristae**, increasing the surface area for attachment of groups of enzymes responsible for producing energy for the cell. These appear as knob-like particles on the inside of the cristae. The central space in a mitochondrion is filled with fluid and is termed the **matrix**. It contains mitochondrial DNA and enzymes that give mitochondria the unusual feature of being able to replicate (make copies of) themselves. The mitochondria divide by pinching off and then growing, something that usually occurs in very active cells or cells that are about to divide.

Vacuoles – storage and support

Vacuoles are large, permanent, fluid-filled sacs in the cytoplasm of mature plant cells. Each vacuole consists of a watery solution called **cell sap**, surrounded by a single membrane, the *tonoplast* (Fig. 2.27). Cell sap contains substances such as mineral salts, sugars and amino acids, dissolved in water. It may also contain dissolved pigments that give cells their colour (for example the reds, pinks and purples seen in some flower petals). Besides having a storage function, vacuoles play a very important role in providing **support** to plant cells. By filling up with water, the vacuole pushes outwards with the cytoplasm, exerting



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FIGURE 2.27 **a** Diagram of a generalised plant cell showing structures including a vacuole; **b** electron micrograph showing vacuole and tonoplast

a pressure on the cell wall, keeping it firm. As a result of the outward pressure of the cell contents and the resistance of the cell wall, the cell becomes firm or **turgid**.

Small, temporary vesicles may sometimes be found in animal cells, but these do not play a role in cell support, so permanent vacuoles that give turgidity are considered to be a feature exclusive to plant cells.

Chloroplasts – photosynthesis

Chloroplasts are organelles that are green in colour, due to the presence of a pigment called **chlorophyll**. Chloroplasts are responsible for **photosynthesis** – the manufacturing of sugar in plants, using the energy of sunlight. Chloroplasts are not present in all plant cells; they are found only in the green tissue of plants that can photosynthesise. Under the light microscope, they appear as green, disc-shaped structures, smaller than the nucleus. An electron microscope is needed to see the detailed interior.

Chloroplasts belong to a group of organelles called **plastids**, which are biconvex in shape. Plastids contain either pigment or nutrients and vary in colour. Chloroplasts are green plastids. They are larger than mitochondria but are similar in that they also contain their own DNA; the number of chloroplasts per cell varies.

A double membrane surrounds chloroplasts. This allows substances to pass between the cytoplasm and the chloroplast. Unlike mitochondria, the inner membrane of the chloroplast is not folded (Fig. 2.28). The liquid part of the chloroplast is called the **stroma** and it is here that stacks of membranes called **thylakoids** are found. Each stack or group of thylakoids is termed a granum (plural: grana) and the chlorophyll is found on these membranes.



Cell micrographs

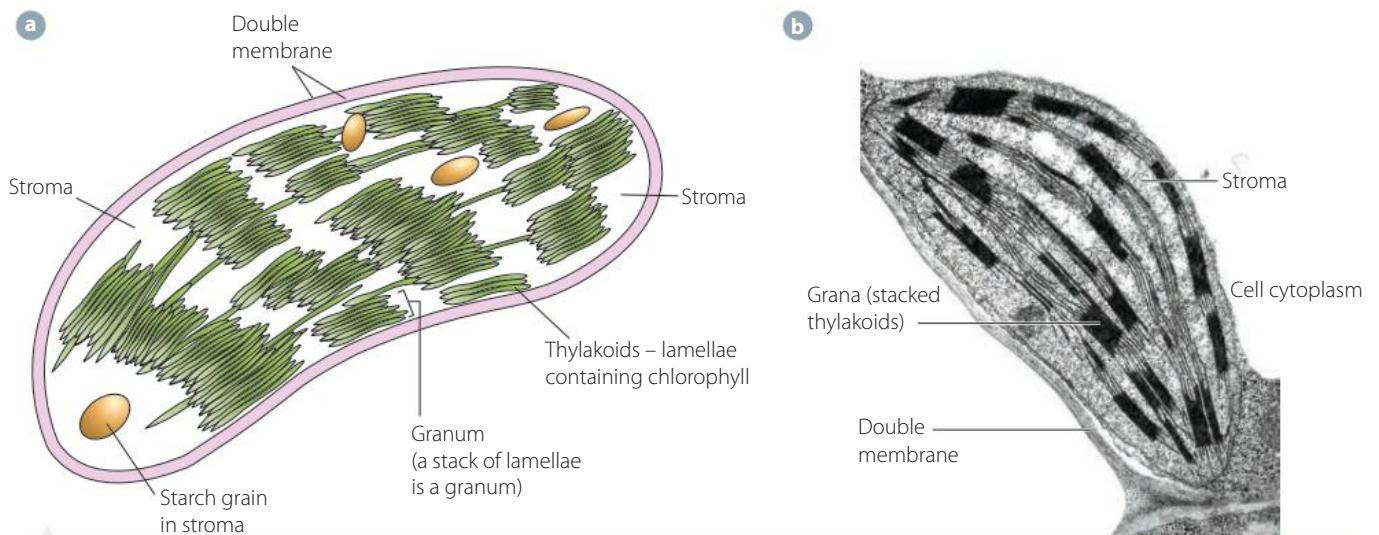


FIGURE 2.28 **a** Diagram of chloroplast seen in longitudinal section; **b** electron micrograph of a chloroplast

The layering of the membranes increases the surface area over which chlorophyll occurs, allowing a large amount of sunlight to be absorbed for the process of photosynthesis. This captured energy of sunlight is then used by the plant to make simple sugars. All the enzymes needed for photosynthesis are present in the stroma, and simple sugars made during photosynthesis are stored in the stroma as starch grains.

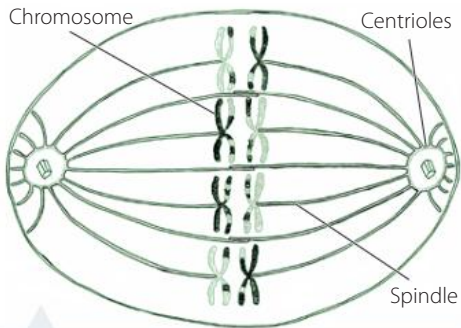


FIGURE 2.29 Centrioles forming the spindles, which hold the chromosomes in a dividing cell

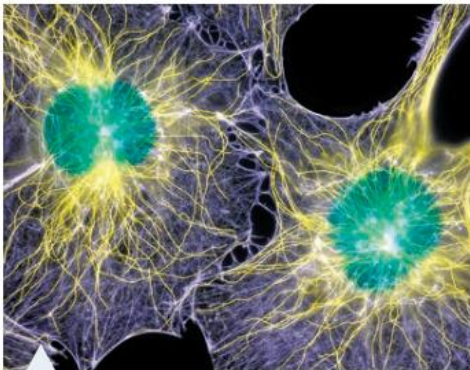


FIGURE 2.30 Fluorescence image of a cell showing the cytoskeleton in yellow

Plant cell wall – shape and support

The **cellulose** cell wall that surrounds plant cells differs from the cell membrane inside it. The cell wall is not selective in terms of what substances it does or does not allow into the cell. Its structure allows it to provide strength and support. The strands of cellulose fibres have a little elasticity and are somewhat flexible so they can resist pressure. Some cell walls are thickened with additional chemicals that make the walls hard and woody (for example, in tree trunks) or that provide waterproofing (for example, in cork or the waxy cuticle of leaves). Cell walls are **permeable** to most molecules.

Centrioles – spindle production in cell division

A dense, granular structure, the centrosome, is often found near the nucleus in animal cells. It consists of two centrioles, which play an important role in cell division, forming the spindle, which holds chromosomes in a dividing cell (Fig. 2.29).

Cytoskeleton – keeps organelles in place

Organelles are not randomly scattered within a cell. Their distribution is organised and they are held in place by a network of tiny microtubules, microfilaments and intermediate filaments called the cytoskeleton (Fig. 2.30) that extends throughout the cytoplasm. It is the framework for the shape of the cell, cell movement, organelle movement and cell division.



Cell structure

KEY CONCEPTS

- Organelles are membrane-bound internal structures, each with a specific function to ensure the efficient functioning of the cell.
- Most organelles have structures that maximise the surface area.
- Organelles and other cell structures vary in size, with only the cell membrane, cell wall, nucleus, chloroplasts and vacuoles being big enough to be observed using a light microscope.
- The function of organelles and other cell structures is summarised in Table 2.2.

TABLE 2.2

ORGANELLE/ CELL STRUCTURE	FUNCTION
Membranes	Selectively permeable boundaries, control the movement of substances into and out of the cell/organelle
Protoplasm	The living content of a cell that is surrounded by the cell membrane
Nucleus	The control and information centre
Endoplasmic reticulum	Transport and processing of proteins and lipids
Golgi bodies	Packaging and sorting the products
Ribosomes	Protein synthesis
Lysosomes	Digestion and cell destruction
Mitochondria	Cellular respiration – production and storage of energy (ATP)
Vacuoles	Storage and support
Chloroplasts	Photosynthesis
Plant cell wall	Shape and support
Centrioles	Spindle production in cell division
Cytoskeleton	Cell shape, organelle placement and movement and cell division

- 1 Identify the organelles/cell structures that can be seen using a light microscope.
- 2 Draw a scientific diagram of a plant cell and an animal cell as seen under a light microscope. Label the structures common to both in one colour and those that are only found in plant cells in a different colour.
- 3 Choose three of the organelles discussed on the previous page. Draw their structure as seen under a light microscope, state their function and explain how their features may help them to carry out their function.
- 4 Construct a table to compare (similarities) and contrast (differences between) the organelles found in an animal cell. Use headings such as 'Membrane present', 'Folding or layers to increase surface area', 'Structure' and 'Function'.

2.5 Cell membranes – gateway to cells

The detailed molecular structure of a cell membrane cannot be seen, even with an electron microscope. Many years of research have led to the development of a number of different models that have attempted to explain the structure of the cell membrane. Our current accepted understanding is based on a model proposed in 1972 by Singer and Nicolson, called the **fluid mosaic model** of cell membranes.

This model, with minor modifications over the years, has been accepted because the behaviour of membranes, estimated surface area, chemical analysis and electron microscope studies are all compatible with the model. It also accounts for most functions associated with cell membranes.

See page 5 for a discussion of models in science.

The fluid mosaic model

The cell membrane controls the exchange of material between the internal and external environments of the cell. It is selectively permeable, meaning that it allows only certain molecules or ions into or out of the cell. The structure of the cell membrane allows the concentration of substances inside cells to remain fairly constant and different from the external environment. In the currently accepted model, the structure of the selectively permeable cell membrane is described as a *fluid mosaic*. This *fluid mosaic model* proposes a 'lipid sea' with 'many and various proteins floating on and in it'.

The fluid mosaic model describes the cell membrane as a double layer of lipids, a **lipid bilayer**, with the ability to flow and change shape, like a two-dimensional fluid. Specialised protein molecules are embedded in the lipid in various patterns like a mosaic. Some of these proteins can move sideways, but others are fixed in position. Both proteins and phospholipids help to control the exchange of materials between the external and internal environments.

Lipid component

The 'fluid' part of the cell membrane is composed of two layers of **phospholipids** forming a phospholipid bilayer. Each phospholipid in these layers can be represented by a head and two tails, as shown in Figure 2.31. A phosphate group on the head makes this end **hydrophilic** (able to absorb water or dissolve in water), otherwise known as 'water loving'. The fatty acid tails are **hydrophobic** (water avoiding or unable to dissolve in water) or 'water hating'.

When these molecules form a bilayer, the water-attracting heads are positioned facing outwards – towards the cytoplasm on one side and to the outside of the cell on the other side. The water-repelling tails are positioned inwards – towards each other (Fig. 2.32). This layering is termed a 'bilayer'. It is not rigid in structure, hence the term 'fluid' mosaic.

A type of lipid called cholesterol is interspersed among the phospholipid molecules in animal cells. This makes the membrane more flexible. Membrane flexibility in plants is increased by a different lipid – phytosterol.

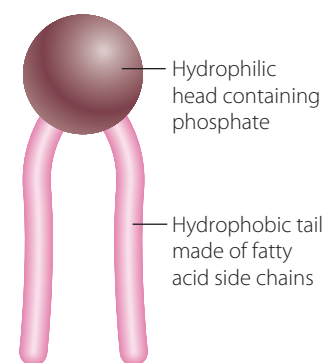
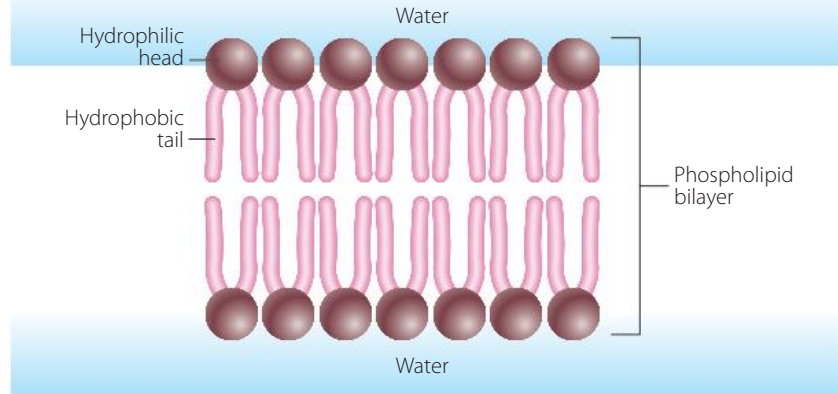


FIGURE 2.31 A phospholipid molecule. The hydrophilic head is attracted to water whereas the hydrophobic tails repel water.

FIGURE 2.32 A representation of the way phospholipids form a bilayer in membranes



The lipid components of all membranes allow them to be flexible and repair themselves. This means that the cells can change shape and grow. Cell membranes are able to break and reassemble themselves during processes such as cell division.

This structure forms the basis of the cell membrane and all other membranes within cells, such as those surrounding organelles. Proteins are then interspersed throughout this structure.

Membrane proteins

Protein molecules are scattered throughout, and suspended in, the lipid bilayer. Some proteins penetrate all the way through the bilayer, forming channels that allow some materials to cross the membrane. Other proteins may be partly embedded in the membrane. It seems that some proteins are fixed in place, while others travel about freely. The proteins are described as 'floating' in the lipid bilayer 'like icebergs in a lipid sea', giving a *mosaic* effect (Fig. 2.33).

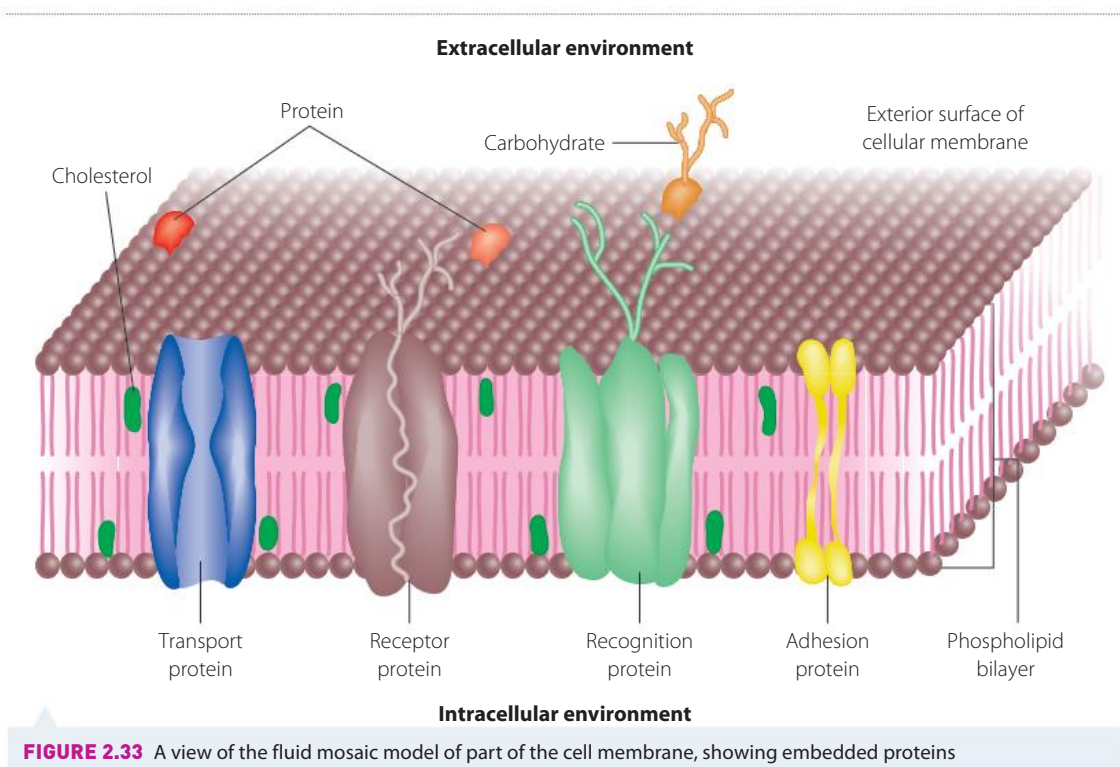


FIGURE 2.33 A view of the fluid mosaic model of part of the cell membrane, showing embedded proteins

Some proteins function as pores (temporary or permanent) or form active carrier systems or channels for transport, while other proteins (glycoproteins) have carbohydrates attached for cell recognition.

These proteins enable cell-to-cell interaction and communication, and the exchange of substances between the cell and the external environment. For example, in **multicellular organisms**, **adhesion proteins** link cells together and help maintain the organism's three-dimensional structure.

Transport proteins act like passageways that allow specific substances to move across the membrane.

Membrane proteins are also involved in cellular communication. **Receptor proteins** are different in different types of cells. They cause the cells to respond only to certain signals from substances such as hormones that bind to them, giving them specific functions.

Membrane **recognition proteins** or **glycoproteins** are made up of a protein molecule with a carbohydrate molecule attached. These proteins identify the cell and are called **antigens** or marker molecules. They allow the immune system to distinguish between foreign particles ('non-self') and the body's own ('self') cells. This ensures that the immune system will destroy only foreign particles that display 'non-self' markers.



Cell membrane



Cell membrane

Complete the interactive activity and build a cell membrane. Draw a labelled diagram of your cell membrane.

INVESTIGATION 2.2

Modelling the structure and function of the fluid mosaic model

Models are used in science for a number of reasons, including to simplify a concept or make a visual representation of something that can't be seen. There are many ways of modelling the structure and function of a cell membrane.

AIM

To model the structure and function of the fluid mosaic model of the cell membrane

MATERIALS

Structure:

- rectangular cake or polystyrene block approximately 20 cm × 10 cm × 10 cm
- knife
- icing sugar, food colouring or fondant or buttercream
- marshmallows
- liquorice or modelling chocolate
- selection of lollies
- labels/toothpicks

Function:

- 2 × tea strainers
- icing sugar
- lollies, such as Smarties
- elastic band
- coloured paper
- salt
- sugar granules
- tea leaves





RISK ASSESSMENT

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Knife/scalpel	Sharp edges can cause cuts	Use knife/scalpel with care and keep fingers away from sharp edge of knife.
Traces of chemicals	Contamination of table tops	Do not eat the cake if it was prepared in a science laboratory.

METHOD

Structure

- 1 Trim cake to approximately the suggested size.
- 2 Using fondant or icing, completely coat the surface of the cake.
- 3 Place marshmallows to completely cover the top surface of the cake. Then place one line of marshmallows along the top and bottom of all sides of the cake, lined up with the marshmallows on the top edge of the cake.
- 4 Using liquorice or modelling chocolate, make 'tails'. Stick two of these tails per marshmallow onto the side of the cake, leading from the marshmallow to the centre.
- 5 Using modelling chocolate or lollies, construct 'proteins' that penetrate the whole cell membrane layer, and 'proteins' that are only partially embedded in the membrane.
- 6 Attach lollies or modelling chocolate to some of these 'proteins' to represent the glycoproteins.
- 7 Use lollies or modelling chocolate to represent cholesterol and phytosterols.
- 8 Attach labels to all parts of the model.

Function

- 9 Place two teaspoons of icing sugar and two teaspoons of lollies into one of the tea strainers.
- 10 Tie the handles of the tea strainers together with the elastic band.
- 11 Shake the tea strainer over a piece of coloured paper.
- 12 Record in the table provided which substances pass through.
- 13 Repeat this process using a variety of other substances (those on the equipment list or others).

RESULTS

Structure

- 1 Draw a diagram or take a photo of your model.
- 2 Copy and complete Table 2.3 to indicate what each part of your model represents in the fluid mosaic model.

TABLE 2.3

STRUCTURE IN FLUID MOSAIC MODEL	REPRESENTATION IN YOUR MODEL
Phospholipid	

Function

- 1 Draw a diagram or take a photo of your model.
- 2 Complete Table 2.4 to indicate what each part of your model represents in the fluid mosaic model.

TABLE 2.4

SUBSTANCES IN MIXTURE	SUBSTANCES THAT PASSED THROUGH HOLES IN TEA STRAINER
Icing sugar and lollies	



Investigation 2.2

» DISCUSSION

Structure

- 1 Outline the purpose of your model.
- 2 What are the benefits of your model of the fluid mosaic model of the cell membrane?
- 3 Discuss the limitations of your model.
- 4 Justify the validity of your model. See page 4 for a discussion of validity.

Function

- 5 Outline the purpose of your model.
- 6 What are the benefits of your model of the fluid mosaic model of the cell membrane?
- 7 Discuss the limitations of your model.
- 8 Justify the validity of your model. See page 4 for a discussion of validity.

CONCLUSION

Write a summary statement that relates to the aim of this investigation, including a brief summary of what you did and what you found.

KEY CONCEPTS

- The cell membrane is selectively permeable and performs the function of controlling the movement of substances into and out of the cell.
- The currently accepted model of the structure of the cell membrane is the fluid mosaic model.
- This model depicts a 'fluid' phospholipid bilayer with different types of proteins embedded in it, creating a 'mosaic' effect. Proteins either penetrate from one side to the other or are only partially embedded.
- Some membrane proteins form pores (temporary or permanent), some form active carrier systems or channels for transport, and others (glycoproteins) have carbohydrates attached for cell recognition.
- Cholesterol (in animals) or phytosterols (in plants) provide some flexibility to the membrane.
- Models are used in science for a number of reasons, including to simplify a concept, make a visual representation of something that can't be seen, or make predictions of expected results.
- Before a model is accepted, it needs to be *validated* – that is, certain predictions should be made and, when tested using the model, should hold true.
- When modelling a concept in the laboratory, all parts of the model should be related to actual parts of what is being modelled.
- The limitations of the model should also be documented.

CHECK YOUR UNDERSTANDING

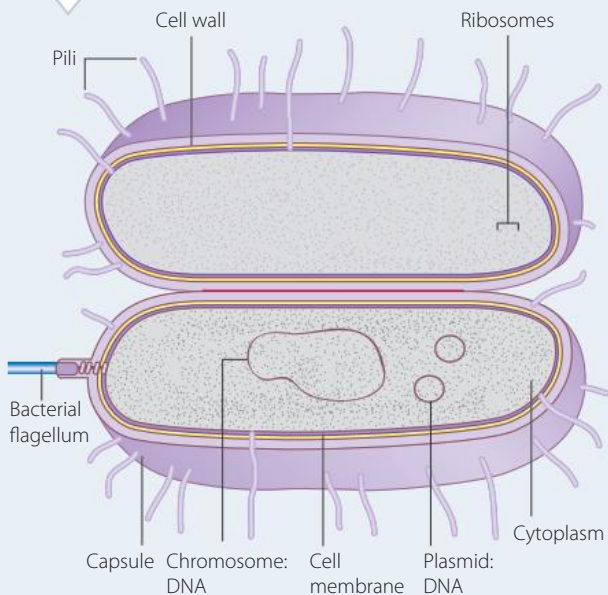
2.5

- 1 Explain the structure of a lipid bilayer.
- 2 Outline the fluid mosaic model of the cell membrane.
- 3 List the proteins found in the cell membrane and state the function of each.
- 4 Explain why models are used in science and how they are validated.
- 5
 - a Sketch a two-dimensional scientific diagram of the transverse section of a cell membrane.
 - b Label all the different parts.
 - c Outline the function of each part that you have labelled.
- 6 Explain why the cell membrane needs to be selectively permeable for a cell to function.

Cell structure and technologies: What distinguishes one cell from another?

PROKARYOTIC CELLS

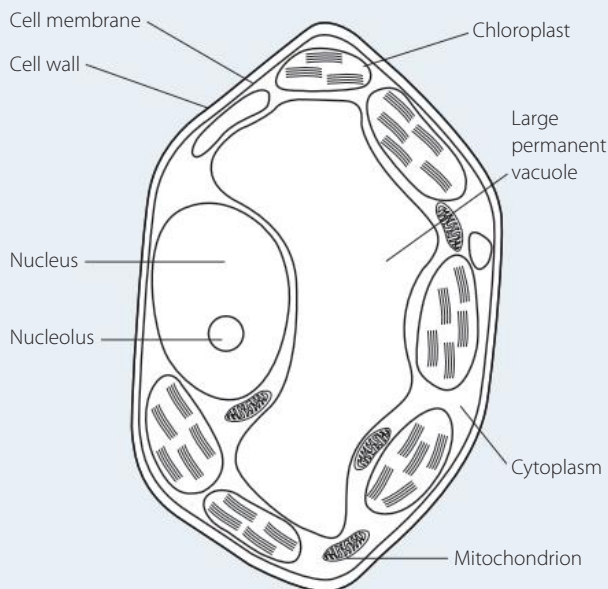
- No nucleus
- Possess cytoplasm, cell membrane, ribosomes and genetic material



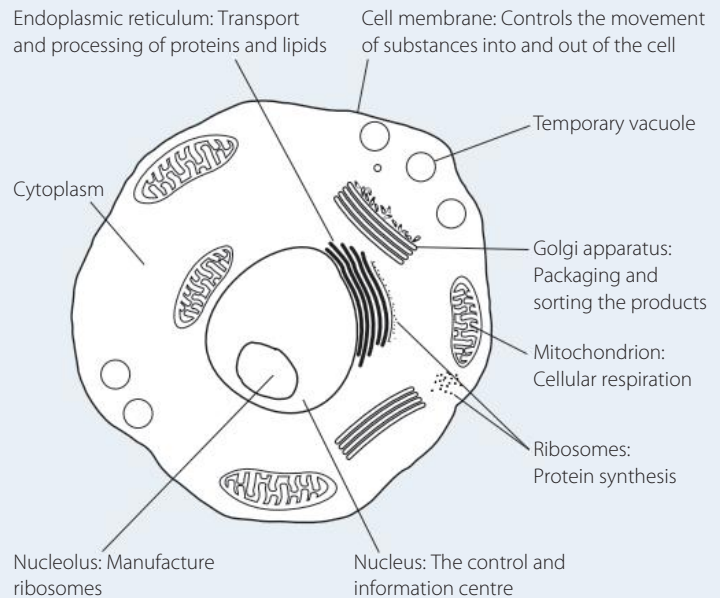
EUKARYOTIC CELLS

- Membrane-bound nucleus
- Membrane-bound organelles

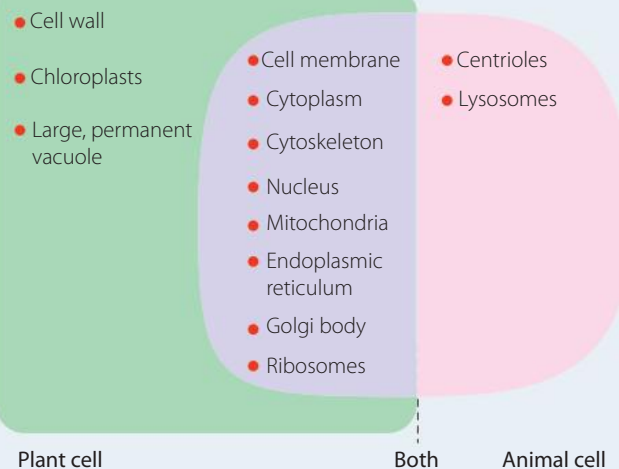
Plant cell



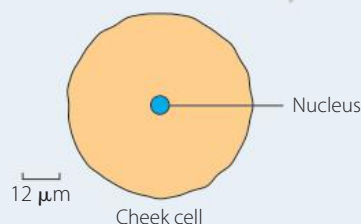
Animal cell



COMPARISON OF ANIMAL AND PLANT CELLS



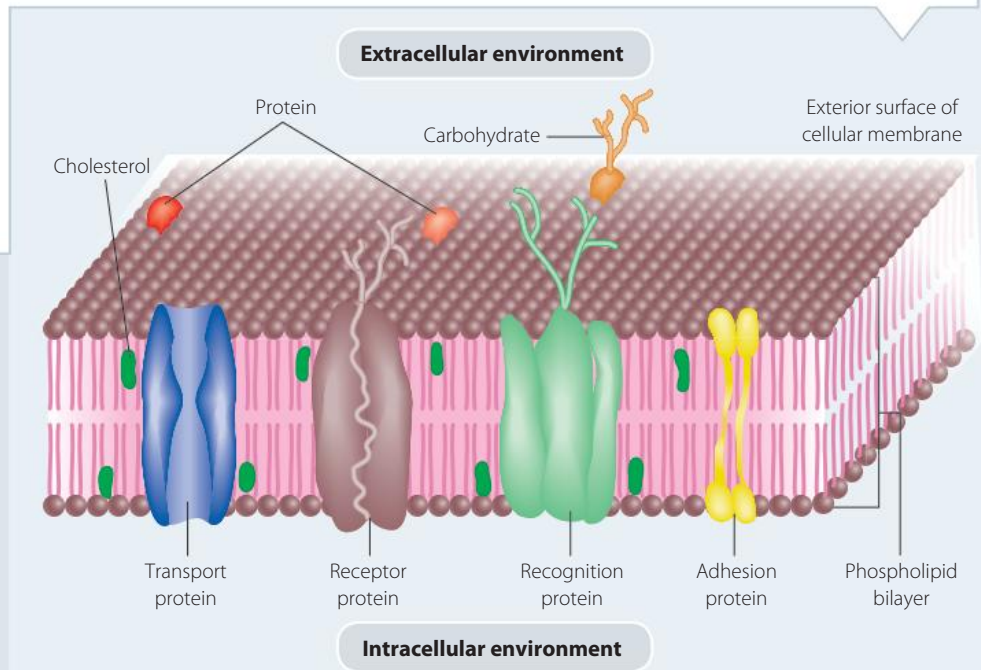
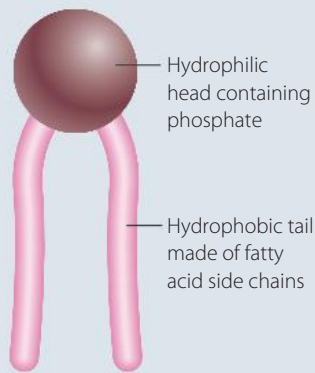
BIOLOGICAL DRAWING



FLUID MOSAIC MODEL OF CELL MEMBRANE

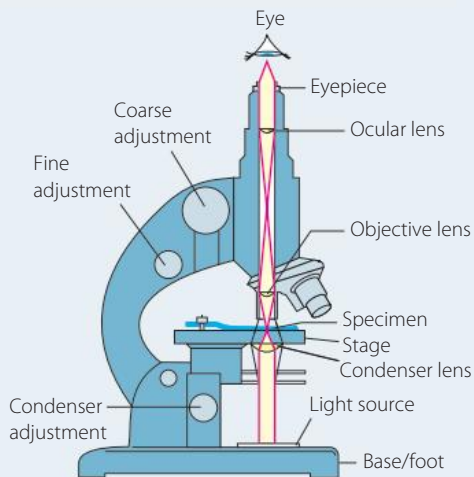
Controls the exchange of material between the internal and external environments of the cell.

- This model depicts a 'fluid' phospholipid bilayer with different types of proteins embedded in it, creating a 'mosiac' effect. Proteins either penetrate from one side to the other, or are only partially embedded.
- Some membrane proteins form pores (temporary or permanent). Some form active carrier systems or channels for transport. Others (glycoproteins) have carbohydrates attached for cell recognition.



TECHNOLOGIES USED TO DETERMINE CELL STRUCTURE AND FUNCTION

Light microscope

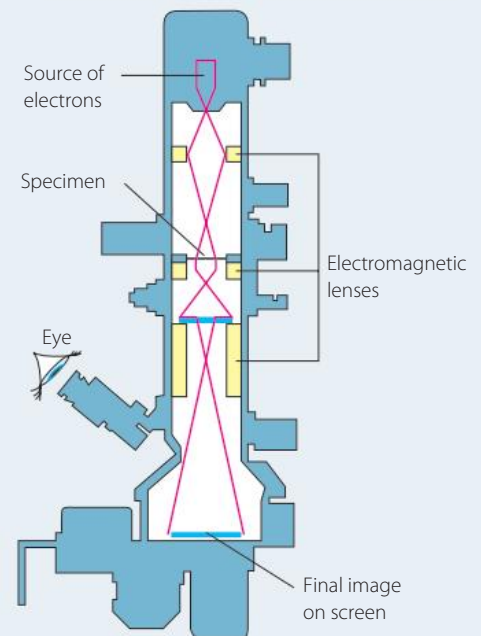


Total magnification = Ocular magnification × Objective lens magnification

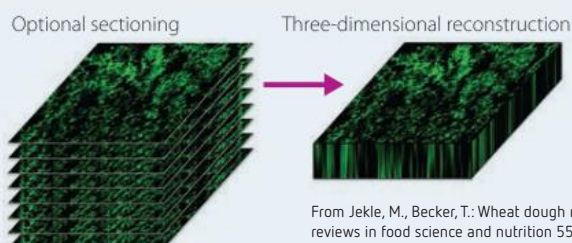
Fluorescent microscope



Electron microscope



Confocal laser scanning microscope



From Jekle, M., Becker, T.: Wheat dough microstructure: The relation between visual structure and mechanical behavior. Critical reviews in food science and nutrition 55 (2015), 369–382

- 1 **a** Identify the features that are common to all cells.
b Outline the features that are unique to:
 - i** prokaryotic cells
 - ii** eukaryotic cells.
- 2 A large cell of 0.3 mm was observed. Ribosomes were present in the cytoplasm, but no other organelles.
 - a** Do you think this would be a prokaryotic or eukaryotic cell? Justify your answer.
 - b** Identify further evidence that would be useful in making your decision.
- 3 When examining different types of cells, a student looks at a human cheek cell under a light microscope. Which cellular structures would be visible?
- 4 **a** Identify whether the photograph in Figure 2.34 is of a cell viewed with an electron microscope or a light microscope. Give your reasons.
b Some organelles may be present in this cell, but are not shown in the photograph. Suggest reasons why this might be the case.
c Figure 2.34 is a plant cell. Identify the organelles with the arrows pointing to them.

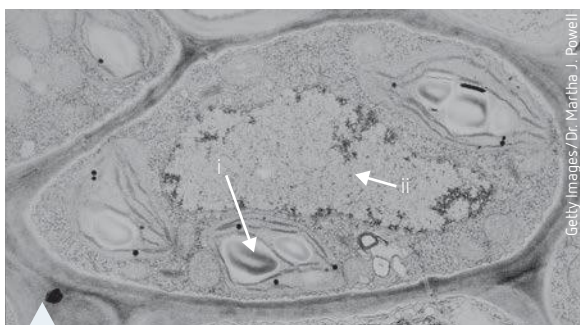


FIGURE 2.34 An unidentified cell

- 5 Outline how advances in technology have contributed to our knowledge about cells.
- 6 Draw up a table to compare the following types of microscopes. Headings that could be used in your table could be: 'Energy source', 'Focus', 'Specimen preparation', 'Magnification', 'Resolution', 'Can live specimens be viewed?' and 'Advantages and disadvantages'.
 - a** Light microscope
 - b** SEM
 - c** TEM
- 7 Outline the advantages of fluorescence microscopy.
- 8 Describe how a confocal laser scanning microscope produces a three-dimensional image of a cell.

- 9 Draw a scaled diagram of an animal cell that is circular and has a diameter of 10 μm .
- 10 Copy and complete Table 2.5 to outline the structure and function of the organelles listed.

TABLE 2.5 The structure and function of some organelles

ORGANELLE	STRUCTURE	FUNCTION
Endoplasmic reticulum		
Nucleus		
Mitochondrion		
Lysosome		
Chloroplast		
Golgi body		

- 11 Describe the relationship between the protoplasm and cytoplasm.
- 12 **a** Name the organelle that directs the activities of eukaryotic cells.
b Identify the substance present in this organelle that is responsible for this.
- 13 State the function of ribosomes. Explain why you would expect to find more ribosomes in a protein-producing cell than a red blood cell.
- 14 Explain why you would expect human muscle cells to contain more mitochondria than a cell in the skin of your big toe.
- 15 White blood cells engulf foreign particles in the body and destroy them. Explain why there are a large number of lysosomes present in white blood cells.
- 16 Identify the structures in the cell membrane that are responsible for each of the following characteristics of the cell membrane:
 - a** flexibility
 - b** movement of ions into cells
 - c** ability to bind hormones.
- 17 Outline the role of receptor proteins in cell membranes.
- 18 **a** In the model of the cell membrane, which section is identified as the 'fluid' part and which is identified as the 'mosaic' part?
b Explain why these terms are used.
- 19 Using examples, describe how the structures of organelles are related to their function.

3

Cell function

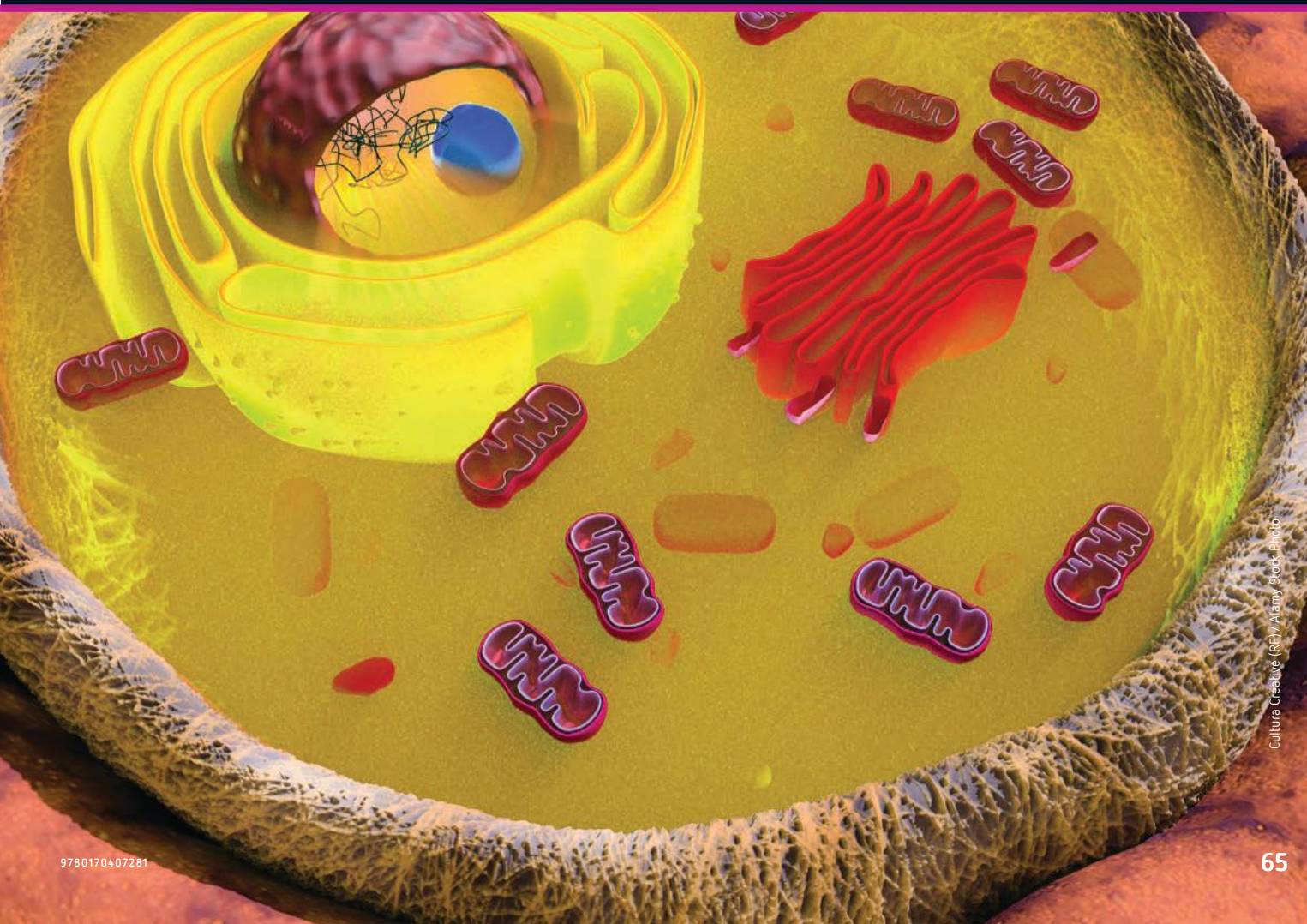
INQUIRY QUESTION

How do cells coordinate activities within their internal environment and the external environment?

Students:

- investigate the way in which materials can move into and out of cells, including but not limited to:
 - conducting a practical investigation modelling diffusion and osmosis (ACSBLO46) [ICT](#)
 - examining the roles of active transport, endocytosis and exocytosis (ACSBLO46)
 - relating the exchange of materials across membranes to the surface area to volume ratio, concentration gradients and characteristics of the materials being exchanged (ACSBLO47) [ICT N](#)
- investigate cell requirements, including but not limited to:
 - suitable forms of energy, including light energy and chemical energy in complex molecules (ACSBLO44)
 - matter, including gases, simple nutrients and ions
 - removal of wastes (ACSBLO44)
- investigate the biochemical processes of photosynthesis, cell respiration and the removal of cellular products and wastes in eukaryotic cells (ACSBLO49, ACSBLO50, ACSBLO52, ACSBLO53) [ICT](#)
- conduct a practical investigation to model the action of enzymes in cells (ACSBLO50)
- investigate the effects of the environment on enzyme activity through the collection of primary or secondary data (ACSBLO50, ACSBLO51) [ICT N](#)

Biology Stage 6 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2017





The development of technologies to view the internal structure of cells enabled scientists to determine the different types of cells and the structures they possess. With this knowledge our curiosity about how cells function grew. Further development of technologies led to the study of the biochemical processes of photosynthesis and cellular respiration, which are carried out by cells in their internal environment to ensure the efficient and successful functioning of the organism. In order for these biochemical processes to occur, cells must obtain the materials necessary from their external environment and must be able to remove any wastes produced from their internal environment (Fig. 3.1) and coordinate these activities.

FIGURE 3.1 Cell requirements and waste removal



Coordination of the biochemical activities of the cell to ensure efficient cellular metabolism is the responsibility of the nucleus. The cell membrane controls the movement of cellular requirements from the external environment of the cell into the cell and the removal of cellular products and wastes from the internal environment of the cell into the external environment.

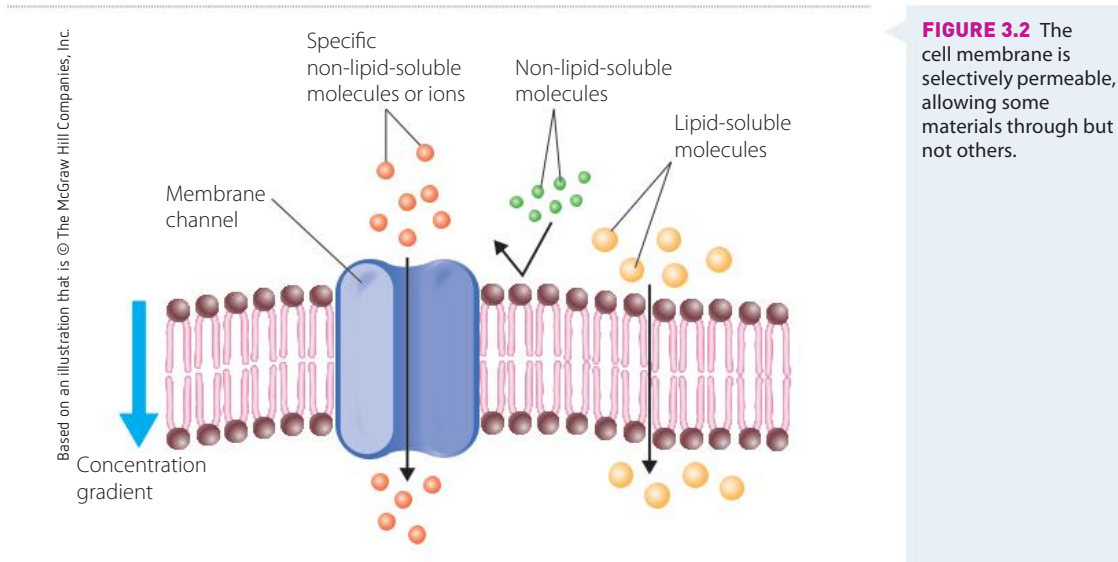
3.1 Movement of materials in and out of cells

For any cell to function effectively, it must interact with its surrounding environment and with the cells that surround it. Substances required by cells for their functioning need to move into the **internal environment** of cells and waste substances and cellular products need to pass out of cells into the **external environment**. These substances move from the internal environment to the external environment by passing through the cell membrane.

Substances needed by cells are *gases* (oxygen and carbon dioxide), *nutrients* (sugars, amino acids, glycerol and fatty acids) and water, the main solvent in cells. Mineral salts dissolved in the water are also required. Substances that must leave cells are *wastes* such as urea, uric acid and excess carbon dioxide. They could also be *products* **secreted** by cells that may be needed to coat the outside of cells (for example, mucus) or may pass to other cells (for example, hormones).

In both plant and animal cells, the cell membrane is in direct contact with the cytoplasm inside the cell. The cell membrane is selectively permeable (or sometimes referred to as **differentially permeable**), meaning it controls what passes across it (Fig. 3.2). The membrane controls the passage of *water* and *other molecules* (many in a dissolved form) into or out of living cells. In contrast to the selectively

permeable nature of a cell membrane, a cellulose cell wall in plant cells is permeable – it is a non-selective boundary that allows water and most molecules to pass freely inwards or outwards. The movement of these molecules is restricted only when they come into contact with the cell membrane.



To understand how the cell membrane controls and regulates the movement of substances, biologists examine the structure of the cell membrane and relate this to its functioning.

Movement of molecules across cell membranes

The permeability of a cell membrane to a molecule depends on the molecule's:

- size
- electrical charge
- lipid solubility.

Small molecules can move across membranes quickly. Larger molecules have more difficulty moving across membranes.

Water-soluble (hydrophilic) molecules have difficulty penetrating a membrane, whereas lipid-soluble molecules do not. This is due to the phospholipid bilayer structure of the cell membrane. The lipid 'tails' impede the progress of **hydrophilic molecules** and enhance the movement of lipid-soluble molecules such as urea and ethanol.

Electrically charged molecules, such as sodium and potassium ions, are not very soluble in lipids and therefore have *low membrane permeability*. Neutral molecules such as carbon dioxide and oxygen gas are soluble in lipids and have a high permeability.

Although water is a polar molecule that is not lipid-soluble, membranes have pores that make them *highly permeable* to it. Water moves through special tiny hydrophilic pores in the membrane, called **aquaporins**, by a process called osmosis.

Molecules that have low permeability rely on carrier proteins to transport them across membranes in cells. This will be dealt with in more detail later in this chapter.

- Substances move from the internal environment of the cell to the external environment (and vice versa) by passing across the cell membrane.
- The cell membrane is selectively permeable and controls the movement of substances into and out of the cell.
- Gases, nutrients, water and ions are required by the cell, while wastes and cellular products need to be removed from the cell.
- The permeability of a membrane to a particular molecule depends on its size, electrical charge and its lipid solubility.
- Plant cell walls are permeable to most substances.

Diffusion

The movement of materials into and out of cells takes place either *passively* or *actively*. **Passive movement** requires no energy input and includes the processes of diffusion and osmosis.

Diffusion is the net movement of *any* molecules from a region of high concentration to a region of low concentration of that substance, until **equilibrium** is reached (Fig. 3.3). Equilibrium is reached when there is no net movement of molecules in either direction – the molecules move equally in each direction. This process does not require an energy input.



FIGURE 3.3 Diffusion of potassium permanganate in water from a region of high concentration until the potassium permanganate is evenly distributed throughout the water.

For example, if someone sprays a burst of perfume in the back corner of a laboratory, the students closest to the corner (where the perfume is the most concentrated) will smell it quickly. Students at the front of the room (where the concentration of perfume particles is very low) will not smell it until some time later. The perfume molecules will gradually move from the back of the room where it has the highest concentration to the front of the room where it has the lowest concentration. This will continue until the concentration is the same throughout the whole room (that is, it is in equilibrium). The perfume is said to have diffused throughout the laboratory. No energy input has been required for this process to occur.

Movement from a high concentration to a low concentration is described as movement *along a concentration gradient* (a gradient is a slope). Molecules moving down a concentration gradient can be likened to the movement of rocks rolling down a hill, needing no energy input.

The rate of diffusion changes depending on the concentration gradient. If there is a greater difference in the concentration of substances, the concentration gradient will be steeper and diffusion will occur faster.

Diffusion can also speed up or slow down, depending on the temperature: heat increases the rate of diffusion because the kinetic energy of the particles increases.

INVESTIGATION 3.1

An investigation to model the process of diffusion through the cell membrane

In this investigation you will model diffusion through the cell membrane using semipermeable dialysis tubing to represent the selectively permeable nature of the cell membrane (Fig. 3.4). The starch solution is milky white in colour and will be used to represent the contents of the cell. The iodide ions in the yellow iodine potassium iodide (IKI) solution represent a cell requirement that will readily diffuse through the cell membrane.

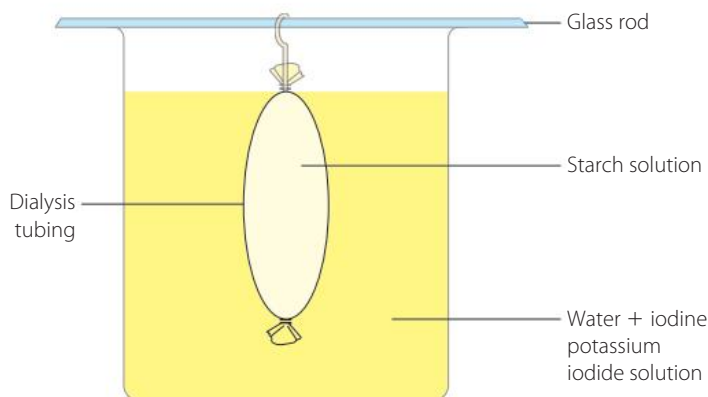


FIGURE 3.4
Investigation set-up

AIM

To model the process of diffusion through the cell membrane

MATERIALS

- 2 × 800 mL beakers
- Starch solution
- Iodine potassium iodide (IKI) solution
- 2 × 20 cm section of dialysis tubing
- Filter funnel
- Fine string or cotton thread
- 50 mL measuring cylinder
- 2 × glass rod
- Scissors

RISK ASSESSMENT

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Iodine potassium iodide solution	Irritant to skin and eyes Poisoning if ingested Irritant if inhaled	Do not ingest chemical. Do not use in confined spaces. Wear safety glasses.
Broken glass	Cuts to skin	Take care when using glassware.



METHOD

- 1 Use one of the beakers to soak the dialysis tubing in water for 5 minutes.
- 2 Fill the other beaker three-quarters full with tap water. Add 10 drops of IKI solution and mix.
- 3 Remove the tubing from the water and, under running water, rub the end of the tubing between your fingers to separate the sides.
- 4 Tie one end very securely with string.
- 5 Measure 30–40 mL of starch solution into the measuring cylinder and pour into the tubing using a filter funnel.
- 6 Tie off the top end of the tubing very securely with string, leaving a length of string to secure the tubing to the glass rod.
- 7 Wash the outside of the tubing.
- 8 Tie the end of the string to the middle of the glass rod.
- 9 Place the rod across the top of the beaker to suspend the tube containing the starch solution in the water + iodine potassium iodide solution. Ensure that the tube is fully submerged.
- 10 Leave undisturbed for 15–20 minutes.
- 11 Observe and record any colour changes that occur.
- 12 Use the other beaker to set up a control, leaving out the iodine potassium iodide solution.

RESULTS

Record your observations in a table like Table 3.1 for the experiment and control.



Investigation 3.1

TABLE 3.1

SOLUTION	INITIAL COLOUR	FINAL COLOUR
Starch		
Water + iodine potassium iodide		
Control		

DISCUSSION

- 1 Copy and complete Table 3.2, which identifies the correlation between your model of diffusion and diffusion across the cell membrane.

TABLE 3.2

DIFFUSION ACROSS THE CELL MEMBRANE	COMPONENT OF MODEL
Selectively permeable membrane	
Large molecules inside the cell	
	Small iodide ions
Lower concentration of required substances inside the cell	

- 2 Using the results obtained, copy and complete Table 3.3, which indicates the initial and final concentrations of starch molecules and iodide ions both inside and outside the dialysis tubing. Use terms such as 'highly concentrated', 'none present', 'decreased concentration', 'increased concentration', and 'no change'.

**TABLE 3.3**

SUBSTANCE	INITIAL CONCENTRATION		FINAL CONCENTRATION	
	INSIDE TUBING	OUTSIDE TUBING	INSIDE TUBING	OUTSIDE TUBING
Iodide ions				
Starch molecules				

- Describe evidence from your investigation to support your conclusions in Table 3.3 about the change/no change in the concentration of:
 - iodide ions
 - starch molecules.
- Explain how this investigation has modelled the process of diffusion through the cell membrane. Use the term 'concentration gradient' and 'control' and refer to the selectively permeable nature of the cell membrane and to the size of the molecules.
- Discuss the benefits and limitations of the model.

CONCLUSION

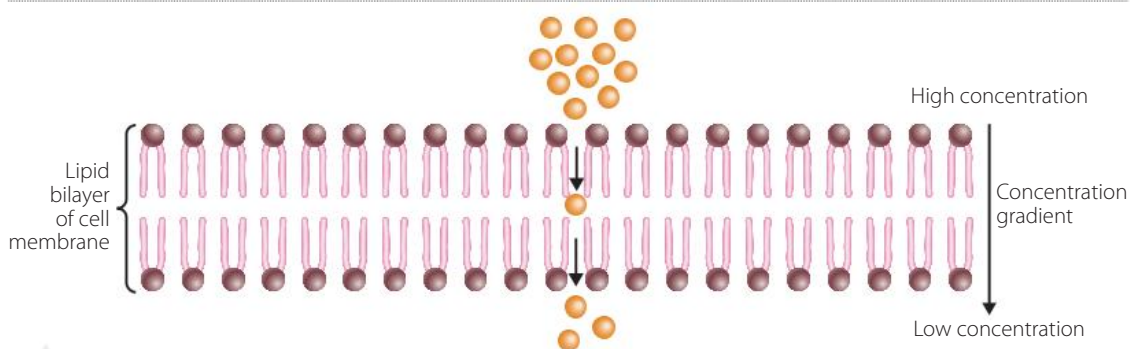
Write a conclusion to link your results to the aim of the investigation.

Diffusion across a cell membrane

Small uncharged particles such as carbon dioxide and oxygen move easily through the cell membrane by simple diffusion (Fig. 3.5). These particles pass between the phospholipid molecules from a region of high concentration to a region of low concentration. The concentration gradient is usually maintained for the diffusion of oxygen molecules because oxygen is removed for use in the cell. Oxygen is continually used in the process of cellular respiration, keeping its concentration low inside the cell. This promotes the diffusion of oxygen from outside the cell where it is in high concentration.

**Diffusion**

Watch the animation and describe the process of diffusion.



Adapted from Biology: Principles & Processes by Roberts, Reiss & Monger (Nelson Thornes Ltd 2000)

FIGURE 3.5 Simple diffusion of small molecules through the cell membrane is dependent on the concentration gradient.

Facilitated diffusion

Relatively large molecules (such as glucose and amino acids) and charged particles (such as sodium and chloride ions) do not readily pass through the phospholipid bilayer. They require certain proteins called **carrier proteins** and **channel proteins** in the cell membrane to assist them in diffusing into the cell. This process is called **facilitated diffusion**.

**Facilitated diffusion**

Watch the animation about facilitated diffusion and create a dot point summary of the process.

As shown in Figure 3.6, the carrier proteins bind to molecules on one side of the membrane. They then change shape and release the substance on the other side. The direction of movement, whether into or out of the cell, depends on the direction of the concentration gradient.

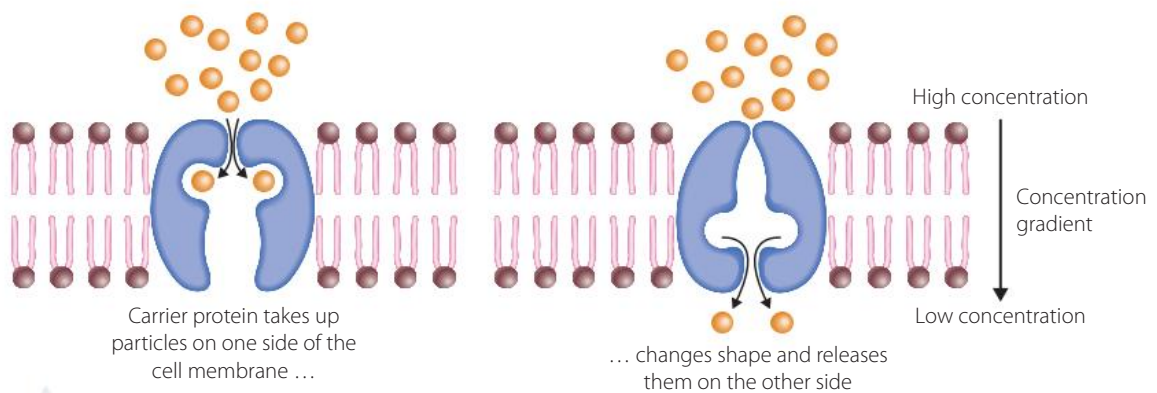


FIGURE 3.6 Facilitated diffusion using a carrier protein in the cell membrane of a cell moves particles such as glucose along the concentration gradient.

Small ions such as sodium ions diffuse rapidly through the cell membrane, from a high ion concentration to a low ion concentration, via narrow passageways called channel proteins. These channel proteins are specific for particular ions (Fig. 3.7).

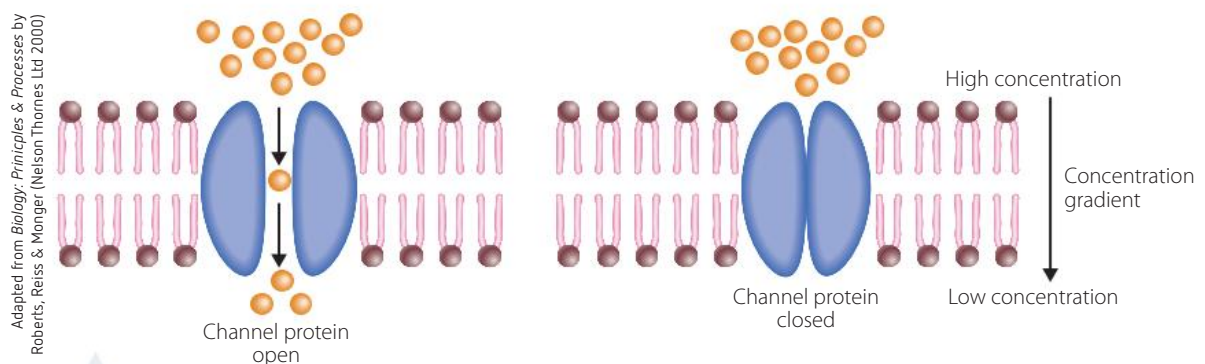


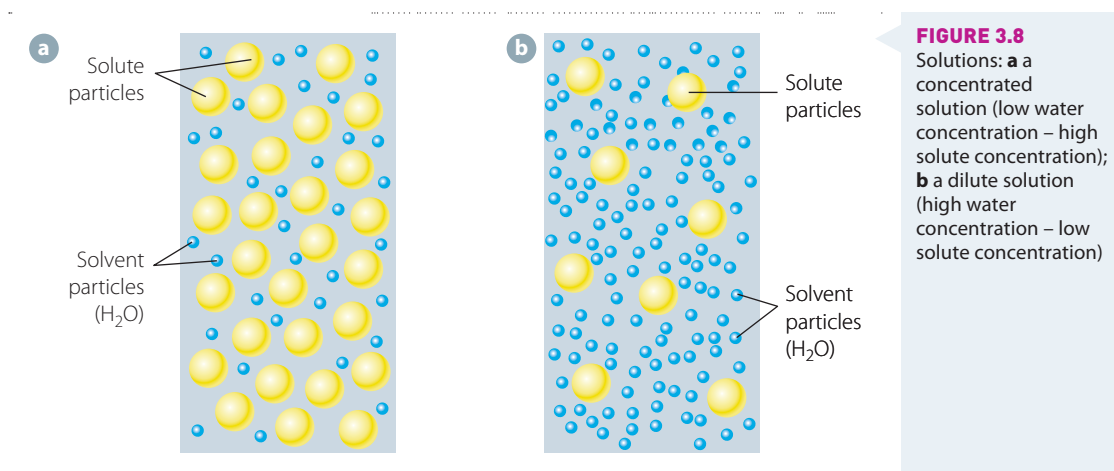
FIGURE 3.7 Facilitated diffusion through a channel protein in the cell membrane of a cell. Movement is along the concentration gradient.

KEY CONCEPTS

- Diffusion is the movement of particles from a region of high concentration to a region of low concentration until equilibrium is reached.
- At equilibrium, there is no net movement of particles in either direction.
- Diffusion does not require the input of energy.
- Diffusion occurs faster with a higher temperature or a steeper concentration gradient.
- Small, uncharged molecules such as oxygen and carbon dioxide will diffuse easily across the cell membrane.
- Facilitated diffusion allows larger molecules and small electrically charged ions to diffuse across the cell membrane aided by carrier or channel proteins.

Osmosis

Osmosis is a special type of diffusion. It is the net movement of solvent molecules from a region of high solvent concentration to a region of low solvent concentration through a semipermeable membrane (Fig. 3.8). When water is the solvent, just like diffusion the movement of water occurs along the concentration gradient and does not require an energy input.



Water is very important to living things. It is the medium in which many of the biochemical reactions in cells occur. Water helps keep cells in shape, it forms the fluid that bathes tissues and it also transports materials in **solution**.

A solution is formed when a **solute** (such as salt or sugar) dissolves in a **solvent**. The amount of solute dissolved in a given quantity of solvent determines the concentration of the solution.

Water is the most common solvent in a solution. A **concentrated solution** contains a large amount of solute in relation to the amount of water, so the water is said to be in low concentration. A **dilute solution** contains a small amount of solute in relation to the amount of water and the water is said to be in high concentration.

Osmosis is the process by which water moves through the cell membrane. Because water is not lipid-soluble, the movement is not directly through the lipid bilayer. Water moves through special tiny protein channels in cell membranes called aquaporins ('water pores').

- When water is more highly concentrated outside the cell (low solute concentration) than it is inside the cell (high solute concentration), water will move by osmosis through the selectively permeable cell membrane into the cell and the cell may swell up.
- Alternatively, if the concentration of water is lower outside the cell than inside, water will move out of the cell by osmosis and the cell may shrink.

The pressure created by water moving across a semipermeable membrane due to osmosis is called the **osmotic pressure**. The more water that moves across the membrane, the higher the osmotic pressure created (Fig. 3.9).

If the fluids inside and outside a cell are of equal solute concentration, the external solution is said to be **isotonic** ('iso' = same) to the cell contents; water molecules jostle on both sides of the membrane, moving in both directions equally (Fig. 3.10). When cells are surrounded by a solution that contains a lower solute concentration than their cytoplasm, the external solution is said to be **hypotonic** ('hypo' = lower) to the cell contents. Net movement of water molecules will be through the membrane into the cells (Fig. 3.11). The reverse applies if the cells are surrounded by a solution of higher solute concentration: the external solution is **hypertonic** ('hyper' = higher) to the cells and net movement of water molecules will be out of the cells.



Osmosis

Explain the process of osmosis. Define the terms 'isotonic', 'hypertonic' and 'hypotonic'.

FIGURE 3.9 Diagram showing the concentration of water and solute molecules (solute) on either side of a semipermeable membrane and the resulting movement of water molecules

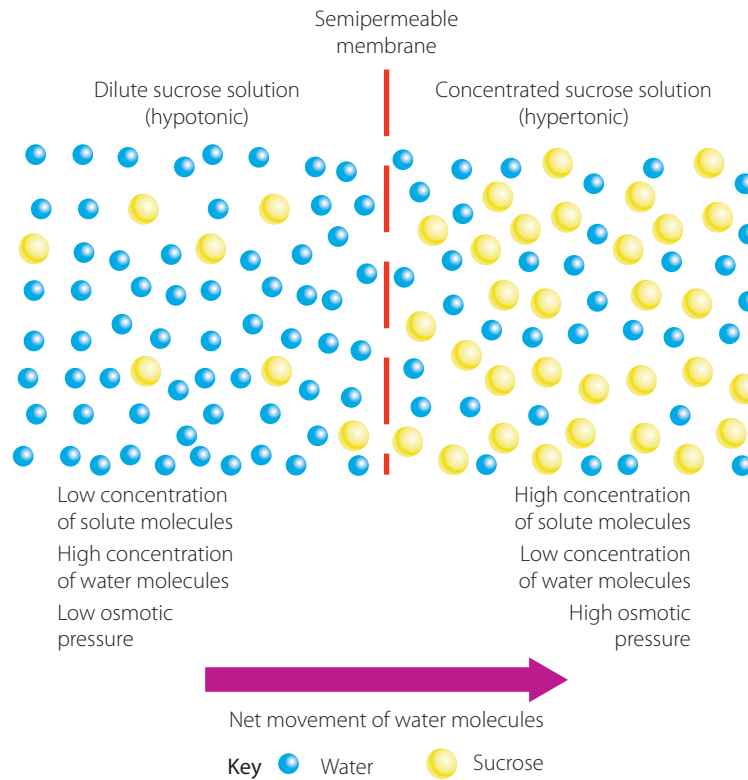


FIGURE 3.10 Isotonic solutions separated by a semipermeable membrane will show no net movement of water molecules.

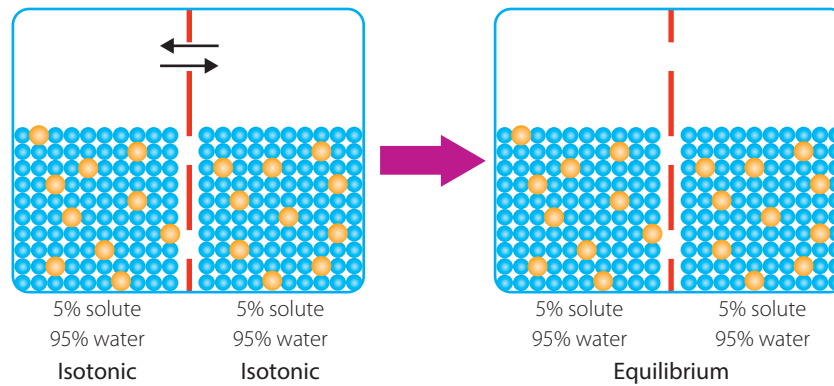
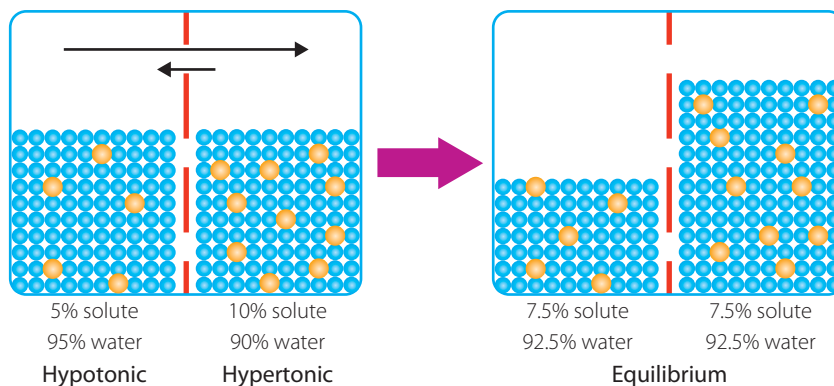


FIGURE 3.11 Water molecules will move by osmosis through a semipermeable membrane from a hypotonic solution into a hypertonic solution until equilibrium is reached.



INVESTIGATION 3.2

An investigation to model the process of osmosis

In this model of osmosis, the semipermeable dialysis tubing represents the selectively permeable cell membrane. The sucrose solution represents the cytoplasm of the cell and the distilled water represents the extracellular fluid.

AIM

To model the process of osmosis

MATERIALS

- 3 × 600 mL beakers
- Distilled water
- Sucrose solution
- Fine string
- 2 × glass rods
- 2 × 20 cm strips dialysis tubing
- 25 mL measuring cylinder
- 100 mL measuring cylinder
- Filter funnel
- Marking pen
- Plastic clingwrap
- Digital camera (optional)

RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THE RISK?
Broken glass	Injury to body	Take care at all times when using glassware.



METHOD

- 1 Cut two pieces of dialysis tubing to 20 cm lengths and soak in a beaker of water for about 5 minutes.
- 2 Tie one end of each piece of tubing securely with a piece of string, leaving the other end untied.
- 3 Run the untied end of the tubing under water and rub it between your fingers to open it.
- 4 Using a filter funnel and a measuring cylinder, pour a measured volume (about 30–35 mL) of sugar solution into the tubing so that the tubing is two-thirds full. (Record the exact volume of sugar solution used.)
- 5 Tie the top of the tubing with string. Attach it to a glass rod as shown in Figure 3.12. This is your *experimental* apparatus.
- 6 Repeat the previous two steps, this time filling the tubing with distilled water instead of sugar solution. This is your *control* apparatus.
- 7 Using a measuring cylinder, fill each beaker about half-full and record an accurate measurement of the volume of water in each.
- 8 Suspend the experimental and the control apparatus each in a beaker of distilled water as shown in Figure 3.12. Ensure that the tied ends of the dialysis tubing are just above the distilled water in the beaker to prevent leakage. Do not have the tubing too far out of the water because evaporation may occur and this will interfere with the accuracy of your results.



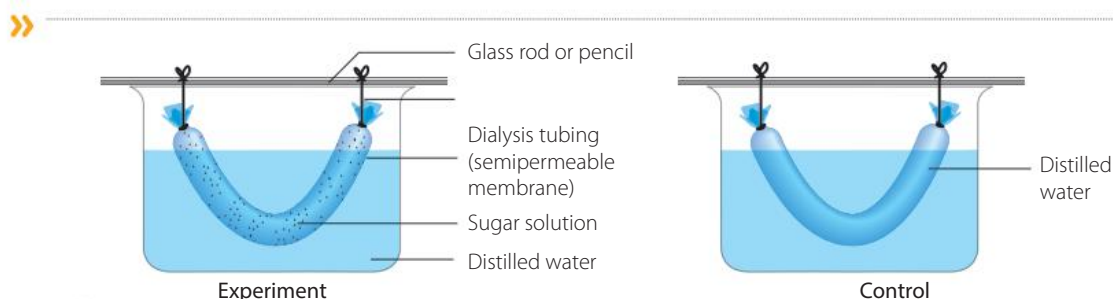


FIGURE 3.12 Investigation set-up

- 9 Mark the level of water in the beaker with a marking pen.
- 10 Cover the top of the experiment with plastic wrap to prevent the water in the beaker from evaporating. Leave the apparatus to stand overnight.
- 11 Measure the volume of the solutions in each bag after they have been left overnight.
- 12 Record the volumes of the solutions in each dialysis bag and in each beaker at the end of the experiment. Compare this with the volume recorded at the start of the experiment.
- 13 Also record the number of hours the experiment was left standing.
- 14 Observations such as the change in the fullness of the dialysis tubing and the changing water level should also be recorded.

RESULTS

Your results will be both **quantitative** (measured quantities such as the volume of sucrose solution) and **qualitative** (descriptive and with diagrams).

- 1 Draw up a suitable table to record your measurements.
- 2 Describe any change in water levels in both the beakers and the dialysis tubing. Diagrams are often useful tools to aid descriptions.

DISCUSSION

- 1 Identify each of the following in your investigation:
 - a the independent variable
 - b the dependent variable
 - c the controlled variables.
- 2 Why was the dialysis tubing with distilled water used with the beaker with distilled water?
- 3 Complete Table 3.4, which identifies the correlation between your model of osmosis and osmosis across the cell membrane.

TABLE 3.4

OSMOSIS ACROSS THE CELL MEMBRANE	COMPONENT OF MODEL
Selectively permeable membrane	
Hypertonic solution inside cell	
	Distilled water in beaker

- » 4 Describe how your investigation has modelled the process of osmosis.
- 5 Outline any limitations of your model.
- 6 Discuss improvements that could be made to your model of osmosis.

CONCLUSION

Write a conclusion to link your results to the aim of the investigation.

KEY CONCEPTS

- A solution is formed when a solute dissolves in solvent.
- A concentrated solution has a high concentration of solute and a low concentration of water.
- A dilute solution has a low concentration of solute and a high concentration of water.
- Osmosis is the process by which water moves from a region of high concentration of water (dilute – low solute) to a region of low concentration of water (concentrated – high solute).
- Osmosis requires no energy input.
- The more water that moves across the membrane, the higher the osmotic pressure created.
- Isotonic – fluids inside and outside a cell are of equal solute concentration – no net water movement.
- Hypertonic – a solution of higher solute concentration (lower water concentration) that surrounds a cell – net movement of water molecules will be out of the cell.
- Hypotonic – a solution of lower solute concentration (higher water concentration) that surrounds a cell – net movement of water molecules will be into the cell.

Osmosis in animal cells

The cells of unicellular eukaryotes are surrounded only by a cell membrane. Hypertonic solutions, such as fresh water, pose a problem because water moving into animal cells by osmosis can cause the cell to swell and eventually burst the cell membrane, killing the organism.

Cells in most animals are not directly exposed to the external environment and are bathed in isotonic extracellular fluid. This means that cells can function efficiently because water diffuses equally in both directions, resulting in no net movement of water into or out of cells. The water concentration in animal cells needs to be kept constant to coordinate biochemical reactions.

Osmosis in plant cells

Unlike animal cells, plant cells will not burst when soaked in fresh water (hypotonic solution), even though water moves into the cells by osmosis.

Plant cells usually have large, fluid-filled vacuoles and firm, semipermeable cell walls that surround the cell membrane. Plant cell vacuoles contain cell sap that has a high concentration of solutes and therefore a low concentration of water. When a hypotonic solution surrounds a plant cell, water molecules move by osmosis into the vacuole. This causes the vacuole to swell and pushes the cell membrane outwards against the cell wall. The tough cell wall prevents the cell from bursting. When the cell wall stretches as much as possible, no more water can enter and the cell is said to be turgid (Fig. 3.13a). In this state, the osmotic pressure inside the cell is equal to the opposing pressure exerted by the cell wall.

If the plant cells were to be placed into a hypertonic solution, the water in the cell would leave the cell by osmosis, the vacuole would shrink and cause the cell membrane to move away from the cell wall in a process called **plasmolysis** (Fig. 3.13b).

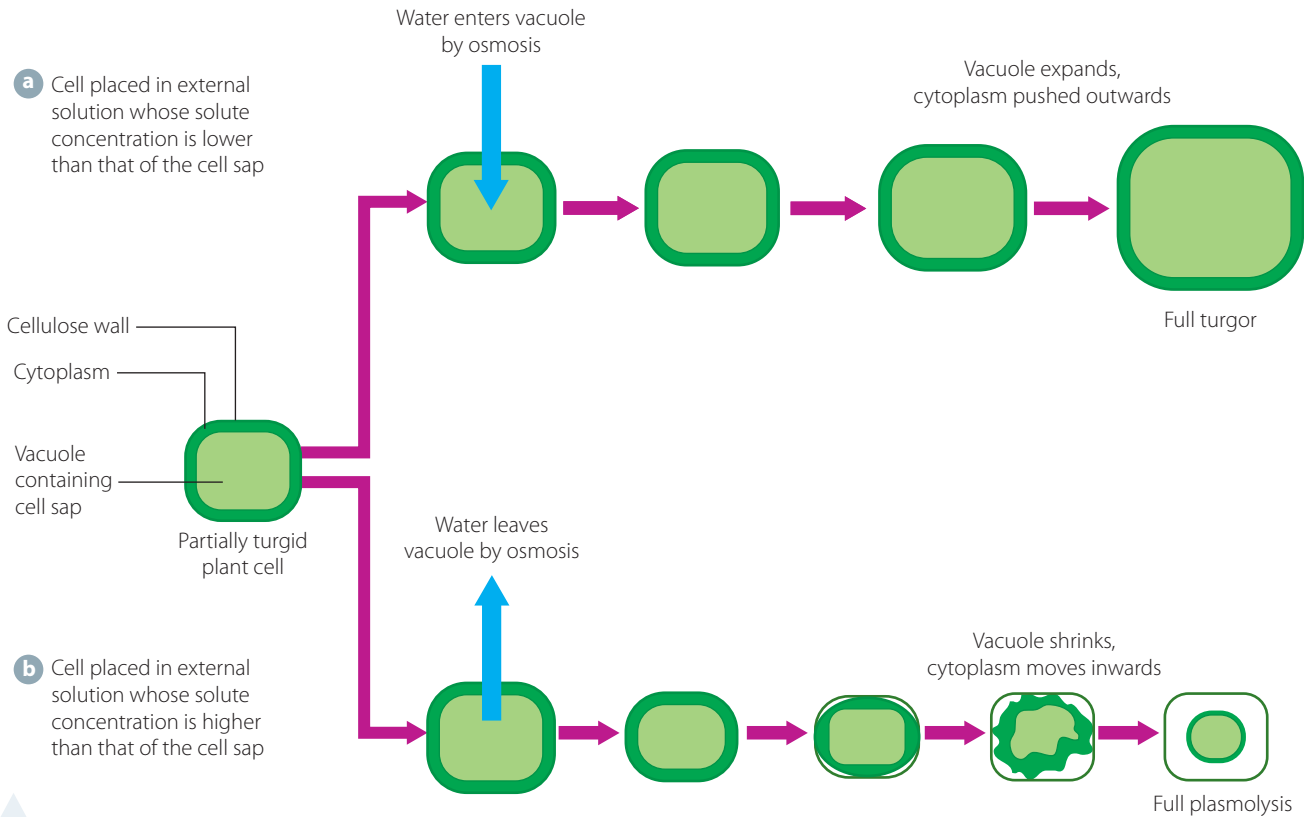


FIGURE 3.13 The effect of immersing a partially turgid plant cell in **a** pure water (hypotonic solution) and **b** a high solute concentration (hypertonic solution)

CHECK YOUR UNDERSTANDING

3.1a

- 1 Draw a generalised diagram to represent a cell. On this diagram, indicate with arrows going into the cell the substances that a cell requires. Also indicate the wastes that have to be removed from the cell, using arrows pointing out of the cell.
- 2 Distinguish between a permeable membrane and a selectively permeable membrane.
- 3 **a** Identify and outline three characteristics of molecules that affect the permeability of the cell membrane to them.
 - i** Neutral molecules such as carbon dioxide and oxygen gas
 - ii** Sodium and potassium ions
 - iii** Water and ethanol
 - iv** Large molecules such as proteins
- 4 A sugar solution is a mixture of sugar and water. Identify the **a** solute and **b** solvent.
- 5 **a** Outline the process of diffusion.
 - b** Identify two factors that could increase the rate of diffusion.
- 6 **a** Identify the substances that are able to move across the cell membrane by diffusion.
 - b** Describe the process of facilitated diffusion.
 - c** Which substances move across the cell membrane using this process?
- 7 **a** Describe the process of osmosis.
 - b** What is the relationship between diffusion and osmosis?
 - c** Define the terms 'isotonic', 'hypotonic' and 'hypertonic'.



- 8 Refer to Figure 3.14. In which direction would water move in this situation? Explain your answer.

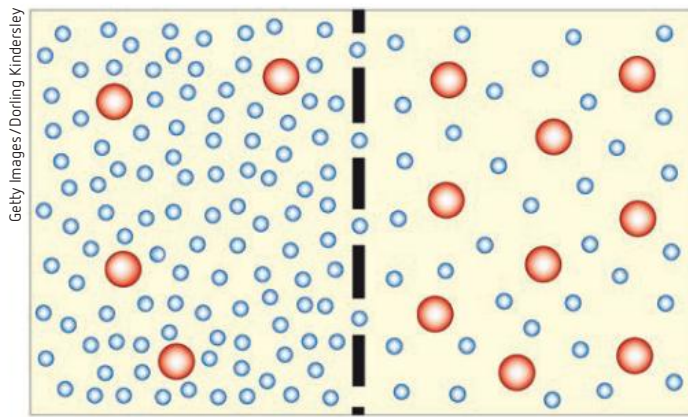


FIGURE 3.14

- 9 If salad greens such as celery are left on the kitchen bench for a period, they become limp. To restore their crispness, you can soak them in cold water. Explain why this occurs.

Active transport

Active transport is the movement of molecules from a region of *low concentration* to a region of *high concentration*, and requires the input of energy. This movement goes against the concentration gradient and involves movement across a cell membrane that has receptors for the molecules.

Diffusion and osmosis both rely on a concentration gradient to direct the passive flow of substances from regions of high concentration to regions of low concentration. Sometimes in living things, a chemical may need to be moved *against* the concentration gradient, such as when kidney cells reabsorb glucose and amino acids so they are not lost in urine. Active transport requires a carrier protein that spans the membrane to actively move chemicals from a low to a high concentration, utilising cellular energy (Fig. 3.15).

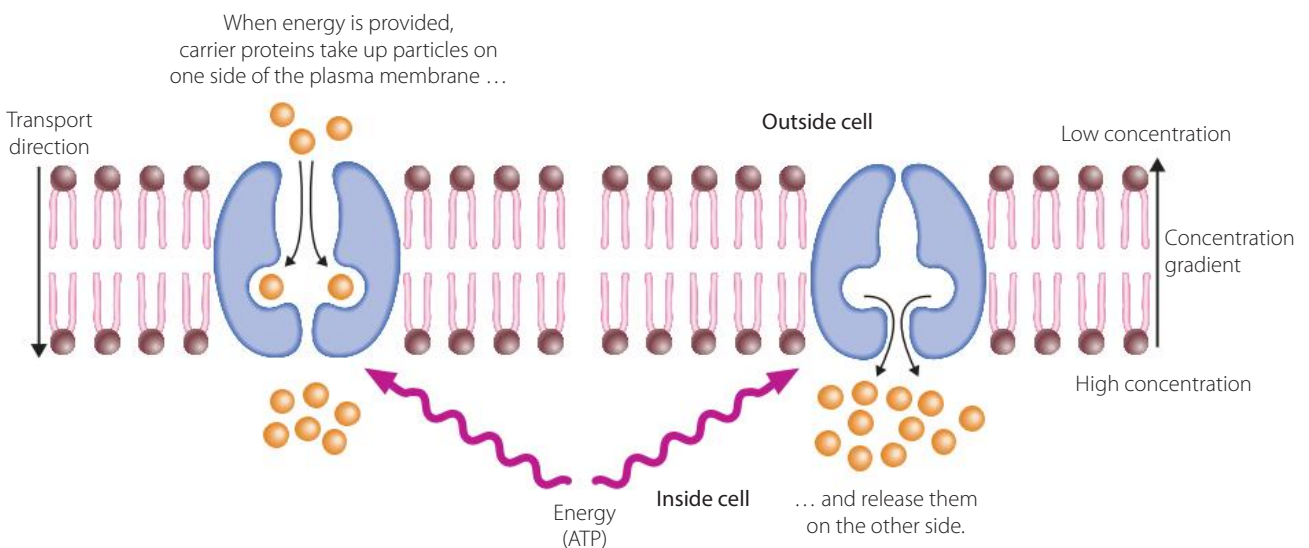


FIGURE 3.15 Active transport via a carrier protein in the cell membrane of a cell. Energy is transferred to the carrier protein, enabling it to move the particles against a concentration gradient.

A summary of the processes of diffusion, osmosis and active transport is shown in Figure 3.16.

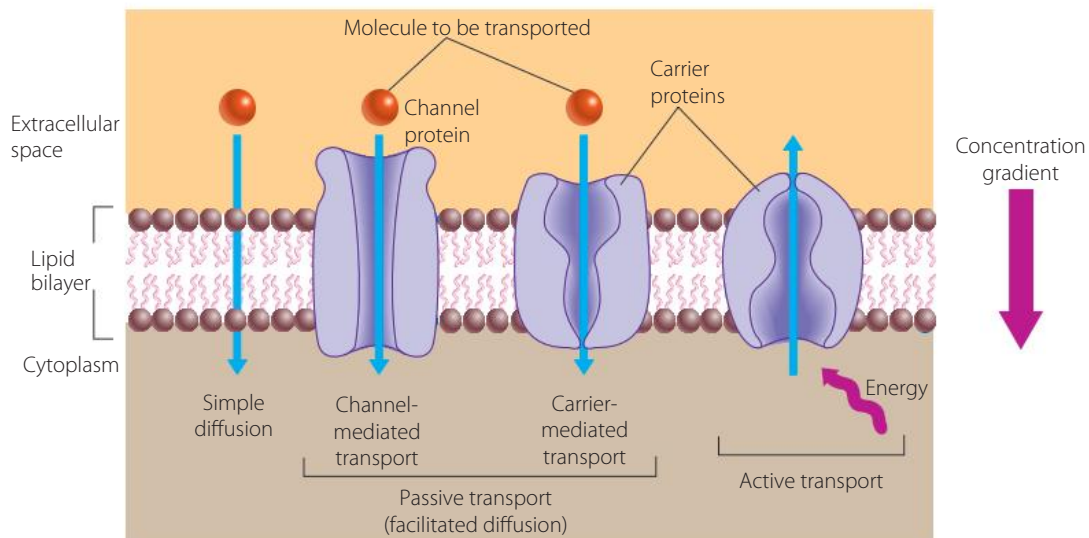
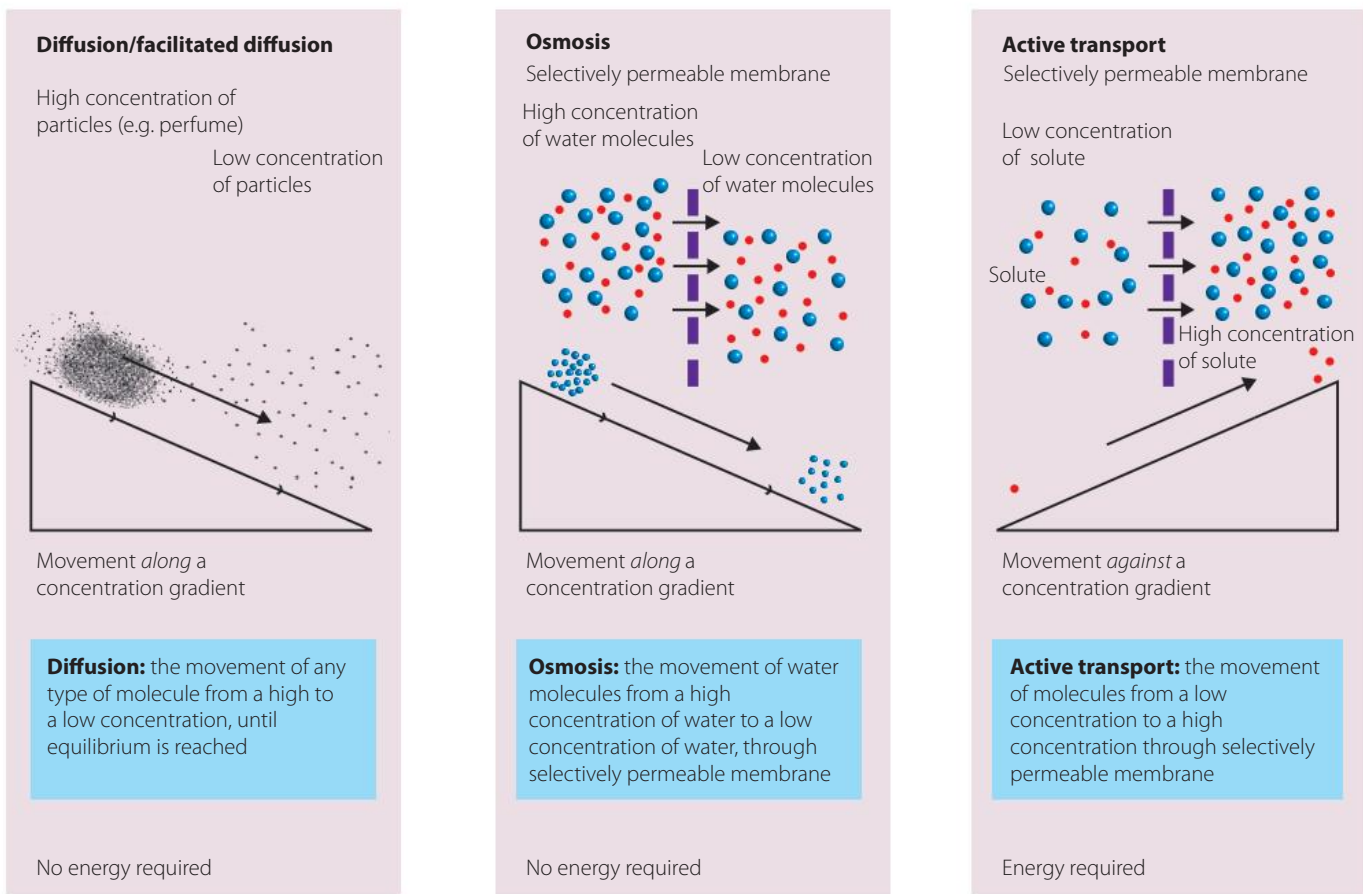


FIGURE 3.16 Diffusion, osmosis and active transport across cell membranes

Comparing processes

View the animation to compare the processes of diffusion, facilitated diffusion and active transport.

KEY CONCEPTS

- Active transport is the movement of molecules from a region of *low concentration* to a region of *high concentration*.
- Active transport moves against the concentration gradient and requires the input of energy.

Endocytosis and exocytosis – transport of large molecules

Sometimes particles that are too large to move through the cell membrane by either diffusion or active transport need to enter or leave a cell.

Endocytosis

When a large particle has to be moved into a cell, the cell membrane can change its shape to surround the particle and engulf it by the process of **endocytosis**. If a solid particle is engulfed, the process is termed **phagocytosis** ('cell eating'). Sometimes fluid is engulfed and the process is then called **pinocytosis** ('cell drinking').

One example of phagocytosis occurs when a unicellular amoeba feeds on a smaller organism. The amoeba changes shape by sending out membrane projections filled with cytoplasm that surround the prey. When the cell membrane of the projections meets, membrane fusion occurs. This results in the formation of a vesicle, which then stores or transports the material within the cytoplasm (Figs 3.17 and 3.18).

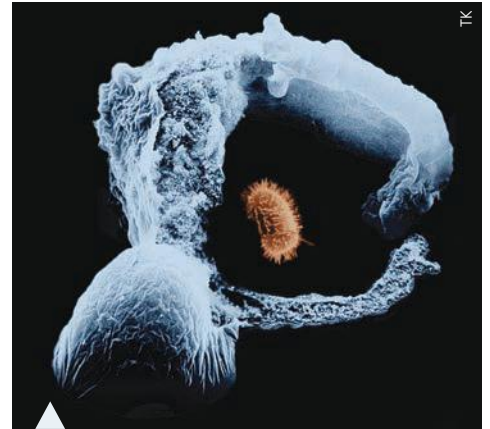


FIGURE 3.17 A scanning electron micrograph of an amoeba surrounding its prey (*Tetrahymena*) for ingestion

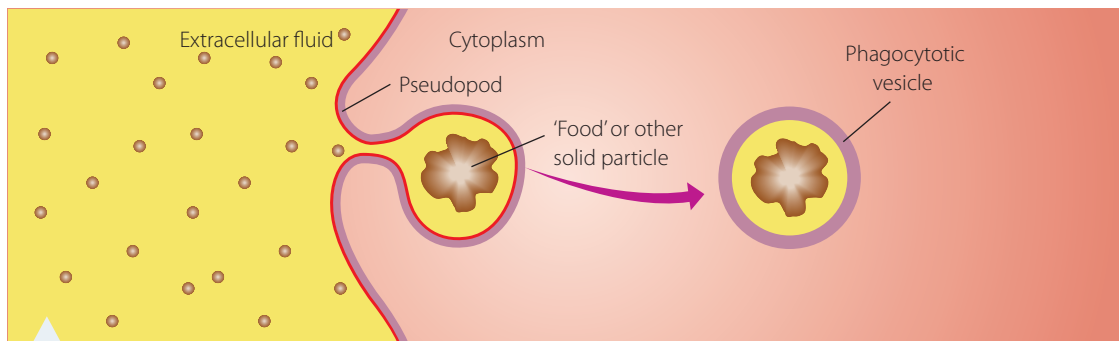
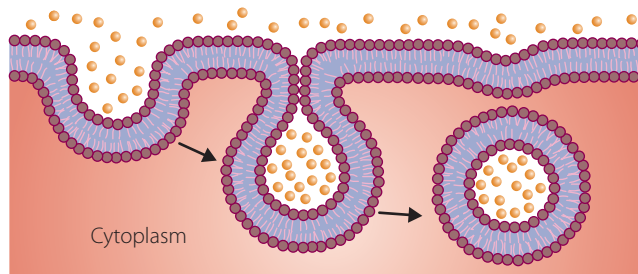


FIGURE 3.18 The process of phagocytosis

Pinocytosis occurs when the cell membrane engulfs a drop of extracellular fluid in much the same way as phagocytosis (Fig. 3.19). Fat droplets found in the small intestine after a meal move into cells by means of pinocytosis.

FIGURE 3.19
The process of pinocytosis



Exocytosis

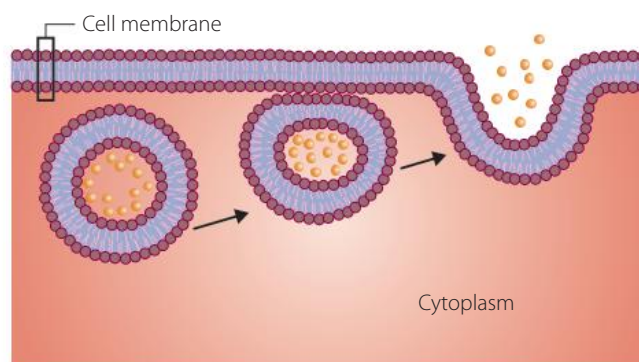
Specialised animal and plant cells produce a variety of substances, such as antibodies, neurotransmitters and enzymes, that have important functions elsewhere in the organism. These substances are contained within vesicles inside the cell. Cells also produce waste products that need to be moved out of the cell. **Exocytosis** is the process by which these substances are transported to the external environment of the cell.

During exocytosis, a membrane-bound vesicle moves to the cell membrane, fuses with it and then releases its contents to the exterior of the cell (Fig. 3.20). The vesicle membrane becomes part of the cell membrane.



Movement in and out of cells

FIGURE 3.20 The process of exocytosis



KEY CONCEPTS

- Endocytosis moves large molecules that cannot cross the cell membrane into a cell. It requires the expenditure of energy.
- In endocytosis, the cell membrane changes shape and surrounds and engulfs the particle so that it enters the cell.
- Phagocytosis is the process whereby solid particles are engulfed by the cell membrane.
- Pinocytosis is the engulfing of fluid substances by the cell membrane.
- Exocytosis involves a membrane-bound vesicle moving to the cell membrane, fusing with it and then releasing its contents to the exterior of the cell.

CHECK YOUR UNDERSTANDING

3.1b

- 1 Define the process of active transport and provide an example of where this occurs.
- 2 Distinguish between the processes of active transport and simple diffusion.
- 3 Describe the process of endocytosis and provide an example of where it is used.
- 4 Describe how the cell membrane is involved in each process listed below and provide an example of the use of each:
 - a exocytosis
 - b endocytosis.
- 5 Identify three types of substances that are removed from cells.

Factors affecting the exchange of materials across membranes

The characteristics of the cell membrane and the physical and chemical properties of the material will determine whether it can move through the cell membrane.

Chemical factors

The chemical properties of a substance affect its transport across cell membranes. Many uncharged molecules, such as ethanol, can easily penetrate the cell membrane because they can dissolve in the phospholipid bilayer. Hydrophilic, charged ions such as sodium (Na^+) and potassium (K^+) cannot cross the hydrophobic centre of the membrane. Channel proteins specific for each ion allow their movement through the cell membrane.

Water is not lipid-soluble and therefore cannot move through the hydrophobic 'tails' in the cell membrane. Water moves through the membrane through the special aquaporins.



Crossing the cell membrane

View the animation to determine how different substances cross the cell membrane.

Physical factors

The physical properties such as size and shape of the molecules affect the movement of substances across the cell membrane. Small molecules are able to diffuse easily between the phospholipids.

Glucose and amino acids are examples of large molecules that use carrier proteins to move through the cell membrane.

Very large molecules that need to be transported into or out of the cell are moved by the process of endocytosis or exocytosis.

Concentration gradient

The relative concentration of the substance on either side of the membrane affects the rate of diffusion of that substance. If the concentration gradient is high (that is, there is a large difference between the concentrations on either side of the membrane), then the substance will diffuse rapidly. As the concentration gradient decreases, the rate of diffusion will be slower. In order to maintain a rapid rate of diffusion, cells need to maintain a high concentration gradient. When the concentration reaches equilibrium, there will be no net movement across the cell membrane.

Plant cells carry out a process called **cytoplasmic streaming**, which involves organelles and cytosol flowing around the cell in a circular movement. This enables the cell to maintain a steeper concentration gradient as materials that diffuse into the cell are rapidly moved to another area of the cell.

Surface-area-to-volume ratio

The surface area (SA) divided by the volume (V) is called the surface-area-to-volume ratio (SA:V). This also affects the movement of substances into and out of the cell through the cell membrane.

The surface area of a cell is the total area of the cell membrane that is around the cell. The volume of the cell is the space taken up by the internal contents of the cell (that is, the cytoplasm and the nucleus). A cell needs to have enough surface area to supply its volume with requirements and remove wastes.

The SA:V of a cell has a large impact on the movement of substances into and out of cells. A smaller cell has more surface area in relation to its volume – a higher SA:V. Think of the distance from the surface of a small cube to its centre. This distance is much less than the distance from the surface to the centre in a large cube. Therefore, a smaller size allows a faster movement of substances between the centre and the surface of the cell (that is, into or out of the cell). Anything that the cell needs can get to all parts of a small cell quickly and wastes can be removed easily. This then allows the cell to perform at an optimum level of functioning. Figure 3.21 illustrates SA:V for simplified cubic cells, but SA:V is important for the movement of substances into and out of cells of any shape.

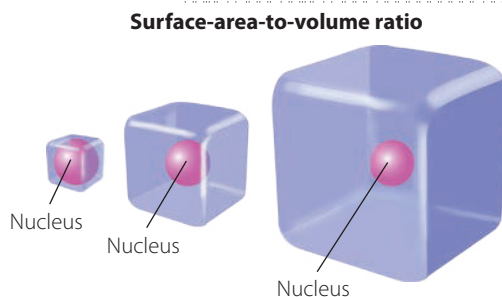


FIGURE 3.21

The smaller the cell, the higher the SA:V and the more efficient the exchange of substances into and out of the cell.

A larger cell has a smaller amount of surface area in relation to its volume – a lower SA:V (the centre of the cell is further from the surface). This means the efficiency with which a cell obtains its nutrients and removes its wastes is reduced as its size increases. A cell increasing in size reaches a point where the inward movement of essential substances and the outward movement of wastes across the surface area by diffusion are not fast enough to service the increasing volume of the cell. When a cell reaches this size, if it is capable of dividing it will often do so. For this reason, individual cells tend to be very small.

WORKED EXAMPLE 3.1

Calculate the SA:V of a cube $1\text{ cm} \times 1\text{ cm} \times 1\text{ cm}$ (Fig. 3.22).



Area of one side = length $\times$ width



Surface area of cube = length $\times$ width $\times$ 6
Volume of cube = length $\times$ width $\times$ height

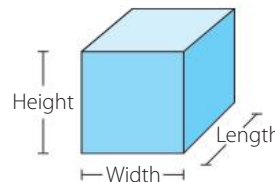


FIGURE 3.22 Calculating surface area and volume of a cube

ANSWER	LOGIC
Surface area of a cube = $6 \times \text{length of side} \times \text{width of cell}$ Surface area = $6 \times 1 \times 1$ $= 6\text{ cm}^2$	- Insert the correct formula. (Note: a cube has six sides.) - Extract the data from the question and insert into the formula. - Calculate the answer.
Volume of a cube = length $\times$ width $\times$ height Volume = $1 \times 1 \times 1$ $= 1\text{ cm}^3$	- Insert the correct formula. - Extract the data from the question and insert into the formula. - Calculate the answer.
Surface area: volume (SA:V) = $6 \div 1$ $= 6:1$	- Calculate SA:V. Insert the numbers into the formula. - Calculate the answer.

TRY THESE YOURSELF

Calculate the SA:V of a:

- a** 2 cm cube **b** 3 cm cube.

The shape of the cell also makes a difference to the SA:V. Spherical cells have a relatively small SA:V compared with cells of other shapes. Long, flat cells have a higher SA:V than a spherical cell with the same volume.

Table 3.5 shows the SA:V for three hypothetical spherical cells. It demonstrates that the smaller cell A with a diameter of 1 mm has a higher SA:V of 6:1 than the larger diameter cells B and C. Cell B has a SA:V of 3:1 and cell C a SA:V of 2:1. This means that for each unit of volume, cell A has 6 units of surface area, cell B has 3 units of surface area and cell C has 2 units of surface area. It then follows that the inward movement of essential substances and the outward movement of wastes across the surface area by diffusion would occur much more rapidly in cell A than in cell B and be slowest in cell C.

TABLE 3.5 SA:V of three hypothetical spherical cells

	CELL A	CELL B	CELL C
Diameter (mm)	1.0	2.0	3.0
Surface area (mm^2)	3.14	12.57	28.28
Volume (mm^3)	0.52	4.19	14.14
SA:V	6:1	3:1	2:1

Cells often have specific features that ensure they have the highest SA:V possible. An example is seen in the root hairs that cover the root tips of most plants. The long, thin extensions of the single cells that form root hairs increase the surface area through which water and mineral salts can be absorbed (Fig. 3.23).



FIGURE 3.23 Scanning electron micrograph of root hairs in oregano, *Origanum vulgare*. The root hairs greatly increase the surface area for absorption of water.

KEY CONCEPTS

- SA is calculated by finding the total area of the surface of the shape.
- Volume is the total space that a shape takes up.
- SA:V is calculated by dividing the surface area of an object by its volume.
- The surface-area-to-volume ratio (SA:V) of a cell will determine how efficiently substances move into and out of a cell.
- A high SA:V allows the most efficient movement of substances into and out of the cell.
- Large cells have a low SA:V. Small cells have a large SA:V.
- Long, flat cells have a higher SA:V than a spherical cell with the same volume.

SA:V

Explain in terms of SA:V why cells are limited to a very small size.



Surface-area-to-volume ratio

- 1 Explain how the following factors affect the movement of substances across cell membranes. Provide examples to support your explanation.
 - a Physical factors
 - b Chemical factors
- 2 Describe how the concentration gradient affects the rate of diffusion into and out of the cell.
- 3 a Define the following terms in relation to a cell:
 - i surface area
 - ii volume
 - iii SA:V.
- 4 Describe the importance of SA:V in relation to the movement of substances into and out of a cell.
- 5 Explain how increasing the size of a cell affects the cell's ability to obtain and remove substances by diffusion.
- 6 Figure 3.24 represents two cells with the same volume: (a) a flattened cell and (b) a cube-shaped cell.

CHECK YOUR UNDERSTANDING

3.1c

a Flattened cell

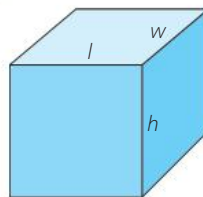


To calculate surface area (mm^2)
 $SA = 2 \times (l \times w) + 2 \times (w \times h) + 2 \times (l \times h)$
 To calculate volume (mm^3)
 $V = l \times w \times h$

Example



b Cube-shaped cell



To calculate surface area (mm^2)
 $SA = 6 \times (l \times h)$
 To calculate volume (mm^3)
 $V = l \times w \times h$

Example

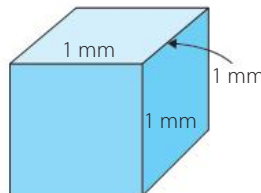


FIGURE 3.24

a A flattened cell;
 b a cube-shaped cell



- a Use the information from Figure 3.23 to complete Table 3.6.

TABLE 3.6

CELL	SURFACE AREA	VOLUME	SA:V
a Flattened cell			
b Cube-shaped cell			

- b Which cell would be more efficient in obtaining nutrients and removing wastes? Explain your answer.

3.2 Cell requirements

Wherever life exists, it depends on a source of energy and a supply of matter. Cells need to obtain nutrients in the form of **organic** substances such as glucose, amino acids, fatty acids and glycerol, **nucleotides** and vitamins. Organic substances are synthesised by living things and contain carbon and hydrogen atoms. Cells also need **inorganic** nutrients such as *gases* (oxygen and carbon dioxide), *minerals* (for example phosphates, sodium ions and chloride ions) and *water*. These inorganic nutrients are part of the non-living world and do not contain carbon and hydrogen in long chains.

The substances needed by living cells for their functioning, are used in two main ways:

- 1 as essential building blocks from which cells and living tissues are made
- 2 as a source of stored energy for the cell.

Organic nutrients are the main supply of stored energy in living things, but they are also used in the structure of cells. Inorganic nutrients are essential as structural parts of cells and tissues.

Inorganic nutrients

Some inorganic nutrients that occur in cells are listed in Table 3.7.

TABLE 3.7 Inorganic nutrients in cells

INORGANIC NUTRIENT	POSITION IN CELLS	USES IN CELL ACTIVITIES
Water: • oxygen • hydrogen	90% of the protoplasm (cytoplasm and nucleus)	• The <i>transport medium</i> in cells and in organisms • An important solvent for many molecules inside cells • The medium in which all <i>chemical reactions</i> in cells take place; water may be used in the reactions
Mineral salts: chlorides, nitrates, phosphates and carbonates of sodium, magnesium, calcium, potassium and ammonium (e.g. sodium chloride (NaCl))	Dissolved as ions in the cytoplasm and in vacuoles in plant cells	• Assist all chemical reactions • Are used in the synthesis of many macromolecules and body tissues (e.g. calcium for bones and teeth, and iron in blood cells) • Sodium ions (Na^+) and chloride ions (Cl^-) assist in water balance in cells and are essential for cell membrane functioning and the function of nerve and muscle cells.
Gases: • carbon dioxide (CO_2) • oxygen (O_2)	Dissolved in the protoplasm; used and/or produced in chloroplasts and mitochondria	Carbon dioxide: • used during the process of photosynthesis • released as a product of aerobic cellular respiration (plants and animals). Oxygen: • used by all living organisms during aerobic cellular respiration to release energy for cells to function • released as a product of photosynthesis.

Organic compounds

Every living cell requires large organic molecules as part of their structure and to maintain the biochemical processes involved in effective functioning. These large organic molecules are called **biomacromolecules**. There are four main types based on their chemical composition and structure: complex carbohydrates, lipids, proteins and nucleic acids (Fig. 3.25).

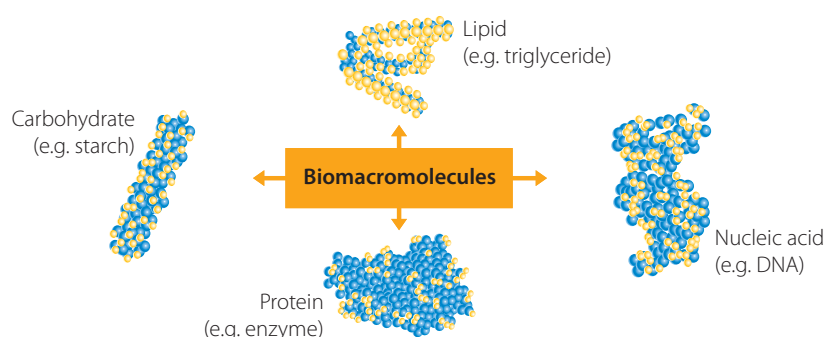


FIGURE 3.25 The major types of biomacromolecules

Plants and other organisms that carry out photosynthesis absorb inorganic nutrients from the soil and the air and use these to make their own organic nutrients. In contrast, organisms that do not carry out photosynthesis need to ingest food to obtain organic nutrients for their cells.

Carbohydrates

Carbohydrates are a group of organic molecules made up of carbon (C), hydrogen (H) and oxygen (O) atoms in the ratio of 1:2:1, giving the general formula for carbohydrates as $(CH_2O)_x$.

Carbohydrates are classified as **monosaccharides** (simple sugars), **disaccharides** and **polysaccharides** (see Table 3.8) depending on how many **monomers** are linked. The product of photosynthesis, glucose, is a monosaccharide.

TABLE 3.8 Classification and uses of carbohydrates

TYPE OF CARBOHYDRATE – DEFINITION	DIAGRAM OF STRUCTURE AND EXAMPLES	USES
Monosaccharides (mono = 1) Simple sugars consisting of a single monomer	Monosaccharides Glucose Galactose Fructose 6-carbon sugars Ribose Deoxyribose 5-carbon sugars	Source of 'quick energy' in both plant and animal cells
Disaccharides (di = 2) Complex sugars consisting of two monomers	Disaccharides Maltose Lactose (milk sugar) Sucrose (cane sugar)	
Polysaccharides (poly = many) Complex molecules consisting of more than five and up to hundreds of monomers joined together	Polysaccharides Starch (plants) Cellulose Glycogen (animal starch) Different bonds	Starch – stored energy in plant cells Cellulose – structural part of cell walls – strength and support Glycogen – stored energy in animal cells

Lipids

Lipids contain many carbon (C) and hydrogen (H) atoms with a few oxygen (O) atoms. The fats and oils in the cells of organisms are typically composed of **triglyceride** molecules (Fig. 3.26). These atoms are arranged as a glycerol molecule to which three chains of fatty acids attach.

Lipids are relatively insoluble in water and have an oily, greasy or waxy consistency.

In cells, lipids have three important functions:

- 1 energy storage (they store approximately twice the amount of energy as carbohydrates)
- 2 structural component of membranes
- 3 essential structural parts of hormones, which are chemical messengers produced by cells (for example, steroids).

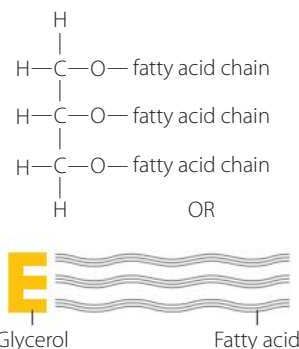


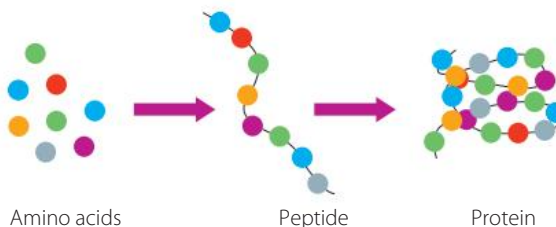
FIGURE 3.26 A triglyceride molecule contains a glycerol unit and three fatty acid chains.

Proteins

Proteins are made up of the elements carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. These elements combine to form **amino acids**, which are the building blocks of proteins.

There are about 20 different amino acids; they can be put together in chains of up to 300 amino acids to form a **peptide/polypeptide** chain (Fig. 3.27). Proteins are made up of one or more of these polypeptide chains twisted together into a particular shape. The DNA in the nucleus of the cell controls the sequence and arrangement of the amino acids, and this determines the type of protein.

FIGURE 3.27 Amino acids joined together by peptide bonds form the peptide/polypeptide chains that make up proteins.



Proteins have many roles in cells:

- They form structural components in cells and tissues.
- They are an important structural component of cell membranes.
- Some proteins have a functional role, such as enzymes, which control all of the metabolic (chemical) reactions in the cell, and hormones, which control the functioning of other cells.
- Proteins occur suspended in the protoplasm of cells or combine with other macromolecules to form an important structural part of all membranes within the cell.

Plant cells can synthesise their own amino acids. Animal cells produce most of the amino acids required for protein production. Nine of the amino acids are called 'essential' because they cannot be synthesised by cells in the body and must instead be sourced as nutrients from the external environment, such as in food.

Nucleic acids

Nucleic acids are very large biomacromolecules that contain the elements carbon, hydrogen, oxygen, nitrogen and phosphorus. There are two types of nucleic acids: DNA (deoxyribonucleic acid), and RNA (ribonucleic acid).



Chemicals in cells



Types of organic compounds

- DNA is a double-stranded molecule that stores the information that controls the cell. It is the main chemical making up the nucleus. Small amounts are also found in mitochondria and chloroplasts.
 - RNA is found in small amounts in the nucleus and in larger amounts in the cytoplasm.
- The building blocks of DNA and RNA are called nucleotides. Each nucleotide consists of a sugar, a sub-unit called a base, and phosphate.
- DNA nucleotides contain the four bases adenine, guanine, cytosine and thymine. They also contain the sugar deoxyribose.
 - DNA nucleotides are required by cells to make DNA during cell replication.
 - RNA nucleotides contain the four bases adenine, guanine, cytosine and uracil. They also contain the sugar ribose.
 - RNA nucleotides are required for cells to make ribosomes and to make RNA so that cells can make proteins.

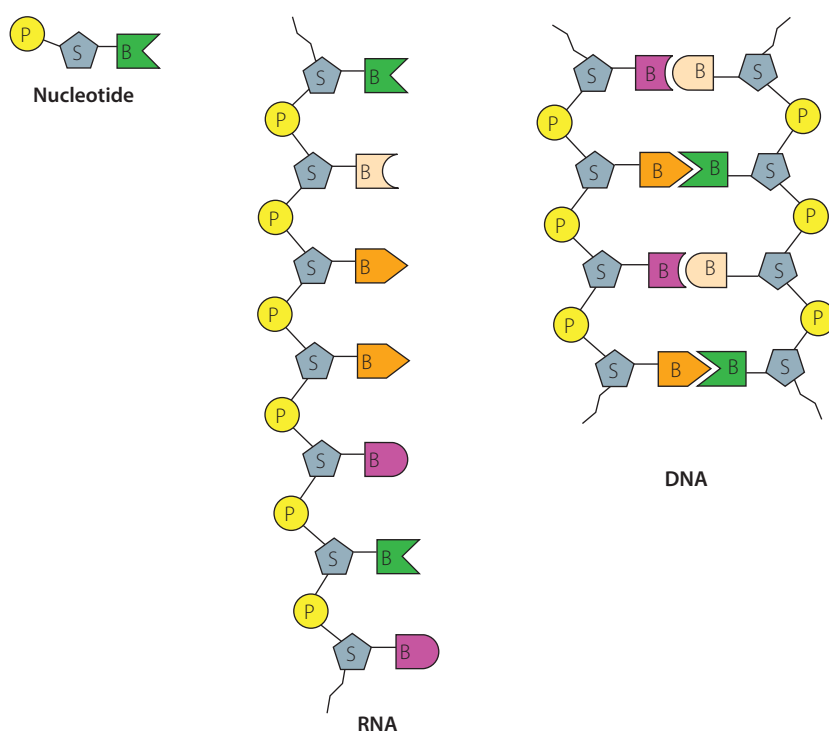


FIGURE 3.28

Nucleotide monomer, made up of phosphate (P) – sugar (S) – base (B), and segments of RNA and DNA biomacromolecules. RNA usually consists of a single chain, whereas DNA consists of two chains in opposite directions.

KEY CONCEPTS

- The four main groups of biomacromolecules are carbohydrates, proteins, lipids and nucleic acids.
- These four groups of organic compounds are made up of carbon, hydrogen and oxygen atoms, but they are in different proportions. Proteins also contain nitrogen and sometimes sulfur. Nucleic acids also contain nitrogen and phosphorus.
- Autotrophic organisms can build their own organic compounds, whereas consumer organisms must make their organic compounds from their food.
- Carbohydrates can be used as a source of energy, for storage of energy, and sometimes as a structural component of the cell.
- Lipids are used for energy storage, structural parts of membranes and components of hormones.
- Proteins have a structural role in cells and tissues. Proteins such as enzymes also have a functional role.
- The two types of nucleic acids are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).
- DNA contains chemical information that controls the cell activities and the production of proteins. RNA assists in the manufacture of the proteins.

CHECK YOUR UNDERSTANDING

3.2

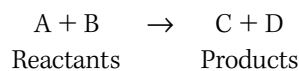
- 1 Outline the requirements of a cell.
- 2 Identify the four main types of biomacromolecules.
- 3 Outline:
 - a the chemical composition of a carbohydrate
 - b the types, structures and uses of carbohydrates.
- 4 State where in a cell you would expect to find DNA and RNA.
- 5 a Outline some of the uses of lipids in cells.
b Describe the uses of lipids in cells.
- 6 Distinguish between:
 - a organic and inorganic nutrients
 - b amino acids, polypeptides and proteins.
- 7 Explain why there are so many different kinds of protein.

3.3 Enzymes

Enzymes are protein molecules that control all metabolic reactions in living cells. Without enzymes, the reactions that occur in cells would be so slow as to hardly proceed at all. Enzymes act as biological **catalysts**, controlling the rate of each step of the complex chemical reactions that take place in cells. Catalysts are chemical substances that can accelerate (speed up) chemical reactions, are unchanged at the end of the reaction, and can be reused many times.

Metabolism is the sum of all chemical reactions occurring within a living organism. Over 1000 different reactions can take place in each cell. A specific enzyme catalyses each of these reactions. There are as many enzymes in living organisms as there are types of chemical reactions.

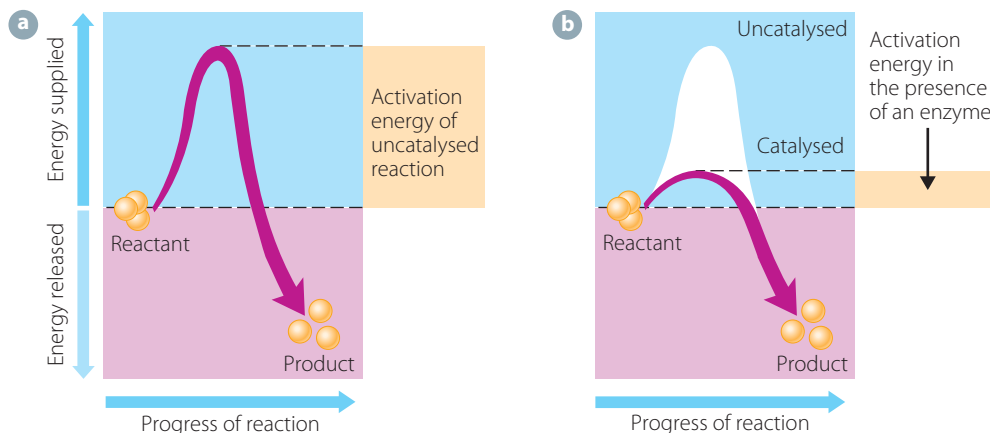
Atoms and molecules are in constant motion and colliding. If the reactants are supplied with enough energy, such as heat, to break their bonds, then the reaction will proceed and products will be formed. The minimum amount of energy required to start the reaction is called the **activation energy**.



Enzymes speed up reactions by lowering the activation energy required for the reaction. They do this by combining with the reactants and holding them in a way that makes the reaction more likely to occur (Fig. 3.29).

FIGURE 3.29

Scheme of activation energy required for chemical reactions: **a** without a catalyst, activation energy must be supplied for a chemical reaction; **b** catalysts accelerate specific reactions by lowering the amount of activation energy needed to initiate the reaction.



Properties of enzymes

Enzymes are composed of protein molecules that are often highly folded to create a particular chemical 'shape'. The surface of the enzyme with a specific shape is called the **active site**. It is here that the reactants, also known as the **substrates**, in a chemical reaction temporarily bind. When this occurs, a **substrate–enzyme complex** is formed and the reaction proceeds. The products of the reaction are then released from the active site of the enzyme. The enzyme remains unchanged. It is again available for the same process to occur.

An enzyme is specific for a particular reaction as the shape of the active site will accommodate only substrates that match that particular shape.

Models of enzyme activity

Two models have been developed to try to explain how the substrate binds at the active site to form the substrate–enzyme complex.

First a **lock-and-key model** was proposed: it was thought that the active site is rigid and the small substrate molecule is reciprocally shaped and fits exactly into the active site, like a key into a lock. Once this substrate–enzyme complex has formed, the close proximity of the molecules allows the reaction to be rapidly catalysed and the products of the reaction are released. To validate this model, predictions were made and tested. The results led to the proposal of the currently accepted amended version of the model, known as the **induced-fit model**. This model is based on the realisation that proteins are not rigid. Evidence suggests that the binding of a substrate to the active site of an enzyme induces the enzyme to alter its shape slightly, to fit more tightly around the substrate (Fig. 3.30).

Factors affecting enzyme activity

Enzymes require particular conditions in order to function at their optimal efficiency. Any change to these conditions means the enzyme will either work very slowly or not at all.

Enzymes are temperature sensitive

Enzymes within cells function best at the body temperature of the organism in which they occur. In most living things, enzymes function normally at temperatures up to 40°C (Fig. 3.31a). Some organisms that live in hostile environments have optimal temperatures that are much lower or much higher than this. In humans, the optimal temperature for the functioning of enzymes is 37°C.

As the temperature increases, the rate of reaction increases until the optimal temperature is reached, at which point the enzyme activity is at its maximum level. Above this temperature, the enzyme activity slows until it stops altogether at temperatures of approximately 50–60°C.

At high temperatures the motion associated with heat energy can make the protein structure bend and flex so much that it changes the shape of the active site. This renders it incapable of accommodating the substrate that would normally bind there. Therefore the enzyme will not function as it should. The heat has caused the enzyme to **denature**. This change in the structure and shape of the molecule due to excessive heat is irreversible.

Excessive cold also causes the enzyme to change shape and its functioning to slow down or stop. This change in shape due to excessive cold is, however, often reversible.

Enzymes are pH sensitive

pH is a measure of the acidity or alkalinity of a substance or solution. Acidic solutions have pH values below 7, while alkaline solutions have pH values above 7. Neutral solutions have a pH value of 7.



Enzymes

Watch this animation and draw a flow chart of the way in which enzymes function.



How enzymes function

Explain how enzymes function.

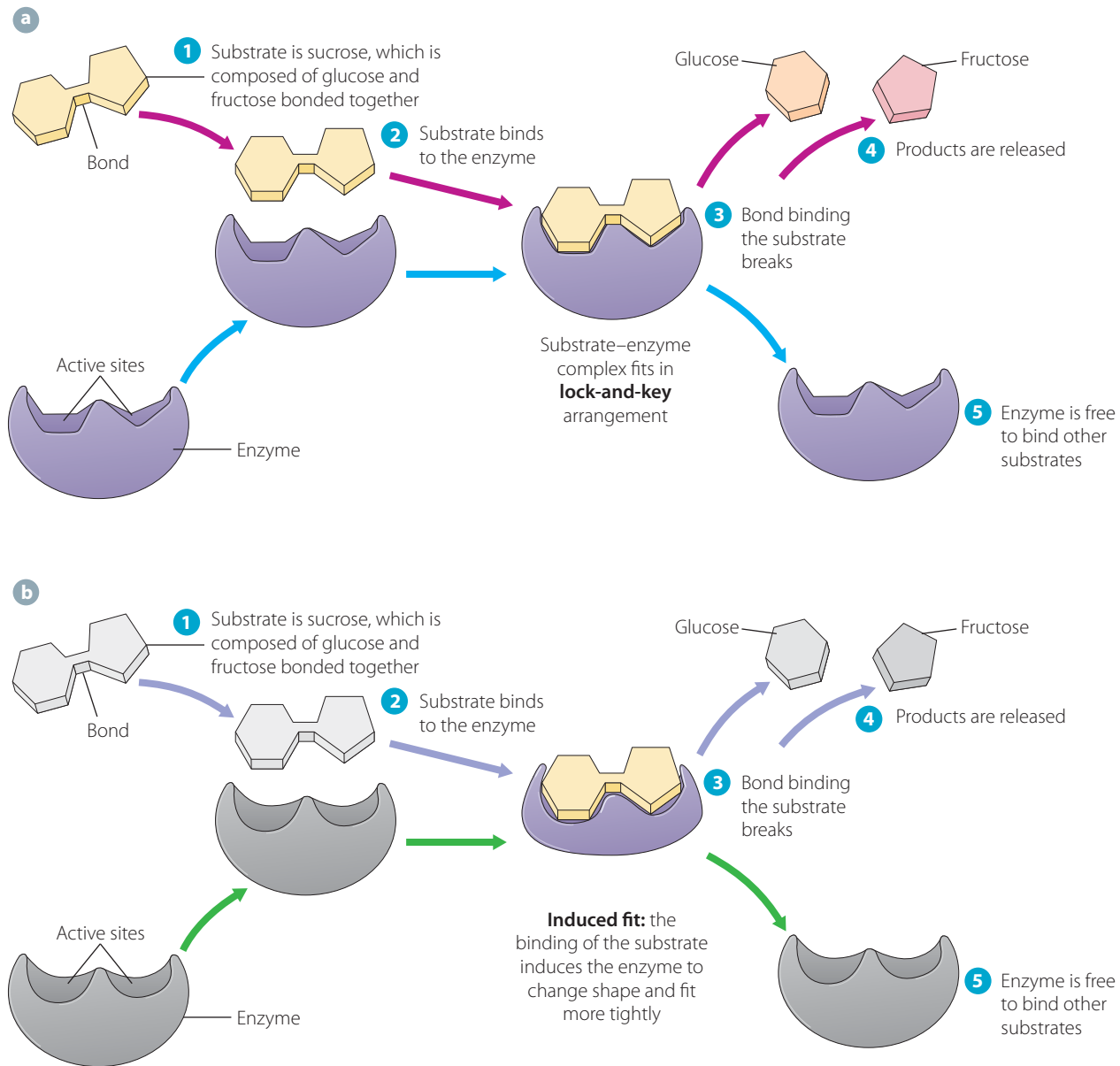


FIGURE 3.30 Sequence of steps in the 'lock-and-key'/'induced-fit' model of specificity of substrate–enzyme action: **a** lock-and-key model of enzyme functioning; **b** induced-fit model of enzyme functioning. Note the change in shape of the active site in this model.

Each enzyme has its own narrow range of pH within which it functions most efficiently. Levels of alkalinity or acidity outside the optimum pH for an enzyme have a similar effect to that of temperature change – they alter the shape of the enzyme and slow down or stop its functioning. Extremes of pH, like temperature, cause the enzymes to denature. Within cells, most enzymes function at or near neutral, but enzymes in the digestive tract function in an acidic or alkaline medium. For example, the protein-digesting enzymes pepsin and rennin, found in gastric juice in the stomach, function best in a strong acid/low pH (Fig. 3.31b).

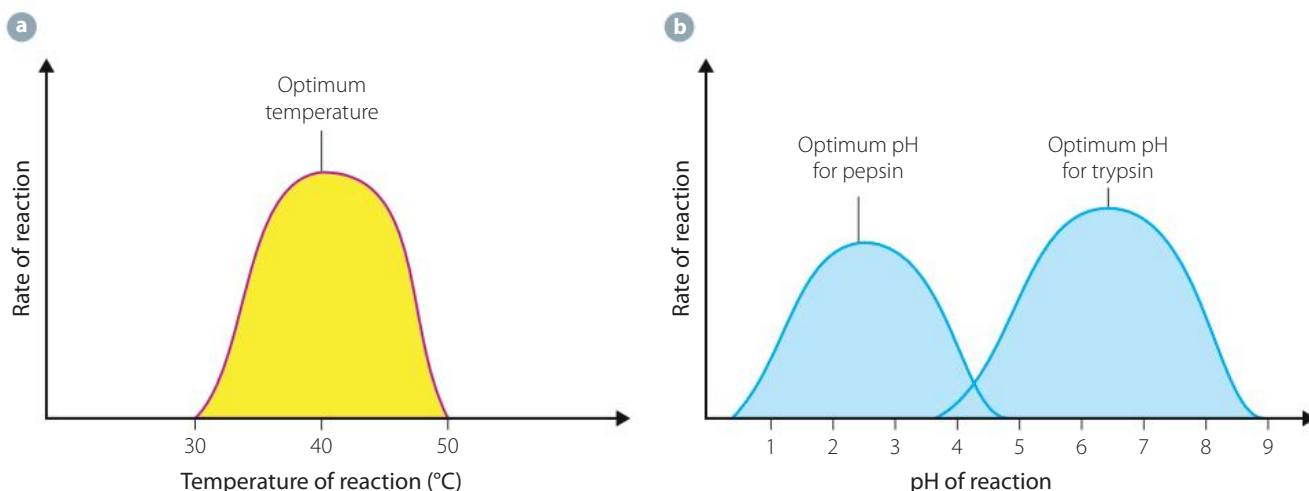


FIGURE 3.31 Graphs showing **a** the effect of temperature on the rate of enzyme action; **b** the pH-specificity of two digestive enzymes

Substrate concentration and enzyme activity

The rate of an enzyme-controlled reaction is affected by the *concentration of the substrate*. The higher the substrate concentration, the greater the rate of enzyme reaction, until all available enzymes are being used to catalyse reactions. This point is known as the **saturation point**. Increasing the substrate concentration beyond the saturation point will not increase the rate of reaction, since all enzymes are working at their maximum turnover rate and will have to be reused to act on the additional substrate. The only way to increase the reaction rate would be to increase the enzyme concentration (Fig. 3.32).

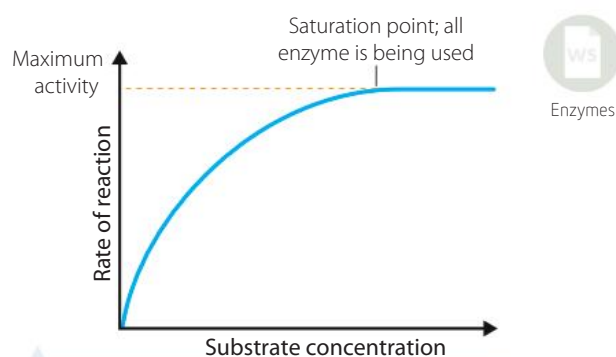


FIGURE 3.32 The effect of increases in substrate concentration on the rate of an enzyme-catalysed reaction. At saturation, further increases in substrate concentration do not increase the rate of the reaction.

INVESTIGATION 3.3

A practical investigation to model the action of enzymes in cells

Catalase is an enzyme present in all living things. It is responsible for catalysing the breakdown of hydrogen peroxide (H_2O_2). Hydrogen peroxide is produced as a result of cellular respiration within the cell. If it is allowed to accumulate, it will be toxic to the cell and cause its death. When hydrogen peroxide is broken down, it forms the non-toxic substances oxygen and water:



This investigation models the action of enzymes in cells (to justify the substrate–enzyme binding action and re-usability of enzymes). It investigates the effect of substrate concentration on the activity of an enzyme. Models make predictions to explain how things work. In this model, if enzymes bind with substrates to



catalyse a reaction, then an increase in substrate concentration should result in the saturation of enzymes at a particular substrate concentration. If further substrate is added beyond the saturation point and the enzyme concentration is kept the same, there will be no further increase in the rate of reaction.

Hydrogen peroxide will represent the substrate, and catalase in potato is the enzyme. As oxygen gas is a product of this reaction, the activity of the enzyme is determined by measuring the height of the bubbles produced in the hydrogen peroxide.

Similar investigations can be performed with hydrogen peroxide and potato to determine the effect of temperature and pH on the activity of an enzyme.

AIM

- 1 To model the action of enzymes in cells (based on the substrate–enzyme binding action and re-usability of enzymes)
- 2 To investigate the effect of substrate concentration on the activity of an enzyme

HYPOTHESIS

The activity of the enzyme will increase as the substrate concentration increases until it reaches saturation point, after which the activity of the enzyme will remain constant.

MATERIALS

- 7 × test tubes (same size)
- Test tube rack
- Hydrogen peroxide (6%)
- 2 × 10 mL measuring cylinders
- Cork borer or blender
- 30 cm rule
- Marking pen
- Potato
- Labels
- Stopwatch

RISK ASSESSMENT



WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Hydrogen peroxide	Toxic if ingested, eye and skin irritant	Wear safety goggles and disposable gloves. Do not ingest.
Potato	Can be a skin irritant	Wear disposable gloves.

METHOD

- 1 Label the seven test tubes with the numbers 1 to 7.
- 2 Measure the quantities of hydrogen peroxide and water specified in Table 3.9 using the measuring cylinders and place them in the appropriately numbered test tube.

TABLE 3.9

TEST TUBE NO.	VOLUME H ₂ O ₂ (mL)	VOLUME H ₂ O (mL)
1	10	0
2	10	0
3	8	2
4	6	4
5	4	6
6	2	8
7	0	10

- 3 Mark the level of liquid in each test tube using the marker pen.
- 4 Using a cork borer, obtain six cylinders of potato of the same diameter.
- 5 Cut the potato cylinders so that they are of equal length (Fig. 3.33).



» (Note: An alternative way to prepare the potato is to puree cubes of potato with a small amount of water in a blender – a few mL of this pureed potato would then be measured into the test tubes instead of the cylinders of potato.)

- 6 Place a cylinder of potato into each of the test tubes numbered 2–7 and allow the reaction to proceed for approximately 5 minutes.
- 7 At the completion of this time, place another mark on the test tube to indicate the maximum height to which the bubbles reached.
- 8 Measure the difference between the level of the liquid and the height to which the bubbles reached in each test tube. Record your results in a results table like Table 3.10.
- 9 Compare your results with those of other groups in the class.



FIGURE 3.33 Preparing potato cylinders of the same diameter and length

RESULTS

1 TABLE 3.10

TEST TUBE NO.	HEIGHT OF BUBBLES (cm) (ACTIVITY OF ENZYME)
1	
2	
3	
4	
5	
6	
7	



Investigation 3.3

- 2 Graph the results obtained using a line graph. Remember that the independent variable goes on the x -axis and the dependent variable is on the y -axis.

DISCUSSION

- 1 Identify the:
 - a enzyme
 - b substrate in this model of enzyme activity.
- 2 Describe how test tubes 1 and 2 model the action of enzymes in cells.
- 3 Was this a valid model? Justify your answer.
- 4 Identify the following variables:
 - a independent variable
 - b dependent variable
 - c controlled variables.
- 5 Why was test tube 1 with no potato added used?
- 6 Discuss the validity of the experimental design.
- 7 Describe the trend obtained on your graph.
- 8 Is the hypothesis supported by these results?
- 9 Compare your results with other groups in the class and comment on the reliability of the investigation.

CONCLUSION

Write a conclusion that relates the aims of the investigation to the results of your investigation.

See p. 4 for a discussion of validity and reliability.



» DESIGN YOUR OWN INVESTIGATION

- 1 Investigate the effect of pH or the effect of temperature on enzyme activity. This can be undertaken using the same substrate and enzyme and a similar method, or you may wish to research methods using other readily available enzymes and substrates.
- 2 Define a research question and hypothesis for your investigation.
- 3 Follow the steps outlined in Chapter 1 to assist you with your investigation.

KEY CONCEPTS

- Cellular products and wastes must be removed from the cell to maintain efficient cell functioning.
- Enzymes, or biological catalysts, are proteins that control cellular reactions.
- In enzyme-catalysed reactions, the substrate attaches to the shape on the surface of the enzyme (the active site) and forms an enzyme–substrate complex.
- The reaction then occurs and the products are released. The enzyme can be re-used for the same reaction.
- There are two models of enzyme action – the lock-and-key model and the induced-fit model.
- The activity of an enzyme increases as temperature increases until the optimal temperature is reached. With further temperature increases the enzyme activity decreases and then stops completely when the high temperatures destroy (denature) the structure of the enzyme.
- Each enzyme has an optimum pH at which it functions most efficiently.
- Enzyme activity is affected by the substrate concentration. As the substrate concentration increases, the activity of the enzyme increases until all the enzymes are saturated. After this, further increases in substrate concentration will not lead to increases in enzyme activity.

CHECK YOUR UNDERSTANDING

3.3

- 1 Summarise the characteristics of enzymes.
- 2 Describe how an enzyme catalyses a reaction.
- 3 Outline how enzymes affect the activation energy required by reactants for a reaction to occur.
- 4
 - a Identify three factors that can affect the activity of an enzyme.
 - b Outline how each of these factors affects the activity of enzymes.
- 5
 - a Describe the lock-and-key model of enzyme activity.
 - b How does the induced-fit model differ from the lock-and-key model?
- 6
 - a What does the term 'denature' mean when applied to enzymes?
 - b Outline how enzymes can be denatured.
- 7 Discuss why enzymes are important for the maintenance of life.
- 8 Explain why there are thousands of different types of enzymes in the human body.
- 9 Explain why doctors would get worried if their patient develops a temperature in excess of 42°C.

3.4 Biochemical processes in cells

Eukaryotic cells contain many membrane-bound organelles that contain specific enzymes that catalyse specific biochemical processes. For example, chemical reactions in lysosomes break down compounds brought into the cell by using strong digestive enzymes in an acidic environment. Having the lysosome enclosed in a membrane prevents the enzymes from destroying the cell. These reactions within cells require energy, which is provided in the form of ATP.

The two major biochemical processes that cells carry out are *photosynthesis* in plant cells and *cellular respiration* in all living cells.

Energy transfer between reactions

Provision of energy is vital to ensure that all essential life processes take place. All cells use glucose as the primary source of energy to drive the thousands of chemical reactions that occur constantly in each living cell. When glucose is broken down in the process of aerobic cellular respiration, the large amount of energy contained within it is released. This released energy is trapped and stored in small packets in many high-energy molecules called **adenosine triphosphate (ATP)**. The cell accesses the energy contained in ATP to power all cell functioning. ATP is a small mobile molecule that can deliver the energy to wherever it is required.

ATP is composed of a complex molecule called adenosine (adenine attached to a ribose sugar group) that in turn attaches to three phosphate groups. This is where the name adenosine *triphosphate* comes from. The bond that attaches the third phosphate group is a high-energy bond. When energy is required by the cell, this bond is broken and the energy it contains is released. ADP (adenosine diphosphate) and a free phosphate group are formed. To store the energy produced by the cell, a free phosphate group is attached to the ADP molecule by a high-energy bond, forming ATP. The storage and release of energy is a cycle between ADP, free phosphate groups and ATP, as shown in Figure 3.34.

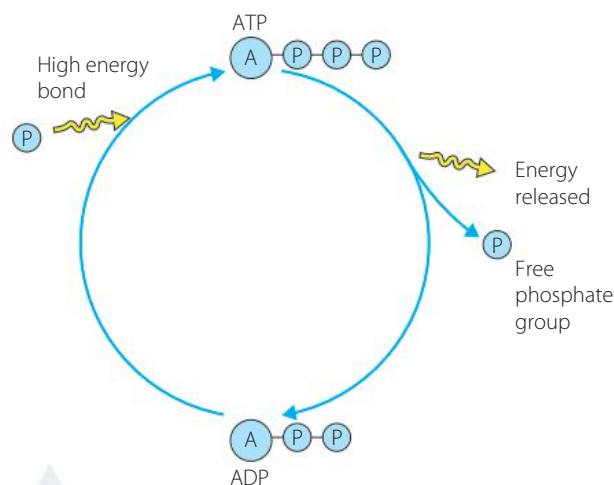


FIGURE 3.34 The storage and release of energy: the ATP–ADP cycle

Photosynthesis

Photosynthesis is the process by which plants utilise light energy, usually from the sun, which is trapped by chlorophyll (contained in the chloroplast). It uses this energy to break apart water and carbon dioxide molecules, and build them up into oxygen, energy-storing glucose molecules and water molecules (Fig. 3.35).

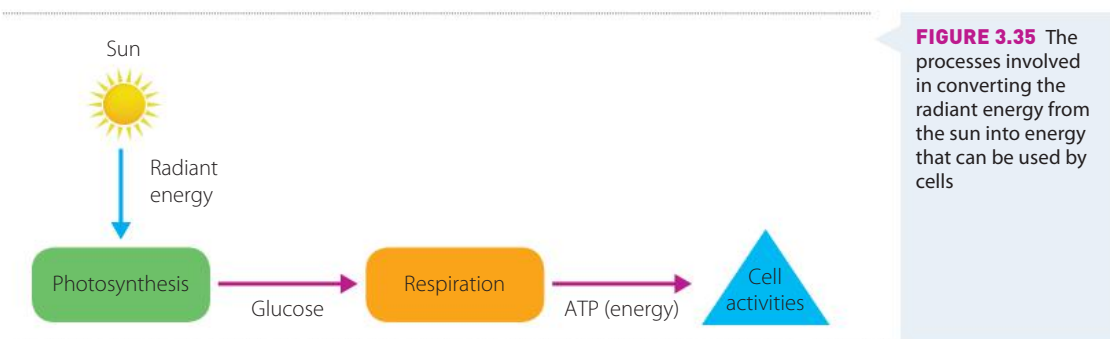
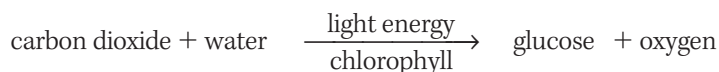
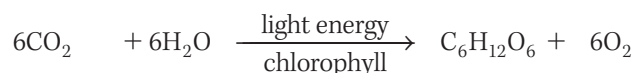


FIGURE 3.35 The processes involved in converting the radiant energy from the sun into energy that can be used by cells

Photosynthesis can be summarised by the word equation:



The balanced overall chemical equation is:



The process of photosynthesis is summarised by the general equation above. The actual process of photosynthesis occurs in two stages, each consisting of a series of many chemical reactions that take place in the chloroplasts of green plant cells and the cells of some photosynthetic bacteria.



Photosynthesis

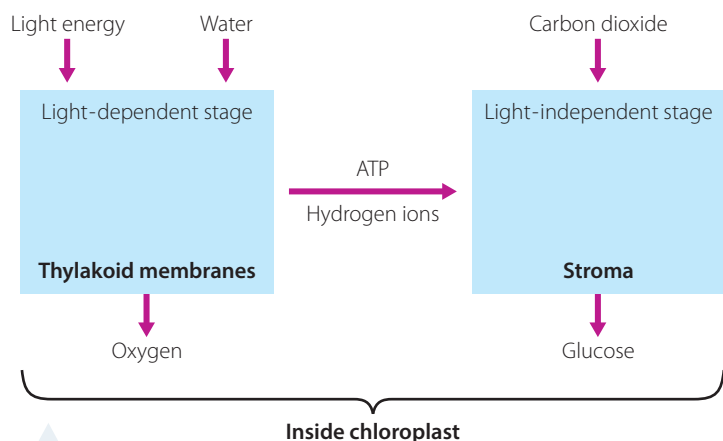


FIGURE 3.36 Photosynthesis is a series of reactions occurring in two stages: the light-dependent and the light-independent stages

Phase 1: the light-dependent stage

The **light-dependent stage** (**photolysis**) (photo = light, lysis = splitting) occurs in the grana of chloroplasts. It involves the absorption of light energy by the chlorophyll in the thylakoid membranes of the chloroplast (Fig. 2.28 on page 55). This energy is used to split the water (H_2O) molecules into hydrogen ions (H^+) and oxygen (O_2). The oxygen is released into the atmosphere and the hydrogen ions are carried to the next phase. ATP is also formed at this stage.

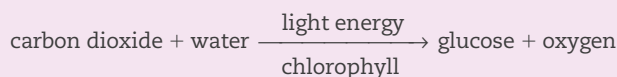
Phase 2: the light-independent stage

The **light-independent stage** (**carbon fixation**) occurs in the stroma of the chloroplasts. It involves combining carbon dioxide (CO_2) with the hydrogen ions produced in the light-dependent stage to form glucose ($\text{C}_6\text{H}_{12}\text{O}_6$). The ATP formed in the light-dependent stage is required to provide the energy for this reaction. No light is required in this stage (Fig. 3.36).

Glucose produced by photosynthesis can be converted by plants into complex carbohydrates, lipids and/or proteins. These end-products are stored by the plants and are the source of organic nutrients, not only for the plants themselves but also for consumer organisms that eat the plants.

KEY CONCEPTS

- Energy in cells is transported within cells by small and mobile ATP molecules.
- ATP stores energy in a high-energy bond that attaches the third phosphate group to the ADP molecule.
- When energy is required, the high-energy bond is broken, releasing energy, a phosphate group and ADP.
- Photosynthesis is the process where plants use light energy, trapped by chlorophyll, to break down water and carbon dioxide molecules, and build them up into oxygen, glucose and water molecules.



- Photosynthesis is a series of smaller reactions occurring across two stages.
- The light-dependent stage occurs in the grana where light energy splits the water molecules into oxygen and hydrogen.
- The light-independent stage occurs in the stroma where carbon dioxide and hydrogen combine to form glucose.

CHECK YOUR UNDERSTANDING

3.4a

- Describe the relationship between ADP and ATP.
 - Outline the advantages of using ATP as an energy storage molecule.
- Outline the purpose of the process of photosynthesis.
 - Identify the products of the light-dependent stage that are used as inputs in the light-independent stage of photosynthesis.
- Write a balanced equation for photosynthesis.
 - Explain why this is considered to be a summary equation.
- Do all living plant cells carry out photosynthesis? Justify your answer.
- Distinguish between the light-dependent and the light-independent stages of photosynthesis in terms of location, requirements and products.

Cellular respiration

All organisms break down glucose as a source of energy to drive cellular metabolism.

Glucose can be broken down either in the presence of oxygen (aerobic cellular respiration) or in the absence of oxygen (anaerobic cellular respiration). Different products and amounts of energy are released in each of these processes.

Anaerobic cellular respiration

Many organisms, such as some bacteria and archaea, live in environments lacking oxygen. Cells such as muscle cells sometimes cannot get enough oxygen, but still are able to release energy via an anaerobic pathway in the cytosol of cells. Two commonly used biochemical pathways enable energy to be produced using molecules other than oxygen: **alcohol fermentation** and **lactic acid fermentation**.

In alcoholic fermentation, yeast, many bacteria and plants (or parts of plants) carry out **anaerobic** cellular respiration. This process involves the breakdown of glucose in the absence of oxygen to form ethanol (an alcohol) and carbon dioxide. Two molecules of ATP are produced as a result.



Humans make use of this process in the production of beer, wine and bread.

Lactic acid fermentation is carried out when an organism cannot produce enough energy by aerobic cellular respiration. This occurs in periods of strenuous exercise when our bodies cannot deliver enough oxygen to the muscles to produce the energy required. In lactic acid fermentation, one molecule of glucose is broken down in the absence of oxygen, to produce two molecules of lactic acid as well as two molecules of ATP. The equation below represents this:



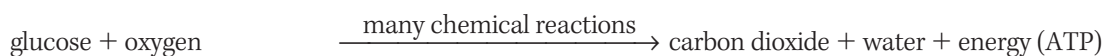
Once the strenuous exercise has finished, there will be more oxygen available. The lactic acid changes to a compound called pyruvate and is converted by aerobic respiration into carbon dioxide, water and energy (ATP) (see below).

Aerobic cellular respiration

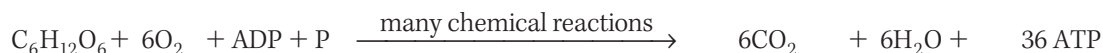
Aerobic cellular respiration is a chain of many biochemical reactions that occur in the cells of the organism in the presence of oxygen. It is generally summarised as follows, to depict the main changes that occur during respiration.

The general equation for aerobic cellular respiration expressed as a:

- word equation:



- balanced equation:



There are at least 20 separate reactions, each catalysed by a specific enzyme that makes up this overall pathway.

The first step in the biochemical pathway to break down glucose is the process of **glycolysis**. This process occurs in the cytosol of the cell and involves the breakdown of glucose (a six-carbon molecule) into two pyruvate molecules (each with three carbon atoms). This is accompanied by the release of energy in the form of two molecules of ATP. This overall reaction is actually a series of 10 smaller reactions, each catalysed by a specific enzyme.

The two molecules of pyruvate formed from one molecule of glucose then enter the mitochondria of the cell where the rest of the series of reactions that make up aerobic cellular respiration occur.



Cellular respiration

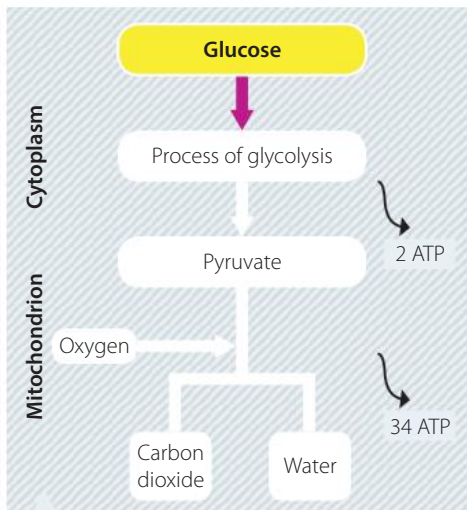


FIGURE 3.37 Glycolysis, the first stage of cellular respiration, occurs in the cytoplasm and releases two ATP. The second stage of aerobic cellular respiration occurs in the mitochondria and releases 34 ATP.

Each of these reactions is catalysed by a specific enzyme and culminates in the production of more energy, carbon dioxide and water. The energy from these reactions is released in the form of 34 ATP molecules to make a total of 36 ATP molecules produced for the breakdown of every glucose molecule. This process is summarised in Figure 3.37.

Photosynthesis and aerobic cellular respiration

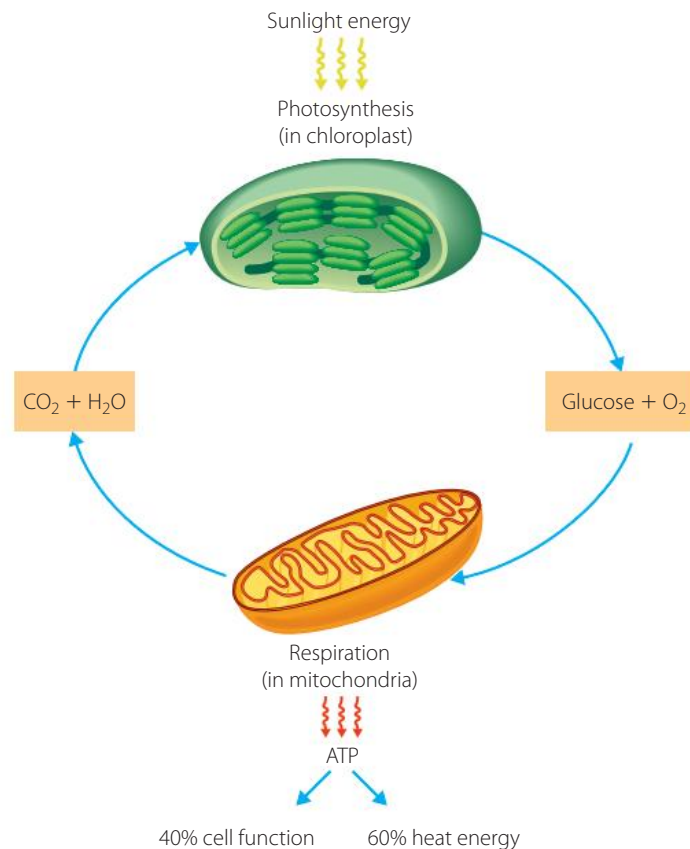
Photosynthesis and aerobic cellular respiration are related (Fig. 3.38). When you look at the general equations for photosynthesis and aerobic cellular respiration, it appears that these processes may be the reverse of each other. That is not the case because they are each made up of a series of chemical reactions that are very different.

Photosynthesis and aerobic cellular respiration are, however, closely related and interdependent.

The products of photosynthesis are used in the process of aerobic cellular respiration. Similarly, the products of aerobic cellular respiration are used in the process of photosynthesis.

In cells that contain both chloroplasts and mitochondria, the two processes will occur in the same cell. In cells that do not contain chloroplasts (such as plant root cells), the products of photosynthesis (glucose and oxygen) must be supplied to the cells for the process of aerobic cellular respiration to occur.

FIGURE 3.38 The close relationship and interdependence of the processes of photosynthesis and aerobic cellular respiration



Removal of cellular products and wastes

The products of the reactions in the cell that are not required by the organism are called wastes. They need to be transported to other cells and/or need to be removed for efficient cell functioning. Removal from the cell will usually occur by diffusion through the cell membrane. Oxygen and carbon dioxide gases are easily removed from the cell by diffusion through the cell membrane.

Any excess water that is not required by the cell moves out of the cell by osmosis. Wastes formed from the breakdown of proteins also leave the cell by diffusion through the cell membrane.

Waste chemical products that dissolve in water are removed from the cell at the same time as the water. Oily, fat-soluble substances are attached to small electrically charged molecules by the cell to make them water-soluble so they can be removed when the water diffuses out.

When parts of the cell break down, wear out or die, they also need to be removed. Lysosomes, which contain digestive enzymes, are responsible for breaking down these 'old' cell parts and other cellular waste. Any of these wastes that can't be eliminated in this way by the lysosome are packaged and removed by exocytosis.

Proteins such as hormones and enzymes, and other substances such as mucus, are produced by an animal cell. These cellular products are packaged into vesicles and leave the cell by the process of exocytosis. Wastes that leave a cell are said to be *excreted* from the cell. Useful products that leave a cell to be used elsewhere are said to be *secreted*.

The process of exocytosis was discussed on p. 81.

KEY CONCEPTS

- When glucose and oxygen combine in the process of aerobic cellular respiration, energy is produced along with water and carbon dioxide. This process is made up of many reactions.
- $\text{glucose} + \text{oxygen} (+ \text{ADP} + \text{P}) \xrightarrow{\text{many chemical reactions}} \text{carbon dioxide} + \text{water} + \text{energy (ATP)}$
- The energy produced is stored in ATP molecules.
- The first step of this process occurs in the cytoplasm and is called glycolysis. In this step, one glucose molecule is broken down into two pyruvate molecules and two ATP.
- The second step in the reaction occurs in the mitochondria where pyruvate, in the presence of oxygen (aerobic cellular respiration), is broken down to release carbon dioxide, water and 34 ATP.
- A total of 36 ATP molecules is produced for every molecule of glucose broken down in aerobic respiration.
- Anaerobic (without oxygen) cellular respiration produces ethanol and carbon dioxide in bacteria, yeast and plant cells, and lactic acid in animal cells. Two ATP molecules are produced in this process for the respiration of each molecule of glucose.
- Wastes are the products of cellular reactions that are not required.
- Many of these wastes can be removed by simple diffusion through the cell membrane.
- Other wastes can be removed by exocytosis or destroyed by the enzymes present in lysosomes.

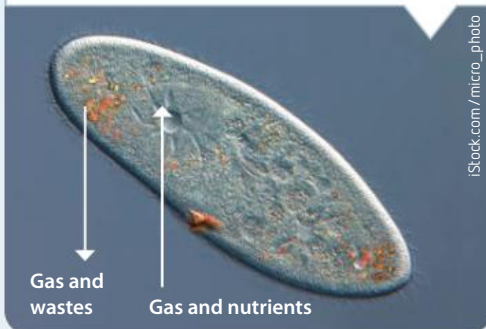
- 1 Write a balanced equation for the process of aerobic cellular respiration.
- 2 Outline the role of aerobic cellular respiration in living organisms.
- 3 **a** Identify the initial reactant and the final product in the process of glycolysis.
b Identify where in the cell glycolysis occurs.
- 4 Compare the products of aerobic cellular respiration with the products of anaerobic cellular respiration in plants and animals.
- 5 Outline where the carbon dioxide is produced and name any other products formed in the process of aerobic cellular respiration.
- 6 **a** Outline the conditions under which lactic acid is formed.
b Outline the fate of the lactic acid when more oxygen becomes available.
- 7 Summarise the ways in which wastes can be removed from the cell.
- 8 Outline the importance of plants coordinating the processes of photosynthesis and respiration.

CHECK YOUR UNDERSTANDING

3.4b

Cell function: How do cells coordinate activities within their internal environment and the external environment?

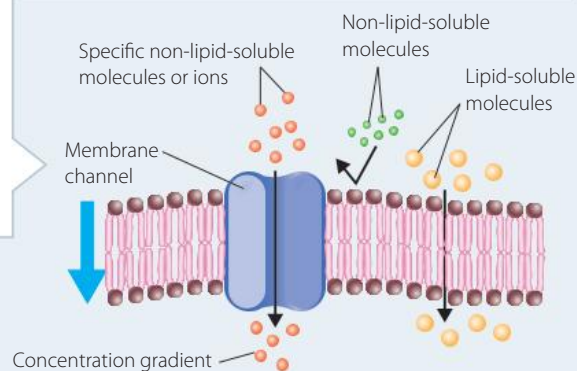
CELL REQUIREMENTS AND PRODUCTS



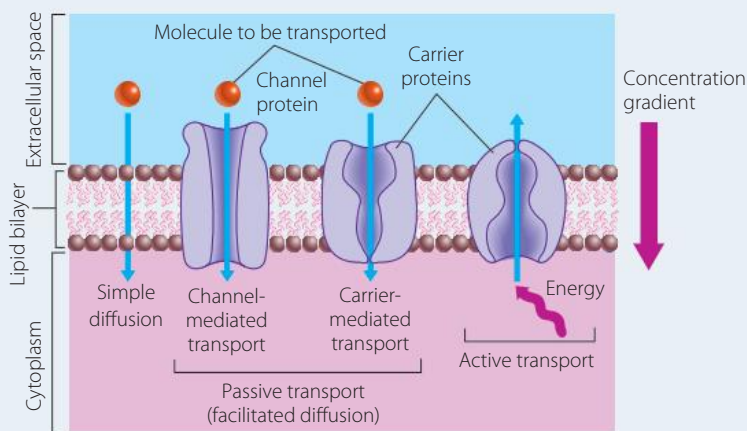
MOVEMENT OF SUBSTANCES INTO AND OUT OF CELLS

Related to:

- characteristics of materials
- concentration gradient
- SA:V

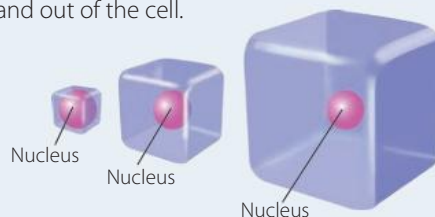


Based on an illustration that is © The McGraw Hill Companies, Inc.



Surface-area-to-volume ratio

The smaller the cell, the higher the SA:V and the more efficient the exchange of substances into and out of the cell.

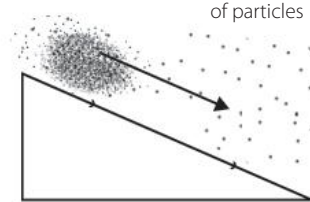


Types of movement into and out of cells

Diffusion/facilitated diffusion

High concentration of particles (e.g. perfume)

Low concentration of particles



Movement *along* a concentration gradient

Diffusion: the movement of any type of molecule from a high to a low concentration, until equilibrium is reached

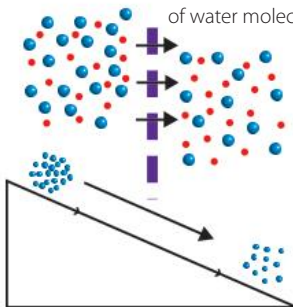
No energy required

Osmosis

Selectively permeable membrane

High concentration of water molecules

Low concentration of water molecules



Movement *along* a concentration gradient

Osmosis: the movement of water molecules from a high concentration of water to a low concentration of water, through selectively permeable membrane

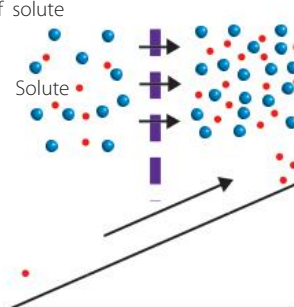
No energy required

Active transport

Selectively permeable membrane

Low concentration of solute

High concentration of solute



Movement *against* a concentration gradient

Active transport: the movement of molecules from a low concentration to a high concentration through selectively permeable membrane

Energy required

TRANSPORT OF LARGE MOLECULES

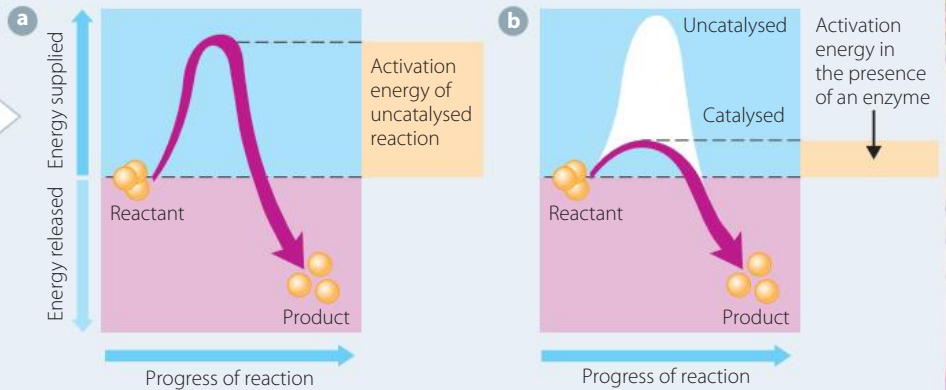
Endocytosis (into cell): phagocytosis (solid) and pinocytosis (liquid) → Exocytosis (out of cell)

ACTION OF ENZYMES

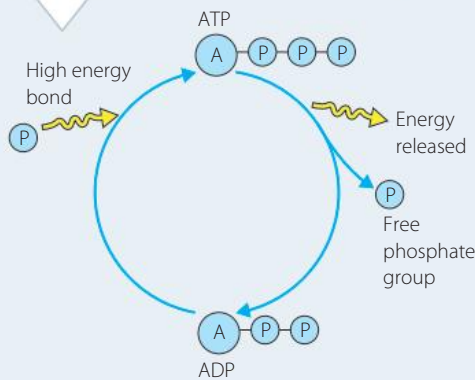
- Decrease activation energy
- 2 models: Lock and key and induced fit

EFFECT OF ENVIRONMENT ON ENZYME ACTION

- Temperature
- pH
- Substrate concentration

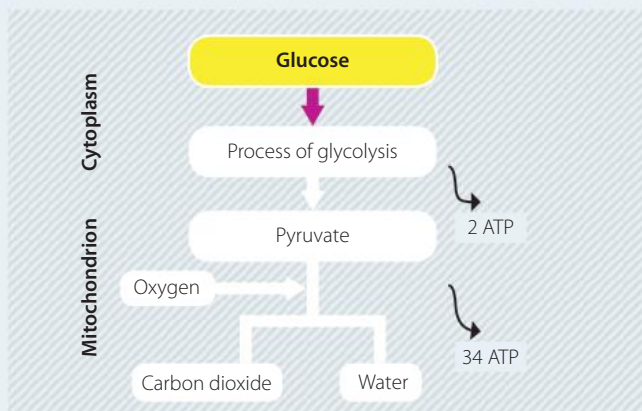
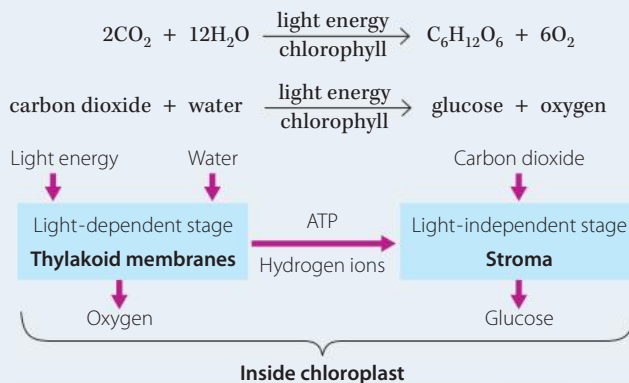


BIOCHEMICAL PROCESSES



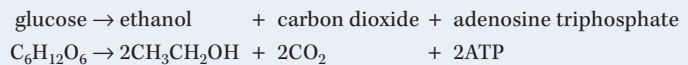
Photosynthesis

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



Anaerobic respiration

Plants: fermentation

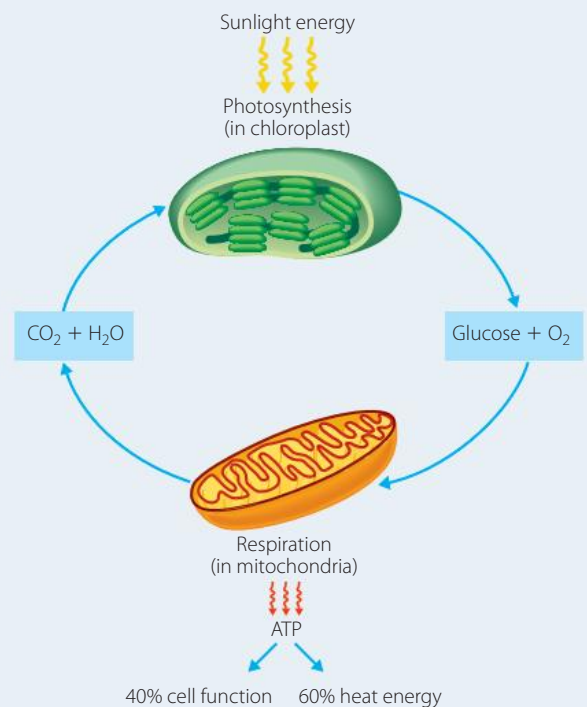
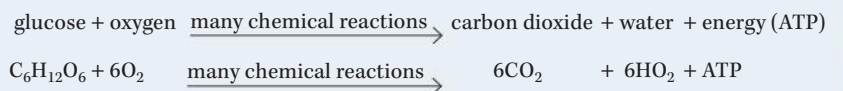


Animals:



Aerobic respiration

Glycolysis, the first stage of cellular respiration, occurs in the cytoplasm and releases two ATP. The second stage of aerobic cellular respiration occurs in the mitochondria and releases 34 ATP.



The close relationship and interdependence of the processes of photosynthesis and aerobic cellular respiration.

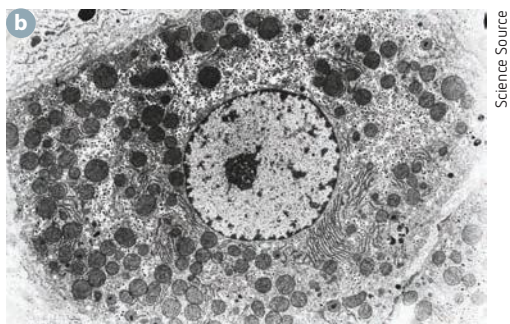
- 1 Distinguish between the following:
 - a diffusion and facilitated diffusion
 - b diffusion and osmosis
 - c osmosis and active transport
 - d exocytosis and endocytosis.
- 2 Construct a table to identify and outline the different means by which substances move in and out of cells. Include examples of substances that use each of these means to enter or leave the cell.
- 3 Draw a diagram of a unicellular freshwater organism that is placed in seawater, labelling the direction of the net movement of water. Justify the direction of the net movement of the water.
- 4 Outline one reason why plant cells do not burst when placed in a hypotonic solution.
- 5 Blood cells were placed in three different solutions. After some time, cells in solution X became shrivelled. Cells in solution Y burst and cells in solution Z remained the same.
 - a Which solution was hypertonic compared with the blood cells?
 - b Which cell was isotonic compared with the surroundings?
- 6
 - a Which of the following shapes with the same volume would have a higher SA:V – a flattened rectangular cell or a spherical cell?
 - b Which of these shapes would be more efficient in ensuring the movement of substances to all areas of the cell? Justify your answer.
- 7 A beaker is half-filled with water and 10 drops of food colouring are added. After half an hour, the food colouring is evenly distributed throughout the water.
Explain the process that caused this to occur. In your answer, use the terms 'net movement', 'concentration gradient', 'diffusion' and 'equilibrium'.
- 8 Suggest why it is said that carbon is the element on which all life depends.
- 9 Construct a table to compare the chemical composition, structure and function of carbohydrates, lipids, proteins and nucleic acids.
- 10 Identify the inorganic nutrients that are important to cells and describe their uses in cells.
- 11 Construct a table to identify and describe three factors that affect the activity of enzymes.
- 12 List the conditions necessary for photosynthesis.
- 13 Compare the processes of photosynthesis and aerobic respiration, including where in the cell they occur, their requirements, their products and their purpose.
- 14 Explain why one enzyme can catalyse only one particular reaction.
- 15 Explain why cells cannot grow to a big size.
- 16 Describe how the lock-and-key model explains the effect of denaturing enzymes.
- 17 Describe the inputs of photosynthesis from which oxygen gas is produced.
- 18 ATP is an energy-carrier molecule. Relate its structure to its function.
- 19 A human enzyme works best at 37°C.
 - a Predict what would happen to the enzyme's activity at very low temperatures.
 - b Outline how this may differ from the activity of the enzyme at very high temperatures.
 - c Describe what has happened to the active site in both cases.
- 20 Your friend says she doesn't believe the air she breathes out contains carbon from the food she's eaten. Outline what you would say to convince her.

Answer the following questions.

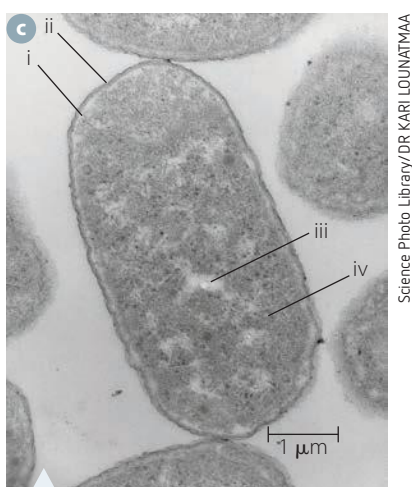
- 1 Use the images in Figure M1.1 to answer the following questions.



Getty Images/BIPHOTO ASSOCIATES



Science Source

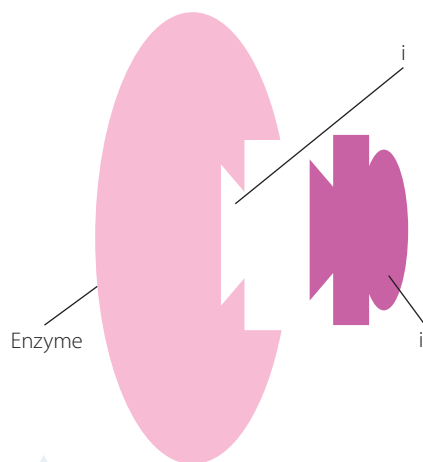


Science Photo Library/DR KARI LOUNATMAA

FIGURE M1.1

- i For each of the images (a), (b) and (c), identify whether they are prokaryotic, eukaryotic plant or eukaryotic animal cells. Justify your decision in each case.
- ii Label the areas indicated on image (c).
- iii Use the scale provided to determine the length of the cell in image (c).

- 2 a Distinguish between the processes of diffusion and osmosis.
- b When a patient in a hospital is hooked up to an intravenous drip, fluid is being added to the blood plasma.
 - i Explain why it is important to the red blood cells that the concentration of the fluid in the drip is equal to the concentration in the blood plasma.
 - ii Outline the effect on the red blood cells if the solution in the drip is hypertonic to the blood plasma. Explain why this occurs.
- 3 Identify the organelle that is responsible for respiration and the organelle that is responsible for photosynthesis. In the form of a table, compare their structure and their function.
- 4 The processes of aerobic cellular respiration and photosynthesis are the reverse of each other. Assess the accuracy of this statement.
- 5 a Label the areas (i) and (ii) in Figure M1.2.



Enzyme

FIGURE M1.2

- b Explain why the temperature of the human body has to be maintained at approximately 37°C and why the body self-regulates its temperature at 37°C, with only small increases in temperature (a couple of degrees) being tolerated.
- 6 Two cells have the same volume. One is spherical and the other is flat and thin. One student in class maintained that the flat and thin cell would be more efficient in obtaining nutrients and removing wastes. Evaluate this statement.

- 7** Describe how each of the following substances moves across the cell membrane.
Relate the movement of each substance to the structure of the cell membrane.
- a** Carbon dioxide
 - b** Glucose
 - c** Sodium ions

- 8** Models are often used to illustrate and simplify biological concepts.
- a** Describe one investigation in 'Cells as the basis of life' in which you used a model. In your description you should relate the different components of the model to the actual structure or process being modelled.
 - b** Outline the purpose and limitations of the model used.
- 9** 'Muscle cells cannot contract when they are not being supplied with enough oxygen.'
Evaluate this statement using your knowledge of pathways for cellular respiration.

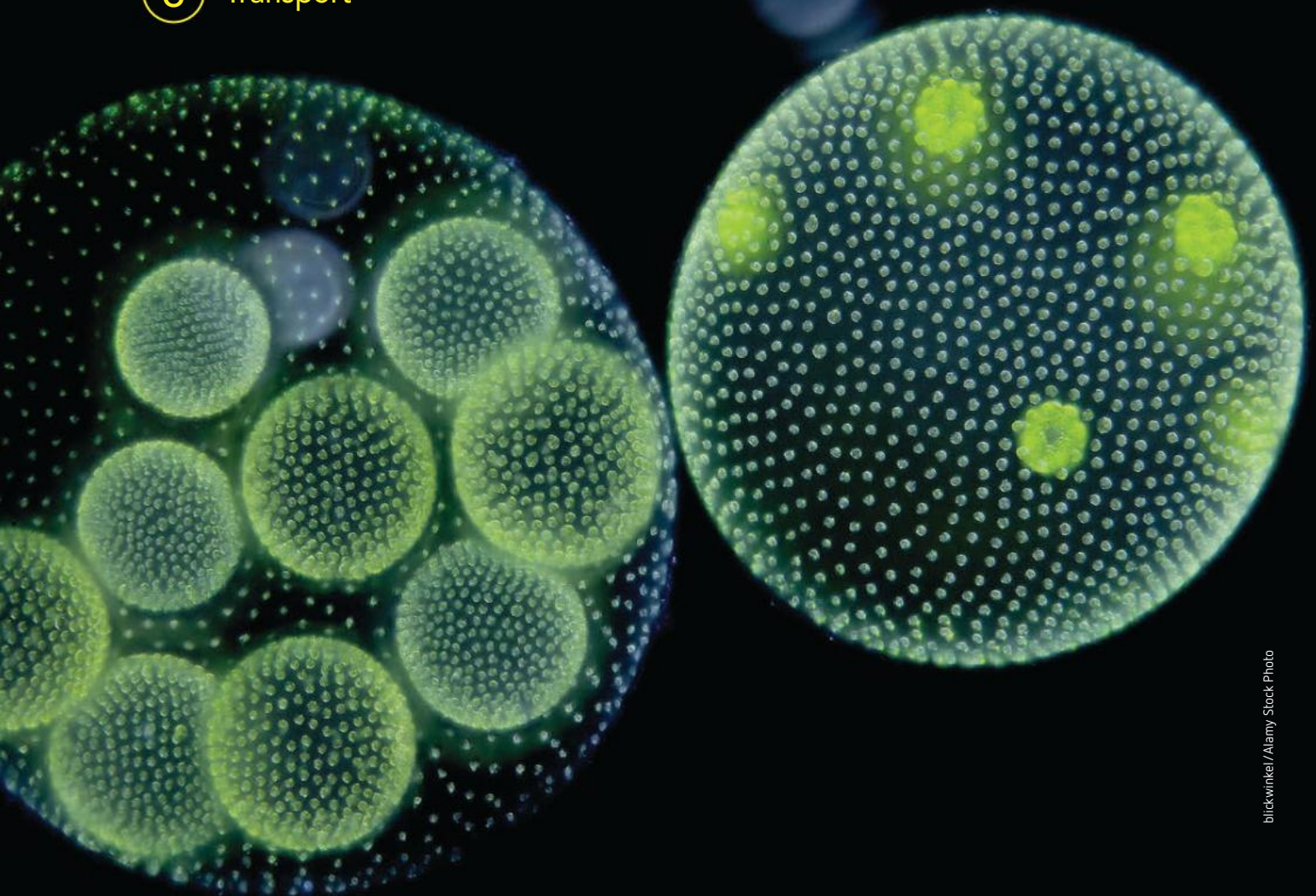
DEPTH STUDY SUGGESTIONS

- Find out about the advances in microscope technology and applications of synchrotron radiation in biology.
- Study microbes in hydrothermal vents for clues as to whether life can exist on the moons of Jupiter.
- Investigate spectromicroscopy applications in living plant cells and photosynthesis.
- Find out about the discovery of water channels in cell membranes (which won a Nobel Prize in 2003).
- Investigate the effects of cell shape, cell size and cell structure on SA:V and rates of diffusion.
- Find out about quantum biology's application to a better understanding of biological processes such as enzyme functioning.
- Look into how the study of the uptake of chemicals across barriers could lead to treatment of diseases (for example, drugs and brain infections, chemotherapy).
- Find out about the development of the fluid mosaic model of the cell membrane.
- Investigate the development by CSIRO of an enzyme-based product that can rapidly degrade unwanted pesticide residues in agricultural soil and water.

» MODULE TWO

ORGANISATION OF LIVING THINGS

- ④ Organisation of cells
- ⑤ Nutrient and gas requirements
- ⑥ Transport



4 Organisation of cells

INQUIRY QUESTION

How are cells arranged in a multicellular organism?

Students:

- compare the differences between unicellular, colonial and multicellular organisms by:
 - investigating structures at the level of the cell and organelle
 - relating structure of cells and cell specialisation to function
- investigate the structure and function of tissues, organs and systems and relate those functions to cell differentiation and specialisation (ACSBLO55) [ICT](#)
- justify the hierarchical structural organisation of organelles, cells, tissues, organs, systems and organisms (ACSBLO54) [CCT](#)

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It is amazing that the many living things on Earth are so very different in their structure and appearance. They may be composed of only one cell (unicellular), a group of cells existing together (colonial) or many cells, each with a specific function contributing to the efficient functioning of the organism (multicellular) (Fig. 4.1). If you were to look past the obvious differences between these types of organisms, you would realise that at a cellular level there are many similarities. Each cell needs to obtain the required nutrients, carry out metabolic functioning and successfully dispose of waste.



FIGURE 4.1 Despite its size, the blue whale has cells that are similar in shape, size and functionality to a unicellular organism.

4.1

Comparing different types of organisms

Organisms can exist as a single cell (unicellular), single cells working together (colonial) or as an organism made up of many cells (multicellular).

Similarities between each of these types of organisms include the following:

- They are all composed of cells.
- These cells all possess cell membranes, cytosol, ribosomes and some sort of genetic material.

Differences occur in the number of cells present in the organism, the types of cells and the organisation of the cells.

Unicellular organisms

Unicellular organisms contain only one cell, which can be either prokaryotic or eukaryotic (for example, *Paramecium* (eukaryotic) and bacteria (prokaryotic) (Fig. 4.2).

In all unicellular organisms, a single cell is responsible for all of its own life processes. Prokaryotes are unicellular organisms composed of one prokaryotic cell. Prokaryotes have been on Earth for 3.5–4 billion years. The conditions on Earth have dramatically changed since then but prokaryotes have evolved to remain the most widespread group of organisms on Earth. The lack of organelles and simple structure in prokaryotes does, however, limit the number of metabolic reactions that can occur at any particular time. Unicellular eukaryotic organisms can carry out all the necessary life processes in a more efficient manner than the prokaryotes by means of specialised organelles.

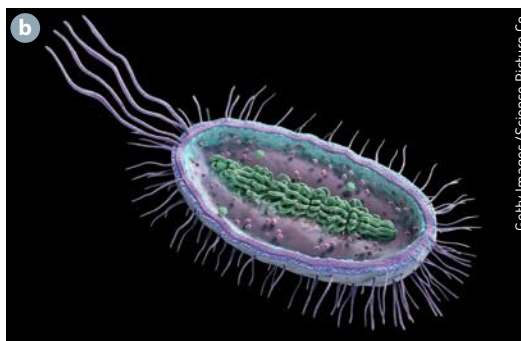


FIGURE 4.2 **a** *Paramecium*; **b** a model of a bacterial cell

Unlike multicellular organisms, all unicellular organisms are always directly exposed to the external environment. Their microscopic size means that they have a high surface-area-to-volume ratio (SA:V). This enables all required substances (such as nutrients, gases and water) to move across the cell membrane into all areas of the cell for its functioning. Wastes can also be efficiently removed from all parts of the cell by movement through the cell membrane.

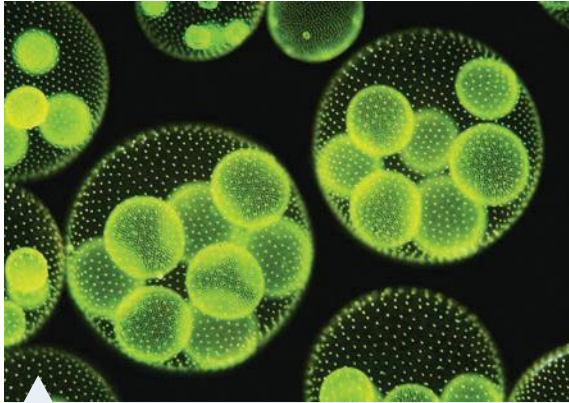


FIGURE 4.3 *Volvox*, a colonial organism, with daughter colonies forming inside each sphere

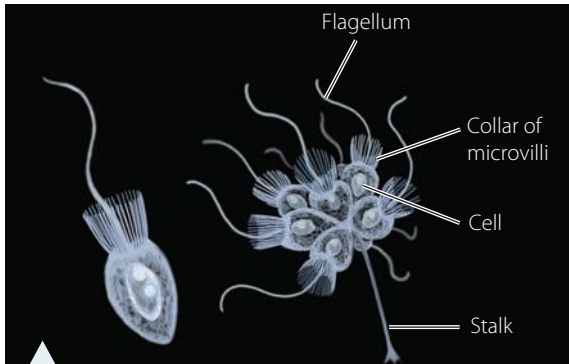


FIGURE 4.4 Choanoflagellates are thought to be an important link in the evolution of multicellular organisms.

Colonial organisms

Colonial organisms are made up of a group of identical single-celled organisms collectively called a **colony**. All individuals in the colony are capable of carrying out each function necessary for life and therefore could be classed as single-celled organisms. Some colonial organisms contain cells that have specialised functions that are coordinated with other cells in the colony. This contributes to more efficient functioning of all members of that colony. Examples of colonial organisms are *Volvox* (see Fig. 4.3), coral and jellyfish.

Volvox, a colony of algal cells, was first observed by Anton van Leeuwenhoek (1632–1723). He ground his own lenses and made his own microscopes through which he observed many microscopic organisms from a variety of sources, including pond water. His descriptions at the time were so precise that modern microbiologists can now identify many of the micro-organisms he saw.

A *Volvox* colony is a hollow sphere made up of 500 to 60 000 algal cells, each with two flagella and connected by strands of cytoplasm. This allows them to swim in a coordinated fashion. Each colony is only one cell thick. Each cell in the colony has a red ‘eyespot’ that can detect light. The cells on one end of the colonial sphere have more developed eyespots and this allows the *Volvox* colony to swim towards the light. Every cell in the colony contains chloroplasts, although some of the colonies may obtain what they need by absorption of nutrients from their environment. Even though *Volvox* exhibits some specialisation, it lacks tissues and organs, and is therefore classed as a unicellular colony rather than a multicellular organism.

Eukaryotic choanoflagellates (collared flagellates; Fig. 4.4) are another example of a colonial organism. Each possesses an ovoid or

spherical cell body with a single collared flagellum. Choanoflagellates can exist as free-living unicellular organisms or grouped together in colonies. Research involving the study of the genetic make-up of choanoflagellates supports their role as an evolutionary link between unicellular and multicellular organisms.

Multicellular organisms

Multicellular organisms are made up of many different types of cells. Similar cells are grouped together and perform specialised functions that combine together for the efficient functioning of the organism. These specialised cells in multicellular organisms cannot live independently of each other, unlike those of unicellular and colonial organisms.

The processes of obtaining nutrients and getting rid of wastes in unicellular and colonial organisms rely on diffusion, and are less successful and efficient than those in multicellular organisms.

Multicellular organisms are larger in overall size and so their total SA:V is smaller. As a result, passive transport is insufficient to address their needs. This problem is overcome by the functional organisation of multicellular organisms:

- Large organisms are made up of *numerous small cells*, so that each cell has its own large SA:V. This leads to an increase in the efficiency of diffusion and osmosis in individual cells.
- Multicellular organisms are not simply thousands of similar cells lumped together. Cells have become *organised into groups* called **tissues** (for example, blood tissue and skin tissue in humans, photosynthetic tissue and epidermal tissue in plants).
- Some small multicellular organisms still rely on diffusion and osmosis for nutrient and gas exchange between their cells and the surroundings, but large multicellular organisms have their tissues further organised into organs and systems, such as those which have developed for the efficient uptake of nutrients (digestive system) and gases (respiratory system).
- In multicellular organisms, a *division of labour* occurs – different cell types (tissues) are structurally suited to carry out different functions. This increases their effectiveness in carrying out their functions: some cells are involved in obtaining nutrients, whereas other tissues function in movement, growth and excreting.
- Young cells (called **embryonic cells**) are similar to each other in structure and, in early life, their only function is to divide and give rise to new cells. Embryonic cells require protection and nutrients to grow, and it is only once they begin to mature that they develop suitable structural changes that allow them to carry out specialised functions: some cells fight infection, others store nutrients, some process and transmit information, some secrete substances like hormones, and others have a protective function (Fig. 4.5).

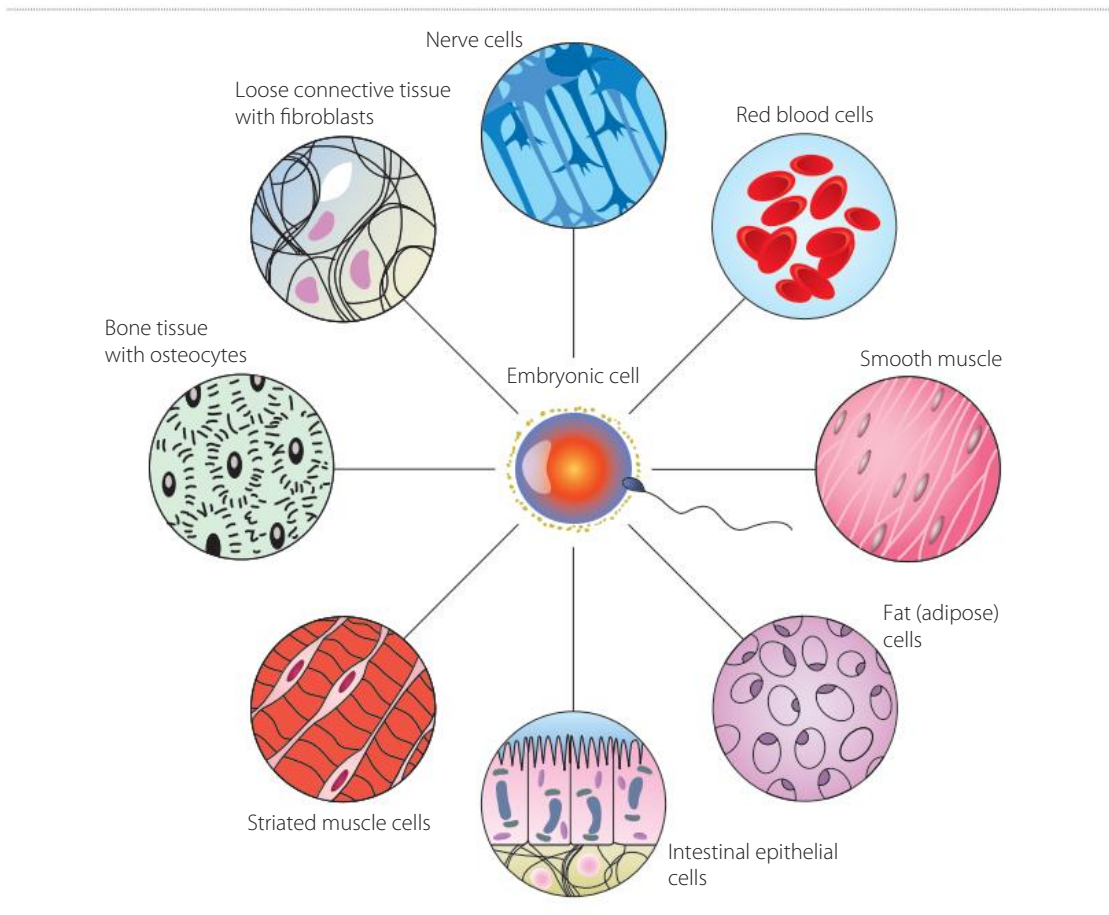


FIGURE 4.5 Some of the many specialised cells that make up a multicellular organism such as a human

INVESTIGATION 4.1

A practical investigation to compare the cells of unicellular, colonial and multicellular organisms

Unicellular, colonial and multicellular organisms differ in their cell number, cell functions and cell specialisation. In this practical investigation, you will observe the features of these different types of cells.

AIM

To observe and compare the features of different types of cells from unicellular, colonial and multicellular organisms

MATERIALS

- Light microscope
- Mini-grid
- Chopping board
- Knife or scalpel
- Forceps
- Dissecting needle
- Microscope slides
- Coverslips
- Pipettes
- Prepared or fresh specimens of:
 - unicellular eukaryotes, such as *Euglena*, *Amoeba* and *Paramecium*
 - a colonial organism, such as *Volvox*
 - plant cells, such as onion epidermal cells, *Spirogyra* and root hair cells
 - animal cells, such as human nerve cells or epithelial cells from internal organs such as the trachea or the small intestine
- Labelled diagram of a bacterial cell

RISK ASSESSMENT



WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Knife/scalpel	Sharp edges can cause cuts	Use the knife/scalpel with care, hold it by the handle and keep your fingers away from the sharp edge of the blade.
Microscope slides/coverslips	Sharp edges can cause injury if broken	Handle with care. Push gently on the coverslip. Always focus by moving the objective lens away from slide.

METHOD

- 1 Observe one specimen from each of the categories provided and draw a labelled diagram. Include the magnification used.
- 2 Estimate the size of the cell observed.
- 3 Record any other relevant information about the cells you observed.

RESULTS

- 1 On your diagrams of the cells you observed, label them as one of the following types of cell: unicellular prokaryote, unicellular eukaryote, colonial organism or multicellular organism.
- 2 Copy and complete Table 4.1 to summarise the type of cell (for example, unicellular prokaryote), the size of the cell and any other relevant features of each cell.

Review the correct use of microscopes (pp. 36–38), preparing a wet mount (p. 37) and determining the field of view and size of specimens (p. 45).

Revise scientific drawing skills from Chapter 2, Investigation 2.1, page 37.



» **TABLE 4.1** Summary of cells observed

NAME OF SPECIMEN	TYPE OF CELL	ESTIMATED SIZE (μm)	OTHER RELEVANT INFORMATION



Investigation 4.1

DISCUSSION

- 1 Outline the similarities of the cells studied.
- 2 Describe the differences between each of the cell types.
- 3 Compare the complexity of the cells of unicellular organisms with the cells from the multicellular organisms.

CONCLUSION

Write a brief summary statement that addresses the aim and summarises the results.

KEY CONCEPTS

- Unicellular organisms are made up of one cell that has to carry out all metabolic processes. This cell could be either prokaryotic or eukaryotic.
- Prokaryotic cells have no membrane-bound nucleus or organelles. Their simple structure limits the number of reactions they can carry out.
- Eukaryotic cells possess a membrane-bound nucleus and organelles, increasing the efficiency of metabolic reactions.
- Cells of unicellular organisms have a high SA:V, which allows efficient movement of substances into and out of the cell.
- Colonial organisms are thought to be the evolutionary link between unicellular and multicellular organisms.
- Colonial organisms are composed of individual cells living together in a colony.
- All cells in the colony are capable of carrying out all of the metabolic functions necessary for life; however, simple specialised cells can be present in the colony to improve the efficiency of functioning of the organism.
- Two examples of colonial organisms are Volvox and choanoflagellates.
- Multicellular organisms are composed of many different types of specialised cells. Similar specialised cells are grouped together and perform specific functions that combine for the efficient functioning of the organism.
- Individual cells in multicellular organisms cannot live independently of each other.

- 1 Answer each of the following questions and include a justification for each of your answers.
 - a Which of the three types of organisms (multicellular, unicellular and colonial) would have been the earliest form of life?
 - b Can cells within a multicellular organism live independently of other cells?
 - c Which has the higher SA:V – multicellular organisms or unicellular organisms?
 - d Name the two broad categories of unicellular organisms.
 - e Can colonial organisms show some simple specialisation of cells?
- 2 Outline one advantage and one disadvantage of:
 - a unicellular organisms
 - b colonial organisms
 - c multicellular organisms.

CHECK YOUR UNDERSTANDING

4.1a





- 3 **a** Describe how an amoeba gains its nutrients and removes its wastes.
b Outline the features of this unicellular organism that assist in these processes.
- 4 Identify and describe an example of a colony made up of eukaryotic cells.
- 5 **a** Describe how cells are organised in a multicellular organism.
b Outline how this affects the effective functioning of the organism.

Cell structure and specialisation is related to function

As seen above, there is a vast array of structures and types of cells in multicellular organisms. The structure and arrangement of these cells in the organism are closely related to their specific function. These specialised cells work together to ensure the most efficient functioning of the organism.

Forming specialised cells

When cells become specialised to perform a particular function, they are said to **differentiate**. They develop suitable structural features that allow them to carry out their specific functions; this makes them structurally *different* from other types of cells and from the embryonic cells from which they arose.

All **specialised cells** originate from cells that are known as **stem cells**. These stem cells are undifferentiated, and are able to divide many times over a long period and become specialised. Stem cells may be found in embryos, where they are known as embryonic stem cells, or can be adult stem cells. Adult stem cells are found in a number of places in the body, such as the stem cells in the human brain and the blood-producing stem cells in the bone marrow.

Cell specialisation refers to the particular functions that a cell has. *Differentiation* is the process that a stem cell goes through to become specialised (Fig. 4.6).

When organisms are growing and developing, their cells, with the exception of the sex cells (sperm and ova), are constantly dividing by the process of **mitosis**. In this process of division, identical copies of the original cell are produced. All cells in the organism, excluding the sex cells, contain the same genetic information in their genes. The cell does not use all of this information; different cells develop as a result of only certain parts of this genetic information being 'switched on'. The genetic information that is activated will depend on the location of the undifferentiated cells in the body of the organism. For example, cells in the outer layers become skin cells, cells beneath that become muscle cells, and so on. The genes that are activated control the types of proteins produced by the cell. This in turn determines the particular structure of the cell and therefore its specialised function. Some cells will be specialised to fight infection, others to store nutrients, some to process and transmit information, some to secrete substances like hormones, and others to have a protective function.

Once they have become specialised to form a particular type of cell, differentiated cells lose their capacity to develop into other types of cells. Many even lose their ability to divide and give rise to the same type of cells.

In plants, the meristematic tissue, which is present in the young growing regions such as the root and shoot tips, contains undifferentiated cells. As these cells continue to divide and mature, they are differentiated into the specialised cells, such as phloem cells and xylem tissue, which the plant requires to function effectively (Fig. 4.7).



Using analogies:
cell specialisation

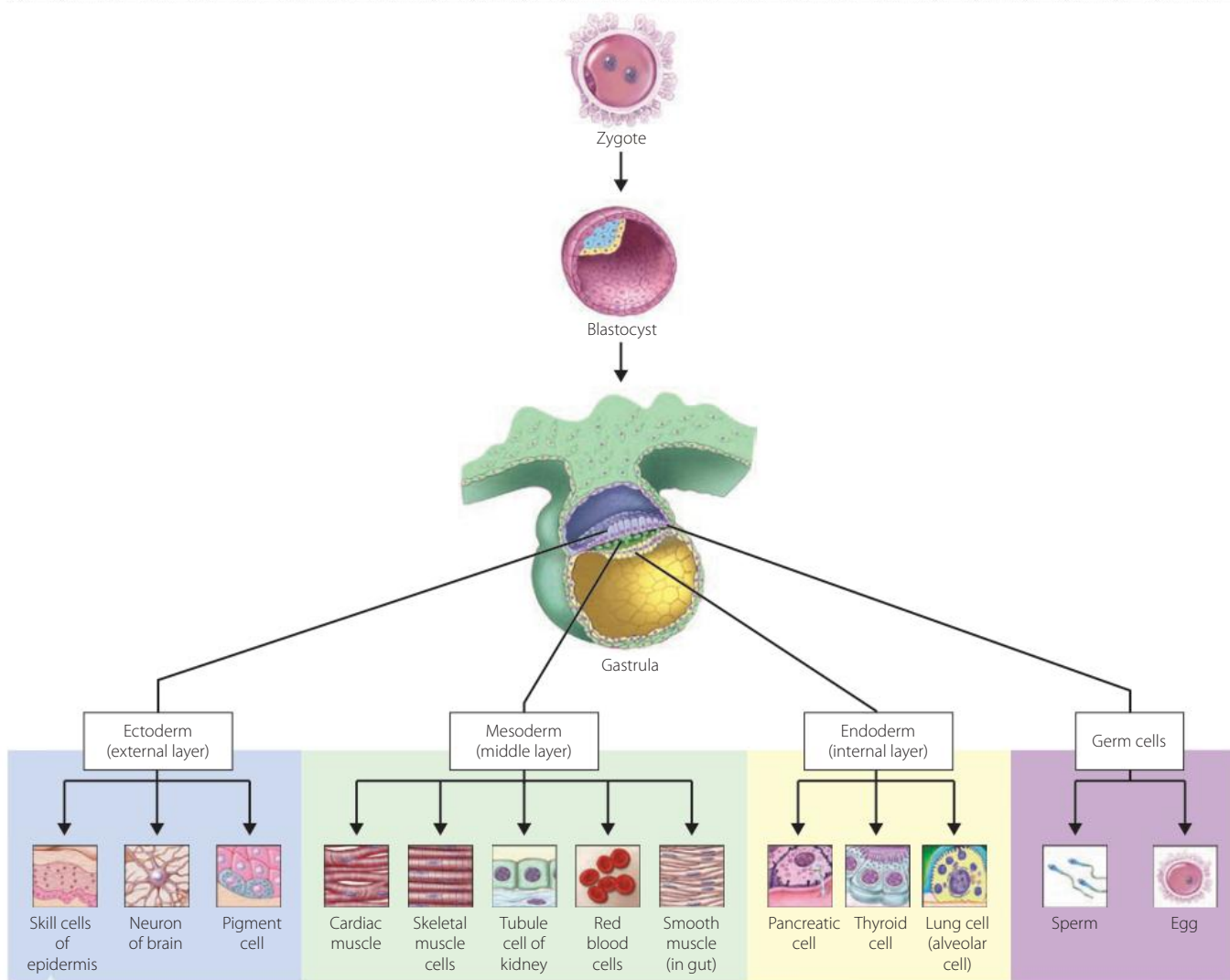


FIGURE 4.6 Differentiation is a process in which cells become more specialised as they mature.

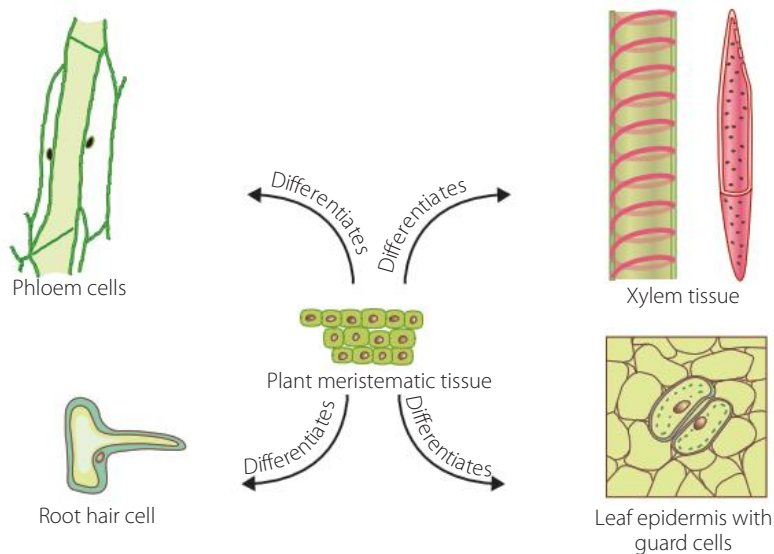


FIGURE 4.7 Cell differentiation and specialisation in plants

- Stem cells are undifferentiated cells with no specialised structure or function.
- Specialised cells are formed when differentiation of the stem cells occurs and they develop suitable structural features that allow them to carry out their specific functions.
- The type of cell that is formed is determined by the location of the undifferentiated cells in the organism and the particular genes that are switched on.
- Stem cells can be either embryonic or adult stem cells.
- In plants, specialised cells are formed by the differentiation of meristematic tissue.

Cells working together

While multicellular organisms have many benefits, including being able to grow to a large size and efficiently carry out many and varied activities, the specialised cells that make up the organism are incapable of surviving on their own. They are reliant upon the other cells to carry out the functions that they cannot. In order to function efficiently, there is a requirement for well-developed communication and coordination between the many specialised cells. In animals, chemical secretions and nerve cells play an important part in this by relaying messages efficiently around the body. Blood cells bind oxygen in blood that is pumped by heart muscle cells, and other cells provide nutrients and remove wastes. In plant cells, communication is brought about by chemical and physical contact between cells because there are no nerve cells and no centralised control centre.

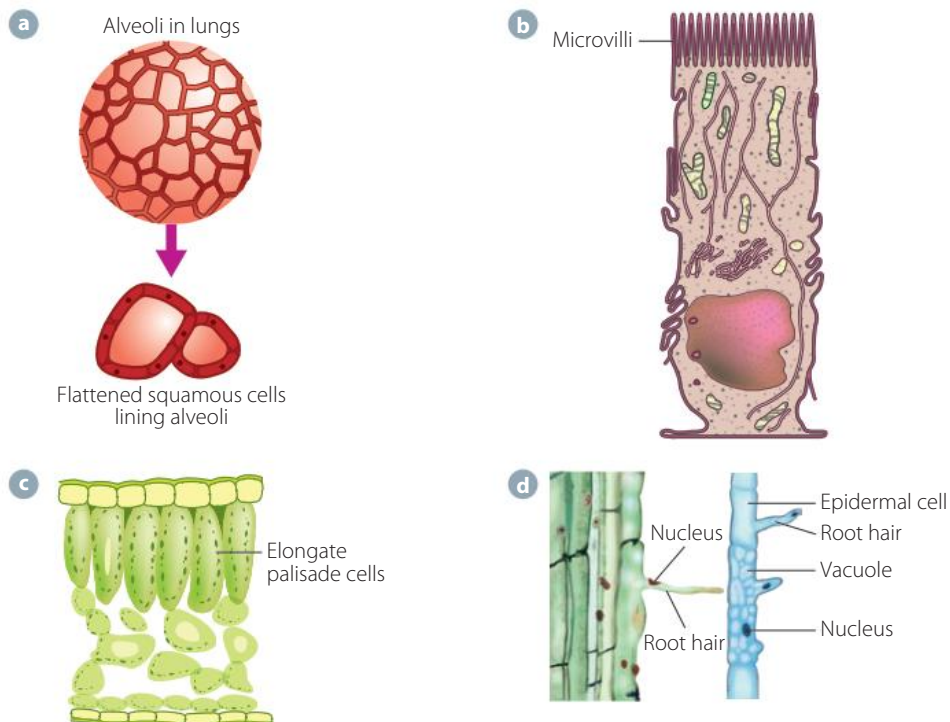
Relationship between cell structure and function

There are many examples of how the structure and specialisation of a cell are related to its function.

The cells of those parts of the body involved in exchanging substances with the environment have special structural features to increase their SA:V, allowing them to exchange the required materials more efficiently (Fig. 4.8):

- Cells may be flattened (for example, in the tissue lining the air sacs in lungs: Fig. 4.8a) or elongated (for example, photosynthetic cells in leaves: Fig 4.8c). These shapes give a greater SA:V than cube-shaped cells, allowing the more efficient exchange of substances.

FIGURE 4.8 Cells that are structurally modified to increase surface area: **a** flattened, squamous epithelium of air sacs in lungs; **b** an endothelial cell of the small intestine showing membrane folded to form microvilli; **c** elongate palisade cells in a leaf; **d** extension of the cell membrane to form a 'root hair'



- The exposed edges of the cells may be extended into folds (for example, root hair cells that absorb water and mineral salts in plants (Fig. 4.8d), or the cells lining the wall of the small intestine that absorb nutrients (Fig. 4.8b)).

Red blood cells provide another example of how the structure and specialisation of cells are related to their function. The function of red blood cells is to transport oxygen around the body in the blood. Both the very small size and the biconcave shape of the red blood cell increase the SA:V, allowing the rapid diffusion of oxygen (Fig. 4.9). The small size also allows the red blood cell to squeeze through the tiny capillaries that are in contact with every cell in the body. The absence of a nucleus or organelles in the cell allows more **haemoglobin** to be carried in the cell. The haemoglobin contained within the red blood cell chemically binds with the oxygen in the lungs and releases it to the body cells.

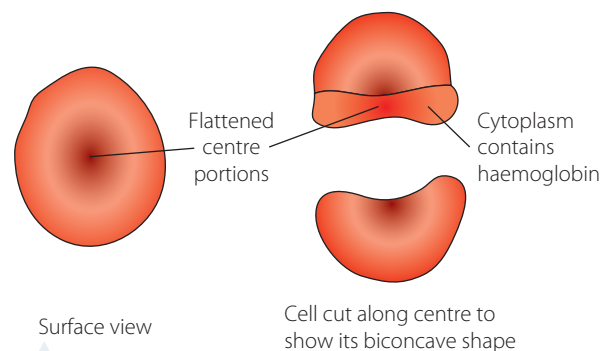


FIGURE 4.9 Specialised structure of the red blood cell, showing the biconcave shape, the absence of a nucleus and the presence of haemoglobin in the cytoplasm



Information and communication technology capability



Specialised cells

Identify some specialised cells and relate their structures to their function.

KEY CONCEPTS

- Cell structure is related to the particular function of the specialised cell.
- Cells whose functions involve exchanging substances with the external environment will probably be flat and long to increase SA:V, or have many folds to increase surface area. Examples are root hair cells and the cells lining the small intestine.
- Another example of the relationship between the structure of cells and function is that red blood cells are very small and have a particular shape to increase SA:V for the exchange of oxygen. They lack a nucleus and organelles, enabling more haemoglobin to be carried in the cell.

- 1 Identify the type of cell that specialised cells are formed from.
- 2 Outline the relationship between cell differentiation and specialisation.
- 3 What are the advantages and disadvantages of a cell becoming specialised?
- 4 Stem cells are different from other cells in the body. Outline three ways in which they differ.
- 5 The structure and function of specialised cells in multicellular organisms are different. Explain why this is possible if they all possess the same genetic information.
- 6 Describe how it is possible for the specialised cells in a multicellular organism to work together to achieve the efficient functioning of the organism.
- 7 Investigate and outline three uses or potential uses of stem cells in curing human disease.
- 8 Explain how two named examples of cells are structurally suited to the function that they perform.

CHECK YOUR UNDERSTANDING

4.1b

4.2 Structural organisation of multicellular organisms

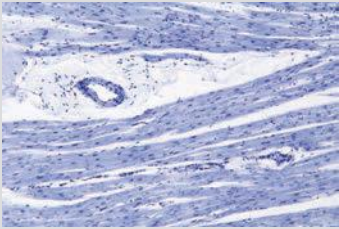
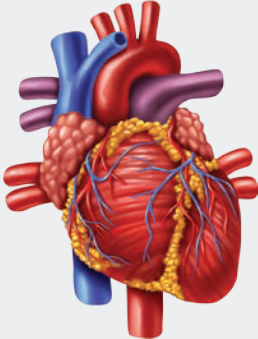
As we have seen, the many and varied multicellular organisms contain many different types of specialised cells. For multicellular organisms to function effectively and live successfully so that they can reproduce and pass on their genetic information, there needs to be a high level of organisation in the arrangement of these specialised cells.

Atoms make up molecules that form the chemical substances that are an essential part of every cell. These chemical substances are arranged to form the organelles that are present in eukaryotic cells. These organelles are specialised for particular functions within the cell, with their activity coordinated by the nucleus.

Specialised cells that perform a similar function are collectively organised into tissues. For example, heart muscle cells form heart muscle tissue. Different types of tissues that are grouped together to perform a particular function are called **organs**. For example, the heart is an organ that contains muscle tissue, connective tissue, nerve tissue and epithelial tissue. These tissues, each composed of specialised cells, work together to ensure the efficient and effective functioning of the heart to pump blood around the body. Different organs are grouped together to form an **organ system** that is responsible for a particular bodily function. Thus the cardiovascular system in humans is a transport system, responsible for the movement of many substances around the body. The heart, different types of blood vessels and blood are the organs that are part of the circulatory or cardiovascular system.

Numerous organ systems make up multicellular organisms. These systems work cooperatively so that all necessary processes are carried out to ensure the survival of the organism (Table 4.2).

TABLE 4.2 Hierarchical structural organisation in a multicellular organism

LEVEL OF ORGANISATION	EXAMPLE	ILLUSTRATION
Organelles 	Mitochondria, nucleus	
Cells 	Cardiac muscle cells	
Tissues 	Cardiac muscle tissue	
Organs 	Heart	



» LEVEL OF ORGANISATION	EXAMPLE	ILLUSTRATION
Organ systems 	Cardiovascular system	 iStock.com/leonello
Organism	Human	 Shutterstock.com/Gehrke

INVESTIGATION 4.2

A secondary-source investigation into the levels of organisation in multicellular organisms

For multicellular organisms to function effectively and live successfully so that they can reproduce and pass on their genetic information, there needs to be a high level of organisation in the arrangement of their specialised cells.

AIM

To justify the hierarchical structural organisation of organelles, cells, tissues, organ systems and organisms

METHOD

- 1 Use a number of sources to research the levels of organisation in multicellular organisms. Interactive activities could be very useful in achieving the aim of this investigation.
- 2 When using a search engine, insert key words such as 'levels of organisation in multicellular organisms' + 'interactive'.



Critical and creative thinking



Information and communication technology capability



» 3 Using the information you have gathered:

- a Create a flow chart that places the following levels of organisation in order from the least complex to the most complex:
organs, cells, organelles, tissues, organism, organ systems
- b Write a summary of each level of organisation listed.
- c Create an illustrated flow chart showing the relationship between each of the levels of organisation for any system other than the cardiovascular system shown in Table 4.2.
- d Include a list of the websites and other resources used.

RESULTS

- 1 Draw a simple flow chart with the levels of organisation in the correct order.
- 2 Write a brief summary of each level.
- 3 Create an illustrated flow chart showing the relationship between each of the levels of organisation.

DISCUSSION

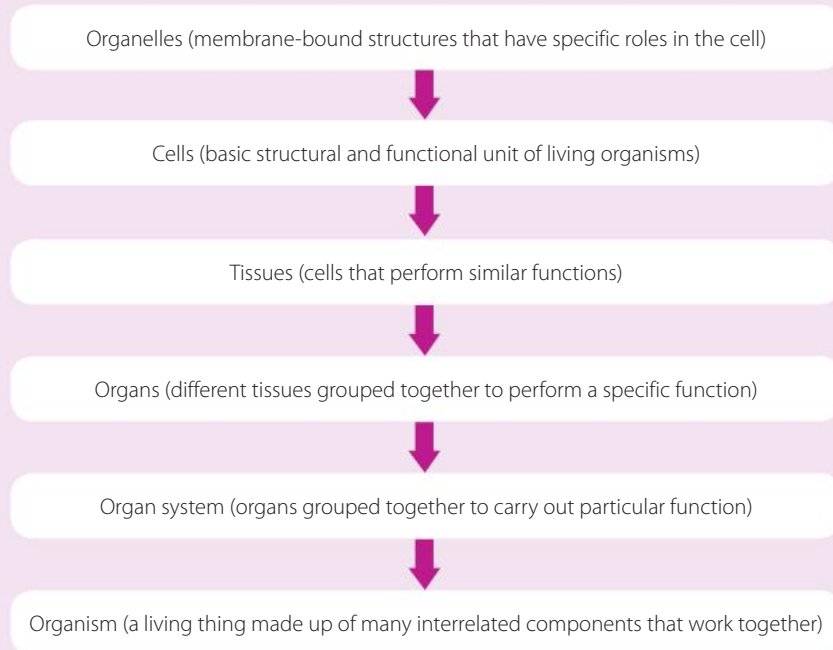
Explain why these levels of organisation are found in multicellular organisms.

CONCLUSION

Write summary sentences related to the aim of this investigation.

KEY CONCEPTS

- The flow chart below shows the structural organisation of multicellular organisms:



- 1 Explain the relationship between the following pairs of terms:
 - a atoms and cells
 - b atoms and organs
 - c tissues and organ systems
 - d atoms and organ systems.
- 2 Provide an example of an organ system starting at the cellular level.
- 3 How do organ systems relate to a multicellular organism?

4.3

Cell organisation, specialisation and functioning

Specialised cells make up tissues, with different types of tissues forming organs that carry out particular functions within an organ system.

Animal cells

The many different types of specialised cells found in complex animals are components of the four general types of tissues found in these animals (Fig. 4.10). These are epithelial tissue, connective tissue, nervous tissue and muscle tissue. Each general type of tissue further contains many different functional types based on the specialised cells that comprise them.

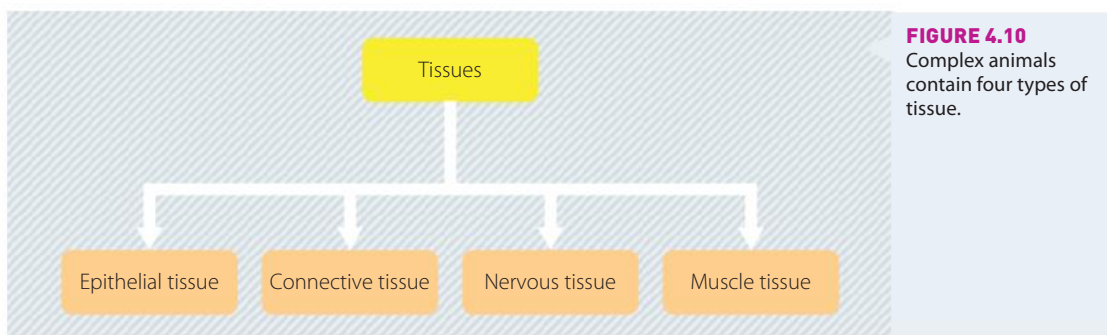


FIGURE 4.10
Complex animals
contain four types of
tissue.

Animal cell specialisation
and organisation

These tissues are components of organs that in turn make up organ systems. The function of the organ will determine which type of tissues it contains.

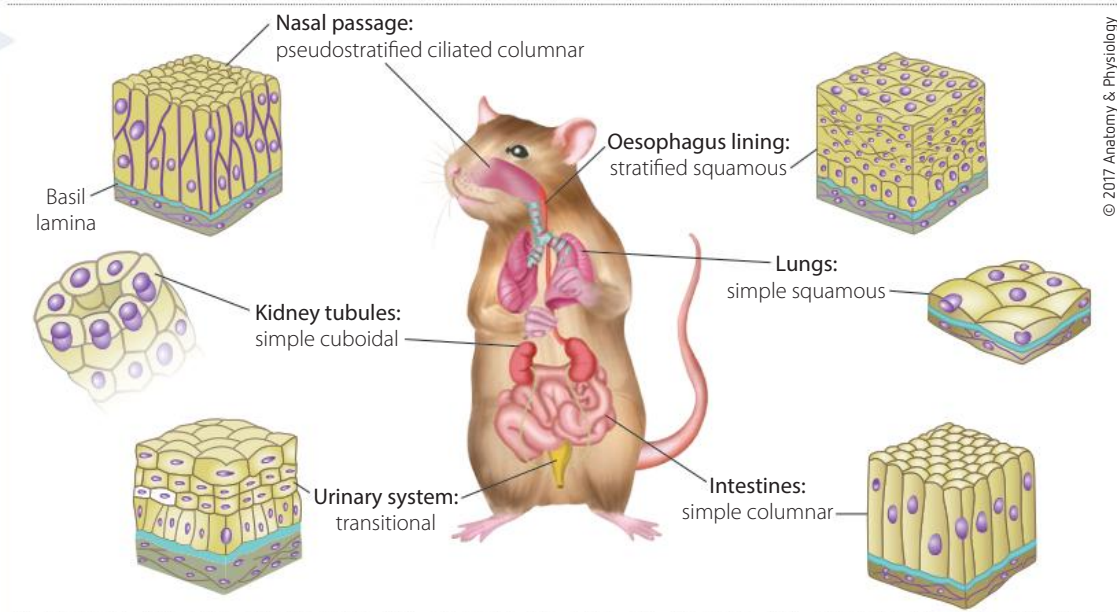
Epithelial tissue

Epithelial tissue is a tissue that covers body surfaces, protects organs and forms glands (Fig. 4.11). The cells in this tissue are densely packed and can occur in either single sheets or layers, depending on their location and function. Epithelial tissue does not contain blood vessels and relies on the underlying connective tissue for nutrients. There are two distinct surfaces on epithelial tissue. One of these is the surface that is exposed to the exterior or the body cavity; the other is the surface that is exposed to the adjacent tissue. The skin is composed of epithelial tissue, as is the surface of the organs of the digestive system, the respiratory system, and many other organs within the body. The cells of the epithelial tissue are organised very close to each other, aiding their role as barriers to injury and infection.

Some epithelial tissue may also be specialised for absorption or secretion. For example, the epithelial tissue that lines the larynx secretes mucus to keep the surface moist.

FIGURE 4.11

There are different types of epithelial tissue in different organs.



The type of specialised epithelial cells and their function depend on their location and the organ or organ system they are part of.

Connective tissue

Connective tissue varies greatly in both the form it takes and its function (Fig. 4.12). All connective tissue does, however, share the common characteristic of an **extracellular matrix** with cells scattered through it. This matrix is made up of the protein fibres **collagen** (for strength) and **elastin** (for flexibility), and another substance to fill the spaces.

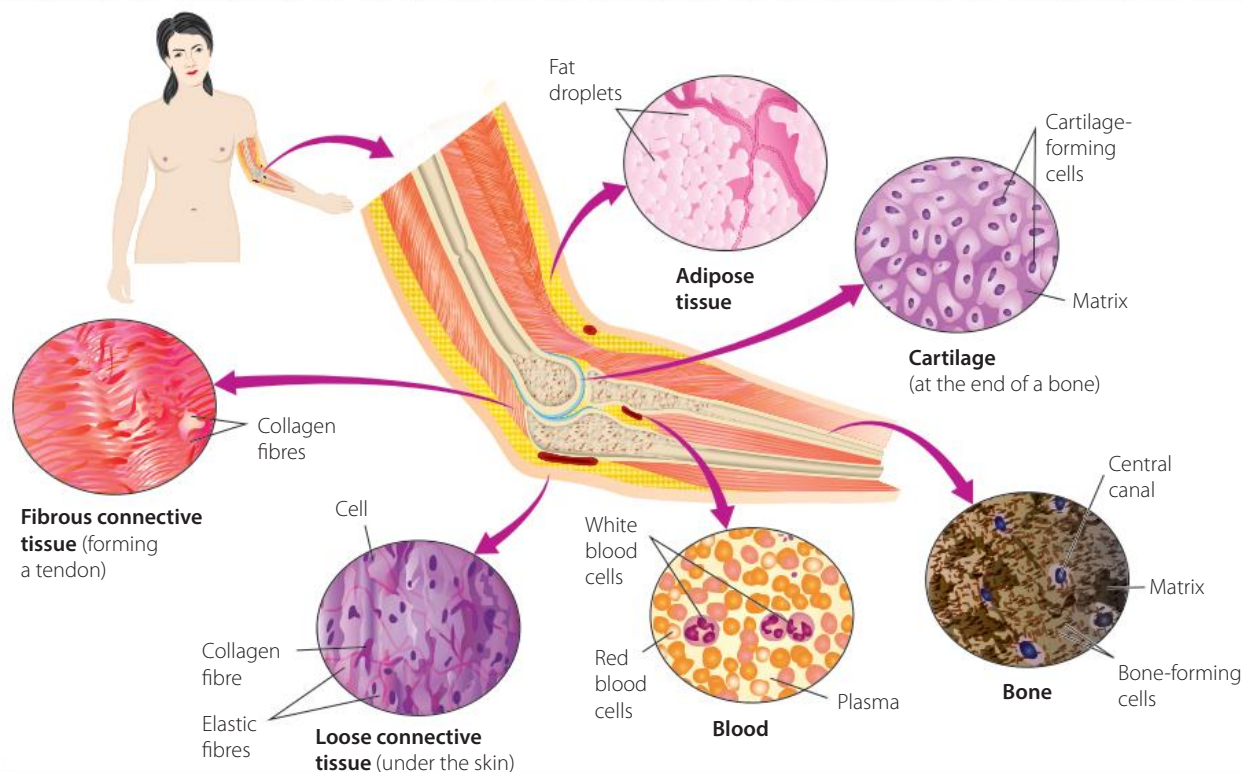


FIGURE 4.12 Examples of different types of connective tissue

Connective tissue provides support, ensures that different parts of the body are bound together and protects against damage.

The different types of connective tissue vary in their density of cells and the ways in which the cells are specialised. There are numerous types of connective tissue, including **fibrous connective tissue**, **loose connective tissue**, **adipose tissue**, **cartilage**, bone and blood. The differences between these types of tissue are due to the arrangement of cells and their specialised structure and function. Some examples of connective tissues are:

- ▶ adipose tissue, which consists of fat storage cells that function as energy storage, insulation and for protection and cushioning. These cells contain a large fat droplet that takes up most of the space and pushes the nucleus to one side
- ▶ cartilage, which is composed of lots of dense collagen fibres that provide not only strength but also flexibility and cushioning. Cartilage is found in areas that require these properties, such as the nose, rib cage, trachea and the ends of the long bones
- ▶ collagen in the connective tissue in skin, which is involved in stopping the skin from tearing away from the bone. The elastic fibres function to restore the skin to its original place and shape.

Nervous tissue

The nervous system comprises the brain, spinal cord and peripheral nerves. It contains **nervous tissue** that is highly specialised for communication between all parts of the body. The nerve cells (or **neurons**) that make up the nervous tissue are highly specialised for their function of passing messages between themselves and other cells in the body. Neurons consist of multi-branched **dendrites** and an **axon** that extends out from the cell body.

The extensive branching of the dendrites increases the surface area to receive messages. The electrical message then passes through the cell body and is transferred along the axon to be passed onto the neighbouring neuron, muscle or gland.

The branching of the dendrites and the long axon of the neuron are specialised to their function of conveying messages around the body (Fig. 4.13).

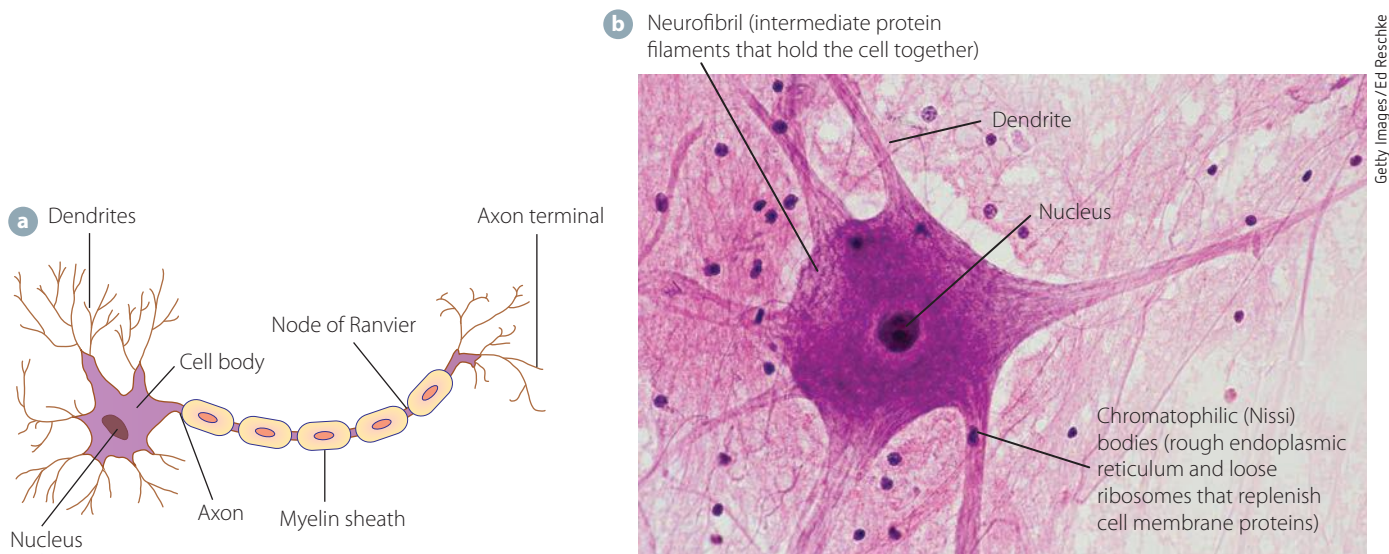


FIGURE 4.13 **a** Diagram of a motor neuron; **b** microscopic image of a motor neuron

Muscle tissue

Muscle tissue contains muscle cells called muscle fibres that are highly specialised for contraction. The three types of muscle cells – skeletal, cardiac and smooth – are all elongated (Fig. 4.14). They contain the proteins actin and myosin, which interact with each other to cause the cells to lengthen and shorten.

Skeletal muscle fibres are long and have **striations** (light and dark areas). These striations are caused by the arrangement of the actin and myosin in them. Skeletal muscles are attached to bones and their contraction causes movement in the organism. Skeletal muscles are classed as voluntary because they require conscious thought to function.

Cardiac muscle fibres are present in the heart and also have striations. The individual cells have connection junctions that are necessary for the coordinated beating of the heart.

Smooth muscle fibres do not have striations and their contractions push substances through specialised organs such as the gastrointestinal tract, the blood vessels and the urethra, which leads from the bladder.

Both cardiac and smooth muscle can be classed as involuntary because they function automatically.

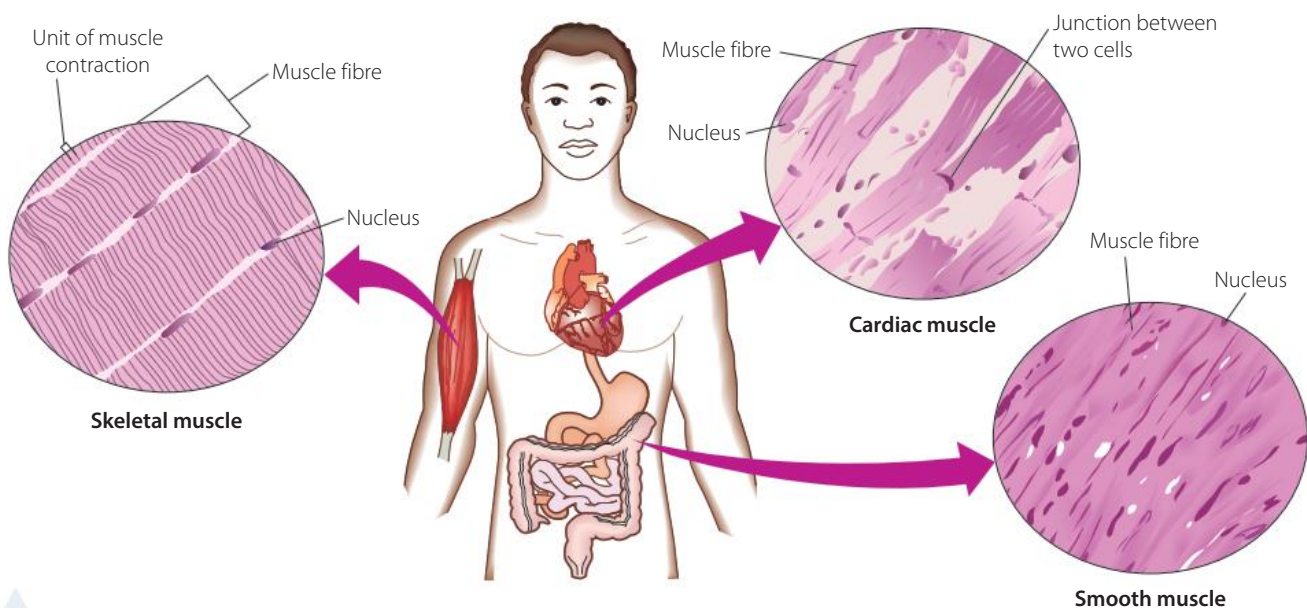


FIGURE 4.14 The different types of muscle tissue

Plant cells

Plants follow a similar pattern of levels of organisation as animals, from the organelles in cells to the systems that make up the whole organism. Cells of similar structures are grouped together in tissues to perform a shared function (for example, vascular tissue). An organ contains different tissues grouped together to carry out a specific function (such as the leaf). A number of organs are then grouped together to form an organ system that, along with other organ systems, contributes to the overall functioning of the organism and ensures that each part of the plant receives what it needs.

The organs of a plant can be grouped into three systems:

- 1 The shoot system is the part of the plant above the ground. It supports the plant, enables the transport of substances around the plant, exchanges gases, and carries out photosynthesis and reproduction. Organs that are part of the shoot system include the leaves, the stem and the reproductive organs.
- 2 The root system is that part of the plant below the ground. It is responsible for absorbing water and nutrients from the soil for the use of the rest of the plant. The roots, including the root hairs, are organs of the root system.

The vascular system of the plant is covered in more detail in Chapter 6.



Plant cell specialisation and organisation

- 3 Sometimes plants are said to have a third system – the vascular system for transport. It is made up of xylem and phloem vessels.

The four main types of tissues found in a plant are meristematic tissue, dermal tissue, vascular tissue and ground tissue.

Meristematic tissue

Meristematic tissue is found at the tips of roots and shoots. In woody plants it can also be found in buds and in a ring around the stem (Fig. 4.15). It is in these meristematic areas that the cells divide to produce new growth. Cell differentiation to produce specialised cells can also take place here. Meristematic cells are cube-shaped and very small.

Dermal tissue

The **dermal tissue** protects the plant tissues and can be found on the outer layers of the stems, roots and leaves. It protects the plant from damage and controls interactions with the plant's surroundings. The epidermal layer is the outermost layer of the dermal tissue. It secretes a waxy layer called the cuticle, which is vital to reduce water loss from the plant. There is a wide variety of these epidermal cells and most lack chloroplasts. Epidermal cells can also produce fine hairs on the surfaces of the leaves and stems. These hairs trap a layer of air next to the leaf, preventing the flow of air and decreasing the evaporation of water from the leaf. Other types of hairs on the epidermal layer contain substances harmful to the insects that feed on them. Some specialised epidermal cells on the root have very fine projections called the root hairs, which increase the surface area for the movement of water into the root, thus increasing water and mineral uptake. In woody plants, a bark layer forms when layers of specialised cells (which soon die) replace the epidermis.

Vascular tissue

The **vascular tissue** in a plant is responsible for the transport of substances around the plant and is found in the roots, stems and leaves. There are two main types of vascular tissue: the **xylem** and the **phloem**. Xylem tissue transports water and mineral salts from the roots to the leaves. Phloem tissue transports the products of photosynthesis around the plant.

Ground tissue

Ground tissue is all of the internal cells of a plant other than the vascular tissue (Fig. 4.16). This tissue is the bulk of the plant tissue and consists of a variety of different cell types that are specialised for food storage, support and photosynthesis.

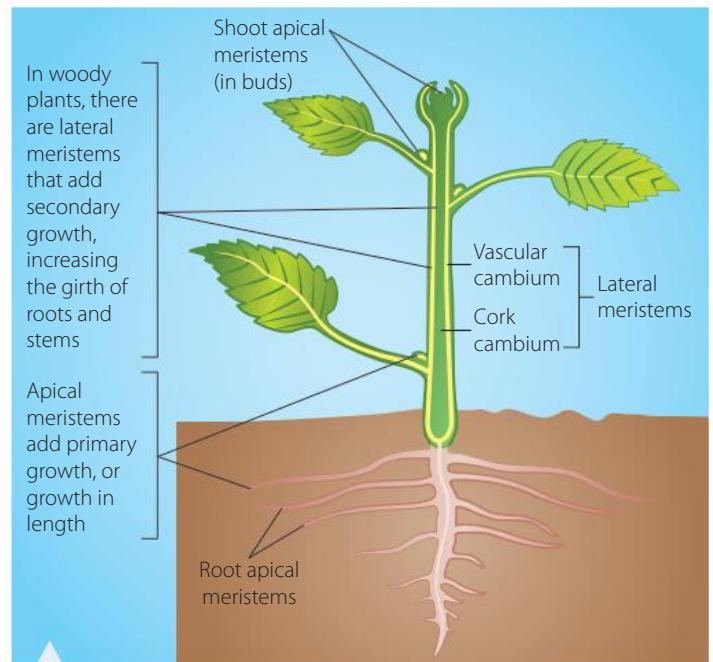


FIGURE 4.15 The location of the meristematic tissue in a vascular plant

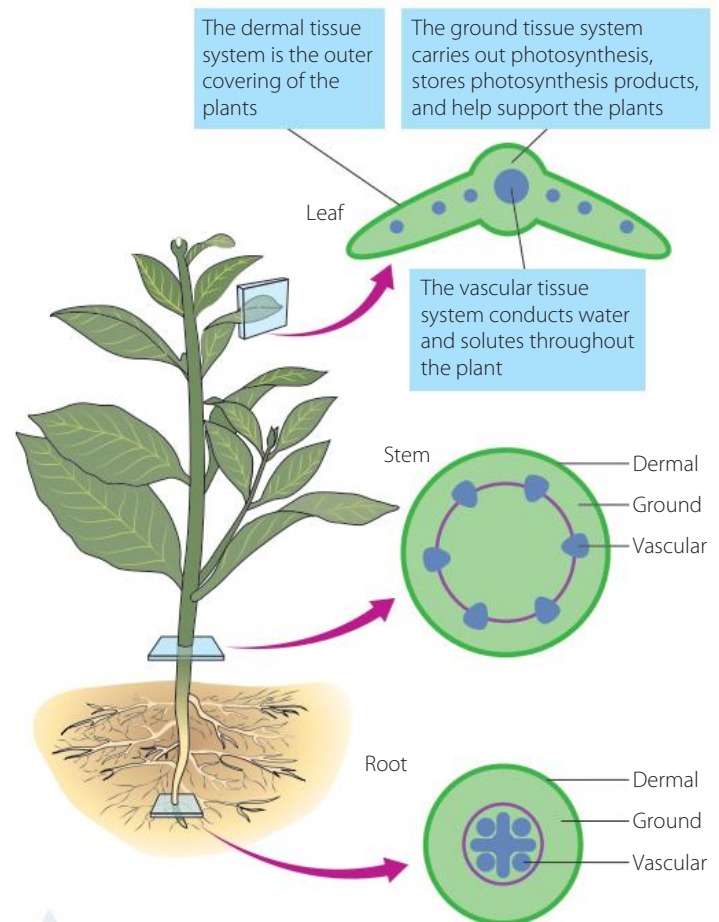


FIGURE 4.16 Ground, dermal and vascular tissue location in the roots, stems and leaves of plants

INVESTIGATION 4.3



Information and communication technology capability

A secondary-source investigation to examine the structure and function of tissues in multicellular organisms

The hierarchical organisation of cells enables the efficient functioning of multicellular organisms. Cell differentiation and specialisation produce cells with specific functions that are then grouped together as tissues. In this investigation, you will be observing the cells of different tissues both digitally and through the light microscope.

AIM

To examine different types of tissues present in multicellular organisms and relate their structure to their function

MATERIALS

- Prepared slides of the following types of tissue:
 - connective (for example, cartilage or adipose tissue)
 - epithelial (for example, lung tissue)
 - nervous (for example, neuron)
 - muscle (for example, skeletal)
 - plant epithelial (for example, root hairs)
 - plant vascular (for example, phloem)
- Light microscopes
- Computer with access to the Internet

RISK ASSESSMENT



WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Microscope slides/coverslips	Sharp edges can cause injury if broken	Handle with care. Always focus by moving the objective lens away from the slide.

METHOD

- 1 Using the light microscope, observe two different examples of animal tissue and one example of plant tissue from those listed in the 'Materials' section above.
- 2 Focus using low power and then high power to see the maximum amount of detail.
- 3 Draw up a results table like Table 4.3 – landscape mode would be the best option.
- 4 For each tissue observed, draw a diagram of a few of the cells in the results table. Remember to follow the guidelines given on p. 45 and include magnification.
- 5 Describe the structure of the cells, using your observations and the images you have researched.
- 6 Outline the function of these tissues and explain how the structure is related to that particular function.
- 7 Identify the organ and organ system that each tissue observed is part of.

RESULTS

Write your results in a table like Table 4.3.

TABLE 4.3

TYPE OF TISSUE	EXAMPLE	DIAGRAM	DESCRIPTION OF THE STRUCTURE	FUNCTION	HOW IS THE STRUCTURE RELATED TO THE FUNCTION?	ORGAN OR ORGAN SYSTEM



Investigation 4.3

» DISCUSSION

- 1 Identify one similarity and two differences in the structure of:
 - a two different animal cells
 - a plant cell and an animal cell.
- 2 Explain how the function of cells is related to cell differentiation and specialisation.
- 3 Find online images of two cell types as seen under a fluorescence microscope and a scanning electron microscope.

CONCLUSION

Write summary sentences related to the aim of this investigation.

KEY CONCEPTS

- There are four main types of animal tissue: epithelial tissue, connective tissue, nervous tissue and muscle tissue.
- There are many different forms of each of these types of tissues.
- The four main types of plant tissue are meristematic tissue, vascular tissue, dermal tissue and ground tissue.
- The arrangement of cells into tissues, organs and systems in multicellular organisms maximises the efficient functioning of the organisms.
- The interaction and cooperation between cells, tissues, organs and systems provides multicellular organisms with abilities that are beyond the limitations of a single cell.

- 1 Draw a table that summarises the features of each level of organisation. Start your table with organelles.
- 2 Organ systems in the body work together in a coordinated way to ensure that the body functions effectively. Describe an example where several organ systems work together to carry out a particular function in the human body.
- 3 Specialised cells in the body, with specific functions, all play an essential part in the body's overall effective functioning. The structure of these specialised cells assists them to carry out their function. Refer to Figure 4.8(b) an endothelial cell of the small intestine and (c) elongate palisade cells. The function of the palisade cells is to capture the sunlight and use its energy to carry out photosynthesis. The function of the microvilli of the endothelial cell is to absorb digested food particles. Describe how the structure of both of these cells assists them in carrying out their specific function.
- 4 **a** Copy and complete Table 4.4 to identify the four different types of tissues in complex animals, describe their features/function, and provide examples of each type.

CHECK YOUR UNDERSTANDING

4.3

TABLE 4.4

TYPE OF TISSUE	DESCRIPTION OF FEATURES/FUNCTION	EXAMPLES

- b** Explain how the structure of each of these types of cells assists them to carry out their function successfully.
- 5 Identify the major systems in most plants, and the organs that are part of each system.
 - 6 Identify the four major tissue types in plants, and outline their functions.
 - 7 Describe the similarities in function of the dermal tissue in plants and the epithelial tissue in animals.

Organisation of cells: How are cells arranged in a multicellular organism?

All cells possess:

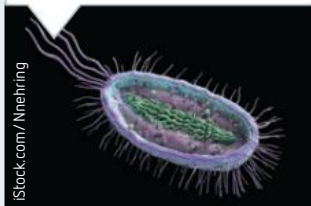
- Cell membrane
- Cytosol
- Ribosomes
- Genetic material

TYPES OF ORGANISMS

Unicellular organisms

Unicellular organisms are made up of one cell that has to carry out all metabolic processes.

Unicellular organisms have a high SA:V of cells, which allows efficient movement of substances.



Prokaryotic

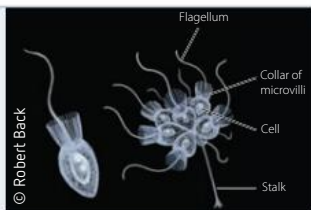
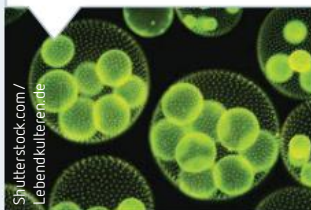
Prokaryotic cells have no membrane-bound nucleus or organelles. Their simple structure limits the number of reactions they can carry out e.g. bacterial cell

Eukaryotic

Eukaryotic cells possess a membrane-bound nucleus and organelles, increasing the efficiency of metabolic reactions e.g. paramecium

Colonial organisms

- Colonial organisms are composed of individual cells living together in a colony.
- All cells in the colony are capable of carrying out all of the metabolic functions necessary for life; however, simple specialised cells can be present in the colony to improve the efficiency of functioning of the organism.



E.g. (i) Volvox

(ii) Choanoflagellates

Multicellular organisms

- Multicellular organisms are composed of many different types of specialised cells. Similar specialised cells are grouped together and perform specific functions that combine for the efficient functioning of the organism.
- Individual cells in multicellular organisms cannot live independently of each other.
- The flow chart below shows the structural organisation of multicellular organisms.



Organelles (membrane-bound structures that have specific roles in the cell)

Cells (basic structural and functional unit of living organisms)

Tissues (cells that perform similar functions)

Organs (different tissues grouped together to perform a specific function)

Organ system (organs grouped together to carry out a particular function)

Organism (a living thing made up of many interrelated components that work together)

SPECIALISED CELLS IN MULTICELLULAR ORGANISMS

- Stem cells are undifferentiated cells with no specialised structure or function.
- Specialised cells are formed when differentiation of the stem cells occurs and they develop suitable structural features that allow them to carry out their specific functions.
- The type of cell that is formed is determined by the location of the undifferentiated cells in the organism and the particular genes that are switched on.
- Stem cells can be either embryonic or adult stem cells.
- In plants, specialised cells are formed by differentiation of meristematic tissue found at the tips of roots and shoots.

Examples of cells

(i) Animal cells



Thyroid cell



Tubule cell of kidney



Skin cells of epidermis

(ii) Plant cells



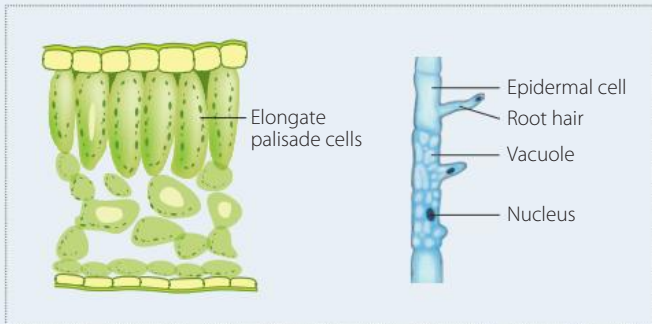
Root hair cell



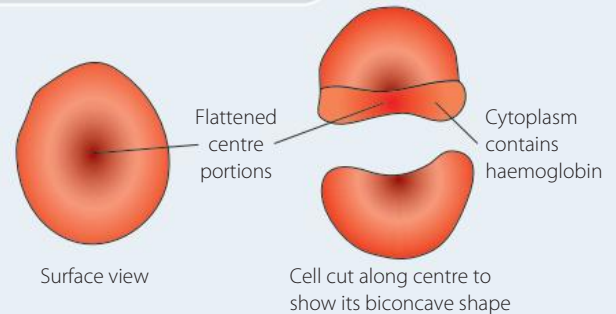
Phloem cells

RELATIONSHIP BETWEEN CELL STRUCTURE AND FUNCTION

- Cell structure is related to the particular function of the specialised cell.
- Cells whose functions involve exchanging substances with the external environment will probably be flat and long to increase SA:V, or have many folds to increase surface area. Examples are root hair cells and the cells lining the small intestine.



Red blood cells and oxygen

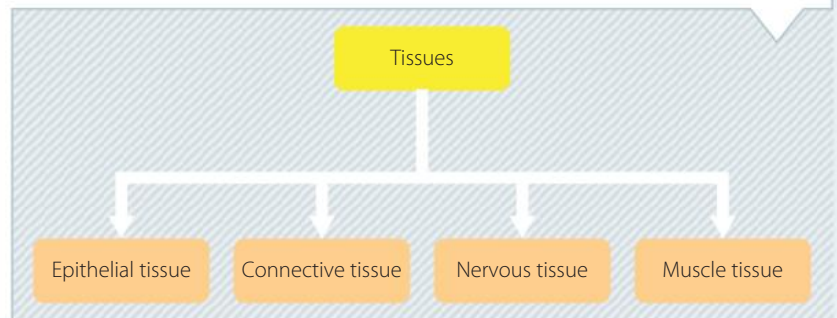


CELL ORGANISATION, SPECIALISATION AND FUNCTIONING

Animals

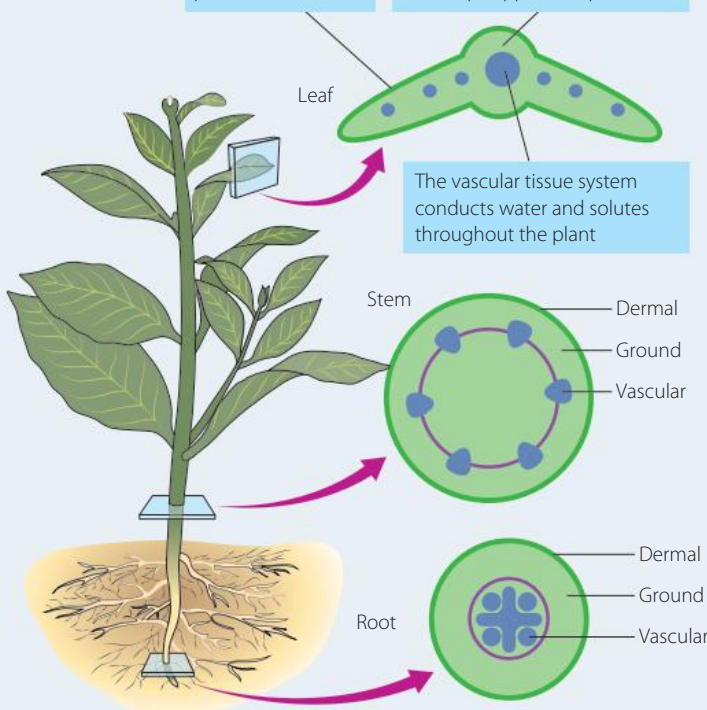
Specialised cells make up tissues, with different types of tissues forming organs that carry out particular functions within an organ system.

- There are four main types of animal tissue: epithelial tissue, connective tissue, nervous tissue and muscle tissue.
- There are many different forms of each of these types of tissues.



The dermal tissue system is the outer covering of the plants

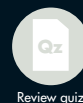
The ground tissue system carries out photosynthesis, stores photosynthetic products, and help support the plants



Plants

- The four main types of plant tissue are meristematic tissue, vascular tissue, dermal tissue and ground tissue.
- The arrangement of cells into tissues, organs and systems in multicellular organisms maximises the efficient functioning of the organisms.
- The interaction and cooperation between cells, tissues, organs and systems provides multicellular organisms with abilities that are beyond the limitations of a single cell.

4 CHAPTER REVIEW QUESTIONS



- 1 List the following in order from the simplest to the most complex:
molecules, cells, atoms, chemical substances, organelles
- 2 Copy and complete Table 4.5 to compare the characteristics of unicellular, colonial and multicellular organisms.

TABLE 4.5

CHARACTERISTIC	UNICELLULAR		COLONIAL	MULTICELLULAR
	PROKARYOTIC	EUKARYOTIC		
Composed of cells				
Cells possess a cell membrane, cytosol, ribosome and genetic material				
Number of cells				
Membrane-bound nucleus and organelles				
Cells can live independently of other cells				
How the organism gains its nutrients				
SA:V				
Organisation of cells in the organism				
Specialisation of cells in the organism				

- 3 Using the information in completed Table 4.5, construct Venn diagrams for the following combinations of organisms:
 - a unicellular and colonial
 - b colonial and multicellular
 - c unicellular and multicellular
 - d prokaryotic unicellular and eukaryotic unicellular.
- 4
 - a Describe the features of one example of a colonial organism.
 - b Outline a similarity this example shares with unicellular organisms and with multicellular organisms.
- 5
 - a Differentiate between the terms 'cell specialisation' and 'cell differentiation'.
 - b Identify the types of cells that specialised cells originate from in animals.
 - c Describe the process that occurs to produce specialised cells.
- 6
 - a Plants also possess undifferentiated cells that will mature and form specialised cells.
Identify the name of the tissue that contains undifferentiated cells and the regions in the plant where this is found.
- 7
 - a Most cells in the body contain genetic material. This genetic material is identical in all of these cells.
Explain how it is possible for cells with identical genetic material to exhibit different structural features.
 - b Draw a Venn diagram to compare specialised cells and stem cells.
- 6 Investigate the reasons why stem cell research has caused such great ethical debate.
- 7
 - a Identify two examples (one plant, one animal) of specialised cells.
 - b For each cell, describe how their structure assists them to carry out their specific function effectively.

8 Copy and complete Table 4.6.

TABLE 4.6

LEVEL OF ORGANISATION	DESCRIPTION	EXAMPLES
Organelles		
Cells		
Tissues		
Organs		
Organ systems		

- 9 The four basic types of tissue in the human body make up all of the organs of the body. Describe the specialised characteristics of each type of tissue and how they contribute to the effective functioning of the body.
- 10 Describe how the different types of tissue in a plant work together to ensure the efficient functioning of the plant.
- 11 Predict the effect on the functioning of an organism if the process of cell differentiation did not occur properly.
- 12 'The interaction and cooperation between cells, tissues, organs and organ systems provide multicellular organisms with abilities that are beyond the limitations of a single cell.' Discuss this statement.

5

Nutrient and gas requirements

INQUIRY QUESTION

What is the difference in nutrient and gas requirements between autotrophs and heterotrophs?

Students:

- investigate the structure of autotrophs through the examination of a variety of materials, for example: (ACSBLO35) **ICT**
 - dissected plant materials (ACSBLO32)
 - microscopic structures
 - using a range of imaging technologies to determine plant structure **ICT**
- investigate the function of structures in a plant, including but not limited to:
 - tracing the development and movement of the products of photosynthesis (ACSBLO59, ACSBLO60) **ICT**
- investigate the gas exchange structures in animals and plants (ACSBLO32, ACSBLO56) through the collection of primary and secondary data and information, for example:
 - microscopic structures: alveoli in mammals and leaf structure in plants **ICT L**
 - macroscopic structures: respiratory systems in a range of animals **ICT L**
- investigate the exchange of gases between the internal and external environments of plants and animals **ICT L**
- trace the digestion of foods in a mammalian digestive system, including: **ICT L**
 - physical digestion
 - chemical digestion
 - absorption of nutrients, minerals and water
 - elimination of solid waste
- compare the nutrient and gas requirements of autotrophs and heterotrophs **L ICT**

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There are many substances that *all* living organisms require for their efficient functioning. Inorganic and organic substances are essential nutrients for both **autotrophs** and **heterotrophs** (Fig. 5.1). These nutrients are required to supply energy to the organism and to provide the raw materials to be used in building the structure of cells and living tissues.

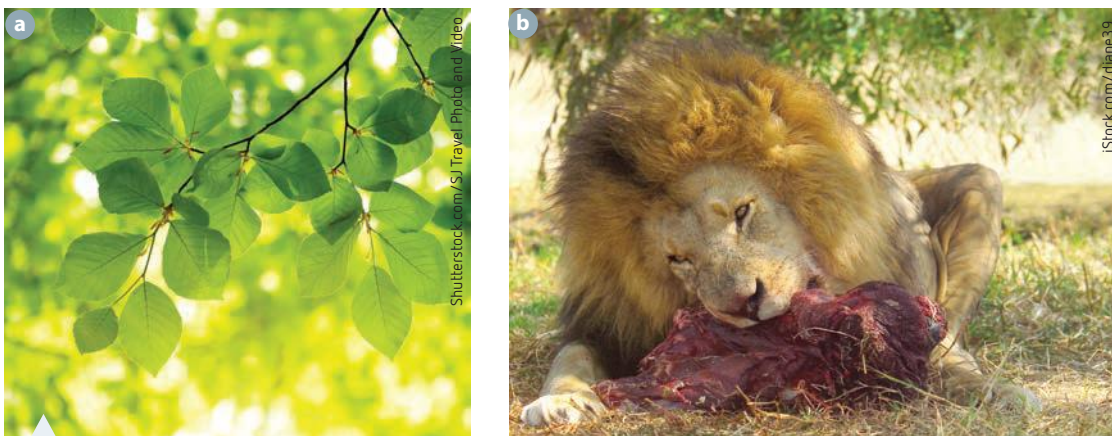


FIGURE 5.1 **a** Autotroph; **b** heterotroph

Organic nutrients include substances such as glucose, amino acids, fatty acids, glycerol, nucleotides and vitamins. Inorganic nutrients include minerals such as phosphates, sodium ions and chloride ions, and water. Heterotrophs need to take in all of these nutrients from external sources. Autotrophs can produce their own organic nutrients and need to obtain water, mineral ions and the gases carbon dioxide and oxygen from external sources.

5.1 Autotroph structure and function

The majority of autotrophic organisms are plants. Most plants are described as **vascular plants** because they possess a transport system to move substances from one part of the plant to another. A small number of plants are termed **non-vascular plants** because they do not possess this transport system. These plants, such as mosses and liverworts, have a very simple structure, and all nutrients are absorbed and wastes removed by diffusion and osmosis through the surfaces of the plant.

Plants have specialised cells that are grouped together into tissues (such as photosynthetic tissue). These tissues, along with other tissues, form organs (such as the leaf) that carry out particular functions to support the effective and efficient functioning of the plant. These tissues all have specific functions within the plant, including transport of substances, photosynthesis, reproduction and gas exchange.

The structure of a vascular plant ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs. These organs are part of the ‘body’ systems – the root, the shoot and the vascular system – found in plants (Fig. 5.2).

In a vascular plant, there are specialised cells and tissues that distribute organic compounds, water, minerals and gases around the plant. The vascular system involved in the transport of substances in plants is composed of two different types of tissues: xylem and phloem.

Xylem is responsible for the transport of water, along with water-soluble nutrients and minerals, absorbed from the soil through the root system.

Phloem is conductive tissue composed of thin-walled cells that transport sugars, in the form of dissolved **sucrose**, and other plant products from one part of a plant to another.

Xylem and phloem will be studied in greater detail in Chapter 6.

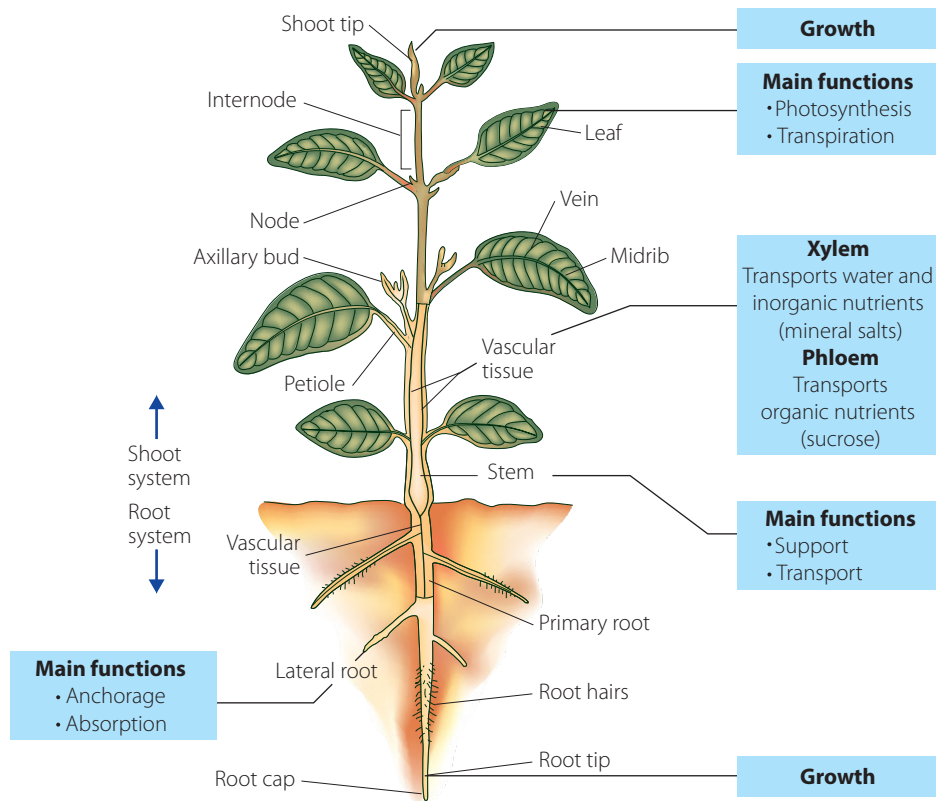


FIGURE 5.2 Structure of a vascular plant, showing some of the organs and the three systems: root, shoot and vascular

KEY CONCEPTS

- Non-vascular plants (such as mosses) do not possess specialised structures for support and transport.
- Most plants are vascular plants and possess a transport system to move substances around the plant and provide support.
- Vascular plants contain a number of 'body' systems – the root, shoot and vascular system.
- Each system has specialised organs to carry out specific functions.
- These organs allow the plant to obtain the required nutrients and gases and to carry out all functions efficiently and effectively.
- The two types of vascular tissue are xylem and phloem.
- Xylem tissue transports water and mineral ions.
- Phloem tissue transports dissolved sucrose and other plant products around the plant.

The root system

The main functions of the root system are anchoring the plant and absorbing water and inorganic nutrients from the soil. The root system is usually underground.

The roots have a very large surface area that allows water and inorganic mineral salts to be absorbed efficiently. The epidermis is the outermost layer of the root and it is through specialised epidermal cells that the absorption of water and minerals occurs.

An increased surface area in roots is achieved in the following ways:

- Extensive branching of root systems in the mature region increases the surface area of the root for absorption, and also provides good anchorage for the plant.

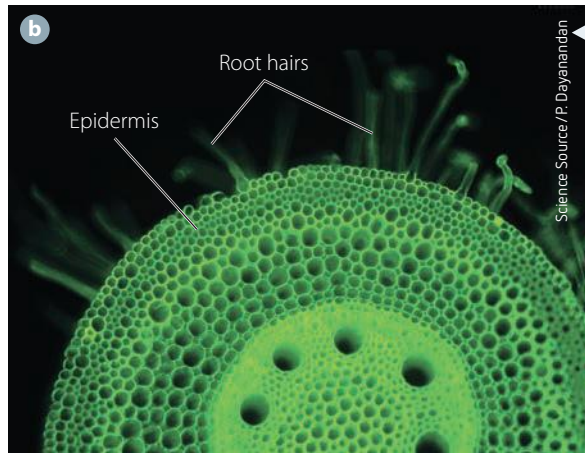


FIGURE 5.3

a The root tip of a young germinating plant showing the many root hairs that increase surface area for absorption; **b** a fluorescence image of a cross-section through a root, showing the root hairs seen as extensions of the epidermal cells

- The root hair zone is in the younger part of each root, near the tip. In this region, the **epidermal** cells protrude outwards into the surrounding soil, as microscopic extensions called **root hairs**. Their presence increases the surface area of a root up to 12 times (Fig. 5.3).
- Water enters the root through the epidermal cells across the entire surface of the root system. The flattened nature of these cells increases their exposed surface, but the surface area of general epidermal cells is smaller than that of root hair cells and so less water is absorbed per cell than in the root hair zone.

Movement of substances into the roots

Water moves into the roots by the process of osmosis while mineral ions usually move into the roots by diffusion. If the movement by diffusion is too slow or the concentration gradient is not high enough, facilitated diffusion and active transport may also be involved.

Cells of the root cannot photosynthesise because they do not contain chloroplasts and are not exposed to sunlight. They do carry out aerobic cellular respiration like all living cells. Oxygen diffuses into the cells from the air pockets in the soil and carbon dioxide diffuses out (Fig. 5.4).

See Chapter 3 to revise facilitated diffusion, osmosis and active transport.

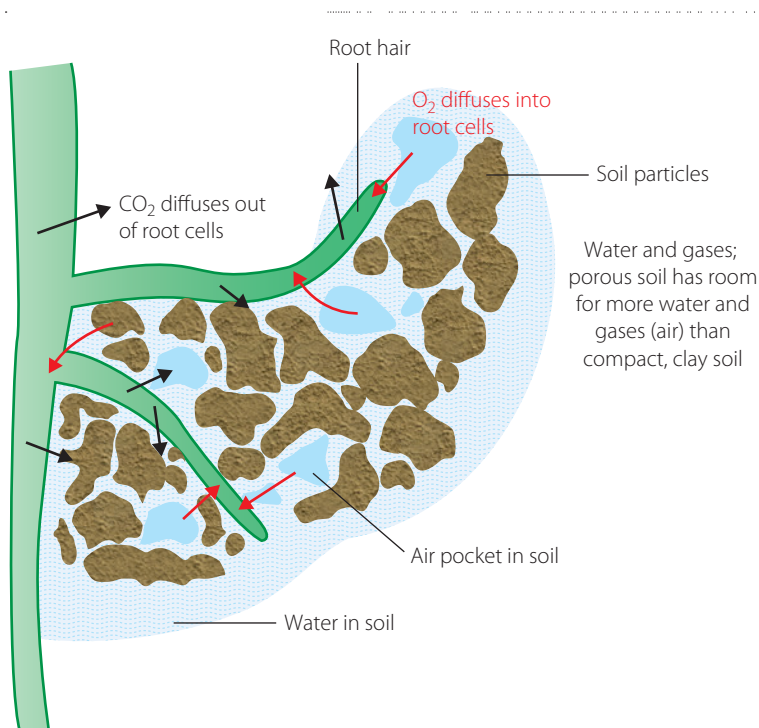


FIGURE 5.4 Gas exchange across root hairs in soil

KEY CONCEPTS

- The main functions of the root system are to anchor the plant in the soil and absorb water and mineral ions.
- A large surface area is required for efficient absorption of water and mineral ions.
- This large surface area is achieved with flattened epidermal cells that possess fine extensions called root hairs.
- Branching root systems increase the surface area for absorption.
- Water moves from the soil into the root by osmosis.
- Mineral ions usually move into the root by diffusion, but if the concentration gradient is too low they are moved in by facilitated diffusion or active transport.
- Root cells do not contain chloroplasts and do not photosynthesise but, as with all living cells, they carry out aerobic cellular respiration.
- Oxygen gas diffuses into the root cells and carbon dioxide gas diffuses out.

The shoot system: stems

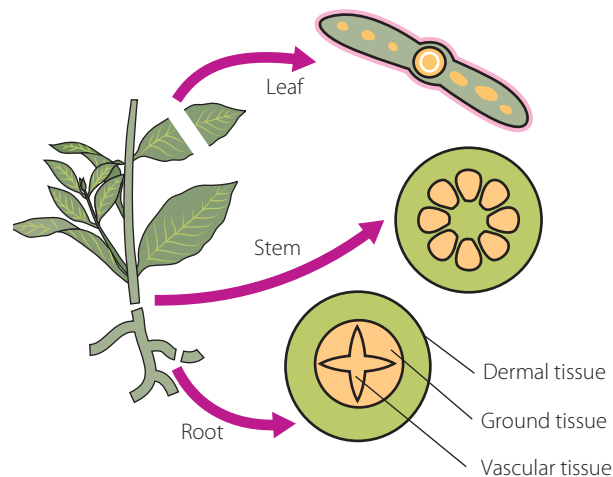
The two main structures that make up the shoot system are the stems and the leaves.

The stem provides both structural support and a transport pathway between the roots and the leaves. The stem contains dermal tissue, vascular tissue and ground tissue (Fig. 5.5):

- The dermal tissue makes up the outer layer of the stem and provides waterproofing as well as protection and control of gas exchange.
- The vascular tissue is composed of xylem and phloem tissues that are arranged in the stem in structures called vascular bundles and reach from the roots to the leaves. These provide structural support and enable transport of materials. The water and mineral ions that are absorbed by the roots and have moved into the xylem continue their journey to the leaves through the stem. The products of photosynthesis move from the leaves to all parts of the plant through the phloem tissue in the stem. The arrangement of vascular tissues varies between different plant species.
- Ground tissue in the stem fills in around the vascular tissue.

The three types of tissue carry out functions such as storage, photosynthesis and extra support for the plant.

FIGURE 5.5 Plant organs showing the types and structures of the different tissues they contain



KEY CONCEPTS

- The stem provides structural support and a transport pathway between the roots and the leaves.
- There are three main types of tissue in the stem:
 - Dermal tissue is the outer layer of the stem.
 - Vascular tissue consists of the xylem and phloem tissue organised in vascular bundles.
 - Ground tissue is all the parts of the stem that are not dermal tissue or vascular tissue.

INVESTIGATION 5.1

A practical investigation to observe the structure of the root and the stem

The main functions of roots in a vascular plant are to anchor the plant and to obtain the water and the mineral ions that are required by the plant.

The stem of a vascular plant provides support and a pathway for the movement of water, mineral ions and the products of photosynthesis. The xylem and phloem tissues are grouped together in vascular bundles that stretch from the roots to the leaves (Fig. 5.6).

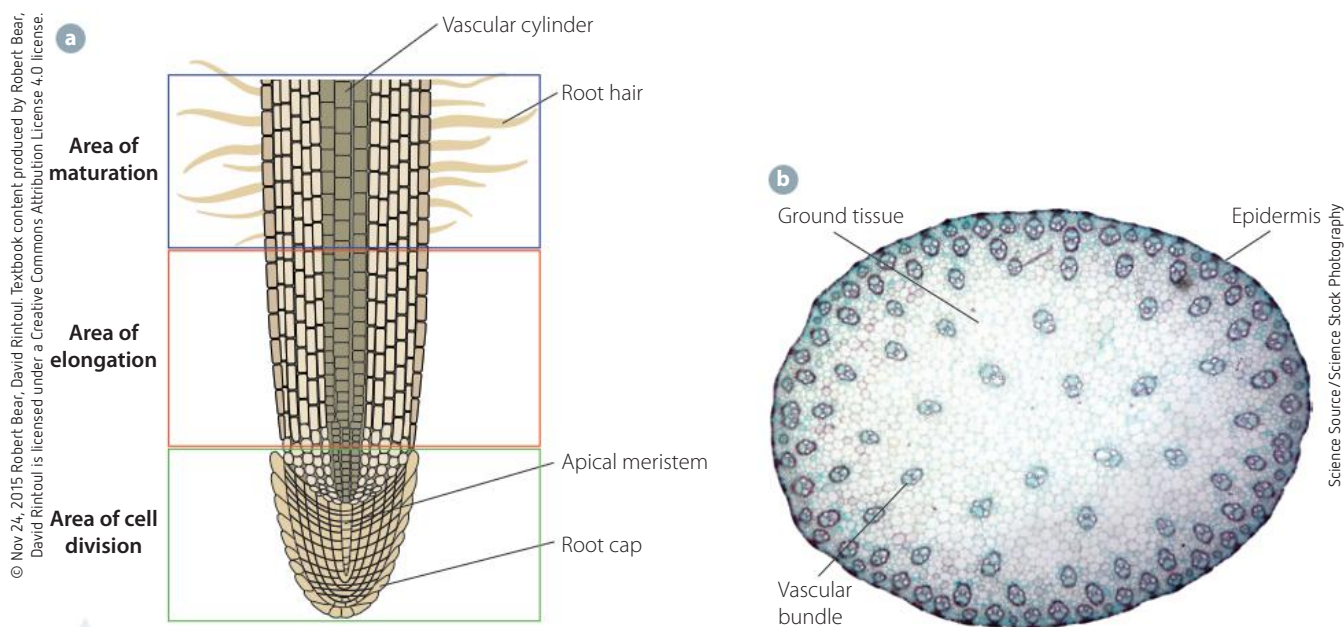


FIGURE 5.6 **a** Longitudinal diagram showing the structure of a young root; **b** transverse section (TS or slice) of a stem showing the different types of tissues present

AIM

To observe the structure of a young root and the stem of a vascular plant

MATERIALS

- Germinating bean seeds
- Hand lens
- Microscope slides
- Coverslips
- Scalpel
- Forceps
- Dissecting needle
- Light microscope
- Stereomicroscope
- Prepared slide of longitudinal section (LS) of an onion root tip
- Prepared slides of transverse section of the stem of a vascular plant





RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Glass	Can cause cuts	Be careful not to break microscope slides.
Microscope	Can drop on toes	Carry with two hands. Do not place near the edge of the bench.
Electrical plug	Electrocution or electric shock	Make sure switch is turned off before pulling out the plug. Do not place the microscope cord near water.

METHOD

Part A: The root

- 1 Observe the young root using a hand lens and the stereomicroscope, and identify the regions shown in Figure 5.6a.
- 2 Draw a labelled scientific diagram of the structure of the young bean root.
- 3 Using the monocular microscope, observe the prepared slide of the longitudinal section of an onion root tip and again identify the areas shown.
- 4 Draw a sketch of the internal structure of the root. Label the vascular tissue (xylem and phloem), dermal tissue and ground tissue.
- 5 Using a scalpel, cut the thinnest transverse section possible of the young root and prepare a wet mount of this tissue.
- 6 Observe using the light microscope.
- 7 Observe a prepared slide of the transverse section of a root and compare with the slide you prepared.
- 8 Draw a labelled scientific diagram of the transverse section of the root. Include a few cells of each tissue type, drawn to show structural detail.

Part B: The stem

- 1 Observe the prepared slides of the transverse section of a stem using the light microscope, identifying the areas indicated in Figure 5.6b.
- 2 Draw a labelled plan diagram (line diagram) of the arrangement of the different tissues in the stem.

RESULTS

- 1 Draw a labelled diagram of the following:
 - a the external structure of the young bean root
 - b the transverse section of the root
 - c the internal longitudinal structure of the onion root tip
 - d the arrangement of tissues in the transverse section of the stem.

DISCUSSION

- 1 Describe how the young root maximises its surface area. Explain why this is important.
- 2 Describe the function of the different types of tissue that you observed in the transverse section of the stem.
- 3 Relate the structures viewed in the root and stem to their functions in obtaining and transporting nutrients and in gaseous exchange.

CONCLUSION

Summarise how your observations can be used to determine the structure of roots and stems.

Refer to p. 37 to review biological drawing.

- 1 Distinguish between:
 - a vascular and non-vascular plants
 - b xylem tissue and phloem tissue.
- 2 Identify the following:
 - a three systems present in most plants
 - b two plant tissues
 - c two organs present in plants.
- 3 a Outline two functions of the root system.
 - b Describe the ways in which the roots increase surface area for absorption.
 - c Explain how the structure of the root hair cell is related to its function.
- 4 Outline the processes by which water and mineral ions move into the roots.
- 5 Construct a table to summarise the different types of tissue in the stem and the function of each type.

The shoot system: leaves

The main function of a leaf is to absorb sunlight and carbon dioxide and produce the organic compound glucose in the process of *photosynthesis*. Leaves are also the site of **transpiration**, a process by which water evaporates from the leaf. This aids in the movement of water from the roots to the leaves and also cools the plant. The structure of a leaf greatly assists it to carry out these functions in an efficient and effective manner.



Structure of vascular plants

Absorbing sunlight

The leaves of plants are adapted to absorb the maximum amount of sunlight possible to provide the energy to break the bonds in water molecules during the first stage of photosynthesis.

The thin, flat structure of most leaves is very well suited to this function. A large surface area allows maximum absorption of light energy by the chlorophyll inside the chloroplasts of the cells.

The thin structure of the leaf means that no internal cell is too far from the surface to receive light. The outermost layer of cells, the epidermis, is transparent, allowing the sun to penetrate through to the photosynthetic cells beneath.

The cells that occur in the **mesophyll**, or middle layers of the leaf, are responsible for most of the plant's photosynthesis. Two main types of cell make up the mesophyll. They are the **palisade cells** and **spongy cells** (Fig. 5.7):

- Palisade cells are elongated cells that are dense with chloroplasts and are the main photosynthetic cells in leaves. They are situated vertically, immediately below the upper epidermis, so they are exposed to the maximum amount of sunlight. The large number of chloroplasts in these cells ensures a maximum rate of photosynthesis.
- Spongy mesophyll cells are the second most important photosynthetic cells. These cells are situated between the palisade cells and the lower epidermis. They have fewer chloroplasts than the palisade cells and are irregular in their shape and distribution.

In hot, dry habitats, plants risk losing a lot of water through evaporation. Waxy cuticles and other adaptive characteristics of the leaf reduce the amount of water lost.

Plants that live in different environments have different leaf shapes. **Rainforest** plants that grow on the ground below the canopy receive a minimal amount of sunlight. They possess very large, thin and flat leaves that are dark in colour so they absorb as much sunlight as possible. Due to the high humidity in this position in the rainforest, there is less concern about water loss by evaporation.



Comparing tissues
and cells in leaves

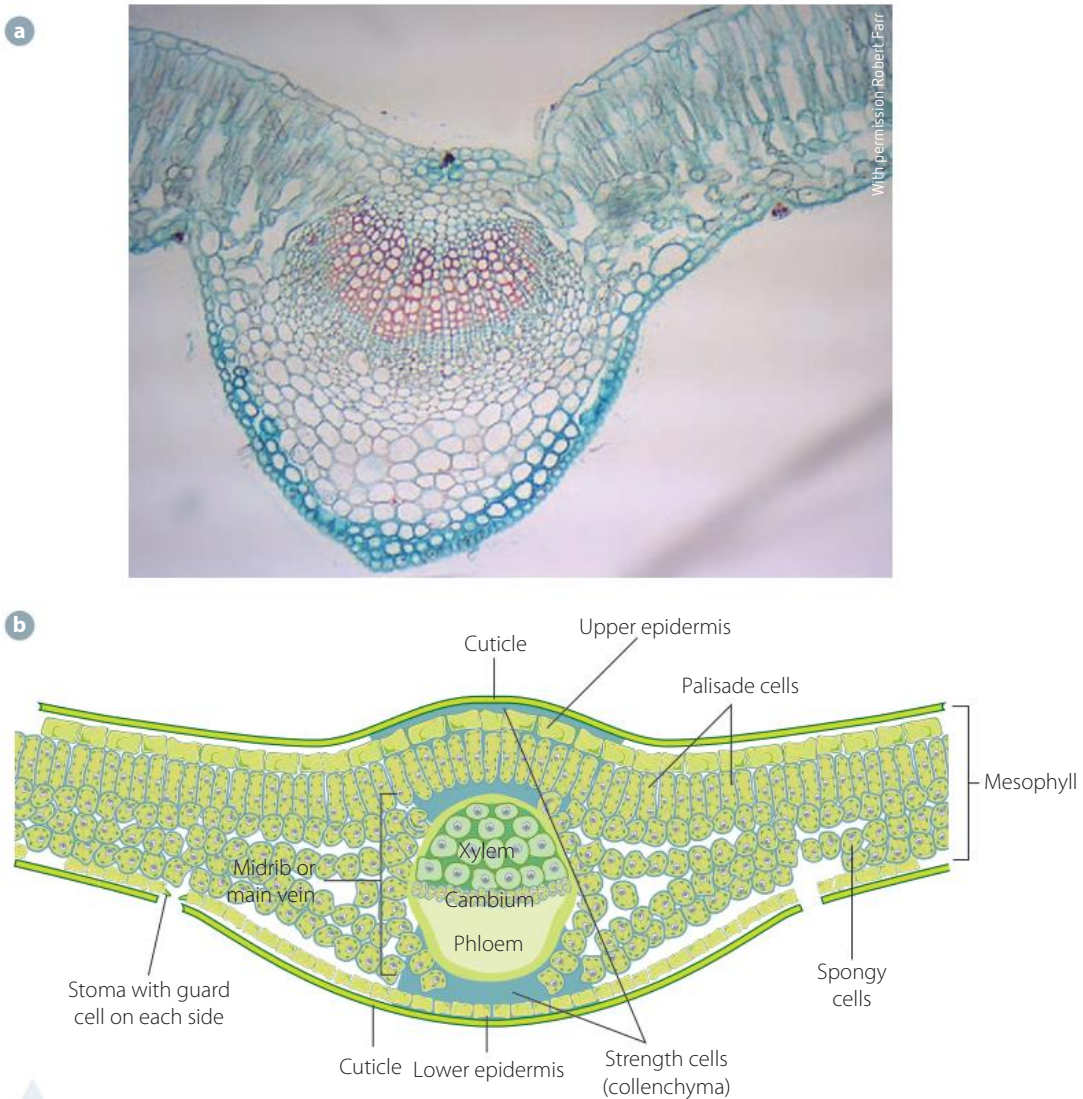


FIGURE 5.7 Structure of a leaf: **a** light micrograph cut in a transverse section; **b** plan diagram in a transverse section

Plants that live in hot, dry environments have copious amounts of sunlight but high rates of evaporation of water. They often possess leaves that are very small, with minimal surface area that can still absorb the necessary amount of sunlight while reducing water loss to a minimum. Many Australian plants have this adaptation.

Gaseous exchange

A protective layer of cells, the epidermis, covers the surface of leaves. These are simple, flattened cells on the top surface (upper epidermis) and lower surface (lower epidermis) of leaves. Epidermal cells protect the delicate inner tissues and are able to secrete a waterproof cuticle to prevent the evaporation of water from the increased surface area of leaves. They are transparent to allow light to pass to the cell layers below (Fig. 5.7).

Within the epidermis, there are specialised cells called **guard cells** that control both the exchange of gases (such as carbon dioxide and oxygen) and the loss of water (as water vapour) through leaves (Fig. 5.7). Guard cells are bean-shaped cells that occur in pairs, surrounding a pore (opening) known as a **stoma** (plural: stomata). Stomata usually occur on the under surface of the leaf, but can occur on both the upper and lower surfaces of leaves.

Gas exchange in
plants will be treated
in more detail on
page 145.

Transport

The vascular tissue in the centre of the root is continuous, passing up the stem and into the leaves as ‘veins’ in the leaf, and serves as the main transport tissue in the plant. The main vein in the leaf is called the **midrib** and many smaller veins branch out from it. The veins contain xylem and phloem tissue. The distribution of vascular tissue throughout the leaf ensures that no leaf cells are too far away from a source of transport. Vascular tissue also plays an important role in *supporting* the thin leaf blade.

Cellular respiration in plants

It is important to remember that plants carry out cellular respiration as well as photosynthesis. Cellular respiration is a function of *all* living cells; in leaves it is simply ‘masked’ or hidden by photosynthesis and so the observed exchange of gases by plants during the day differs from that at night.

In all plant cells, cellular respiration occurs during both the day and the night.

During the day:

- The oxygen required for cellular respiration comes from the oxygen produced as a by-product of photosynthesis. Photosynthesis usually occurs at a greater rate than respiration during the day, so any oxygen not used during cellular respiration is released by the plant to the outside environment.
- The carbon dioxide released as a result of cellular respiration during the day is used as a reactant in photosynthesis. When the rate of photosynthesis is high, this carbon dioxide supply is usually insufficient, so plants absorb more carbon dioxide from the air. The net gaseous exchange observed during the day is therefore that associated with photosynthesis, despite the fact that cellular respiration is occurring.

INVESTIGATION 5.2

A practical investigation to observe leaf structure

Leaves are made up of a number of different tissues, arranged in a highly organised way to maximise their efficiency in carrying out their functions.

AIM

To observe the structure of a typical plant leaf and relate these structures to their functions

MATERIALS

- Fresh, soft leaves from herbaceous plants
- Light microscope
- Microscope slides and coverslips
- Scalpel
- Forceps
- Dissecting needle
- Petri dish of water
- Stereomicroscope, magnifying glass or hand lens
- Prepared slides of leaf transverse section





RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THESE RISKS?
Scalpel	Can cause cuts to the skin	Handle the scalpel very carefully and report any injuries to your teacher immediately.
Glass	Can cause cuts	Be careful not to break microscope slides.
Microscope	Can drop on toes	Carry with two hands. Do not place near the edge of the bench.
Electrical plug	Electrocution or electric shock	Make sure switch is turned off before pulling out the plug. Do not place the microscope cord near water.

METHOD

- 1 Observe a fresh leaf and note the position of the midrib and the veins.
- 2 Use a stereomicroscope, hand lens or magnifying glass to make a closer observation of the external characteristics of the leaf.
- 3 Draw a diagram of the leaf and sketch in the position of the transport tissue (midribs and veins).
- 4 Cut the leaf in half in a transverse direction (Fig. 5.8).
- 5 Place the freshly cut half between two microscope slides with the freshly cut edge protruding very slightly.
- 6 Use the scalpel to slice a thin section from this edge into a Petri dish containing water. Repeat a number of times.
- 7 Using the thinnest transverse section, prepare a wet mount.
- 8 View the section with a light microscope, using low power to begin with and then high power.
- 9 Identify the different tissues present: upper and lower epidermal tissues, palisade cells, spongy mesophyll cells, vascular tissue, guard cells and stomata.
- 10 Draw a labelled diagram of the structures observed.
- 11 Use the light microscope to view a prepared slide of a transverse section of a leaf and compare it with the section you prepared.
- 12 Use a mobile phone or digital camera, if possible, to take a photograph through the eyepiece.

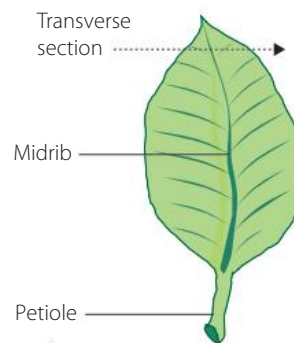


FIGURE 5.8 Leaf showing midrib, veins and direction of transverse section

RESULTS

- 1 Draw a labelled diagram of the leaf you observed. Include the position of the midrib and veins.
- 2 Describe any other characteristics of the leaf that you noted.
- 3 Draw a labelled scientific diagram of the transverse section of the leaf either from your section or from the prepared section. Alternatively, print out the digital photograph and label the structures.

DISCUSSION

- 1 Outline the distribution of veins in the leaf. Suggest why this is important to the cells in the leaf.
- 2 Identify the cells in the leaf that carry out photosynthesis. Describe the distribution of these cells and discuss the advantages of this in terms of their function.
- 3 Comment on the thickness of the upper and lower epidermal layer, and suggest reasons for any difference.
- 4 Outline how the structures of tissues in the leaf are suited to providing nutrients and gases to the plant.

CONCLUSION

Summarise the structures that you investigated and relate their structure to their function.

- The main function of the leaf is to absorb sunlight and carry out photosynthesis to produce the organic compound glucose.
- The thin, flat structure and orientation of the leaf maximise surface area for absorption of sunlight.
- A waxy cuticle minimises water loss from the leaf.
- Palisade cells containing many chloroplasts are lined up vertically near the upper surface of the leaf to absorb sunlight.
- Spongy mesophyll cells are loosely and irregularly organised to allow easy movement of gases through the leaf.
- Transport tissue in the leaf is organised into veins. This provides support as well as a pathway for the movement of water and the products of photosynthesis.
- Guard cells, which are often more numerous on the underside of the leaf, change shape to open and close 'pores' known as stomata.
- The gases oxygen and carbon dioxide are exchanged between the inside and outside of the leaf through stomata.
- All plant cells carry out cellular respiration both at night and during the day.
- Oxygen produced in photosynthesis is used in this process.

Imaging technologies used to determine plant structure

The development of technologies that are much more advanced than light and electron microscopes has led to a greater depth of understanding of not only plant structure but also plant functioning.

The rapid development of these technologies has been facilitated by the ability to capture an image, manipulate it and process it using advanced computer modelling. Various technologies have been developed to study aspects of plant structure and function.

A three-dimensional (3D) image of a plant can be produced by using a digital camera to take photos from different angles. These photos are then combined by a computer program that produces a 3D image of the plant. Measurements can be made and external structure studied using this image.

MRI (magnetic resonance imaging) uses radio waves and a magnetic field to take a series of images of the plant structures that are used to produce a computer-generated 3D image of the structure (Fig. 5.9). One application is to grow plants in clear containers so that the structure of roots can be studied by MRI. These structures can then be analysed in greater detail than through simple observation.

The MRI image can be combined with images formed by other technologies such as **PET** (positron emission tomography) or **NT** (neutron tomography) to provide not only greater detail but also functional information about transport and processes (Fig. 5.10). Both of these technologies involve the detection of radiation produced by a radioisotope (see page 144).

X-ray computed microtomography (micro-CT) is another emerging technology being used to gain a much deeper knowledge of the internal structure of a plant (Fig. 5.11). This process is non-destructive and similar to the CT scan used in hospitals, but on a smaller scale and with a higher resolution. A sample positioned in an X-ray beam is rotated and hundreds of images from different angles are recorded. These are then analysed and reconstructed into a 3D computer-generated image. Any angle can be observed and the spatial arrangement of internal tissues of the plant can be studied.

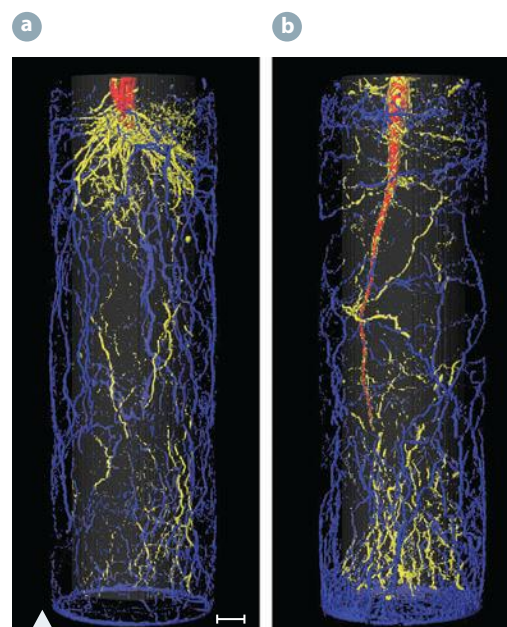


FIGURE 5.9 MRI image of the roots of a sugar beet grown in a cylindrical pot. The outer roots are blue, the inner roots yellow. The starch storage area is red.

Reproduced from Poorter et al (2012), with permission from CSIRO Publishing.



FIGURE 5.10 Image of maize roots produced by MRI and NT technologies

Tracing the development and movement of the products of photosynthesis

The mechanism by which the process of photosynthesis occurs has been investigated over a long period. It was originally thought that sunlight acted on carbon dioxide in the initial stages of photosynthesis. Melvin Calvin used a **radioactive tracer, carbon-14**, to show that sunlight actually acts on the chlorophyll to begin the manufacturing of organic compounds. He was awarded the Nobel Prize in 1961 for his ground-breaking work.

Isotopes are different forms of the same element. **Radioisotopes** are isotopes that emit radiation – they are said to be **radioactive** (they emit radioactive waves or particles to try to achieve a stable state).

The emission of these radioactive particles or waves can be measured using a number of methods. Radioisotopes are very useful as tracers – technologies can be used to trace their paths in physical, chemical and biological systems.

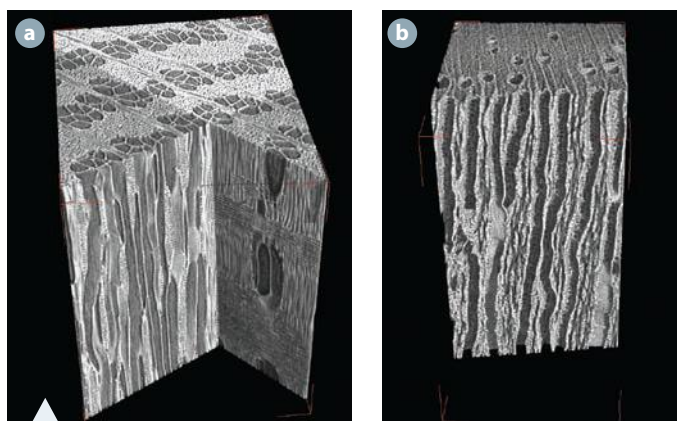


FIGURE 5.11 Micro-CT image of xylem tissue in two different plants

With permission from Steven Jansen

Radioisotopes were used to determine whether the oxygen released during photosynthesis originated from the oxygen atom in water or that in carbon dioxide. Plants that were given water that contained radioactive atoms of oxygen showed that all of the radioactive oxygen atoms from the water molecules were released as oxygen gas, showing that *water* (and not carbon dioxide) was the source of oxygen gas released during photosynthesis.

The pathway of the glucose produced in photosynthesis can also be traced using radioisotopes. To do this, carbon-14 is added to the carbon dioxide supply of a plant. This carbon-14 then takes part in the reactions of photosynthesis and is incorporated into the glucose molecules produced. The pathway of movement of glucose molecules can be traced using the radiation being emitted by the carbon-14 and recorded in an autoradiograph. This can be achieved by placing the experimental plant against photographic film; the dark areas on the film show where the carbon-14 has accumulated.

Modern computer software can convert the information into 3D images so that investigators can 'see' where the radioactively labelled chemicals are moving or stored in living organisms. **Real-time radioactive imaging system (RRIS)** is a non-destructive imaging system that visualises the movement of substances in the phloem.

PlanTIS is a PET scanner for plants. It is used to trace the radioisotope carbon-11, which in the process of decay emits radiation that is detected by the scanner. This traces the movement of carbon-11, which has been incorporated into the glucose molecule.

- Radioisotopes are forms of an element that emit radiation, which can be detected by a number of means. They act as tracers and are used to follow the pathways of molecules involved in photosynthesis.
- Radioisotopes were used to determine that oxygen produced in photosynthesis came from the water molecule and not the molecule of carbon dioxide.
- Carbon-14 added to the carbon dioxide supply traced the movement of the glucose produced through the plant.
- New technologies can be used to produce 3D images of the structures and pathways involved in the movement of products of photosynthesis.

CHECK YOUR UNDERSTANDING

5.1b

- 1 Identify the main functions of a leaf.
- 2 Describe the features of most leaves that allow them to absorb the maximum amount of sunlight for photosynthesis.
- 3 Use examples to explain why leaves in different environments have different features.
- 4 Outline the function of the following structures:
 - a epidermal tissue
 - b palisade mesophyll cells
 - c spongy mesophyll cells.
- 5 When do plant cells carry out:
 - a photosynthesis?
 - b cellular respiration?
- 6 Describe the distribution of vascular tissue in the leaf and how this assists the leaf to carry out its functions.
- 7 Discuss how the products of photosynthesis and respiration can be reused by the plant.
- 8 Identify and outline two imaging technologies that are used to determine plant structure.
- 9 Describe how radioactive tracers can be used to trace the products of photosynthesis.

5.2 Gas exchange structures

Gas exchange is an important process in all organisms. All living cells require a constant supply of oxygen and the removal of carbon dioxide. Both plants and animals possess specialised structures that allow the efficient movement of gases into and out of the organism (gaseous exchange). The surface that the gases cross is called the respiratory surface, and the movement of these gases across the surface is by diffusion.

In unicellular organisms or small multicellular organisms, the movement of substances between the inside and outside of the organism occurs across the entire cell membrane or the thin body wall.

In large multicellular organisms, specialised structures and systems are required to ensure the efficient movement of these gases.

Gas exchange in plants

The structure of leaves is well adapted for gaseous exchange. Leaves may be large and are usually flat, maximising the surface area available in comparison to the relatively small volume of each leaf. They contain open air spaces within the leaf formed by the irregular shape and arrangement of the spongy mesophyll tissue. This provides even greater surface area and allows the gases to move freely through much of the leaf without having to pass through cells. The surfaces of these cells are moist so that gases are dissolved, allowing for more effective movement. Most gaseous exchange in plants occurs through the stomata and **lenticels**.



Stomata

The waxy cuticle of leaves is non-porous to both water and gas. Leaves possess pores in the epidermis through which the gases oxygen and carbon dioxide move into and out of the plant. These pores are called stomata (or stomates) and are mostly found on the undersurface of the leaf. The upper epidermis may also have some, but there are usually much fewer than on the lower epidermis.

Plants have their stomata arranged in different ways. For example, Australian eucalypts have leaves that hang vertically to help minimise exposure to the hot midday sun. These leaves have their stomata distributed on both surfaces. Plants that float on water usually have stomata only on their upper surfaces, while plants that grow under water often do not have stomata.

Stomata are bordered by two bean-shaped guard cells. These guard cells are unlike other epidermal cells because guard cells contain chloroplasts. The inner wall of each guard cell is thicker than the outer wall (Fig. 5.12a).

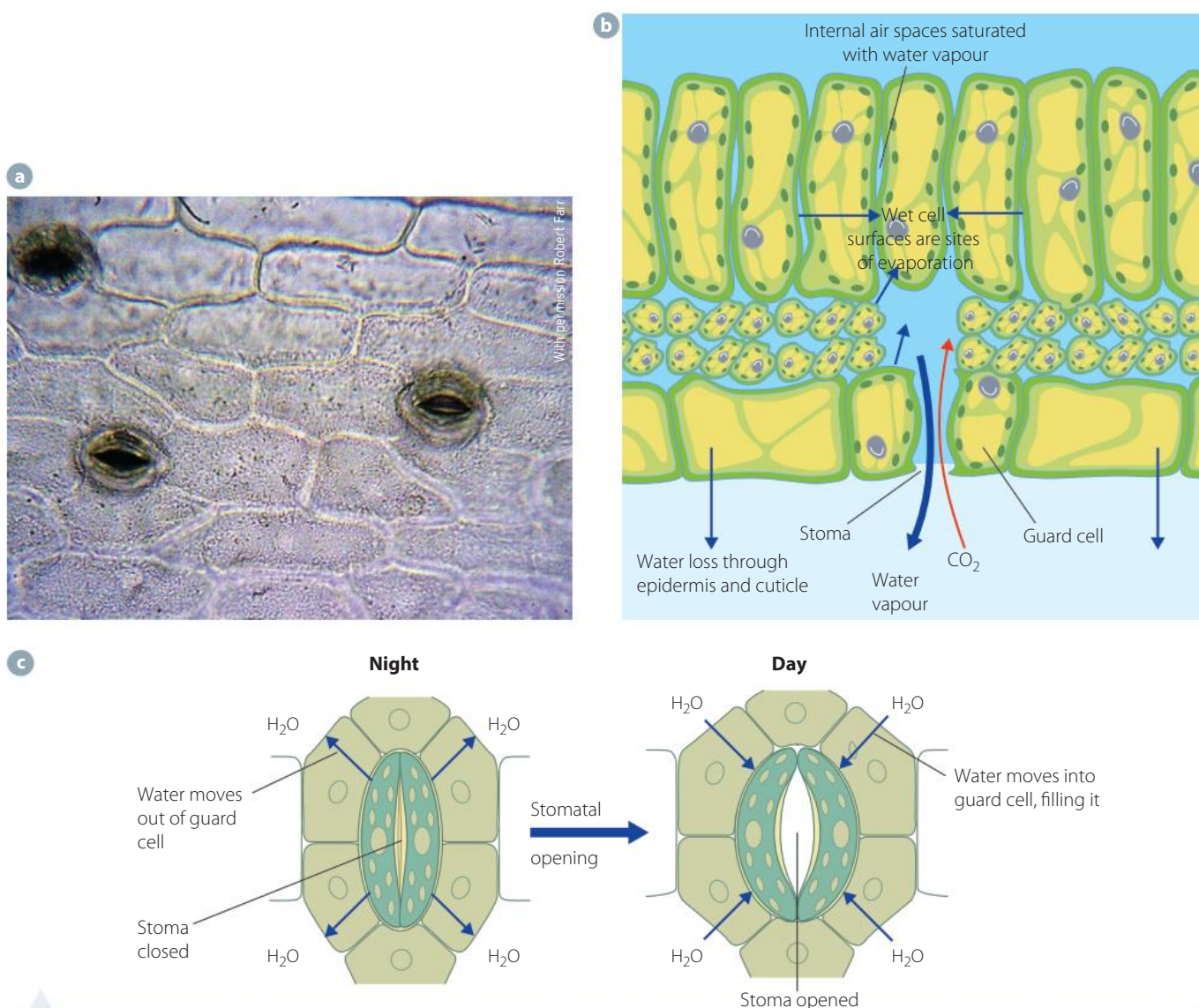


FIGURE 5.12 Stomata: **a** microscopic surface view of epidermal and guard cells; **b** transverse section through guard cells (highly magnified); **c** the functioning of stomata (closed and open)

Plants have to balance the exchange of gases without losing too much water. This is assisted by the ability of the stomata to open and close (Figs 5.12b, c). When stomata are open, gases are able to diffuse through them, but when they are closed, no gases are transported and no water is lost. When the guard cells fill with water and become turgid, the thin outer walls (which are more elastic) stretch outwards, but the thick inner walls (which are fairly inelastic) do not bulge, so they are pulled apart and the pore between them widens. When stomata lose water, the outer walls no longer bulge, so the inner walls move together again, closing the pore. What causes water to move into and out of the guard cells is still being researched, but current theories suggest it is linked to the movement of potassium ions.

The opening and closing of stomata depend on a number of environmental factors. Light is the main factor that causes the opening and closing of the stomata. Generally they open at daybreak and close at night. When the stomata are open, water is lost from the plant. Plants need to balance their gaseous requirements while minimising water loss. When the temperature increases, more and more water vapour is lost through the open stomata. If more water is lost than is taken up by the plant, the water content of the plant falls. If this continues, the guard cells will lose some of their water and the stomata will close. When water availability is decreased, photosynthesis may be limited and the concentration of carbon dioxide inside the leaf will rise. This will cause the stomata to close, restricting the entry of carbon dioxide. Conversely, if the internal concentration of carbon dioxide decreases, it can cause the stomata to open, allowing carbon dioxide to diffuse into the plant.

If the air is saturated with water vapour (high humidity), the rate of water evaporating from the leaf is reduced, enabling the stomata to remain open.

Lenticels

Lenticels are pores through which gaseous exchange occurs in the woody parts of plants, such as the trunks and branches of trees and woody shrub (Fig. 5.13). They appear as small dots to the naked eye, but on microscopic examination it can be seen that they are clusters of loose cells in the cork layer of bark.

The diffusion of oxygen, carbon dioxide and water vapour through lenticels is relatively slow.

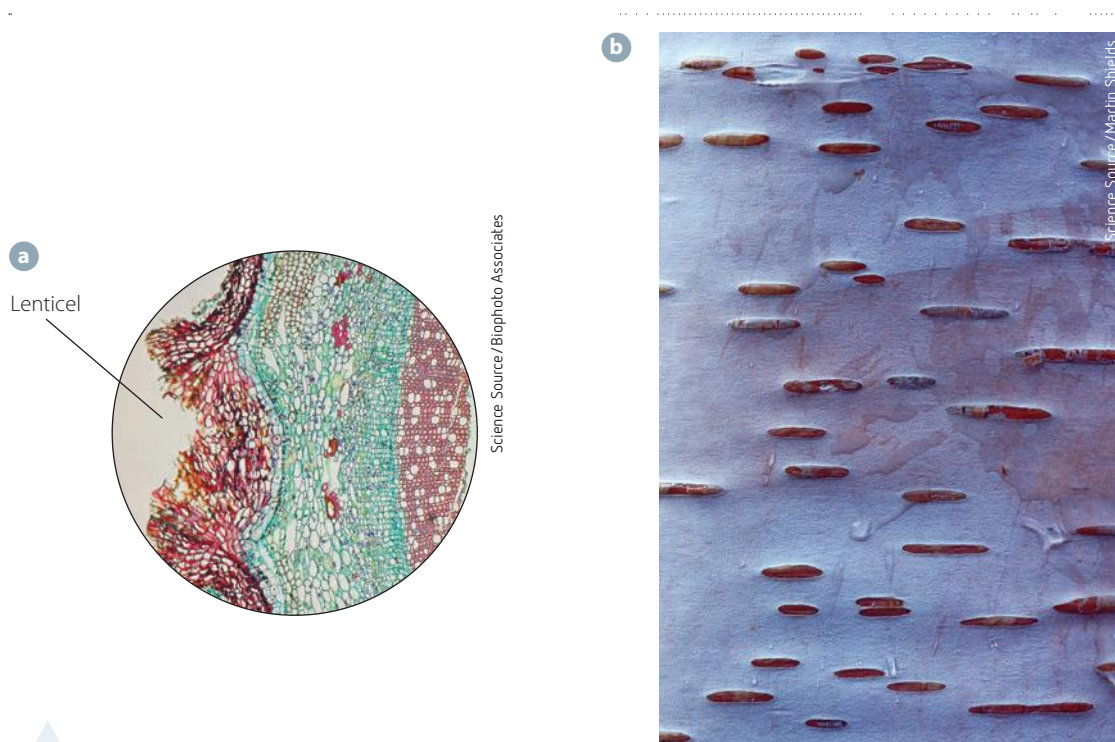


FIGURE 5.13 Lenticels are pores in the bark of stems through which gases are exchanged. **a** Microscopic view of cross-section through bark showing a lenticel; **b** external view of bark with lenticels

Opening and closing stomata

Watch the video to see how guard cells open and close the stomata.

Types of plant tissue

Read the information about the different types of plant tissue and answer the questions.

INVESTIGATION 5.3

A practical investigation to observe the structure of stomata

BACKGROUND INFORMATION

The thin lower epidermal layer can be removed from some soft-leaved plants. A wet mount can be prepared using this membrane and the guard cells and stomata can be observed using the light microscope.

AIM

To observe the structure of guard cells and stomata

MATERIALS

- Soft leaves such as pennyworts (freshly picked)
- Forceps
- Dissecting needle
- Disposable pipettes
- Microscope slide
- Coverslip
- Light microscope
- Prepared slide of stomata
- Paper towel

RISK ASSESSMENT



WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Glass	Can cause cuts	Be careful not to break microscope slides.
Microscope	Can drop on toes	Carry with two hands. Do not place near the edge of the bench.
Electrical plug	Electrocution or electric shock	Make sure switch is turned off before pulling out the plug. Do not place microscope cord near water.

METHOD

- 1 Obtain a soft leaf such as a pennywort (Fig. 5.14).
- 2 Hold the leaf on either side. Pull one side of the leaf forwards and towards the other side of the leaf to expose a portion of the lower membrane.
- 3 Remove a section of this membrane with the forceps and place it on the microscope slide (Fig. 5.15).
- 4 Ensure that the membrane is not folded over on itself.
- 5 Add a few drops of water.
- 6 Lower the coverslip gently (see page 37).
- 7 Remove any excess water using the paper towel.
- 8 View the specimen you have prepared under low power and then high power.
- 9 Sketch a few of the guard cells that you observed.
- 10 Using the microscope, view a prepared slide of the lower epidermis of a leaf showing the guard cells (Fig. 5.16).



FIGURE 5.14 Pennywort leaf – these are often found in sandy areas near water.



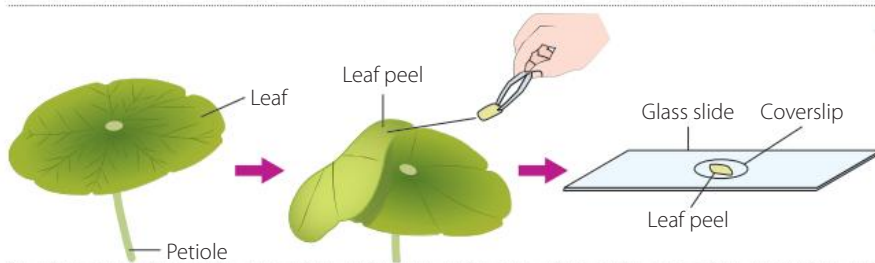


FIGURE 5.15
Preparing a wet
mount of tissue from
the underneath
surface of a leaf

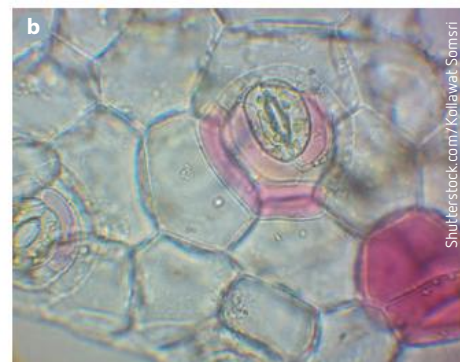
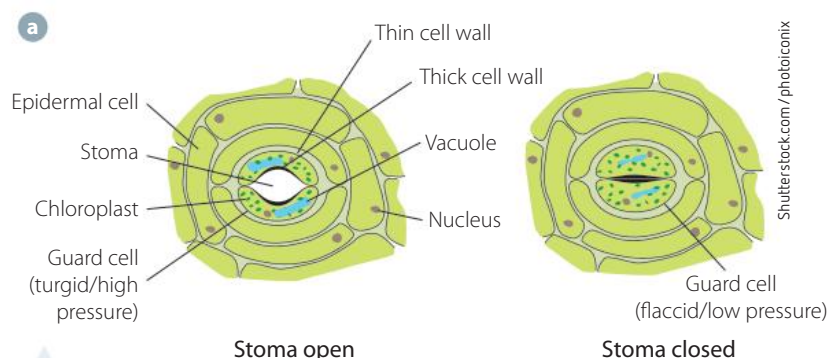


FIGURE 5.16 **a** Diagram of the cells in the membrane taken from the undersurface of the leaf, showing the guard cells and the open and closed stomata; **b** high-power magnification of stomata

RESULTS

- 1 Draw a labelled diagram of a few of the guard cells you observed (see page 37).
- 2 Were the stomata on your slide open or closed? Explain why.
- 3 Compare your slide with the prepared slide. Did you see the same basic structures? Were the stomata open or closed?

DISCUSSION

- 1 Outline the function of the stomata.
- 2 Suggest reasons why the stomata on your slide were open or closed.
- 3 Explain how the guard cells are involved in the opening and closing of the stomata.
- 4 Describe conditions that may cause the stomata to open or close.
- 5 Explain the relationship between the movements of stomata and the gas requirements of a plant.

CONCLUSION

Write a few sentences to summarise what you did and what you learnt.

KEY CONCEPTS

- Gas exchange in plants occurs through the stomata and lenticels.
- When guard cells fill with water, they bend outwards and open the stoma, allowing for gas exchange.
- When water is lost from the guard cells they straighten and close, preventing both gas exchange and water loss.
- Plants have to balance their requirement for gas exchange and the necessity for water conservation.
- Stomata open in light and close in the dark.
- Lenticels are pores through which gaseous exchange occurs in the woody parts of plants, such as the trunks and branches of trees and woody shrubs.

- 1 Distinguish between stoma, stomata, guard cells and lenticels.
- 2 Identify the three gases that are exchanged through stomata.
- 3 Describe the changes in the guard cells that cause the opening and closing of the stomata.
- 4 Compare how gases move in and out of leaf cells with how they are transferred in root cells.
- 5 Identify the origin and outline the use of each of the three gases that move in and out of the leaf cell.
- 6 Describe conditions that affect the opening and closing of the stomata.

Gas exchange in animals

Gaseous exchange occurs in all animals and involves the movement of gases between the internal and external environments by diffusion across cell membranes. Gases required by the organism to carry out normal cell functioning move into the cells, while the waste gases produced as result of these reactions diffuse out.

Oxygen is essential for all cells to carry out cellular respiration to release energy from the nutrients they have consumed. As a result of this process, carbon dioxide is produced and must be removed, as it is toxic if its concentration is too high, changing the pH of cells and interfering with enzyme functioning.

The **respiratory system** enables the exchange of gases between an organism and its environment. It contains organs made up of specialised tissues that allow an organism to take in oxygen and to remove carbon dioxide from its body.

Different animals possess different respiratory organs: mammals possess lungs, **gills** are present in fish and insects have what is known as a **tracheal system**. In microscopic organisms, gas exchange occurs by diffusion across their cell membrane. In larger terrestrial animals, the gas exchange system is inside the body to prevent dehydration of the gas exchange surfaces.

All gaseous exchange structures share common characteristics to ensure efficient functioning and maximum exchange of gases.

They all:

- have a large surface area that has been enhanced by folding, branching or flattening, depending on the structure. This large surface area allows a faster rate of diffusion to supply oxygen and to remove carbon dioxide.
- have a moist, thin surface to ensure that the oxygen and carbon dioxide dissolve for easier diffusion – thinness decreases the distance that the gases have to travel
- are in close proximity to an efficient transport system that will transport the gases to and from all cells in the body
- have a greater concentration of required gas on one side of the membrane than the other, so that a concentration gradient is maintained.

Gaseous exchange in mammals

The respiratory systems of **terrestrial** animals are internal to reduce the loss of water from the respiratory surface (Fig. 5.17). The gaseous exchange surfaces in mammals are located in the lungs. These structures are known as **alveoli** (singular: alveolus). Each thin-walled alveolus is composed of an air sac that is connected to the external environment and is surrounded by tiny thin-walled blood vessels called **capillaries**.

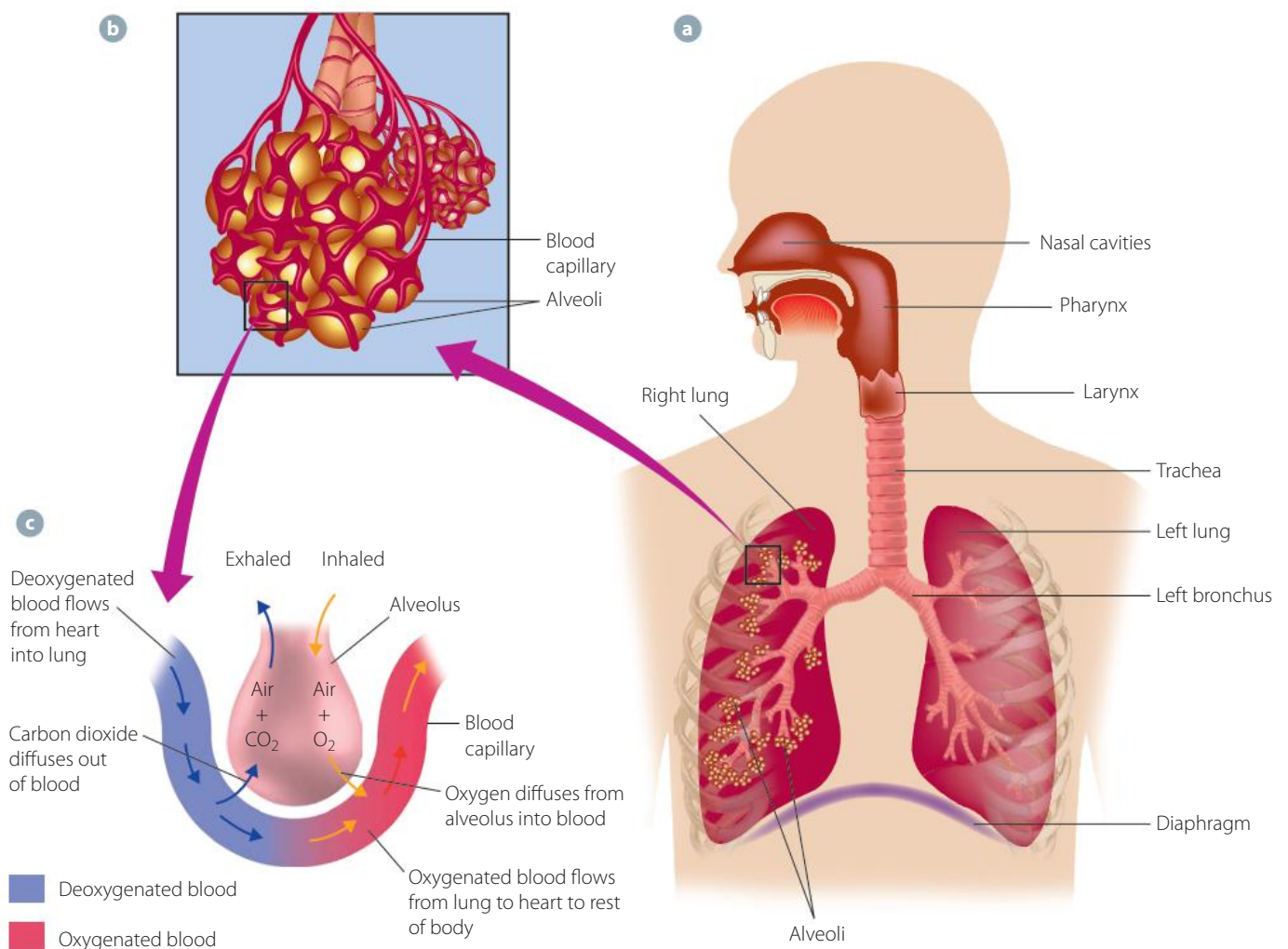


FIGURE 5.17 **a** Human respiratory system showing detail of alveoli in the lungs; **b** alveoli and blood supply; **c** one alveolus cut through in section, showing exchange of gases with an adjacent capillary

The alveoli as gaseous exchange surfaces

The alveoli in the lungs have all the features that allow for efficient gas exchange:

- Increased surface area is achieved by the approximately 300 million microscopic alveoli that are supplied by 280 million capillaries. Each alveolus has folding of the thin interior lining, thus further increasing surface area.
- Each alveolus has a thin lining made of flattened cells that are in a single layer, facilitating the efficient diffusion of gases across a very small distance.
- The surface of all parts of the respiratory system is moist. The air inside the alveoli is saturated with water vapour and the mucus-lined epithelium reduces the evaporation of this water. This ensures that the oxygen and carbon dioxide that diffuse across the gaseous exchange surface are in a dissolved form, enhancing the efficiency of diffusion.
- The numerous blood capillaries that closely surround the outside of each alveolus ensure that all alveoli are in close contact with the blood.

The movement of gases between the air in the alveoli and the bloodstream occurs by diffusion across a concentration gradient. Inhaled air contains approximately 20 per cent oxygen and 0.04 per cent carbon dioxide. Exhaled air contains approximately 15 per cent oxygen and 4 per cent carbon dioxide.



Gas exchange
in animals



Human
respiratory system

Oxygen in the incoming alveolar air is in a higher concentration than in the bloodstream, so oxygen diffuses from the air sacs into the bloodstream; carbon dioxide (a by-product of cell metabolism) is in higher concentration in the bloodstream, so it diffuses along a concentration gradient from the capillaries, through the alveolar lining and into the alveolar air, from where it will be exhaled.



Alveoli

Information on how the alveoli are adapted to allow efficient gas exchange

KEY CONCEPTS

- The movement of gases between the external environment (alveolar air) and internal environment (bloodstream) is known as gaseous exchange.
- Different animals possess different specialised structures to exchange gases with their environment.
- Common characteristics of all respiratory surfaces are that they have:
 - a large surface area
 - thin, moist surfaces
 - a close proximity to transport system
 - the concentration gradient maintained for continued diffusion.
- Terrestrial animals have internal respiratory systems to reduce water loss.
- Alveoli, located in the lungs, are the gaseous exchange surfaces in mammals.
- Millions of alveoli in the lungs create a very large surface area for the exchange of gases.
- The surface of the alveoli is very thin and moist. Many capillaries surround each alveolus.
- Oxygen diffuses from where it is more concentrated in the alveoli into the capillaries where it is less concentrated.
- Carbon dioxide is more concentrated in the capillary and diffuses out into the alveolar space.

INVESTIGATION 5.4



Information and communication technology capability



Literacy

A practical investigation to observe the alveoli in mammals

Alveoli are the gas exchange surfaces in the lungs of a mammal. They possess all the requirements of efficient respiratory surfaces.

In this practical investigation, you will observe a prepared slide of alveoli as well as images sourced from secondary sources.

AIM

To observe the gas exchange surfaces in mammals – the alveoli

MATERIALS

- Prepared slide of alveolar tissue
- Light microscope

RISK ASSESSMENT



WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Glass	Can cause cuts	Be careful not to break microscope slides.
Microscope	Can drop on toes	Carry with two hands. Do not place near the edge of the bench.
Electrical plug	Electrocution or electric shock	Make sure switch is turned off before pulling out the plug. Do not place the microscope cord near water.



» METHOD

- 1 Set up the microscope and place the prepared slide of alveolar tissue on the stage.
- 2 Focus using low power and then high power.
- 3 Draw a labelled diagram of a portion of the tissue you observed.
- 4 If possible, use a phone or digital camera to take a photo of the magnified tissue through the ocular lens.
- 5 Research images, from the Internet and other sources, of alveolar tissue as seen through the light microscope and the electron microscope.

RESULTS

- 1 Use the drawing skills you have developed to draw a labelled diagram of a portion of the alveolar tissue. Include the magnification.
- 2 Include the photographic image (if collected) and other images that have been sourced. Provide a detailed caption for each image.

DISCUSSION

- 1
 - a Outline the position of the capillaries in relation to the alveolar sacs.
 - b How thick are the walls of the alveolar sacs?
 - c Relate your answers in (a) and (b) to the ability of the alveoli to exchange gases efficiently.
- 2 Outline two other features of efficient respiratory surfaces and relate them to the structure of alveoli.
- 3 Compare the image you observed with the light microscope with the images you sourced. Account for any differences.

CONCLUSION

Write a few sentences to summarise what you did and what you learnt.

Respiratory systems in other animals

Some animals have evolved other structures to exchange gases. These structures depend on the environment in which the organism naturally lives.

Fish

Aquatic animals also need to obtain oxygen and remove carbon dioxide from their bodies to function effectively and efficiently. Gases have a low solubility in water so their concentration in water is much lower than their concentration in air. The gas exchange structures (gills) that fish possess have characteristics that can extract the maximum possible amount of oxygen from the water. Gills have all the characteristics of respiratory surfaces in animals, but are very different in structure. They require water flowing over them to ensure maximum oxygen uptake. The water flows in only one direction, entering when the fish opens its mouth as it swims. This causes the water to enter and flow over the gills and then leave the fish through the **gill slit** or slits. As the water flows over the gills, gaseous exchange takes place (Fig. 5.18).

Insects

The terrestrial habitat of the insect presents a challenge to the insect to reduce the loss of water from its internal respiratory surfaces. Insects take in and expel air through structures called **spiracles**, which are in effect breathing pores. To ensure that these spiracles are not continually exposed to the drying effects of the environment, they have valves to regulate their opening and closing. As well as this, little or no gaseous exchange can occur through their body coverings. Insects do not have lungs or blood capillaries. Because they are small organisms, they can

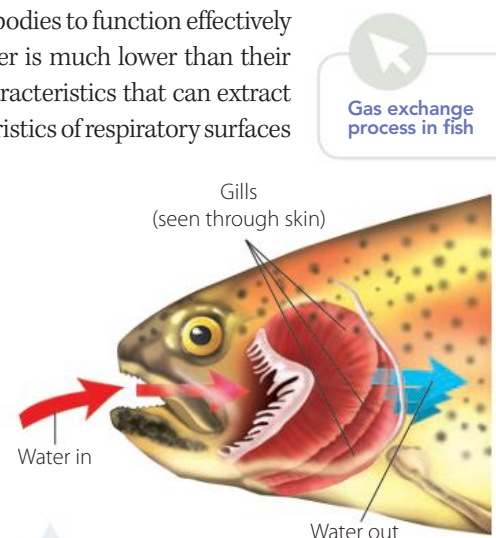
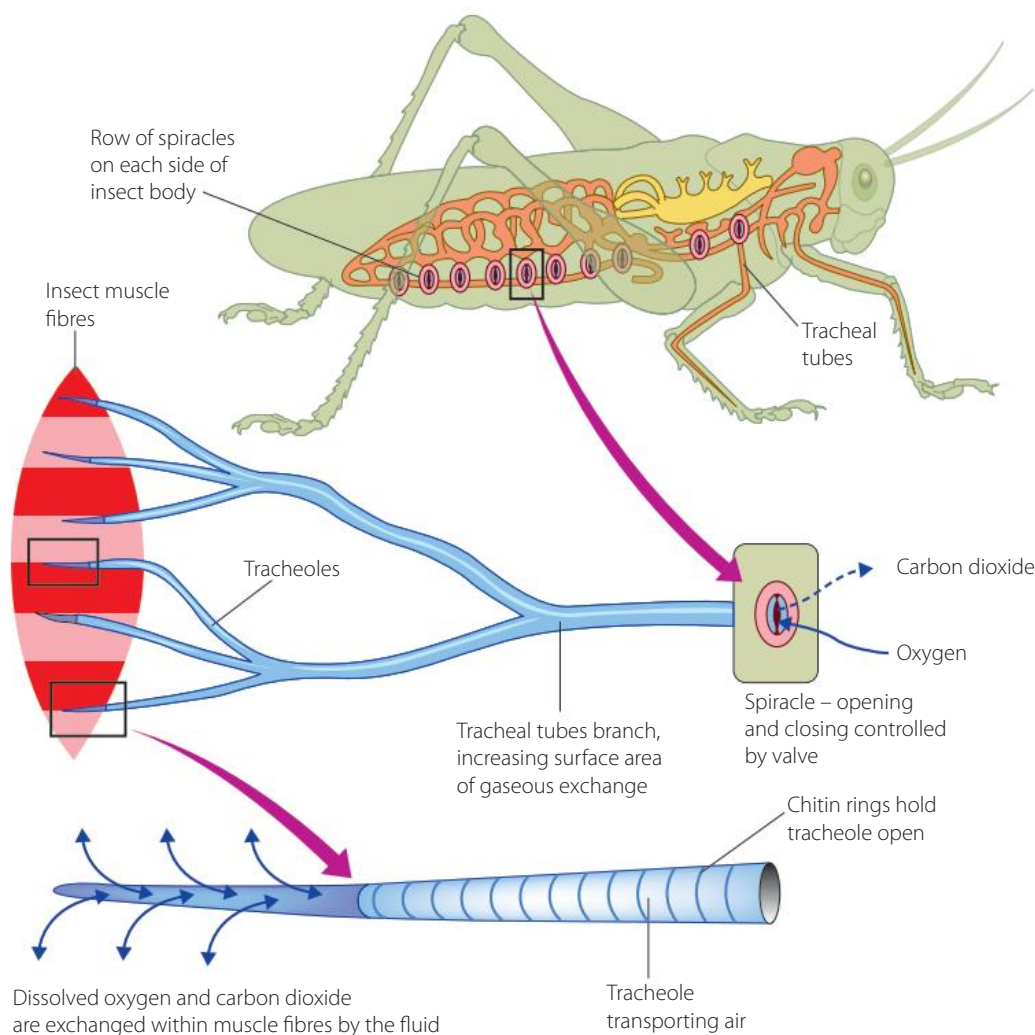


FIGURE 5.18 Respiratory system of a fish – water enters the mouth, flows over the gills and exits through the gill slits.

achieve the exchange of gases using a much simpler system. This system involves branching air tubes called **tracheal tubes**, which carry air directly to the cells of the body. Air that enters the spiracles is drawn into these tracheal tubes or tracheae. These are kept open by spiral rings of a tough supportive substance called chitin. Tracheae branch into smaller tubules called **tracheoles**, which create a very large surface area for gaseous exchange. Tracheoles bring the air directly to and from the cells of the insect.

The respiratory surface in insects differs from all other internal respiratory systems in that it has no blood or blood capillaries involved in the transport of gases. The ends of the tracheoles are filled with a watery fluid in which the gases dissolve. Oxygen from the air, dissolved in this fluid, diffuses directly into the cells and carbon dioxide diffuses directly out of the cells into the tracheoles. The number of open and closed spiracles generally controls the rate of respiration in insects – more are open when the insect is active. Muscular movements of the **thorax** and **abdomen** during movement and general body movements when flying also help to ventilate the tracheal system (Fig. 5.19).

FIGURE 5.19
Tracheal gas exchange
system of insects



KEY CONCEPTS

- Fish have specialised structures called gills to absorb the small amount of oxygen that is dissolved in water. Gills are well supplied with blood capillaries.
- Insects exchange gases via pores called spiracles, which lead to tracheal tubes, which then branch into smaller tubes called tracheoles.
- The tracheoles bring air directly to and from the cells of the insect. Blood is not involved in the transport of gases in an insect.

INVESTIGATION 5.5

A practical investigation comparing gas exchange in plants and animals

The exchange of gases between the internal and external environments of a plant and animal can be demonstrated in a number of ways. One of these involves the detection of the gas carbon dioxide. The concentration of carbon dioxide gas can be determined by measuring the pH of the solution it is dissolved in. When carbon dioxide gas dissolves in water, it forms carbonic acid, which lowers the pH of the water. This can be shown by the use of an indicator.

The indicator used in this experiment is hydrogen carbonate indicator solution, which:

- is red when the level of carbon dioxide is equal to that in the atmosphere
- becomes more orange/yellow with an increase in carbon dioxide levels
- changes from red to magenta to purple with decreased carbon dioxide levels.

It can be inferred that if the rate of cellular respiration is greater than the rate of photosynthesis, more carbon dioxide is being produced than used, so the pH of a solution surrounding a plant or part of a plant would decrease.

A decrease in the pH of a solution during an investigation indicates that respiration is occurring and that carbon dioxide is diffusing out of the plant. The rate of gas exchange would vary depending on the conditions for photosynthesis. For example, in this investigation, the presence or absence of light could change the rate of photosynthesis and therefore the rate and direction of gas exchange.

AIM

To investigate the exchange of gases between the internal and external environments of plants and animals

HYPOTHESIS

In the light, the level of carbon dioxide in solutions surrounding the organisms will increase with animals and decrease with plants.

In the dark, the level of carbon dioxide in solutions surrounding the organisms will increase with both animals and plants.

MATERIALS

- 8 × small test tubes of the same size
- Rubber stoppers to fit test tubes
- 2 × test tube racks
- Waterproof marker
- Light source
- Ambulia* cut into 5 cm lengths
- Aquatic snails
- Labels
- Scissors or scalpel
- Hydrogen carbonate indicator solution

RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Glass	Can cause cuts	Be careful when using test tubes, ensuring that they do not break.
Aquatic plants and animals	Could cause infection	Wear gloves, wash hands at conclusion of investigation.



METHOD

- 1 Place four test tubes in one test tube rack and four in the other rack (Fig. 5.20).

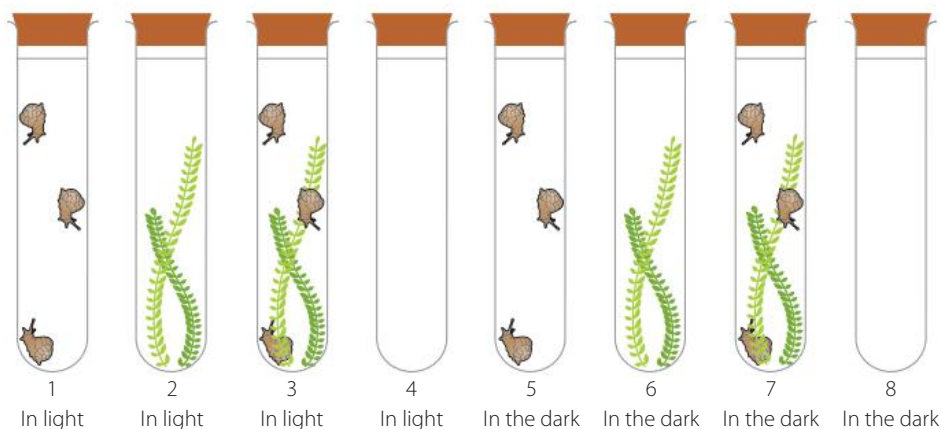


FIGURE 5.20

- 2 Label the test tubes 1 to 8.
- 3 Fill each test tube with hydrogen carbonate indicator to about 2 cm from the top.
- 4 Add the same number of aquatic animals to test tubes 1 and 5.
- 5 Add the same amount of *Ambulia* to test tubes 2 and 6.
- 6 Add the same amount of *Ambulia* and same number of aquatic animals to test tubes 3 and 7.
- 7 Test tubes 4 and 8 should contain only indicator solution.
- 8 Place a rubber stopper in the top of each test tube.
- 9 Observe and record the colour of the indicator in each test tube.
- 10 Place test tubes 1–4 under an artificial light source such as a fluorescent light.
- 11 Place test tubes 5–8 in a dark area such as inside a cupboard.
- 12 Leave both sets of test tubes for the same length of time – at least 12 hours.
- 13 Observe and record the colour of the indicator in each test tube.

RESULTS

Copy and complete Table 5.1.

TABLE 5.1

COLOUR OF INDICATOR	TEST TUBE NUMBER							
	1	2	3	4	5	6	7	8
Start								
Finish								

ANALYSIS

Copy Table 5.2 and use the results obtained to complete it.



» **TABLE 5.2**

	TEST TUBE NUMBER							
	1	2	3	4	5	6	7	8
Change in CO ₂ *								
Cellular respiration carried out **								
Photosynthesis carried out **								
Net movement of CO ₂ gas***								

* More, less or no change

** Yes or no

*** Internal to external, external to internal

DISCUSSION

- 1 Identify the following variables:
 - a independent variable(s)
 - b dependent variable
 - c controlled variables.
- 2 Identify the control(s) used in your investigation.
- 3 Why were these controls used?
- 4 a The exchange of which gas was being detected in this investigation?
 - b Explain the results obtained in the following groups of test tubes in terms of the processes of photosynthesis and cellular respiration:
 - i 1 and 5
 - ii 2 and 6
 - iii 3 and 7.

CONCLUSION

With reference to the data obtained and its analysis, write a conclusion based on the aim and hypothesis of this investigation.

CHECK YOUR UNDERSTANDING

5.2b

- 1 Identify the characteristics of an efficient gas exchange surface and relate these to the structure of the gaseous exchange structures in mammals.
- 2 Explain why living things need to continually exchange gases with their external environment.
- 3 Identify the structures involved and outline the process of gas exchange in:
 - a fish
 - b insects.
- 4 Draw a labelled diagram of an alveolus surrounded by capillaries. Use arrows of different colours to represent the gases being exchanged and the direction of their movement.

5.3 Mammalian digestive system



Human digestive system

Heterotrophs are living things that need to take in or 'eat' all of their nutrient requirements to supply energy and the building blocks for organic compounds. Complex foodstuffs are eaten, or **ingested**, and are broken down by our digestive system into simpler molecules that can be absorbed into the bloodstream (Fig. 5.21).

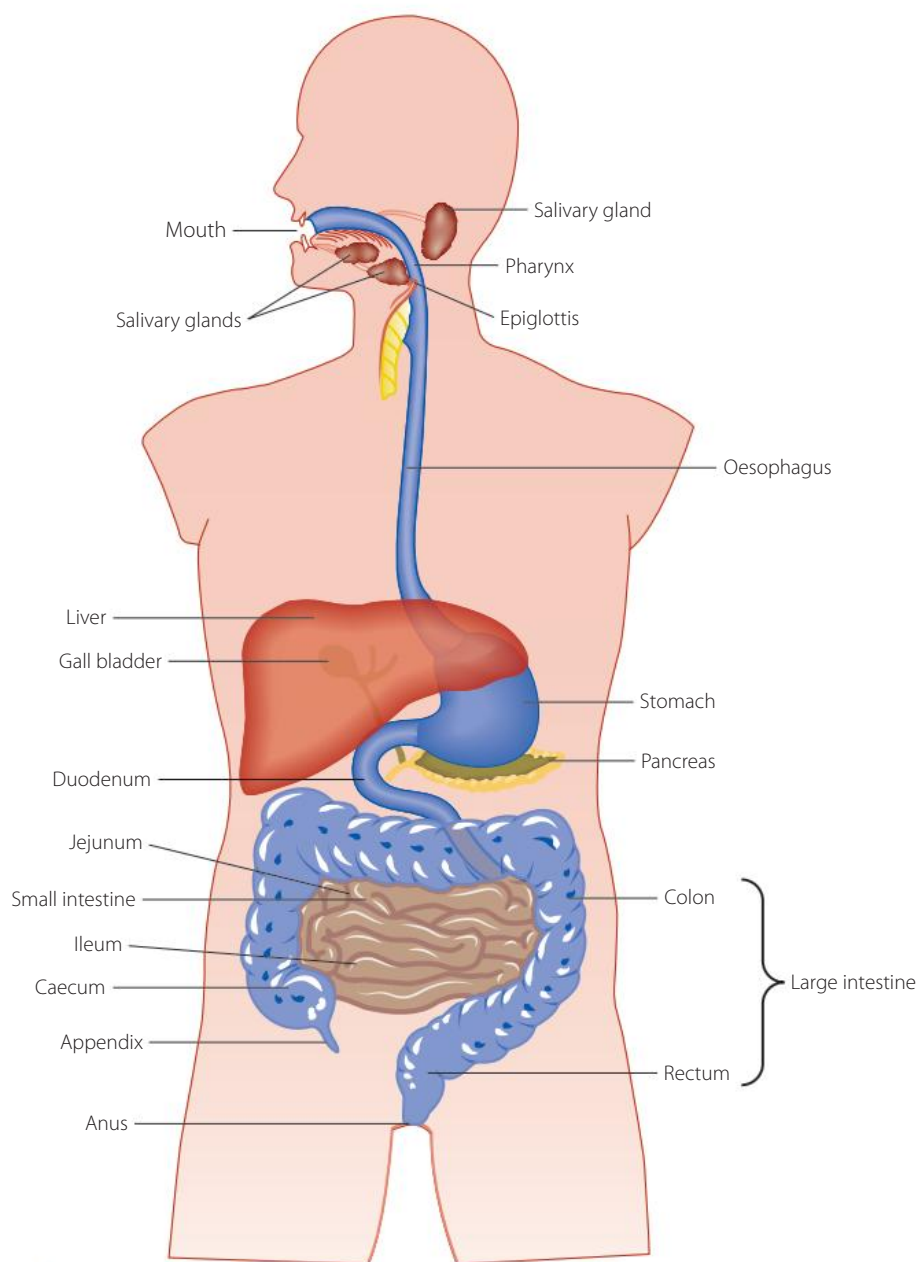


FIGURE 5.21 The human digestive system

The process of digestion

Digestion is the breaking down of large and complex food particles into much smaller and simpler particles. There are two types of digestion: mechanical and chemical. The overall aim of digestion is to break down the particles into substances that are small enough to be absorbed through the intestinal walls into the bloodstream.

Mechanical digestion

This involves the physical breakdown of food particles. Mechanical digestion begins in the mouth when the different types of teeth break food into smaller pieces by cutting, tearing, chewing and grinding the food. The churning motion of the stomach continues the process of mechanical digestion. The aim of this mechanical digestion is to start the process of breaking food into smaller pieces so that its surface area is increased and it can then be acted on by enzymes in chemical digestion.

Chemical digestion

Chemical digestion is the process of using digestive enzymes to chemically break down the large, complex molecules in the food that has been ingested into their smaller, simpler forms. Some of the simple substances obtained are glucose from complex carbohydrates, amino acids from proteins, glycerol and fatty acids from lipids, and nucleotides from nucleic acids.

- Digestion is the breakdown of food into particles small enough to be absorbed into the bloodstream.
- Mechanical digestion is the physical breakdown of the food into smaller pieces to increase the surface area for the action of enzymes.
- The teeth and the churning motion of the stomach are the main ways in which mechanical digestion occurs.
- Digestive enzymes enable the chemical breakdown of large, complex molecules into the small molecules that can then be absorbed into the transport systems of the body.
- Complex molecules and their simple products formed after digestion are listed below:
 - Proteins are broken down into amino acids.
 - Carbohydrates are broken down into simple sugars, such as glucose.
 - Lipids are broken down into glycerol and fatty acids.

Pathway through the digestive system

Mechanical and chemical digestion occur in the digestive system. Different organs of the digestive system are specialised to perform different functions to achieve digestion of the food that we eat.

Mouth

After food enters the mouth, mechanical digestion begins the process of the breakdown of the food. Teeth break the food up into smaller pieces with greater surface area for the more efficient action of enzymes. Salivary **amylase** is released into the mouth, and is mixed with the food by the tongue and the action of chewing. This enzyme begins the chemical breakdown of the complex carbohydrate starch into the simpler sugar maltose.

Once the food has been chewed into small pieces and mixed with saliva, the tongue forms it into a ball shape called the **bolus**. This is then swallowed and enters the **oesophagus**.

Oesophagus

Once the bolus enters the oesophagus, it travels along the soft-walled, muscle-ringed tube to the stomach. As it passes the entrance to the trachea, a flap of skin, the **epiglottis**, closes over this entrance to prevent the entry of food into the respiratory system. The bolus of food does not move down the oesophagus just due to gravity. Muscular contractions also move the bolus by a process called **peristalsis**. The chemical digestion of starch continues during movement along the oesophagus.

The stomach

At the entry and exit of the stomach, there are narrow openings whose opening and closing are controlled by circular sphincter muscles (Fig. 5.22). This controls the movement of substances into and out of the stomach. Once inside the stomach, relaxation and contraction of the stomach walls continue mechanical digestion. The bolus breaks up into pieces that combine with gastric juices contained within the stomach to form a mixture known as **chyme**. Gastric juices, secreted from the wall of the stomach, contain water, hydrochloric acid, pepsinogen and pepsin. The acid causes the pH of the interior of the stomach to be 2.0–3.0. Mucus lining the stomach prevents the acid from ‘eating away’ the walls of the stomach.

The enzyme pepsinogen is converted into an active form called pepsin in the acidic environment and begins the chemical breakdown of the long-chained proteins into shorter chained peptides. Pepsin also breaks down nucleic acids (DNA and RNA) in the food to their component nucleotides.

The chyme remains in the stomach for about 6 hours.

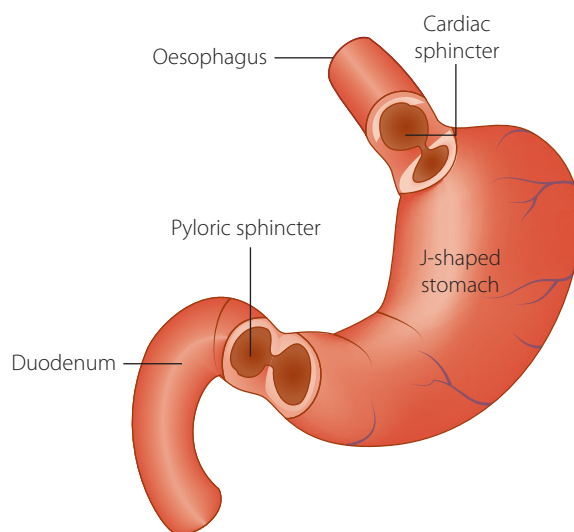


FIGURE 5.22 The structure of the human stomach

- Mechanical digestion occurs in the mouth by use of the teeth and the tongue.
- Chemical digestion begins in the mouth with the enzyme salivary amylase breaking the complex carbohydrate starch down into simpler sugars.
- Mechanical digestion is continued in the stomach.
- Pepsin begins the chemical digestion of proteins in the chyme to form shorter peptide chains and the digestion of nucleic acids to nucleotides.

The small intestine

The chyme from the stomach enters the small intestine gradually through a small muscular opening, the **pyloric sphincter** (Fig. 5.22). The highly folded small intestine is approximately 7 m long in an adult and contains 3 main regions: the **duodenum** (at the start of the small intestine), the **jejunum** (middle section) and the **ileum** (end region).

As the chyme enters the duodenum, it stimulates the release of a hormone, which in turn stimulates the release of pancreatic juices into the area. Pancreatic juices are secreted by the **pancreas** and contain a mixture of the digestive enzymes amylase, **trypsin** and **lipase**, as well as bicarbonate ions. The bicarbonate ions act to neutralise the acidic chyme leaving the stomach. Amylase and trypsin continue the chemical breakdown of carbohydrates and proteins.

When there are lipids present in the chyme, **bile** is released into the duodenum. Bile is produced by the liver and is stored in the **gall bladder**. Bile is not a digestive enzyme. It acts in the same way as detergent acts on fats when washing a greasy saucepan – it breaks down (**emulsifies**) the fats into smaller pieces or fat droplets. This increases the surface area for the action of the digestive enzyme lipase to chemically break the lipids into fatty acid and glycerol molecules.

From the duodenum, food enters the jejunum where most of the absorption of the digestive products occurs.

Absorption in the digestive tract

The absorption of substances mostly occurs in the jejunum section of the small intestine. Some substances, such as alcohol and drugs, are absorbed quickly in the stomach. The products of digestion, including amino acids, glucose, fatty acids and glycerol, move into the transport systems of the body in the small intestine. These products are moved by diffusion or active transport through tiny projections, called **villi**, which line the intestinal wall. These projections greatly increase the surface area for much more efficient diffusion. Villi walls are moist and are one cell thick. They have a rich blood supply in the tiny capillaries that are wrapped around a **lacteal**. Lacteals are connected to another transport system in the body – the **lymph system** (Fig. 5.23). Glucose and amino acids are absorbed into the capillaries, while fatty acids and glycerol move into the lacteal. Some water absorption will also occur here.

Absorption in the small intestine

Watch the animation and outline the absorption of products of digestion in the small intestine.

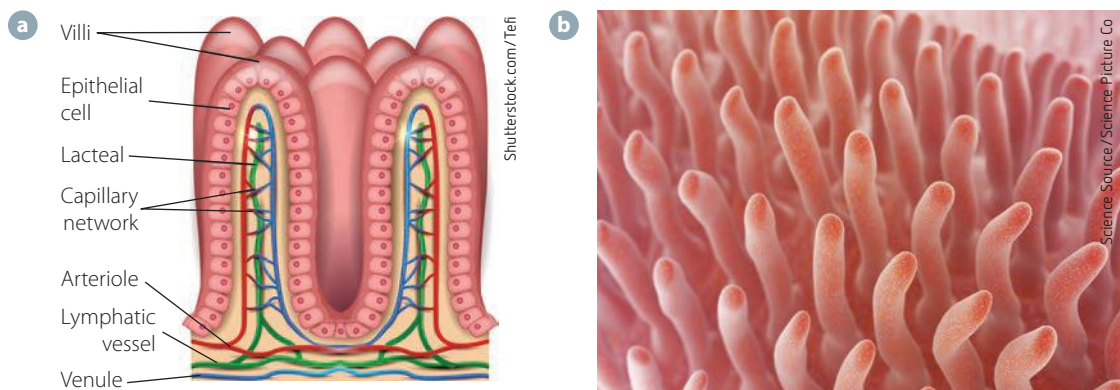


FIGURE 5.23 **a** The internal structure of intestinal villi (longitudinal section); **b** villi lining the small intestine (external view)

The liver – an accessory gland

Digested food, once absorbed into the bloodstream, travels to the liver, which is the centre of food metabolism. It plays an important role in keeping sugars, glycogen and protein levels in balance in the body. It also detoxifies the blood.

KEY CONCEPTS

- The small intestine is very long and folded and has three regions: the duodenum, the jejunum and the ileum.
- Most digestion is completed in the duodenum.
- The pancreas releases many different digestive enzymes and bicarbonate ions.
- Bicarbonate ions neutralise the acidic chyme as it enters the small intestine.
- Bile produced by the liver and stored in the gall bladder emulsifies fat molecules to increase surface area for breakdown by lipases.
- Other enzymes complete the chemical breakdown of larger molecules.
- Most absorption of products of digestion occurs in the jejunum.
- Villi are microscopic projections on the wall of the jejunum that are one cell thick. There are blood capillaries and lymph vessels in close contact with these cells. Small molecules diffuse or are actively transported through the walls of the villi into the capillary or lymph vessels to be distributed throughout the body.

The large intestine

When all of the required digestive products have been absorbed in the small intestine, the remaining undigested material moves to the **large intestine**. This material is composed of substances such as water, salts and dietary fibre. The large intestine has two main sections: the **colon** and the **rectum**. In the colon the water and some salts are absorbed back into the bloodstream, with the undigested material compacting into a more solid substance. Vitamins A and K, which are produced by bacteria in the colon acting on the undigested matter, are also absorbed into the bloodstream.

The remaining waste material, known as faeces, is moved into the rectum by peristalsis and then **egested**, or eliminated, from the body through the **anus**.

The fate of digestive products

The end products of digestion can be built up by the body into useful substances, as either new biological material or an energy source. For example, in mammals such as humans, blood transports the products of digestion to where they are needed in the body. They can then be reassembled by the cells of the body into structural parts (for example, lipids and proteins form a structural part of cell membranes, and protein fibres in muscle tissue) or into energy storage (for example, fatty tissue or fat beneath the skin, or the carbohydrate glycogen, a form of 'animal starch', in the liver and muscles). Protein cannot be stored.

KEY CONCEPTS

- Water and mineral salts are absorbed from the large intestine into the bloodstream.
- The remaining undigested material is called faeces and is stored in the rectum before being eliminated from the body.
- Digestive products absorbed into the body are used in many different ways, including for structural purposes and for energy storage.

 Digestion in two and three dimensions

 The digestive system

Create a flow chart of the pathway of food through the digestive system.

 Mammalian digestive system

- 1 Define the term 'digestion'.
- 2 Outline the main functions of the digestive system.
- 3 **a** Distinguish between the processes of mechanical and chemical digestion.
b Identify where in the digestive tract each of these occurs.

CHECK YOUR UNDERSTANDING

5.3





- 4 Identify, and create a flow chart to show, the structures that food must pass through in a typical mammalian digestive system.
- 5 Identify the simple digestive products formed from the breakdown of proteins, nucleic acids, carbohydrates and lipids.
- 6
 - a What is bile?
 - b Identify where it is produced and where it is stored.
 - c Outline its function.
- 7 Identify:
 - a the structure that prevents the entry of foreign materials such as food into the respiratory system
 - b the muscular contractions that move food along the digestive tract.
- 8 Outline the function of the following enzymes: amylase, pepsin, trypsin and lipase.
- 9
 - a Identify the structures that increase the surface area of the internal wall of the small intestine.
 - b Draw a labelled diagram of one of these structures.
 - c Explain how this structure assists the absorption of the products of digestion.
- 10 Construct a summary table identifying each organ of the digestive system and its function.
- 11 Determine whether the material egested from the digestive system is part of the internal or external environment. Justify your answer.

5.4 Comparing nutrient and gas requirements

Autotrophs and heterotrophs have a fundamental difference in their functioning that is reflected in their different methods of obtaining their nutrient and gas requirements (Table 5.3; Fig. 5.24).

TABLE 5.3 Comparison of nutrient and gas requirements of autotrophs and heterotrophs

NUTRIENT / GAS REQUIREMENT	AUTOTROPH	HETEROTROPH
Oxygen gas	Diffuses into the plant across cell surfaces	Diffuses through the respiratory surface
Carbon dioxide gas	Diffuses into the plant	Not required
Water	Diffuses into roots	Ingested into the digestive system
Glucose	Produced by photosynthesis	Ingested into the digestive system as either simple or complex carbohydrates, and absorbed into the bloodstream
Proteins, lipids	Produced by the plant from glucose and mineral ions	Ingested into the digestive system and absorbed into the bloodstream as amino acids, fatty acids or glycerol
Mineral ions	Move into the plant through the roots by diffusion and active transport	Ingested into the digestive system and absorbed into the bloodstream

Autotrophs carry out the process of photosynthesis: they use the energy from the sun by incorporating it into high-energy bonds in molecules of glucose. This energy is then released for use by the organism when these bonds are broken during the process of cellular respiration.

To carry out photosynthesis successfully, most autotrophs require the raw materials carbon dioxide and water. Autotrophs also require oxygen gas in order to carry out cellular respiration, which provides the energy required for all life processes. They manufacture the glucose that is required for cellular respiration. Autotrophs also have the ability to convert some of the glucose they produce into other organic compounds, such as lipids, proteins and complex carbohydrates.

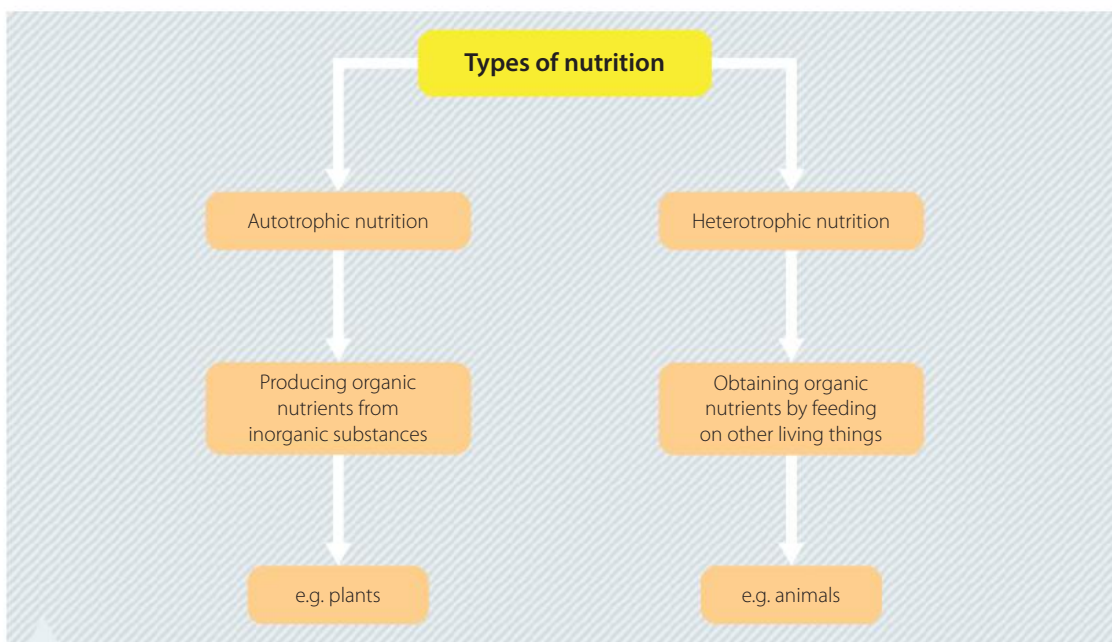


FIGURE 5.24 The basic difference between autotrophic and heterotrophic nutrition

Conversely, heterotrophs do not require carbon dioxide because they do not carry out the process of photosynthesis. Instead, they need to ingest glucose and all other organic compounds because they are not able to manufacture them. Organic substances that are ingested are broken down in the body and then reconfigured into the substances that are needed. Heterotrophs also require the intake of oxygen to carry out cellular respiration to produce the energy required by the cells.

Both heterotrophs and autotrophs require inorganic and organic substances, water and oxygen gas. Autotrophs also require the gas carbon dioxide.

Heterotrophs need to take in all of these nutrients. Autotrophs produce their own organic nutrients using the energy from the sun, and need to obtain inorganic substances such as water, mineral ions and the gases carbon dioxide and oxygen from the external environment (air, water and/or soil).

KEY CONCEPTS

- Autotrophs and heterotrophs require gases and nutrients to maintain efficient and effective metabolic function.
- Both heterotrophs and autotrophs require inorganic and organic substances, water and oxygen gas. Autotrophs also require carbon dioxide gas.
- Heterotrophs need to take in all of their nutrients. Autotrophs produce their own organic nutrients using the energy from the sun, but need to obtain water, mineral ions and the gases carbon dioxide and oxygen.
- Autotrophs manufacture their own glucose and other organic substances from inorganic nutrients.
- Heterotrophs must obtain all of their organic nutrients by consuming autotrophs or other heterotrophs.

- 1 Describe how:
 - a autotrophs obtain their organic nutrients
 - b heterotrophs obtain their organic nutrients.
- 2 Identify the gases required by:
 - a autotrophs
 - b heterotrophs.
- 3 Construct a Venn diagram to compare the nutrient and gas requirements of autotrophs and heterotrophs.

CHECK YOUR UNDERSTANDING

5.4

Nutrient and gas requirements: What is the difference in nutrient and gas requirements between autotrophs and heterotrophs?

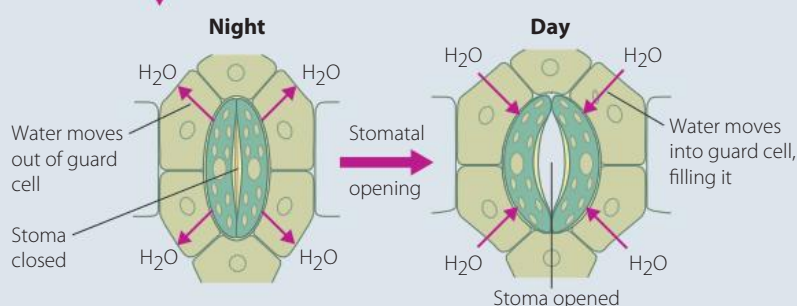
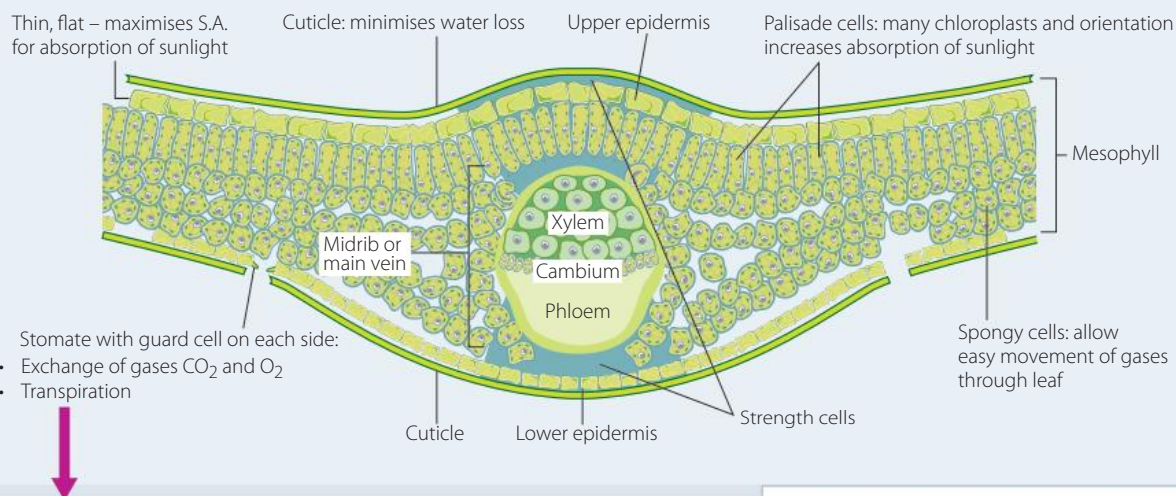
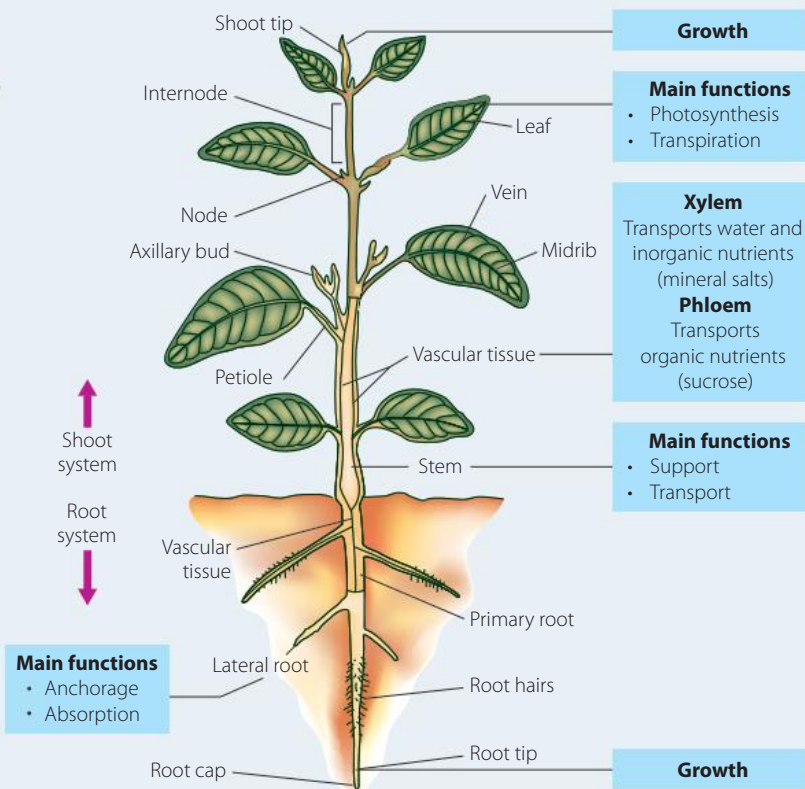
AUTOTROPH STRUCTURE AND FUNCTION

Systems

- 1 Root system
 - Anchorage
 - Absorption of water and mineral ions
 - Large surface area of root hair cells and branching root systems allow efficient absorption
- 2 Shoot system
 - Transport
 - Photosynthesis

Stem – transport between roots and leaves via xylem and phloem

Leaf – absorbs sunlight, exchange gases, transpiration and carry out photosynthesis



Gas exchange structures

- Occurs through the stomata
- Balance required between gas exchange and water conservation
- Light is the main factor that causes the stomata to open and close
- Low levels of water will cause stomata to close

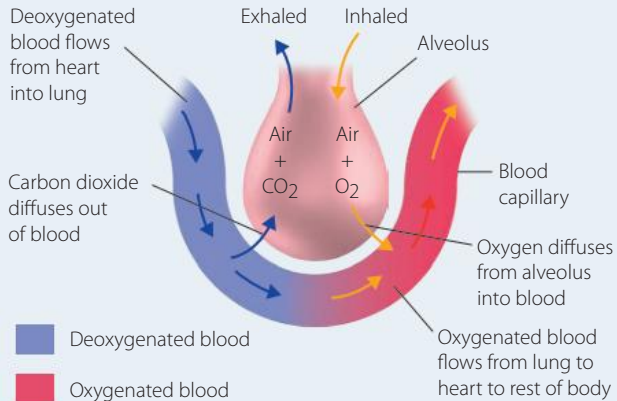
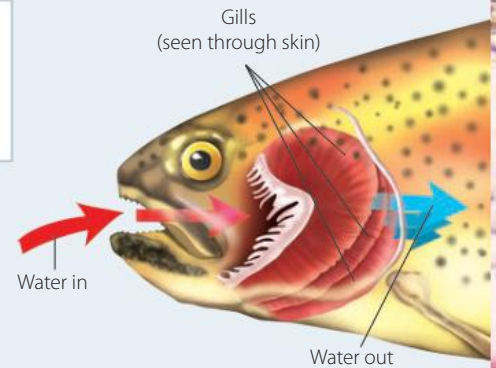
ANIMALS (HETEROTROPH) GAS EXCHANGE

Common features of gas exchange structures in animals:

- A large surface area
- Thin, moist surfaces
- Close proximity to transport system
- Concentration gradient maintained

Mammals – Alveoli in lungs are the gas exchange structures

Fish – gills are the gas exchange structures



MAMMALIAN DIGESTIVE SYSTEM

Digestion – breakdown of food into particles small enough to be absorbed.

- 1 Mechanical – physical breakdown of food → teeth and stomach
- 2 Chemical – digestive enzymes break large molecules → small molecules

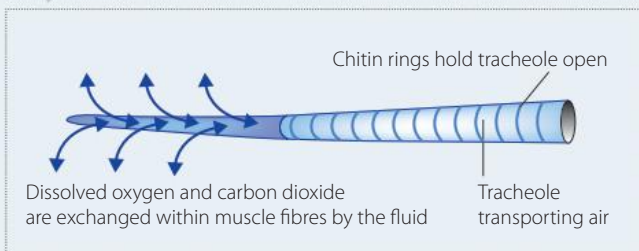
Protein → amino acids

Carbohydrates → simple sugars

Lipids → glycerol and fatty acids

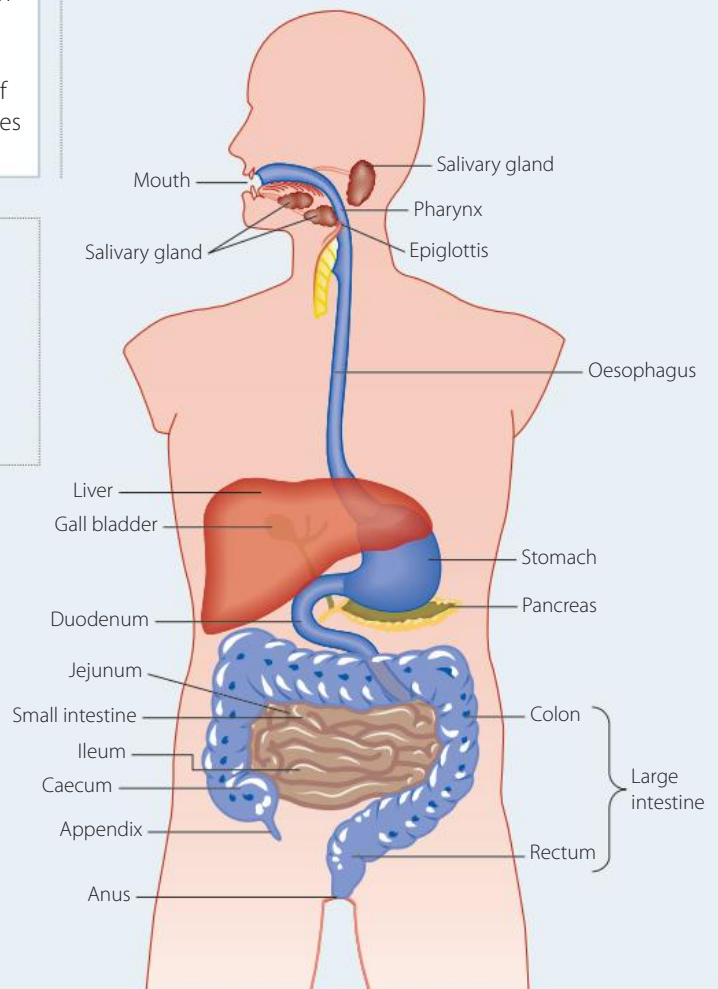
Insects

- Insects exchange gases via pores called spiracles, which lead to tracheal tubes, which then branch into smaller tubes called tracheoles.
- The tracheoles bring air directly to and from the cells of the insect. Blood is not involved in the transport of gases in an insect.



COMPARISON OF NUTRIENT AND GAS REQUIREMENTS

- Both heterotrophs and autotrophs require inorganic and organic substances, water and oxygen gas. Autotrophs also require carbon dioxide gas.
- Heterotrophs need to take in all of their nutrients. Autotrophs can produce their own organic nutrients using the energy from the sun, but need to obtain water, mineral ions and the gases carbon dioxide and oxygen.



- 1 Identify the major resources that plants must exchange with their environment.
- 2 **a** Draw a labelled diagram of a longitudinal section through the root system in plants and outline the function of each part.
b Draw a root hair cell and outline the advantage of this structure.
- 3 **a** Describe the basic internal structure of the stem of vascular plants.
b Identify the functions of the stem.
- 4 **a** Outline how plants that grow in areas of high temperatures limit water loss.
b Describe the effect this has on leaf function.
- 5 Using Figure 5.25:
 - a** Label the different components of the leaf.
 - b** Use two arrows of different colours to indicate the exchange of gases between the internal and external environment of the leaf and the pathway of oxygen and carbon dioxide through the leaf.
 - c** Identify the processes in which these gases would be used or produced, and where these processes occur.
- 8 Plants are able to use oxygen produced in photosynthesis for the process of respiration and carbon dioxide produced in respiration for photosynthesis.
 - a** Suggest under what circumstances the plant would be able to supply its own gaseous requirements.
 - b** Predict when the plant would need to take in oxygen or carbon dioxide from the outside environment.
 - c** Explain why a plant may lose weight when kept in the dark.
- 9 Distinguish between the uptake of mineral ions and the uptake of water from the soil.
- 10 Draw a flow chart of the structures, in order, when:
 - a** molecules of oxygen flow through the human respiratory system, from when they enter the mouth until they enter the blood
 - b** food enters the human digestive system in the mouth until the wastes leave the body.
- 11 Identify the part of the human body in which the following processes occur:
 - a** absorption of fatty acids
 - b** absorption of water from the products of digestion
 - c** absorption of oxygen into the bloodstream
 - d** digestion of protein
 - e** initial digestion of complex carbohydrates
 - f** ingestion
 - g** addition of bile to the digestive system.
- 12 You have eaten a very large meal of lean chicken. Chicken contains a lot of protein and a small amount of fat. Explain how the structure and function of your digestive system will assist the delivery of amino acids to your cells.
- 13 The major function of the large intestines is to absorb water. When you suffer from diarrhoea, you absorb 10 mL of water over 4 hours. When you suffer from constipation, you absorb 100 mL over 4 hours. Predict the amount of water you would absorb if your body were functioning normally.
- 14 Compare and account for different nutrient requirements of autotrophs and heterotrophs.

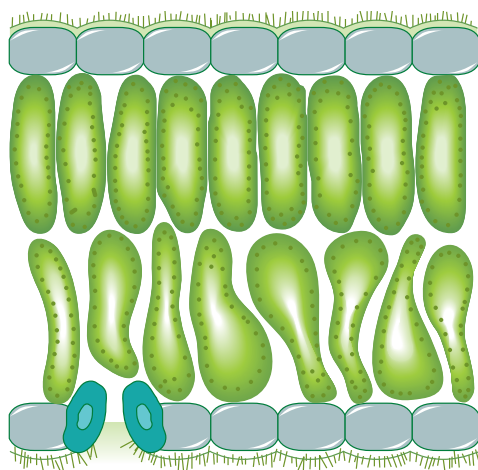


FIGURE 5.25

- 6 Explain the advantage of the flat and thin structure of leaves.
- 7 Describe how the absorption of carbon dioxide and the loss of water are controlled in leaves.

6 Transport

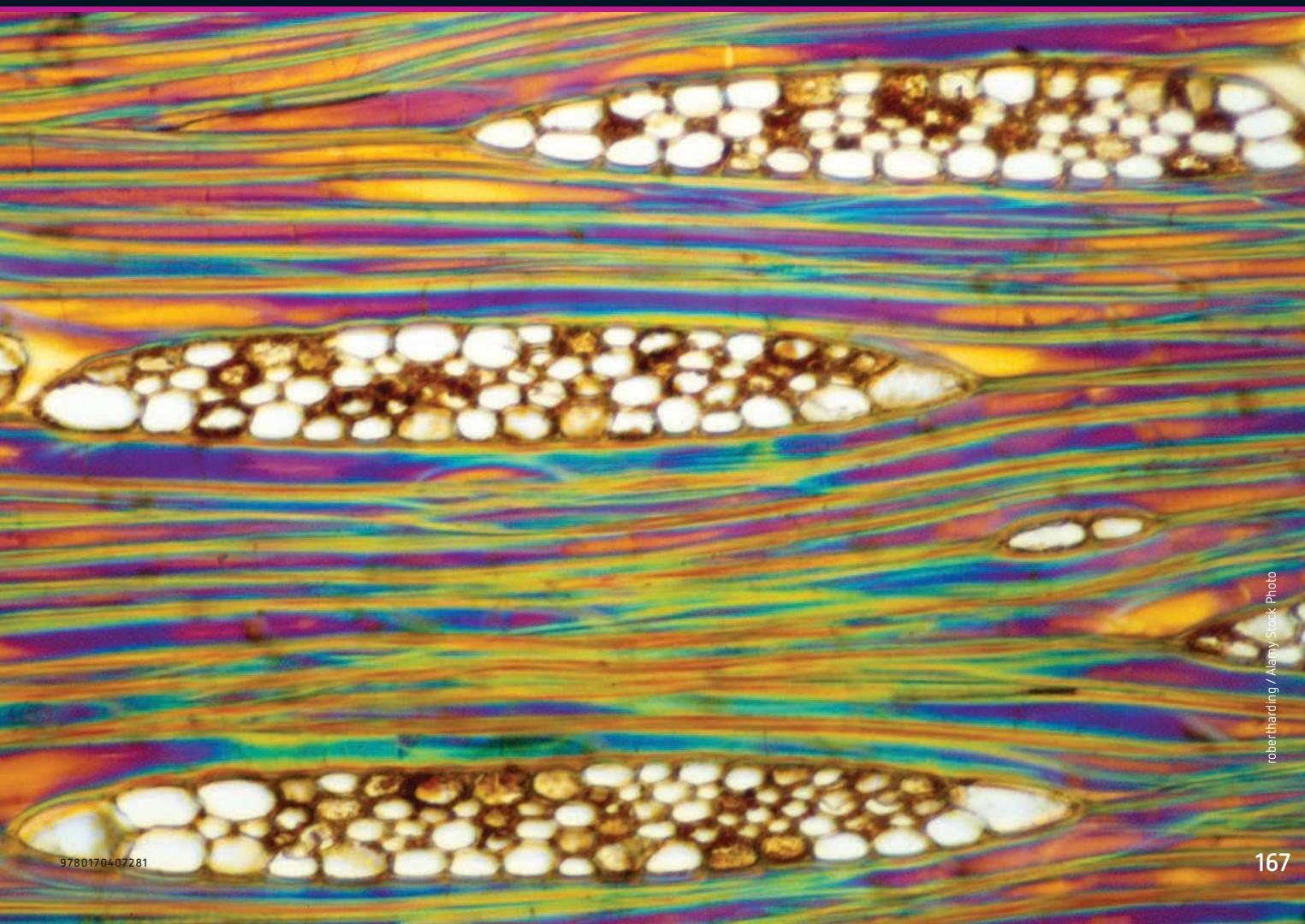
INQUIRY QUESTION

How does the composition of the transport medium change as it moves around an organism?

Students:

- investigate transport systems in animals and plants by comparing structures and components using physical and digital models, including but not limited to: (ACSBLO32, ACSBLO58, ACSBLO59, ACSBLO60) **ICT L**
 - macroscopic structures in plants and animals
 - microscopic samples of blood, the cardiovascular system and plant vascular systems **ICT**
- compare the structures and function of transport systems in animals and plants, including but not limited to: (ACSBLO33)
 - vascular systems in plants and animals
 - open and closed transport systems in animals
- interpret a range of secondary-sourced information to evaluate processes, claims and conclusions that have led scientists to develop hypotheses, theories and models about the structure and function of plants, including but not limited to: (ACSBLO34) **CCT ICT L**
 - photosynthesis
 - transpiration-cohesion-tension theory
- compare the changes in the composition of the transport medium as it moves around an organism

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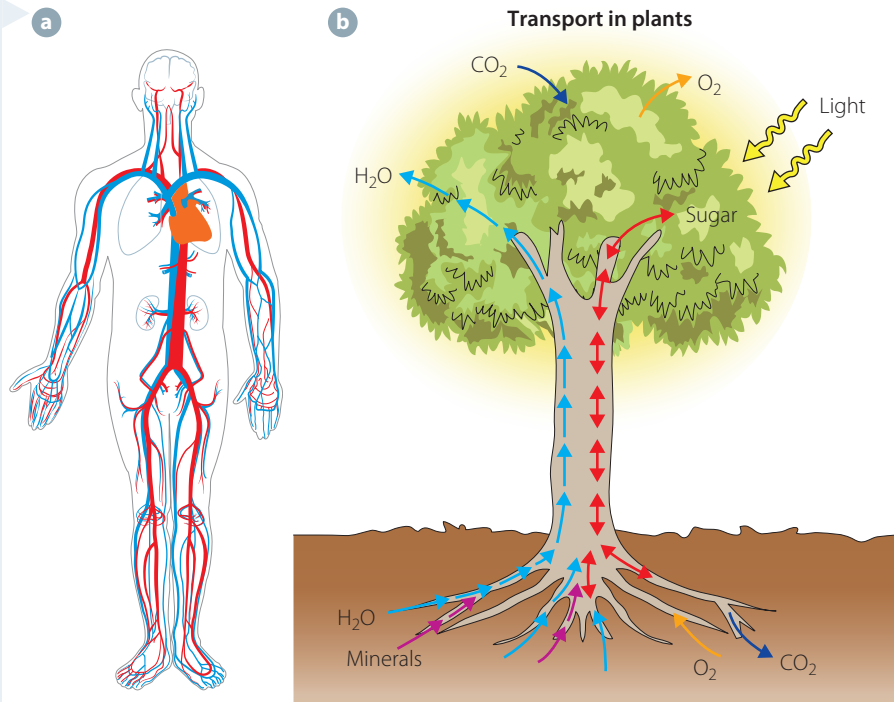


Unicellular and very simple multicellular organisms obtain their nutrients and dispose of their wastes by diffusion, osmosis and active transport directly between the surface of the organism and the surrounding environment.

For all of the cells in a multicellular organism to function efficiently and effectively, a system needs to be in place to move substances around the organism. Transport systems in both plants and animals serve this purpose and ensure that all cells are supplied with the nutrients and gases they require (Fig. 6.1). Transport systems also remove the wastes produced in cellular metabolism.

FIGURE 6.1

Transport systems in
a humans; **b** plants



Effective transport systems in multicellular plants and animals, although very different, have certain similarities. They all possess:

- a system of *vessels* in which substances are transported
- a suitable transport medium (fluid)
- a driving mechanism to ensure that substances move in the correct direction.

The differences between the transport systems in plants and animals are found in the *type* of structures and components that are present, the *substances* that are transported and the mechanisms that *drive* the movement of these substances.

6.1 Transport systems in plants

The transport system in plants involves vascular tissue arranged in vascular bundles made up of xylem and phloem tissue. Xylem tissue transports water and mineral ions from the roots through the stem to the leaves. Phloem tissue transports the products of photosynthesis to all regions of the plant (Fig. 6.1).

Xylem tissue

Xylem is specialised tissue for the transport of water and dissolved mineral ions from the roots to the leaves. This movement occurs in only one direction – upwards from the roots.

Structure

Xylem tissue consists of two main types of elements – **xylem tracheids** and **xylem vessels** (Fig. 6.2) – with other cells such as parenchyma and fibres in between. Tracheids are long structures with end walls that taper to a point, where they come into contact with each other and overlap. The water molecules and dissolved ions pass from one tracheid to the other through the many small holes called pits. The water molecules and dissolved ions pass from one tracheid to the other through the many small holes called pits.

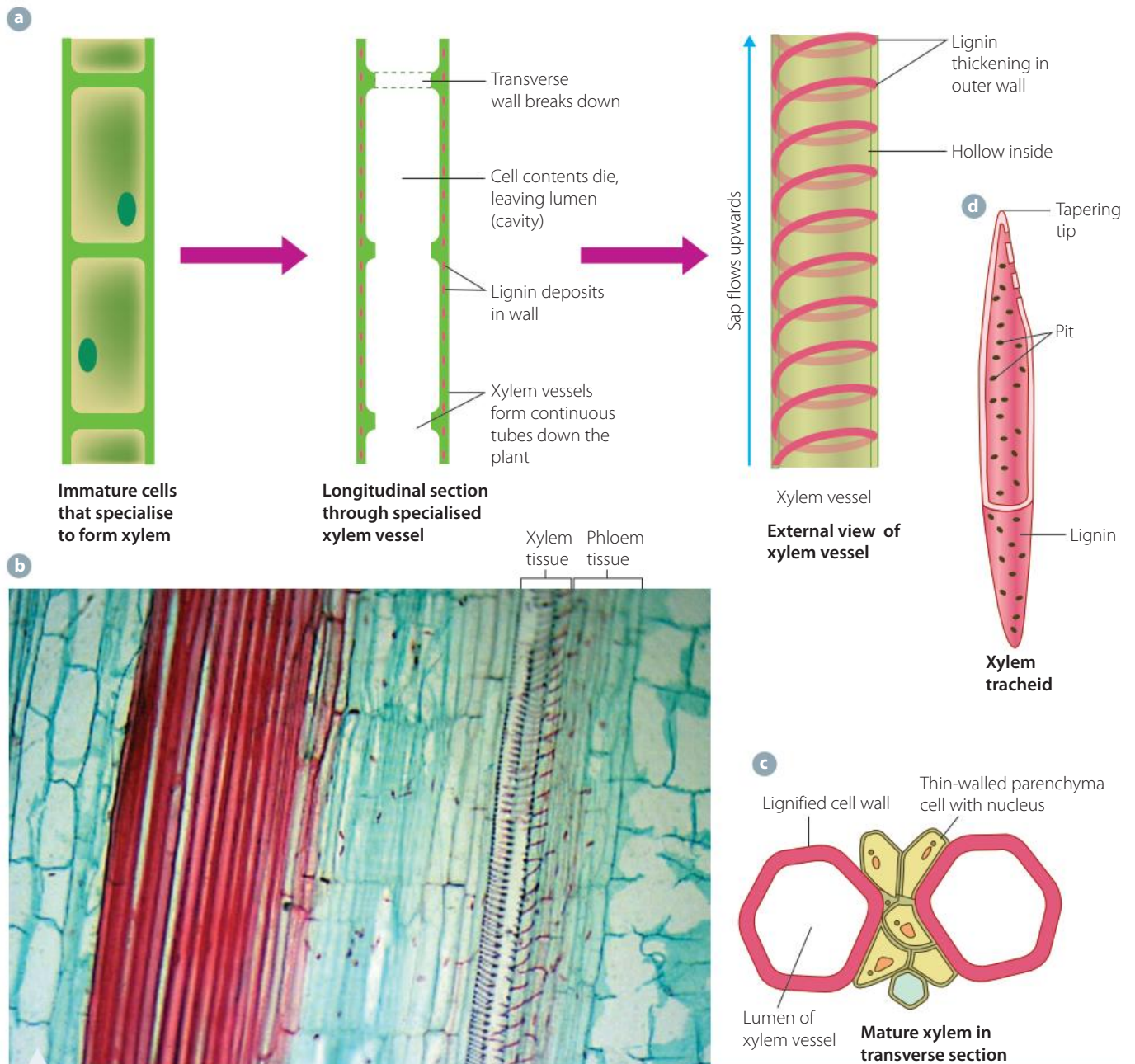


FIGURE 6.2 Xylem tissue: **a** schematic showing specialisation of xylem; **b** photomicrograph of mature xylem tissue showing a variety of wall thickenings (light microscope view in longitudinal section); **c** mature xylem tissue seen in a transverse section (schematic light microscope view); **d** xylem tracheid

Most of the xylem in flowering plants occurs in the form of xylem vessels. Xylem vessels form continuous tubes for the transport of water. When cells specialise to become xylem vessels, their walls break down, so the cells that are stacked on top of each other become continuous tubes. The cell contents die, leaving hollow vessels for the easy flow of water and dissolved mineral ions. The walls of xylem vessels and tracheids are reinforced with **lignin** thickenings laid down in rings, spirals or other regular patterns. These thickenings prevent the vessels from collapsing, and help the easy movement of water and dissolved substances.

Fibres give support to the xylem tissue, and the parenchyma tissue conducts materials from one region of xylem to another and may function in storage.

The transpiration-cohesion-tension theory

The upward movement of the materials in the xylem can be explained by the transpiration-cohesion-tension theory (Fig. 6.3).

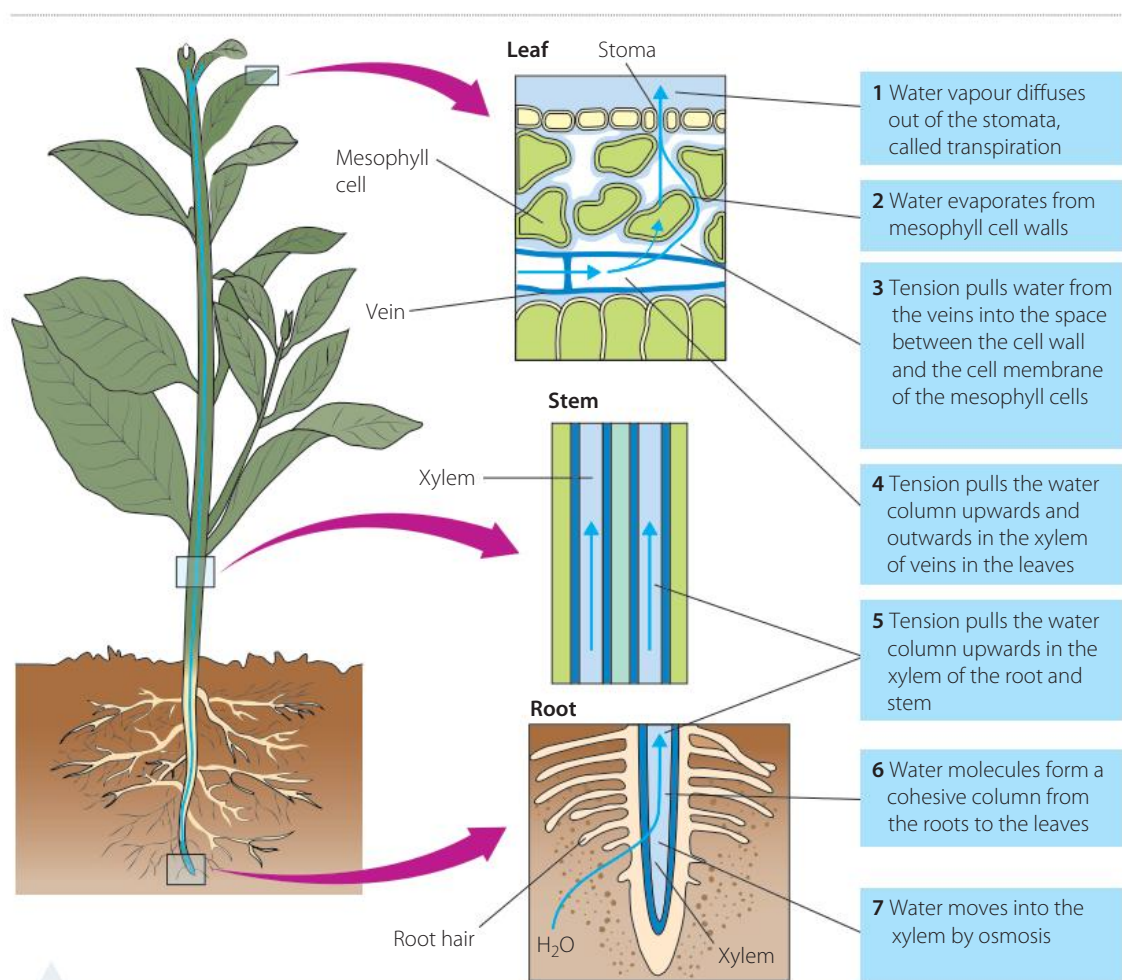


FIGURE 6.3 Transport in the xylem – the transpiration-cohesion-tension theory

This theory has at its core the evaporation of water from the leaves (transpiration) creating a suction pull of water up the stem from the roots. The movement of this column of water up the stem due to the evaporative pull of transpiration is known as the **transpiration stream**.

Transpiration-cohesion-tension theory
Summarise the process of movement of water in the xylem tissues.

The concentration of water vapour outside the leaf is lower than inside the leaf, leading to the diffusion of water vapour out of the leaf (transpiration). When water is lost from the intercellular spaces by transpiration, it is replaced by water from the surface of the mesophyll cells that surround the intercellular spaces. This causes an increase in the *surface tension* of the water on the outside of these mesophyll cells. Water is then drawn from the xylem tissue in the veins to replace the water lost from the mesophyll cells. This in turn increases the *tension* on the column of water in the xylem and draws more water up from the roots.

The movement of this column of water from the roots is aided by a number of other factors:

- 1 The **cohesion** of water molecules to each other (Fig. 6.4). These cohesive forces arise from the fact that water molecules are **polar**. This means that one end of the molecule has a slight positive charge and the other end has a slight negative charge. This causes the water molecules to stick together with the positive and negative ends attracted to each other. This forms a continuous stream of water so that when molecules of water are drawn up the xylem other water molecules move with them.
- 2 **Adhesive** forces between the water molecules and the walls of the xylem vessel cause the water to rise up the sides. The narrower the vessel, the higher the water will rise up. The combined forces of adhesion and cohesion ensure the continuous column of water moves through the xylem tissue in the stem of the plant.
- 3 The narrow, thickened, lignified walls of the xylem vessel can withstand the tension created in the water column and offers little resistance to the flow of water.
- 4 Once water has been absorbed into the roots of plants (by osmosis) along with mineral ions (by diffusion and active transport), these substances move across the root into the xylem. A small amount of **root pressure** results from the continual influx of more water and ions, forcing the solution already present in the xylem to move upwards. This pressure is not sufficient to lift the water and ions very high.

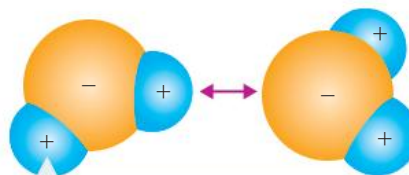


FIGURE 6.4 The cohesive force between water molecules – the positive and negative ends of the molecules – are attracted to each other.

INVESTIGATION 6.1

A practical investigation of the movement of materials in the xylem

BACKGROUND INFORMATION

Xylem is specialised tissue for the transport of water and dissolved mineral ions from the roots to the leaves. This movement occurs in only one direction – upwards from the roots.

AIM

To investigate the direction and structures through which water and dissolved dye move through a celery stem

HYPOTHESIS

Water and dissolved nutrients are transported by xylem tissue in stems.

Refer to p. 135 for information about transverse and longitudinal sections.



» MATERIALS

For each group:

- A stick of celery with leaves that has been standing in red food dye or eosin for several hours, cut 2 cm from its base
- Scalpel
- Stereomicroscope
- Light microscope
- Microscope slides and coverslips

RISK ASSESSMENT

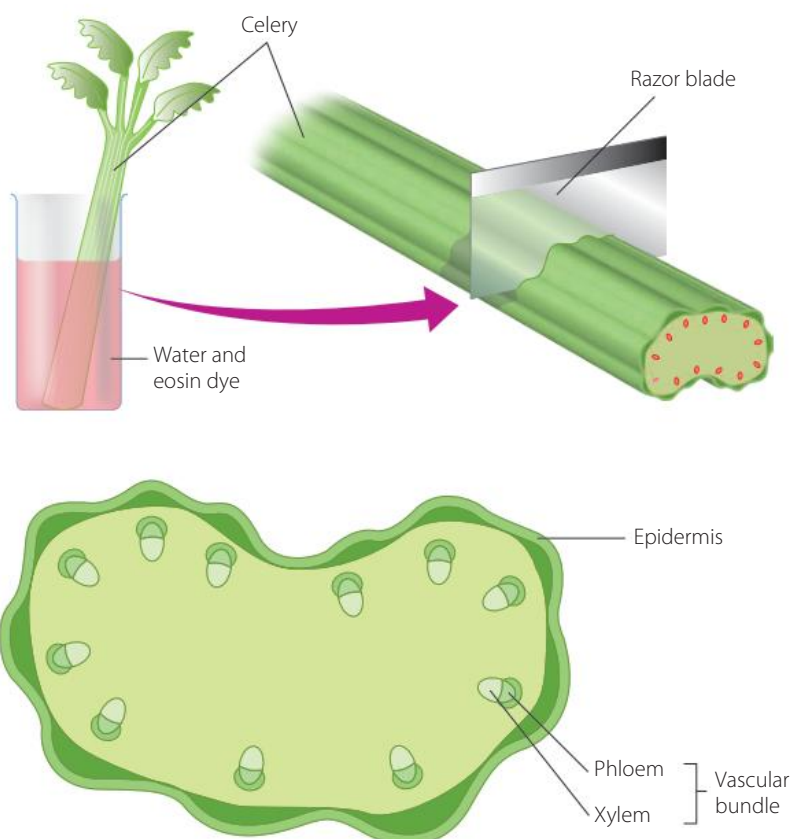


WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Scalpel	Cause cuts and injury	Handle the scalpel with care.
Eosin	Possible irritant to skin Poisoning if ingested	Wear disposable gloves. Do not ingest.
Celery	Celery stalk contains eosin, which could cause poisoning if eaten	Do not eat.

METHOD

- 1 Remove the celery from the coloured solution.
- 2 Examine the stalk and leaves for spread of the dye, observing the areas where the dye is concentrated.
- 3 Sketch the leaf and draw in the distribution of dye.
- 4 Cut across the stalk and observe where the eosin solution is concentrated. Sketch the outline of the cut celery stalk and draw the position of the coloured water (Fig. 6.5).

FIGURE 6.5
Movement of
materials in xylem



- » 5 Cut a very thin transverse section (< 1 mm) across the stem and place it on a microscope slide. View using the stereomicroscope and draw a diagram of what you see.
- 6 Using the scalpel, cut a longitudinal section of the celery stalk following the pathway of one of the tubes with coloured water.
- 7 Sketch the outline of the longitudinal section and draw in the position of the tube with the coloured water.
- 8 Using your fingers, gently peel the tube away from the stalk. Cut a small section (about 5–10 mm) and place it on a microscope slide.
- 9 Use the scalpel to pry it apart and cover with a coverslip. Put a small amount of even pressure on the coverslip to squash the section of tube further. Be careful not to break the coverslip.
- 10 Observe using the light microscope. Draw any structures that you observe, such as the spiral rings of lignin.

DISCUSSION

- 1 Explain the purpose of the eosin dye in this experiment.
- 2 Describe how the dye is distributed in the plant. Has the whole stem turned a little orange or is the dye found in particular places? Explain your answer.
- 3 Describe the appearance of the xylem tubes.
- 4 Suggest what causes the dye to travel to the leaves.
- 5 Was the hypothesis supported? Justify with evidence from the experiment.

CONCLUSION

Write a few sentences addressing the aim, summarising what was done and whether the results supported the hypothesis.

KEY CONCEPTS

- Transport systems in plants carry water and mineral ions in one direction only, from the roots to the leaves, in the xylem tissue. The products of photosynthesis are delivered wherever required around the plant in the phloem tissue.
- Xylem tissue is composed of xylem vessels and xylem tracheids.
- Xylem vessels are long, thin, continuous tubes composed of dead tissue with lignin-strengthened walls.
- The transpiration-cohesion-tension theory currently explains the movement of substances up the xylem vessels.
- Water evaporates from the leaves and creates tension, which pulls more water from the veins and then up the xylem vessel.
- Cohesion between water molecules and adhesion between the water molecules and the walls of the xylem maintain the column of water. When molecules of water are pulled up, other molecules follow.
- A small amount of root pressure forces the water already present in the xylem vessel upwards.

- 1 a Identify the main functions of transport systems in multicellular organisms.
b Outline the features that all effective transport systems possess.
- 2 Draw an outline of a tree and use arrows to indicate the pathway of the water and dissolved mineral ions from the roots, up the stem to the leaves, and the movement of water out of the plant.
- 3 Draw a labelled diagram of a:
 - a xylem vessel
 - b xylem tracheid.
- 4 Describe the structure of xylem tissue and outline how its structure assists its function.

CHECK YOUR UNDERSTANDING

6.1a





- 5 a Define the term 'transpiration'.
- b Explain why the process of transpiration is considered to be the main driving force in the transport of water up through the stem to the leaves.
- c Identify and describe the other factors that assist the movement of water up the stem to the leaves.

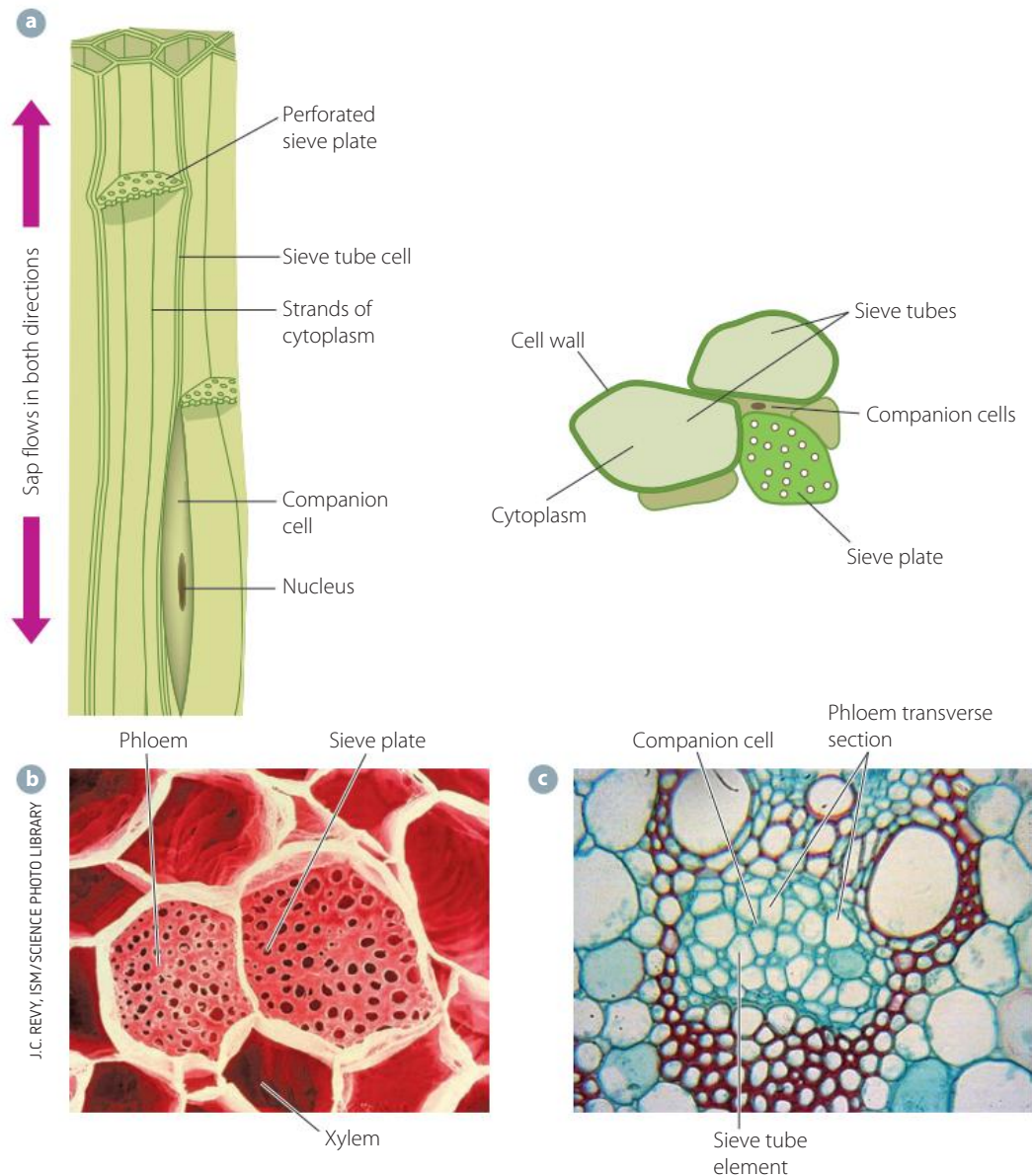
Phloem

Phloem is specialised tissue that transports sugars and other products of photosynthesis from the leaves, where they are produced, to the rest of the plant where they are either used or stored.

Structure

There are two types of phloem cells: **sieve tube cells** and **companion cells** (Fig. 6.6). Sieve tube cells are long, thin phloem cells that have large pores through the cell walls at either end. These perforated cell walls

FIGURE 6.6 Phloem tissue: **a** diagram of longitudinal and transverse section; **b** light micrograph showing sieve plate (in transverse section); **c** transverse section (light microscope view)



are called **sieve plates**. Sieve tube cells (or sieve elements) possess some mitochondria and endoplasmic reticulum but have no nuclei or other organelles. They are arranged end-to-end into sieve tubes.

The sieve tube cells share cytoplasm. As a result, each sieve tube forms a channel through which sugars and other plant products can flow. Companion cells are found alongside the sieve tubes. Companion cells have a cell nucleus and other cell organelles that are lacking in sieve tube cells. The function of companion cells is uncertain, but they are thought to assist the effectiveness of their neighbouring sieve tube elements. They could do this by providing ATP and nutrients and assisting the loading and unloading of sugars into the sieve tube cells.

The source-sink theory

After glucose has been produced in the leaves in the process of photosynthesis, it is either stored as starch or converted to sucrose and distributed to all parts of the plant. The distribution process is called **translocation** and occurs in the phloem tissue. Unlike the one-way movement of substances in the xylem tissue, substances transported in the phloem move in whichever direction is required. Amino acids and some mineral nutrients are also carried with sucrose in phloem.

Up to 90 per cent of the dissolved substances in the sap of the phloem is sucrose. When sucrose reaches the cells, it may be converted back to glucose for cellular respiration or to starch for storage.

The driving force for the movement of substances is caused by the formation of high- and low-pressure regions within the phloem tissue. Movement occurs from the region of high pressure to the region of low pressure. The high-pressure region is in close proximity to where the sucrose is produced and is known as the **source**. The low-pressure region is where the sucrose is required and is known as the **sink**.

At the source, energy is required to actively pump sugars into the phloem tissue. This creates a very concentrated solution in the phloem, which then draws in water by osmosis from the nearby xylem tissue. This creates a region of high pressure at the source.

At the sink, which could be the roots, flowers, or any other part of the plant that requires nutrients, energy is again required to actively remove the sugars from the phloem. This creates a dilute solution, which causes water to leave the phloem tissue by osmosis and return to the xylem tissue. Hence, a low-pressure region is formed.

The difference in pressure between the source and sink drives the movement of substances in the phloem. The phloem sap flows from the region of high pressure (the source) to the region of low pressure (the sink). The direction of flow depends on where the sink areas of the plant are in relation to the source (leaves). The flow is continuous, because sucrose is continually being added at one end and removed at the other (Fig. 6.7).

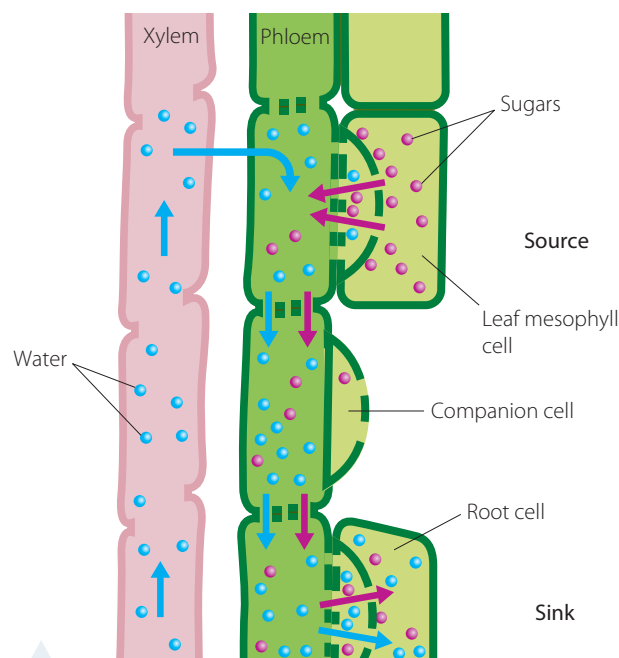


FIGURE 6.7 Pressure flow: moving organic nutrients in the phloem



Movement in the phloem

Summarise the processes involved in the movement of substances in the phloem.

INVESTIGATION 6.2



A practical investigation into the structure of xylem and phloem tissue

BACKGROUND INFORMATION

The vascular system in plants moves substances around the plant and is made up of two types of tissue: xylem and phloem. The structures of these two tissues are different, as are the substances they carry, the direction of movement, and the driving force that causes the transport within each type of tissue.

In most prepared slides, the xylem has pink-stained walls and the phloem appears green (Fig. 6.8).

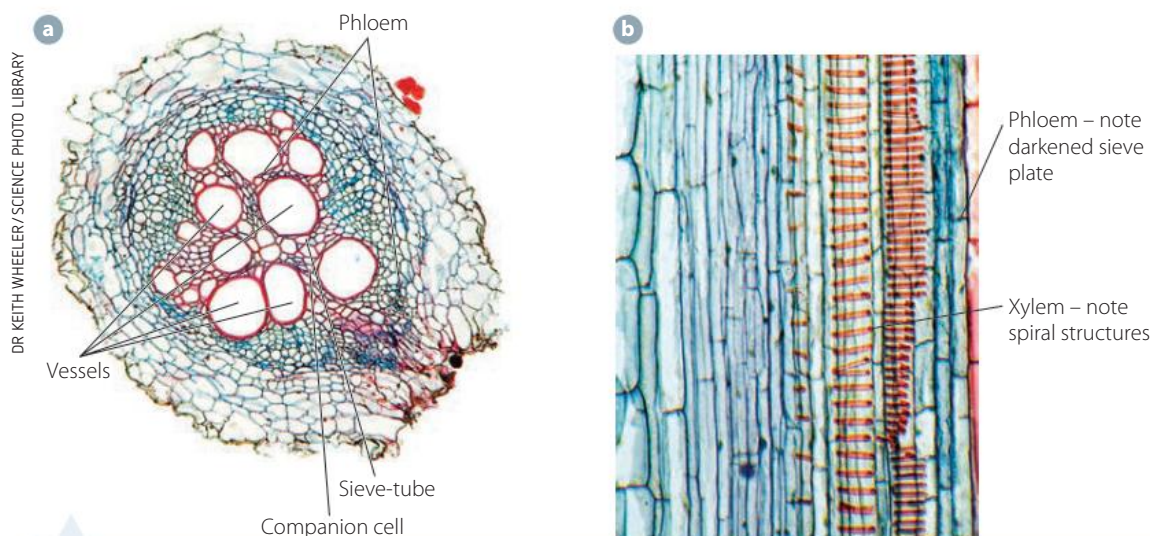


FIGURE 6.8 Light microscope images of xylem and phloem tissues in a stem: **a** transverse section; **b** longitudinal section

AIM

To observe the microscopic structure of the xylem and phloem tissues

MATERIALS

- Prepared slides of longitudinal and transverse sections of a plant stem
- Light microscope

RISK ASSESSMENT



WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Microscope slide	If broken could cause cuts to the skin	Handle with care.

METHOD

- Place a prepared slide of a longitudinal section (LS) of a plant stem on the microscope stage.
- Focus on low power and identify the xylem and phloem tissues.
- Focus on high power and again identify the xylem and phloem. Draw a diagram of these structures.
- Write a heading for each diagram, label each part identified and state the magnification.
- When drawing the xylem in LS, include at least two different patterns of wall thickening.
- When drawing phloem tissue, include sieve tube elements, companion cells and sieve plates.
- Repeat the process using a prepared slide of the transverse section of a stem.

- » 8 From your low power observations, draw a labelled diagram of the distribution of the vascular bundles in the stem.
- 9 From your high power observations, draw labelled diagrams of the transverse sections of both xylem and phloem tissue.
- 10 Research images of digital models of the xylem and phloem tissue. Micro-computed tomography (micro-CT) is one method of producing these images.

RESULTS

Draw diagrams of longitudinal and transverse sections of xylem and phloem. Provide images of digital models of xylem and phloem with detailed labels.

DISCUSSION

- 1 Identify the difference between transverse and longitudinal sections.
- 2 Identify the main types of cells that make up the xylem and phloem tissues.
- 3 Outline the differences in structure of the xylem and phloem tissues that you observed.
- 4 Describe how the structure of the xylem and phloem tissues relates to their function.
- 5 In what way did the digital images increase your depth of understanding of the structure of the xylem and phloem tissues?
- 6 Describe the change in the chemical composition of transport fluids as they move around the plant.

CONCLUSION

Write a few sentences that relate to the aim of this investigation, and outline what was observed and the results obtained.

KEY CONCEPTS

- Phloem tissue is composed of two types of living cells: sieve tube cells and companion cells.
- Sieve tube cells are lined up one under the other and have sieve plates at each end. The products of photosynthesis move through these tubes in a process called translocation.
- Companion cells assist the sieve tube cells.
- The movement of the products of photosynthesis in any direction is explained by the source-sink theory.
- Sugars are actively loaded at the source of production; water diffuses in from xylem by osmosis, creating a high-pressure region.
- Sugars are actively unloaded where required at the sink; water diffuses out by osmosis, creating a low-pressure region.
- Materials in the phloem move from a high-pressure region to a low-pressure region.

- 1 Draw labelled diagrams of a longitudinal and transverse section of phloem tissue.
- 2 Describe the structure of phloem tissue.
- 3 Describe the source-sink theory that is used to explain the movement of sucrose around the plant. Use a labelled diagram to assist your explanation.
- 4 Construct a table that compares the structure and function of the xylem and phloem vessels. Features to compare could include substances transported, direction of movement, structure, and processes involved in the movement of substances.
- 5 Draw the following labelled diagrams as seen through the light microscope:
 - a a transverse section of a stem showing the position of the vascular bundles
 - b transverse sections of xylem and phloem tissues
 - c longitudinal sections of xylem and phloem tissues.

CHECK YOUR UNDERSTANDING

6.1b

6.2

Hypotheses, theories and models about plant function

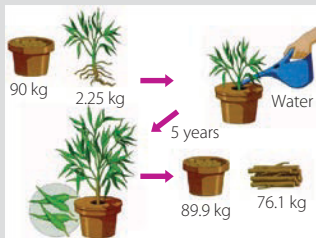
The way in which scientists investigate, using the scientific method, is discussed in Chapter 1.

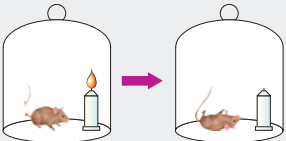
Scientists have a great depth of knowledge about the structure and function of plants and the processes that occur in them. This knowledge has not happened all at once, but has been gradually built up over hundreds of years as scientists investigate and build upon each other's discoveries. Many discoveries are made when scientists wonder about why and how things happen, and then perform experiments to try to find out. Some discoveries are made accidentally while a scientist is experimenting on something entirely different. The development of more and more sophisticated technologies has also enabled more and more information to be obtained about plant structure and function. Collaboration and cooperation between scientists is always an advantage for the speedy solution to scientific queries.

The processes in plants that allow them to survive and grow have long intrigued scientists, and many experiments have built upon each other to produce our current understandings. Investigations into the process of photosynthesis began with experiments carried out in the 17th century to determine whether plants 'ate the soil' in order to grow.

Table 6.1 provides information about early experiments into the process of photosynthesis: information about the experiments carried out by the scientist and the results and conclusions reached. An evaluation of these processes, claims and conclusions has also been included.

TABLE 6.1 Investigations that led to our understanding of the process of photosynthesis

SCIENTIST	EXPERIMENT	FINDINGS / CONCLUSION	EVALUATION
Jan Baptista van Helmont 1580–1644 	Van Helmont thought that the soil formed all of the plant matter. 1 He weighed 90 kg of dried soil and planted a 2.25 kg willow seedling. 2 Van Helmont then watered the plant for 5 years. 3 He separated the seedling from the soil, dried the soil and weighed both. 	The soil weighed 89.9 kg – a small decrease. The plant weighed 76.1 kg – a large increase. Van Helmont concluded that all of the plant matter came from the water.	1 Van Helmont's conclusion was incorrect – he was testing whether the soil provided the matter for the plant, but concluded that it was the water – nothing else was considered. His conclusion should have been that very little of the plant matter came from the soil. 2 The experiment itself was flawed: – The mass of lost leaves was not included in his measurements. – There was no control to test whether the plant grew just as much if only water was used (as it should have if Van Helmont's conclusion was correct). 3 There was no repetition – only one plant was tested. 4 There were many inaccuracies – his description of the experiment was incomplete, he did not measure how much water he added, and weighing accurately was impossible as the soil could not be fully separated from the plant.

SCIENTIST	EXPERIMENT	FINDINGS/CONCLUSION	EVALUATION
Joseph Priestley (1733–1804) Getty Images/James Sharples 	1 Priestley noticed that in an enclosed space a candle would go out and a mouse would die.  2 He put a mint plant into the enclosed space with an extinguished candle. He put another mint plant into the space with a mouse. 	Priestley found that when the plant was present in the enclosed space, a candle lit with focused sunlight remained alight and the mouse survived. He concluded that the plant restores to the air whatever the candle and the mouse had removed.	1 He thought that the candle and the mouse that breathed the air somehow 'injured' the air. 2 He also thought that the plant growth itself was responsible for replacing the factors that the mouse and candle had removed. 3 Priestley's experiments were well designed and his conclusions matched the knowledge of the time. 4 These experiments contributed greatly to the eventual understanding of photosynthesis.
Jan Ingenhousz (1730–1799) Alamy Stock Photo/Paul Fearn 	1 Ingenhousz set up a similar experiment to Priestley, with a candle and plant in the bell jar. 2 He covered the bell jar so that no light could enter and left it for a number of days. 3 Ingenhousz also submerged a small aquatic plant in water that was exposed to light. 4 He then subjected the experimental set-up to darkness.	1 The candle did not light. Ingenhousz showed that light is necessary to restore air after it has been 'fouled' by candles or animals. He demonstrated that light is necessary for plants to make oxygen. 2 When the aquatic plant was exposed to light, bubbles were formed around the leaves and the green parts of the stem. When it was in darkness, the bubbles stopped. Ingenhousz concluded that light was necessary for the plant to produce the gases that 'purify' the air.	1 Ingenhousz took Priestley's work even further and is credited with discovering photosynthesis. 2 His experiments tested what he set out to test. 3 He demonstrated that light and the green sections of the plant are required for the plant to produce the gas oxygen.

Many investigations are still occurring into the process of photosynthesis and the structure and function of plants as more advanced technology is developed. Experiments and results are analysed and used as a basis for further investigation. In some cases hypotheses, theories and models are changed in response to the results of subsequent experiments. Other hypotheses, theories and models are still in place because there is a great body of evidence to support them. This is what investigation in science is all about.

INVESTIGATION 6.3

A secondary-source investigation into our understanding of plant function



Critical and creative thinking



Information and communication technology capability



Literacy

Many other scientists continued to perform experiments to deepen the understanding of photosynthesis. These include Jean Senebier, Nicolas-Théodore de Saussure, F. F. Blackman, Cornelis van Niel, Samuel Ruben and Martin Kamen and Melvin Calvin.

The transpiration-cohesion-tension theory attempts to explain how water and mineral ions move in the xylem tissue. This theory has been developed based on investigations performed by scientists over many years, including John Joly, Henry Horatio Dixon, Stephen Hales, Eugen Askenasy, and Steven Jansen and H. Jochen Schenk.

To evaluate the processes scientists used in their investigations, a judgement is made about whether the scientific method was followed. This judgement should be accompanied by evidence to support the judgement.

To evaluate the claims or conclusions made by scientists, a judgement is made about whether the correct conclusion was made from the results of the investigation. Whether the conclusion was supported by further experiments should also be commented upon.

AIMS

- 1 To evaluate the processes, claims and conclusions proposed by scientists that contributed to our understanding of the process of photosynthesis
- 2 To evaluate the processes, claims and conclusions proposed by scientists that contributed to the transpiration-cohesion-tension theory

METHOD

- 1 Choose any two of the scientists listed above who have contributed to our understanding of photosynthesis.
- 2 Research the experiments these scientists performed, the results they obtained and the conclusions they reached. Use a variety of secondary sources, making sure that they are relevant, valid and reliable. See Chapter 1 for guidelines about this.
- 3 Evaluate the processes each scientist followed and the conclusions they reached.
- 4 Repeat steps 1 to 3 choosing scientists who contributed to the transpiration-cohesion-tension theory.

RESULTS

Present your information in two separate tables as shown in Table 6.1, or in a way of your choosing.

CONCLUSION

Write a few sentences to summarise your findings.

See p. 17 for information on evaluating investigations. Information on the use of models is on p. 5.

KEY CONCEPTS

- Our scientific understanding of the structure and functioning of plants has been developed by scientists over many years.
- Hypotheses, theories and models are modified when required if new information and results indicate they are no longer correct.
- Many scientists have contributed to our understanding of photosynthesis and the transpiration-cohesion-tension theory.

- 1 How do scientists discover information about the world?
- 2 Why do models change over time?
- 3 Distinguish between a hypothesis and a theory.

6.3 Transport systems in animals

The cells of multicellular organisms require a constant supply of nutrients and oxygen and the continual removal of waste products. A circulatory system is the most efficient way to achieve this.

Open and closed circulatory systems

The transport systems of multicellular animals can be divided into two types: open and closed. These systems are similar in that they each contain the **heart** as a driving mechanism, a fluid that transports substances and a system of vessels. There are numerous differences, but the major one is that in a **closed circulatory system** the transport medium remains enclosed in the system of vessels at all times. In an **open circulatory system**, the transport fluid leaves the vessels, enters cavities in the body and comes in direct contact with the organs.

Open circulatory systems

An open circulatory system is made up of one or more hearts and open-ended blood vessels. It is not sealed. The heart pumps blood into a cavity that surrounds organs, after which the blood is returned to the heart through special openings. Open circulatory systems exchange only nutrients and wastes with cells of the organism's body – gases are exchanged via a different system. Open circulatory systems are not as efficient as closed systems because the fluid pressure is low, causing the transport fluid to circulate slowly.

An open circulatory system is characteristic of invertebrate animals such as spiders, insects, crabs and snails. When the long, pulsating vessel (the heart) contracts, it pumps the transport fluid away from it and into shorter vessels near the head end of the body. These vessels empty into large spaces in the body cavity called **sinuses** (Fig. 6.9). The transport fluid in an open circulatory system is called

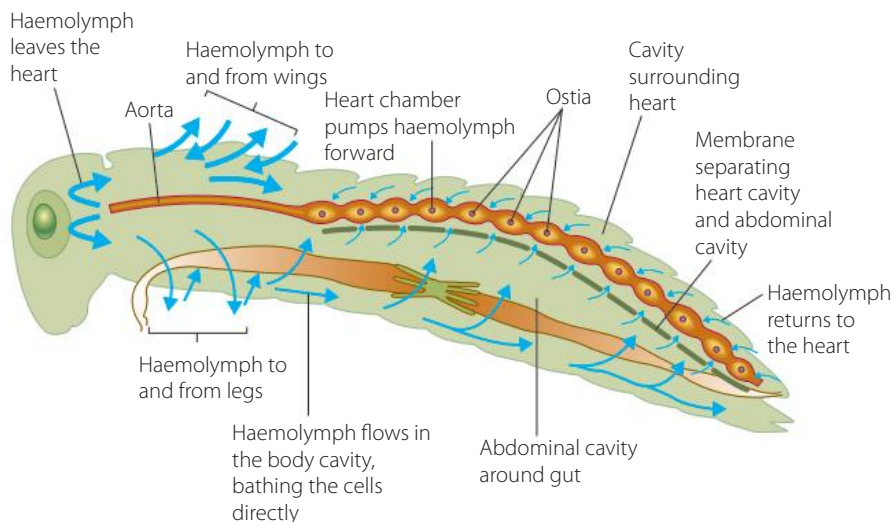


FIGURE 6.9 The open circulatory system of a locust. The heart is a long tubular structure on the upper (dorsal) side and the gut stretches along the lower (ventral) side.

haemolymph and is a mixture of blood and tissue fluid. Haemolymph flows into the sinuses in the body cavity, bathing the cells directly. The movement of the organism aids this flow of haemolymph around the cells. Exchange of nutrients and wastes occurs by direct diffusion between the haemolymph and the cells.

When the heart expands, it causes haemolymph to return to the heart by moving it from the posterior (rear) sinuses back into the open end of the tubular heart, or the haemolymph may enter the heart through tiny holes in the sides called **ostia**.

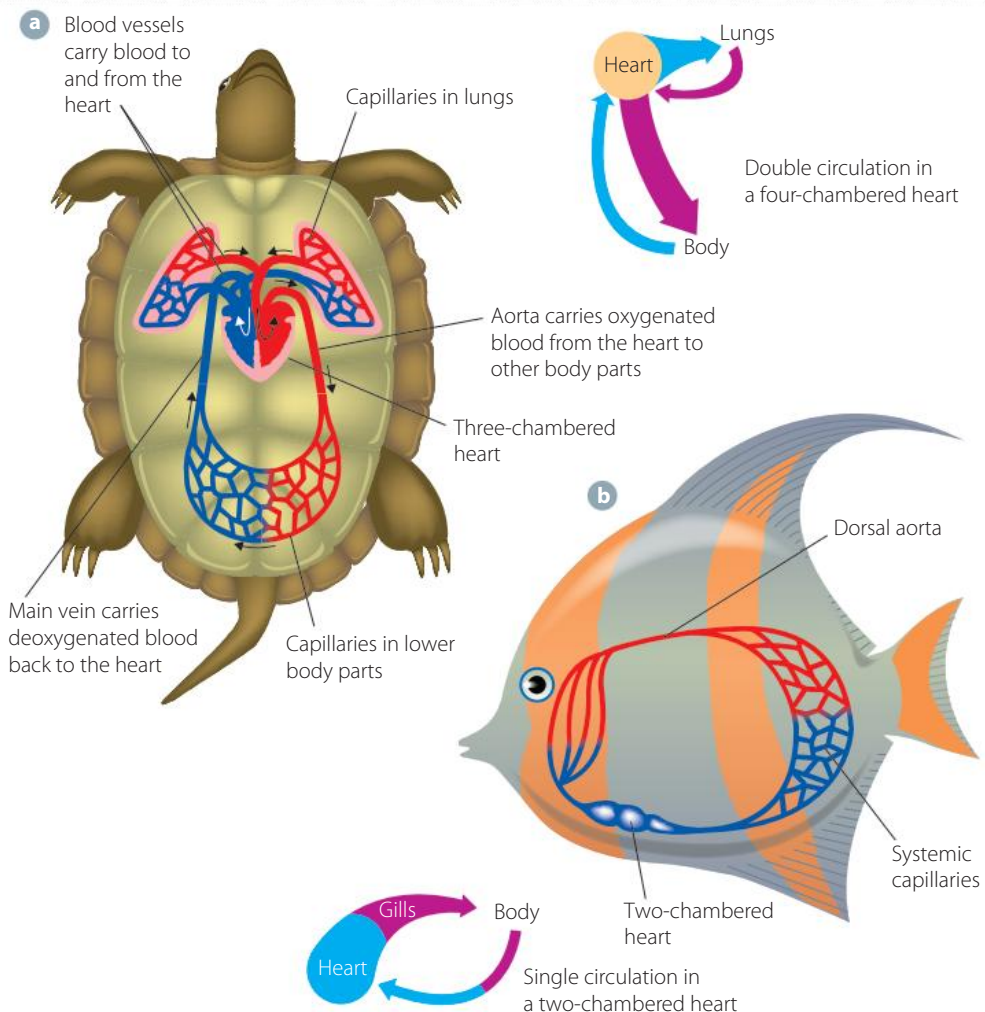
Closed circulatory systems

A closed circulatory system is found in all vertebrate animals and is made up of blood vessels and a heart, which form a sealed system. This system transports nutrients and oxygen to all cells and carries wastes away from cells. In mammals, the main transport system is known as the **cardiovascular system**, and is made up of a driving mechanism (the heart) to move the blood (transport medium) in the correct direction through a series of vessels (Fig. 6.1a).

A closed transport system is like a system of roads where useful requirements can be taken to the houses, which could be likened to cells. These useful substances would be used at the house and the products or wastes removed from these houses via the system of roads.

A closed circulatory system (Fig. 6.10) is found in vertebrates such as fish, frogs, reptiles, birds and mammals (including humans). The transport fluid is **blood**, which is contained in vessels *at all times* and never flows through body cavities. The heart pumps the blood around the body.

FIGURE 6.10 The closed circulatory system of vertebrates



The heart may be two-chambered (as in fish), three-chambered (as in frogs and some reptiles) (Fig. 6.10), or four-chambered (as in other reptiles, all birds and mammals) (Fig. 6.11).

Blood flows through three types of **blood vessels**: **veins**, which carry blood from body organs towards the heart; **arteries**, which carry blood away from the heart to the organs; and capillaries, which form a link between arteries and veins. The arteries branch into smaller **arterioles**, which subdivide further into a network of capillaries. These capillaries branch extensively throughout the tissues, so that no cell is very far from a capillary (Fig. 6.10).

The exchange of nutrients, wastes and gases takes place between blood in the capillaries and fluid surrounding the cells, which the capillaries supply. Blood remains in the capillaries at all times, but any chemical substances required by cells leave the capillaries in a dissolved form and move to the fluid that surrounds the cells. This fluid is called the **interstitial fluid** or tissue fluid. It is the link between the capillaries and the cells – the nutrients, gases and wastes move through this fluid on their transfer between the blood and the cells. Capillaries join up to form **venules**, which in turn join up to form veins, returning blood to the heart.

In a closed circulatory system, the muscular heart pumps blood under high pressure, ensuring efficient transport, which suits large, active animals such as vertebrates. A four-chambered heart is the most efficient pumping mechanism, as it keeps **oxygenated** blood and **deoxygenated** blood separate.

KEY CONCEPTS

- Open circulatory systems contain a heart that contracts and pushes haemolymph through vessels to bathe the organs.
- When the heart muscle relaxes, the heart expands and the fluid is drawn back into the heart.
- Haemolymph transports only nutrients and wastes; gases are exchanged in a different system.
- Closed circulatory systems contain blood that is totally enclosed in vessels, with a heart providing the driving force to push the blood around the body.
- The pathway of blood in blood vessels from the heart, around the body and back to the heart is shown in the flow diagram:
arteries → arterioles → capillaries → venules → veins → heart

- a State the main function of the circulatory system in multicellular animals.
 - b Identify the two types of circulatory systems in multicellular animals.
 - c Outline the main difference between these two types.
- a Draw a labelled schematic diagram of an open circulatory system.
 - b Identify the name and the composition of the transport fluid in an open circulatory system.
 - c Describe how substances are transported in an open circulatory system.
- a Identify the main components of a closed circulatory system.
 - b Draw a flow chart to show the pathway of blood through a closed circulatory system.

CHECK YOUR UNDERSTANDING

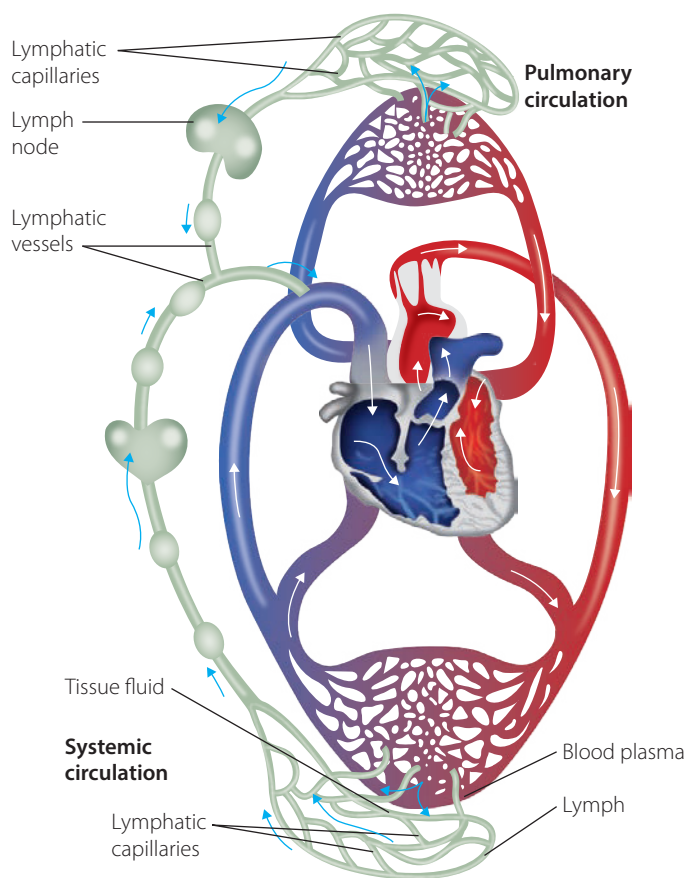
6.3a

Lymphatic system

The **lymphatic system** forms part of the transport system in mammals. The fluid that surrounds cells diffuses out of the capillaries as they pass through the tissues (Fig. 6.11). To prevent this interstitial fluid from building up in the tissues, **lymph vessels** in the tissues absorb it. This fluid, along with other substances present in the lymph vessels, such as white blood cells and the end products of lipid digestion, is known as **lymph**.

FIGURE 6.11

Simplified diagram showing the interaction between the cardiovascular and lymphatic systems



The lymph flows in the lymph vessels in one direction, from the tissues to the heart. This movement is assisted by the contraction of muscles in close proximity to the vessels. **Valves** are present in the lymph vessels to prevent the lymph going backwards.

The lymphatic vessels from all regions of the body eventually join up to form two main lymphatic channels. In the region of the shoulders, these lymphatic channels drain into the veins, allowing the lymph fluid to rejoin the blood. As well as preventing the build-up of excess fluid in the tissues, this helps to maintain the volume of the blood and therefore blood pressure. The lymphatic system also plays an important role in the defence of the body.

Blood as a medium of transport

Blood is the fluid transport medium that flows through the heart and blood vessels of the cardiovascular system in vertebrates. It consists of two main components: blood cells and plasma.

If blood is **centrifuged**, 55 per cent of it is found to be the watery **plasma** that collects on top of the cells. It has many substances dissolved in it. Forty-five per cent is the heavier red and white blood cells that collect below the plasma (Fig. 6.12).

Human blood usually has a temperature of 38°C (it carries heat and so is 1°C higher than overall body temperature) and a pH of 7.35 (slightly alkaline). The volume of blood in the human body varies slightly from one person to the next, but an adult human has approximately 5 litres of blood. For the normal functioning of the body and its enzymes, these levels of temperature, pH and blood volume must be carefully maintained.

The role of the lymphatic system in the defence of the body will be studied in more detail in the Year 12 course.

Blood distributes heat around the body, as well as the nutrients and gases required by the body and the wastes to be excreted from the body. It also carries other chemicals such as hormones, antibodies to fight infections, clotting factors, and many other substances required by the body to function efficiently.

Red blood cells

The main function of red blood cells is to transport oxygen. There are approximately 4–6 million red blood cells per millilitre (mL) of blood.

Red blood cells (erythrocytes) form in bone marrow. At first each cell has a nucleus, but as the cell matures, the nucleus disintegrates. A red pigment called haemoglobin develops inside the cell. The absence of a nucleus allows the red blood cell to carry more haemoglobin (an oxygen carrier). The mature red blood cells are small, with a diameter of approximately 7 μm (micrometres). Red blood cells are round, biconcave and slightly flattened towards the centre (similar to a donut without the hole totally taken out) (Fig. 6.13). This shape makes them more pliable and elastic so that they can squeeze through capillaries that are sometimes narrower than their actual size.

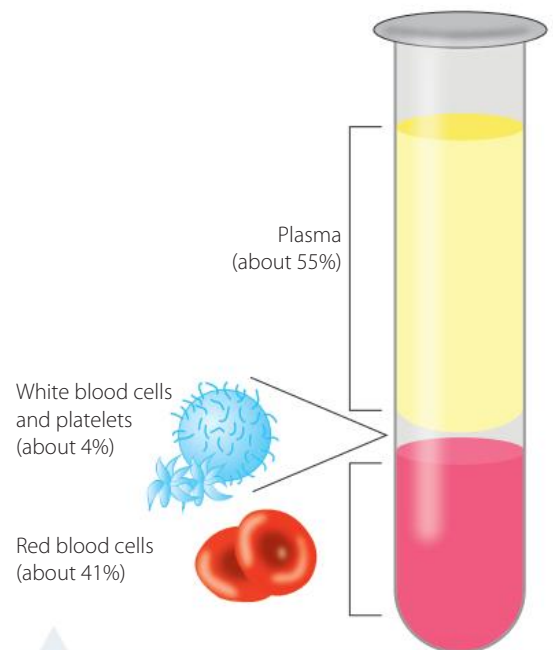


FIGURE 6.12 Components of blood

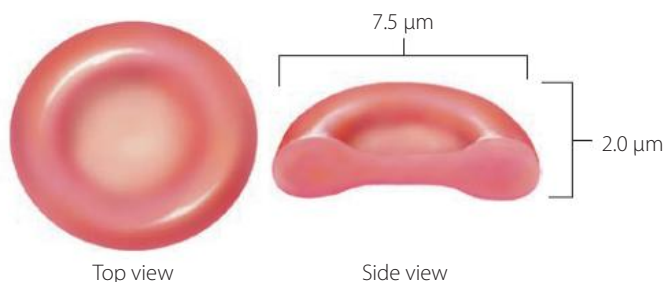


FIGURE 6.13 The shape and dimensions of a red blood cell

Red blood cells have a lifespan of approximately 4 months, and when they die they are broken down and replaced by newly formed blood cells from the bone marrow.

White blood cells

White blood cells (leucocytes) are also produced in bone marrow. They function as part of the **immune system**. Their main role is in the defence of the body against invading foreign bodies (Fig. 6.14). There are approximately 4000–11 000 white blood cells per mL of human blood.

There are several types of white blood cells – some live for only a few minutes to days, and others can live for years. Each type carries out a specific function in defending the body. They are found in the tissues as well as in the blood. Leucocytes can pass through capillaries by squeezing between the cells that make up the wall of the capillary and so get to regions of damaged cells.



FIGURE 6.14 A scanning electron micrograph of a white blood cell engulfing a yeast cell

Getty Images/Media – Biology

The role of leucocytes in the defence of the body will be studied in more detail in the Year 12 course.

White blood cells are larger than red blood cells (about 50 per cent bigger) and not as abundant. All white blood cells have a nucleus; in some white blood cells, it may be an unusual shape. In prepared microscope slides of blood, the staining technique imparts a purple colour to the nucleus (Fig. 6.15).

FIGURE 6.15 a A standard blood smear showing blood cells under a light microscope (white blood cells with irregular nucleus, platelets – tiny fragments near red blood cells); **b** a scanning electron micrograph of blood cells (red cells, white cells and platelets)

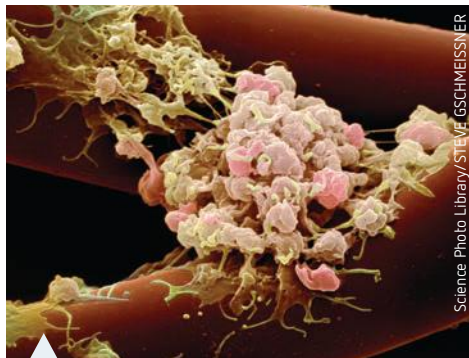
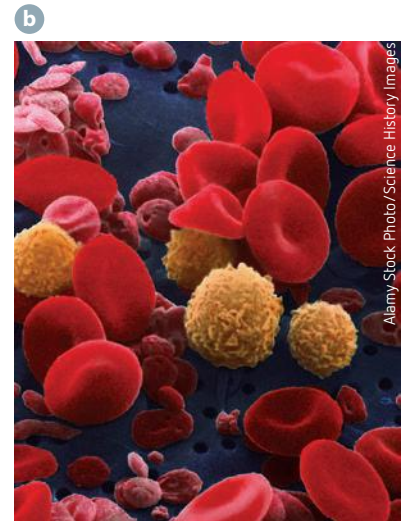


FIGURE 6.16 Platelets creating their blood-clotting web, which has trapped some red blood cells

Platelets

Platelets (thrombocytes) are fragments of special cells, also produced in the bone marrow. They are crescent-shaped, about half the size of red blood cells, and there are about 400 000 per mL of blood. Platelets have a function in the clotting of blood – they stick to each other and to the fibres that develop at the site of a wound when blood is exposed to air (Fig. 6.16). The contact between fibres and platelets causes the platelets to break open and release an enzyme, **thromboplastin**. This sets in progress a sequence of steps to seal the blood vessels and cause blood to clot, preventing excessive blood loss. If blood clots form

inside blood vessels without exposure to air, this causes blockages to circulation as occurs in **deep vein thrombosis (DVT)**.

Plasma

Plasma, the yellow, watery fluid part of blood, consists of about 90 per cent water, and the other 10 per cent consists mainly of proteins.

Plasma makes up most of the volume of blood and it carries many substances in either dissolved or suspended form. Besides carrying the blood cells it also carries:

- *plasma proteins*: clotting factors, immunoglobulins (antibodies to fight infections) and albumen, as well as enzymes
- *nutrients*: the end products of digestion – amino acids (from digested proteins), glucose (from digested carbohydrates), glycerol and fatty acids (from digested lipids), and cholesterol
- *gases*: oxygen and carbon dioxide

- *excretory waste products*: nitrogenous wastes such as urea, uric acid and ammonia
- *ions* (mainly sodium chloride and calcium and magnesium phosphates)
- *regulatory substances* such as *hormones* – chemical messenger molecules involved in the coordination of body systems
- *other substances*, such as vitamins.

KEY CONCEPTS

- There are two transport systems in mammals: the cardiovascular system and the lymphatic system.
- The lymphatic system transports excess tissue fluid back to the cardiovascular system and is made up of lymph vessels and a fluid called lymph.
- The cardiovascular system is made up of blood, the heart and blood vessels.
- Blood is composed of 55 per cent plasma and 45 per cent blood cells (red, white and platelets).
- Red blood cells have no nucleus, have a biconcave shape and contain haemoglobin, which carries the oxygen.
- White blood cells contain a nucleus and play a role in defence of the body.
- Platelets have a tiny, crescent shape and play a key role in blood clotting.
- Plasma is a pale yellow liquid that carries the blood cells and many other dissolved substances that are required by the cells.

CHECK YOUR UNDERSTANDING

6.3b

- 1 Identify the major roles of the lymphatic system.
- 2 Identify the transport medium in the lymphatic system and outline its composition.
- 3 Distinguish between the lymphatic system and the circulatory system.
- 4 **a** Describe the pathway of this transport medium through the lymph vessels from the tissues to the heart.
b Identify the internal structures of these vessels and outline how they assist this movement.
- 5 **a** Draw a diagram or pie chart to show the composition of blood.
b Outline the function of blood in the circulatory system.
- 6 Construct a table to identify the three different types of blood cells and their characteristics. Include information about their size, shape and function.
- 7 **a** Outline the role and composition of plasma.
b Identify the substances carried in plasma.
- 8 Explain how the features of red blood cells assist them to carry out their function.

Blood vessels

The blood vessels are an integral part of the transport system in mammals.

The function of the blood vessels is to carry blood around the body, transporting nutrients, gases and wastes. Each of the blood vessels – arteries, capillaries and veins – has a specific structure related to its function. Arteries carry blood away from the heart, veins carry blood back to the heart and capillaries form a network to reach all cells in the body.

These three vessel types share a similar basic structure, but they differ in terms of the layers of tissue that make up the wall of each and the size of the lumen (central cavity), so that each vessel is structurally modified to best carry out its specific transport function (Fig. 6.17).

FIGURE 6.17
Transverse sections
through arteries,
capillaries and veins

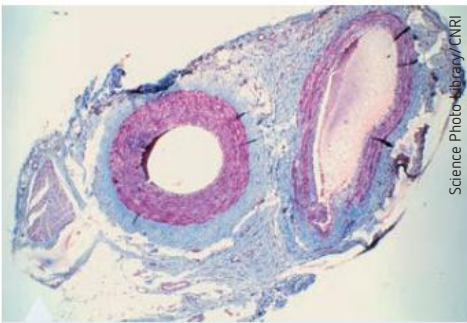
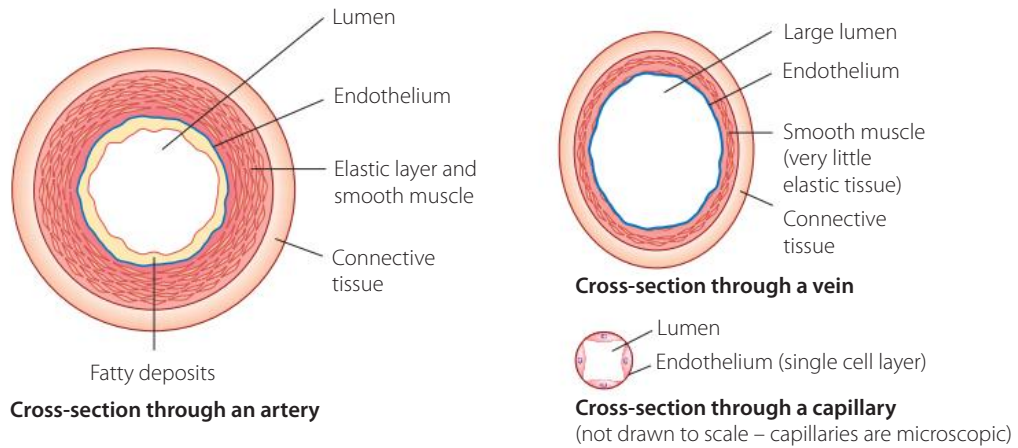


FIGURE 6.18 Microscopic image of transverse section of an artery (left) and a vein

Arteries

The blood that enters arteries is under very high pressure as it is pumped out of the heart in regular bursts. The walls of the arteries are much thicker than those of veins so that they can withstand this pressure. The elasticity of the artery wall allows it to expand when a pulse of blood moves through and then contract back to the original diameter. This contraction also squeezes the blood forward and propels it along.

Veins

Veins return blood to the heart. Veins have walls that are thinner than those of arteries, since the blood that they receive flows under lower pressure. The walls have very few elastic fibres because they do not need to stretch and recoil. The internal diameter is much wider than that of an artery, allowing for easy flow of blood (Fig. 6.18).

Since blood seeps into veins and is not pumped, two mechanisms prevent the backflow of blood:

- 1 When the muscles in the tissue that surrounds the veins contract, the walls of the veins are compressed, propelling the blood towards the heart.
- 2 Veins have valves situated at regular intervals along their lengths. These valves prevent blood from flowing backwards. They work like one-way swing doors – they open to allow blood to flow through in one direction (towards the heart), but the pressure of blood trying to flow backwards causes them to swing shut and stop the reverse flow (Fig. 6.19).

Capillaries

Capillaries are extremely tiny vessels that bring the blood into close contact with the tissues, enabling the exchange of chemical substances between cells and the bloodstream. The walls of capillaries consist of only one layer of cells. Diffusion is a fairly slow, passive process and so the structure of capillaries is suited to slowing down the flow of blood.

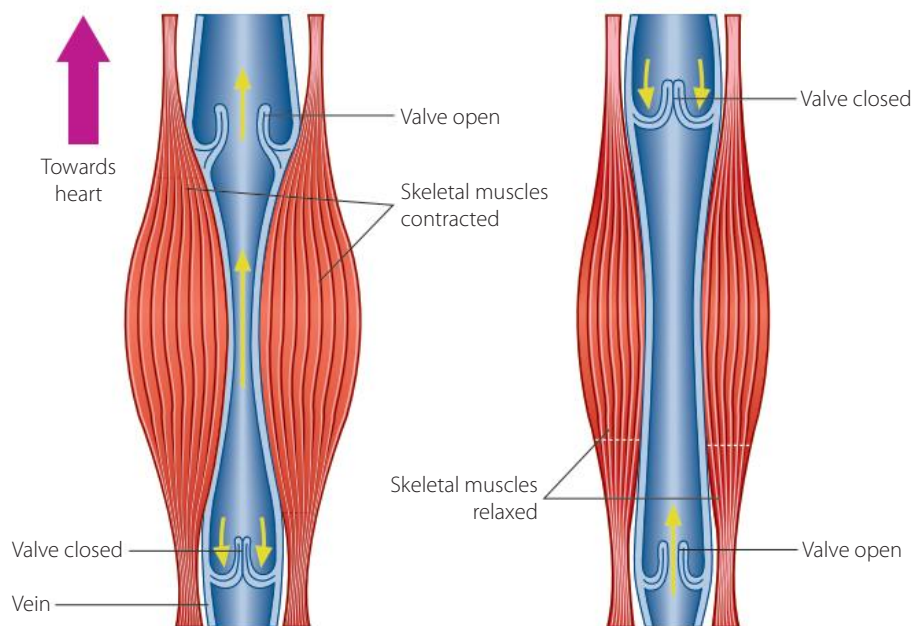


FIGURE 6.19
Functioning of valves

To maximise exchange of substances between the blood and cells of the body, capillaries have:

- thin walls to allow for the efficient diffusion of substances, so that they do not have far to travel between the blood and body cells, and
- an internal diameter only slightly larger than the diameter of red blood cells. This forces the red blood cells to pass through in single file, slowing down their flow and increasing their exposed surface area for exchange of gases, nutrients and wastes (Figs 6.20 and 6.21).

Capillaries form an expansive network to spread blood flow over a large surface area so that no cells are far from the blood supply.

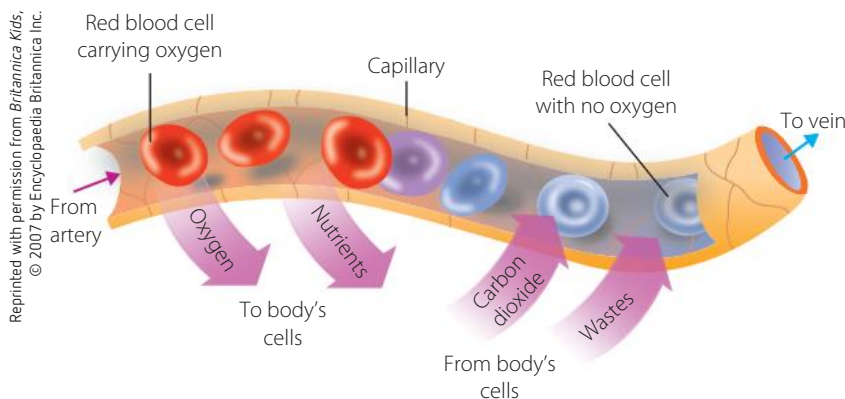
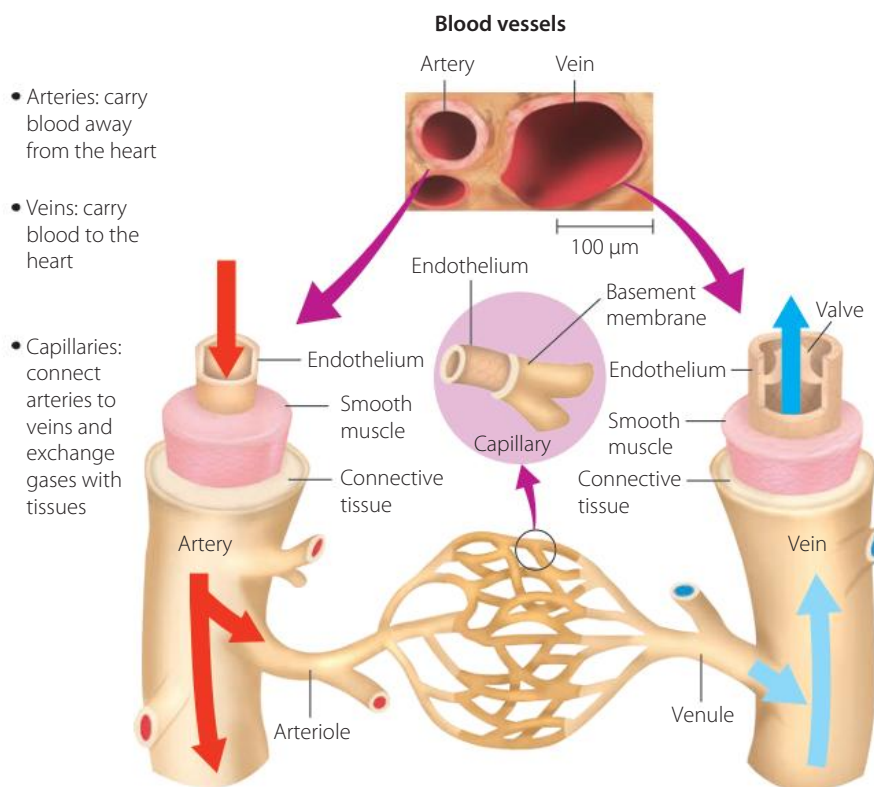


FIGURE 6.20
Capillaries are microscopic vessels with very thin walls to allow for efficient exchange of materials with all cells.

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FIGURE 6.21 The structure and movement of blood through the arteries, capillaries and veins



INVESTIGATION 6.4

A practical investigation of blood cells and blood vessels



In this practical investigation, prepared slides will be used to view the microscopic structure of blood cells and blood vessels. On the prepared slides of blood cells, red blood cells will be stained a pale red. The white blood cells will be purple in colour and contain a nucleus (often an irregular shape).

When viewing the transverse sections of blood vessels, you may find that capillaries are very difficult to see. The walls of the veins are thinner than the arteries and often the internal space is smaller.

AIM

To observe red blood cells, white blood cells and transverse sections of blood vessels

MATERIALS

- Prepared slides of blood smears
- Prepared slides of transverse sections of blood vessels
- Light microscope

RISK ASSESSMENT

WHAT IS THE HAZARD?	WHAT RISK DOES THE HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Microscope slide	If broken, could cause cuts to the skin	Handle with care



» METHOD

- 1 Place the prepared slide of the blood smear on the microscope stage and focus under low power.
- 2 Focus under high power and observe the structure of both the red and white blood cells and the platelets, if visible.
- 3 Draw a labelled diagram of each type of blood cell.
- 4 Place the prepared slide of the transverse section of the blood vessels, focus on low power and identify the artery and vein.
- 5 Focus under high power to observe the structure of each more closely.
- 6 Draw a diagram of the artery and the vein showing the different layers and thicknesses of the walls and the difference in size of the internal cavity.
- 7 Go to the weblink and observe the three-dimensional structure of the red blood cell.

RESULTS

- 1 Draw labelled diagrams of the red and white blood cells, and record the magnification.
- 2 Draw labelled diagrams of the transverse sections of an artery and a vein, and record the magnification.
- 3 Record a three-dimensional image of a red blood cell.

DISCUSSION

- 1 Describe the shape of the red blood cell.
- 2 How did the three-dimensional model of the red blood cell increase your understanding of the structure of the red blood cell?
- 3 Describe the function of the red blood cell and explain the advantages of its structure in relation to its function.
- 4 Describe the structure and function of the white blood cell.
- 5 Compare the structures of the artery and the vein.
- 6 How is the structure of each vessel related to its function?

CONCLUSION

Write a few sentences related to the aim, outlining what was done and the results obtained.



KEY CONCEPTS

- The three types of blood vessels are arteries, capillaries and veins.
- Arteries carry blood away from the heart and have thick, elastic walls to cope with the pressure of pulsing blood. These walls expand and return to their original diameter, helping to propel the blood.
- Veins carry blood back to the heart and have thinner walls because they do not have to cope with blood under pressure.
- Veins contain valves to ensure that the blood moves in only one direction.
- The movement of blood in veins is caused by the contraction of surrounding muscles.
- Capillaries form networks so that all cells can be supplied with nutrients and gases, and wastes can be removed.
- Capillary walls are one cell thick to allow easy exchange between blood and cells.
- Only one cell at a time can move through capillaries; this increases their exposed surface area for exchange of gases, nutrients and wastes.

The heart – the driving force

The heart is the driving force in the circulatory system of animals. Mammals have a four-chambered heart, which pumps blood around the body.

Each side of the heart has two chambers – the top chambers are the **atria** (singular: atrium) and the bottom chambers on either side are called the **ventricles** (Fig. 6.22).

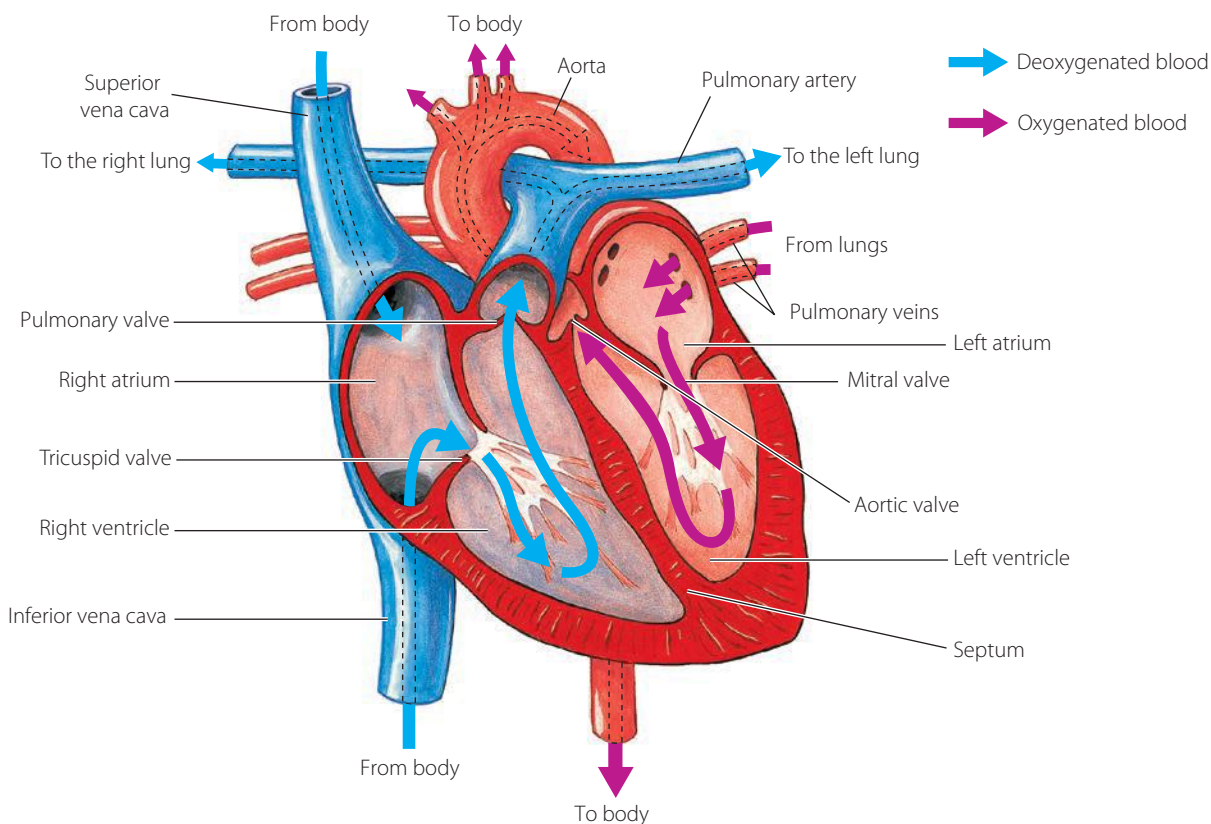


FIGURE 6.22 The human heart (longitudinal section)

Heart

Use arrows on the heart to indicate the pathway of blood through each side of the heart.

The heart is really a double pump with each side beating almost simultaneously. The one-way direction of blood flow in the heart is maintained by the presence of valves. Deoxygenated blood returns from the body to the right atrium of the heart via two large veins, the **superior vena cava** and the **inferior vena cava**. It then moves to the right ventricle from where it is pumped via the **pulmonary artery** to the lungs. There, carbon dioxide diffuses from the blood into the alveoli and oxygen diffuses from the alveoli into the blood.

The blood is now oxygenated and returns to the left atrium of the heart via the **pulmonary vein**. It then moves to the left ventricle from where it is pumped via the major artery, the aorta, to all areas of the body. A muscular wall called the **septum** separates the left- and right-hand sides of the heart.

The heart is composed of cardiac muscle tissue, which produces the heartbeat when it contracts. Because the ventricle on the left-hand side of the heart has to pump blood to all areas of the body, it has much thicker walls of muscle tissue than the right ventricle. The right ventricle only has to pump the deoxygenated blood to the lungs, which are situated in very close proximity to the heart.

The pumping of oxygenated blood to all parts of the body and the return of deoxygenated blood to the heart is called **systemic circulation**. The pathway of blood from the heart to the lungs and back to the heart is called **pulmonary circulation** (Fig. 6.23).

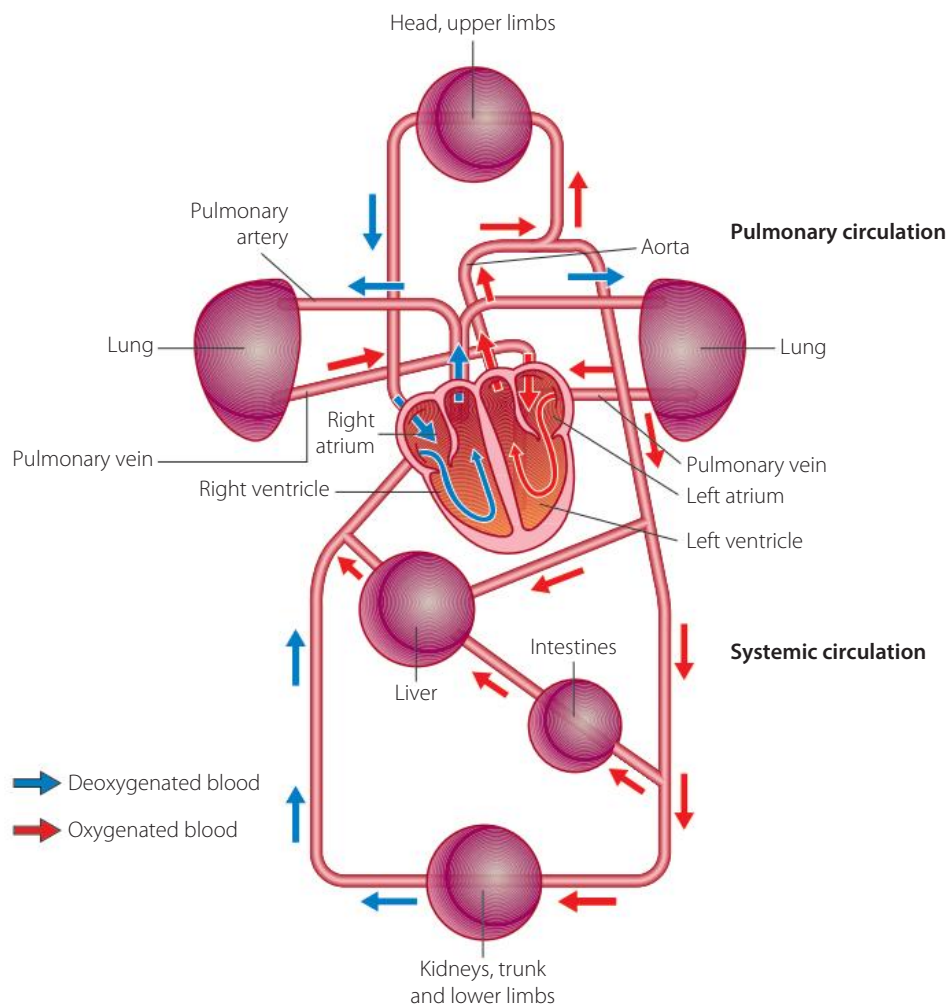


FIGURE 6.23 Systemic and pulmonary circulation in humans

[Manipulate the heart](#)

[Dissection of the mammalian heart](#)

KEY CONCEPTS

- Mammals have a four-chambered heart with two chambers on each side. The top chamber on each side is called the atrium and the bottom chamber on each side is the ventricle.
- The septum separates the two sides.
- The left ventricle has a thicker muscular wall because it has to pump blood all around the body while the right ventricle only has to pump the blood to the lungs.
- Deoxygenated blood enters the right atrium and then moves to the right ventricle from which it is pumped to the lungs to gain oxygen.
- Oxygenated blood flows back to the left atrium and then to the left ventricle from which it is pumped to the rest of the body before it once again returns to the right atrium.

- 1 Outline the basic similarities between arteries, veins and capillaries in terms of their function and their structure.
- 2 Construct a table that summarises the specific structure and function of each type of blood vessel.
- 3 Draw a labelled diagram of a transverse section of tissue that contains an artery and a vein.
- 4 Explain, in terms of their functions, why:
 - a the walls of arteries need to be thicker than those of veins
 - b the walls of capillaries are so thin
 - c veins have valves.
- 5
 - a Draw a schematic diagram of the heart and label the four chambers, the valves, and the blood vessels attached to the heart.
 - b Use different-coloured arrows to represent oxygenated and deoxygenated blood. Show the direction of movement of oxygenated and deoxygenated blood in the heart.
- 6 Distinguish between systemic and pulmonary circulation.
- 7 Create a simplified diagram that traces the path of blood throughout the body from the time deoxygenated blood enters the right atrium of the heart until it returns to the right atrium. Label all structures that it passes through. Shade the pathway of deoxygenated blood blue and oxygenated blood red.

6.4

Change in composition of the transport medium

The function of the transport system in animals is to deliver nutrients and gases to the cells and to collect and remove wastes. As the blood moves around the animal, the basic compositions of blood cells and plasma remain the same, but the concentration of dissolved substances and gases change depending on the organ it is passing through. Each organ has its own particular role that contributes to the efficient functioning of the organism as a whole. As the blood passes through the organ, changes to the composition of the blood will occur, whether it is adding required substances or removing wastes:

- One commonality in this changing composition is that, as the blood passes through all organs and tissues (with the exception of the lungs), the concentration of oxygen decreases and the concentration of carbon dioxide increases. This is a result of the process of cellular respiration where the cells remove oxygen and carbon dioxide is produced.
- As the blood moves through the lungs, it gains oxygen by diffusion from the alveoli and removes carbon dioxide.
- Another common feature is that as blood moves through all of the organs and tissues, nutrients such as glucose move out of the blood and into the cells, and wastes move in the opposite direction.
- An increase in digestive end products (glucose and amino acids) is seen in blood that has passed through an organ involved in absorbing digested food, such as the small intestine. These products of digestion travel in the bloodstream from the digestive tract directly to the liver (Fig. 6.23).

In the stomach, water diffuses into the blood, along with some substances such as alcohol.

Fatty acids empty into the bloodstream via the lymphatic system. Blood entering the heart has a high lipid content. This is then metabolised in the liver.

In the liver:

- A decrease in digestive end products (such as glucose, fatty acids and amino acids) is evident once blood has passed through the liver, because the liver is the centre of food metabolism.

- Glucose may be added or removed.
- Urea is added to the blood when proteins are broken down and nitrogen removed.
- Toxins and substances such as alcohol are removed from the blood.
- Some vitamins and iron are removed.

In the kidneys, the amount of urea is decreased because the kidneys filter nitrogenous wastes out of the blood. Blood leaving the kidneys has the lowest percentage of nitrogenous wastes. Excess water and salts are removed from the blood.

In the large intestine, water, salts and vitamins are absorbed into the blood.

When blood passes through endocrine glands, hormones are added to the blood.

KEY CONCEPTS

- The composition of blood changes as it moves around the body and depends on the organ it is moving through.
- In all organs and tissues except the lungs, blood loses oxygen and gains carbon dioxide. In the lungs, it gains oxygen and loses carbon dioxide.
- In all organs except the small intestine, blood loses nutrients, such as the products of digestion, and gains wastes. Blood gains products of digestion in the small intestine.
- In the kidneys, blood has less urea when it leaves, and the concentration of water and salts will have changed according to the needs of the body.

- 1 Outline two common features in the change in composition of the blood as it moves through most organs and tissues.
- 2 Copy Table 6.2 and complete the changes in the composition of blood.

CHECK YOUR UNDERSTANDING

6.4

TABLE 6.2

TISSUE/ORGAN	CHANGE IN COMPOSITION
Organs and general body tissue	1 2
Lung	
Small intestine	
Stomach	
Liver	
Kidneys	
Large intestine	
Endocrine gland	

- 3 Outline the change in the composition of blood as it moves through the:
 - a brain
 - b kidneys.

Transport: How does the composition of the transport medium change as it moves around an organism?

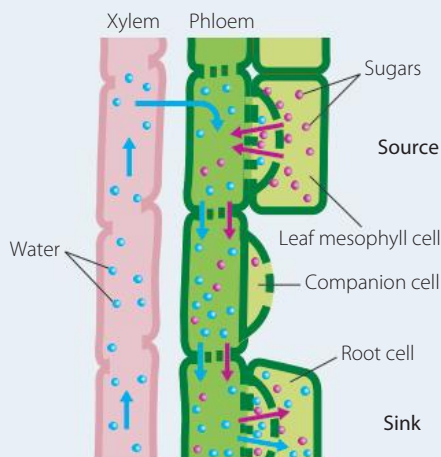
TRANSPORT SYSTEMS IN PLANTS

- Ensure all cells are supplied with required water, nutrients and gases
- Remove wastes

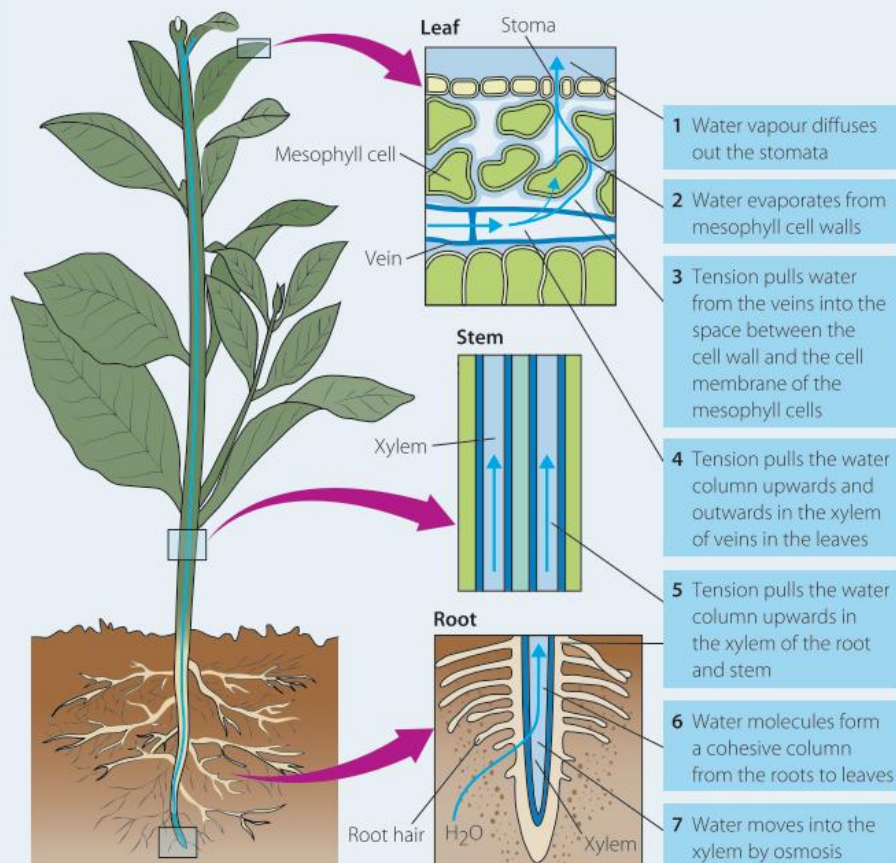
They contain:

- A system of vessels
- A transport medium
- A driving mechanism

Source-sink theory

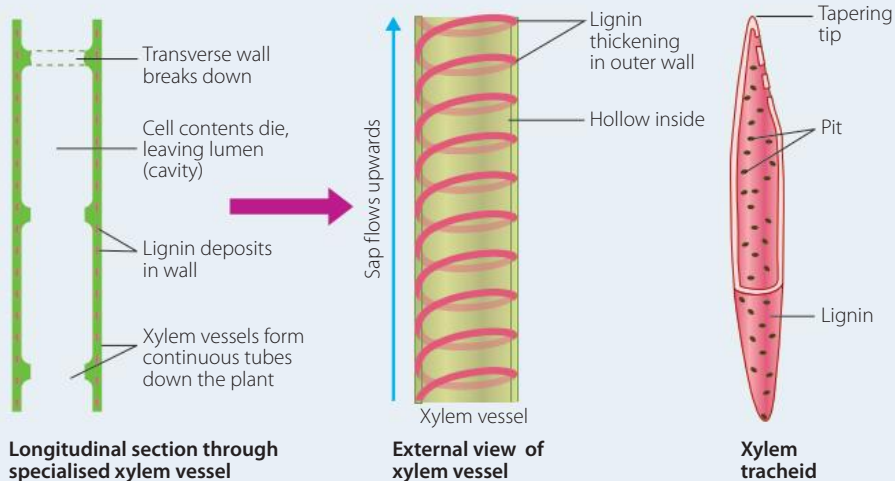


Transpiration: Cohesion-tension theory



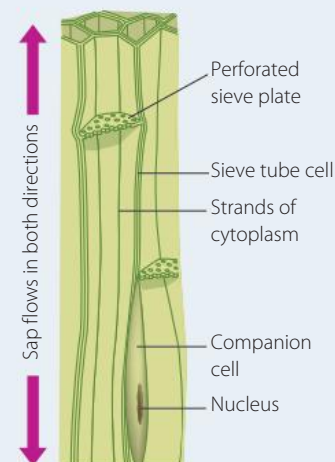
Xylem tissue

Transport water and mineral ions in one direction only from roots to leaves



Phloem tissue

Transport products of photosynthesis in whichever direction required

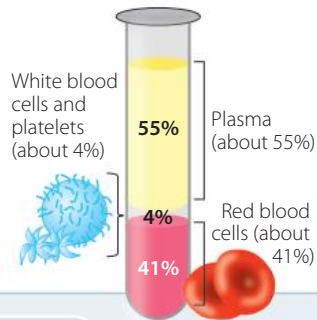


Transport medium: blood

TRANSPORT IN ANIMALS – CIRCULATORY SYSTEMS

Open: Transport fluid leaves the vessels, enters body cavity and bathes the organs.

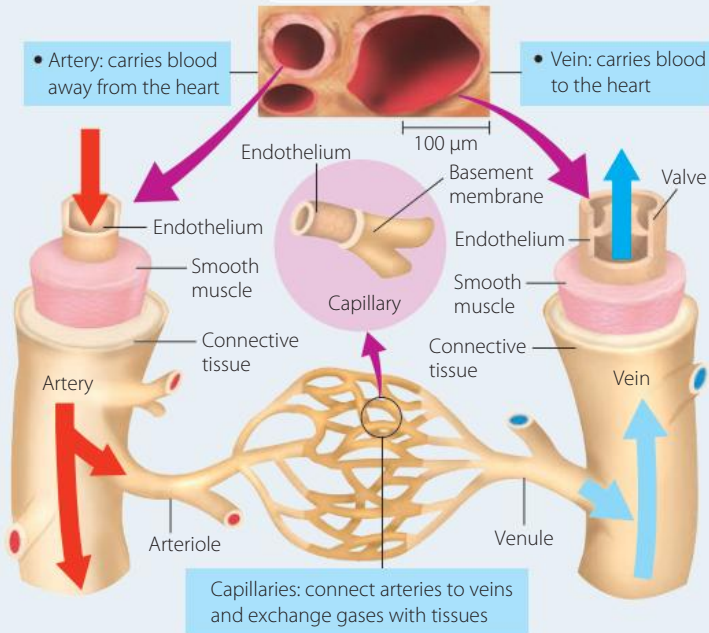
Closed: Transport medium remains enclosed in the system of vessels at all times with heart providing the driving force.



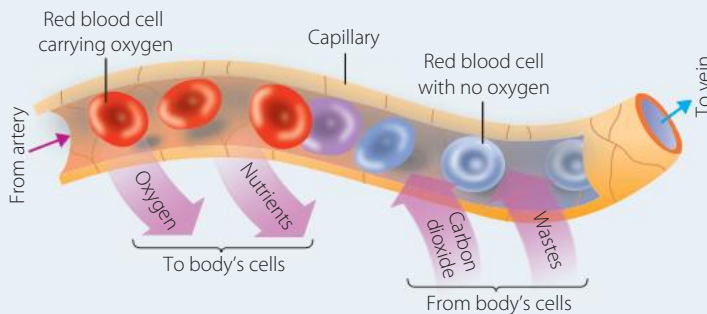
Blood vessels

• Artery: carries blood away from the heart

• Vein: carries blood to the heart



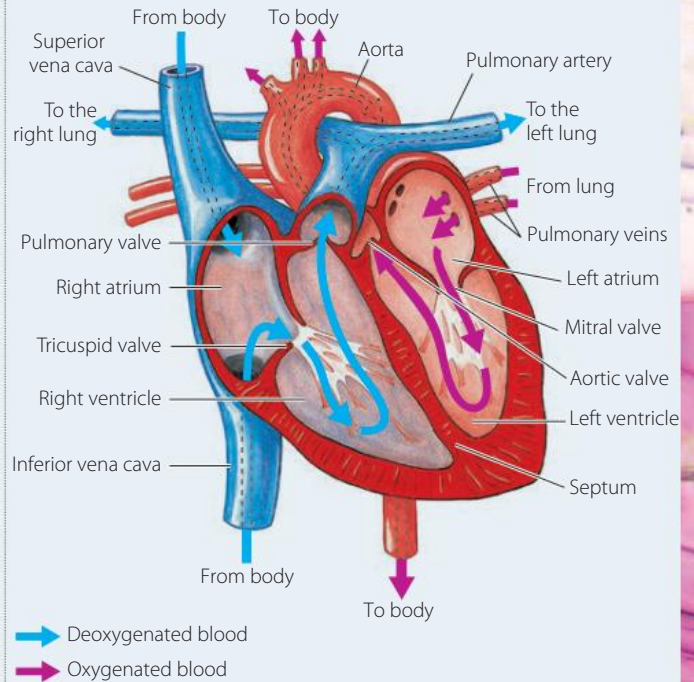
Capillaries are the microscopic vessels with very thin walls to allow for efficient exchange of materials with all cells.



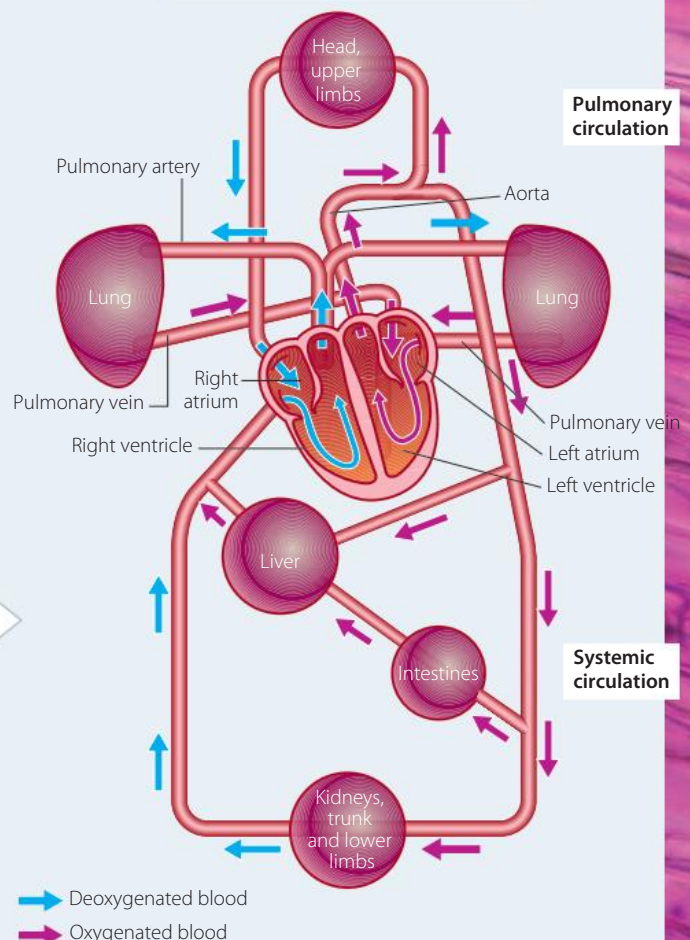
Changes in composition

- Blood composition changes as it moves around the body and depends on the organ it is moving through.
- In all organs and tissues except the lungs, blood loses oxygen and gains carbon dioxide. In the lungs, it gains oxygen and loses carbon dioxide.
- In all organs except the small intestine, blood loses nutrients, such as the products of digestion and gains wastes. Blood gains products of digestion in the small intestine.
- In the kidneys, blood has less urea when it leaves, and the concentration of water and salts will have changed according to the needs of the body.

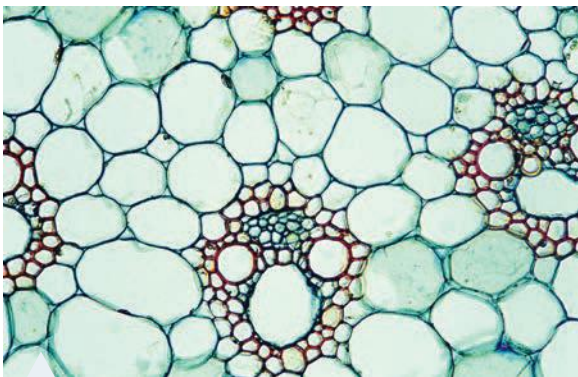
Driving force: The heart



Circulation in humans



- 1 **a** Outline the components of all efficient transport structures.
- b** Relate these components to the structures in the transport systems of multicellular plants and animals.
- c** Outline the major differences between the transport systems in multicellular plants and animals.
- 2 Distinguish between the uptake of mineral ions and the uptake of water from the soil through the roots.
- 3 **a** Identify the two types of vascular tissue in a plant.
- b** Copy Figure 6.24 showing the transverse section of a stem, and label the two types of tissue.



Alamy Stock Photo/age fotostock

FIGURE 6.24 Transverse section of stem tissue

- 4 Describe the structure and function of:
 - a** the xylem tissue
 - b** the phloem tissue.
- 5 **a** Describe the processes involved in the movement of water through the xylem tissue.
- b** Identify the energy source for this process.
- 6 **a** Describe how the products of photosynthesis are moved throughout the plant.
- b** Explain why this process requires the close proximity of xylem tissues.
- c** Identify the source of energy for this process.
- 7 Discuss the advantages and disadvantages of the process of transpiration to a plant.
- 8 Evaluate the processes and conclusions of one scientist's investigations into:
 - a** the development of the transpiration-cohesion-tension theory
 - b** the development of our understanding of the process of photosynthesis.

- 9 Summarise the structure and function of the lymphatic system.
- 10 Create a table to compare the structures and functions of an open and a closed circulatory system.
- 11 Identify the organs that make up the cardiovascular system.
- 12 Valves are structures found in lymph vessels, in some blood vessels and between various chambers of the heart. Describe their function and explain how their structure assists them to carry out this function.
- 13 Compare the processes involved in the movement of blood through the three different types of blood vessels: arteries, capillaries and veins.
- 14 Copy Figure 6.25 and label the artery and the vein.



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FIGURE 6.25 Transverse section of tissue showing an artery and a vein

- 15 Identify the components of blood and outline the function of each component.
- 16 Imagine you were a red blood cell in the body. Describe your pathway through the body from the time you entered the right atrium lacking oxygen to your journey back to the right atrium. Identify all structures, components and tissues that you passed through and any changes that occurred to you as you passed through these components.
- 17 Outline the changes that occur to the composition of the blood as it moves through the:
 - a** liver
 - b** skin.

Answer the following questions.

- 1 Aphids are small insects that feed on the sap of plants by inserting their sharp, needle-like mouthparts into the phloem tissue. They are commonly called 'sap sucking' insects, but this is incorrect since the material just flows into the aphid's body.

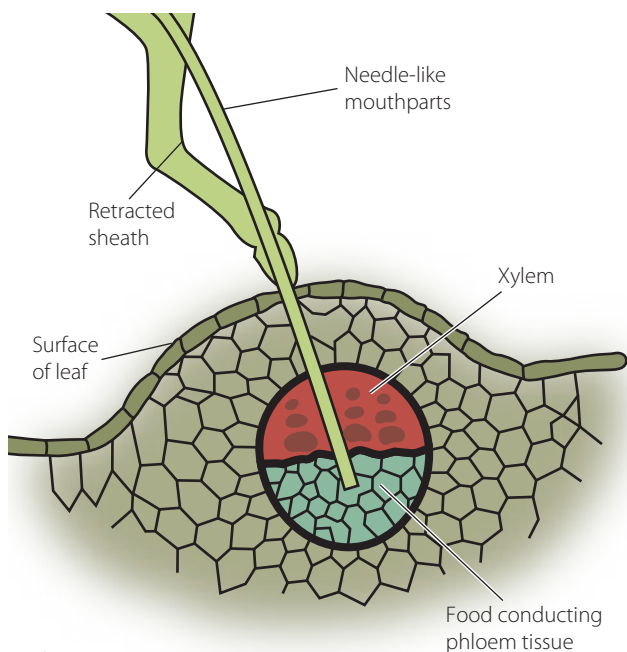


FIGURE M2.1 The needle-like mouth parts of aphids inserted into the phloem tissue of a leaf

Use your knowledge of the movement of substances in the phloem to explain why the material just flows out of the phloem and does not have to be 'sucked' by the aphid.

- 2 Jessica and Adam were discussing unicellular and multicellular organisms. Jessica said that she believed that unicellular organisms would be much more efficient in obtaining nutrients and disposing of wastes than multicellular organisms. Adam disagreed with her. Describe the evidence that each student might use to support his or her opinion.
- 3 Explain, in terms of their function, why:
- the walls of arteries need to be thicker than those of veins
 - the walls of capillaries are so thin
 - veins have valves.
- 4 a Distinguish between cell differentiation and cell specialisation. Provide an example of each.

- b Describe the structure of two different specialised cells and relate their structure to their function.

- 5 Gall stones are hard deposits that form in the gall bladder. They range in size from very small to the size of a golf ball. At times gallstones can become lodged in the bile duct and prevent the entry of bile into the digestive tract. Describe the effect of a lack of bile on the chemical digestion of food particles.

- 6 Compare the gas exchange structures and the process of gas exchange in mammals and one other type of animal.

- 7 Distinguish between an open and a closed circulatory system and name one animal in which each occurs.

- 8 a Identify and explain the effect that a lack of transpiration would have on the movement of materials through plants in xylem tissue.
b Identify and describe the other forces that assist the movement of substances in the xylem tissue.

- 9 Observe Figure M2.2 (page 200) and, taking into account the information given with the diagram, answer the questions that follow.
Leaves need light for photosynthesis. Photosynthesis takes place in chloroplasts.

- a Compare the abundance of chloroplasts in the epidermis, the palisade cells and the spongy mesophyll cells.
b Discuss the distribution of chloroplasts within the leaf in relation to the function of each of the types of leaf tissue.

- 10 The composition of blood changes as it moves through the circulatory system.

In each of the following, the blood that has passed through an organ has been analysed and shown to have changed in the following ways:

- less oxygen, less urea, less glucose, more carbon dioxide
- more oxygen, less carbon dioxide, fewer nutrients
- less oxygen, more carbon dioxide, more glucose and amino acids.

Identify the organ that the blood has passed through in each case. Justify your answer to each scenario.

- 11 Explain how the requirements of a cell found in mammalian tissue are linked to the function of the mammalian digestive, gas exchange and transport systems.

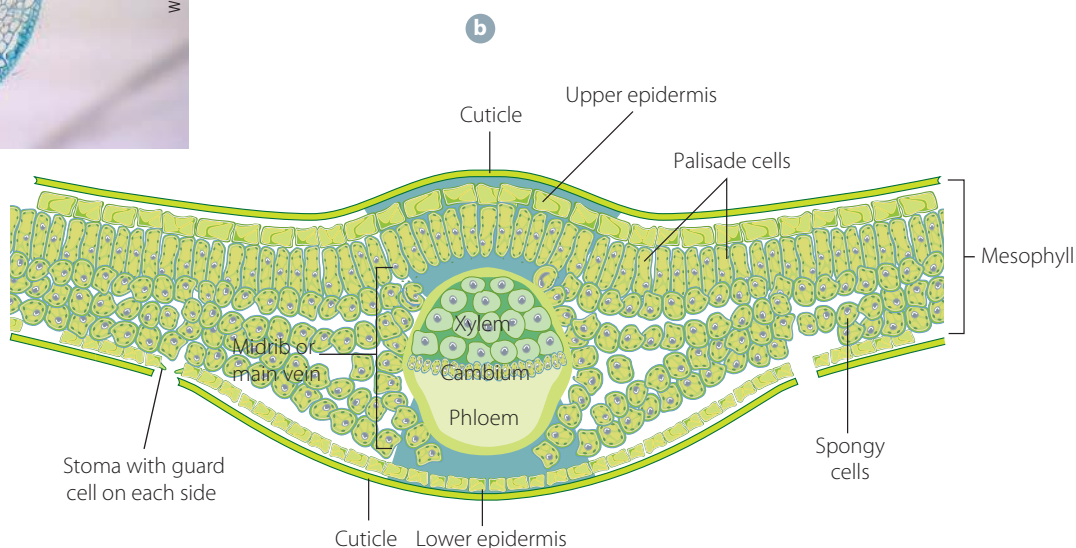
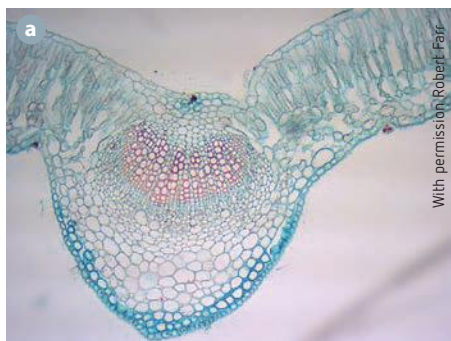


FIGURE M2.2

- 12** Table 6.3 shows the composition of phloem sap from the castor oil plant (*Ricinus communis*). This sap was collected from the phloem closest to the root system.

Table 6.3

COMPONENT	CONCENTRATION (MG/ML)
Sucrose	80.0
Potassium	2.3
Chloride	0.355
Phosphate	0.350
Magnesium	0.109

- Outline where each of these components came from.
- Identify where each of these components entered the phloem.
- Describe the differences you would expect in the composition of phloem sap that had been collected closer to the leaves of the plant.
- Describe two possible uses of the sucrose in the root system.
- What other major component of phloem sap would be added at the root system?

- 13** Refer to Figure 4.16 on page 125. Provide an explanation for the differing distribution of vascular tissue in the root and stem of a plant.

- 14** An investigation was carried out in the laboratory to determine the effect of environmental conditions on the evaporation of water.

In this investigation, 5 pieces of filter paper of the same size were weighed and then moistened with the same amount of water and weighed again. Each piece of filter paper was then subjected to a different environmental condition as follows:

A: heat, B: wind from a fan, C: heat and wind, D: classroom environmental conditions (shade, no wind), and E: enclosed in a plastic bag and heated.

After 15 minutes each piece of filter paper was weighed again and the percentage water loss for each piece calculated.

- For this investigation, identify the:
 - independent variable
 - dependent variable
 - controlled variables.

- b** Predict which of the environmental conditions A, B, C, D or E would have led to the:
- i** greatest percentage water loss
 - ii** smallest percentage water loss.
- c** Match the specific climatic condition (from the list below) to each of the environmental conditions used in the laboratory:

Hot and dry, windy, hot and windy, moderate temperature, high humidity.

- d** Relate this investigation to the process of transpiration in plants and outline how different climatic conditions may affect the rate of transpiration.

DEPTH STUDY SUGGESTIONS

- Construct a model to demonstrate the breathing mechanism of a mammal, fish or frog.
- Irish researchers recently discovered a 'new organ' in the digestive system. Research this and explain how this discovery reflects the scientific method, what observations were made and what hypotheses were proposed and tested.
Evaluate the claims and conclusions proposed by these researchers.
- Investigate the digestive tracts of a variety of animals and how they are specialised to cope with their diet.
- Review an in-depth study of one area of plant biology in which you are interested.
- Investigate the use of imaging technology to drive understanding in biology.
- Investigate the understanding of plant architecture to optimise the capture of sugars for biofuels.
- Investigate the discovery of blood circulation by William Harvey and predecessors.
- Explore evidence that could be used to determine whether sponges should be considered as a colony of cells or simple multicellular animals.
- Investigate the use of stem cells and continuing research with the associated ethical and scientific debates.
- Investigate the development of a specialised 3D printer that can produce tissue similar to human tissue.

» MODULE THREE

BIOLOGICAL DIVERSITY

- ⑦ Effects of the environment on organisms
- ⑧ Adaptations and survival
- ⑨ The Theory of Evolution by Natural Selection
- ⑩ Evidence to support the Theory of Evolution by Natural Selection



7

Effects of the environment on organisms

INQUIRY QUESTION

How do environmental pressures promote a change in species diversity and abundance?

Students:

- predict the effects of selection pressures on organisms in ecosystems, including: (ACSBLO26, ACSBLO90) [CCT L](#)
 - biotic factors
 - abiotic factors
- investigate and determine relationships between biotic and abiotic factors in an ecosystem, including:
 - measuring populations of organisms using sampling techniques (ACSBLO03, ACSBLO15)* [ICT N](#)
- investigate changes in a population of organisms due to selection pressures over time, for example: (ACSBLO02, ACSBLO94) [S CCT ICT L N](#)
 - cane toads in Australia
 - prickly pear distribution in Australia

(* from Module 4)

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The Blue Mountains region of New South Wales consists of a sandstone tableland, deeply incised with canyons and gorges and dominated by biodiverse forests with over 90 plant species. It provides a habitat for large numbers of animal species, including 186 vertebrate, 105 bird, 14 bat, 28 reptile and 10 frog species. To the north-east of the Blue Mountains, the Hunter Valley region has soils of high clay content. It has four dominant eucalypt species and **woodlands** of native shrubs, grasses, daisies, lilies and orchids. It is home to animals such as the brush-tail rock wallaby, spotted-tail quoll and the speckled warbler. Further south, closer to Sydney, the soil becomes increasingly sandy, which is good news for beach lovers. The sandy soil and drier and windier conditions see plants such as banksia scrub, acacia, spinifex, *Leptospermum* and *Xanthorrhoea* (grass tree) species dominate.

Species have characteristics that suit them to the area they live in (Fig. 7.1). The diversity that is seen within an environment has developed over time due to the survival and reproduction of organisms with favourable characteristics.



FIGURE 7.1 Different conditions are encountered between different areas in New South Wales, meaning different species inhabit each area.

7.1 Ecosystems



Biotic and abiotic factors in an ecosystem

An **ecosystem** is the combination of all the organisms (**biotic factors**) living in a **community** (a group of different **populations** in an area or **habitat**) and all the non-living features (**abiotic factors**) with which they interact. Within an ecosystem, the **environment** is made up of all the non-living (abiotic) factors. There is a fine balance between the biotic and abiotic factors in ecosystems. There are many diverse ecosystems found in Australia. The distribution of the different Australian ecosystems is due to the variation in biotic and abiotic factors found within each particular area (Fig. 7.2).

The arid zone represented by the light tan section of the map in Figure 7.2 is distinguished by its ancient and infertile soils with low levels of phosphorus and nitrogen. Rainfall is unpredictable with plants such as Sturt desert pea, saltbush and spinifex able to withstand these conditions. Fire is an important ritual in Aboriginal culture, with patch burning creating spaces for **ephemeral** plants with a short life cycle. Invertebrate species of animals such as grasshoppers, crickets, beetles and termites dominate. Native medium-sized mammals such as the desert bandicoot, lesser bilby and the long-tailed hopping mouse have all become extinct in the last 200 years as introduced species, such as the rabbit and camel, have invaded their habitat.

Types of ecosystems

In both terrestrial and aquatic ecosystems, biotic and abiotic components significantly influence species diversity. Terrestrial environments and the abiotic factors within them affect organisms found on land (for example, in desert or rainforest ecosystems) (see Table 7.1). Aquatic environments are affected by abiotic factors such as salt concentrations, light availability, pressure and many other

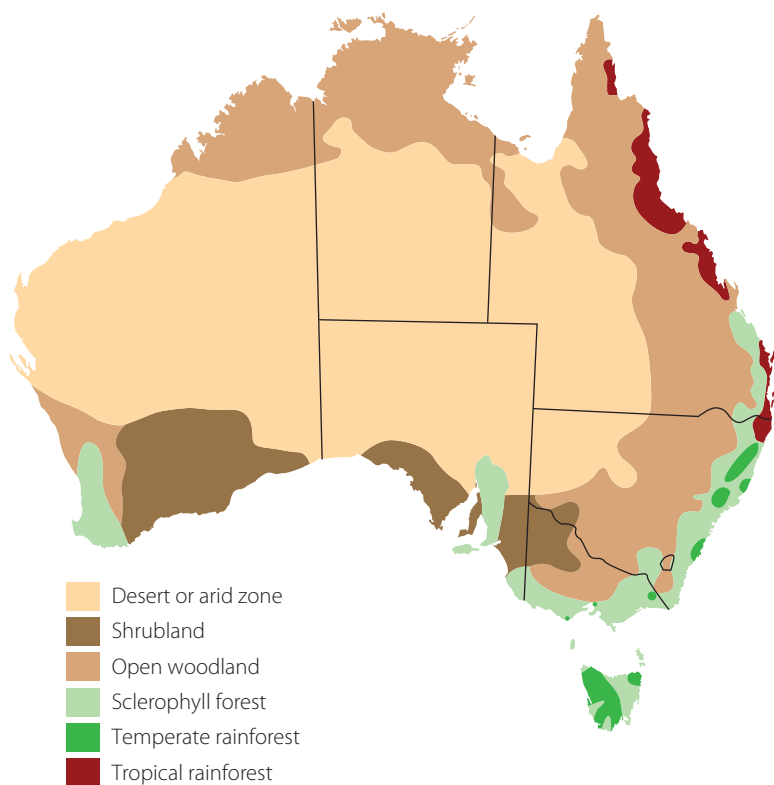


FIGURE 7.2 The distribution of Australian terrestrial ecosystems

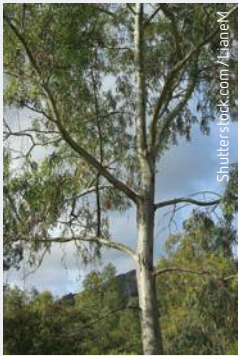
factors. There are two main types of aquatic (water) environments: saltwater or marine environments (for example, coral reefs) and freshwater environments (for example, lakes) (Fig. 7.3). However, some aquatic environments are exposed to both fresh water and salt water, such as an *estuarine* environment affected by tidal changes. The main types of organisms found in aquatic environments are influenced by the level of water salinity.



FIGURE 7.3 Examples of aquatic environments

Examples of aquatic ecosystems include wetlands and mangrove swamps; rock platforms; estuaries, rivers and lakes; and oceans and coral reefs. Common terrestrial ecosystems found in Australia are described in Table 7.1.

TABLE 7.1 Examples of common terrestrial ecosystems found in Australia (ordered from lowest to highest rainfall)

TERRESTRIAL ECOSYSTEM	APPEARANCE	DESCRIPTION
Desert		Annual rainfall < 250 mm High temperatures through the day (approx. 40°C) and low temperatures through the night (approx. 0°C) Often sandy soil, sometimes rocky Typical organisms include sparse grasses and saltbushes; the spinifex hopping mouse; and insects, lizards and snakes
Grassland		Annual rainfall 250–750 mm Temperature can be high or mild Typical organisms include grasses (e.g. spinifex), kangaroos, rabbits and snakes
Shrubland		Annual rainfall 200–400 mm Temperatures are high Typical organisms include mallee trees, mulga, kangaroos, rabbits and snakes
Woodland		Annual rainfall 400–750 mm Temperature can be mild, and sometimes high Canopy cover 10–30% Typical organisms include grasses, shrubs, eucalypt trees, mice, birds, insects, spiders and wallabies
Temperate forest		Annual rainfall > 750 mm Temperature is mild Canopy cover 30–70% Typical organisms include eucalypt trees of various types
Tropical rainforest		Annual rainfall > 1500 mm Air is humid and temperature can be high or mild Canopy cover is dense (70–100%) and layers (strata) develop (i.e. canopy, understorey, forest floor) Typical organisms inhabit a diverse number of habitats and include species such as bird's nest ferns, palms, lianas, bracken ferns and leaf litter organisms

Biotic and abiotic factors differ significantly between ecosystems. Abiotic factors create selection pressures that select for different types of organisms and hence affect biotic factors. The underlying abiotic factors of an ecosystem therefore must be studied in order to determine the possible effect that they may have on the living (biotic) components of that ecosystem.

An organism's ecosystem provides it with nutrients, water, shelter and opportunities to mate. Other living things compete with it for these resources. This competition results in some organisms being able to survive and reproduce, while others are unable to compete successfully for resources. As a result, individuals in the successful **species** will have a range of favourable characteristics (**adaptations**) uniquely suited to the specific set of environmental factors in their habitat. The population is said to be adapted to this habitat. Unless the environment changes, the species will continue to survive, reproduce and pass on these characteristics to their offspring.

KEY CONCEPTS

- An ecosystem is made up of organisms (biotic) living in an area that interact with each other and with the non-living (abiotic) environment in which they live.
- Biotic features of ecosystems vary widely in response to the abiotic features of the environment.
- Abiotic and biotic factors act on the characteristics of the organisms and affect the ability of an organism to survive and reproduce in a particular environment.

- 1 Distinguish between biotic and abiotic factors.
- 2 Distinguish between 'ecosystem' and 'environment'.
- 3 List two abiotic factors.
- 4 List and briefly describe the main differences between aquatic and terrestrial environments.
- 5 Explain how abiotic factors in an ecosystem can select certain organisms over others. Provide an example.

CHECK YOUR UNDERSTANDING

7.1

7.2 Selection pressures in an ecosystem

Why do some organisms survive when there is change in the environment, yet others do not? Natural selection comes into play when organisms in an environment are subjected to **selection pressures**. That is, a change in environment often results in some resources becoming limited, and individuals have to compete for these limited resources. Selection pressures therefore drive natural selection. Those individuals within the population that have random variations that make them better suited to survive in the changed environment are more likely to survive. If their variations have a genetic basis (for example, they are the result of mutations), these variations are passed from the surviving parents to offspring. Over several generations, the only individuals to survive are those that have the variation. The surviving population is now different from the original population and the organisms within it are described as being 'adapted' to suit their environment. **Biodiversity** within a population is therefore essential for the survival of the population. If the variation did not already exist within the population, then few or no individuals would have survived the selection pressure.

Selection pressures can include abiotic factors such as temperature, light intensity, soil type, water availability and gas concentration in water, and biotic factors such as competition between members of a species for the same limited resources, predators and availability of prey. For example, saltbushes (genus *Atriplex*) are found growing in desert environments with very low rainfall, whereas ferns (phylum Filicophyta) are found growing in tropical rainforests where the amount of rainfall is high (see Table 7.1). The amount of rainfall therefore is an abiotic selection pressure that determines which species are best able to survive and reproduce.



Selection pressures in an ecosystem

INVESTIGATION 7.1



A secondary-source investigation into biotic and abiotic selection pressures

Choose one ecosystem from Table 7.1 to research further. Using the Internet, books and journals as resources, describe your ecosystem in terms of biotic and abiotic factors.

Choose one organism that lives within your chosen ecosystem. State the everyday and scientific name for that organism. Use a table to show how each of the described biotic and abiotic factors affects the organism you have selected. Some may have no known effect, and these also need to be shown in your table.

Answer the following questions as part of your research:

- 1 What is meant by selection pressure?
- 2 Give examples of abiotic selection pressures in an ecosystem.
- 3 Explain how adaptations are passed from one generation to the next.
- 4 Identify and justify which factors may have acted as selection pressures on the organism you have selected.
- 5 Predict which factors may act as selection pressures in the future.

Abundance and distribution of a species

One of the most important features of any population is its size. Population size has a direct bearing on the ability of a given population to survive.

The **distribution** of a species describes where it is found and the **abundance** of a species determines how many individuals of that species live throughout the ecosystem. Abiotic and biotic selection pressures affect the distribution and abundance of organisms in an ecosystem by causing fluctuations or changes in population numbers and movement. Populations may occupy certain areas and not others due to the resources that are available.

Abiotic selection pressures

In terrestrial environments, abiotic factors such as temperature range, light and water availability most commonly affect the abundance and distribution of a species. In aquatic environments (freshwater and marine), salinity is a key selection pressure. Further aquatic selection pressures are shown in Table 7.2.

TABLE 7.2 Some important abiotic factors affecting the distribution and abundance of species in freshwater and marine environments

FRESHWATER ENVIRONMENT	MARINE (SALTWATER) ENVIRONMENT
Temperature variation	Salinity
Dissolved gases (O ₂ and CO ₂)	Dissolved gases (O ₂ and CO ₂)
pH (acidity) of water	Tidal movements and wave action
Light availability	
Clarity of water	

Biotic selection pressures

Just as important as the abiotic factors are the biotic selection pressures that may influence an organism's existence in an ecosystem. Even though there is a much greater variation in biotic factors between

ecosystems (for example, the availability of worms as a food source for kookaburras in one ecosystem may be much higher than for kookaburras in another), a few key selection pressures will affect organisms within an ecosystem. Examples of biotic factors that may determine the distribution and abundance of a species include:

- availability and abundance of foods
- number of competitors
- number of mates
- number of predators
- number and variety of disease-causing organisms.

Environmental pressures in terrestrial Australian ecosystems

Generally, in Australia, rainfall, temperature and landform patterns significantly affect the abundance and distribution of vegetation and ecosystems. As can be seen in Figure 7.2, most of the rainforest ecosystems are distributed along the east coast of Australia, particularly in the northern regions. Abiotic factors such as high temperatures and high rainfall create a suitable tropical environment for this type of ecosystem. Desert ecosystems, in contrast, are distributed among the central areas of Australia. Abiotic factors such as a high temperature range and low rainfall (arid conditions) create an environment suitable for desert ecosystems. Of course, the distribution and abundance of organisms within these ecosystems may also vary due to biotic factors such as the availability of food, competition within and between species, the availability of mates for reproduction, exposure to predators, and exposure to disease.

Ecology

Ecology is the study of *interrelationships* between different types of organisms and between organisms and their environment. These interrelationships determine the distribution and abundance of **flora** and **fauna**. To understand and record environmental changes in plant and animal populations over time, ecologists collect information on the distribution and abundance of organisms in each ecosystem. Ecologists study distribution and abundance for a variety of reasons, including assessing biodiversity so that management plans can be put into place before development and land clearing goes ahead in environments such as coastal areas, bushland and natural grasslands and forests. For example, the Pittwater Coastal Zone Flora and Fauna Study shows how an ecological study was performed to develop a coastal management plan. A survey of the Blue Mountains National Park revealed at least 211 native species, of which 21 are threatened species. Ecological studies such as those in the Lower Hunter Valley have identified corridors that support a transition from one ecosystem to another and migratory passages that are essential to the survival of inland animals during periods of drought.

When ecologists study biodiversity, they usually wish to determine the size of a population (total number of organisms present); however, it is also useful to know the density of organisms (the total number of organisms per unit area) because it is often a reflection of how many organisms a particular environment can support. Ecologists also need to determine the distribution of organisms in order to look at any patterns that are formed and the possible reasons for this. This information enables them to determine whether a population is increasing or decreasing in size and what particular aspects of the habitat are favoured over others. It comes down to two main questions:

- 1 Why is a species only present in particular places?
- 2 What determines the number of individuals (size) of a population in one particular place?

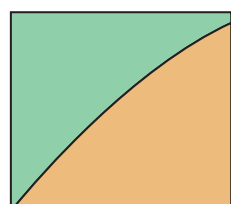
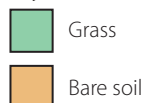
In other words, what factors influence the distribution and abundance of populations in particular environments? If the distribution and abundance of flora and fauna in a particular ecosystem changed due to climate or development, what would be the associated biodiversity risks?

- Biotic and abiotic factors exert selection pressures that influence the survival and reproduction of an individual, population or species.
- Biotic and abiotic selection pressures affect the distribution and abundance of organisms in an ecosystem.
- Rainfall, temperature and landform patterns significantly affect the abundance and distribution of organisms in ecosystems in Australia.
- Ecologists study the distribution and abundance of organisms and how these properties are affected by interactions between the organisms and their environment.

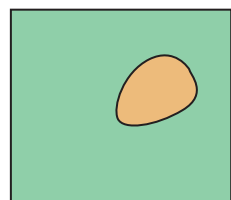


FIGURE 7.4 Quadrats are commonly used in the field for estimating percentage cover for plant species (or slow-moving animal species) – for example, on a rock platform in the Sydney area.

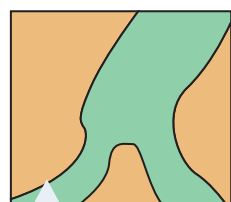
Key



Quadrat 1: estimate of **50%** grass cover, 50% bare soil



Quadrat 2: estimate of **90%** grass cover, 10% bare soil



Quadrat 3: estimate of **40%** grass cover, 60% bare soil

FIGURE 7.5 Calculation of the percentage of grass cover – a sample of three quadrats from the 10 recorded

Measuring plant abundance

It is easy to calculate the abundance of plant species because plants stay in the one place. However, calculating the number of an entire plant species in many cases would be an endless task, so ecologists commonly use **sampling techniques** to estimate plant species abundance. Usually one or more samples are taken randomly from a population and assumed to be representative of the total population.

There are a few different techniques used to estimate abundance in plants. The one that is simple and easy to use in the field is the *percentage cover method*. This method uses **quadrats** (1 m × 1 m squares) to cover randomly selected representative areas for estimating the percentage cover of an area (Fig. 7.4). This method is beneficial when numbers of a plant species are too high to count individually.

Percentage cover calculations require randomly plotting a number of quadrats (for example, 10), estimating the percentage cover for each one and then finding an average percentage cover. If the area of the ecosystem is known or estimated, then the percentage cover can be converted to area (see the example below).

Estimating the abundance of grass

If the school gardener, Mr G, needs to purchase new turf for the football ground, he needs to know how much grass cover the football oval has. To find this out he uses the percentage cover method to estimate the grass cover. Ten 1 m × 1 m quadrats were randomly placed on the oval and the grass cover was drawn to scale and plotted for each one.

A sample of three of the quadrats is shown in Figure 7.5. Back in the office, estimates of percentage cover were made for each of the 10 quadrat drawings (see the results in Table 7.3), then the percentages were added up and averaged.

Total of the 10 quadrats = 540

An average of the percentage of grass cover for the entire oval is calculated.

$$\begin{aligned}\text{Average \%} &= \text{total \%} \div \text{no. of quadrats} \\ &= 540 \div 10 \\ &= 54\%\end{aligned}$$

Therefore the oval is estimated as having 54 per cent grass cover.

If the area of the oval is measured at 250 m², then the estimated area of grass cover is 54% × 250 m² = 135 m². Mr G can now safely assume he needs to purchase 115 m² (250 m² – 135 m²) of turf to fill the bare areas. He can then repeat the same process the following year to determine if the turf replacement has successfully changed the percentage grass cover of the football oval. See Table 7.3.

TABLE 7.3 Results of quadrat percentage cover

Quadrat	1	2	3	4	5	6	7	8	9	10	
Estimated percentage cover	50	90	40	60	20	70	90	80	10	30	Total percentage cover 540



WORKED EXAMPLE 7.1

If 42 individuals have been counted in ten $1\text{ m} \times 1\text{ m}$ quadrats, what is the estimated abundance of the species in an area of 200 m^2 ?

Estimated abundance of a species in an area = $\frac{\text{total number of individuals counted}}{\text{area of each quadrat} \times \text{number of quadrats}} \times \text{total area}$

ANSWER	LOGIC
$\frac{42}{1\text{ m}^2 \times 10} \times 200$ $= 840 \text{ individuals per m}^2$	- Apply the formula above. - Calculate the answer.

TRY THESE YOURSELF

- 120 daisies have been counted in ten $1\text{ m} \times 1\text{ m}$ quadrats. What is the estimated abundance of the weeds in an area of 800 m^2 ?
- 341 dandelions have been counted in ten $1\text{ m} \times 1\text{ m}$ quadrats. What is the estimated abundance of the dandelions in an area of 650 m^2 ?

INVESTIGATION 7.2

A practical investigation to measure weed abundance

Within weeks of growing turf on a school oval, weeds will appear. The distribution and abundance of weeds are generally not uniform across the whole oval. Abiotic factors such as the amount of light and water can affect growth. Weed control measures can be put in place, so it is useful to discover in which areas control measures should be used.



AIM

To use quadrats to estimate the population density of weeds in a school oval

MATERIALS

- Quadrat ($1\text{ m} \times 1\text{ m}$)
- Paper and pen or electronic device to record observations

RISK ASSESSMENT

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Exposure to sun	Sunburn	Apply sunscreen and wear protective clothing such as a hat.
Biting insects	Insect bites	Apply insect repellent.



METHOD

Work in pairs.

- 1 Determine the total area (in square metres) of the school oval.
- 2 Select 10 sites for 1 m × 1 m quadrats placed throughout different parts of the oval.
- 3 Record the amount of light (full sun, semi-shade, full shade) and water (moist, damp, dry) for each quadrat.
- 4 Identify a type of weed – for example, a dandelion (Fig. 7.6).
- 5 Count and record the number of identified weeds in each quadrat.



FIGURE 7.6 Dandelion weed

RESULTS

- 1 Calculate and record the average number of weeds per quadrat.
- 2 Using the total area of the school oval, calculate and record your estimate of the size of the weed population in the school oval.
- 3 Construct a table to record, for each quadrat: the abiotic factors (light and water), the total number of weeds, the average number of weeds. Also calculate the total weed population in the school oval.

ANALYSIS OF RESULTS

Compare your results with data from other groups.

DISCUSSION

- 1 Account for any differences between the data from your group and data from other groups.
- 2 Decide whether your group's data or combined data from all groups would be more accurate. Explain reasons for your answer.
- 3 Discuss the effect of differing amounts of light and water on weed density.

CONCLUSION

Describe the benefits of quadrat sampling in estimating the population density of weeds in a school oval.

Measuring animal abundance

Obviously, it is a little more difficult to calculate the abundance of animals than of plants, and attempting to count every animal species in an area is often very difficult. For animals that are slow moving, counts can be made; however, for those that move around much more quickly estimates may need to be taken. Hence, estimating abundance is a much easier way of finding out roughly how many animal species exist in an area. This is a little more difficult than the method used for plants because animals may move around constantly or hide. That is why ecologists use a sampling technique called the *mark–release–recapture* technique. Animals are captured; the sample animals are tagged and then released; these animals are given time to mix again, another sample is captured, and the number tagged in the second sample is counted.

Estimating abundance using the mark–release–recapture technique

The formula for calculating the estimated abundance of animals using the mark–release–recapture method is as follows:

$$\text{Abundance} = \frac{\text{number captured} \times \text{number recaptured}}{\text{number marked in recapture}}$$

Here is an example of the mark–release–recapture technique:

- 1 Capture: a random sample of animals from the population is selected.
 - ▶ Twenty small birds (superb blue wrens) were captured, using bird nets.
- 2 Mark and release: marked animals from the first capture are released back into the natural population and left for a period to mix with unmarked individuals.
 - ▶ The 20 birds are tagged with leg bands, released back into their area and left for three weeks to mix with the population.
- 3 Recapture: a second sample is captured to look at the proportion of animals marked from the previous sample.
 - ▶ After 3 weeks a second sample of 10 birds is captured and it is found that there are four birds marked from the first capture.

- 4 Insert the values into the formula:

Number captured = 20

Number recaptured = 10

Number marked in recapture = 4

$$\text{Abundance} = \frac{\text{number captured} \times \text{number recaptured}}{\text{number marked in recapture}}$$

$$\begin{aligned}\text{Abundance} &= \frac{20 \times 10}{4} \\ &= \frac{200}{4} = 50\end{aligned}$$

Therefore, we have estimated the total superb blue wren population size in that area as being 50.

WORKED EXAMPLE 7.2

In the first sample, 20 individuals were marked. In the second sample, 50 individuals were recaptured and of these recaptured animals 10 were marked. What is the total population?



$$\text{Total population } (N) = \frac{\text{no. marked in first sample } (M) \times \text{total number of animals recaptured } (n)}{\text{number of recaptured animals that are marked } (m)}$$

$$N = \frac{M \times n}{m}$$

ANSWER	LOGIC
$N = \frac{M \times n}{m}$ $\text{Total population} = \frac{20 \times 50}{10}$ $= \frac{1000}{10}$ $= 100 \text{ individuals in the total population}$	▪ Apply the formula above. ▪ Substitute numbers from the question into the formula. ▪ Calculate the answer.

TRY THESE YOURSELF

- 1 In the first sample, 30 individuals were marked. In the second sample, 50 individuals were captured and 10 of these were marked. What is the total population?
- 2 In the first sample, 100 individuals were marked. In the second sample, 200 individuals were captured and 50 of these were marked. What is the total population?

The mark–release–recapture technique is based on a number of assumptions for accurate estimates of the total population to be calculated:

- 1 There is no population change through migration, births or deaths between the sampling periods.
- 2 All animals are equally able to be caught (individuals are not ‘trap happy’ or ‘trap shy’).
- 3 Marked animals are not hampered in their ability to move and mix freely with the rest of the population.

Table 7.4 summarises the sampling techniques for determining abundance.

TABLE 7.4 Summary of sampling techniques for determining abundance

SAMPLING TECHNIQUE	EQUIPMENT AND METHOD	ADVANTAGES	DISADVANTAGES
Quadrat sampling	- Measuring tape, metre rulers or quadrats are used to measure randomly placed 1 m × 1 m square areas. - The occurrence of organisms in the quadrat is recorded and repeated a number of times. - Individual species can be counted if in small numbers or percentage cover can be calculated for larger numbers by estimating the percentage cover for each quadrat and then finding an average of the quadrats taken.	- Easy and inexpensive method for measuring abundance in large populations - Minimal disturbance to the environment - Quadrats can also be used for determining the distribution of species along a transect	Only suited for plants and slow-moving animals
Mark–release–recapture	- Animals are captured (e.g. traps, nets, pits), tagged or marked (e.g. limb bands) and then released. - After a suitable time to mix with others, a sample is recaptured. - The number of tagged or marked animals recaptured is counted. - Numbers are then entered into the formula: $\text{abundance} = \frac{\text{number captured} \times \text{number recaptured}}{\text{number marked in recapture}}$ <i>Note:</i> Technology is sometimes used for marking very mobile animals by means of tracking bands and tracing their movements by GPS systems and satellites.	A simple method that provides an estimate of abundance for animals in large populations that are difficult to count	- Only suitable for mobile animals - Can be time-consuming depending on the type of species captured, the method of tagging, and the time suitable for waiting while the tagged group mixes with others - Can be disturbing to the environment

Trapping techniques

Capturing animals requires various trapping techniques, all designed so that animals are unhurt (for example, traps, nets and small pits) (Fig. 7.7). Some techniques, such as radio-tracking and the use of electronic detection devices, avoid the need for recapturing the animals.

Unmanned aerial vehicle (UAV) or ‘drone’

UAVs (unmanned aerial vehicles) or ‘drones’ are now becoming a more common way to monitor wildlife populations (Figs 7.8 and 7.9). At the time of writing, there are several studies being conducted by scientists as to the best way to use this emerging technology. The advantage of drones is the improvement in spatial and temporal resolution of the data collected. Instead of relying on humans to count birds, computer technology can be linked to drone images to identify and count targeted species automatically. Some of the concerns have been that they may place undue stress on animals, particularly nesting birds who will continue to sit in a nest and incubate eggs despite the presence of a nearby drone. However, there is a general opinion that the data collected by drones could substantially improve the accuracy of population estimates, particularly in places that may be inaccessible to humans on foot. This technology has the potential to improve the management of invasive species as well.

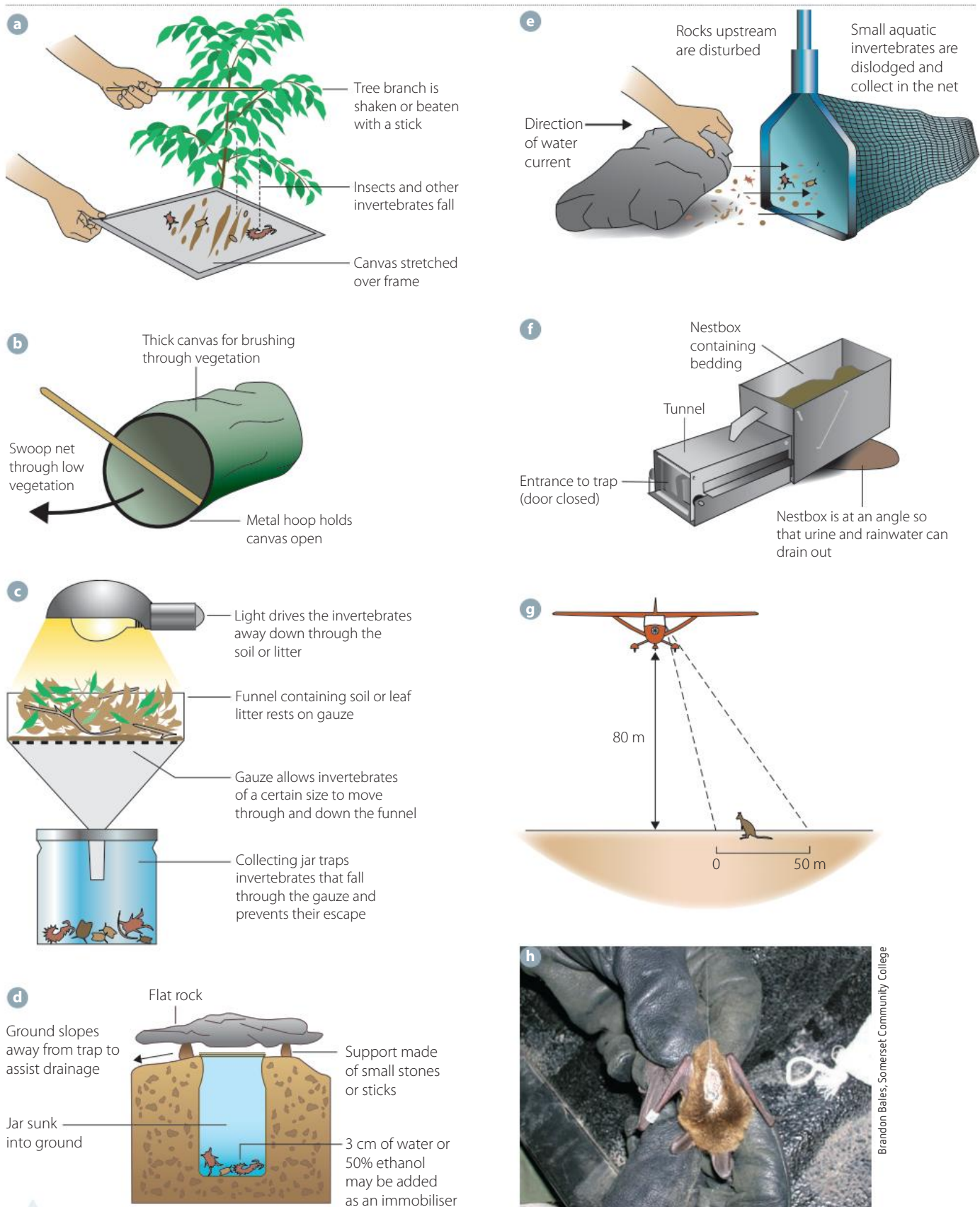


FIGURE 7.7 Examples of animal sampling techniques: **a** beating tray; **b** sweep net; **c** Tullgren funnel; **d** pitfall trap; **e** kick sampling; **f** Longworth small mammal trap; **g** counting from a plane; **h** radio transmitters attached to animal body

Brandon Bales, Somerset Community College



FIGURE 7.8 Drones are an efficient and accurate tool for estimating wildlife numbers, especially in remote areas that are hard to access.



FIGURE 7.9 Scientists are being trained in the use of drones to minimise stress on animal populations.

CHECK YOUR UNDERSTANDING

7.2a

- 1 List two abiotic factors and two biotic factors that act as selection pressures in an ecosystem.
- 2 Distinguish between the abundance and the distribution of a species.
- 3 List three significant factors that affect abundance and distribution of organisms in Australian ecosystems.
- 4 Briefly describe how an ecologist would go about recording the distribution of plants in a rainforest ecosystem.
- 5 Propose a method you would use to estimate population numbers of kookaburras in an area.
- 6 Describe an investigation you conducted using the quadrat method. List one advantage and one disadvantage of this method.
- 7 Choose the best technique to capture:
 - a a ground dwelling insect
 - b an aquatic insect
 - c a nocturnal insect
 - d a large roaming mammal.
- 8 Describe an emerging technology used to estimate abundance and distribution of populations. Find one advantage and one disadvantage of this technology.
- 9 A new school is being built and you have been given the responsibility of planning the equipment purchases for the science department. Write a list of the items you would recommend should be purchased to enable students to complete a field trip that involves the estimate of distribution and abundance of a few local species of plants and animals.
- 10 Outline some of the advantages and disadvantages of using computer technology in the field of ecology.

Population trends

Examining population trends can lead to inferences about the species and what abiotic and biotic characteristics they are most suited to. Several different techniques may be used to measure the distribution of a species in an ecosystem. In large areas, **transects** are commonly used to give an idea of the variation that may occur. A transect is a narrow strip that crosses the entire area being studied, from one side to the other. Transects provide an accurate and easy method of representing an area simply.

Mangrove species

When studying a tidal estuary, a transect line from the sea to inland is most likely used to look at the abundance of a mangrove species along an area. If results were graphed, something like Figure 7.10 would be seen. Mangrove species C is highest in abundance inland, species A is highest closest to the

sea, and species B is most abundant in between A and C. Mangrove species A, being most abundant closest to the sea, appears to be made up of those individuals that have the variation to tolerate saline conditions, which is the selection pressure in this example. Members of species B are not as tolerant of saline conditions so they are found further back from the sea. Members of species C either do not have the variation to tolerate saline conditions or have a variation to tolerate less saline conditions, and are therefore found the furthest from the sea. This example shows the importance of species diversity. Due to the diversity of species A, B and C, mangroves are able to populate the whole tidal estuary rather than just a small part of it.

Trends in population estimates can be seen easily when abundance values have been graphed.

Eucalyptus species

Figure 7.11 illustrates the abundance of different eucalyptus species at different altitudes in south-east New South Wales. Although the species tend to overlap as altitude increases, each different eucalypt species appears to be more abundant in, and therefore more suited to, a specific altitude range. *Eucalyptus pauciflora* numbers dominate the higher altitudes, while *Eucalyptus longifolia*, even though it has a smaller abundance, still dominates the lowest altitude ranges. *Eucalyptus radiata* appears to be suited to most altitudes; however, it is most abundant in the middle altitude range.

Australian marsupial species

Figure 7.13 illustrates the effect of increasing the food supply for a population of small marsupial carnivores, *Antechinus stuartii* (Fig. 7.12), over 12 months. In a historic study, supplementary food was provided to two groups of *Antechinus stuartii*; however, the food supply was discontinued in one group along the way. Looking at the graph in Figure 7.13, you can see that all groups rapidly increase in numbers up to March 1981 and then stabilise for a few months. Each group reaches a peak in August 1981 before rapidly declining in numbers to a point similar to 1980 figures in November 1981. The control group (not supplemented with any food) have not reached as high numbers as the supplemented groups. When food was discontinued for one group a dramatic drop occurred in numbers, but it seemed to recover quickly and increase and return to the same pattern as the other groups. This suggests that the natural variation within the population enabled those individuals that were able to survive on less food to survive, and recover to reproduce when more food was introduced. Without this diversity within the population, numbers would have decreased even when more food was provided.

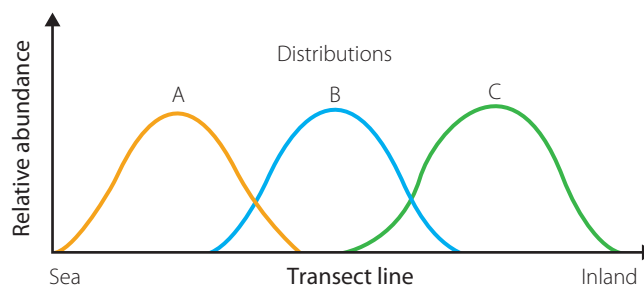


FIGURE 7.10 Three mangrove species and their distances from the sea

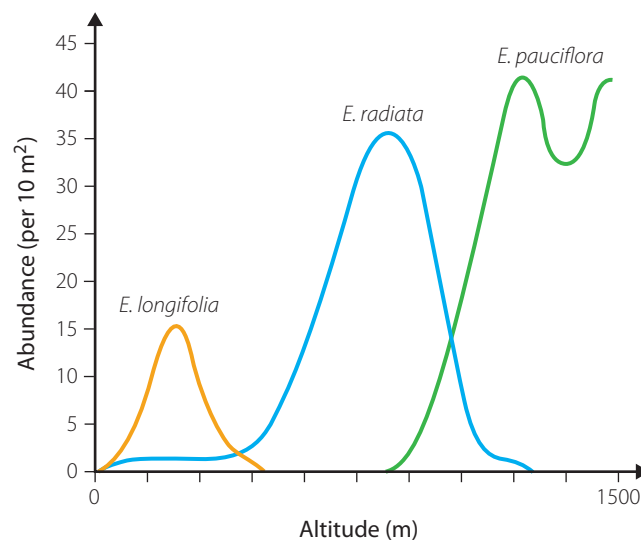


FIGURE 7.11 Three eucalypt species at different altitudes



FIGURE 7.12 Australian marsupial, *Antechinus stuartii*

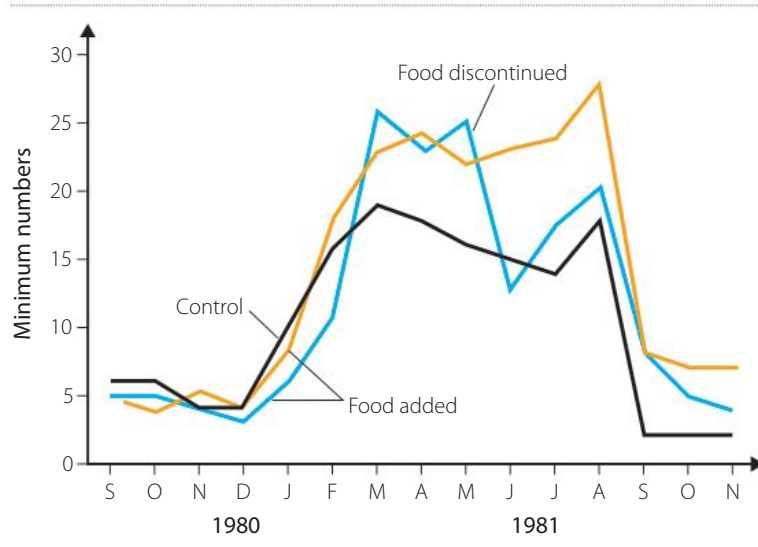


FIGURE 7.13 Australian marsupial *Antechinus stuartii* numbers when supplemented with food

Knowledge of the distribution and abundance of a species can be used to make predictions about the potential response of a species when faced with selection pressures.

INVESTIGATION 7.3

A practical investigation of the effect of abiotic factors on organisms

Critical and creative thinking

Numeracy

Literacy

Organisms live in different habitats such as ponds, streams, forests and deserts. To study the selection pressures that act on organisms and to help explain species diversity and abundance, careful measurements and descriptions are carried out. *Quantitative* measurements of abiotic factors and *qualitative* descriptions of their habitats allow us to understand how organisms live and how changes to their habitat may affect them.

AIM

To design and carry out an investigation that measures the abiotic factors operating in an environment to gain insight into how environmental factors influence species diversity

HYPOTHESIS

Make a prediction. What does your group expect to be the effect of some chosen abiotic factors on a specific organism in your chosen ecosystem?

MATERIALS

Work in groups of three or four students.

Materials will vary depending on the investigation chosen by your group. Instruments available to the class must be considered when planning the investigation. Suitable instruments may be available to measure variations in the following abiotic factors:

temperature, light, air pressure, pH, oxygen, humidity, wind speed, turbidity (amount of suspended material in water), soil or water nutrients, salinity, rainfall

» RISK ASSESSMENT

WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Exposure to sun	Sunburn	Apply sunscreen and wear protective clothing such as a hat.
Biting insects	Insect bites	Apply insect repellent.
Working in a public area	Council regulations may restrict activities.	Observe council regulations. Always work with another student.



METHOD

- 1 Choose an area that is convenient for you to study. Your investigation might be done over a day or carried out for a short time every few days over many weeks.
- 2 Choose which abiotic factors you want to study in the area and which organisms they may affect. Design an investigation that shows how those abiotic factors influence the organisms within your area (for example, how light and temperature affect plant growth).
- 3 Before proceeding, write a proposal to present to your teacher, describing the area, the abiotic factors and the affected organisms you have chosen and how you propose to carry out the investigation. Include a risk assessment table in your proposal. Make sure that you have suitable materials and equipment to carry out your investigation.
- 4 Make sure you have thought through how your data will be presented.
- 5 You may have to consider assigning different tasks to carry out throughout the investigation to different people in your group. Make sure everyone in your group is clear on the role they need to carry out.
- 6 Carry out your investigation.

Refer to p. 15 for information on designing a valid investigation.

RESULTS

- 1 Draw a suitable table for your results. Where possible, present the data in graphical form.
- 2 Describe the abiotic factors and organisms you chose to investigate.
- 3 Describe the area that you chose to investigate.
- 4 Explain the procedure you chose to follow for your investigation. Include details of your risk assessment.
- 5 Discuss why certain variables were measured and how often they were measured.

DISCUSSION

- 1 Describe what the data indicates about the distribution of the plant and animal species in your area.
- 2 Discuss the possible relevance of abiotic factors in contributing to the population size of the plant and animal species you estimated.
- 3 Describe any problems you experienced in conducting your investigation. Explain how you overcame them.
- 4 Suggest how your methods could be adjusted to increase accuracy.

CONCLUSION

Discuss how the abiotic factors in your chosen area influence the organisms living there.

EXTENSION

Now that you have completed this investigation, plan and design an investigation to measure the effect of an abiotic factor on an organism in another ecosystem.

KEY CONCEPTS

- Sampling techniques are used to calculate the abundance of organisms. These techniques include the use of quadrats to estimate percentage cover for plant species and the mark-release-recapture technique for animal species.
- Examining population trends can lead to inferences about the species and what abiotic and biotic factors they are most suited to.

- 1 Name the most likely environmental pressure affecting the abundance of different eucalyptus species in south-east New South Wales (Fig. 7.11).
- 2 Identify two factors that might determine the distribution and abundance of mangroves in their estuarine environment.
- 3 Look at the data from Figure 7.13. Select the data that provides evidence for the suggestion that food is considered to be an environmental pressure in *Antechinus stuartii*.
- 4 State the purpose of the control for the investigation shown in Figure 7.13.
- 5 Explain how knowledge of the distribution and abundance of species can be used to make predictions about the diversity of species within an environment.

7.3 Changes in populations over time

Collections of individuals of the same species in a population have a range of characteristics (*traits*). The diversity of the variations can be small (for example, flower colour in pea plants (white or purple)) or large, like the colour, texture, amount and distribution of hair on humans. Those members in a population that survive and reproduce in their habitat carry the traits most suitable for the conditions. They pass these traits onto their offspring. Over time, as long as the selection pressures in the environment do not change, the population becomes more suited, or better adapted, to its environment.

If selection pressures in an environment change, some individuals with traits best suited to the changed selection pressures (adaptations) will survive and reproduce. Individuals whose traits no longer suit them to

the changed conditions will struggle to survive and reproduce. Over time, the number of individuals in the population with successful adaptations to the changed conditions will increase. In other words, there is a change in species diversity.

One of the best studied examples of changes in populations over time due to selection pressure is provided by the peppered moth, *Biston betularia*. The peppered moth normally rests in shaded sites on lichen-covered trees. It depends on its speckled white colour to blend in with the background. There is another much darker form of moth that occurs naturally, but in much smaller numbers (Fig. 7.14).



FIGURE 7.14 The light and dark forms of the peppered moth, *Biston betularia*, on a lichen-covered tree

The first dark moths were reported in an industrial region of England in 1848 during the time of the industrial revolution. After that, the number of dark moths increased rapidly in various parts of Britain. In the 1950s, an extensive study of the abundance and distribution of the light and dark form was conducted in different parts of the country. It was found that dark moths were more common where smoke and soot from factory chimneys had blackened the bark of trees.

This observation can be explained. The peppered moth is preyed upon by birds that peck them off the tree. In polluted areas, the dark form is invisible against the darkened branches, whereas the light form stands out. In non-polluted areas, the reverse is true: the light form is camouflaged against the background of soot-free branches, but the dark form is clearly seen.

As a result, the frequency of dark moths is higher in polluted areas because light moths are more readily seen and eaten. As industrial pollution is reduced, the frequency of dark moths decreases.

More severe instances of environmental pressures promoting a change in species diversity are seen after natural disturbances. Erupting volcanoes, massive flooding, hurricanes and fire are events that change environmental pressures and affect species diversity.

For example, Kati Thanda–Lake Eyre in South Australia is a salt lake; its edges are crusted with white crystals. It has an annual rainfall of just 120 mm and much of the time it is dry or has low water levels. Significant rains and floods caused floodwater from Queensland to make its way to Kati Thanda–Lake Eyre in 2014 and 2015. This influx of water into the lake drastically changed the environmental selection pressures and increased species diversity. There was an increase in populations of the birds, fish and mammals living there (Fig. 7.15). Snails, beetles and mosquitoes took advantage of the water, providing food for tens of thousands of birds such as pelicans and other waterbirds.



FIGURE 7.15 Species diversity increases after heavy rain fills Kati Thanda–Lake Eyre.

Cane toads in Australia

The cane toad (*Bufo marinus*; Fig. 7.16) is native to South and Central America. It was deliberately introduced into Australia in 1935 to control the greyback cane beetle (*Dermolepida albobirtum*) in sugar cane plantations. The toads quickly spread from their original release sites in northern Queensland and have expanded their range to include the Northern Territory and northern New South Wales. The cane toad ‘frontline’ is currently travelling up to 60 km a year. From the 102 toads originally released, their population is now estimated at 200 million.

Cane toads have a unique combination of structural and behavioural features that have enabled them to thrive in the Australian environment:

- They feed mainly at night.
- They are ground dwellers.
- They eat insects, snails and a wide variety of other opportunistic foods such as pet food left out overnight, and they have been observed to eat anything that will fit in their mouths, including frogs, birds, small mammals and small reptiles.
- They absorb water through their skins.
- They have no known predators.
- They can breed all year round.
- Females lay up to 30 000 eggs at a time; these can hatch in 2–3 days.

Cane toads contain toxins that kill many native animals that try to eat them. Glands on the toad’s shoulders produce bufotoxin, which acts on the heart and central nervous system, causing rapid heartbeat, hypersalivation, convulsions and paralysis. The toxin can be absorbed through membranes around the eyes, mouth and nose.

However, not every predator is equally vulnerable. There is variability among the characteristics of native animals. The toxin does not affect all members of a population in the same way. Some individuals are more tolerant of the toads’ poison than others, and some members of populations are more reluctant to try to eat toads than others.

Cane toads in Australia are considered to be a selection pressure because those predators with characteristics such as vulnerability to bufotoxin and increased preference to eat cane toads are removed



FIGURE 7.16 Cane toads have selectively affected the survival of native predators.

from the population (selected against). Predators that have increased resistance to bufotoxin and those that are reluctant to eat cane toads are the ones that survive and reproduce (selected for).

Not only have population characteristics of cane toad predators changed, but cane toad characteristics have also changed. Individuals at the frontline of the expanding invasion show distinctive changes that result in more rapid dispersal.



FIGURE 7.17 Red-bellied black snake

Red-bellied black snakes

The red-bellied black snake (Fig. 7.17) provides an example of how the effects of the cane toad in an ecosystem (biotic factor) have acted as a selection pressure that has led to changes in the characteristics of another population of organisms (red-bellied black snakes) over time.

In cane toad areas, the head size of red-bellied black snakes (*Pseudechis porphyriacus*) is getting smaller. Research on museum specimens of snakes caught before and after cane toads were introduced showed that the poison-sensitive snakes became longer by about 3–5 per

cent, but that other snake species in the museum collection that were not affected by the poison did not change in length. Bigger snakes have a smaller head in comparison to their body length.

Because larger cane toads produce more poison, those snakes with larger heads ate larger toads and received a greater dose of toxin, and died. Smaller headed snakes were unable to open their jaws wide enough to eat the larger toads. The cane toad is a selection pressure acting on snake head size.



FIGURE 7.18 A northern quoll

Northern quoll

Northern quolls (*Dasyurus hallucatus*; Fig. 7.18) are small Australian native mammals that suffered a drastic population reduction when the cane toad arrived in its habitat. For unknown reasons, quoll populations in Queensland have stopped eating cane toads. Scientists suspect a genetic and/or behavioural reason. It is possible that there is a gene that makes the quolls 'toad averse'. Quolls with this gene do not eat the toad and have a reproductive advantage over quolls without this gene.

Therefore, the toad toxin has acted as a selection pressure on the quoll population in Queensland, and the genetic diversity among individuals in the quoll population has led to the survival and adaptation of this species in the area. No such effect is seen in Northern Territory quolls, which continue to eat and to be poisoned by the cane toad. There is a 'taste aversion' training program underway for these quolls and it is hoped that, once trained, they will be released and can live alongside the toads.

Changes in cane toad characteristics

There is some evidence to suggest that cane toads themselves are evolving by a process called *spatial sorting*. As the toads expand their territory, those toads that have the fastest hopping style (straight hoppers) have accelerated the speed of the invasion front from 10–15 km per year to 60 km per year. These fast toads at the front have offspring who themselves are fast. Therefore the genes responsible for the variation in toads related to the fastest hopping style are now concentrated at the invasion front. There has been some work suggesting that this rapid hopping style is causing an increase in pressure on the spine of the toads, leading to a 10 per cent incidence of spinal arthritis. New research suggests that faster cane toads may have vulnerable immune systems due to the stress on their bodies. This may be a target for future control programs (for example, using lungworm parasites to kill toads).



Measuring
changes in
population

Prickly pear distribution in Australia

The prickly pear (*Opuntia monacantha*; Fig. 7.19) was initially introduced into Australia from the Americas to start a cochineal dye industry at the time Spain had a monopoly of the expensive red dye, which was used in the clothing industry. The cactus was initially introduced in the 1800s with the recommendation that it could also be used as a strong hedge plant and an alternative source of food for stock.

The plant is a succulent characterised by spine-covered fleshy growths. The leaves are actually small scales. It can be established by seeds or by vegetative propagation. The parent plant contains branches that can easily become detached. Wherever these branches or ‘pads’ come into contact with the soil they will readily grow.

These growing conditions enabled the plant to propagate and cover four million hectares of land by 1900, and 24 million hectares by 1920. It became a pest, and a lot of time and money was invested into reducing its numbers. Early control measures included burning, crushing and the use of herbicides. All these measures were of little use and the plant continued to spread.

By 1912 the Prickly Pear Travelling Commission was established. Members of the Commission travelled to countries where the plant was indigenous and looked for possible control agents that were not present in Australia. Two species of insects – the cochineal beetle and cactoblastis moth – were imported. Initial tests supported the use of the beetle with a promising reduction in plant numbers. But it was the use of the cactoblastis moth (*Cactoblastis cactorum*) that showed the best results. By 1932 the larvae of the cactoblastis (see Fig. 7.20) had eaten its way through three million of the previously infected hectares of land. The eradication program was so successful that it has now been used in other countries. The use of a natural predator to control the numbers of a pest organism is known as **biological control**.

Due to a lack of selection pressures, prickly pear plants had spread rapidly through the country. The only problem they faced was that a lack of selection pressure meant that there was a lack of diversity among the prickly pear population. Introducing the cactoblastis moth provided a strong selection pressure that worked on the lack of diversity and quickly reduced the numbers and distribution of the prickly pear plants.



FIGURE 7.19 Prickly pear

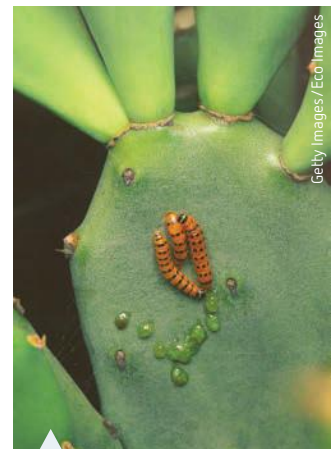


FIGURE 7.20
Cactoblastis cactorum moth
larvae feeding on a prickly pear

KEY CONCEPTS

- If selection pressures in a habitat change, some individuals with characteristics best suited to the changed selection pressures will survive and produce more offspring than those individuals with less suited characteristics.
- Cane toads have caused rapid population changes in the diversity of native animal species in the course of their Australian invasion.
- Introduction of a biological predator acted as a selection pressure to reduce the abundance and spread of prickly pear in Australia.



- 1 Explain how the industrial revolution in England offers an example of selection pressures changing the frequency of population characteristics.
- 2 List four features that have enabled the cane toad to thrive in the Australian environment.
- 3 In cane toad areas, the head size of red-bellied black snakes (*Pseudechis porphyriacus*) is getting smaller. Predict reasons for this change.
- 4 Explain why a ‘toad averse’ characteristic is advantageous to northern quolls.
- 5 Describe the change in selection pressure on the prickly pear that halted its spread throughout Australia.

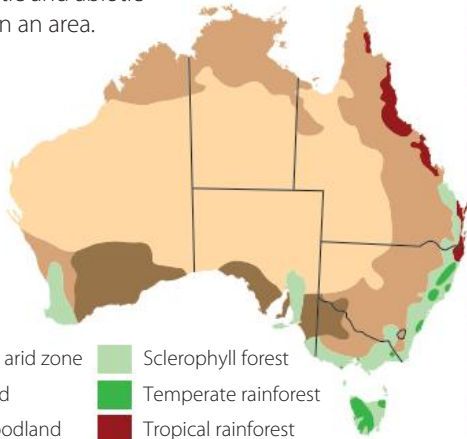
CHECK YOUR UNDERSTANDING

7.3

Effects of the environment on organisms: How do environmental pressures promote a change in species diversity and abundance?

Ecology is the study of the interactions that determine the distribution and abundance of organisms.

Ecosystems are the combination of all the biotic and abiotic factors within an area.



Types of ecosystems

Terrestrial examples include desert, grassland, woodland and rainforests.



Aquatic examples include coral reefs, rivers, lakes and oceans.

These characteristics differ between ecosystems

Factors that affect ecosystems

Abiotic selection pressure: non-living components including temperature, salinity and dissolved gases.

Biotic selection pressure: living components, including availability of food, mates, predators and competitors.

Environment is all the abiotic factors within an ecosystem – provides selection pressure on living things.

Biodiversity enables

Organisms are living things have specific features that enable them to survive.

A change in selection pressure

affects

Population trends – a change in the species distribution or abundance

Adaptations are characteristics that enable a species to survive in its environment.

Cane toad – as its numbers increase, native species abundance and distribution are affected.



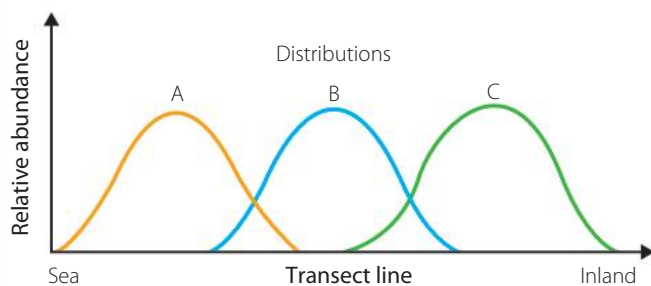
Prickly pear – introducing a predator reduced its abundance.



Biotic and **abiotic** factors affect the distribution and abundance of organisms in an ecosystem.

Ecosystem characteristics can be measured to provide information.

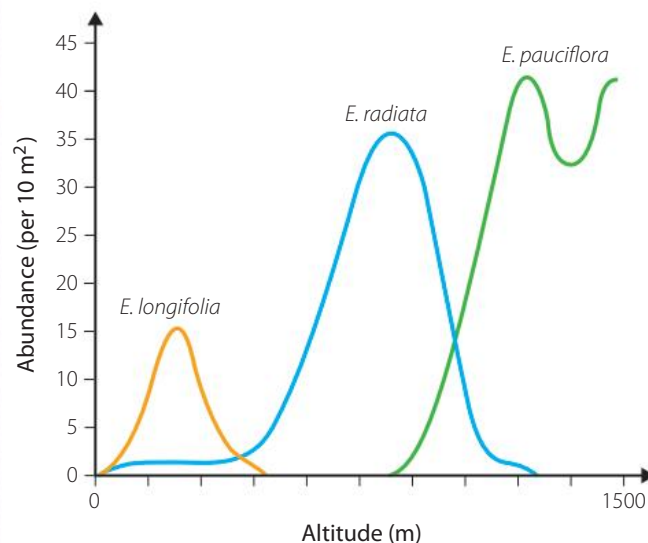
Distribution is where a species is found



Can be measured by transects, drones



Abundance is how many individuals of that species live throughout the ecosystem



Can be measured by quadrats, capture-recapture – trapping techniques include pitfall traps.



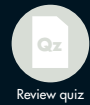
Ecosystem the interaction between living and non-living components

Community interactions among different populations

Population a group of organisms of the same species in an ecosystem

Organism the individual living thing, a unit of reproduction and natural selection

7 CHAPTER REVIEW QUESTIONS



- 1 Define the term 'selection pressure'.
- 2 Describe what an ecologist studies.
- 3 List four different types of selection pressure that could have an effect on the diversity of organisms living in a particular environment.
- 4 Name the abiotic selection pressure that can cause an increase in species diversity in Kati Thanda–Lake Eyre.
- 5 Name the biotic selection pressure that limited the spread of prickly pear in Australia.
- 6 Suggest two reasons why some native animals are no longer dying in cane toad-infested areas.
- 7 Spinifex hopping mice live in desert regions of central Australia. They sleep in burrows during the day and emerge at night to feed. The hopping mice lose very little water in their urine. Describe the possible selection pressures that may have determined these characteristics.
- 8 Explain the reasons why ecologists may opt for population estimates rather than individual organism counts.
- 9 Suggest why the use of quadrats is not suitable for estimating the abundance of wombats in a certain area.
- 10 Construct a concept map illustrating the relationship between the following terms:
abiotic factors, biotic factors, community, ecosystem, environment, habitat, population
- 11 Table 7.1 describes features of a tropical rainforest. The annual rainfall is very high, the air is humid and the temperature is mild to hot. Canopy cover is dense and layers (canopy, understorey, forest floor) develop. A diverse number of species (for example, bird's nest ferns, palms, lianas, bracken ferns and leaf litter organisms) live in this ecosystem.
 - a Name the abiotic factors in this ecosystem and relate them to the diversity of species found there.
 - b Predict what effect logging large trees would have on the diversity of species in the tropical rainforest.
- 12 Describe how changes in cane toad characteristics are selectively advantageous.
- 13 Choose one abiotic factor and explain how a change in this factor could influence a population of a named organism.
- 14 Figure 7.21 shows organisms living in a marine rock pool.
 - a List three biotic factors acting as selection pressures in this pool.
 - b List two biotic factors acting as selection pressures in this pool.

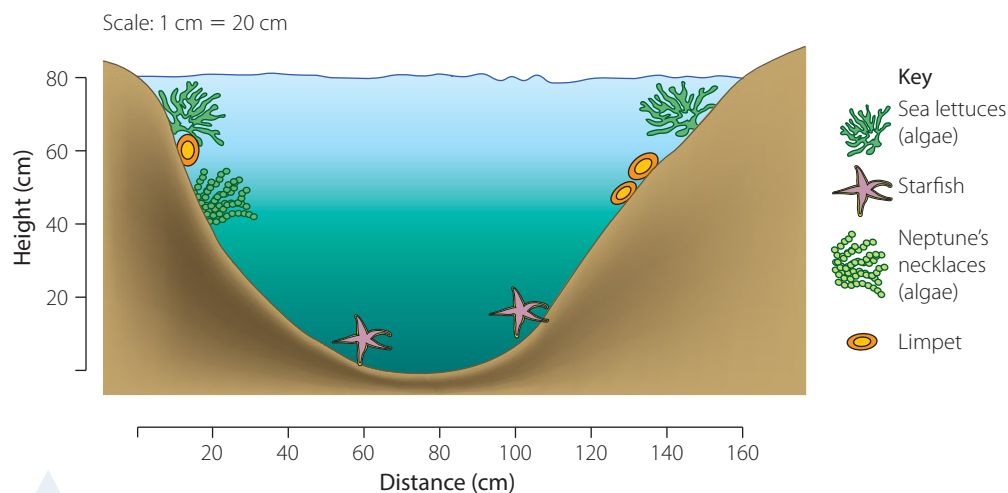


FIGURE 7.21 Profile sketch of a marine rock pool

- c** Explain how the abundance of the species at different locations in the rock pool can lead to inferences about the abiotic and biotic characteristics each species is most suited to.
 - d** Predict the impact on species diversity over time if there is a change in a selection pressure. In your answer, name the selection pressure, the species affected and the expected change in the population.
- 15** Provide support for the statement that 'examining population trends can lead to inferences about what biotic and abiotic factors a species is most suited to'.
 - 16** Using an example, illustrate how selection pressures can change a population of organisms over time.
 - 17** Examine the use of the cane toad as a biological control of the greyback cane beetle. In terms of selection pressures on the species involved, comment on the success of this strategy.
 - 18** Justify the use of the biological control methods used to control the prickly pear population in Australia.

8

Adaptations and survival

INQUIRY QUESTION

How do adaptations increase the organism's ability to survive?

Students:

- conduct practical investigations, individually or in teams, or use secondary sources to examine the adaptations of organisms that increase their ability to survive in their environment, including: [CCT](#) [ICT](#) [WE](#)
 - structural adaptations
 - physiological adaptations
 - behavioural adaptations
- investigate, through secondary sources, the observations and collection of data that were obtained by Charles Darwin to support the Theory of Evolution by Natural Selection, for example: [ICT](#) [L](#)
 - finches of the Galapagos Islands
 - Australian flora and fauna

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Have you ever experienced what it is like to spend winter outdoors in the freezing cold of the Snowy Mountains, or summer in the hot, dry, desert regions of central Australia? Most of us are not very comfortable at these temperatures, yet native Australian flora and fauna live there year after year. These organisms are able to do this because they are well adapted to their natural environments, as a result of evolutionary change by natural selection.

The bilby shown in Figure 8.1 is well adapted to survive in harsh desert environments. It is a nocturnal animal, only coming out at night so as not to be exposed to the heat of the day. It has small eyes and hence poor vision, but this is more than made up for by its very large ears. The ears serve two important functions: it has excellent hearing, but also it is able to lose excess heat through its ears where the blood vessels are very close to the surface. It has small but powerful front digging claws so it can dig burrows and find food, and a long nose that gives it an excellent sense of smell.



FIGURE 8.1 A bilby is well adapted to survive in its natural environment.

8.1 Adaptations

An adaptation is a characteristic that an organism has inherited and that makes it suited to its environment. An organism does not intentionally change to suit its environment, nor can it intentionally produce offspring that have these changes. An adaptation is a result of a change or variation that arises, at random, when cells divide and replicate during the process of reproduction. The new organisms produced possess a changed feature and this random difference may happen to benefit the organisms by making them more suited to the environment they live in. This difference may then be passed on to its offspring in turn, through gametes. An organism's chances of survival may be increased by many such adaptations working together. Adaptations are found in all organisms across all kingdoms. In this chapter we are going to focus on adaptations found in the plant and animal kingdoms.

Australian environments are varied and diverse with some harsh conditions for organisms to survive in. The three main abiotic factors that affect survival in Australian environments are water, temperature and sunlight. Over thousands of years, Australian organisms have adapted to survive adverse conditions such as lack of water, high temperatures and high exposure to sunlight.

The three types of adaptations that are found in organisms are:

- 1 structural – how an organism is built
- 2 physiological – how an organism functions
- 3 behavioural – how an organism acts or behaves.

These three types of adaptations are often intertwined and can be difficult to separate. For example, if dogs did not have legs (structural), or their cells did not release energy (physiological), they would not be able to run (behavioural).

KEY CONCEPTS

- An adaptation is a characteristic that an organism has inherited and that makes it better suited to survive in its environment.
- The three types of adaptations that are found in organisms are structural, physiological and behavioural.

- 1 Define the term 'adaptation'.
- 2 List the three different types of adaptations that an organism can have.
- 3 Outline the three main abiotic factors that terrestrial organisms in Australia need to be adapted to if they are going to survive.
- 4 List the adaptations shown by the bilby.

8.2 Structural adaptations

A **structural adaptation**, as the term suggests, is to do with how the organism is built or structured, and how this aids their survival in their natural habitat. Structural adaptations are physical features, on both the inside and outside of an organism. The webbed feet of a platypus enables it to swim fast; thin, pointed leaves on spinifex grass reduce water loss; and the caecum in a koala enables it to digest the cellulose in plant cell walls in order to absorb the maximum amount of nutrients from its food.

Structural adaptations of plants

The main problems facing desert plants are to balance photosynthesis with loss of water through the stomata and staying cool. The main form of water loss in plants is through transpiration – evaporation of water from the stomata of leaves. Transpiration serves two main functions – it pulls water and dissolved mineral ions into the roots and up the stem to the top of plant, with some water being used in the chemical reaction of photosynthesis. This continuous transpiration stream is also a form of evaporative cooling, a process that is essential in regulating temperature in plants. Those plants that live in areas where water is in limited supply (usually hot, dry areas) must achieve a balance between photosynthesis and how much water the plant can afford to lose for cooling purposes before it risks dehydration.

Xerophytes, such as some Australian plants, live in hot, dry habitats where they are exposed to high temperatures and bright sunlight. Structural adaptations maximise the absorption and storage of water and minimise the loss of water.

Some plants known as **succulents**, such as pigface (*Carpobrotus glaucescens*) (Fig. 8.2a), have adaptations such as fleshy stems or leaves. They are able to swell up and retain moisture when it is available; they then survive by using this moisture during dry periods. Australia has some succulent species, including the desert plant *Calandrinia* (parakeelya). This is an important food for Aboriginal people, who use the leaves as a green salad leaf and a source of moisture in desert environments.

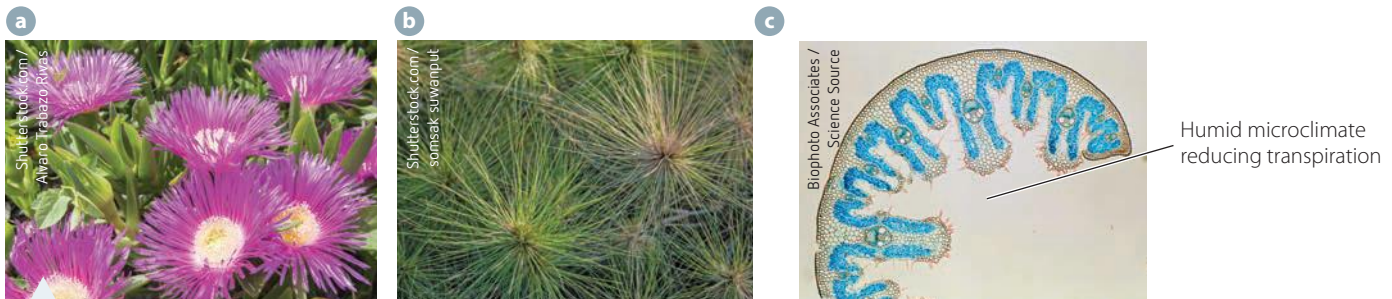


FIGURE 8.2 **a** Pigface with its fleshy stems; **b** spinifex grass with pointed narrow leaves to reduce water loss; **c** a transverse section through a leaf of an Australian xerophyte (dune grass) showing a rolled leaf with sunken stomata to reduce water loss during the heat of the day

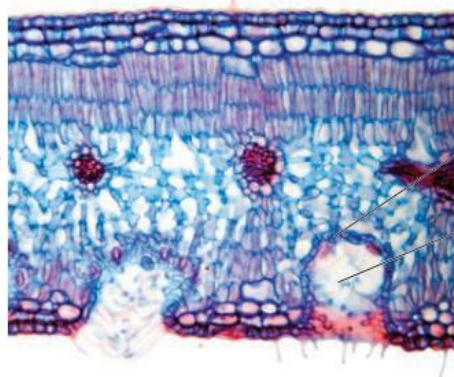


Eucalypts and banksias have coarse, leathery leaves with a thick coating of wax, or **cuticle**, over the leaves to protect them from the excessive sunlight. It also provides insulation, has reflective properties and reduces the amount of evaporation that sometimes occurs through thinner leaf cuticles. These features also ensure that all the epidermal cells are waterproof, preventing loss of water by evaporation from these surface cells to the outside.

Leaf shape is important in retaining water. Cypress pines have tiny cylindrical leaves that have a very small surface-area-to-volume ratio. This reduces water loss through transpiration. All spinifex species have tough, pointed and narrow leaves for reducing water loss (Fig. 8.2b). Porcupine grasses (*Miscanthus sinensis*) roll their leaves during the hottest part of the day so stomata (leaf pores) are on the inside of the roll and not exposed to the dry atmosphere. This creates a humid microclimate inside the rolled leaf which further reduces transpiration (Fig. 8.2c).

Other types of plants have a range of structural adaptations to deal with water loss. Sclerophyllous (hard) leaves minimise water loss with a waxy or hairy surface, sunken stomata or greatly reduced leaves. Sunken stomata or stomatal pits occur in *Hakea* and in the **cladodes**, or flattened stem, of she-oaks. The actual stomata are lower than the main surface of the leaf; this allows moist air to be trapped in the pit, therefore reducing the difference in osmotic pressure immediately outside the stoma (in the pit) and inside the leaf. Hairs in the stomatal pit trap water vapour from transpiration, creating a humid microclimate that further reduces transpiration (Fig. 8.3).

Science Photo Library/DR KEITH WHEELER



Stomata deep within pit

Hairs trapping water and creating a humid microclimate

FIGURE 8.3 Sunken stomata in an oleander leaf. The hairs in the stomatal pit trap water vapour from transpiration, creating a humid microclimate.

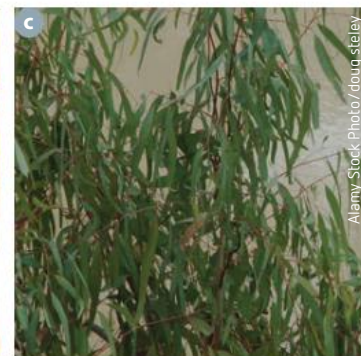
Epidermal hairs on the surface of the leaf also trap a moist layer of air. This results in a smaller difference between the concentration of water in the leaf tissue and the water vapour in the layer of air trapped by the hairs. For example, the coastal banksia (*Banksia integrifolia*) has hairs on the undersurface of leaves and leaves of *Melaleuca urceolaris* are hairy all over (Fig. 8.4a).



Elaine Cochrane



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Alamy Stock Photo/doug stealey

FIGURE 8.4 **a** The leaves of *Melaleuca urceolaris* are covered with hairs to reduce transpiration; **b** *Hakea* fruits (*Hakea drupacea*) are woody rather than fleshy to reduce water loss; **c** the leaves of shoestring wattle (*Acacia stenophyllodes*) hang vertically to reduce the amount of light they are exposed to.

Fruits are structures that plants produce to contain seeds so they can be dispersed and ensure the continuation of the species. When you think of a fruit, you would think of a moist, fleshy orange or apple. Many Australian plants, such as *Hakea*, produce woody fruits rather than fleshy fruits, as an adaptation to a water-restricted climate (Fig. 8.4b).

Desert acacias (wattles) have vertically flattened leaflets that are oriented towards the ground, thus reducing the amount of light absorbed and consequent water loss (Fig. 8.4c). Deep root systems are able to access water supplies deep underground. Some plants also possess shallow root systems that enable the rapid uptake of moisture when it becomes available after rainfall.

INVESTIGATION 8.1

A practical investigation of structural adaptations in plants

Plants are made up of the shoot and root systems. The shoot system is above the ground and made up of stems, leaves, fruits and flowers. The root system is below the ground and made up of a variety of different roots such as fibrous roots, tap roots and adventitious roots. These structures may have modifications to suit specific sets of environmental conditions.

AIM

To observe macroscopic structural adaptations of Australian plants and to relate these to increased chances of survival

MATERIALS

- Disposable gloves, safety goggles
- Forceps
- Stereomicroscope
- Camera
- Leaf, stems, roots, fruit and/or flower samples of Australian sclerophyllous plants such *Hakea*, eucalypt, wattles and spinifex; and succulents such as pigface and cactus species

RISK ASSESSMENT



WHAT ARE THE HAZARDS?	WHAT RISK DOES THIS HAZARD POSE?	HOW CAN YOU SAFELY MANAGE THIS RISK?
Some plants produce irritants or poisons.	Can affect eyes, skin and mucous membranes.	Wear disposable gloves and safety goggles, and wash your hands thoroughly after completing the investigation.
Thorns and spikes	Can pierce skin.	Be careful when handling plant material. Use forceps if they are available.

What other hazards can you think of and how can you manage them?

METHOD

- 1 Carefully observe (see, smell, feel) each sample, looking at stems, leaves, fruits and flowers if available.
- 2 Place each sample in turn under the stereomicroscope to view adaptations more closely.
- 3 Record any adaptations that enable the plant to conserve water (such as hairs on the underside of the leaf, woody fruits or grey underside of leaf).
- 4 Draw a scaled biological diagram (see page 45) or take a photo. Label the specific adaptations observed.



- » 5 Observe and note any other types of adaptations that enable the plant to survive in its natural environment.
- 6 Record any variations that you observed in plants that you could not relate to survival in their natural environment.
- 7 Use resources such as the Internet or books to find out the natural environment of each plant.

RESULTS

Construct a table like Table 8.1 to identify the adaptations in each plant. Explain how each identified adaptation assists in the plant's survival. Add rows as required.

TABLE 8.1

NAME OF PLANT	ADAPTATION	DIAGRAM OR PHOTO	NATURAL ENVIRONMENT OF THE PLANT	HOW DOES THIS ADAPTATION ASSIST IN SURVIVAL OF THE SPECIES?



Investigation 8.1

DISCUSSION

- 1 List the adaptations that you identified as those that assist the plant in:
 - a conserving water
 - b reflecting light
 - c staying cool.
- 2 List any other types of adaptations that enable the plant to survive in its natural environment and describe how each adaptation aids survival.
- 3 List any adaptations observed in plants that you could not relate to their survival.
- 4 Outline one limitation of making inferences about structures in plants.
- 5 How did you ensure that your observations were reliable?

CONCLUSION

Write a valid conclusion linking your findings to the aim of the investigation.

Structural adaptations of animals

Australian animals, like plants, need to be adapted to their natural environment in order to survive. The main survival issues for animals are gaining enough water and food, keeping cool or warm, finding space to live, reproducing and deterring predators.

For example, the thorny devil (*Moloch horridus*; Fig. 8.5) is a small lizard, about 20 cm long, that lives in the Western and Central Australian deserts. It lives on a diet of black ants and termites. The body of the thorny devil is covered with large prickly spikes, making it look ferocious and hard to swallow. This helps to deter predators from eating it. Water from rain and dew is captured by a complicated set of layered scales all over the lizard's body. Each scale is attached by a hinge joint that enables the lizard to collect water and funnel it to the back of its mouth. The thorny devil then uses its tongue to draw the water into its mouth.



FIGURE 8.5 Thorny devil (*Moloch horridus*) in its natural environment

On the top of its head is a 'false head' made up of bony material. If the thorny devil is threatened, it will tuck its real head between its front legs, causing its body to look a lot larger. The predator may see the false head and attack this to no effect. The gold and brown coloration over the body of the devil camouflages it against the red soils in the desert, making it difficult to be seen by predators.

The common wombat (*Vombatus ursinus*) is a nocturnal animal that lives in an extensive burrow. The burrow can be up to 11 m in depth and 30 m long. Because wombats are prolific diggers, they have large muscular shoulders and long claws on their front feet.



FIGURE 8.6 A wombat has a backward-facing pouch to protect its young while digging.

As a marsupial, a wombat gives birth to an underdeveloped young (the joey), which remains in the pouch for five months. The pouch is rear-opening (Fig. 8.6). This is a structural adaptation in response to the wombat's digging habit. The pouch orientation ensures that the joey will be protected from the dirt that would otherwise fill the pouch if it was forward-facing. Because the pouch is facing backwards, the joey has a higher chance of survival. This eliminates potential harm to the young, vulnerable joey from dirt, sticks and roots. This adaptation assists in the survival of the species as it ensures that the offspring is protected from threat until it is able to venture out on its own.

Wombats are **herbivorous**, eating only plant material such as grass and leaves. This constant gnawing of tough, fibrous material wears down their teeth, which could lead to starvation and death in any other animal. Their teeth are adapted to cope with their diet. A wombat has 24 rootless teeth that grow continuously to replace those that are worn down. It has a pair of large deep-rooted incisors for snapping off grass, no canines, and a large space between its incisors and premolars. The premolars provide a large surface area for grinding plant material.

INVESTIGATION 8.2

Information and communication technology capability

Literacy

Work and enterprise

A secondary-source investigation of structural adaptations in an Australian animal

In this investigation you will choose one native Australian animal that has not been described above. Use secondary sources to research its natural environment, and the structural adaptations that this animal has that enable it to survive there.

AIMS

- 1 To gather information from secondary sources
- 2 To analyse the information and relate adaptations to survival in a specific environment

METHOD

- 1 Working in groups of three, each student selects a different Australian animal to research. Use a variety of different resources from current textbooks, websites, journals and experts to gather relevant information about your chosen animal's adaptations. You may wish to work in a Google Doc so you can share information later on.
- 2 Use the CRAAP method described on page 10 to ensure the information that you have gathered is relevant, free from bias, and current.
- 3 Present your information in a table, as described under the 'Results' heading.

Refer to p. 10 for the CRAAP method of evaluating sources.

- » 4 Compare the adaptations in the Australian animal you have researched with those of the animals researched by other members in your group.

RESULTS

- 1 Summarise your findings in a table with specific headings that describe the environment in which your chosen animal lives, outline the adaptations and link the adaptation to survival.
- 2 Compare all animals researched by your group with regard to:
 - a the environment in which they live
 - b the factors in the environment to which they are adapted
 - c two structural adaptations they have that make them better suited to their environment, and how these are similar or different.

DISCUSSION

- 1 How did you ensure that the information you gathered was accurate, reliable and relevant?
- 2 Comment on whether you think your chosen animal is well adapted to survive in its natural environment. Justify your answer.
- 3 Are there any other adaptations not observed in your selected animal that could make it better adapted to survive in its natural environment? List and describe them, outlining the purpose of each.
- 4 Explain why making inferences about adaptations can be difficult.

CONCLUSION

Use the data gathered to make a general statement relating the structural features observed to the survival of organisms in a specific environment.

Refer to p. 17 for information on assessing reliability, accuracy and validity in investigations.

KEY CONCEPTS

- A structural adaptation refers to how an organism is built or structured so that it can survive in its natural environment.

CHECK YOUR UNDERSTANDING

8.2

- 1 Define structural adaptation.
- 2 Describe the main survival problems facing desert plants in Australia.
- 3 List two adaptations of desert plants that assist them in overcoming the problems listed in your answer to question 2.
- 4 Outline the main survival problems facing animals in Australia.
- 5 Describe two adaptations of animals that assist them in overcoming each of the problems listed in your answer to question 4.
- 6 Explain why you would not find broad-leaved tropical plants living in the Australian desert.

8.3 Physiological adaptations

Physiology consists of all the processes involved in an organism carrying out its function. **Physiological adaptations** are adaptations related to how organisms function that increase the organisms' chances of survival in their natural environment. They involve variations in the metabolism or physiology of organisms at a cellular, tissue, organ or system level, giving them specific advantages for a particular set of environmental circumstances. For example, the intertidal marsh crab has gills and kidneys that

function to concentrate and excrete excess salt. Flamingos can tolerate the alkaline waters of soda lakes, which would kill other birds. Plant cells found in the growing tips of stems are sensitive to the hormone auxin, which causes them to grow towards light.

Physiological adaptations in plants

The abiotic factors in a surrounding environment play an important part in determining the vegetation that may be prevalent in an ecosystem. The plant life in turn influences the animal life in the area, since animals must consume plants directly, or indirectly by eating other animals that rely on plant nutrition in order to survive. Some species have physiological adaptations in order to survive in habitats where abiotic factors are a selection pressure.

Temperature

Australia has not only very hot environments such as deserts, but also very cold environments. Plants that inhabit environments where the **ambient** temperature is extremely low (for example, in alpine areas) have strategies to reduce the risk of ice forming within and between their cells. Ice crystals pierce cell membranes, killing the cells and ultimately the plant. Some alpine plants produce organic compounds that act as an 'anti-freeze' substance, reducing the temperature at which the cytoplasm or cell sap in the vacuole freezes.



FIGURE 8.7 The deciduous beech (*Nothofagus gunnii*) shows beautiful autumn colours as the chlorophyll is broken down in the leaves and masked pigments are exposed.

Also in response to low temperatures, **deciduous** trees lose their leaves in winter (leaf fall) and undergo a period of **dormancy**. This allows them to survive not only the extremely low temperatures, but also the water shortages and lower availability of sunlight. For example, the deciduous beech (*Nothofagus gunnii*), found in Tasmania, is one of the few indigenous Australian winter-deciduous trees. It loses its leaves in late April and May after they turn into a range of autumn colours (Fig. 8.7). The **abscission** (falling off) of leaves occurs in response to the shortening of days in autumn. The decreased period of daylight leads to a waterproof layer forming at the base of each leaf. Without water, photosynthesis cannot occur and the pigment anthocyanin is exposed as chlorophyll degrades, giving the leaves their spectacular autumn coloration.

Some plants flower in response to low temperatures; for example, tulip bulbs must be exposed to between 6 weeks and 3 months of intense cold before they will flower. This is called **vernalisation** and is an adaptation to living in northern hemisphere winters in central Asia. Australian gardeners often mimic vernalisation by removing tulip bulbs from the ground in winter and storing them in a refrigerator, before replanting them in spring, to ensure that they flower.

Many responses of plants to temperature change (such as leaf fall and flowering) are the result of temperature and/or light changing the concentration of hormones in plants. Responding to temperature change and the regulation of internal temperatures is important not only for the individual plant, but also for the continuation of the species.

Salt

Salt, even in relatively small concentrations in soil water, has a damaging effect on cell structure and metabolism. Plants that are adapted to saline environments are called **halophytes**. The plants use either

salt tolerance (salt accumulation) or *salt avoidance* (salt exclusion) as strategies to survive in environments where they are exposed to high salt concentrations.

Salt-tolerant plants (for example, sea grass and mangroves) are able to maintain metabolic functioning even though their cells accumulate sodium and chloride ions. They minimise salt toxicity by increasing their water content in large vacuoles. In contrast, *salt-avoidant plants* (salt excluders) minimise the salt concentrations of cells through structural and physiological adaptations such as stopping salt from entering at the roots.

The saltbush *Atriplex vesicaria* is a salt excluder – it actively transports excess sodium and chloride ions into bladder cells situated on the tip of hairs on the surface of leaves (Fig. 8.8). When the bladder cell reaches capacity, it bursts, releasing the salts into the environment. Palmer's grass (*Distichlis palmeri*) also actively secretes salts from specialised cells to avoid high salt concentration within the cells.

Succulents minimise the salt toxicity through increasing water content in large vacuoles, where the accumulation of excess salt is balanced with additional water drawn into the cells. Pickleweed (*Salicornia*) uses this method and also actively transports salts from the cytoplasm by a sodium–potassium pump on the vacuole membrane. Pigface (*Carpobrotus glaucescens*) tolerates salt by increasing water uptake to dilute the salt. It also stores excess salt in a location away from sensitive cells.

Mangroves are extremely well adapted to changing salt concentration, with both salt-avoidance and salt-tolerance strategies to cope in their high salt environment (Fig. 8.9). The river mangrove (*Aegiceras corniculatum*) can tolerate a higher than normal concentration of solutes in its cells. Salt that accumulates in bark and leaves is lost when the bark strips off the tree or the leaves fall. Salt can also be actively secreted through glands on the leaf surface. Salt can be excluded from entering the roots (research shows that up to 97 per cent of salt can be excluded), reducing the amount of salt entering the plant's cell tissues.

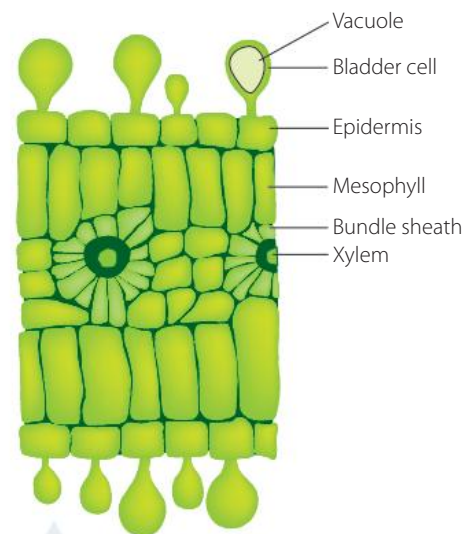


FIGURE 8.8 Salt-excreting bladder cells in the saltbush *Atriplex vesicaria*

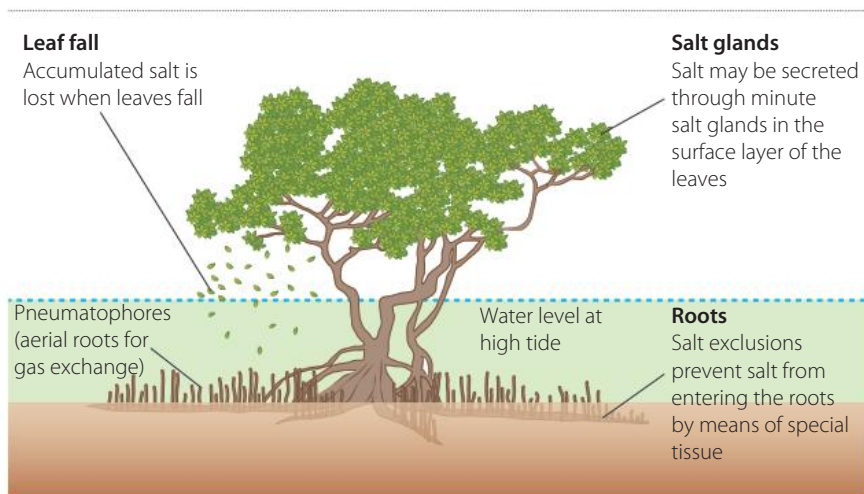


FIGURE 8.9 Mangroves have a variety of physiological adaptations to tolerate living in high salt environments.

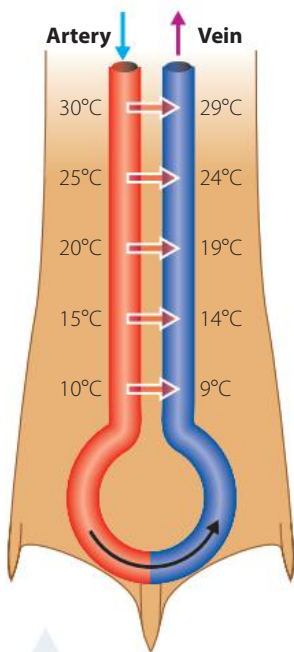


FIGURE 8.10 The countercurrent heat exchanger in the extremities of penguins helps to reduce heat loss.



FIGURE 8.11 An aestivating snail is able to survive hot, dry summers.

Physiological adaptations in animals

Animals, like plants, have certain physiological adaptations that enable them to survive in their natural environment. Animals are able to move between environments and so can be exposed to a large range of environmental conditions.

Water

The spinifex hopping mouse (*Notomys alexis*) and some other desert mammals are able to reduce water loss by excreting highly concentrated urine. This is due to their ability to reabsorb most of the water from their urine back into their bloodstream. They are also able to use the water produced as a by-product of cellular respiration (about 0.56 grams per gram of carbohydrate). It is by this means that the desert hopping mouse produces enough metabolic water to supply its needs.

Freshwater fish have the opposite problem to the hopping mouse. Because they have a concentration of ions in their tissues that is higher than the surrounding water, water molecules tend to enter their tissues. To counter this, they rarely drink water and have a high kidney filtration rate, which produces large amounts of dilute urine.

Temperature

Penguins can live in very cold environments such as the Antarctic. In common with many aquatic birds, penguins have a very convenient system of keeping their extremities warm – the countercurrent heat exchanger (Fig. 8.10). Blood travelling through the arteries to the foot warms the blood returning to the body in the adjacent veins. The outgoing blood to the foot is cooled in the process but not enough to affect cell activities. Because the gradient of temperature difference between the foot and the surroundings is reduced, less heat is lost.

Penguins, seals, polar bears and whales convert a large proportion of their diet into a thick layer of fat (blubber) to insulate them from the cold. The layer of blubber in polar bears can be up to 12 cm thick. A polar bear is so well insulated by its blubber that it cannot run very far, otherwise it will overheat.

Some animals survive hot summers by reducing their metabolic rate so that their body temperature is lowered to that of the environment. This is called **aestivation** and is the opposite of hibernation. This enables the animal to retain water, ration its fat storages and conserve energy. Land snails of the genus *Helix* will move into the shade, seal the opening to their shell with a mucus-type material and aestivate (Fig. 8.11). The cane toad, a pest species that is rapidly moving across Australia, will aestivate by burrowing underground and sealing itself in a water-tight mucus cocoon.

INVESTIGATION 8.3

A secondary-source investigation into physiological adaptation



Literacy



Information and communication technology capability

Work in pairs and choose one Australian plant and one Australian animal to research. One member of the pair will work on the plant, while the other will work on the animal.

Use resources such as journals, books and the Internet to research one physiological adaptation in the chosen plant or animal to overcome an environmental problem. Each person is to produce a one-page report, with photos and diagrams, that states the environmental problem that the adaptation overcomes and shows the mechanisms that the plant or animal uses to overcome this problem.

Peer review each other's reports, providing at least two positive comments and one area for improvement.

- Physiological adaptations are those that relate to how an organism functions and increase its chances of survival in its natural environment.

CHECK YOUR
UNDERSTANDING

8.3

- 1 Distinguish between a physiological adaptation and a structural adaptation. Use examples to illustrate your answer.
- 2 Outline two physiological adaptations of plants that enable them to live in:
 - a very cold environments
 - b high salt environments.
- 3 Outline two physiological adaptations of animals that enable them to live in:
 - a very cold environments
 - b very hot environments.

8.4 Behavioural adaptations

Behavioural adaptations refer to those actions performed by an organism in response to a stimulus that improve its chances of survival. For example, puffer fish are able to pump air into their stomachs and blow up to twice their size to frighten predators. Antarctic penguins form a large huddle during winter to survive the freezing cold winds. They constantly rotate through the huddle, with those on the outside working their way to the inside so as reduce the time each is exposed to the cold.

Behavioural adaptations in plants

Plants generally do not move much. It is strange to think of plants as exhibiting behaviour, but they do. It is just more subtle and by no means as obvious as behaviour shown by animals.

Turgor pressure

Mimosa pudica is a houseplant originally from tropical America that responds to the stimulus of touch. When a leaf is touched, for example by a predator or insect, it folds inwards, defending itself from any harm (Fig. 8.12).

The Venus flytrap is a plant that is adapted to live in nitrogen-poor soils. It is able to act rapidly when a small insect alights on it. Part of the plant is able to snap shut when the insect touches delicate sensory hairs. The insect becomes trapped and the plant secretes digestive enzymes onto the insect and, as it is digested, nutrients (mainly nitrogen from proteins) are absorbed by the plant (Fig. 8.13).

These two examples are behaviours that result in fast changes in turgor pressure. Turgor pressure usually keeps plant cell vacuoles full and pressing against the cell wall. In these two plants, however, as a result of touch the water flows quickly out of the vacuoles, resulting in a loss of turgor pressure and the cells collapse. So it really is a physiological adaptation, leading to a behavioural adaptation.

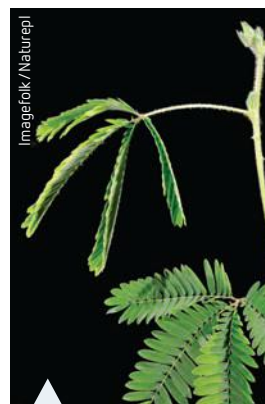


FIGURE 8.12 *Mimosa pudica*, also known as touch-me-not or shy plant



Mimosa pudica

Watch a *Mimosa* leaf fold up in response to touch.



FIGURE 8.13 Venus flytraps supplement their diet by catching and digesting insects.



Venus flytrap

Watch a Venus flytrap catch a fly.

Behavioural adaptations in animals

Animals display a much greater range of behavioural adaptations than plants. These behaviours can be shown by individuals or by groups. The result of each behaviour is to increase the chances of survival of the individual or the individuals within the group.

Temperature

Under laboratory conditions, the body temperature of **ectotherms**, such as lizards, tends to fluctuate (rise and fall) over a wider range of temperatures than in the wild because it is influenced by the ambient temperature. The organism has only a limited ability to control its body temperature. In nature, these organisms use their behaviours to regulate their body temperature. If it is measured in the wild (using a radio telemetry device), their body temperature does not show as wide a range of fluctuations.

For example, the eastern brown snake (*Pseudonaja textilis*) is found in hot, dry areas of Australia, along the eastern seaboard. Brown snakes are found across most of Australia, inhabiting a range of habitats from open grasslands to desert scrub, but not in rainforest areas. Brown snakes are usually **diurnal** (awake during the day), but may become active at night if the daytime temperature is too high. If the ambient temperature rises beyond the brown snake's tolerance level, it will seek shelter in the shade during the day and become active in the later part of the day when it is cooler, or even at night. If the ambient temperature drops below the optimum, snakes bask in the sunlight to gain additional heat. In very cool weather, the snake becomes less active, slowing down its metabolism and using fat reserves. If the cold period is prolonged (for example, in winter), the snake will undergo **brumation**, a process where it will become less active when it becomes colder in winter.

The central netted dragon (*Ctenophorus nuchalis*; Fig. 8.14) is a desert-adapted lizard that inhabits central Australia's plains and open scrub. It is able to withstand variations in body temperature from 13°C to 44°C. In low ambient temperatures, the dragon will lie in the sunlight and alter its body position to expose more of its body surface area to the sun's rays, increasing its core body temperature. It shelters from cold winds and may move out into the sun on warmer days. If the ambient temperature

rises above its heat tolerance level, the central netted dragon will retreat into the shade of rocks and vegetation or into a burrow and reduce its activity to avoid overheating. It will then emerge at night to hunt when the ambient temperature is cool.

Endothermic animals tend to avoid the heat and light of the day. For example, the bilby hides in burrows to stay cool and reduce water loss by evaporation. The largest of the kangaroo species, the red kangaroo (*Macropus rufus*), rests throughout the day, gathers in large family groups at dusk where food is abundant, and feeds on grasses and herbs. Some species of wallabies lick their wrists where the blood vessels form a dense network close to the skin surface. Even though this means loss of precious water, the evaporation of water from the saliva has a cooling effect.

Social behaviour

Some species exhibit social behaviour aimed at increasing the survival of the group. For example, sugar gliders (*Petaurus breviceps*) produce a pungent aroma from scent glands located on the head, on their chest or about the genital opening. Members of a group are permeated by the scent of the dominant male and therefore are able to locate each other successfully in fading light.

Meerkats live in large social communities. They are burrowing carnivores that spend a great amount of each day with their heads in the ground searching for food. This makes them vulnerable to attack by predators, but one animal is usually posted as a sentry (Fig. 8.15). When a threat is imminent, the sentry



Animal adaptations



FIGURE 8.14 Central netted dragon



FIGURE 8.15 A meerkat sentry watches for danger.

produces a series of distinctive calls – a warning for all meerkats to be alert. The rest of the colony responds by standing on their hind legs and scanning the area for predators.

KEY
CONCEPTS

- Behavioural adaptations refer to those actions performed by an organism in response to a stimulus that improves its chances of survival.

INVESTIGATION 8.4

A secondary-source investigation of different types of adaptations in an organism

Choose one plant or one animal to research. Use resources such as journals, books and the Internet to research the structural, physiological and behavioural adaptations in your chosen plant or animal. Present your findings as a PowerPoint presentation (or similar), showing one adaptation per slide. Include photographs and/or videos. Make sure that you cite all your sources correctly.



Literacy



Information and
communication
technology capability

- 1 Define 'behavioural adaptation'.
- 2 Provide an example of a behavioural adaptation in a plant. Explain how it assists in increasing the plant's chances of survival.
- 3 State three behaviours used by an ectothermic animal to assist in regulating its body temperature.
- 4 Provide three behaviours used by an endothermic animal to assist in keeping cool during the heat of the day.
- 5 Outline one example of social behaviour in animals that increases the chances of survival of the group.

CHECK YOUR UNDERSTANDING

8.4

8.5

Charles Darwin, adaptations and natural selection

The diversity of living things on Earth has long been of interest to humans. As early as 580 BCE, Anaximander, a Greek philosopher, suggested that humans could not have appeared on Earth in their current form. A thousand years later, the Greek Empedocles theorised that the early Earth was inhabited by monsters that became extinct and better suited organisms survived. In 1744 CE, Carl Linnaeus suggested that God had created a small number of organisms that interbred to produce a greater variety of living forms. It was not until 1794 that James Hutton proposed that the best-adapted organisms would persevere and multiply. This was the first time that the idea of **natural selection** was formally and clearly stated. Hutton's hypotheses suggested that environmental pressures and adaptations in organisms could be related, leading to the idea that changes in species were linked to species diversity and abundance.

In his book *Zoonomia*, published in 1794, Erasmus Darwin, the grandfather of Charles Darwin, suggested that all cold-blooded (now known as endothermic) animals had a common origin. In 1800

**FIGURE 8.16**

Charles Darwin spent 5 years travelling the world on the HMS *Beagle*.

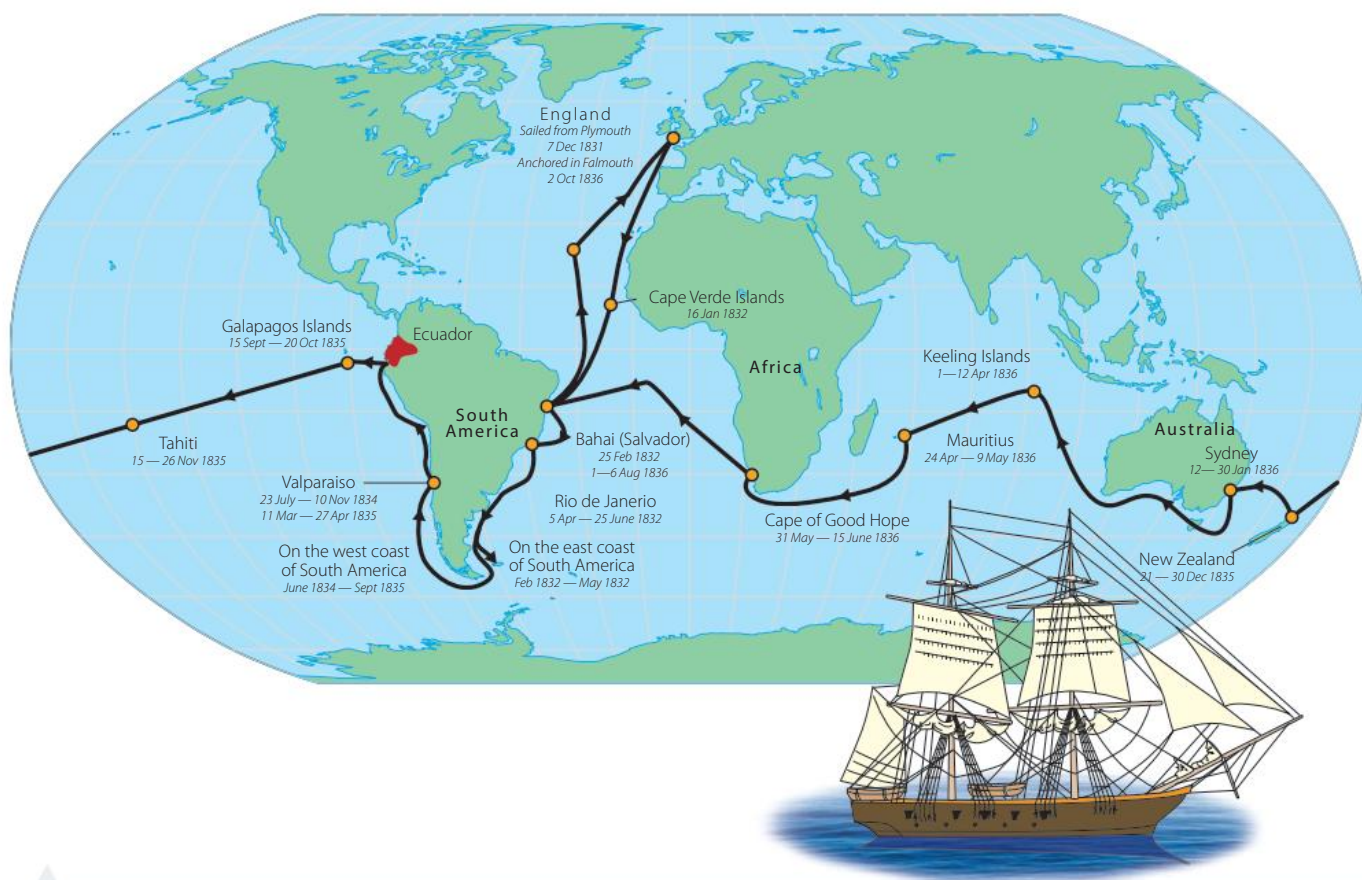
Jean Baptiste Lamarck incorrectly suggested that characteristics acquired during an individual's lifetime could be passed onto their offspring. Many other scientists weighed in on the conversation with varying ideas about how organisms evolved on Earth. It was not until 1858 that Charles Darwin and Alfred Russel Wallace realised that they had been independently working on exactly the same ideas about evolution. They decided to work together and copresented their theory to the Linnean Society in 1858. They had added an extra step to their theory by proposing possible mechanisms to try to explain how this change may come about.

The voyage of the *Beagle*

In 1831, 22-year-old Charles Darwin (Fig. 8.16) boarded the survey ship HMS *Beagle* as ship's naturalist and a dining companion for the captain, young Robert Fitzroy. He began a voyage that would not only change his life forever, but would lay the foundation for modern biology. Darwin's father, a medical doctor, wanted his son to become a parson. Darwin, however, was more inclined to study natural history.

The voyage visited several continents, including South America, Australia and Africa (Fig. 8.17). In his role as naturalist Darwin kept extensive and meticulous notes during his five-year journey on the *Beagle*. He also was able to collect thousands of specimens, which he took back to England for identification. The prevailing belief at the time was that all species on Earth had been independently created, a view that Darwin also shared at one time.

During his first stop in St Jago in the Canary Islands, he was able to see that the fossilised invertebrates in the rock strata on the beach were similar to the shells of present-day organisms that littered the beach. As he travelled along the coast of Argentina to Bahia Blanca, he was able to observe the outer shell of an

**FIGURE 8.17** Map of the voyage of the HMS *Beagle* with the young Charles Darwin

armadillo (Fig. 8.18a); he later unearthed the fossil shell of a glyptodont (Fig. 8.18b) and he recognised its remarkable similarity to the shell of the armadillo. Darwin was beginning to wonder if there was a relationship between ancient extinct species and present-day living species.

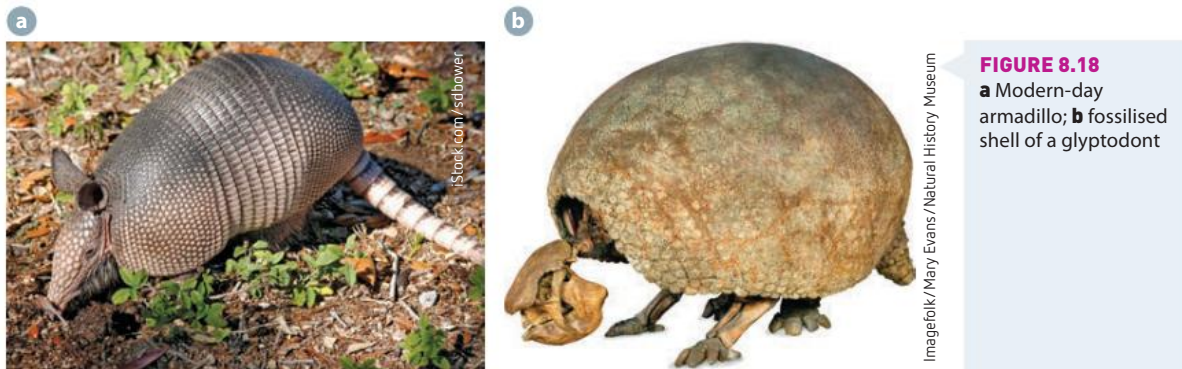


FIGURE 8.18
a Modern-day armadillo; **b** fossilised shell of a glyptodont

Darwin in the Galapagos Islands

It was his visit to the Galapagos Islands, off the coast of Ecuador, that provided him with further evidence that helped strengthen his ideas. The Galapagos Islands (Fig. 8.19) are an archipelago of volcanic islands that span the equator. They are made up of 18 main islands, three smaller islands and a number of smaller rocky islands and islets. The islands are home to a large number of species, including fur seals, sea lions, tortoises, sea turtles, marine iguanas and the now famous Galapagos or Darwin's finches.

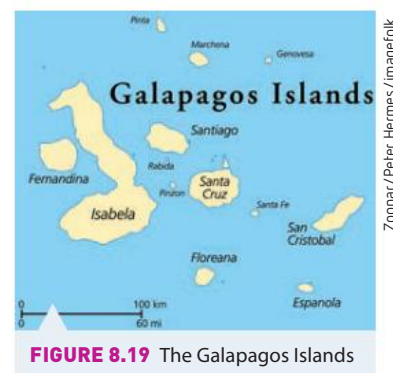


FIGURE 8.19 The Galapagos Islands

Darwin's finches of the Galapagos Islands

Darwin observed small ground finches on the Galapagos Islands. He collected specimens of the finches that were living on each of the islands. On his arrival back in England, he presented these specimens to the Royal Society and then to John Gould, a famous English ornithologist, who classified them as 14 different species, 12 of which were new. Gould commented that the birds were similar to those found in South America.

Armed with this information, Darwin took another look at these finches. What piqued Darwin's interest was the shape of their beak; he wrote, 'The most curious fact is the perfect gradation in the size of the beaks in the different species of *Geospiza*, from one as large as that of a hawfinch to that of a chaffinch ...' (Fig. 8.20) He began to wonder if the Galapagos finches could have all descended from an original population from mainland South America that had gradually been modified.

Darwin reasoned that the different finches he found from island to island could be explained as follows. A few South American finches must have arrived on one of the remote islands of the Galapagos. These finches had naturally occurring variations in, for example, their colour, beak size and leg length. The descendants of these birds gradually populated the other islands, each of which had different environmental conditions. Depending on which island they lived on, and the conditions they found themselves in, some birds thrived and reproduced. Those finches that were not adapted to the conditions on the island died out.

Classification of Darwin's finches is attributed to John Gould, ornithologist at the Zoological Society of London in 1837. This classification was highly significant for Darwin because it led him to the realisation that species on separate islands were related to species on the South American mainland. These provided further evidence to Darwin that species could split from a common ancestor and might exist at the same time, even in the same geographical area. John Gould later moved to Tasmania and classified more than forty per cent of all Australian bird species.



Observations and inferences

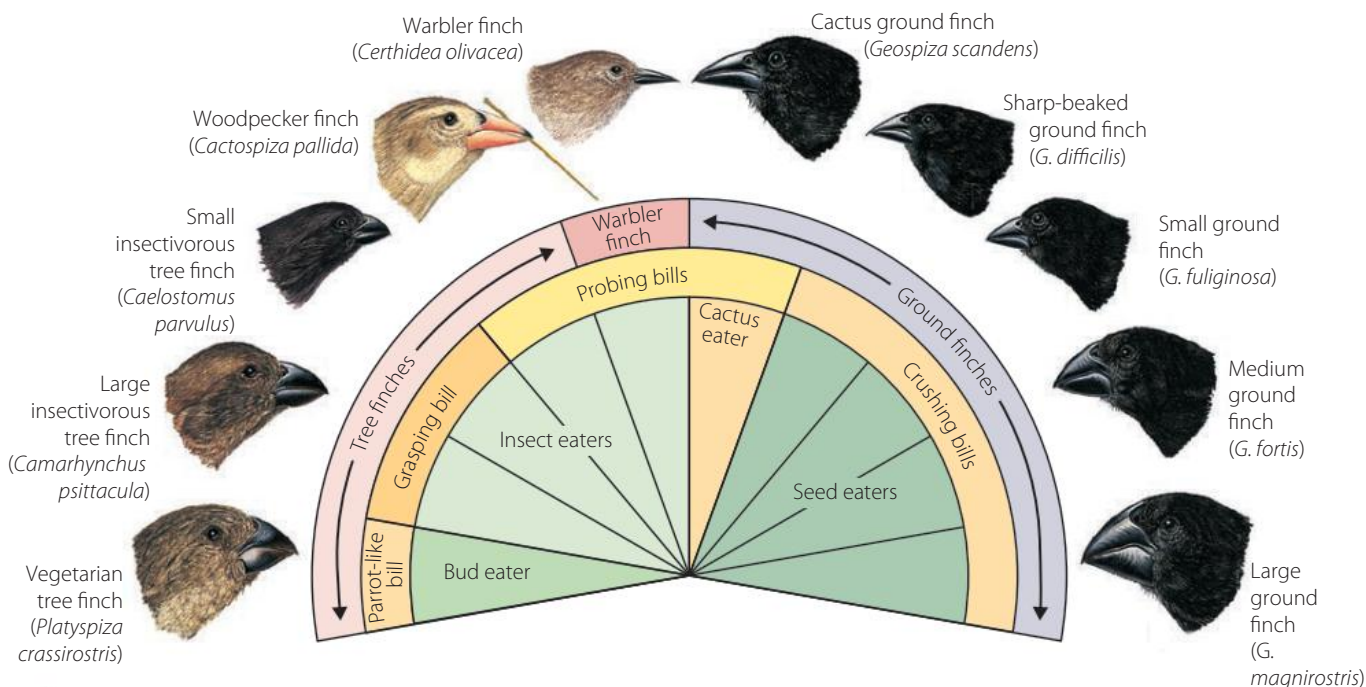


FIGURE 8.20 The finches observed by Darwin on the Galapagos Islands, showing how their beaks evolved in response to the selection pressure of available food

INVESTIGATION 8.5

Interpreting and analysing secondary-source data on Darwin's finches



Critical and creative thinking



Numeracy



Information and communication technology capability

Peter and Rosemary Grant from Princeton University spent 40 summers on Daphne Major in the Galapagos Islands studying evolution first hand. When the Grants began their investigation in 1973, the food available to the finches on Daphne Major was abundant soft small seeds.

AIM

To interpret and analyse data on beak size, available food and climate, and find patterns and trends to draw your own conclusions

INTRODUCTION

The Grants caught, measured and tagged the finches that lived on Daphne Major over a 40-year period. One of the measurements that they took was beak depth, using the method shown in Figure 8.21.

RESULTS

The results obtained by the Grants for the year 1976 are shown in Figure 8.22.

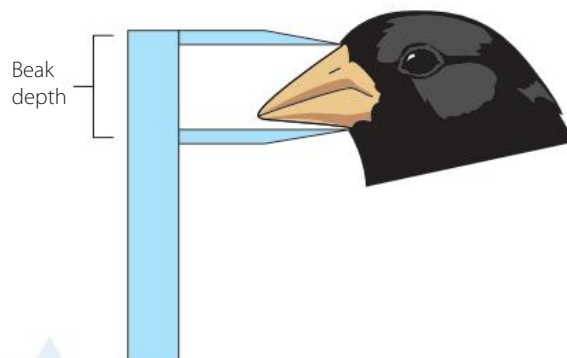


FIGURE 8.21 The method used to measure beak depth

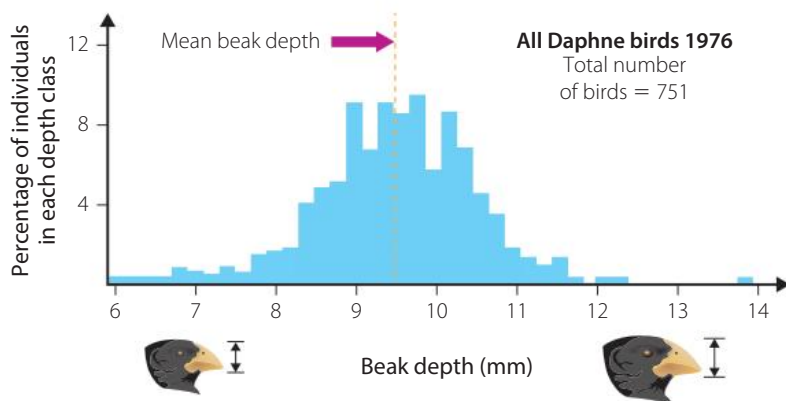


FIGURE 8.22 Beak depth data from 1976

QUESTIONS

- Using Figure 8.22, describe the abundance of birds with different beak lengths living on Daphne Major in 1976.
- What relationship can you infer from this data in terms of the type of food available to the birds in 1976? Justify your answer. (Refer to Fig. 8.20 to look for a relationship between beak length and diet in finches.)
- Figure 8.23 shows the rainfall and temperature data for Daphne Major between the years 1973 and 1978. Analyse the climate data provided for these years. Describe the relationships evident in the data.

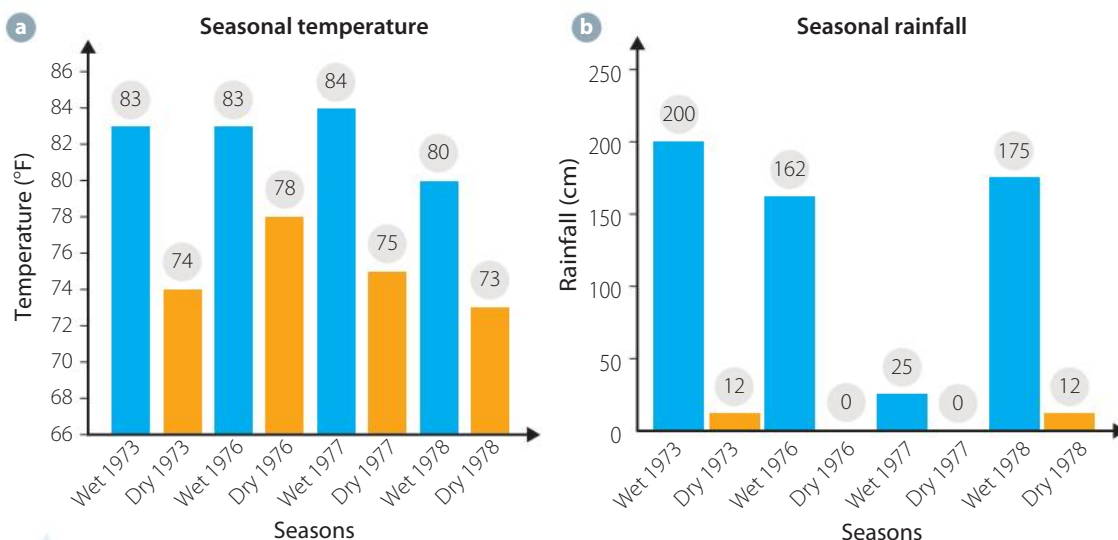


FIGURE 8.23 **a** Temperature and **b** rainfall data for Daphne Major, 1973–78. Because the Galapagos Islands lie on the equator, they only have two seasons – wet and dry.

Figure 8.24 shows the results of the beak depth measurements for 1978.

- Describe the abundance of birds with different beak lengths living on Daphne Major in 1978.
- Compare the beak length data from 1976 to that of 1978. Describe any changes.
- What can you infer from this data in terms of the type of food available to the birds in 1978?
- Using all the data presented, explain how this change might have come about.
- What might this change mean for future generations of finches on Daphne Major?



The beak of the finch

Watch the video and answer the quiz questions.



» CONCLUSION

Write a concluding statement about the changes that occurred on Daphne Major from 1976 to 1978, based on the patterns and trends that you have identified in this investigation.

EXTENSION

Research another species and develop a hypothesis that can be tested by collecting and processing data. For example, is there a relationship between body size and environment in the platypus?

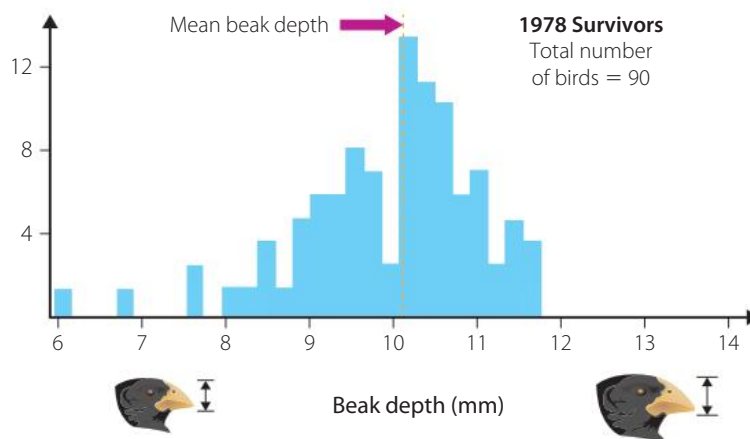


FIGURE 8.24 Beak depth data from 1978



FIGURE 8.25 Watercolour and gouache of a platypus, completed in 1820 by J.W. Lewin

Darwin in Australia – native flora and fauna

On 12 January 1836, the *Beagle* sailed into Sydney Harbour. What Charles Darwin saw during his 2-month stay in the colony provided him with a wealth of information. It helped him to make observations and further formulate his ideas on evolutionary change.

While in Sydney, Darwin embarked on an overland journey to Bathurst. He was the first British scientist to observe a rat-kangaroo and a platypus in their natural environments just near Wallerawang. He was able to infer that the platypus was very similar to the water rat in England, and that the rat-kangaroo was similar to the rabbit, in both behaviour and appearance. See Table 8.2 for more of Darwin's observations.

TABLE 8.2 Darwin's observations and how they related to his theory of evolution

DARWIN'S OBSERVATION	HOW DARWIN'S OBSERVATION RELATED TO HIS THEORY OF EVOLUTION BY NATURAL SELECTION
Magpies and crows are similar to the jackdaws in England, but obviously belong to different species. The potoroo (rat-kangaroo) is similar to the rabbit in England. The potoroo is a miniature kangaroo the size of a European rabbit, behaving somewhat like a rabbit, darting about in the undergrowth. The platypus is similar to water rats: 'I ... had the good fortune to see several of the famous platypus. They were diving and playing in the water; but very little of their bodies were visible, so that they only appeared like so many water rats.'	Darwin's observations of birds, marsupials and monotreme mammals in Australia revealed similarities with European mammals that lived in similar environments. This led him to the idea that organisms could evolve to become similar (convergent evolution). If organisms live in similar habitats, similar variations that they possess would be favoured by natural selection to enable them to survive and breed in those conditions. These favourable variations would then be passed on to the next generation.
Ant lions (same genus but different species?) to that of England: 'I observed a conical pitfall of a Lion-Ant: a fly fell in and immediately disappeared; ... without doubt this predacious lava [sic] belongs to the same genus, but to a different species from the European one ... Now what would the Disbeliever say to this? Would any two workmen ever hit on so beautiful, so simple and yet so artificial a contrivance? I cannot think so. The one hand has worked over the whole world.'	Their behaviour is similar to those in England. Same genus but different species?





DARWIN'S OBSERVATION	HOW DARWIN'S OBSERVATION RELATED TO HIS THEORY OF EVOLUTION BY NATURAL SELECTION
Vegetation: Darwin describes eucalypts: 'the nearly level country is covered with thin scrubby trees, bespeaking the curse of sterility'. He also mentions 'the leaves are not shed periodically'.	In Darwin's observations of plant life in Sydney, he made the link between the harsh environment and the adaptations observed in the vegetation. He also mentions that many of the trees in Australia and other southern continents are evergreen as opposed to those in the northern hemisphere.

Source of quotes: Darwin, 1859, *On the Origin of Species*, <http://Darwin.thefreelibrary.com/The-Origin-of-Species>

As a result of his observations, Darwin began to wonder why a Creator would create such different creatures for such similar environments.

He tried to reason this out in his diary:

Surely two distinct creators must have been at work; their object however has been the same and certainly the end in each case is complete ... Would any two workmen ever hit on so beautiful, so simple & yet so artificial a contrivance?

Source: Charles Darwin, <http://austhrutime.com/darwin.htm>



Darwin's trip to Australia

Darwin went on to write *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life* (1859). It is now simply called *Origin of Species* and the theory that he proposed is sometimes known as *survival of the fittest*.

This theory has five main tenets:

- 1 Variation exists within populations.
- 2 More offspring are produced than can survive.
- 3 Those offspring that are better adapted to their environment will survive and reproduce.
- 4 The favourable adaptations are passed on to the next generation.
- 5 Over time, the favourable adaptations will increase in the population (as long as the environment does not change).

KEY CONCEPTS

- Charles Darwin travelled the world for 5 years aboard the HMS *Beagle*, collecting specimens and taking notes.
- The Galapagos Island finches provided essential evidence to his emerging Theory of Evolution by Natural Selection.
- Darwin visited Australia in 1836 and made important observations that helped him solidify his ideas.
- Darwin, along with Wallace, presented their theory to the Linnean Society in 1858. *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life* was published in 1859.

- 1 Outline the theory that Darwin considered could explain the diversity of life on Earth when he started his journey on the HMS *Beagle*.
- 2 Provide two observations that Darwin made and that started to change the way he thought about life on Earth.
- 3 Explain the importance of his observations on the Galapagos Islands in solidifying Darwin's ideas.
- 4 Provide two examples of plants and/or animals that Darwin observed while in Australia that began to make him think differently about life on Earth.
- 5 List the five main tenets of Darwin's Theory of Evolution by Natural Selection.
- 6 Identify at least three other people who assisted Darwin with his work and/or influenced his ideas.

CHECK YOUR UNDERSTANDING

8.5

Effects of the environment on organisms: How do adaptations increase the organism's ability to survive?

An **adaptation** is a feature that an organism inherits that enable it survive in a specific environment.

Types

Structural –

an organism's physical characteristics

PLANT

- Respond to touch in mimosa
- Venus fly trap responds to animals landing on it

ANIMAL

- Puffer fish blow up to evade predators
- Penguins huddle to trap warmth
- Snakes are less active in cold weather and move under rocks in the heat of the day

Physiological –

an organism's function or process

PLANT

- Xerophytes
- Waxy leaves on eucalyptus
- Spinifex have cylindrical leaves to reduce surface area
- Sunken stomata in dune grass
- Epidermal hairs on wattle

ANIMAL

- Covered in spikes for protection from predators – thorny devil
- Claws for digging a burrow in wombats
- Backward facing pouch in wombats

Behavioural –

how an organism acts

PLANT

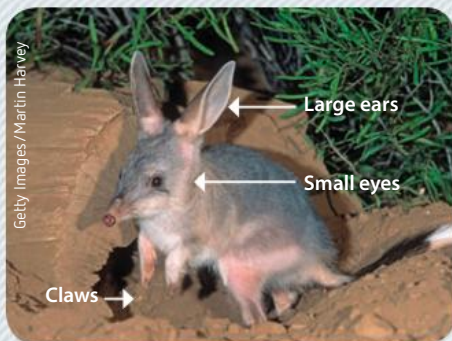
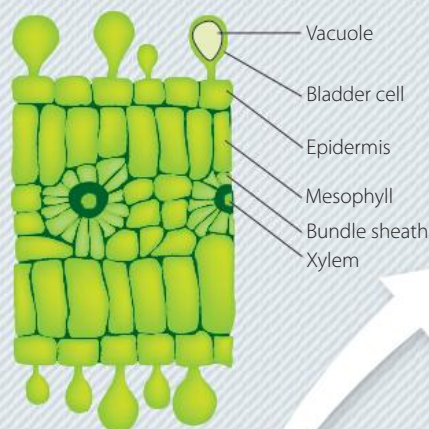
- Salt tolerance in mangroves and other halophytes
- Dormancy and leaf loss during cold weather

ANIMAL

- Production of concentrated urine in areas of low water availability
- Counter-current blood flow in penguin

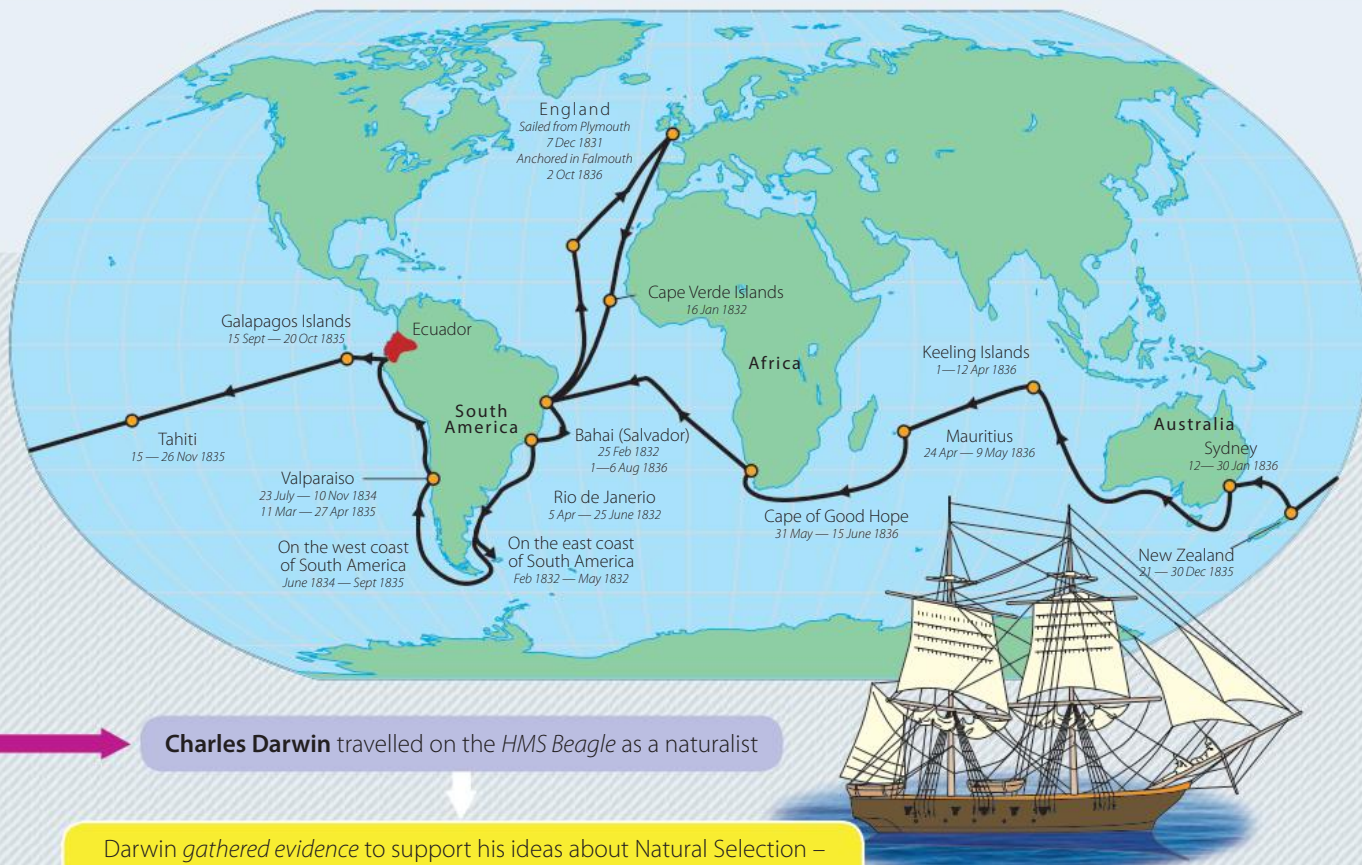


A thorny devil is covered with large spikes making it look ferocious and hard to eat



CHARLES DARWIN PROPOSED THE THEORY OF EVOLUTION OF NATURAL SELECTION

- 1 Variation exists within a population
- 2 More offspring are produced than can survive
- 3 Those offspring that are better adapted to their environment will survive and reproduce
- 4 The favourable adaptations are passed onto the next generation
- 5 Over time, the favourable adaptations will increase in the population (as long as the environment does not change)



Charles Darwin travelled on the *HMS Beagle* as a naturalist

Darwin gathered evidence to support his ideas about Natural Selection – the environment was acting to favour some adaptations over others.

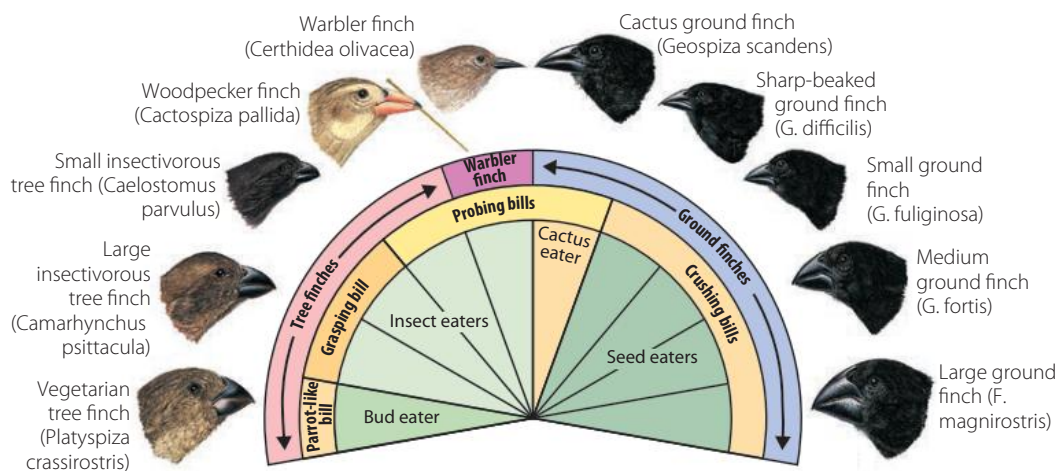
South America

- Observed that armadillo fossils were similar to living species
- Noticed the different beak shapes of Galapagos finches



Australia

- Observed monotremes including the platypus; returned with specimens to England
- Observed similarities between the Australian Magpie and the English Jackdaw
- The potoroo was similar to the rabbit
- Eucalyptus trees – noted how different these plants were to evergreen plants in the northern hemisphere



- 1 Distinguish between structural, physiological and behavioural adaptations.
- 2 Distinguish between an ectotherm and an endotherm.
- 3 Describe the adaptations for a tree living in a cold, alpine region where there is heavy snowfall in the winter months.
- 4 State three structural adaptations that plants may have to assist their survival living in high salt conditions.
- 5 State three physiological adaptations that plants may have to counter extremely high temperatures and low rainfall.
- 6 Explain why it is difficult to explain a physiological adaptation without talking about related structural adaptations as well. Provide an example.
- 7 State two behavioural adaptations shown by the thorny devil that assist it in surviving in its natural environment.
- 8 Explain why autumn leaves turn yellow and brown. How does this assist the respective plants in their survival?
- 9 Describe the similarities in the functioning of sunken stomata and epidermal hairs on the leaves of plants and explain how these adapt plants to their environment.
- 10 Explain, using an example, how social behaviour as an adaptation can increase the chance of survival of a species.
- 11 A plant with broad, thin, shiny leaves is growing in a tropical rainforest. List the survival threats that this plant would face in this environment.
- 12 Name an animal that lives in conditions of either extreme cold or extreme heat. Use a table to summarise the structural, physiological and behavioural adaptations it has to regulate its body temperature.
- 13 The polar bear is a marine mammal that lives in the Arctic. Research and outline the structural, physiological and behavioural adaptations that increase the chances of survival of a polar bear.
- 14 List three pieces of evidence that caused Charles Darwin to change his ideas from the theory of independent creation to the Theory of Evolution by Natural Selection.
- 15 Explain how fossils contribute to the development of understanding about the evolution of species.
- 16 Explain how Darwin built on the work of others to come up with his Theory of Evolution by Natural Selection.
- 17 Using the five main tenets of the Theory of Evolution by Natural Selection, explain how the finches on the Galapagos Islands evolved from one main colonising group from South America.
- 18 Explain how Darwin's ideas about the diversity of life on Earth changed due to observation and evidence. How difficult do you think it would have been for Darwin to so radically change his idea from independent creation to the Theory of Evolution by Natural Selection?

9

The Theory of Evolution by Natural Selection

INQUIRY QUESTION

What is the relationship between evolution and biodiversity?

Students:

- explain biological diversity in terms of the Theory of Evolution by Natural Selection by examining the changes in and diversification of life since it first appeared on the Earth (ACSBL088)
- analyse how an accumulation of microevolutionary changes can drive evolutionary changes and speciation over time, for example: (ACSBL034, ACSBL093) [CCT L](#)
 - evolution of the horse
 - evolution of the platypus
- explain, using examples, how Darwin and Wallace's Theory of Evolution by Natural Selection accounts for:
 - convergent evolution
 - divergent evolution
- explain how punctuated equilibrium is different from the gradual process of natural selection

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Two hundred and fifty years ago, natural scientists proposed the theory of evolution – that living things change over time – to try to explain how living organisms have come to be the diverse group that they are. The concept that we call evolution had been alluded to over many thousands of years, but in the early 1800s biologists took one step further, proposing possible *mechanisms* to try to explain how this change may come about. This has led to the currently accepted *Theory of Evolution by Natural Selection*. In this chapter, we as biologists will look at the links between evolution and the diversity of life, one of the underlying concepts of biology.



FIGURE 9.1 This fossil of a *Masillamys*, an extinct rodent with chisel-like incisors, is exceptionally well preserved. It was recently unearthed from the Messel Pit, Germany.

Living things exist in a variety of different forms, from unicellular organisms like bacteria to the multicellular varieties that include emus and kangaroos. Scientists have discovered about 8.7 million different species and more are found every year. Many more have existed in the past as is evidenced by the presence of **fossils** (such as in Fig. 9.1), but have now completely died out – they have become **extinct**. All the different species that exist today have developed over billions of years. These evolutionary processes are driven by changes in the environment – both natural and, increasingly, those influenced by humans.

9.1 Biological diversity and the Theory of Evolution by Natural Selection

Biological diversity or biodiversity refers to the variety of all forms of life on Earth, the diversity of the characteristics that living organisms have and the variety of ecosystems of which they are components. Diversity within a population is what allows it to adapt to changes in the environment. Biodiversity is also what sustains us and enriches our lives. We depend on it for benefits such as fresh air, food, medicines, clean water, fuel and many other resources. Globally, species are rapidly becoming extinct and this puts entire ecosystems at risk.

Biodiversity exists on three different levels:

- 1 **genetic diversity**, which refers to the total number of genetic characteristics in the genetic make-up of a species
- 2 **species diversity**, which is a measure of the diversity of different species in an ecological community
- 3 **ecosystem diversity**, which is the variation of different ecosystems found in a region.

Evolution, biodiversity and ecology are proving to be far more closely interrelated than was understood in the past. Until fairly recently, evolution was thought to happen gradually, over long periods. Recent research into environmental science, such as changes in climate, are showing that evolutionary change may happen rapidly in response to strong selection pressures.

For example, the small number of endangered Baw Baw frogs (*Philoria frosti*; Fig. 9.2) that exist today are found only in a small area in the central highlands of Victoria. Evidence show that the ancestors of today's Baw Baw frogs were distributed along the Great Dividing Range at a time when Australia had a wetter climate. The Baw Baw frogs we see today are considered to be living relics and they have a very low genetic diversity, suggesting that past climate change had placed the species under great pressure. Ecological field research has shown that the existing population has had a 98 per cent population decline in just 30 years, indicating a high risk of its extinction in the wild. Research indicates that much

of the recent decline in the Baw Baw frog is the result of an introduced disease, the chytrid fungus. The frog also faces the dual threat of climate change resulting from the enhanced greenhouse effect and fragmentation of its habitat through conflicting land use. Melbourne Zoo has introduced a recovery program, breeding these frogs with the intention of trying to establish a genetically diverse community to conserve the species.



FIGURE 9.2 The Baw Baw frog (*Philoria frosti*) is a critically endangered species that may need genetic diversity to survive.

Current studies are showing that not only does evolution rely on biodiversity, but evolution also affects biodiversity and can drive or limit it. This has led to relatively new fields of study in biology such as ecoevolution (the effect of global changes such as climate change on biodiversity) and evolutionary ecology. In evolutionary ecology, studies include topics such as the evolutionary basis of the diversity of life, phenotypic variation and change in populations, evolutionary responses to global change and evolution and coevolution in ecosystems (Fig. 9.3).

Genetic diversity

Genetic diversity within a species is important for populations to adapt to changes in the environment. Environments are constantly changing and in this way pose selection pressures that enable some organisms with favourable characteristics to survive and reproduce more successfully than others.

Populations with reduced genetic diversity risk extinction in the long term. Consider a population of bacteria that has reproduced by binary fission in a Petri dish. Each member of the population is identical to every other member. If a mild acid is introduced into the Petri dish (the selection pressure), and there is no pre-existing ability to survive the change, then no member of the population will survive. The whole population will die out.

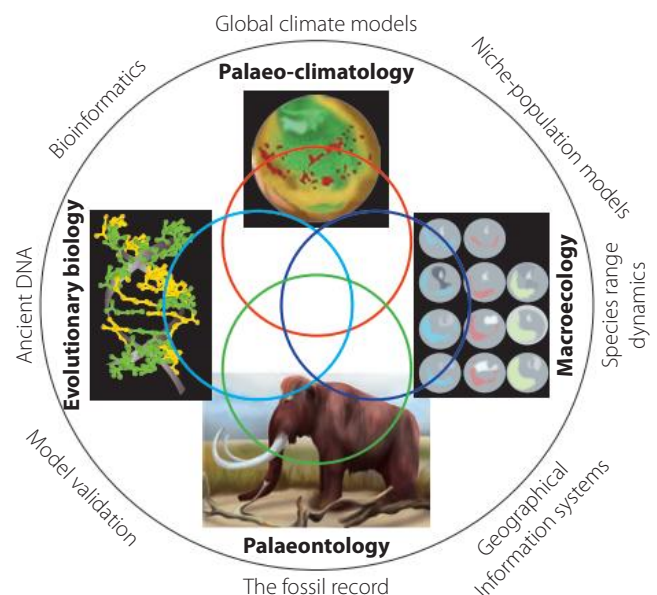


FIGURE 9.3 Evolutionary ecology fields of study at the University of Tasmania



FIGURE 9.4 The calicivirus has been introduced into rabbit populations in Australia to help control numbers. Some rabbits are naturally resistant to the virus.

If, however, there is genetic biodiversity among members of a population or species, there is a chance that some individuals will have a pre-existing ability to survive and go on to reproduce. For example, the calicivirus is a virus that affects rabbits (Fig. 9.4) and has been used as a biological control mechanism (the selection pressure) for a number of years. It kills 95 per cent of rabbits within 72 hours. Some rabbits, however, do not die. These rabbits have an inherited resistance to the virus. It is these rabbits that will go on to reproduce and pass that genetic characteristic onto their offspring. Increasingly the rabbit population will become resistant to the calicivirus. This is the basis of Darwin and Wallace's Theory of Evolution by Natural Selection.

The Darwin–Wallace Theory of Evolution by Natural Selection

Evolution is a *change* in living organisms over a long period. As far back as the 4th century BCE (during the time of Aristotle), the concept that organisms may change over time had been considered, but no testable theory or *mechanism* explaining how it could occur was proposed.

Evolutionary thinking as we know it today had its beginnings in the mid to late 1700s, but it was not until the early 19th century that a mechanism for evolution that was worth serious consideration was proposed by Jean Baptiste Lamarck. Although his theory was later rejected, his ideas opened the way for the proposal of new ideas, resulting in the currently accepted Theory of Evolution by Natural Selection, proposed by Charles Darwin and Alfred Wallace in the late 19th century.

All theories of evolution share some common basic premises:

- ▶ Living organisms arose from common ancestors or a common life form and have changed over time.
- ▶ *Differences* that occur among groups of living organisms imply that living things *change over time*.
- ▶ *Similarities* occur in living things and suggest a *common ancestry* – the basic chemistry, inherited from a common life form, has remained relatively unchanged and has been passed down through generations.

Concepts on which the Darwin–Wallace theory of evolution is based

The Darwin–Wallace Theory of Evolution by Natural Selection is based on the premise that living things arose from a common ancestor and that some populations moved into new habitats where they adapted over time to their environments, leading to the diversity of life.

In terms of this theory, to survive in a particular environment, organisms must possess traits that favour their survival in that environment. We say organisms possess variations that are selected within a population, resulting in a group of organisms becoming adapted to their environment. Charles Darwin and Alfred Wallace's theory of evolution proposes that natural selection and isolation could account for how living organisms become adapted to their surroundings and evolve into new species.

Natural selection depends on the following concepts:

- ▶ variability: all populations have random differences or variation among their members
- ▶ heritability: variation may be inherited
- ▶ over-reproduction: organisms produce more offspring than the environment can support (that is, not all offspring survive)
- ▶ **competition** between organisms and survival of the fittest.

Darwin and Wallace's idea that populations change by natural selection and become adapted to the environment gave rise to their ideas on **speciation** – the formation of new species. They proposed that the

formation of a new species may occur when a population becomes isolated from the original group of organisms. Only those individuals that have variations that allow them to survive the changed conditions will reproduce and pass on their characteristics to the next generation. Eventually, the population becomes so different from the original population that individuals are no longer able to interbreed and produce fertile offspring – the defining condition for a population to be considered a different or new species.

Neo-Darwinism or modern synthesis

Scientists more recently have applied concepts of Mendelian genetics to support and explain Darwin and Wallace's ideas on random genetic variation leading to gradualism and the formation of new species. It was only in the first decade of the 20th century, after Mendel's experimental results were confirmed and accepted, that the Darwinian theory of evolution was extended to include the genetic processes involved in natural selection. Therefore, the explanation of Darwinian evolution based on modern genetics is what we term 'neo-Darwinism'.

In any population, although offspring resemble their parents, they are not identical to them. The term 'variation' applies to differences in the characteristics (appearance or genetic make-up) of individuals within a population: not all humans, dogs, cats or elephants look exactly alike (Fig. 9.5). When organisms reproduce, the offspring resemble their parents in basic structures – the transmission of similar characteristics (heredity) is evident.



FIGURE 9.5 Dogs are a single species, *Canis lupus familiaris*. Note the differences in the characteristics of individuals.

Many variations arise from the interaction of an organism with its environment (for example, access to water and sunlight will affect the growth rate of a plant). This type of variation affects the individual organism. Variations that can be passed on from one generation to the other – heritable characteristics – affect evolution. Heredity and variation are essential for evolution to occur. Variations that pass from one generation to another are often produced in a population as a result of **mutations**.

The variation in the **gene pool** of a population (all the possible varieties of a gene within a group of interbreeding organisms) is important in determining the chances of survival of that population. If there is a sudden change in the environment, those individuals that randomly possess a variation that is an advantage are more likely to survive the changed conditions. Individuals that do not possess that variation may be unable to compete and survive. Those that survive are more likely to reach an age where they can reproduce and pass their favourable characteristics to their offspring. Individuals with less favourable variations will eventually be eliminated from the population as they are out-competed. If individuals within the population become so different that they can no longer interbreed with individuals from the original population to produce fertile offspring, then the population is considered to be a new species.

Therefore, variation in a population is of paramount importance, because it gives the population a better chance of surviving sudden environmental changes.

It is important to remember that an individual does not develop an adaptation in response to the environmental change. Organisms must already possess the random variation that confers an advantage

under the new conditions. This variation is now called an adaptation. An adaptation enables the organism that possesses it to cope better with the selection pressure conferred by the changed environment and out-compete those organisms that do not possess it.

Types of speciation

Allopatric speciation is speciation that occurs when populations become isolated. This process involves several stages:

- 1 In a parent population that has a large range with a common gene pool, there is a regular flow of genes due to mating events between individuals.
- 2 Part of the population becomes separated due to physical barriers. This prevents the flow of genes between the parent population and the isolated population.
- 3 The two populations experience different selection pressures that favour some individuals with specific **genotypes** (the genetic make-up of an organism) over others. This alters the frequency of specific genes. The isolated population will become a subspecies.
- 4 If the populations are separated long enough, the gene pool of each population will change in isolation. Gene flow will not occur, as the populations are not in breeding contact. They may become so different that they can no longer interbreed if brought together.

Closely related species whose distribution overlaps are called **sympatric** species. Species that are geographically isolated are called allopatric species.

A modern day example of evolution

In species that live in fast-changing environments, there is continual selection of individuals with favoured characteristics. This can be seen in species with short generation times such as the bacterium *Staphylococcus aureus*. Usually, *Staphylococcus* infections are treated with a course of antibiotics. Some of these bacteria have a genetic predisposition that makes them resistant to the antibiotics. They survive and go on to reproduce offspring that are also resistant to the antibiotics. A broader range of antibiotics is then introduced to try to treat infections caused by the resistant bacteria. The overuse of antibiotics and failure by patients to complete a course of antibiotics leads to further selection of bacteria in a similar manner, over many generations. As a result, methicillin-resistant *Staphylococcus aureus* (MRSA), also known as 'golden staph', has arisen. *Staphylococcus aureus* bacteria from 50 years ago are genetically different from current golden staph bacteria. This change in a strain of organism over a short period represents what biologists term **microevolution**.

KEY CONCEPTS

- Biological diversity or biodiversity refers to the variety of all forms of life on Earth.
- Genetic diversity refers to the total number of genetic characteristics in the genetic make-up of a species.
- Genetic diversity is the raw material of evolution.
- Those organisms with characteristics that are selected for will survive and go on to reproduce.
- Speciation occurs if two populations become so different that they can no longer interbreed.

CHECK YOUR UNDERSTANDING

9.1a

- 1 Define biodiversity.
- 2 Outline the three main types of diversity and give an example of each.
- 3 Explain the relationship between biodiversity and evolution.
- 4 Describe the relationships between ecology, global change and evolution, and how global change may have led to extinction events.
- 5 Outline how bacteria can develop antibiotic resistance.

Explaining the origin and diversification of life

Biologists have been aware of species that have changed over a longer period by looking at evidence from the fossil record. However, the fossil record does not necessarily show a uniform pattern of change. Rather it shows that, after a major extinction event (widespread and rapid decrease in biodiversity), new life forms flourish. For example, it seems that, after the extinction of the dinosaurs, a group of diverse reptiles, mammals that were once small and rare animals were able to take advantage of the new **niches** left open as their previous inhabitants became reduced in numbers or extinct. Figure 9.6 shows that at the end of the Cretaceous period (65 mya) the number of reptile families decreased (the fifth mass extinction), enabling mammals to occupy those niches and increase in variety and number. How then did life originate and give rise to the diverse range of organisms that lived in past eras, some groups of which still live today?

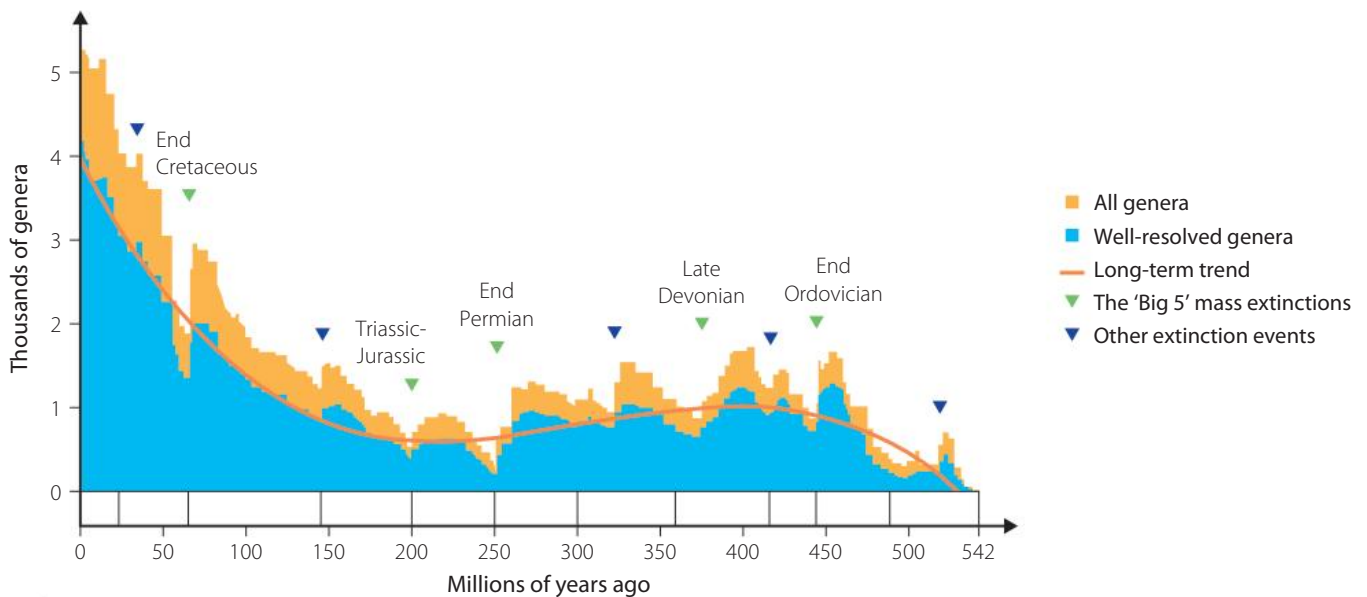


FIGURE 9.6 The five major extinctions in the history of Earth

The origin of life on Earth

It is believed that the environment on early Earth provided conditions for inorganic molecules to form organic molecules. Organic molecules then reacted with each other to form more complex organic compounds. Complex organic compounds then became separated from their surroundings when membranes formed around them. This is thought to account for how the first primitive living cells came to be. They would have had a selective advantage over organic molecules in the primitive soup. The separation of these cells from their environment would have allowed the entities to metabolise more effectively. These are thought to have been the first **prokaryotic cells**.

Further advances are believed to have happened when cells, over time, developed specialised compartments to carry out different chemical reactions. Evidence suggests that this came about by larger cells ingesting smaller cells, resulting in membrane-bound organelles such as chloroplasts and mitochondria occurring inside cells (Fig. 9.7). These would have been the first **eukaryotic cells**. With cells now able to photosynthesise and produce oxygen, the scene was set for increasing diversity, complexity and size of organisms.



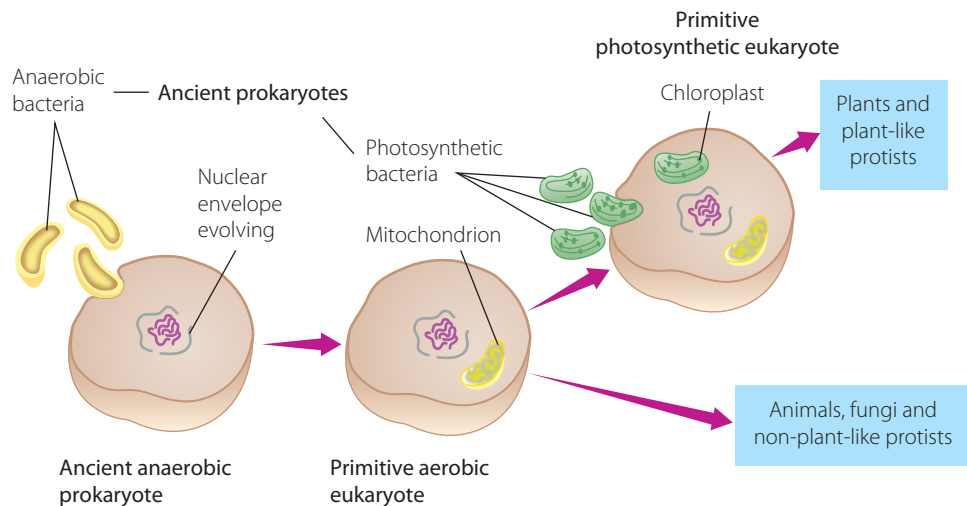
Major changes in the atmosphere and the origins of life on Earth

Diversification of life on Earth

The move from unicellular to **multicellular organisms** began when these cells clustered together. When some cooperation between these cells occurred, **colonial organisms** resulted, giving them a selective advantage over unicells. Once the cells within the group began to specialise to carry out particular functions, this would have led to higher organisation and the selection of multicellular organisms.

FIGURE 9.7

Membrane-bound organelles are thought to have come about by prokaryotic cells ingesting smaller cells.



Of course, these changes would have extended over very long periods and involved far more complex changes than those summarised above. The changes that were believed to occur as one type of organism gave rise to another did not mean that all organisms in a group changed. Some members of these groups are known to have continued in their original forms to the present-day (for example, cyanobacteria, which are modern day prokaryotic, **autotrophic organisms**). All of this would have happened between 4500 million years ago (mya) and 2500 mya in the Precambrian era.

Life then began to diversify further, with the rise of invertebrates from about 600mya, to the rise of fish (425mya) and amphibians (345mya). A large extinction of many invertebrates then occurred and amphibians began to decline in numbers. This was followed by the rise and dominance of reptiles, marking the start of the Mesozoic era (250mya). This era included the Jurassic and Cretaceous periods, when dinosaurs roamed Earth.

With the extinction of the early land reptiles, mammal-like reptiles dominated (230mya). The extinction of marine and aerial reptiles followed. The detailed reasons for major extinction events are still under debate, but there is no doubt that an enormous change to the environment was responsible for each extinction event. Those species that had the diversity to adapt survived, while others perished.

Plants also evolved and diversified, with cycads, conifers and ginkgoes the dominant flora during the Jurassic period. Following the major extinction of marine and aerial reptiles, along with many plants, flowering plants arose (135mya).

The Cenozoic era (12mya) saw the rise of mammals. During the quaternary period, extinctions of large mammals including megafauna occurred in the northern hemisphere, followed by similar extinctions on islands including Australia. These extinctions occurred as humans expanded in range and also coincided with dramatic climate changes and ice ages. There are a number of hypotheses as to the cause of these extinction events, including overhunting by humans, climate change, spread of disease and over-predation by non-humans.

Some of the changes that occurred over very long periods were the result of changes in selection pressures in the environment, leading to the extinction of some species and the survival of others, giving us the diversity of life as we know it today.

Some organisms appear to have changed very little when you look at their fossil record. The coelacanth (fish), cycads (plants; Fig. 9.8) and tuatara (reptile) are examples of these organisms. Rather than suggesting that they have not changed, it is their environments that have not changed, and therefore they have had little selection pressure influencing their evolution. The horseshoe crab is a good example. Fossils of the crab that are 445 million years old appear very similar to the living ([extant](#)) species. This suggests that the environment of the horseshoe crab has remained relatively stable.

In terms of evolution, those organisms that are able to adapt to a variety of environments (that is, have high genetic diversity) are able to survive and out-compete others with less genetic diversity.



FIGURE 9.8 Cycads have changed very little over millions of years.

The geological timescale and diversity of life on Earth

Palaeontology is the scientific study of fossils (the remains of living things). Fossils have provided scientists with evidence of the diversity of living things on Earth.

The geological timescale was a model that was developed to clearly show how the diversity of life changed. Initially miners noticed that specific rock strata contained the remains of living things (fossils). Nicolaus Steno in 1669 established two principles of geology. He stated that all sedimentary rocks were laid down in layers and that the bottom layers were older than the top. James Hutton in 1795 suggested that geological processes were uniform in frequency and magnitude; this is known as the **principle of uniformitarianism**. An amateur geologist and surveyor, William Smith, in 1815 developed a geological map of England; he was able to use fossils to show a logical progression of time, known as the principle of faunal succession. Other scientists have been able to use fossils to define increments within a timescale. This enabled scientists to see how living things have changed over millions of years.

It is evident that natural selection may result in changes within a species (**microevolution**) or it may result in populations that become so different that new species are formed (**macroevolution**). For speciation to occur, isolation is necessary.

When this theory was first proposed, difficulties arose in trying to fully explain it because at that time there was no knowledge of *how* characteristics could be *inherited* or the cause of these differences (variation) in living organisms. The Theory of Evolution by Natural Selection was proposed before there was any knowledge of genes or an explanation of how inheritance could come about.

The major stages in the evolution of living things are shown in Table 9.1.

TABLE 9.1 The geological timescale showing the rise and extinctions of diverse living organisms

Eon	Eras of time	Periods	Age	Millions of years ago	Major biological events
Phanerozoic	Cenozoic	Quaternary	Age of mammals	2	Humans expand in range Major ice ages and extinction of large animals in the northern hemisphere
		Neogene		12	Extensive radiation of flowering plants and mammals Dominance of gastropods
		Paleogene		65	
	Mesozoic	Cretaceous	Age of reptiles	135	First flowering plants Extinction of ammonites, marine and aerial reptiles
		Jurassic		181	Cycads, conifers, ginkgoes, dinosaurs dominant First birds, flying reptiles, marine reptiles
		Triassic		230	Dominance of mammal-like reptiles Dominance of ammonites
	Palaeozoic	Permian	Age of amphibians	250	Extinction of trilobites and many invertebrates Reptiles more abundant as amphibians decline
		Carboniferous		345	Coal swamp forests Amphibians on land First reptiles Algal sponge reefs Echinoderms and bryozoans dominant
		Devonian		405	Oldest land vertebrates Radiation of land plants and fishes Corals, brachiopods and echinoderms
		Silurian	Age of invertebrates	425	Oldest life on land: plants, scorpions First jawed fishes
		Ordovician		560	Diverse marine communities: brachiopods, bryozoans, corals, graptolites, nautiloids First jawless fishes
		Cambrian		600	Evolution of invertebrates with hard skeletons Dominance of trilobites
Proterozoic	Precambrian		Simple organisms Eukaryotes evolve, diversify in the sea	2500	Eukaryotes evolve
Archaen					
Hadean			Origin of primitive life	3800 4500	

- After a major extinction event, there is a flourish of new life forms.
- Early Earth provided conditions for inorganic molecules to form organic molecules.
- Complex organic compounds separated from their surroundings when membranes formed around them, leading to the first prokaryotic cells.
- Larger cells ingesting smaller cells, resulting in membrane-bound organelles, led to the first eukaryotic cells.
- The order of life on Earth appears to have been colonial organisms, multicellular organisms, autotrophs, fish, amphibians, reptiles and mammals.
- Some organisms appear to have changed very little when you look at their fossil record.
- Fossils have provided scientists with evidence of the diversity of living things on Earth.

CHECK YOUR UNDERSTANDING

9.1b

- 1 Outline the significant changes since the origin (beginning) of the evolution of life on Earth.
- 2 Outline the evidence to suggest that prokaryotic cells came before eukaryotic cells.
- 3 What was the impact of a lack of oxygen in the early atmosphere on the biodiversity of early life forms?
- 4 Suggest why some organisms appear to have changed very little over time.
- 5 Identify three major periods in the geological timescale and state the organisms that existed in and dominated each period.
- 6 Outline three extinction events and the subsequent rise of another dominant life form. Suggest reasons for each of these.
- 7 Discuss two examples where the environment may have influenced the evolution of plant species and their biodiversity.
- 8 What is the link between mutation, evolution and biodiversity?
- 9 Identify two species on Earth today that closely resemble their ancestors from millions of years ago. Explain why these may have retained their form with little change, over millions of years.

9.2

Microevolutionary changes and speciation

Evidence suggests that change in the environment is a driving force behind change in living organisms. The environment can be defined as the living (biotic) and non-living (abiotic) surroundings of organisms. The abiotic environment includes:

- physical conditions – factors such as temperature, availability of water, light, wind, slope and tides
- chemical conditions – factors such as the presence (or absence) of gases such as oxygen and carbon dioxide in the environment of living organisms, as well as pH and differing concentrations of chemicals such as salts and heavy metals in the surroundings.

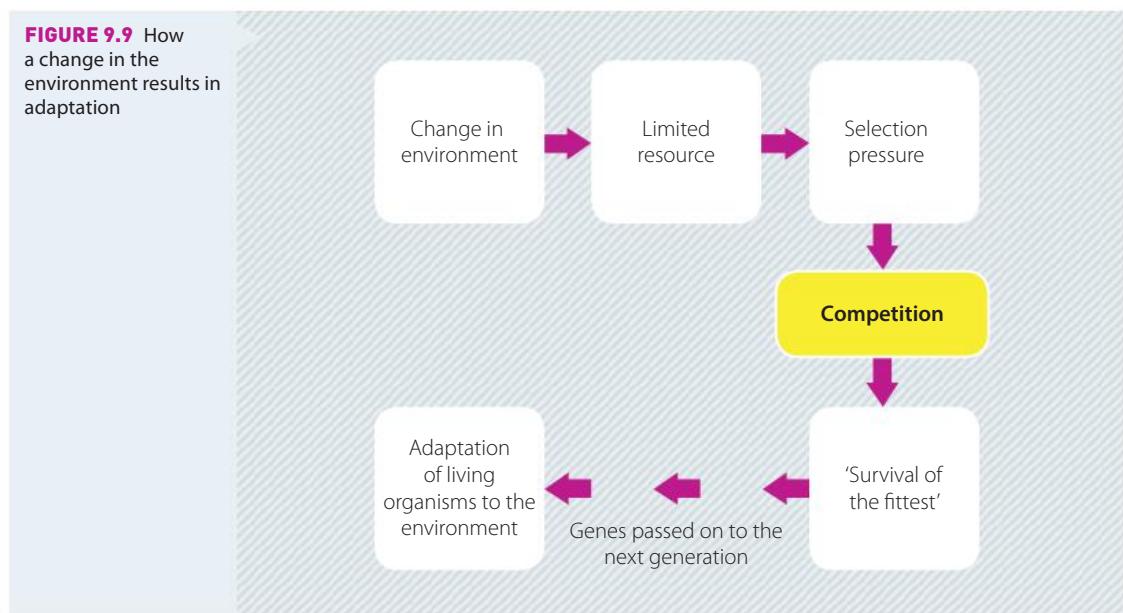
As a result of environmental change, resources may become limited and so living organisms will begin to compete for the available resources in order to survive. Competition will arise between organisms for resources such as light, soil nutrients and water in plants, or food, water, shelter, mates and breeding territory in animals. Change in the environment of a population influences evolution because it results in selection pressure acting on organisms.

You learnt about abiotic and biotic factors in Chapter 7.

Selection pressures include:

- environmental change
- competition
- predation
- disease.

Some organisms have variations in their features that make them better suited than others to the changed environment. If a population consists of a diverse range of individuals, then the population is better able to survive a sudden change in the environment. This diversity allows some organisms to compete more successfully for available resources, and survive to breed and therefore pass on their genes to the next generation. That is, those individuals that compete successfully in the new environment outlive those that do not have such variations; this is termed 'natural selection'. This population is said to be adapted to its environment (Fig. 9.9).



Microevolution and macroevolution

It is commonly accepted that physical and chemical changes in the environment may have been responsible for the evolution of organisms from ancient forms to the forms that we know today, but they may also have been responsible for the very origins of life itself.

Evolution can be considered over very long periods and over shorter periods.

- Macroevolution takes place over millions of years, measured as geological time, and results in new species (and even larger groups such as new families and orders) arising.
- Microevolution takes place over shorter periods and results in changes within populations, but it generally does not produce new species. New forms that arise within populations are sometimes referred to as varieties or races. An example is the different breeds of dogs, which all belong to the same species. (This form of evolution is most commonly seen in current short-term studies of living organisms.)

Small changes in characteristics within a population (microevolution) can lead to speciation. For example, small changes in a dog-sized ancestor led to the evolution of what is now recognised as a horse. The slow progressive accumulation of small changes over a long period led to the dramatic difference between the modern horse and its ancestor.

- Microevolutionary change involves small-scale changes within a population, which is a group of organisms that share the same gene pool and can interbreed.
- Macroevolutionary change refers to the evolution of groups larger than species. This is what we observe when looking at the history of life on Earth or the evolution of mammals.
- Mechanisms like mutations (changes in the genetic material that can give rise to heritable characteristics), migration and natural selection are responsible for major evolutionary change.

- 1 Using an example, distinguish between microevolution and macroevolution.
- 2 What is selection pressure and how does it affect evolution?
- 3 Outline the mechanisms responsible for major evolutionary change.
- 4 How can competition and changes to the environment affect evolutionary change?
- 5 Explain how variation in the gene pool is important for evolution.

Evolution of the horse

The horse is a good example of a study of evolution because it is one of the few organisms that has a complete fossil record. It is a mammal belonging to the family Euidae. Over the course of 50 million years, it has evolved from a small dog-sized, forest-dwelling animal called *Hyacotherium* to the horse of today. It shares a common ancestry with tapirs and rhinoceroses (Fig. 9.10).

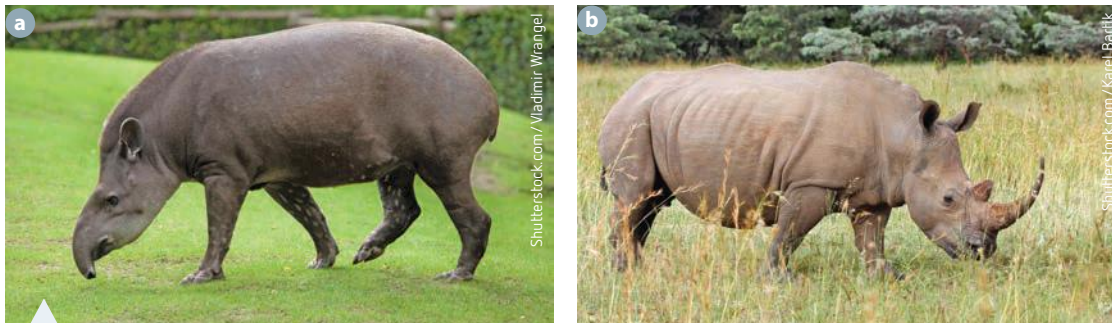


FIGURE 9.10 **a** The tapir and the **b** rhinoceros are distant relatives of the horse.

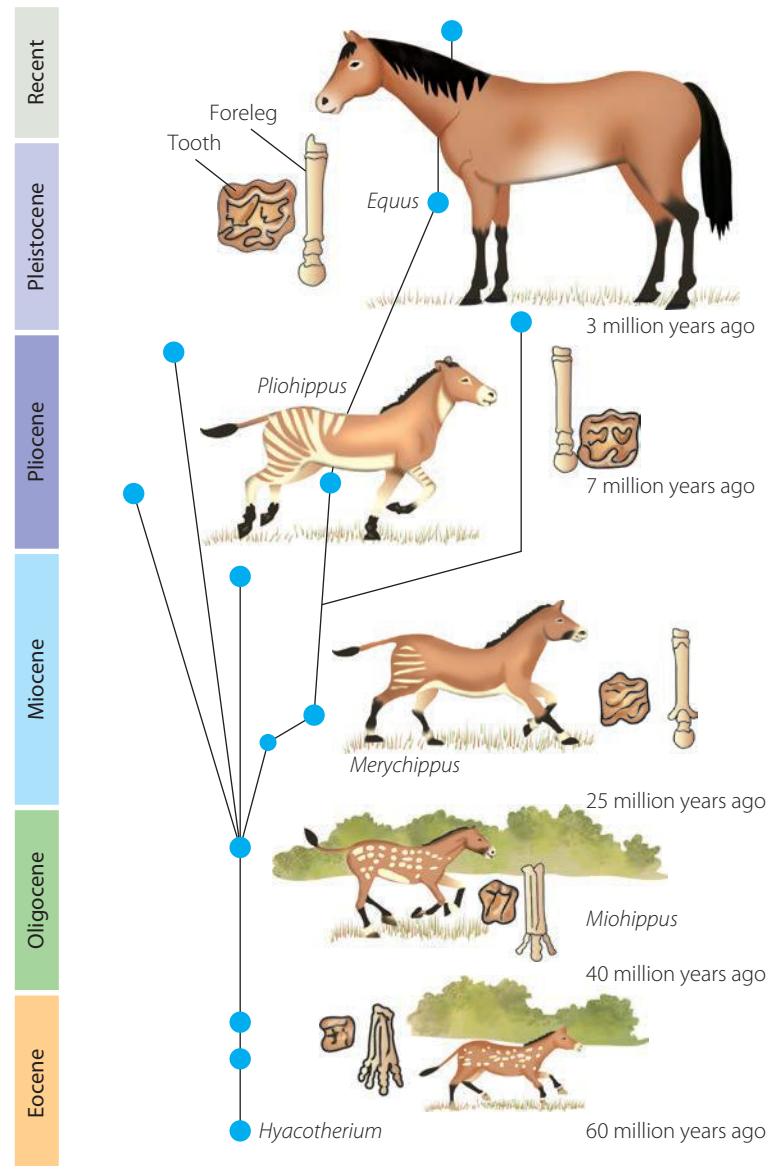
The evolution of the horse is significant because it shows that, rather than a linear evolution with one body type replacing another where transitional forms would exist, horse evolution has a branching nature, demonstrated in an extensive fossil record with many changes (Fig. 9.11). Early studies of fossils suggested a rather simplistic transition from one horse type to another, but later discoveries of fossils showed there were several different migrations, changes in trends from smaller to larger sizes, and sometimes trends that reflected reductions in size. In addition, the rate of evolutionary change (measured in new species per million years) did not appear to be constant.

The fossil record of the horse is very extensive and many trends that can be identified. It is important to note that, as more fossils have been discovered, scientists have been able to add to their understanding and make inferences about evolutionary relationships. Generally, the fossils have shown changes in body size, number of toes, and dentition, with the development of grinding surfaces.

Small horses of the Eocene epoch (55.8–33.9 mya)

The first horse (*Hyacotherium*; Fig. 9.12) bore more resemblance to a dog than a horse, being about 25–50 cm high. It had a long tail, short legs, snout and back, and ate a diet of fruit and soft plant materials.

FIGURE 9.11 An overview of the evolution of the horse, indicating the different branches that led to the modern horse. Changes in the body size, number of toes and type of dentition are evident.



It had a short face with eye sockets in the middle. It possessed a short diastema (space between the front teeth and cheek teeth), and the teeth were low crowned with ridges. As their environment changed, there was significant selection pressure to be larger in size, have fewer toes and have teeth with grinding surfaces.

When we observe horse evolution, it is evident that it was not a linear event and many groups actually coexisted. The first significant change was in dentition with an increase in grinding surfaces, suggesting a diet that included tougher plant material.

Medium-sized horses of the late Eocene and Oligocene (34 mya)

During this period the climate got drier, forests started shrinking and grasses became more prevalent. Therefore there was selection pressure to eat tougher plant materials, to increase in size and to move faster through the grasslands. Horses in this group include *Miohippus* and *Mesohippus*. About 24 mya the *Mesohippus* group began to radiate and evolved a side branch. 'Radiate' refers to the group diversifying rapidly from an ancestral species, so that populations were able to live in a variety of available niches.

Dawn horse (*Hyracotherium*)

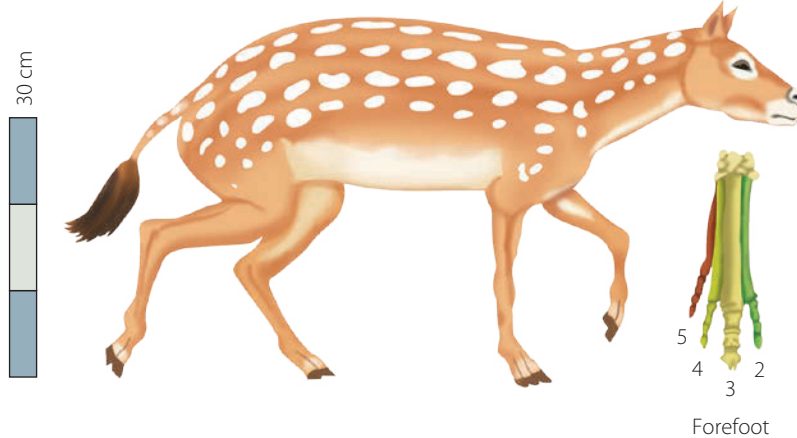


FIGURE 9.12 The first horse (*Hyracotherium*) had a long tail, short legs, snout and back. Note the four toes.

Horses of the Miocene move out onto the plains (from 23 to 5 mya)

About 18mya there was a gradual increase in the height of teeth crowns and horses became better at running, with an increase in both body size and length. Bones in the legs were fused so that the horses could stand on the tips of their toes (an adaptation for running). These horses had three toes with the side toes shorter than the middle (Fig. 9.13). The faces had a longer muzzle with eyes on either side.

Merychippus

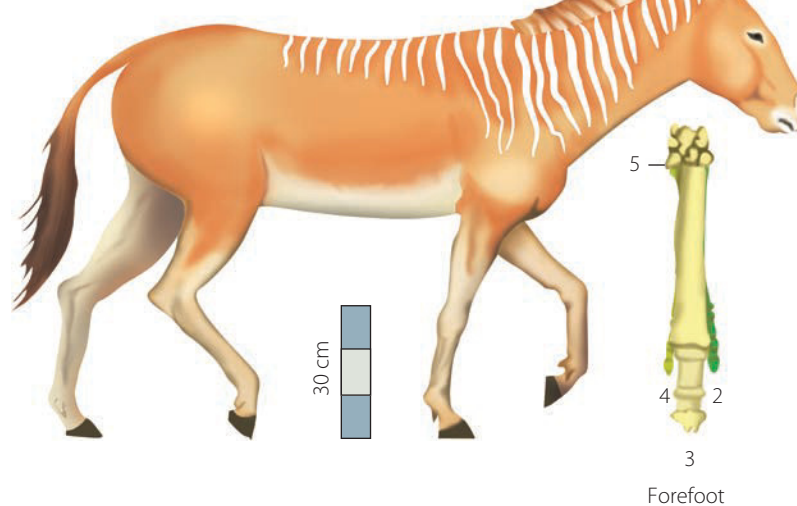


FIGURE 9.13 *Merychippus*. Note the reduction of the number of toes to three.

Horses of the late Miocene, Pliocene and Pleistocene (5 mya)

The 'grandfather' to modern horses – *Pliohippus* – was part of the merychippine line. This group led to the 'true equines', two groups of horses that independently lost their side toes. As side ligaments developed around the fetlock, their central toe was stabilised for running (Fig. 9.14).

Horses in this group include *Pliohippus*, *Astrohippus*, *Dinohippus* and *Equus* (Fig. 9.15). About 2.6 mya some species crossed from the new world (the Americas) to the old world (Africa, Asia and the middle East) and later into Europe, facilitated by land bridges. *Dinohippus* is believed to be the closest relative to *Equus* and includes horses, asses and zebras. *Equus* is the only surviving genus in the horse family and

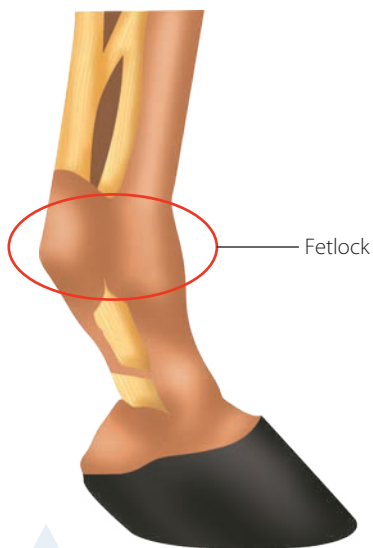


FIGURE 9.14 The fetlock is a strengthening ligament and essential to the reduction in the number of toes from a three-toed horse to a single-toed horse.

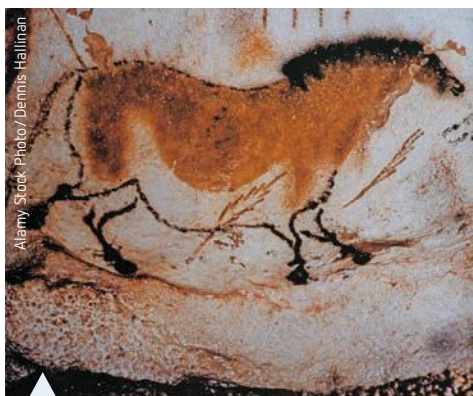


FIGURE 9.15 Cave painting showing a record of human interactions with the horse. This artwork supports the fossil record – note the number of toes in the painting.

has existed for the last 5 million years. Fossils of *Equus* have been found on all the continents except Australia and Antarctica. The modern horse, *Equus ferus caballus*, was domesticated by humans about 3000 years ago.

Explanation in terms of microevolution

Modern theories explain horse evolution in terms of microevolutionary changes in genes, which may have driven speciation over time.

Microevolution can explain why so many different variations of horses existed. Genetic variation caused by mutations, natural selection, genetic drift (variation in the frequency of different genotypes in a small population) and speciation (the formation of a new and distinct species) are all processes that could have contributed to the evolution of the horse.

Microevolution can occur when there are a series of mutations (changes to the genetic make-up of organisms). These result in a change in the frequency of a gene in a population. This change in the gene pool is a result of chance, which is referred to as genetic drift. If the population then becomes isolated, speciation may result, due to natural selection.

Different selection pressures in the respective environments will select for specific favourable genes. If a smaller population with a mutated gene becomes separated from the main population, the frequency of the specific gene will increase as these isolated organisms interbreed, passing on a specific characteristic (for example, a reduction in the number of toes) to their offspring. If this change is favourable (for example, it increases the speed at which the animal runs), it is selected for because these favoured animals have an increased chance of survival in the population and therefore continue to breed, passing on the gene. The isolated population evolves to become significantly different from the original population and eventually, if they were brought together again, would no longer be able to interbreed, resulting in the formation of a new species.

KEY CONCEPTS

- The evolution of the horse is an example of microevolution.
- The evolution of the horse is significant because it shows a branching nature.
- An extensive fossil record provides evidence.

CHECK YOUR UNDERSTANDING

9.2b

- 1 Outline two significant changes that have occurred in horse evolution.
- 2 How is a reduction in the number of toes an advantage to animals like the horse?
- 3 The horse fossil record provides a unique insight into the past. Why is a complete fossil record invaluable in the study of evolution?
- 4 Why is the development of a fetlock important?
- 5 How have mutations and genetic drift contributed to the evolution of the horse?
- 6 Outline the process of genetic drift.

Evolution of the platypus

Have you ever wondered how Australia came to be one of the few continents that have an abundance of mammals like **marsupials** (pouched mammals) and **monotremes** (egg-laying mammals), yet so few **placental** mammals? Marsupials, such as kangaroos and koalas, are the main form of mammal found in Australia. They give birth to live young that are at a very early stage of development; the young then continue their development and are nourished in pouches. Monotremes include the echidna and platypus, animals whose young develop and are nourished as eggs. The platypus is a monotreme native to the eastern rivers of Australia. Placental mammals, of which only a few occur naturally in Australia, nourish their developing young inside the mother's body via a placenta.

Unlike the record for the horse, the fossil record of the platypus is very poor. Monotremes were present in the Mesozoic era, when Australia was part of the supercontinent Gondwana. The evidence suggests that they originated in the Australian/Antarctic section of Gondwana.

The platypus shows features in its anatomy similar to birds (a bill and webbed feet, similar to a duck), reptiles (venom glands, egg-laying) and mammals (hair on the body, suckle their young). This confused natural scientists who voyaged to Australia. The first platypus sample they sent back to the British Museum in 1798 was considered to be a hoax! Scientists there looked for stitching, thinking the voyagers had tried to trick them by sewing the bill of a duck onto a mammal's body. As more specimens of this 'amphibious mole' began arriving in Britain, they were the cause of much puzzled speculation – an 'enigma' to the scientists of the time. Close and detailed examination showed that this was indeed a real animal and in 1799 it was named by Dr George Shaw as *Platypus anatinus*.

The original name was derived from Greek (*platypous*, flat-footed) and Latin (*anatinus*, duck-like). The name was later changed to *Ornithorhynchus anatinus*, after the discovery that the name platypus had already been given to a beetle (*ornitho* bird-like, *rhynchus* snout, in Greek). The classification of the platypus continued to confound and interest biologists across the world for nearly 90 years.

So how did the platypus and mammals in general evolve? An ancient group of reptiles called cynodonts are believed to be the earliest ancestor of mammals. Genetic evidence suggests that monotremes split off first (around 150 mya) and have been evolving ever since. This split was followed by marsupials (130 mya) and the placental line of mammals branching off (110 mya).

(There is a second, less-favoured hypothesis that the monotremes and marsupials split from each other after their common ancestor had diverged from the line that led to the placental mammals. This view is supported by some fossil evidence, but not by calculations based on genetic evidence.)

Biologists use branching diagrams called **cladograms** to depict the evolutionary relatedness of organisms. Each point where the lines branch indicates a split from a common ancestor. Looking at the cladogram in Figure 9.16, can you work out which animals are closely related and which are the most distantly related?

Studies of both fossil evidence and the **genome** of the platypus have led scientists to discover that the platypus is not directly related to birds. It is a descendant of a reptile lineage from many millions of years ago (Fig. 9.16). This lineage gave rise to marsupials, birds, reptiles (including lizards, snakes and dinosaurs) and placental mammals. The platypus split from our placental lineage about 166 mya. As mentioned above, cynodonts are believed to be the earliest ancestor of mammals. Evidence suggests that **therian** mammals gave rise to marsupials and the placentals, which branched off around 148 mya. Recent DNA analysis of modern echidnas and platypus, as well as fossil evidence, suggests that the platypus and echidna share a common ancestor. Technology such as molecular dating, as well as a multigene evaluation using a molecular clock and direct fossil calibrations, have been used to identify that the platypus and echidna split from a common ancestor about 19–48 mya.

The question that scientists debate is: did the platypus arise as a result of the cumulative effect of microevolutionary changes? Although there are different schools of thought on this, studies of the genome of the platypus reveal information about which genes were conserved and which were lost from the time that reptiles and the mammal lineages split. This helps us to understand which genes were present at that time and which genes changed and led to mammals evolving their particular characteristics.

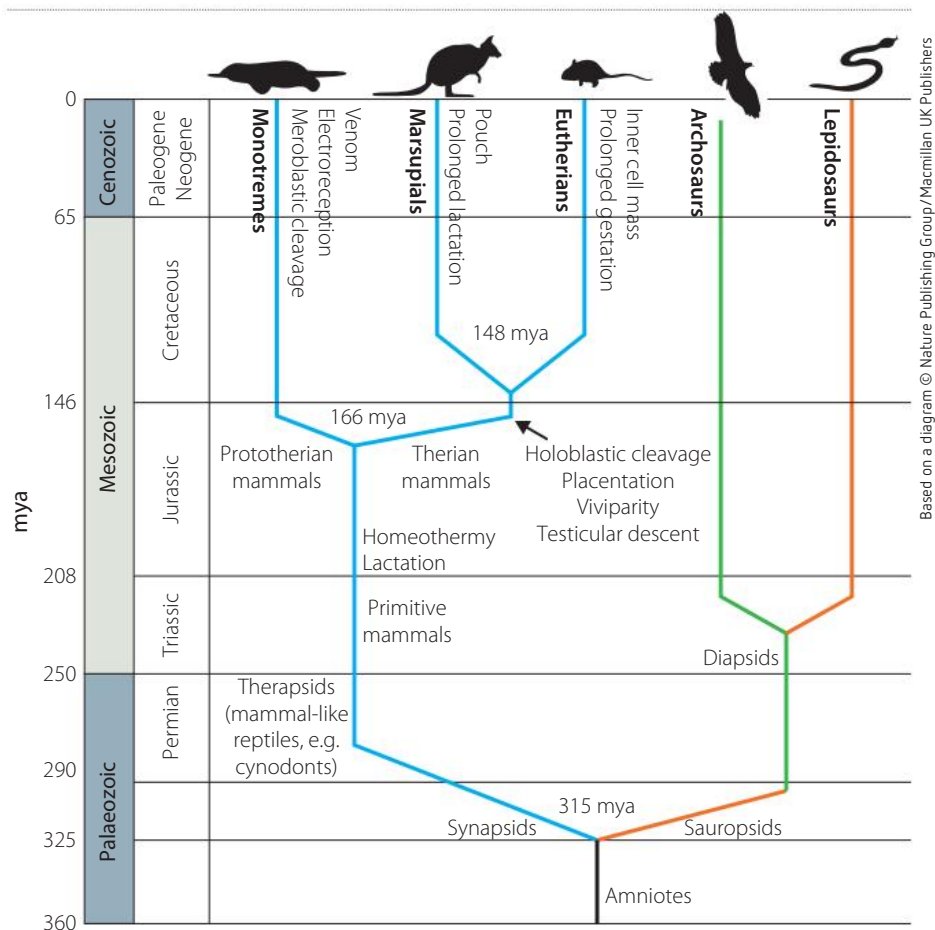


FIGURE 9.16 A cladogram showing emergence of mammals from reptile lineage

Comparing the genomes of the platypus, marsupial and placental mammals shows that about 82 per cent of genes are common to both. The platypus lays eggs with yolk, whereas humans do not produce eggs with yolk. Scientists have discovered a gene in the platypus, absent from humans, for the production of a yolk protein. However, all three groups have two genes related to tooth production which, together with the presence of a third gene for the production of a milk protein, seem to be necessary for lactation (milk production). This tells us that the ability to produce milk as seen in mammals arose before the Jurassic period (Fig. 9.16).

The existence of venom is typical of reptiles such as snakes. The platypus is also able to produce venom in a claw on each of its back limbs. However, this does not mean that the common ancestor for these groups also had venom. Studies of the genomes of the platypus and reptiles show that these probably arose independently, because they are the result of different mutations (duplications) of the same gene. These mutations would have arisen separately in the two lineages.

Recent discoveries of platypus-like fossils have led to a whole new area of research among platypus species. In the past, the modern platypus was thought of as a 'primitive' species that had survived, but current research and discoveries have led to the suggestion that it is a highly evolved form of an ancestor.

Platypus fossils found in Australia include a complete skull of *Obdurodon dicksoni* (Miocene epoch; Fig. 9.17) and parts of a jaw of *Steropodon galmani* (110 mya in the Cretaceous). Only one fossil has been found outside Australia – a fossilised tooth found in Argentina, dating back to 63–61 mya. This shows that monotremes had once lived somewhere other than in Australia. A fossilised tooth found separately in Australia, dating back to a primitive placental mammal 55 mya, showed that placental mammals had once lived here. What led to monotremes surviving in Australia and not South America, but placental



FIGURE 9.17

Riversleigh platypus, *Obdurodon dicksoni*. Fossilised pieces of skull and other skeleton parts were found at Murgon in south-eastern Queensland.

mammals dying out in Australia? Natural selection is believed to have played a role. As Australia drifted northwards and the continent became drier and hotter, the lower resting metabolic rate of marsupials and monotremes meant they could survive using less energy than similar-sized placental mammals, and so they grew in numbers. There is fossil evidence of only three types of carnivorous mammals – the marsupial lion, the thylacine (Tasmanian tiger) and one carnivorous kangaroo – and this relative lack of predators gave them a greater chance of survival in Australia than in South America, where there were up to 60 different carnivore predator species.

Fossil evidence shows that the modern platypus is more specialised than its ancestors; for example, they no longer have teeth, but instead have horny pads. They also have a highly evolved sensory system associated with their bill – an electroreception system for detecting prey in murky water. In addition, the current platypus is distributed in a more limited area than was seen in the past, now restricted to river systems on the east coast of Australia.

Four extinct species related to the platypus have been found in Australia. Some *Obdurodon* fossils found at Riversleigh suggest that this platypus had teeth and ate small frogs (Fig. 9.18). In addition, its bill was considerably bigger than that of its modern counterparts.

Jaw fragments of *Steropodon galmani* found in New South Wales suggest that it is one of the oldest Australian mammals. Comparisons between these fossils and the modern and only living species of platypus suggest that the modern platypus is much more specialised.

The evolution of the platypus is considered typical of macroevolution, having taken place over a very long period and resulting in the evolution of new species. This once again raises the question: is macroevolution the result of an accumulation of microevolutionary changes over a long period?



FIGURE 9.18 *Obdurodon dicksoni* was much larger than the extant species and had teeth, another feature common to other monotreme fossils of the time. Extant monotremes do not have teeth.

INVESTIGATION 9.1

A secondary source investigation into how microevolutionary changes can drive evolutionary change

By researching information regarding the fossil evidence provided by the horse and platypus, you will realise that evolution is not a linear and planned process, but rather the result of many processes working together with many modifications and changes.

There are many more divisions on the timescale the further forward in time you look.

AIMS

- To gather, process and analyse information about the evolution of the horse and platypus
- To understand how different microevolutionary changes have resulted in the species that exist today



METHOD

Use the information provided in this book as well as in the weblinks, library reference books, newspaper articles and experts.

- 1 Gather information to outline some of the changes in the environment leading to significant microevolutionary changes that have occurred in both animals.
To ensure that your information is accurate, relevant and reliable use the CRAAP method outlined in Chapter 1.
- 2 Gather information about the different morphological (physical) changes that have occurred to both the platypus and the horse (for example, number of toes in the horse, bill in the platypus).
- 3 Draw a results table to summarise your findings, including the name of the organism, when it existed as well as information about the environment that it lived in. Include information about its size, number of toes, teeth, and anything else you can find.

RESULTS

Copy and complete Table 9.2.

TABLE 9.2

NAME OF ORGANISM	WHEN DID IT EXIST?	SIZE	NUMBER OF TOES (HORSE)	DENTITION	ENVIRONMENT

DISCUSSION

- 1 Outline some of the major changes that have occurred to the horse over time.
- 2 Identify three of the most significant changes in the horse and platypus over time.
- 3 Identify how these changes in species can be linked directly by scientists to changes in the environment.
- 4 Explain how microevolutionary changes such as these drive evolution.
- 5 When gathering your information for this task, how did you ensure your information was accurate, valid and reliable?
- 6 Why is it more difficult to study the evolution of the platypus than the evolution of the horse?

KEY CONCEPTS

- The evolution of the platypus is an example of macroevolution.
- The evolution of the platypus is significant because it shows that the modern platypus is more specialised than its early ancestors.
- The fossil record that provides evidence for platypus evolution is limited.

CHECK YOUR UNDERSTANDING

9.2c

- 1 Outline two theories about the evolution of the platypus.
- 2 Which of the two theories is better supported by evidence?
- 3 How has modern technology changed our understanding of monotreme evolution?
- 4 Suggest what types of selection pressures could have been responsible for the macroevolutionary changes in the platypus.
- 5 Draw a table to compare the key concepts in platypus and horse evolution.

9.3

Using Darwin and Wallace's ideas: convergent evolution and divergent evolution

Both Darwin and Wallace studied large numbers of living organisms and observed that similarities in structure were common. These similarities could be accounted for in one of two ways:

- 1 In closely related species, the basic similarities between organisms could be a result of their relatively recent divergence from a common ancestor. Natural selection could account for their differences – as they moved into different habitats, they would have been exposed to new selective pressures, which would result in their evolution by natural selection to become different. This is termed **divergent evolution**.
- 2 If more distantly related species (which diverged from a common ancestor further back in time) show similarities, this could be a result of having moved into similar environments – they would have been exposed to similar selective pressures and so natural selection could account for them evolving to become similar. This is termed **convergent evolution** (Fig. 9.19).

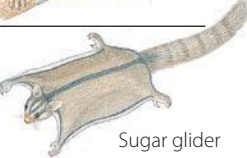
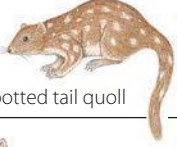
Placental mammals		Australian marsupials
 Mole	Burrower	 Marsupial mole
 Lesser anteater	Anteater	 Numbat (banded anteater)
 Mouse	Mouse	 Dunnart
 Lemur	Climber	 Spotted cuscus
 Flying squirrel	Glider	 Sugar glider
 Ocelot	Cat	 Spotted tail quoll
 Wolf	Wolf	 Tasmanian tiger

FIGURE 9.19

Convergent evolution: placental mammals in North America and Europe show similarities to marsupials in Australia.

The Darwin–Wallace Theory of Evolution by Natural Selection and isolation therefore can account for both divergent and convergent evolution: the organisms in a changed or new environment are under pressure to survive. The environment selects certain variants within a population that have a trait that gives them a better chance of survival. When resources in the environment become limited, those individuals with favourable traits survive, reproduce and pass on their characteristics. The favourable traits that increase the organisms' chances of survival are termed 'adaptations'. Natural selection can result in different organisms that are subjected to similar selective pressures becoming more similar (convergent evolution), or similar organisms becoming different (divergent evolution).

Divergent evolution

Darwin recognised that several different lineages could arise from one common ancestor. The finches mentioned on page 243 are an example of diverging from a common body plan. Different selection pressure therefore favoured some forms over others. The rise of the variety of horse species is also typical of divergent evolution.

Convergent evolution

Darwin studied particular marsupials in Australia and found similarities between them and certain placental counterparts in Europe. Although these pairs of animals were extremely distantly related (as is evident by the vast difference in their types of reproduction), they showed some remarkable similarities that could be accounted for only by the fact that any pair lived in similar environments. This led him to the idea of organisms evolving to become similar (convergent evolution) because, if different organisms live in similar habitats, similar variations would be favoured by natural selection to enable them to survive and breed in those conditions.

Many other examples show similarities in distantly related organisms that occupy similar niches (for example, the fin and flipper structures in sharks (fish), dolphins, whales and seals (mammals) and penguins (birds)). The evolution of venom in reptiles such as snakes and the platypus is thought to be due to convergent evolution – each evolved independently of the other. This is evident when the gene for venom production was analysed in both groups. Although both groups of organism have a mutation to the same gene (the β -defensin gene), the actual mutation in the platypus genome is different from the one seen in reptiles.

A modern example of convergent or divergent evolution

A modern example of microevolution has been studied in underground railway stations in London and parts of Russia. The underground mosquito was first found in the London Underground, with research showing it had evolved from the overground species *Culex pipiens*. Underground mosquitos are found in 10 Russian cities and scientists conducted research to determine whether this was convergent or divergent evolution.

INVESTIGATION 9.2

Underground mosquitoes

Research to find out how scientists came to the conclusion that the evolution of the underground mosquito was divergent evolution, not convergent evolution. How were their findings used to support this hypothesis?

Accounting for differences in closely related species

Adaptive radiation is a term used to describe the evolutionary variation in species that evolved from a common ancestor. Because of the migration of organisms into new environments ('**radiation**', which relates to spreading out), organisms begin to occupy new niches (the term 'adaptive' suggests a change that favours their survival in a new niche in the environment).

KEY CONCEPTS

- In closely related species, the basic similarities between organisms could be as a result of their relatively recent divergence from a common ancestor – divergent evolution.
- More distantly related species which have moved into similar environments and been exposed to similar selective pressures evolve to become similar – convergent evolution.

- 1 Using examples, distinguish between convergent evolution and divergent evolution.
- 2 Explain how gradual evolution can occur.
- 3 How is isolation responsible for speciation?
- 4 Use an example to explain how convergent evolution can occur.
- 5 Explain why bilbies and jackrabbits have a similar body plan even though they do not share common ancestry.

CHECK YOUR UNDERSTANDING

9.3

9.4

Punctuated equilibrium versus gradualism

Punctuated equilibrium and gradualism are two types of evolution that can occur in a species. A species can exhibit one or both of these evolutionary patterns. Some scientists are speculating that the type of evolution is determined by time. Species that have evolved over a longer time exhibit gradualism. Both models are valid in explaining macroevolution.

Gradualism

Gradualism as proposed by Darwin suggests that populations slowly diverge by accumulating changes in characteristics due to different selection pressures. This pattern of evolutionary change suggests that transitional forms should exist. Trilobites are a group of marine invertebrates that show evidence of gradualism in their fossil record.

Punctuated equilibrium

The theory of **punctuated equilibrium** proposes that evolution occurs in short bursts of rapid change, followed by long periods of stability within populations. It has become popular over the last 50 years and, like all science, requires that old knowledge be re-examined in the light of new evidence.

The theory of punctuated equilibrium was put forward in the 1970s by Stephen Jay Gould and Niles Eldridge, based on fossil evidence. It suggests that if evolutionary change is gradual, it could be predicted that there would be fossilised remains showing these ongoing changes. Darwinists use transitional forms to support their perspective of 'gradualism' (a gradual change over an extremely long period).

Gould and Eldridge also use fossil evidence to support their theory. Many fossilised remains show millions of years going by without any noticeable evolutionary change to most species. For example,

soft-bodied organisms dominated the seas for hundreds of millions of years and then, in a period of a few million years, they disappeared and were replaced by organisms with shells and skeletons. Horseshoe crabs have remained almost unchanged for 445 million years.

Supporters of punctuated evolution argue that if evolution occurs gradually, as proposed by Darwinists, there should be a much greater diversity among living organisms than actually exists. Because the fossil record is incomplete, it is difficult to come to an agreement on the rate of evolutionary change. However, the theory of punctuated equilibrium does not call into question the basis of the Darwin–Wallace theory of evolution – that it occurs by natural selection. The question asked is whether it occurs in short bursts of rapid change, or gradually over a long period.

More recently, it has been suggested that both models are valid and can occur in the same species. Both can be used to describe the rate of speciation (the formation of a new and distinct species).

The process of punctuated equilibrium

Punctuated evolution works like this:

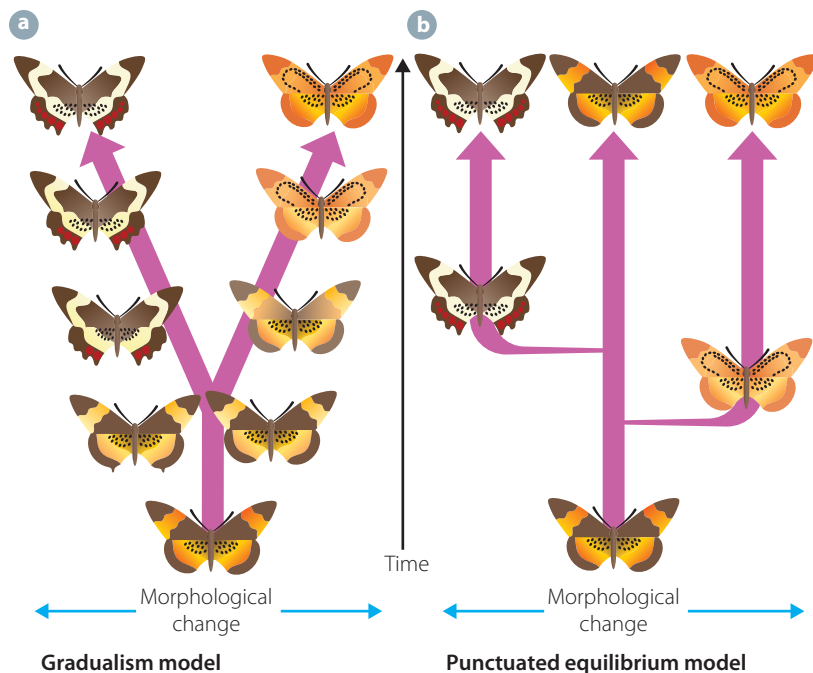
- A population is living in stasis – there is no change in its environment and little change is observed in the fossil record.
- Part of the population is isolated by a change in the environment (for example, tectonic activity or sea level change).
- The small, isolated population experiences strong selection pressure from the sudden change in conditions.
- Due to the small size of the population, there are no fossils representing any transitional forms.
- If environmental conditions change and populations reunite, there may be competition between the populations.
- A larger population and a stable environment make evolutionary changes less likely.

As seen in Figure 9.20, the butterfly demonstrates long periods of no change and then sudden changes appear. The horseshoe crab (Fig. 9.21) demonstrates punctuated equilibrium in its fossil record.

FIGURE 9.20

a In gradualism, the butterfly evolves from a common ancestor. There is selection pressure for the colour of wings. They gradually evolve. Small variations in individuals enable them to survive and pass on these differences to their offspring. Over a long time, the population changes due to these selection pressures.

b In punctuated equilibrium, there are long periods without change; helpful mutations that occur in individuals are passed on. The proportion of the population that has the mutation changes. The species thus changes rapidly over a short period.



Based on a diagram © Pearson Education, Inc., publishing as Benjamin Cummings



FIGURE 9.21 Horseshoe crabs appear to have changed very little in the past 445 million years. In fact, it is their environment that has remained constant. **a** A fossil of a horseshoe crab; **b** a modern horseshoe crab

Comparing gradualism and punctuated equilibrium

Table 9.3 shows the differences between gradualism and punctuated equilibrium.

TABLE 9.3 Comparing gradualism and punctuated equilibrium

GRADUALISM	PUNCTUATED EQUILIBRIUM
Natural selection changes the features of a species by removing less fit organisms from the gene pool	Very little change for long periods, interspersed with periods of sudden rapid changes
Happens over a long period	Happened rapidly in geological time – but little change occurs in the time between speciation events
A single species may evolve separately as a result of isolation.	Speciation is not linear but branched with more than one result
Evolutionary change occurs all the time and does not always result in a change of species	Large widespread species change slowly
Incomplete fossil record is a result of breaks in the formation of fossils. Missing links could be found if the stratigraphic rock sequences were more complete or conditions for fossilisation were better.	The fossil record is incomplete because the speciation event occurred too quickly for fossil formation
Evolutionary change is described as slow, constant and consistent	Evolutionary change is described as fast; a new species can appear suddenly with long periods of no change

KEY CONCEPTS

- Gradualism suggests that populations slowly diverge by accumulating changes in characteristics due to different selection pressures.
- Punctuated equilibrium suggests that evolution occurs in short bursts of rapid change, followed by long periods of stability within populations.

- 1 Distinguish between gradualism and punctuated equilibrium.
- 2 Outline the evidence used to support punctuated equilibrium.
- 3 Using your understanding of evolution, explain how tigers got their stripes, using both gradualism and punctuated equilibrium.
- 4 Why is it possible that organisms can undergo both types of evolution?
- 5 What role does mutation play in the process of evolution?

CHECK YOUR UNDERSTANDING

9.4

The theory of evolution by natural selection: What is the relationship between evolution and biodiversity?

Variation occurs as a result of genetic mutations in the inheritable sex cells

Biodiversity is the variety of all forms of life on Earth, the diversity of the characteristics that living organisms have and the variety of ecosystems of which they are components.

Genetic diversity is the total amount of genetic characteristics in a species.

Species diversity is the total number of species in a community.

Ecosystem diversity is the variation of different ecosystems in an area.

Biodiversity is reflected in

The *fossil record* reflecting specific trends:

- 1 Simple cells to complex cells (prokaryotes to eukaryotes)
- 2 Single-celled to multicellular organisms

Variability is the raw material for natural selection. Selection pressures can either be biotic (living) or abiotic (non-living).

Variability – all populations have random variation

- variation may be inherited
- organisms produce more offspring than the environment can support (that is, not all offspring survive)

Natural selection depends on

Competition between organisms and survival of the fittest

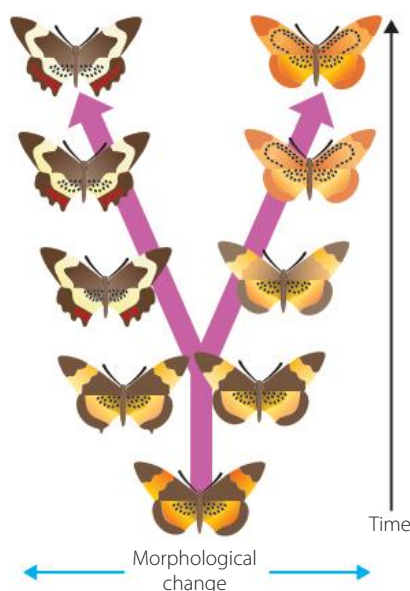


Imagefolk/R Koenig

Evolution can occur along a number of pathways

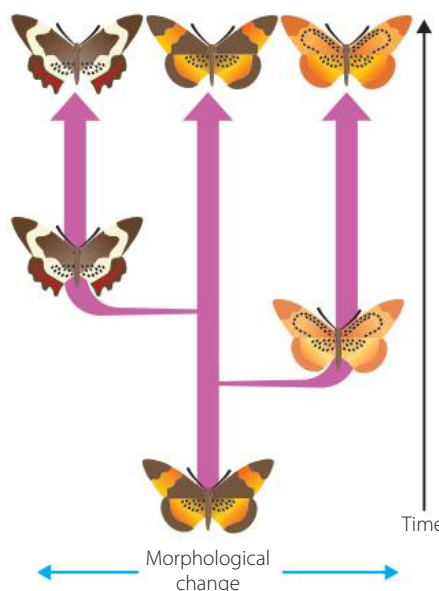
Gradualism happens over a long period gradually

Gradualism model



Punctuated equilibrium means long periods of no change followed by sudden changes

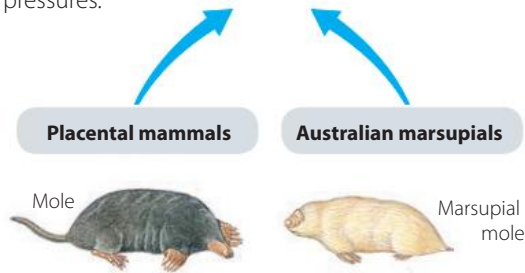
Punctuated equilibrium model



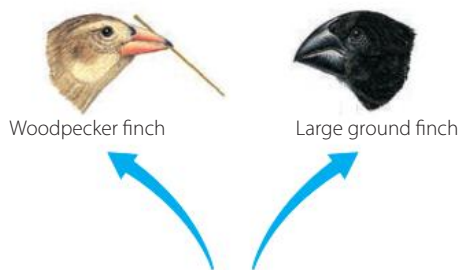
Macroevolution is a major evolutionary change that happens over a long period. The evolution of the platypus is evidence of this type of evolution.



Convergent evolution is where unrelated organisms look similar because of similar selection pressures.



Divergent evolution is where related organisms look different because of different selection pressures.



Isolation leads to:

Speciation – the formation of a new species

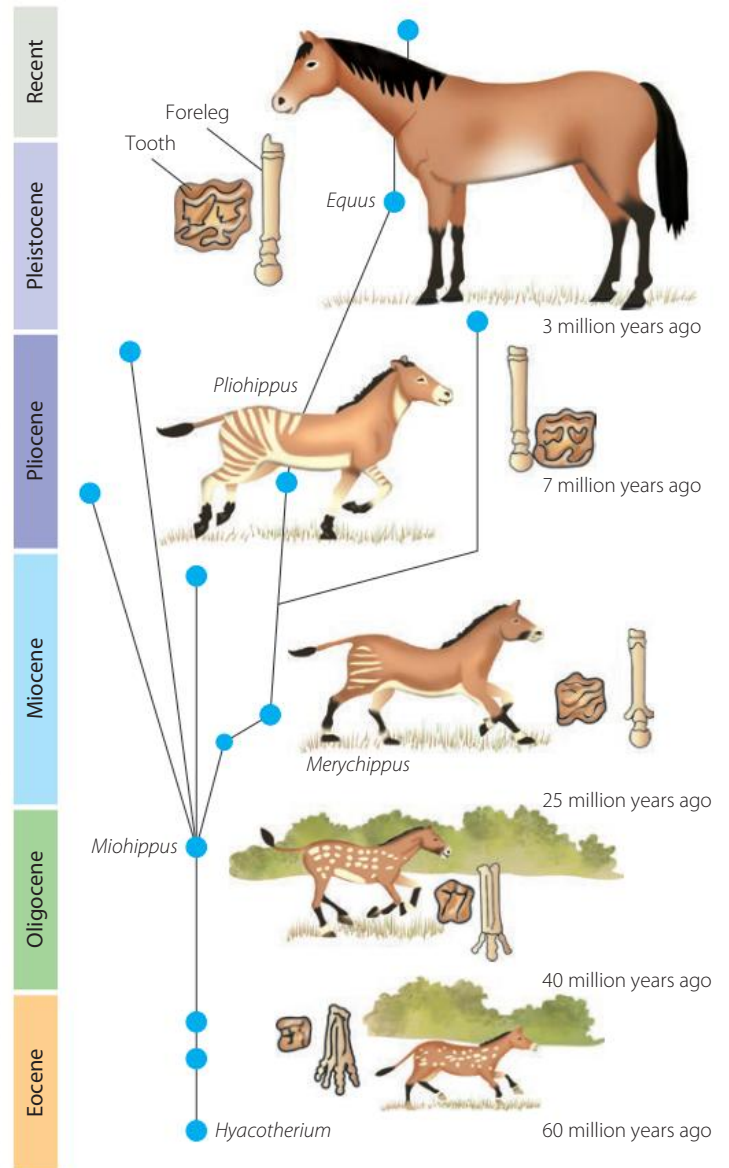
Allopatric speciation

Species that are geographically separated and therefore cannot interbreed for a long time.

Sympatric speciation

Closely related species whose distribution overlaps but that do not interbreed.

Microevolution is a change within a species over a short period – the evolution of the horse is evidence for this type of evolution.



- 1 Distinguish between selection pressure and competition.
- 2 How can variation in a population assist evolution? Using examples, compare divergent and convergent evolution.
- 3 Humans use artificial selection to select specific characteristics in a species. Explain how this could be a problem in the long-term evolution of the species.
- 4 Outline how a sudden environmental change could affect the evolution of a species.
- 5 Explain how the concept of punctuated equilibrium differs from the concept of gradualism proposed by Darwin.
- 6 How would Darwin explain the following concepts in terms of natural selection: divergent evolution and convergent evolution?
- 7 Evaluate the impact of evolutionary processes on the biodiversity of living things.
- 8 Discuss the need to maintain biodiversity in light of your understanding of evolution.
- 9 Use a diagram to distinguish between macroevolution and microevolution.
- 10 Use an example to explain how isolation leads to speciation.
- 11 How would a region with constant environmental conditions affect evolution?
- 12 How can an accumulation of microevolutionary changes drive changes and speciation over time?
- 13 *Hyracotherium* lived in a dense forest dominated by a thick undergrowth of small shrubs and ferns. Why would a small body be an advantage in this environment?
- 14 Using your understanding of evolution, explain why there is only one species of platypus.
- 15 The platypus is distributed in rivers along the east coast of Australia. They are separated into pockets of river tributaries. How could this isolation have affected their evolution?
- 16 Why is it difficult to gather information about the evolution of the platypus?
- 17 The stages labelled a–d below outline how variation leads to evolution according to the theory of natural selection. Arrange them in the correct sequence of events.
 - a Evolutionary change
 - b Radiation
 - c Natural selection
 - d Mutations
- 18 The ancestors of antelopes had short legs and present-day antelopes have longer leg bones. Longer legs enable animals to run faster. Using your understanding of evolution by natural selection, suggest how modern antelopes evolved long legs.
- 19 Explain how a genetic mutation can cause variation in a population.
- 20 Explain why it is important for individuals in a population to vary.
- 21 The platypus is sometimes incorrectly described as a ‘living fossil’, implying that it has changed very little in its evolution. Using your understanding of evolution, suggest why this term is incorrect.
- 22 ‘The geographical distribution of a species plays a significant role in its evolution.’ Discuss this statement in light of your understanding of natural selection and speciation.
- 23 Explain why Australia has a variety of different marsupials that do not exist anywhere else in the world.
- 24 The thylacine (Tasmanian tiger) looks a lot like a European wolf. Use the Theory of Evolution by Natural Selection to explain this similarity.
- 25 The Australian dingo is classified into its own unique species. Use your understanding of evolution to explain why it is not classified as a dog.

10

Evidence to support the Theory of Evolution by Natural Selection

INQUIRY QUESTION

What is the evidence that supports the Theory of Evolution by Natural Selection?

Students:

- investigate, using secondary sources, evidence in support of Darwin and Wallace's Theory of Evolution by Natural Selection, including but not limited to: [ICT L](#)
 - biochemical evidence, comparative anatomy, comparative embryology and biogeography (ACSBL089) [ICT L](#)
 - techniques used to date fossils and the evidence produced [ICT L](#)
- explain modern-day examples that demonstrate evolutionary change, for example: [ICT L](#)
 - the cane toad
 - antibiotic resistant strains of bacteria

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For more information on the Theory of Evolution by Natural Selection, see chapters 8 and 9.

Getty Images/Hulton Archive/Stringer



FIGURE 10.1 Burlington House, Piccadilly, home to the Linnean Society, founded in 1788 and named after the Swedish naturalist Carl Linnaeus.

During the mid-19th century, Charles Darwin and Alfred Russel Wallace proposed the Theory of Evolution by Natural Selection to try to explain how living organisms have come to be the way they are. They proposed that species change over time in response to selection pressures in their environment. The concept of evolution had been alluded to over more than two thousand years, but in the early 1800s biologists took the idea one step further, proposing possible mechanisms to try to explain how this change may come about. This theory was jointly presented to the Linnean Society (Fig. 10.1) by Darwin and Wallace on 1 July 1858. Some of the evidence that was used

by Darwin and Wallace to support their theory will be investigated in this chapter, as well as new evidence that has since been gathered.

10.1

Evidence in support of the Theory of Evolution by Natural Selection

See p. 2 for more information on validating theories in biology.

A **theory** is a scientist's explanation of a natural phenomenon that must be strongly supported by many different lines of **evidence**. Established scientific theories, such as the Theory of Evolution by Natural Selection, have withstood rigorous scrutiny over the years. This theory's strength is its ability to explain modern evidence, evidence that Darwin and Wallace could not have even dreamed of.

Biochemical evidence

Darwin and Wallace argued that all living things shared a common ancestor. It was not until recently that biochemical evidence has shown that all living things share the same macromolecules such as proteins and DNA, and biochemical processes such as cellular respiration.

Biochemistry is the study of chemicals found in cells, and is an integral part of molecular biology and genetics. Recent and detailed evidence involves comparing the sequence of the basic units that make up these chemicals in species that may share evolutionary relationships.

Scientists predicted that when the biochemistry of organisms was compared, it would show that the more closely related the organisms are, the more similar their proteins or DNA will be. To test this prediction, advanced technology was needed to sequence these macromolecules. This led to the development of new technologies that allow scientists to objectively measure similarities and differences between components of macromolecules (such as proteins or DNA) in living organisms to determine their evolutionary relatedness. The quantitative results obtained make it possible to reconstruct the evolutionary history of organisms, both living and extinct.

Amino acid sequencing

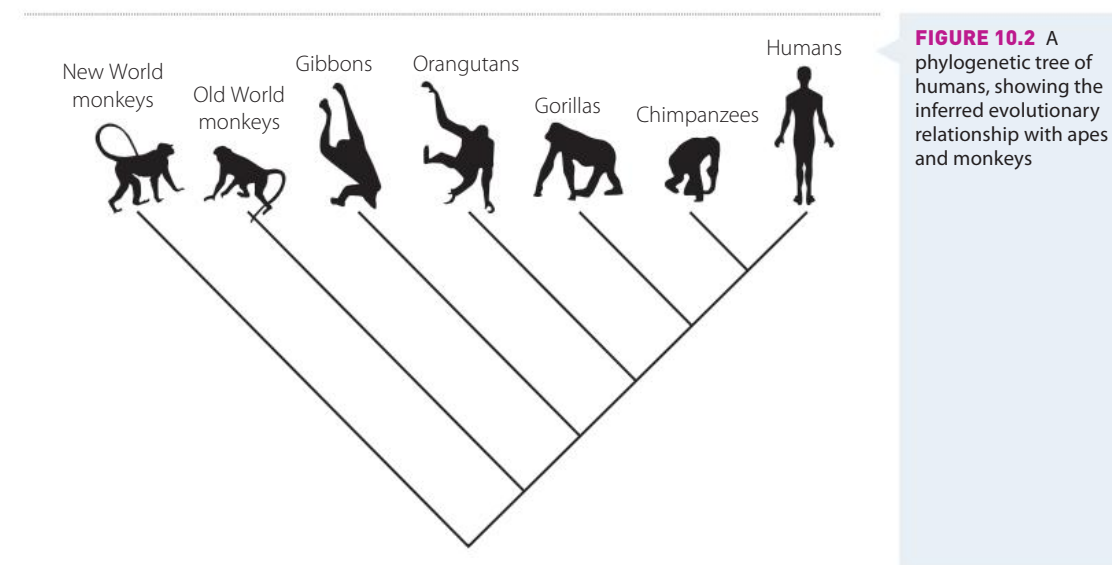
Proteins are found in every living cell as part of the cell membrane and as enzymes in the cytoplasm. Proteins are made up of sub-units called amino acids. Living things contain a combination of about 20 different genetically determined amino acids. It is the number, type and sequence of these amino acids that determine the type of protein. A protein that is found in a wide range of organisms is usually studied

to examine amino acid sequences and evolutionary relatedness. Examples are cytochrome c, a protein in plants and animals that is involved in cellular respiration, and haemoglobin, a blood protein found in animals only.

The sequence of amino acids in the protein is analysed, and similarities and differences between organisms are identified. Similarities imply that the organisms may have shared a common ancestor. The basic chemistry inherited from a common life form has not changed. Differences imply that the organisms have evolved (changed over time).

The number of differences is proportional to the length of time since the organisms separated. This information is used to construct evolutionary trees. Also known as **phylogenetic trees**, these are branching diagrams showing inferred evolutionary relationships.

For example, humans and chimpanzees have an identical sequence of amino acids in their haemoglobin and so they are more closely related than humans and gibbons, which have three differences (Fig. 10.2).



INVESTIGATION 10.1

Comparing proteins of different organisms

Table 10.1 presents the sequence of amino acids in cytochrome c, a protein essential for cellular respiration. Cytochrome c is shown for eight different species, from a human to a yeast. Analyse sequences of amino acids in Table 10.1 to infer answers to the following questions.

- 1 Which species is the most closely related to humans? Explain your reasoning.
- 2 Which species is the least closely related to humans? Explain your reasoning.
- 3 Which amino acid position(s) is probably crucial, and which is probably the least crucial to ensure full protein function? Explain your reasoning.
- 4 Do you think this evidence supports other knowledge you have of relationships between these species? Explain your reasoning.



TABLE 10.1 Molecular homology of cytochrome c

Amino acid position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Human	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile	Met	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Chimpanzee	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile	Met	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Pig	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val	Gln	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Glu	Lys
Chicken	Gly	Asp	Ile	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val	Gln	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Dogfish	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val	Gln	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Glu	Asn
<i>Drosophila</i>	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Leu		Val	Gln	Arg		Ala	Gln	Cys	His	Thr	Val	Glu	Ala
Wheat	Gly	Asn	Pro	Asp	Ala	Gly	Ala	Lys	Ile	Phe	Lys	Thr	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Asp	Ala
Yeast	Gly	Ser	Ala	Lys	Lys	Gly	Ala	Thr	Leu	Phe	Lys	Thr	Arg	Cys	Glu	Leu	Cys	His	Thr	Val	Glu	Lys

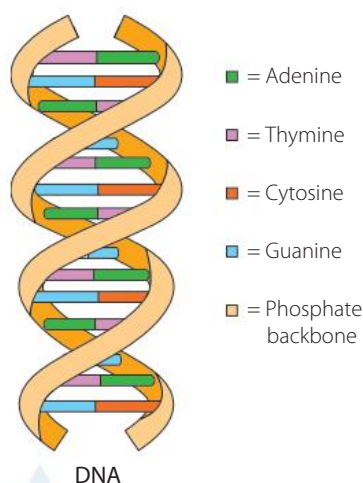


FIGURE 10.3 DNA is a double-stranded molecule made up of four different nucleotide bases attached to a phosphate backbone.

DNA–DNA hybridisation

DNA is the genetic material found in our cells. It has been inherited from our parents. DNA is made up of sub-units called nucleotide bases (Fig. 10.3). The nucleotide bases that make up DNA are adenine (A), guanine (G), cytosine (C) and thymine (T). It is the number, type and order of these bases that determines our genes. DNA is a double-stranded molecule in which adenine and thymine always pair, and cytosine and guanine always pair. This is called the **complementary base pairing**.

DNA–DNA hybridisation is based on the assumption that DNA molecules of closely related species have a similar nucleotide base order. DNA–DNA hybridisation involves splitting the double-stranded DNA molecule lengthwise to expose the nucleotide bases on each individual strand (Fig. 10.4). This is done by applying heat (usually 90–94°C) to cause the **complementary strands** to separate (dissociation). Separated segments of DNA from the two species that are going to be compared are mixed. The two strands from the different species combine (reassociation) and form a ‘hybrid’

(mixed) DNA molecule. The more closely matched the base pairs are, the stronger the binding of the strands. Pairing of DNA chains from different organisms is referred to as DNA–DNA hybridisation.

Heat is once again applied, this time to determine how strongly the bases have combined; higher temperatures are required to separate hybrid strands that are more strongly combined. Closely related species have a very similar order of nucleotide bases and so their DNA strands combine more strongly than species that are distantly related. For example, the DNA of a human and that of a mushroom would be weakly combined, and the DNA would be separated at lower temperatures than the DNA of a human and a chimpanzee.

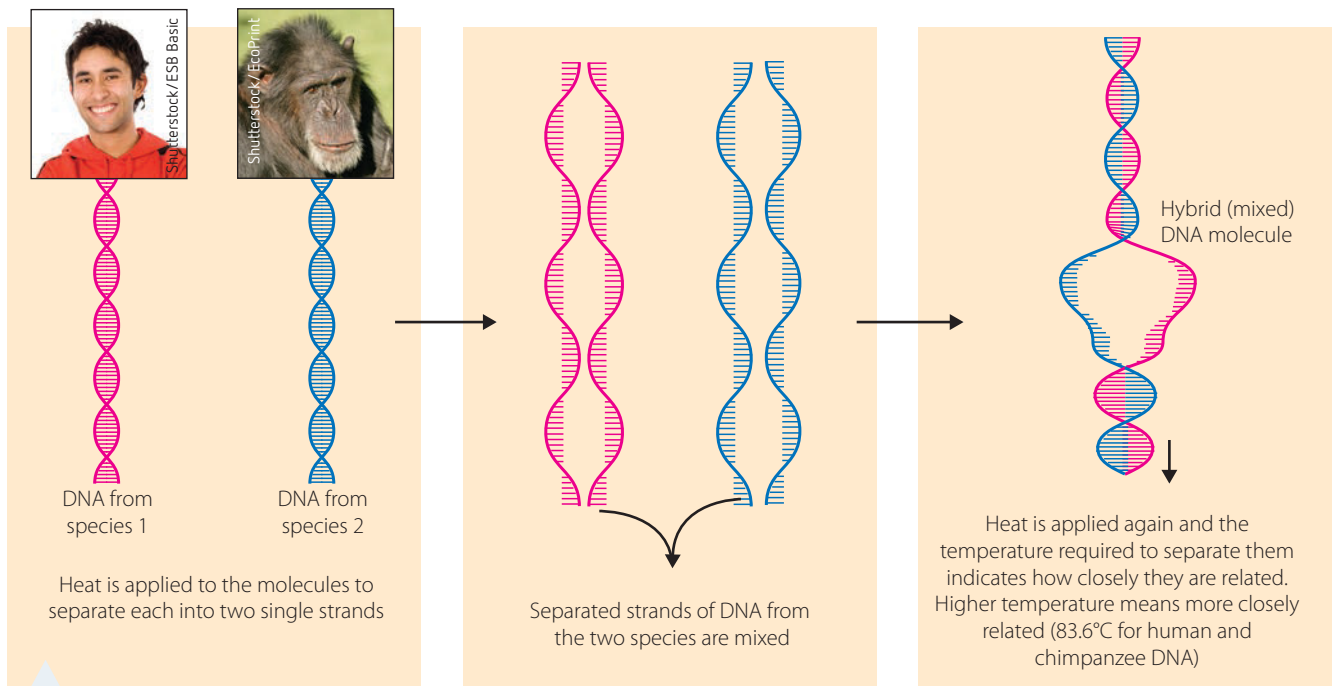


FIGURE 10.4 The process of DNA–DNA hybridisation

DNA sequencing

In DNA sequencing, the exact order (sequence) of nucleotide bases in the DNA of one species is compared with the sequence in a similar DNA fragment of a second species. The more closely related the species, the closer the order of nucleotide bases in the DNA.

In this procedure:

- A piece of DNA (a gene) is isolated from each organism to be compared.
- Multiple copies of each gene are made, using fluorescent dyes to distinguish between the four bases in DNA.
- Computer-linked equipment called a DNA sequencer is used to graph and print out the entire sequences of bases, which are then compared.

Biochemical evidence suggests that organisms that share a common ancestor have fewer differences in the DNA base sequences. DNA sequencing is a more advanced technique that reveals more detailed information than the other biochemical techniques (Fig. 10.5). The limitations of biochemical evidence include that some changes in DNA or amino acid sequences may not be identified if a particular change that occurred in the past has reverted to its original form in a more recent organism. The techniques are complex and expensive, and rely on highly specialised computer technology. They can therefore be performed only in high-technology laboratories.

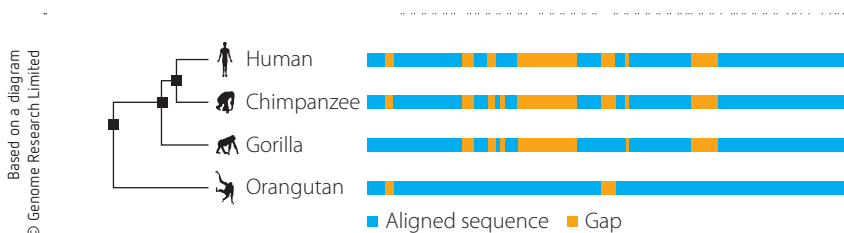


FIGURE 10.5 DNA sequencing of four species. Human and chimpanzee show remarkable similarities in their DNA sequences and less similarity with orangutan.

- Darwin and Wallace used evidence to separately construct the Theory of Evolution by Natural Selection.
- Modern biochemical evidence that can be explained by the Theory of Evolution by Natural Selection includes amino acid sequencing, DNA–DNA hybridisation and DNA sequencing.

CHECK YOUR
UNDERSTANDING

10.1a

- 1 Giving an example, explain how biochemical evidence can be used as evidence for evolution.
- 2 How has our understanding of evolution changed because of biochemical evidence?
- 3 Outline some advantages and limitations of using biochemical evidence as evidence for evolution.
- 4 Use a diagram to outline how the process of DNA–DNA hybridisation works.
- 5 How has our understanding of evolutionary relationships changed because of a technology?

Table 10.2 shows the differences between amino acid sequences in cytochrome c protein for six species.

TABLE 10.2

	HORSE	DONKEY	WHALE	CHICKEN	PENGUIN	SNAKE
Horse	0	1	5	11	13	21
Donkey		0	4	10	12	20
Whale			0	9	10	18
Chicken				0	3	18
Penguin					0	17
Snake						0

- 6 Using the data in Table 10.2, how many differences are there between a chicken and a penguin? between a whale and a penguin?
- 7 Which two organisms in Table 10.2 are more closely related in terms of evolution and common ancestry?

Comparative anatomy

Comparative anatomy is the study of similarities and differences in the structure (anatomy) of living organisms. More similarities in the structure of organisms implies that they must have separated from a common ancestor more recently. For example, since humans and chimpanzees have more structural similarities than humans and cats do, it could be inferred that humans and chimpanzees separated from a common ancestor more recently than humans and cats did. This was one of the first forms of evidence that led to the idea that all living things arose from one common ancestor.

Homologous structures – evidence of divergent evolution

In organisms that are being compared, similarities in structure suggest descent from a common ancestor, whereas differences in structure represent modifications – how organisms have evolved to become different. This is typical of divergent evolution and the similarities are best explained by common descent – that is, sharing a common ancestor.

Organs that have the same basic plan to their structure, but show modifications because they are used in different ways, are termed **homologous** – they have the same evolutionary origins. For example, the **pentadactyl** (five-digit) limbs (Fig. 10.6) of all vertebrates have the same basic bone plan. Therefore, the wing of a bird, the forearm of a lizard and the flipper of a whale are homologous, because all share a common basic bone structure, suggesting that they share a common evolutionary origin.

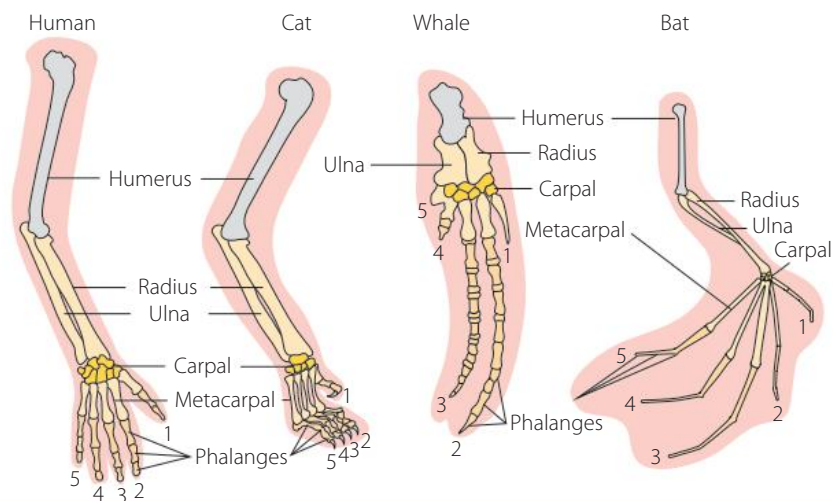


FIGURE 10.6 The pentadactyl (five-digit) limbs of all vertebrates have the same basic bone plan.

Comparative anatomists study such homologies and compare many body parts of organisms to work out the degree of similarity, which helps them to determine the degree of evolutionary relatedness (or **phylogeny**) of the organisms.

INVESTIGATION 10.2

A secondary-source investigation into homologous structures

One of the pieces of evidence that Darwin used to support the Theory of Evolution by Natural Selection is that many animals share similarities in body structure. He argued that this suggested that these animals had evolved from a common ancestral form.

AIM

Write an aim for this investigation.

MATERIALS

Four examples of vertebrate pentadactyl limbs (actual skeletons, models, photographs or illustrations of the limbs, for example, frog, bird, dolphin, dog or cat).

METHOD

Carefully observe each of the samples that has been provided. Collate your observations in a results table.

- 1 Examine the forelimbs and hindlimbs of each specimen carefully and draw a quick sketch in your results table. Record the number of bones that make up each individual digit on the forelimbs and the hindlimb. Include the hand/foot area, wrist/ankle area, forearm/shin area, and the upper arm/thigh area.
- 2 Compare each of your samples to the generalised pentadactyl limb shown in Figure 10.7. Describe any differences that you can see.



Critical and creative thinking



Information and communication technology capability



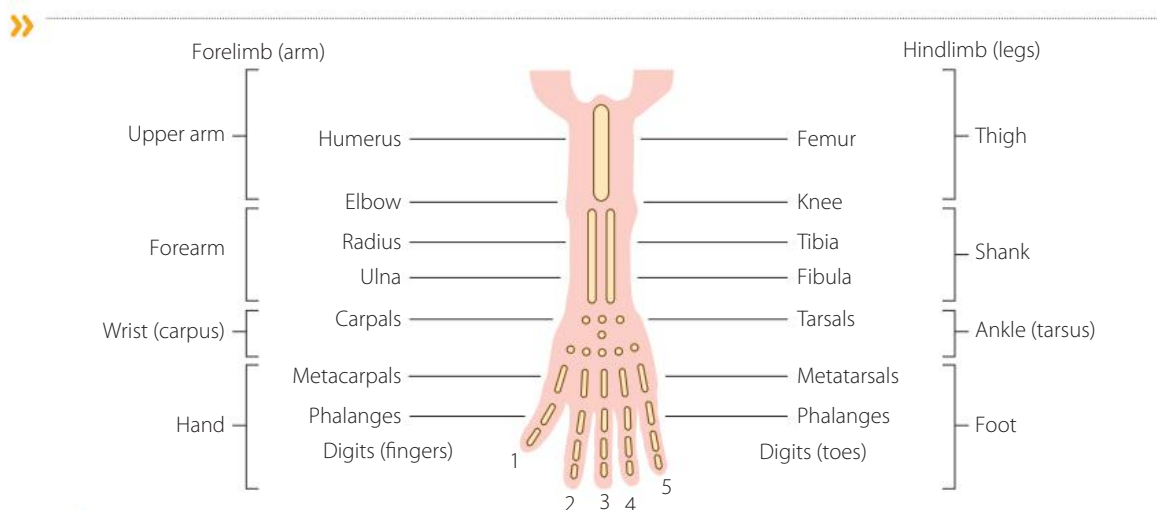


FIGURE 10.7 A generalised pentadactyl limb

RESULTS

Create a results table that includes:

- the name of the organism
- a sketch of the forelimb
- a sketch of the hindlimb
- a summary count of bones
- descriptions of the differences.

DISCUSSION

- 1 Analyse how the number of bones in each area of your specimens compares to those in the generalised pentadactyl limb.
- 2 Identify any other differences apart from bone numbers in your samples.
- 3 Explain reasons for the differences noted for each particular animal.
- 4 Predict what advantage these differences might offer to the species concerned.
- 5 Identify the basic similarities in the different limbs and explain how these can be found in so many different species that may occupy a variety of different habitats.
- 6 Use the Internet to examine the limb structure of other animals to see how they compare to the ones you have examined in this activity. Does it make a difference how closely animals are related to each other in terms of their similarities?
- 7 For two animals studied in this investigation, compare the similarity in limb structure with biochemical evidence and assess whether the evidence of their relatedness is consistent.

CONCLUSION

Write a conclusion that summarises what you have learned.



Comparative anatomy –
vertebrate forelimbs

Analogous structures as evidence of convergent evolution

An interesting pattern of evolution found in studies of comparative anatomy at first led to some confusion. Some body parts of organisms appear to be similar at first, but in-depth studies of their anatomy show that they are really vastly different in their basic structure – for example, the wings of a bird (containing muscles and bones) and the wings of a grasshopper (made of a thin membrane of exoskeleton). Since these organs differ greatly in their basic plan, they are said to be **analogous** – they are thought to have started off

being very different and then to have evolved independently to become similar, because they were selected to be used for a similar purpose, such as flight. This is convergent evolution, where changes in structure are adaptations that favour the survival of these unrelated organisms because they face similar selection pressures. For example, vertebrates, insects and octopuses all have large, well-developed eyes and good vision, but they lack a common ancestor. The evolution of the eyes in each is thought to have occurred independently, making their eyes analogous structures arising as a result of convergent evolution.

The Australian echidna and the European hedgehog (Fig. 10.8) have both developed protective spines to discourage predation but, in terms of most other structures and their reproduction, they are dissimilar.

The presence of analogous features does not provide evidence for evolutionary relatedness, but rather for evolution of structures to serve a common purpose in a common environment. The organisms are distantly related and do not share a common recent ancestor.

Vestigial structures

Vestigial structures are thought to be evolutionary remnants of body parts that no longer serve a useful function within that population. The presence of vestigial structures provides evidence of common ancestry. For example, the presence of a reduced tail (coccyx) in humans (Fig. 10.9), and the pelvic bones in snakes and whales, are difficult to explain unless they are structures that have become reduced because they no longer carry out a useful function in that animal's lifestyle.



FIGURE 10.8 **a** The Australian echidna and **b** the European hedgehog both have spines to deter predators.

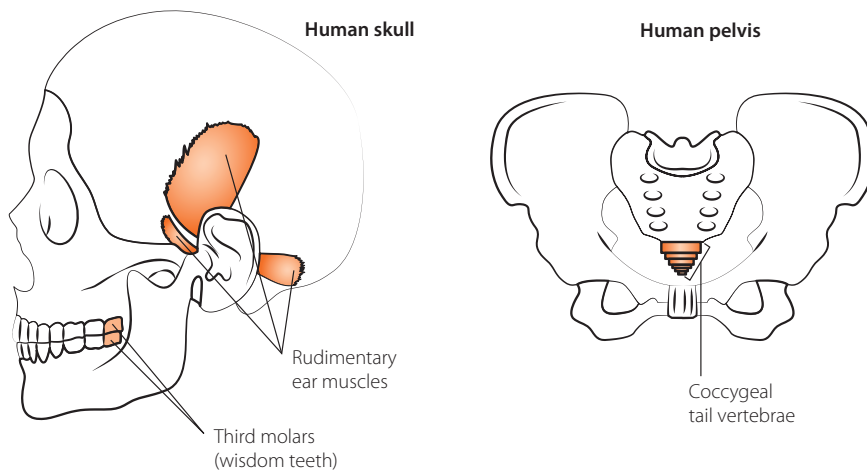


FIGURE 10.9 Vestigial structures in humans are structures that appear to have no function, but are left over from an ancestral form in which they did serve a purpose.

When looking at evidence from comparative anatomy, be aware that the **fossil record** is often incomplete and there is a bias in the animals represented. It can be difficult (and sometimes impossible) to compare the anatomy of numerous structures in living organisms with those of extinct forms. You also need to be aware that some superficial structural similarities may be analogous (or result from convergent evolution) and could cause confusion when looking for common ancestry.

The conclusion that can be drawn is that the greater the number of similarities in structure of organisms being compared, the more closely related the organisms appear to be. Numerous features need to be taken into account to arrive at this conclusion. Comparative anatomy is therefore used

to reinforce inferences about common descent derived from the fossil record and therefore shares similar limitations.

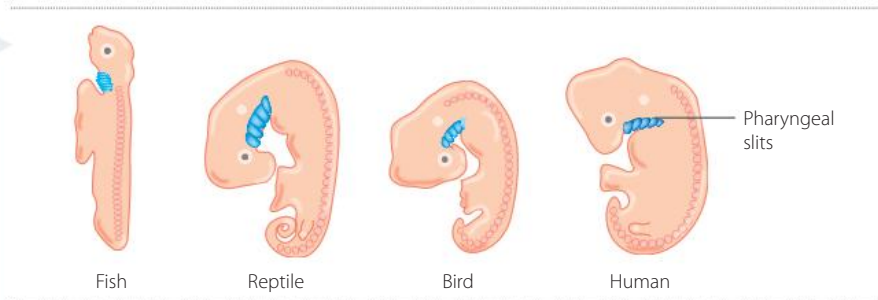
Comparative embryology

Comparative embryology is the comparison of the developmental stages of different species. Similarities can be used to infer relationships between organisms.

The prediction is that related species show similarities in their embryonic development. And indeed studies of vertebrate embryos show similarities in their early developmental stages. For example, fish, amphibians, birds and mammals all show the presence of gill slits (correctly called **pharyngeal slits**), tails and distinct muscle blocks during embryonic development (Fig. 10.10). This is best explained by common ancestry where they are all descendants from a common form. The presence of pharyngeal slits suggests that the common ancestor lived in an aquatic environment. These slits develop into internal gills in fish, external gills in amphibians and **Eustachian tubes** in mammals, the tube that connects the middle ear with the throat.

Comparative embryology and anatomy as evidence for evolution

FIGURE 10.10 The development of fish, reptile, bird and human embryos at 6 weeks, showing pharyngeal slits which go on to develop into different structures in the mature embryo.



The original drawings of embryo development were done by Ernst Haeckel in 1868 as convincing proof of evolution. His drawings are now considered to be inaccurate; they were not an accurate representation of the embryos but were interpretive. This emphasises how important it is to create biologically accurate diagrams. Today technology can be used to track the migration of cells in embryos and this type of evidence is far more accurate than relying on diagrams.

KEY CONCEPTS

- Comparative anatomy is the study of similarities and differences in the structure of living organisms. The more similarities in the structure, then the closer their evolutionary relationship.
- Homologous structures, analogous structures, vestigial structures and comparative embryology are examples of comparative anatomy.

CHECK YOUR UNDERSTANDING

10.1b

- 1 Define the terms 'comparative anatomy' and 'phylogeny'.
- 2 What predictions are possible with the evidence provided by comparative anatomy?
- 3 What are some of the limitations of comparative anatomy?
- 4 How are embryos used to support our understanding of evolution?
- 5 Distinguish between analogous and homologous structures.
- 6 How are analogous structures used to support our understanding of evolution?
- 7 Outline how the pentadactyl limb is used as evidence for evolution.
- 8 Compare the forearm of a cat with that of a bat.
- 9 Justify the use of vertebrate forelimbs as evidence for evolution.

Biogeography

Biogeography is the study of the geographical distribution of organisms, both living and extinct. The Darwin–Wallace theory of evolution proposes that, for a new species to arise, a group of individuals must become isolated (geographically separated) from the rest. (A new species is one where the individuals cannot produce fertile offspring if they mate with individuals of a pre-existing species.) Predictions based on biogeography provide evidence to support this feature of the theory of evolution.

If isolation is a criterion necessary for new species to arise from an original species, the new species should resemble species with which they shared a habitat; for example, they will be more similar to:

- species that lived close by than to species found far away (even if that species is in an area with similar environmental conditions), or
- species that lived in a common area before it split up (for example, organisms that originate from Gondwana).

During his travels, Darwin studied and compared numerous animals (including his now-famous finches) on islands such as the Galapagos. He was the first to point out that, although animals and plants that live on islands are often somewhat different from those on the mainland, they still have a closer resemblance to their counterparts on the nearest mainland than to plants or animals on lands further away. Darwin asked how one could make sense of this if they were all ‘equally and independently created’.

Alfred Wallace noted that the north-western Indonesian islands, including Bali, had bird species most similar to those of the closer Asian mainland, whereas islands in the south-east, including Lombok, had birds that were most similar to those in nearby Australia. It is easy to understand how the closeness of Bali and Lombok led to his conclusion that the island forms may have evolved from mainland forms, which became isolated. In 1859 he proposed a line, called Wallace’s line, to separate the two areas (Fig. 10.11).

A typical example where biogeographical evidence supports macroevolution is that of the flightless birds (ratites) and continental drift. The present-day distribution of flightless birds suggests that these birds originated from a common ancestor on Gondwana and that the different populations evolved on the isolated southern continents as they drifted apart. The result is the distribution of emus in



FIGURE 10.11 Wallace’s line through South-east Asia

Australia, ostriches in South Africa, kiwis in New Zealand and rheas in South America, all of which share similarities suggesting a common ancestor. Further evidence is that there are no similar flightless birds on the northern continents (which were part of Laurasia and became isolated from Gondwana before the flightless birds arose).

The flightless birds are not the only example – Australia's unique mammals and flowering plants are believed to have arisen because of the isolation of the continent. Australian organisms show similarities to fossils found on other southern continents, evidence that they may have had a common origin and later evolved.

This provides further support for the concept of adaptive radiation or the diversification (a variety of different forms) in organisms that evolved from an ancestral species because of migrations into new environments. Adaptive radiation involves the migration of organisms into new environments because they have traits that allow them to exploit resources in the new environment and survive in new niches.

See Chapter 11 for more information on niches.

KEY
CONCEPTS

- Biogeography is the study of the geographical distribution of organisms.
- For a new species to arise, a group of individuals must become isolated from the rest.

CHECK YOUR
UNDERSTANDING

10.1c

- 1 Define the terms 'biogeography' and 'adaptive radiation'.
- 2 How is biogeography used as evidence to support evolution?
- 3 Outline a limitation of biogeographical evidence.
- 4 Describe the macroevolution of flightless birds.
- 5 Define the term 'adaptive radiation'.
- 6 How does adaptive radiation lead to speciation?
- 7 How are the finches on the Galapagos Islands an example of adaptive radiation?
- 8 Why do inhabitants of islands resemble individuals on the nearest mainland?
- 9 The southern beech tree is present on all southern hemisphere continents except Antarctica. Using your understanding of adaptive radiation, suggest why this biogeographic distribution is possible.
- 10 Native mammals exist in Australia, but there are no native mammals other than bats in New Zealand. Suggest a reason for this distribution.

Fossil evidence

Palaeontology is the study of fossils. Fossils provide direct evidence of the existence of an organism in the past. Fossils may be mineralised remains in rock or the actual remains of the organism preserved in rock, ice, amber, tar, peat or volcanic ash.

Even before Darwin's proposal, scholars recognised that the idea of change in organisms over time was supported by evidence in undisturbed rock formations: the sequence in which fossils are laid down in rock reflects the order in which they were formed, with the oldest fossils in the bottom-most layers of the rock and the more modern fossils in the rock layers closer to the top. This is called the law of superposition. Based on this law, predictions could be made and tested to attempt to validate the Theory of Evolution by Natural Selection.

Relative dating

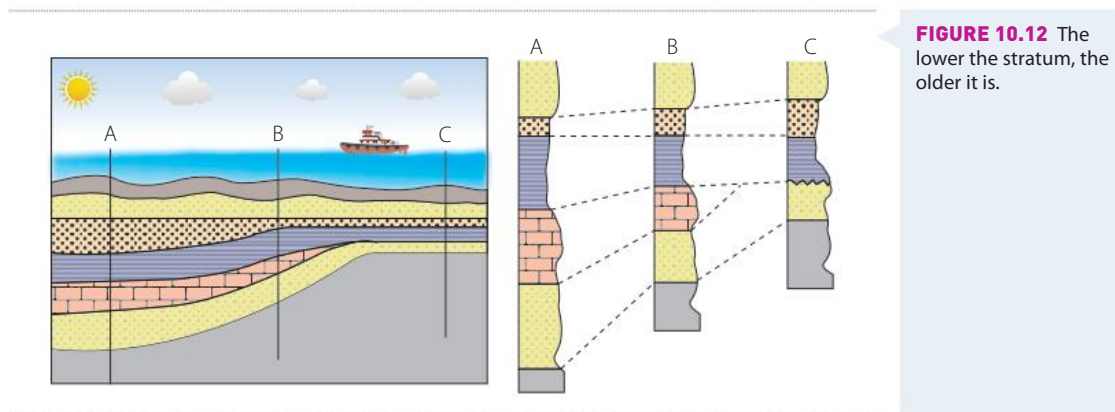
Relative dating relies on the assumption that fossils found up higher in rock strata are younger than the lower fossils, so fossils are dated relative to one another. While the actual age of the fossils cannot

be determined, it is useful to determine the chronological sequence of the fossil. Therefore, it provides evidence as to which fossil is younger or older, depending on which layer it is found in.

Different techniques can be used to relatively date fossils, including chemical analysis, stratigraphy, biostratigraphy and paleomagnetic stratigraphy.

Chemical analysis involves measuring the amount of chemicals in bones, for example uranium and iodine. As the bones are buried, they exchange minerals with the surrounding ground. The longer the bones are buried, the more chemicals they exchange. This technique is useful for determining the relative age of objects found at the same site. In addition, the amount of nitrogen in a sample decreases with age. The higher the uranium and iodine levels, the more recent the bones.

Stratigraphy relies on sedimentary rocks being formed in layers with the oldest rocks being at the bottom and youngest on top. Therefore, fossils contained in these rocks would display the same trend. That is, the lower the fossil in the strata of rocks, the older it is (Fig. 10.12).



Biostratigraphy involves comparing the fossils in different strata. Fossils can be placed in a chronological sequence. **Index fossils** are useful in determining the rock strata in which they are found. The occurrence of a fossil within two different rock locations indicates that the rocks containing the fossil specimens were deposited at about the same time. It is useful in establishing the relative age of specific fossils.

Palaeomagnetism is the study of the record of Earth's changing magnetic field in rocks, sediments or other materials. Some magnetic minerals in rocks lock in a record of the direction and intensity of Earth's magnetic field when the rock was formed. When scientists determine Earth's past magnetic field, they look for traces of iron oxide in the rocks. Iron oxide is magnetic and therefore when the rock formed the minerals will orientate in the direction of the magnetic field. Approximate dates can be determined from previous magnetic reversals (Fig. 10.13).

Absolute dating

Absolute dating (or radiometric dating) enables the actual age of a specimen to be determined using the radioactive elements that are present in the specimen. There are different techniques available depending on the age of the fossil that is being dated.

Fission-track dating is a technique used to establish the age of a mineral sample from its uranium content. A microscope is used to count the tracks left by uranium fission fragments. The concentration of uranium is determined by bombarding the sample with neutrons. The technique is useful to date volcanic minerals and teeth from 5000 to 100 million years. When volcanic

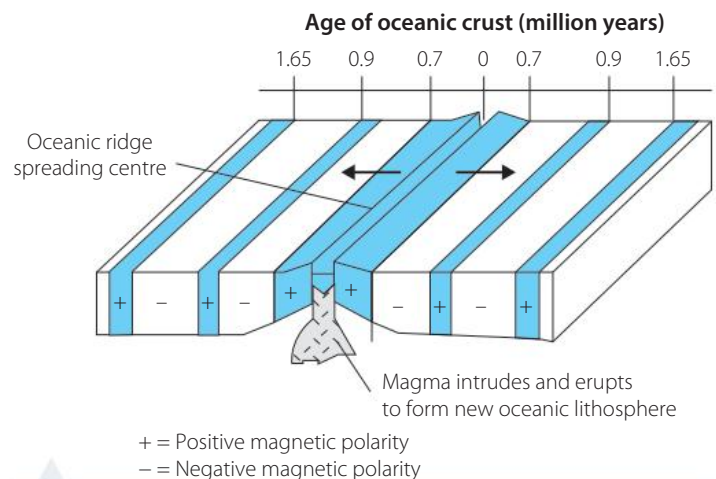


FIGURE 10.13 Magnetic reversals at the mid-oceanic ridge



Fossil dating techniques

rocks are formed, they do not contain fission tracks. Over time the number of fission tracks increases. As uranium-238 decays into a stable lead isotope, more tracks are formed. Therefore, the age of the specimen can be determined by measuring the amount of uranium remaining and the density of fission tracks.

Potassium-argon dating is a technique used to determine the age of a rock by measuring the ratio of radioactive argon to radioactive potassium in the rock sample. This method is based upon the decay of potassium-40 to radioactive argon-40. Potassium/argon and argon/argon are useful to date volcanic rocks and minerals to 200 000 to four billion years. The age of volcanic ash can be determined by measuring the amount of argon-40 and radioactive potassium within the sample. If fossils are buried between layers of volcanic ash, the age of the ash can indirectly indicate the age of the fossil.

INVESTIGATION 10.3



Information and
communication
technology
capability



Literacy

A practical investigation of fossils as evidence of evolution

Evidence of evolution comes from studying organisms living today, but further evidence can be obtained by studying the animals and plants of the past as seen in the fossil record. Fossilisation is a rare occurrence and requires precisely the right conditions to occur. In this investigation you will study how fossils form and how much information they can reveal to us about organisms that lived in the past.

AIM

Write an aim for this investigation.

MATERIALS

- Four fossil samples (for example, fossilised coral, fossil footprint, trilobite, ammonite, shark's tooth or leaf fossil)
- Access to reference material and the Internet
- Stereomicroscope or hand lens (one per group)

METHOD

- 1 Create a table for your observations that includes the following:
 - a sketch of the fossil
 - the name of the organism
 - the phylum or class or order to which each belongs
 - the location or habitat where the fossil was found
 - the type of rock in which the fossil was found.
- 2 Examine the rock surrounding the fossil specimen using a hand lens and try to identify the type of material it is. Check to see if the information provided with the fossils gives you any insight into what the material might be.

DISCUSSION

- 1 Identify and explain how each of the fossils has been preserved. Compare the material the fossil is made of with the original living tissue. Explain how the two are different and how the composition of the fossil may have come about.
- 2 Explain how the rock surrounding the fossil could provide information about the organism or the environment in which it lived.
- 3 Compare the fossilised specimens to similar species that exist today, and identify which parts have been preserved and which parts have disappeared. Explain why this would be the case.

Transitional forms

Darwin himself made the prediction that the fossil record should yield intermediate forms – organisms that show transitions from one group to another ('missing links' between groups). For example, if amphibians have evolved from fish, we would expect to find fossils of organisms that show features of both the fish ancestors and the amphibian forms to which they would eventually give rise.

Today, Darwin's prediction of intermediate forms is supported by evidence in the form of thousands of known fossils that appear to have features common to two known groups, suggesting that a transition occurred in the past from one group to another. These fossils, termed **transitional forms** or **intermediate forms**, represent successive change in organisms over a long period. *Archaeopteryx* (Fig. 10.14) is one example, being a transitional form between feathered dinosaurs and modern birds.

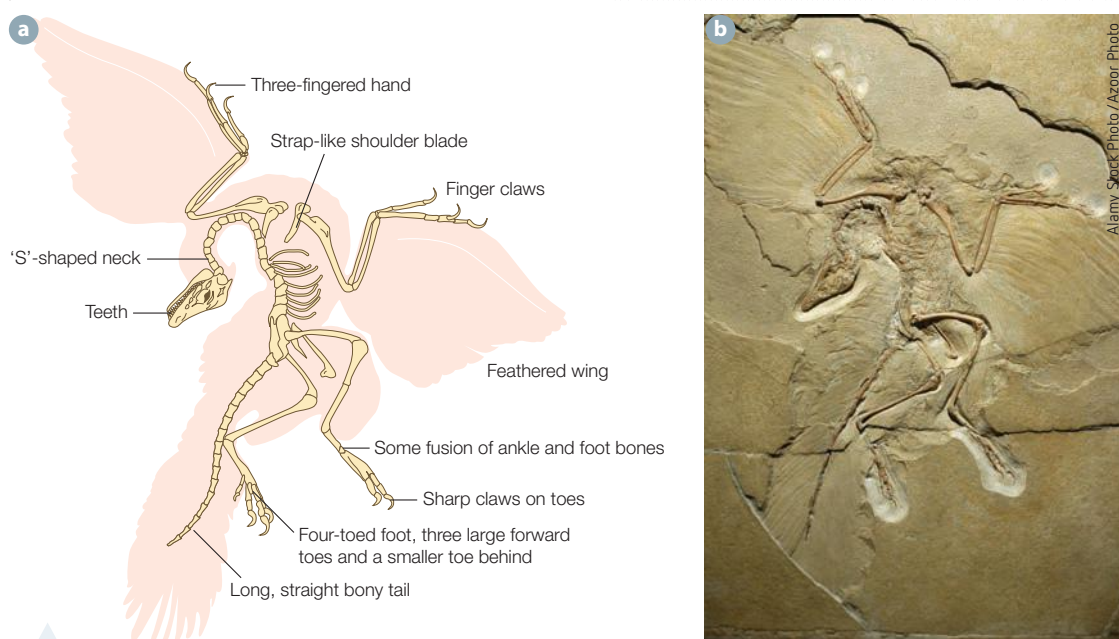


FIGURE 10.14 **a** Drawing of *Archaeopteryx* anatomy based on fossil evidence; **b** photograph of *Archaeopteryx* fossil

Limitations of palaeontology as evidence

The main limitation of the fossil record is that it is incomplete and so it is not a random sample of past life. There is a bias towards organisms whose body parts or environments makes them better suited to becoming fossilised, such as those with hard body parts and those that live in aquatic environments. There is a lack of fossils representing the majority of early or soft-bodied organisms and there is an unequal representation of transitional organisms.

There is also some doubt about the correct age sequence of some fossils, since radiocarbon dating, the commonest method of determining the age of fossils, can be used to date fossils only as recent as up to 50 000 years old (not very old in evolutionary terms). It is therefore necessary to examine additional strands of evidence to further validate the theory of evolution.

KEY CONCEPTS

- Fossils may be mineralised remains in rock or the actual preserved remains of organisms.
- Relative dating relies on the assumption that fossils found in higher rock strata are younger than the fossils found in lower rock strata.
- Absolute dating enables the actual age of a specimen to be determined using the radioactive elements that are present in the specimen.

- 1 Define the terms 'palaeontology' and 'fossil'.
- 2 Distinguish between absolute and relative dating.
- 3 Describe two absolute dating techniques. Outline any limitations of these techniques.
- 4 How does fossil evidence support our current understanding of evolution by natural selection?
- 5 How do transitional forms provide evidence of evolution?
- 6 Outline two limitations of using fossil evidence as the only argument in favour of the Theory of Evolution by Natural Selection.

10.2

Modern examples of evolutionary change

While Darwin's work on evolution has been important to our understanding of evolution, modern evolutionary ideas have been further developed by scientists observing successive generations over a short period. Organisms that can produce a large number of offspring over a short period have been invaluable in our study of evolution.

The cane toad

The cane toad (*Bufo marinus*; Fig. 10.15) was introduced into Australia from Central and South America in 1935 as a biological control (a living organism that is used to control the numbers of another organism), to regulate the cane beetle, which was causing major problems for the cane industry. Before this time, pesticides were used to kill the cane beetle. One hundred and two cane toads were originally released. It is estimated that there are now 200 million cane toads living in Australia.



FIGURE 10.15 The cane toad

Two characteristics of cane toads have enabled them to out-compete native toad and frog species. The first is their rapid reproduction, and the second is that they are poisonous throughout all periods of their life cycle. Without a natural predator, cane toads have reproduced in large numbers and have steadily spread across northern Australia (Fig. 10.16).

Recent studies by the University of Sydney's Professor Rick Shine suggest that the invading front group have specific genes that enable them to move faster. Therefore, the presence of these genes would be a favoured characteristic in the organisms invading new niches. In the 1960s the invasion front was moving at about 10 km per year. Now it is moving at 60 km per year.

Cane toads spread themselves out across the Australian tropics in terms of how fast they can move. Slow toads ended up well behind the invasion front, whereas faster toads ended up at the frontline. Faster movement gives front-runners an adaptive advantage over other cane toads, and allows them to invade new habitats first and spread faster. It was these athletic toads that were able to breed first and have athletic offspring. No wonder therefore that the toads moving across Northern Territory and into Western Australia are the bigger, faster toads, moving in a straight line at around 70 m a day compared to 10 m a day for the slower toads.

Biologists have found it surprising that cane toads have evolved so quickly after their introduction to Australia. Evolution is a process that is thought to occur over thousands or millions of years.

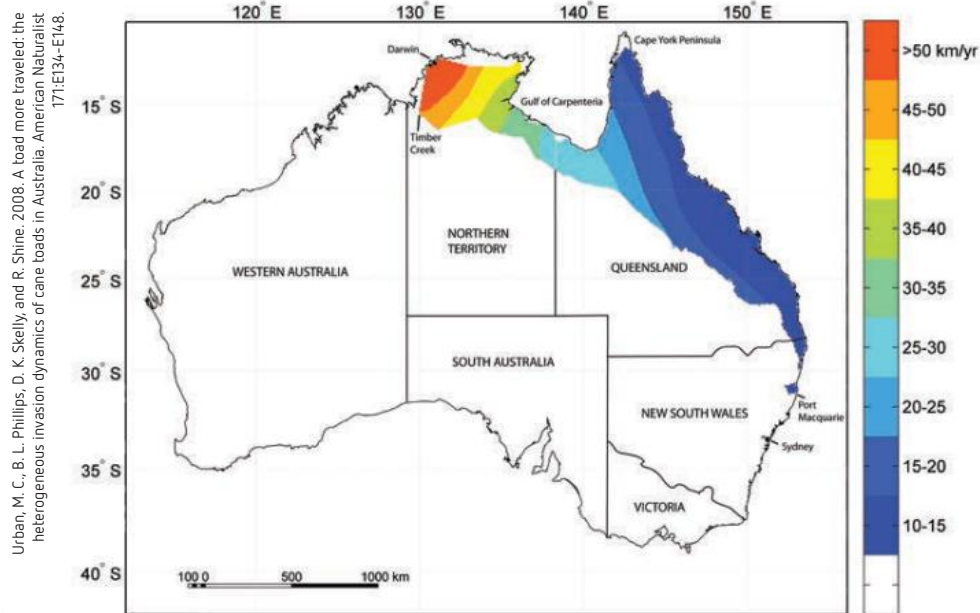


FIGURE 10.16 Cane toad distribution throughout Australia

Scientists are also noticing that in the areas inhabited by cane toads, other species are showing changes in structural and behavioural characteristics. The inference is that the cane toads are exerting a selection pressure on other organisms.

Different native animals are not equally vulnerable to the cane toad. The cane toad exerts selection pressure, killing some animals and not others. The red-bellied black snake has evolved some mechanisms to avoid being poisoned. Researchers from Team Bufo have observed that in areas where they coexisted the snakes had smaller heads, meaning they could not eat the larger, more poisonous, toads. This is most likely because the snakes with larger heads were eating the cane toad and dying. Those snakes with the genes for smaller heads were therefore the ones that were selected for, and went on to reproduce similarly small-headed offspring.

It is now possible for scientists to see microevolution in action, happening at a faster rate than people predicted years ago. Our understanding of modern genetics is enabling us to understand the genetic mechanisms behind this change.

Refer to p. 222 for more information on the co-evolution of the cane toad and red-bellied black snake.

INVESTIGATION 10.4

A secondary-source investigation of modern examples of evolution

Rapidly changing environments and small generation times contribute to a recipe for evolution. Choose one of the following species, or choose another species that is thought to be evolving rapidly, and use secondary resources such as journals, textbooks or the Internet to research and find out how the species is evolving rapidly.

- Tawny owl (*Strix aluco*)
- Yellow-bellied three-toed skink (*Saiphos equalis*)





- Italian wall lizard (*Podarcis sicula*)
- Blue moon butterfly (*Hypolimnas bolina*)
- Mediterranean thyme (*Thymus vulgaris*)

Ask yourself the following questions when researching secondary data (the CRAAP method):

- What is the source of the URL (.com, .edu, .gov, .org, .net)?
- Is this website up to date (when was it published?) → Currency
- Is the information targeted to the appropriate audience and level? → Relevance
- Who is the publisher or author and what are their qualifications? → Authority
- Is the website generally free of inaccuracies and bias? Do other sources make similar claims? → Accuracy
- What is the author intending to do: inform or persuade? → Purpose

Make sure you answer the following questions as part of your research.

- 1 What were the original conditions of the environment in which the organism lived?
- 2 What is the selection pressure? How was it introduced into the environment?
- 3 What characteristic is being selected for?
- 4 What is the outcome of the selection?
- 5 Describe the example in terms of the tenets of Darwin and Wallace's Theory of Evolution by Natural Selection.

Present your research, including any photos and diagrams, as a two-page report or in another format such as a poster, agreed upon with your teacher.

Antibiotic-resistant strains of bacteria

There are many different types of prokaryotic bacteria on Earth. Some of these bacteria cause disease in humans. **Antibiotics** are chemicals that are able to inhibit the growth of bacteria or destroy them. They target the cell wall and inhibit bacterial metabolism.

Alexander Fleming discovered the first antibiotic, penicillin, in 1928. It could not be used at this stage, and it was not until the late 1930s that Howard Florey (an Australian scientist) and Ernst Chain purified and stabilised penicillin. It then became available for medical use in 1941. Many infections and diseases that were once considered very serious and often fatal could be treated successfully with penicillin. This was a revolutionary breakthrough in the treatment of disease caused by bacteria.

When penicillin was first discovered, and then many other antibiotics were produced, the threat posed by infectious diseases was greatly reduced. There was a dramatic drop in the number of deaths from bacterial diseases that were previously untreatable.

With the widespread use of antibiotics, a problem that threatens the successful future treatment of these diseases has developed. Bacteria, during the normal process of natural selection, have evolved strains that are **resistant** to many, if not all, of the antibiotics used to treat infectious bacterial disease in the world today.

The way in which bacteria develop a resistance to antibiotics can be explained by Darwin and Wallace's Theory of Evolution by Natural Selection. Although bacteria normally reproduce by binary fission, producing clones, they can also reproduce sexually through **conjugation**, in which they exchange genetic material (Fig. 10.17). This process can lead to variation in a population of bacteria.

When exposed to an antibiotic (the selection pressure), the bacteria that have variations that are best suited to that environment (resistance to the antibiotic) will survive and reproduce (Fig. 10.18). Therefore, the population will become more resistant to the antibiotic over generations.



FIGURE 10.17 Bacterial conjugation. Genetic material is transferred between bacterial cells through the sex **pilus**. This leads to variation within bacterial populations.

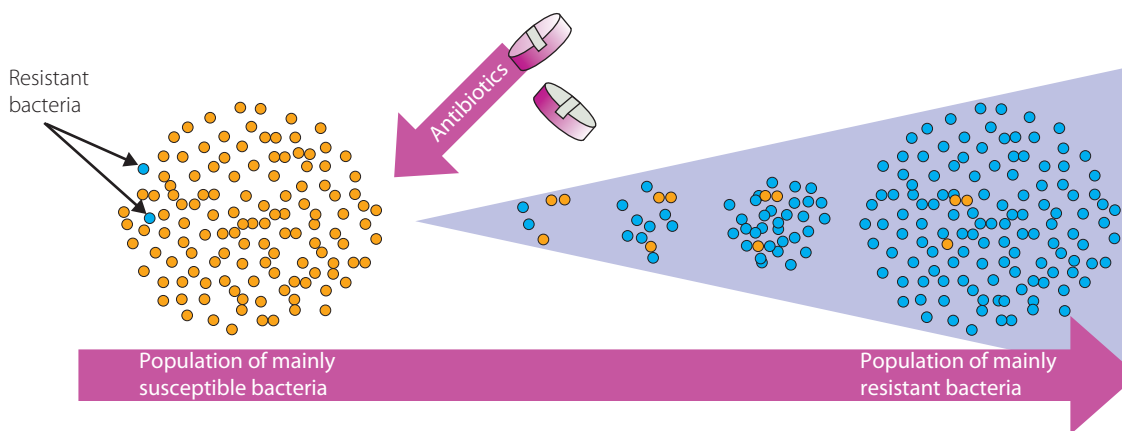


FIGURE 10.18 The selection processes causing antibiotic-resistant bacteria to multiply

What is clear about many micro-organisms is that they do not exist as free cells, but are often attached to each other or other surfaces. They can exist as **biofilms** (groups of micro-organisms that exist on a surface as a community, such as plaque on teeth). These biofilms can have different **phenotypes** (observable characteristics) and properties from the free-living types. This almost multicellular behaviour provides the bacteria with properties and protection that enable them to resist antibiotics. It may be because antibiotics are unable to penetrate the biofilm.

Staphylococcus aureus (also known as golden staph) is a bacterium that commonly lives in the nose, mouth or on the skin of people. It most often causes mild skin infections such as boils, but can cause more serious harm when it infects surgical wounds, the blood, lungs or urinary tract. *S. aureus* has now evolved a strain called **MRSA** (methicillin-resistant *S. aureus*) that is resistant to many of the antibiotics (methicillin, amoxicillin, penicillin and oxacillin) used to treat it. Some antibiotics still work to treat *S. aureus* but overuse of antibiotics, especially in the food industry, is quickly leading to further resistance. For years, antibiotics have been prescribed to combat influenza and the common cold. These diseases are viral and do not respond to antibiotics. Nevertheless, failure to use antibiotics responsibly (such as finishing an entire course) has led to the selection of those bacteria that are able to survive the antibiotic in their environment.

People most susceptible to *S. aureus* infections are those with a weakened immune system, such as patients in hospitals and nursing homes.

KEY CONCEPTS

- Modern examples of evolutionary change enable us to observe evolution by natural selection in action.
- Faster and larger cane toads have been selected for, changing the population of modern cane toads.
- Antibiotic resistance has been selected for in bacteria because of overuse and misuse of antibiotics.

- 1 Describe two features of cane toads that enabled them to become invasive.
- 2 Suggest why cane toads have been able to spread across Australia and increase in numbers.
- 3 Outline how cane toads have changed since their introduction into Australia.
- 4 How do the red-bellied black snakes that live in cane toad areas differ from those in areas where there are no cane toads?
- 5 How are cane toads used as modern evidence for evolution?
- 6 Outline how antibiotics work.
- 7 Use a diagram to explain how antibiotic resistance develops.
- 8 Describe how bacteria can exchange genetic information. Explain how this assists evolution.
- 9 Why do antibiotic-resistant bacteria pose a major threat to people in hospitals?

CHECK YOUR UNDERSTANDING

10.2

Evidence to support the theory of evolution by natural selection: What is the evidence that supports the Theory of Evolution by Natural Selection?

The Theory of Evolution by Natural Selection

A theory is a scientist's explanation of a natural phenomenon that must be strongly supported by many different lines of *evidence*.

Darwin and Wallace used evidence to validate their theory

Biochemical evidence such as amino acid sequencing, DNA-DNA hybridisation, shows how closely related organisms are.

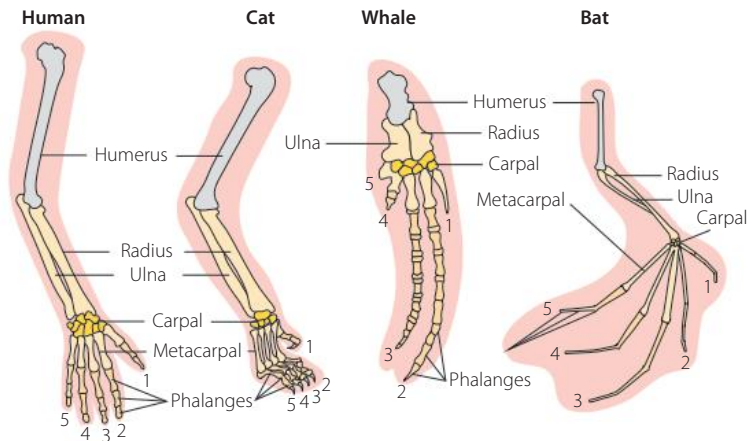


DNA from species 1

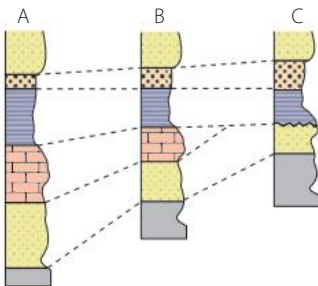


DNA from species 2

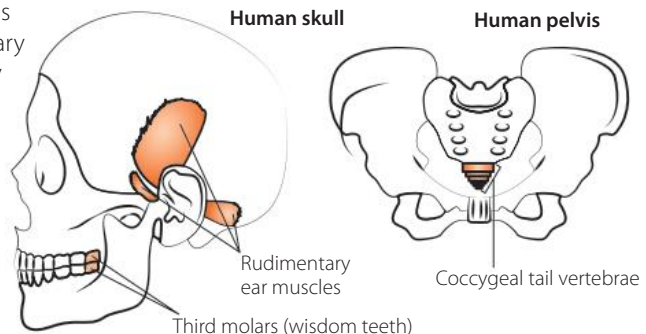
Comparative anatomy studies the similarities and differences in living organisms, such as *homologous* structures of the pentadactyl limb



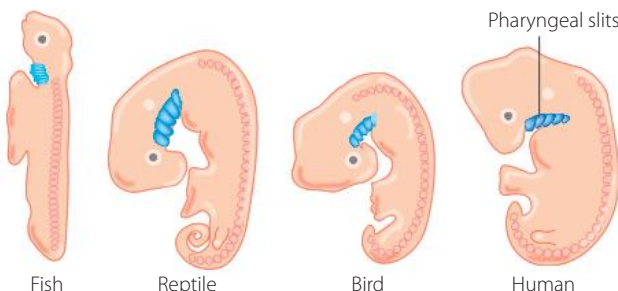
Palaeontology fossil evidence, absolute and relative dating techniques, biostratigraphy, palaeomagnetism



Vestigial structures are the evolutionary remnants of body parts that no longer serve a useful function



Comparative embryology means comparing developmental stages of different species



Biogeography means studying the geographical distribution of living and extinct organisms. An example is the study of the macroevolution of flightless birds such as the emu, ostrich and rhea.

This supports the concept of adaptive radiation: the migration of new organisms into new environments.

Modern examples of evolutionary change observing **Natural Selection**

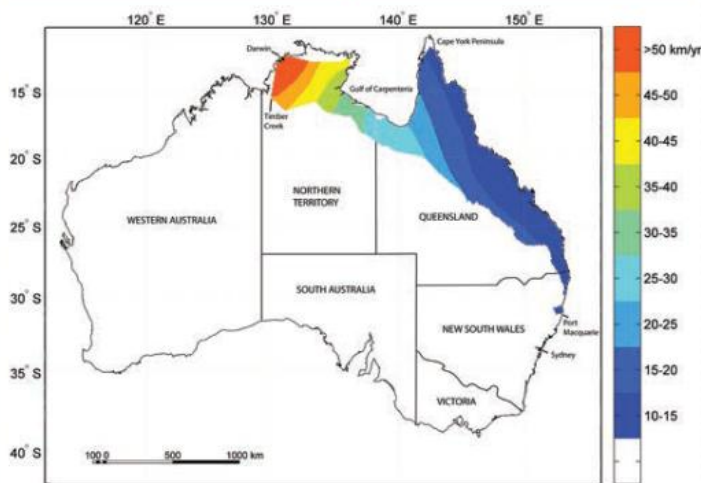
The *cane toad* – used a *biological control* to reduce the abundance of the cane beetle

Those cane toads that can invade a new area first have a survival and reproductive advantage

Selection for faster and larger cane toads



iStock.com/Patrick_Gijsbers

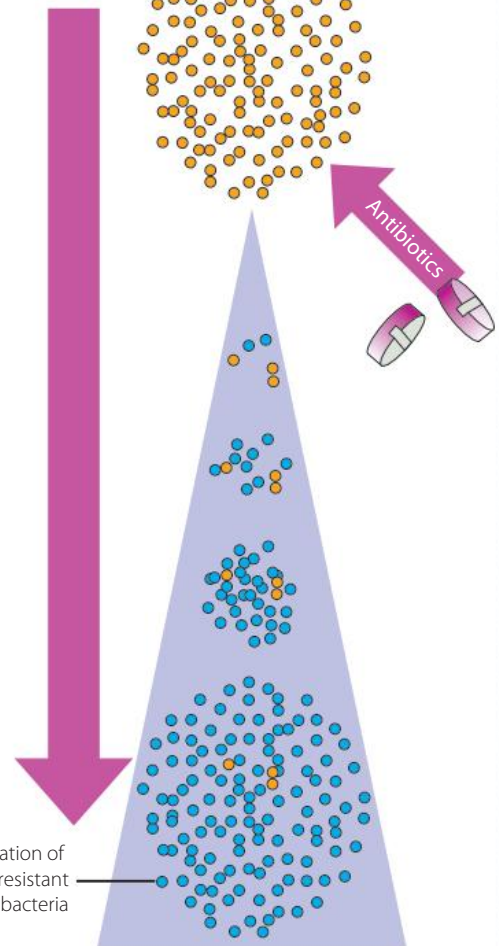


Urban, M. C., B. L. Phillips, D. K. Skelly, and R. Shine. 2008. A toad more traveled: the heterogeneous invasion dynamics of cane toads in Australia. *American Naturalist* 171:E134-E148.

Antibiotic-resistant bacteria

Population of mainly susceptible bacteria

Resistant bacteria



The use of antibiotics has acted as a *selecting agent* with resistant organisms able to pass this characteristic on to their offspring

10 CHAPTER REVIEW QUESTIONS



- 1 How are theories validated in science?
- 2 What do scientists predict regarding the comparison of macromolecules in closely related species?
- 3 Describe the relationship between differences in macromolecules and relatedness.
- 4 Outline qualitative and quantitative evidence that supports the Theory of Evolution by Natural Selection.
- 5 Outline the use of DNA–DNA hybridisation in determining evolutionary relationships.
- 6 Outline the use of DNA sequencing in determining evolutionary relationships.
- 7 Explain why the enzyme trypsin, a protein-splitting enzyme found in animals from protozoa to mammals, could be used to determine the relatedness of these organisms.
- 8 How has technology improved our understanding of evolution?
- 9 Chimpanzees are more closely related to humans than to orangutans. Explain how advances in biochemical technology have changed our understanding of evolutionary relationships between humans and other primates.
- 10 Table 10.3 shows the amino acid positions in the haemoglobin of some primates. From the data:
 - a Determine which two primates are most closely related. Justify your answer.
 - b Which two groups show the least similarity? What is the significance of this in terms of evolution?
- 11 Outline an example of how comparative anatomy can be used to support our understanding of evolution.

TABLE 10.3 Amino acid positions in the haemoglobin of some primates

PRIMATE				
HUMAN	CHIMPANZEE	GORILLA	BABOON	LEMUR
Ser	Ser	Ser	Asn	Ala
Thr	Thr	Thr	Thr	Thr
Ala	Ala	Ala	Thr	Ser
Gly	Gly	Gly	Gly	Gly
Asp	Asp	Asp	Asp	Glu
Glu	Glu	Glu	Glu	Lys
Val	Val	Val	Val	Val
Glu	Glu	Glu	Asp	Glu
Asp	Asp	Asp	Asp	Asp
Thr	Thr	Thr	Ser	Ser
Pro	Pro	Pro	Pro	Pro
Gly	Gly	Gly	Gly	Gly
Gly	Gly	Gly	Gly	Ser
Ala	Ala	Ala	Asn	His
Asn	Asn	Asn	Asn	Asn
Ala	Ala	Ala	Ala	Ala
Thr	Thr	Thr	Gln	Gln
Arg	Arg	Lys	Lys	Lys
His	His	His	His	His

- 12** Whales possess a reduced hipbone even though they do not have legs. Explain why.
- 13** Using an example, suggest how analogous structures provide evidence of evolution. Is this convergent or divergent evolution? Explain why.
- 14** Use an example to explain the existence of the appendix in humans in evolutionary terms.
- 15** Embryos of fish, birds, reptiles and humans appear remarkably similar. Explain how this is evidence in support of the Theory of Evolution by Natural Selection.
- 16** Justify why both humans and dolphins have a humerus bone.
- 17** Describe what Alfred Wallace discovered about Asian bird species and the significance of this discovery.
- 18** Why are most of the fossils found of aquatic organisms and not terrestrial organisms?
- 19** A fossilised fish skeleton is found in sandstone at location X, 1 m from the surface. A very similar skeleton is found at location Y, 2 m from the surface and 1 km away from location X. Another similar skeleton is found at location Z, 3 m from the surface and 3 km away from location X.
 - a** What can be inferred about the way in which the rocks were formed?
 - b** What can be inferred about the age of the fossil at location Y?
 - c** Draw a diagram to illustrate your answer.
- 20** How does biogeography provide evidence of macroevolution?
- 21** Using an example, outline how transitional forms support our understanding of evolution.
- 22** Using your understanding of cane toads, suggest why we should be extremely cautious about introducing new species into Australia.
- 23** Explain how the cane toad provides us with a glimpse of evolution.
- 24** Explain how human-imposed selection pressure has contributed to the surge in antibiotic resistance.

Answer the following questions.

- 1 A moth species exists in two forms, light and dark. Approximately 5% of the moths collected in a pine forest by an ecologist were the dark form. While the dark form is more visible during the day, the light form is more visible at dusk.
 - a Explain why the ecologist caught more light moths at night.
 - b Identify a selection pressure that could favour the dark form of moth.
 - c Why is it beneficial to have a variety of forms in a population? Use the moth to justify your answer.
- 2 a Using an example, define the term 'selection pressure'.
 b How would Darwin explain the significance of selection pressure?
- 3 a Outline some abiotic and biotic factors that have enabled the rabbit to survive.
 b Explain how an understanding of the prickly pear life cycle has enabled it to be successfully controlled.
 c Using Darwin's Theory of Evolution by Natural Selection, explain how the rabbit was able to successfully colonise large parts of the Australian environment.
- 4 a Use an example to define the term 'adaptation'.
 b Outline two problems associated with inferring characteristics of organism's adaptations to living in a specific environment.
- 5 Copy and complete Table M3.1.
- 6 Some animals are able to successfully become inconspicuous in their environments by blending into the background. For example, a stick insect (phasmid) cannot be distinguished from small twigs. Other animals such as Australian parrots are often very brightly coloured and very conspicuous in their environment.
 - a Explain how natural selection could lead to the evolution of camouflage.
 - b Explain how bright plumage may have evolved in birds.
- 7 The Tasmanian tiger (thylacine) is a marsupial and the American wolf is a placental. They possess similar characteristics; for example, they both have large canine teeth, long snouts and a similar body shape.
 - a Suggest a hypothesis to explain why these two organisms look similar.
 - b Explain why these two organisms are different.
 - c Using an example, explain why some organisms do not change substantially over an extended period.
- 8 The Wollemi pine is an example of a living fossil. It was discovered in an isolated valley in the Blue Mountains west of Sydney. It has been suggested that they have not changed significantly since the Cretaceous period.
 - a Identify a factor that has enabled this species to survive for so long.
 - b In terms of evolution, suggest why it has not changed for millions of years.
 - c The Wollemi pine is now being cultivated and grown commercially. Predict a possible consequence of growing this plant in other areas.

TABLE M3.1

ADAPTATION	DESCRIBE FEATURES	EXAMPLE OF AN ORGANISM	HOW DOES IT ENABLE THE ORGANISM TO SURVIVE IN A SPECIFIC ENVIRONMENT?
Structural			
Physiological			
Behavioural			

- 9 Microbiologists were able to grow colonies of bacteria using a broth medium. In one dish the broth was prevented from settling into layers by being agitated (container A homogenous). The other container (B) was left to settle into layers. Scientists observed the appearance of two distinctly different colony types in the layers of the broth of dish B. In dish A the colonies were exactly the same.
- a Identify the independent variable in this experiment.
 - b Suggest why changes in the population in container A were able to occur rapidly.
 - c Explain why the bacteria in the mixed environment were able to evolve.
 - d Predict what could happen if the bacteria from the mixed container B were cultured in and allowed to grow in a homogenous medium.

- 10 A rare fossil of a Miocene koala was discovered at Riversleigh in Queensland.
- a Describe two possible ways that scientists could establish the age of this fossil.
 - b How could common ancestry be inferred between this fossil and modern koalas?
 - c Suggest why biochemical evidence is more accurate than looking at the structure of the fossil skull and comparing it to modern koalas.

DEPTH STUDY SUGGESTIONS

- Investigate cane toad evolution and current research techniques, including radio tracking, veterinary pathology and genetic studies.
- Look into current research into antibiotic resistance and biofilms.
- Investigate the latest research on anti-microbial substances found in Komodo dragons and how these may be used in the future to overcome antibiotic resistance.
- Design and conduct an experiment to model the Theory of Evolution by Natural Selection.
- Make a documentary on the evolution of mammals in Australia, with specific emphasis on the evolution of monotremes.
- Investigate plasticity (non-inheritable evolution) and the role of epigenetics and other transgenerational effects and their effect on adaptation. Is this line of study worth pursuing in the future?
- Write a journal article on the adaptations of an Australian organism, including structural, physiological and behavioural adaptations.
- Create a visual representation about the adaptations of toads that compares a native toad to the cane toad. Why do cane toads out-compete native toads?
- Develop an environmental management plan to create a cane-toad-free or prickly-pear-free sanctuary.

» MODULE FOUR

ECOSYSTEM DYNAMICS

- 11 Population dynamics
- 12 Past ecosystems
- 13 Future management of ecosystems



11 Population dynamics

INQUIRY QUESTION

What effect can one species have on the other species in a community?

Students:

- investigate and determine relationships between biotic and abiotic factors in an ecosystem, including: (ACSBLO19) [S](#) [CCT](#) [ICT](#) [PS](#)
 - the impact of abiotic factors (ACSBLO21, ACSBLO22, ACSBLO25)
 - the impact of biotic factors, including predation, competition and symbiotic relationships (ACSBLO24)
 - the ecological niches occupied by species (ACSBLO23)
 - predicting consequences for populations in ecosystems due to predation, competition, symbiosis and disease (ACSBLO19, ACSBLO20) [S](#)
- explain a recent extinction event (ACSBLO24) [S](#) [L](#)

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FIGURE 11.1 The damage caused by rabbits on Macquarie Island

Macquarie Island lies roughly halfway between Tasmania and Antarctica. It is famous for its beautiful scenery and its unique wildlife, including penguins and seals. It was listed as a World Heritage site in 1997 in recognition of the value of its native plants and animals. However, starting in the late 1800s, feral rats, mice, rabbits and cats were introduced to the island and rapidly spread. There was considerable damage to the flora and fauna of Macquarie Island (Fig. 11.1)

with several species of plants and animals becoming endangered. Grey petrels, a type of seabird, had not been seen on the island for 100 years until the Australian federal and Tasmanian state governments instituted a series of measures to eradicate introduced species. These included baiting, trapping, biological control and the use of tracker dogs. An understanding of the interactions between living things and their physical and chemical environments was vital to conservation ecology and managing this situation.

11.1

Organisation within ecosystems

The **biosphere** is that part of Earth that contains living things. Every living thing exists within a framework that includes both living (**biotic**) and non-living (**abiotic**) factors. Biotic factors include the plants and animals that an organism interacts with. For example, a kangaroo interacts with other kangaroos, with the trees it seeks shelter under, with the grass it eats and with other native and non-native animals that share the area it inhabits. Abiotic factors include physical and chemical factors in the environment such as air temperature, humidity, sunlight and rainfall. The environment is all the abiotic factors that affect an ecosystem. We call an organism's living and non-living surroundings its ecosystem. An ecosystem is composed of a lot of different species of organisms living together within the same environment. Each group of organisms of the same species living together in an area at the same time is known as a population. For example, a group of red kangaroos living in an area is a population.

At all times, the surrounding environment can positively and negatively affect an organism. It is important to understand that abiotic factors are *unevenly distributed* throughout an ecosystem; this affects the abundance and distribution of living things throughout the ecosystem according to the unique needs of different species.

Ecology is the study of *interrelationships* of organisms with each other and the environment, and this in turn determines their distribution and abundance. It explores the effects living things have on each other and their environment, as well as the effect of the abiotic factors in the environment.

Impacts of abiotic factors in an ecosystem

Abiotic factors are not always evenly distributed throughout an ecosystem. For example, water is a very effective filter for sunlight and the deeper the ocean, the dimmer the sunlight. The top layer of the ocean is referred to as the **photic zone**. This has a very significant effect on the types of organisms that inhabit these zones. The main **producers** of the ocean are photosynthetic **phytoplankton**, which provide food for

You studied sampling techniques to measure distribution and abundance in Chapter 7.

other organisms. The availability of phytoplankton is therefore affected by the availability of sunlight. There is rarely any significant light that reaches beyond 200m depth, which makes photosynthesis impossible. There is also a rapid drop in temperature the deeper you go in the ocean as a result of the filtering of sunlight. Oxygen decreases to minimum at 1000m, but rapidly increases again the deeper you go. This is because of the mixing of water with deep, cold and highly oxygenated ocean currents that have their source in polar regions.

Ocean food chains are divided into two main groups based on the differences in the abiotic factors in the surface and deep ocean layers:

- 1 superficial **pelagic** communities of free swimming and floating organisms
- 2 **benthic** communities of organisms that live in the deep ocean.

Each of these communities (groups of different populations in an area or habitat) has its own unique way of thriving within the limits of the abiotic environment. For example, their physical features and behaviours will be ideally suited to deal with such factors. A saltwater fish has the behavioural and **physiological** adaptations that enable it to deal with the high salt load in its environment.

Figure 11.2 shows the distribution of abiotic factors in an aquatic ecosystem and their effect on the distribution of living things.

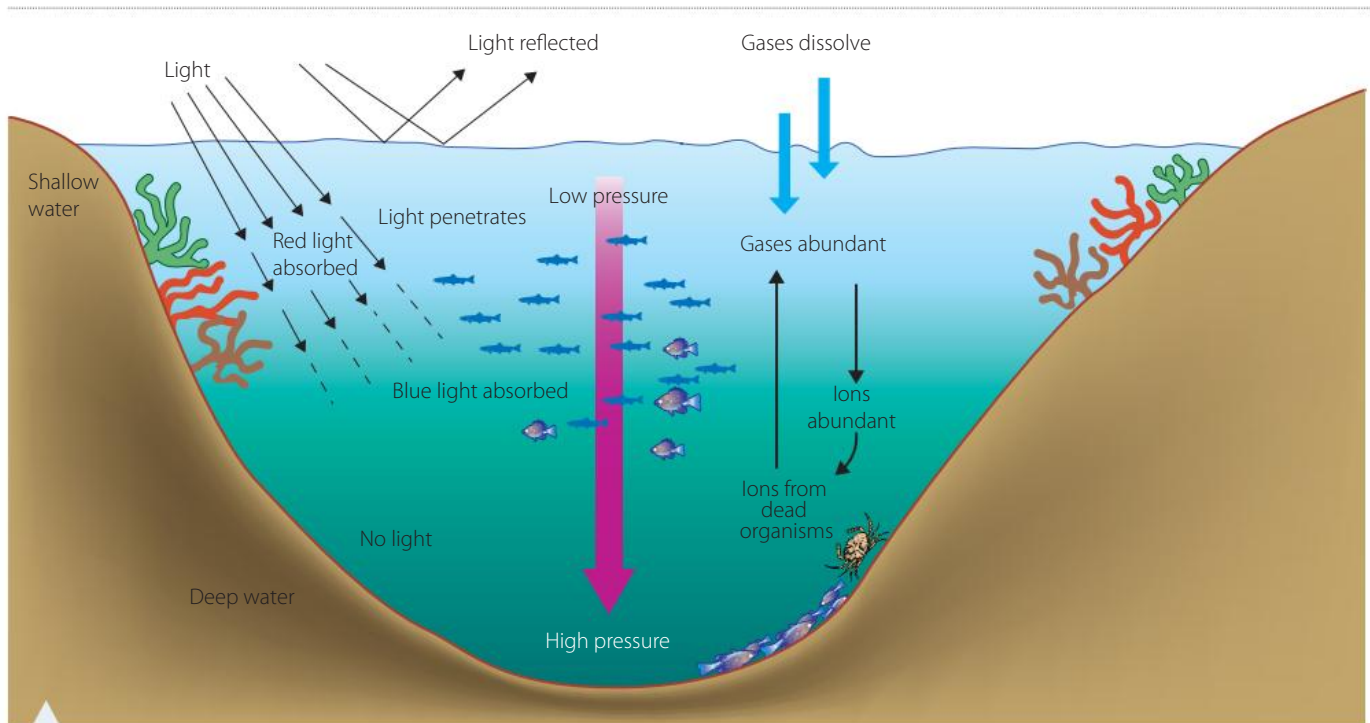


FIGURE 11.2 Comparing abiotic characteristics at different depths of an aquatic marine environment

KEY CONCEPTS

- Every living thing exists within a framework of biotic and abiotic factors called an ecosystem.
- An ecosystem consists of the interaction of living things with each other and with their non-living environment.
- Abiotic factors are unevenly distributed throughout an ecosystem and include temperature, pressure, light availability, water availability, wind and soil nutrient levels.
- Biotic factors are the living things that an organism shares the ecosystem with, including plants, animals, bacteria. Species may be affected directly or indirectly by each other.
- Aquatic ecosystems are mainly affected by salinity, light availability, gas concentrations and water temperature.

CHECK YOUR UNDERSTANDING

11.1a

- 1 Distinguish between an ecosystem and an environment.
- 2 Define the term 'abiotic factor'.
- 3 List the abiotic factors that can affect a species in a terrestrial environment.
- 4 Describe one terrestrial and one aquatic ecosystem in terms of the abiotic factors that are present.
- 5 In your own words, explain why an abiotic factor such as light or nutrient availability would affect the types of organisms that are present in an ecosystem. Use a specific example.
- 6 Why is it important to gather information on an organism's abundance and distribution?
- 7 Are abiotic factors always evenly distributed throughout ecosystems? Give an example.

Impacts of biotic factors in an ecosystem

Living things can affect each other directly by such things as predation and **symbiosis**, but also can have an equally profound effect on each other indirectly by competing for resources. These resources may include other living things as food sources and mates, as well as non-living factors such as light, nutrients and water.

When different species interact with one another, the interactions may be positive, negative or neutral for each species. To simplify matters, we will discuss situations where two species only are interacting.

The simplest community interactions include:

- predation
- competition
- symbiosis – **mutualism**, **commensalism** and **parasitism**.

Predation

A **predator–prey relationship** is a type of feeding relationship where the **predator** obtains its food by killing and eating another animal (the **prey**). Predators are found in aquatic and terrestrial ecosystems. A spider traps flies in its web and eats them, or a blue-tongued lizard (*Tiliqua scincoides*) kills and eats beetles and snails. A killer whale (*Orcinus orca*) feeds on seabirds, turtles, octopus and fish. **Carnivorous** plants such as the Venus flytrap (*Dionaea muscipula*) and the pitcher plant (for example *Nepenthes lowii*; Fig. 11.3) supplement their diet with invertebrates such as insects. Often this is an adaptation to existence in poorly structured soils with low nutrient loads.

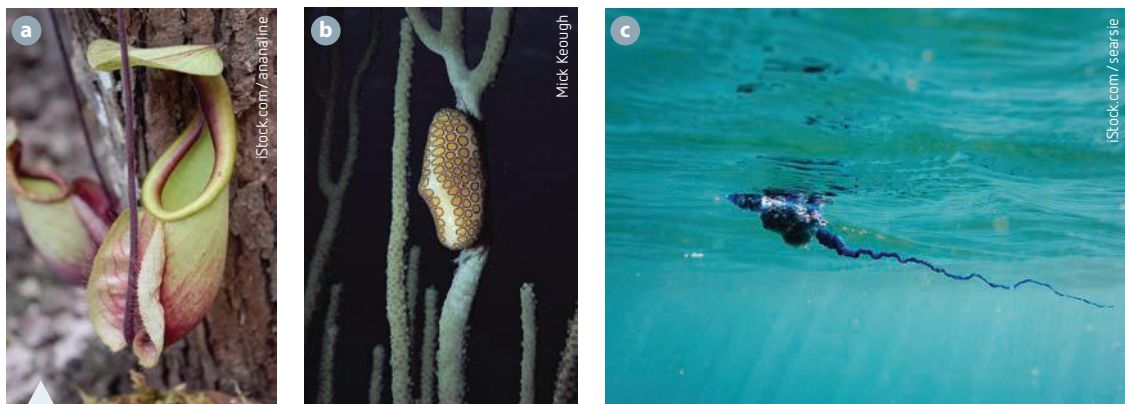


FIGURE 11.3 Plants and marine animals as predators: **a** the pitcher plant traps and digests insects in highly modified leaves; **b** a predatory snail feeds on soft coral; **c** the Australian bluebottle with its large blue float captures its prey using long stinging tentacles

Competition

Weeds in a garden compete with other garden plants for soil nutrients, sunlight and water. Rabbits and wallabies compete for grass as a food source. When two or more organisms use one or more resources in common such as food, shelter and mates, this is referred to as competition (Fig. 11.4). The competition is usually for a resource in the environment that is limited in supply but valuable to survival. All competition involves risk to the competitors and the rewards must outweigh this inherent risk. Species may compete directly by aggression or physical interaction, or may do so indirectly through vocalisation or leaving a scent on an object in their territory.

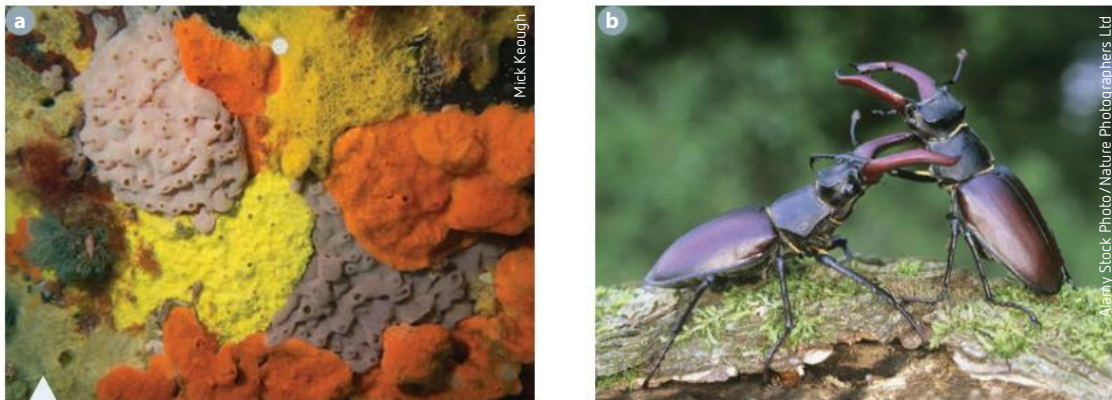


FIGURE 11.4 **a** Interspecific competition: sponges, ascidians and bryozoans in the subtidal zone of a south-eastern Australian seashore aggressively compete for space, with the best eventually claiming more space on which to feed, grow and reproduce. **b** Intraspecific competition: two male stag beetles compete for territory and mating opportunities.

Organisms may compete with:

- members of their own species (**intraspecific competition**), or
- members of another species (**interspecific competition**).

Intraspecific competition is usually more intense as the organisms have far more resource needs in common. In other words, their niches overlap, such as when male red kangaroos fight each other for female reproductive partners. Interspecific competition may lead to the evolution of one of the species in response to the selection pressure exerted by the other species that alters its niche, such as when introduced and native plants compete for water and nutrients in the soil.

Individual plants can compete for a range of resources including soil nutrients, water, space and access to sunlight. Some plants are better able to compete in certain parts of ecosystems. These species try to exclude their competitors from that part of the ecosystem.

Allelopathy is the production of specific biomolecules by one plant that can be beneficial or detrimental to another plant. **Allelochemicals** produced by a plant escape into the environment and subsequently influence the growth and development of other, surrounding plants. Because space is crucial to plants, this mechanism is used by a plant to keep other plants out of its space. The fewer plants around, the more water is available to absorb from the soil, the more soil to support the roots for plant stability, and the more sunlight for absorption.

There are several different types of allelopathy. In one type, the plant that is protecting its space releases growth compounds from its roots into the ground. New plants trying to grow near the **allelopathic** plant absorb those chemicals from the soil, inhibiting root/shoot growth or seed germination. Another type of allelopathy involves the release of chemicals that slow or stop the process of **respiration** or photosynthesis,



Competition within
an ecosystem

and some chemicals may inhibit nutrient uptake. Plants may also release chemicals that can change the amount of chlorophyll in another plant. The plant cannot then make enough food with the changed chlorophyll levels, and dies.

Allelopathic chemicals can be present in any part of the plant. They can be found in roots, stems, flowers, fruits and leaves.

Examples of allelopathy include the following:

- The black walnut plant releases a chemical that inhibits respiration. The chemical is found in all parts of the plant, but it is concentrated in the buds and roots. Plants exposed to this chemical exhibit symptoms such as wilting, yellowing of foliage and eventually death.
- Sorghum species (a cereal grass) release a chemical in the root **exudates** that disrupts mitochondrial functions and inhibits photosynthesis. It is currently being researched extensively as a weed suppressant.
- Eucalyptus leaf litter and root exudates are allelopathic for certain soil microbes and plant species. Some pine trees are also allelopathic. When their needles fall to the ground, they begin to decompose and release acid into the soil. This acid in the soil inhibits other plants from growing near the pine tree.

The more that is learnt about allelopathy, the more we can find out about less destructive alternatives to herbicides. That is, we could prevent unwanted plants or weeds from growing in an area by selecting plants that specifically produce chemicals against them. This is a way that humans can use their knowledge of the effect that one species can have on another in a **community** to create more environmentally sustainable ways of controlling undesirable species.

Animals compete for several different resources within an ecosystem. They may compete for mates from the same species. Animals also compete with the same and other species for:

- food
- shelter or hiding places to avoid predators
- shelter or hiding places in defence of territory or young
- shelter for nest sites.

Animals possess various defence mechanisms that may be used in intraspecific and/or interspecific competition. Some can attack intruders using teeth, claws, stingers and/or chemical means. Some, such as phasmids, use camouflage to hide (Fig. 11.5), while others use **mimicry** to resemble dangerous or unpalatable species. Noxious or unpalatable species, such as some



Shutterstock.com/Peter Waters

FIGURE 11.5 A phasmid hides through the use of camouflage.

frogs and butterflies, advertise the fact with warning colouration such as spots or stripes in bright colours (Fig. 11.6).

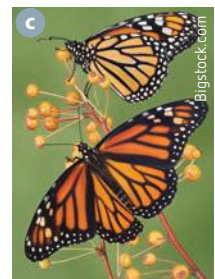


FIGURE 11.6 **a** The Australian frog *Pseudophryne corroboree* is distinctively coloured gold with black stripes. **b** The blue poison arrow frog secretes an alkaloid poison from its skin. The colour is a warning to potential predators. **c** The monarch butterfly (*Danaus plexippus*) advertises its unpalatability by means of warning colouration.

Symbiotic relationships

Symbiosis is the term used for interactions in which two organisms live together in a close relationship that is beneficial to *at least* one of them. Symbiosis usually involves providing protection, food, cleaning or transportation. When one or both species entirely rely on the other for survival, this relationship is **obligate**. For example, **lichen** consists of multiple species of **fungi** and **algae** or **cyanobacteria**, which entirely rely on each other to survive. The fungi benefit because the algae and cyanobacteria provide nutrients through photosynthesis. The algae and cyanobacteria benefit from the protection of the filaments of the fungi. When the organisms that can live independently of each other interact for benefit anyway, this relationship is **facultative**. For example, aphids and ants are not essential to each other's survival, but when present together, the ants protect the aphids from predation and the sugary fluid the aphids produce is a food source for the ants.

There are three types of **symbiotic interactions**:

- 1 mutualism – both species in the relationship benefit from the association (+/+)
- 2 commensalism – one species benefits and the other is unaffected (neither harmed nor helped) (+/0)
- 3 parasitism – one species benefits and the other suffers (usually) non-lethal damage (+/-).

Mutualism

Mutualism is an interspecific interaction in which both species benefit from the association.

For example, reef-building corals have within their tissues symbiotic algae, which provide the yellow-brown pigments that give the coral its colour (Fig. 11.7). The algae live, reproduce and photosynthesise in the host, and use the waste products of the host.

In turn, the coral uses the oxygen and food produced by the algae during photosynthesis to grow, reproduce and form its hard skeleton, which is the basis of the reef. The formation of the Great Barrier Reef depends on this mutualistic relationship. When corals are stressed (that is, when disturbance turns water murky, or sea temperatures increase) they expel the algae; this in turn causes the corals to starve, leaving white skeletons.

The relationship between the sea anemone and the anemone fish (or clown fish) was once thought to benefit only the anemone fish; however, recent studies have suggested that, in fact, both organisms benefit. The anemone fish is neither stung nor eaten by the anemone. The anemone fish repeatedly brushes against the anemone's tentacles until its mucus coating inhibits the anemone's sting. The anemone fish is then protected from predators by hiding in the anemone's tentacles unharmed. It feeds on the anemone's food scraps. The anemone benefits as the anemone fish cleans its host and lures other animals into the anemone's tentacles (Fig. 11.8).

Ant plants have a mutualistic relationship with ants. These associations can take several forms. Some species of ant plant have a swollen base in which there are specialised chambers. The species of ants associated with these particular plants form large colonies within these chambers and carry their



Symbiotic relationships within an ecosystem



FIGURE 11.7 Corals in a symbiotic relationship with algae



FIGURE 11.8 There is a mutualistic relationship between the sea anemone and the anemone fish ('clown fish').

excreta and their prey's corpses to parts of the chambers ('cemeteries') where the plant can absorb the nutrients from these wastes. In other associations, the ants defend their plant from attack by other insects and predators and may in turn benefit by special sugary secretions produced by the plant.

Specialised nitrogen-fixing bacteria (rhizobia) live in the root nodules of legumes such as clovers, peas and beans. Plants are unable to access atmospheric nitrogen (N_2) for their use. The bacteria convert this nitrogen into a form that can be accessed by the plant (ammonia). This is subsequently converted to nitrates by other bacteria. These plants can then grow in soils that are low in nitrogen. In turn, the plant roots provide a stable and protective environment for the bacteria.

Commensalism

Commensalism refers to a situation where one species benefits and the other is neither harmed nor helped. It is less obvious in nature than most other feeding relationships because the effects are not immediately clear.

For example, **epiphytes** such as mosses, small ferns and orchids can be seen on tree trunks in moist forests. They appear to benefit from living on the trunk of the host tree by catching rainwater to dissolve nutrients and by being closer to sunlight. Epiphytes do not appear to affect the host tree negatively. The strangler fig commences its life as an epiphyte. The seed germinates from bird droppings on the host tree and the young fig starts to grow.

The fig benefits and the host at this stage is not affected. However, the fig grows and extends its roots down into the soil below. It envelops its host and prevents trunk growth (Fig. 11.9). The relationship changes from commensalism to competition for space.

The barnacle is a crustacean that normally adheres to a fixed surface; however, some barnacles adhere to the surface of whales and turtles. This does not affect the whales or turtles, but benefits the barnacles, as they are transported to diverse areas rich in food (plankton).



Relationships between
organisms



FIGURE 11.9 **a** A young fig starts to grow and extend its roots downwards; **b** the fig envelops its host.

Parasitism

Parasitism is a relationship in which one species benefits and the other is harmed. A parasite obtains shelter from the **host** organism while it feeds upon its tissues or fluids. The parasite is often smaller than its host and may live on the surface of its host (**ectoparasites**; for example, ticks, fleas and lice) or internally (**endoparasites**; for example, tapeworm, roundworm, heartworm and malarial protozoa) in the gut, in blood vessels or in other tissues such as the liver, brain, kidney and spleen (Fig. 11.10). Parasitic plants such as mistletoe attach to and penetrate the branches of a tree or shrub and absorb water and nutrients from their plant host. **Macroparasites** are visible to the naked eye, whereas **microparasites** can be seen only with the aid of a microscope.

Some parasites always kill their host (parasitoid species) but most usually do not kill because this would destroy their food supply. Competing selection pressures between the host and the parasite mean that most domestic and wild animals live with a low burden of parasites. Recent experimental evidence suggests that some endoparasites suppress their host's immune response to certain antigens, including allergens. This may be of benefit in treating some human diseases.

KEY CONCEPTS

- Biotic factors relate to living features such as organism abundance, distribution and interactions.
- Competition can be between (interspecies) or within species (intraspecies).
- Interactions may be positive, negative or neutral.
- The simplest interactions include competition, predation and symbiosis.
- Organisms compete for resources such as nutrients, water, shelter, sunlight and reproductive partners.

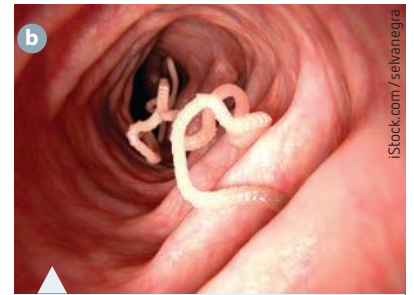


FIGURE 11.10 **a** The flea is an ectoparasite, whereas **b** the tapeworm is an endoparasite.

- 1 Distinguish between intraspecific and interspecific competition, using examples.
- 2 Briefly summarise the ways in which plants compete.
- 3 Why do animals compete within an ecosystem? Identify a possible consequence of competition between two species.
- 4 Define symbiosis. Define and give examples of the following symbiotic relationships:
 - a mutualism
 - b commensalism
 - c parasitism.

CHECK YOUR UNDERSTANDING

11.1b

Ecological niches occupied by species

The part of the ecosystem that the organism occupies is called a niche. A niche refers to all the resources that a species uses, including both biotic and abiotic factors. For example, the niche of a koala includes the time of day it is most active or sedentary, the numbers and types of leaves it eats, the type and sizes of trees it lives in and the other species it interacts with. No two species can occupy the same niche. This is known as the *competitive exclusion principle*. An organism's habitat refers to the location the species is found in. If the habitat is the workplace of a species, the niche is its job.

For example, a noisy miner bird that lives in your suburb hunts for insects among the plants in your garden. It builds a nest to raise young on acacia tree branches using grass and small sticks. In the same area a galah eats seeds mostly from the ground. It nests in the hollow of a eucalypt tree and lines it with leaves. Both birds occupy the same area, but have different food and nesting strategies – they occupy different niches within the same habitat.

Because of competition, organisms are not always able to occupy their ideal or **fundamental niche**. The fundamental or potential niche is the one an organism would occupy if there were no competitors, predators or even parasites. Because of these factors, organisms usually occupy a **realised niche** due to restrictions placed on them by other organisms. Abiotic factors are suitable for the koala to have a widespread distribution along the east coast of Australia, but this distribution is not realised due to predation by dogs and cats, and the impacts of disease, fires and drought.

Often species will partition their resources based on time and location. For example, different bird species in a forest may hunt for insects at different times of night or day, or simply hunt at different heights in the canopy (Fig. 11.11).

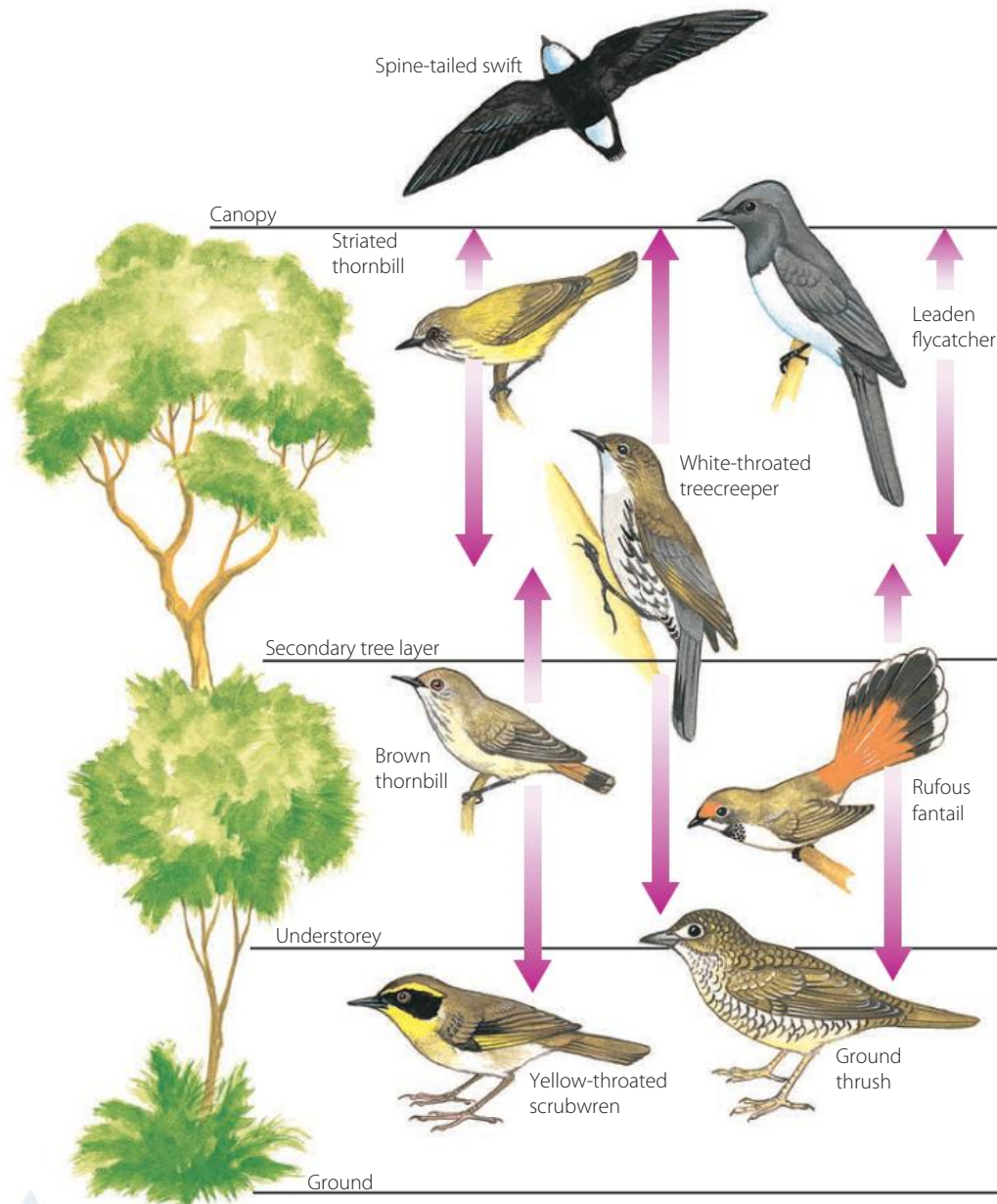


FIGURE 11.11 Resource partitioning by birds in a woodland ecosystem

A variety of niches are possible if there is a diversity of biotic and abiotic factors in an area. Australia is a large continent that spans a wide range of climatic conditions (Fig. 11.12). This means that Australia is potentially extremely biodiverse.

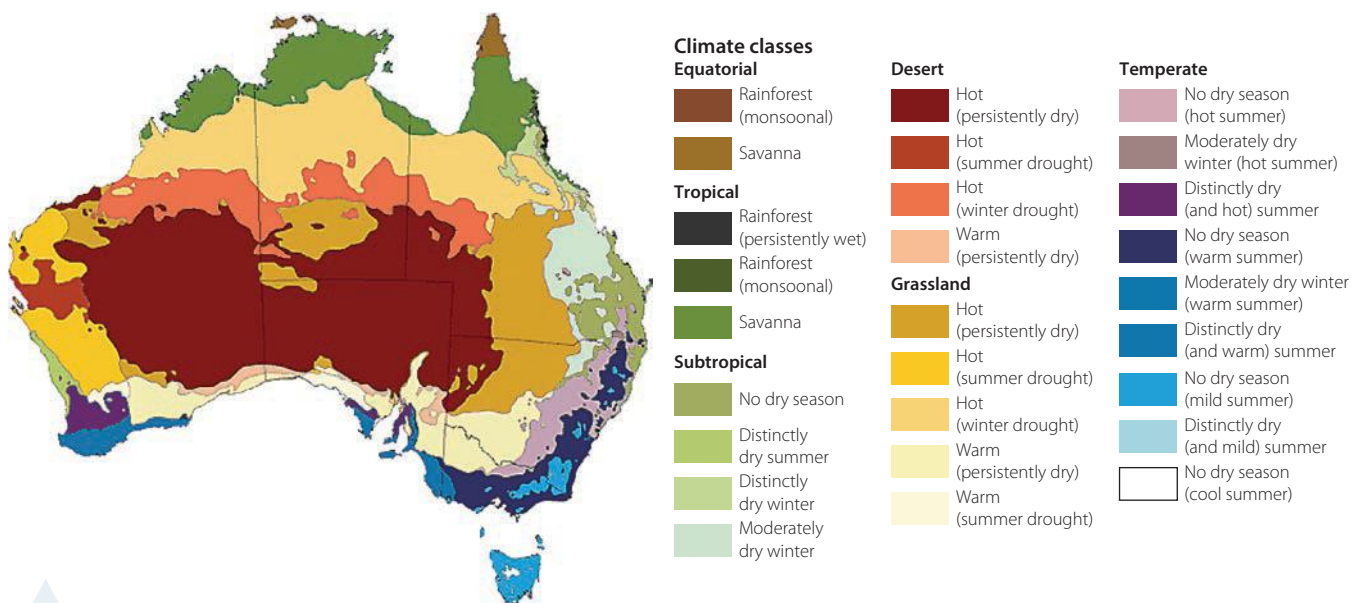


FIGURE 11.12 Ecosystem classification based on dominant plant species and climate

Predicting consequences for populations in ecosystems

Scientists use models such as graphs to easily visualise trends and enable them to make predictions about the future.

Consequences of predation

Predators affect the distribution and abundance of their prey. This is one of nature's means of population control. However, if the prey species can reproduce as fast as it is predated, its population will remain stable. In natural communities, the abundance of a predator and its prey can fluctuate through time, with the predator numbers copying those of the prey. When there are large numbers of prey available, the predator population increases in size. As prey are consumed, their numbers decline, leading to a shortage of food for the predators, whose numbers consequently also decline. This pattern is clearly illustrated in Figure 11.13.

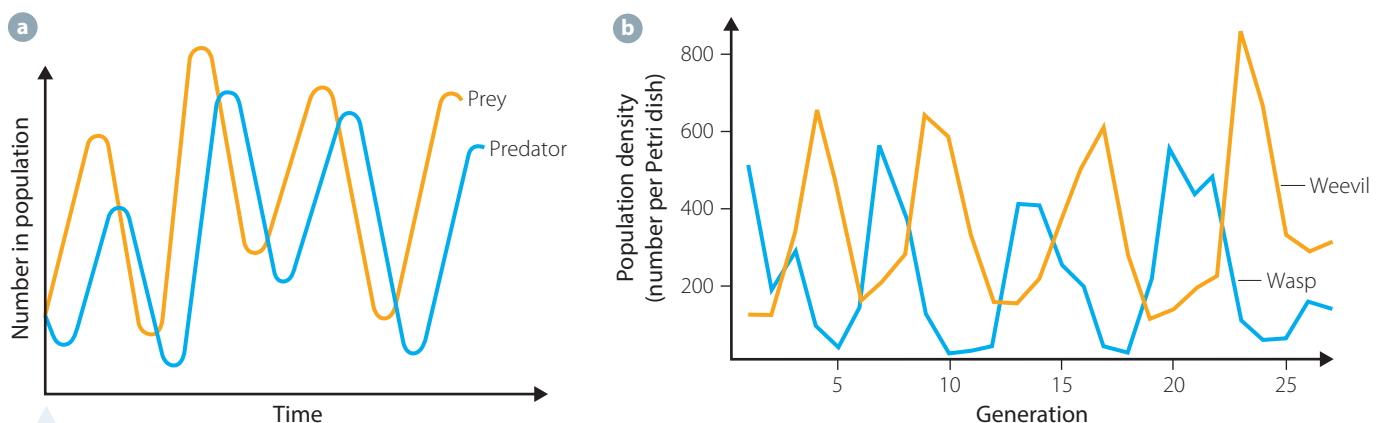


FIGURE 11.13 **a** The typical pattern found in predator–prey relationships demonstrates the lag between responses to changed populations; **b** the number of parasitic wasps fluctuates in relation to their host, bean weevils.

Several different factors may affect the numbers of predator and prey populations:

- number of predators competing for the same prey
- availability of the prey's food
- reproduction rate, depending on:
 - the age of reproductive maturity
 - number of reproductive episodes per lifetime
 - **fertility** (the likelihood of a fertilisation at a reproductive episode/mating)
 - **fecundity** (the number of offspring per reproductive episode/mating)
- death rate (increased by exposure to disease, reduced availability of resources)
- ratio of males to females
- size of the ecosystem for supporting the predator and prey numbers
- movement between ecosystems
- number of shelter sites available.

INVESTIGATION 11.1

Analysing secondary data: population dynamics

BACKGROUND INFORMATION

Analysing data is crucial to understanding the effect of one species on another. Complete the following data-analysis question.

The wedge-tailed eagle (*Aquila audax*) is a predator. It captures most of its prey on the ground in gliding attacks. Its diet includes wallabies, native rats, small kangaroos, reptiles, birds, rabbits and carrion (dead animals).

AIM

Write an aim for this investigation.

METHOD

Using the data in Table 11.1, create a *predator–prey line graph* to demonstrate the relationship between the populations of wedge-tailed eagles and native rats. (Note: these numbers are not factual but are used for the purpose of the exercise.)

TABLE 11.1 Wedge-tailed eagle and native rat populations between the years 2008 and 2017

YEAR	WEDGE-TAILED EAGLES	NATIVE RATS
2017	33	800
2016	46	3500
2015	100	1500
2014	48	550
2013	24	5000
2012	23	4500
2011	109	2800





YEAR	WEDGE-TAILED EAGLES	NATIVE RATS
2010	50	550
2009	36	1500
2008	64	4000

RESULTS

Use Excel or graph paper to construct a line graph.

DISCUSSION

- 1 Describe the trend(s) shown in your graph.
- 2 What is the limiting factor in this ecosystem?
- 3 Why is there a noticeable lag (delay) between the increases and decreases in the two populations?

CONCLUSION

Write a summary statement outlining the relationship demonstrated by these data.

EXTENSION

Now that you have examined the effect of predators on their prey, choose another species and develop an aim and hypothesis that can be tested by collecting and processing data. For example, is there a relationship between populations of red-bellied black snakes and bandicoots?

Consequences of competition

Competition between species for resources affects reproduction and survival rates. Population fluctuations can be directly linked to the competing species and their resource. If the resource is a common food source, for example, as food sources become more readily available the abundance of both species increases. As food sources decrease, so may the abundance of both competing species.

Some species may be more successful competitors than others. In the 1950s, LC Birch conducted an experiment observing the population sizes of two species of grain beetles (Fig. 11.14). When the species were sharing the same environment, one species was always driven to very low numbers, died out completely or became extinct. Individuals of the less successful species were out-competed for food by individuals of the species that eventually replaced it. Interestingly, Birch (in 1953) could reverse this outcome simply by adjusting one aspect of the beetles' environment: temperature.



Consequences on the ecosystem of species competing for resources

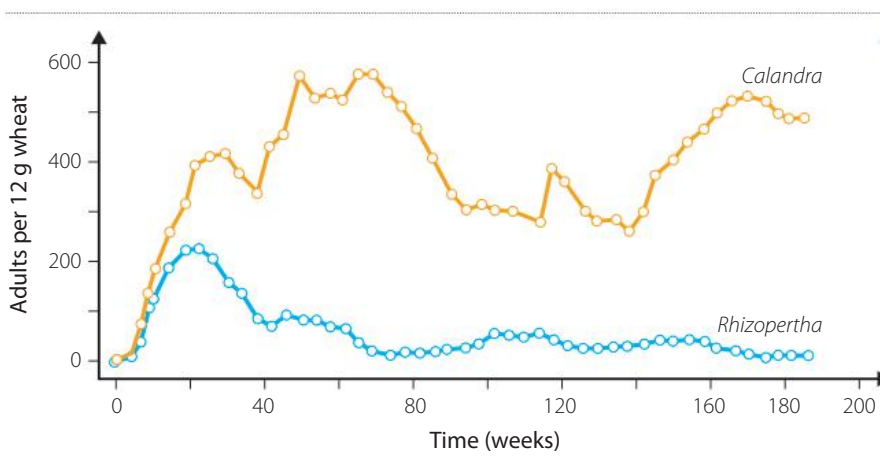


FIGURE 11.14
Numbers of two grain beetle species in competition

In 1934 in another famous experiment, G F Gause and colleagues used two species of *Paramecium* (a single-celled protozoan) to design an experimental model of competition and its effects. When *P. aurelia* and *P. caudatum* were grown in separate test tubes, they grew well. When placed in the same test tube, however, *P. aurelia* drove *P. caudatum* to extinction. It competed successfully for nutrients, but also produced a toxin that killed *P. caudatum*.

When two species compete for a resource, the short-term effect is a decrease in population numbers of one or both species.

In most instances, one species is more successful than the other and the population numbers drop more significantly than the other (due to an increase in deaths and a decrease in reproduction rates). Depending on the continued success of this one species over the other, this trend may continue. However, depending on the supply of the resource they are competing for, the ability of the 'losing' species to adapt by occupying a different niche, or depending on other environmental factors (such as temperature), this trend may change or even reverse, as Birch demonstrated.

If the trend of one species successfully out-competing another species continues, the long periods of decreased reproduction rates and increased deaths will eventually lead to the elimination of the 'losing' species in that area, and on the larger scale lead to possible extinction.

Consequences of symbiosis

The process of symbiosis has profound consequences for all life on Earth. Scientists recognise the potential of symbiosis to contribute to:

- increased evolutionary diversification – biodiversity
- the development of new species from the integration of their genetic material with each other (**symbiogenesis**)
- sources of new capabilities for organisms, which enhance evolutionary 'fitness'.

Symbiosis allows an increase in biodiversity and therefore more resilient ecosystems. For example, coral reefs are only possible because the coral (an animal) has a symbiotic relationship with photosynthetic algae. The coral reefs provide a unique environment for fish and marine invertebrates. This is an example of ecosystem biodiversity.

When eukaryotic organisms first evolved on early Earth, they lacked the capacity for aerobic respiration. It is thought that this was acquired by eukaryotic cells through the symbiosis of primitive mitochondria-like organisms around 1–2 billion years ago. This is an example of symbiogenesis – the formation of a new species by the genetic incorporation of two separate species. Aerobic respiration is an important metabolic process for all eukaryotes because it allows the efficient breakdown of glucose all the way to carbon dioxide with the production of large amounts of chemical energy in the form of ATP molecules.

Many legume plants (such as clovers, alfalfa) have an association with nitrogen-fixing bacteria (**rhizobia**). The bacteria live in the root nodules of plants. The plant supplies the bacteria with their nutritional requirements (sugar derived from photosynthesis), and in turn the bacteria supply the plant with a source of nitrogen by capturing atmospheric nitrogen gas (**nitrogen fixation**) and converting it into useful ammonia (NH₃). Plants use this ammonia to manufacture their amino acids, proteins, nucleic acids and other nitrogen-containing compounds. Scientists are aware of some rhizobia that have developed the ability to 'cheat' the plant by acquiring sugar from it, but not returning the favour in the form of nitrogen fixation. In this case, the relationship has become **parasitic**.

Therefore, symbiosis has many important consequences for the maintenance of biodiversity of life on Earth. Novel associations between living things create new opportunities to exploit the resources available in an ecosystem.

Consequences of disease

Disease can be defined as any process that adversely affects the normal functioning of tissues in a living organism. This includes infectious and non-infectious causes. In wild ecosystems, the greatest threats are generally infectious diseases.

There is usually a pool of disease-causing agents or **pathogens** (such as viruses, fungi and bacteria) already present in the environment. For a disease outbreak to occur, the pathogen must be introduced into a new host population from where the disease spreads through direct or indirect means, or it must be given a selective advantage by a change in the abiotic or biotic conditions. Human-induced changes such as climate change, deforestation, water and soil degradation may contribute to this. This may lead to an increase in the number of breeding sites for **vectors**, an invasion of an ecosystem by a new pathogen or vector, changes in resistant populations of organisms due to the use of antibiotics and pesticides (**herbicides**, **insecticides**, **fungicides**) by humans, or the lowering of resistance to disease in species due to changes in their environment. A simple change in an environmental factor that causes stress on an organism can compromise its barriers to invasion by a pathogen. Loss of habitat with overcrowding is a major factor in many disease outbreaks.

The effect of an emerging disease on an ecosystem is to alter the balance of food webs, sometimes dramatically. Affected species will suffer a decline in numbers, and this has consequences for both their prey as well as those that predate them. Of course, any disease process that emerges in the environment may have dire consequences for human populations. There is an intersection between human health and the health of the environment.

Case study: devil facial tumour disease

Devil facial tumour disease (DFTD) is a *clonally transmissible cancer* (a cluster of cancer cells that can be transmitted from animal to animal) that has spread throughout wild Tasmanian devil (*Sarcophilus harrisii*) populations. It is highly contagious. It is transmitted through social interactions: Tasmanian devils commonly bite each other around the face during fighting.

When an infected animal bites, it transmits some cancer cells into the wound. Unfortunately, the animal's body recognises these tumour cells as 'self' and does not mount an immune response. It is fatal within 6 months of transmission, although there are anecdotal reports of some animals recovering (however, some of those were subsequently reinfected). The lesions (regions of the animal's body that suffer damage) typically consist of large, ulcerated tumours around the eyes and mouth (Fig. 11.15). The animal's ability to see and therefore to find food are severely impaired. There is a possibility that the Tasmanian devil will be extinct in the wild within 25 years. In 2008, the Tasmanian devil was listed as endangered. At the time of writing, there are several reports of successful treatment of DFTD using immunotherapy with modified DFTD cells.

The *Save the Tasmanian Devil Program* was established in 2003 to coordinate a response to save the species. The response involved:

- gathering data on population distributions, breeding patterns and devil numbers
- mapping the distribution of the disease
- the retrieval of unaffected devils from the wild to establish a genetically diverse 'insurance population' free from the disease. These animals will enable the re-establishment of wild populations in the event of total extinction in the wild



FIGURE 11.15 A Tasmanian devil with advanced DFTD

- managing the ecological impacts of a reduced devil population. Tasmanian devils play a role in suppressing the numbers of feral cats, foxes and other introduced carnivores. Increases in cat populations in the wild can have consequences such as increased predation of native birds and small mammals. Cats carry the infectious protozoal disease *Toxoplasmosis*, which represents a danger to native mammals, farm animals and pregnant women
- research into the possibility of a **vaccine**. Work on a vaccine is progressing well but has not yet been finalised.

KEY CONCEPTS

- A niche refers to all the biotic and abiotic resources that a species uses.
- A niche can be fundamental or realised.
- Competition between species may be intraspecific or interspecific.
- No two species can occupy the same niche at the same time.
- All species compete for nutrition, shelter and mates.
- Predation, competition, symbiosis and disease have consequences for populations.

CHECK YOUR UNDERSTANDING

11.1c

- Distinguish between the following pairs of terms:
 - niche and habitat
 - fundamental niche and realised niche
- Provide an example of resource partitioning. Explain how it enables different species to inhabit the same habitat.
- State the consequences of the following to populations:

a predation	c symbiosis
b competition	d disease.

11.2

A recent extinction event: the Australian megafauna

Scientists are able to apply their knowledge of population dynamics to past and sometimes unexplained extinctions. The species that live on this planet now have not always been here. Species that have lived in the past may no longer be represented in the species living today. The type and number of species are constantly changing. Extinction is the death of all the members of one species. Sometimes there are major extinction events, where a number of different species have become extinct at around the same time. This is what happened to the Australian **megafauna** (Fig. 11.16).

During the Pleistocene epoch (1.6 million – 10 000 years ago), Australia was home to a group of giant animals known collectively as the Australian megafauna. Examples included *Diprotodon* (like a large wombat), *Megalania* (like a large goanna) and *Procoptodon* (like a giant, flat-faced kangaroo). Megafauna existed in Europe and North America (woolly mammoths (Fig. 11.17), sabre-toothed cats) as well as Africa (giraffes, hippopotamus, elephants (Fig. 11.18)). In fact, Africa is the only continent to retain most of its megafauna.

There have been many ‘ice ages’ throughout the 4.5 billion year history of Earth. The last ice age is the only one in which humans were present. The continents were in their current positions, and the climate was very cold and dry. Humans and many other mammals survived this epoch, but many species went extinct. The epoch we are in now is referred to as the Holocene epoch, which started 10 000 years ago. It is a period of warming called an **interglacial period**.

There is an ongoing debate as to what led to the changes in the Australian flora and fauna, particularly the extinction of the Australian megafauna. Until recently, many supported the theory that it was the result of climate change associated with the last ice age. Opponents of this theory proposed that it was humans alone who have caused almost all extinctions of animals throughout the world. Current researchers tend to think it may be a combination of the two – initiated by the change in climate, with human impact delivering the final blow.

Designer: Peter Trusler; © Australian Postal Corporation 2006.



FIGURE 11.16
Examples of the Australian megafauna as featured on a set of Australian stamps



FIGURE 11.17 The woolly mammoth is a well-known example of European megafauna.



FIGURE 11.18 Two species of African elephant still exist today, but they are endangered by human activity.

Theory 1: Changes in climate

- The continent dried out due to the ice age.
- Rainforests were contracting due to a drying climate. Because rainforests had stored moisture and returned an enormous amount to the atmosphere through transpiration, monsoon rains once penetrated south and kept the rivers and lakes in Australia full. As the rainforests diminished they were eventually replaced by eucalypt forests, but these were less efficient at retaining water. As a result, less water was returned to the atmosphere.
- As the climate became hotter and drier, fires broke out, initially due to lightning strikes, and the drier vegetation caught fire easily. Those plants and animals that could survive drought and fire reproduced and flourished, bringing about a change to the flora and fauna.

Arguments supporting climate change hypothesis

- ▶ Large animals such as megafauna, which were dependent on an ample supply of water, would have died out when water became scarce.
- ▶ They may also have died out because they could not manage the sudden change in temperature, their breeding seasons may have been affected and possibly the plants that they ate became less freely available and/or less palatable.

Arguments against climate change hypothesis

- ▶ The last ice age was probably like previous ice ages. If so, why would the last one have had such an immense effect, when there is no evidence that the previous ice ages had a similar result?
- ▶ The earlier extinctions seem to have occurred before the peak of the last ice age.
- ▶ Climate change today does not seem to select against large, slow-moving species.

Theory 2: The arrival of humans

Aboriginal people arrived in Australia about 65 000 years ago. They probably ‘island-hopped’ from the north. They were extremely successful predators.

They used fire to burn back the bush – their ‘fire-stick’ farming techniques involved burning the vegetation to regenerate grasses for the animals and for themselves. Increasing population numbers of animals meant that there would be more available for hunting.

Evidence from the Madjedbebe site (300 km east of Darwin) suggests that humans hunted the megafauna and, because the larger animals were slower, they were the ones that were killed. The smaller, faster animals that escaped survived to pass their genes on and so these populations evolved to become smaller (Fig. 11.19).

It appears that the original Indigenous people hunted Australian terrestrial animals that were larger than they were. The introduction of the dingo from Asia about 4000 years ago may have also led to a decrease in the diversity of carnivore predators. It has been suggested that the dingos drove the thylacine and Tasmanian devil to extinction on the mainland.

Arguments supporting the human hypothesis

The main evidence for the theory that humans were involved in the increase in fires is that the increased carbon deposits in fossils are about the same age (40 000 years) as the oldest archaeological sites beyond northern Australia. The smaller species of megafauna that became extinct had short limbs, which would have made them slow; the largest surviving of our present-day species are also among the fastest (for example, red and grey kangaroos).



FIGURE 11.19 Each of these Australian mammals has a megafauna ‘equivalent’

Arguments against the human hypothesis

- There is no fossil evidence of kill sites and very little evidence of humans and megafauna coexisting.
- If you consider the size of the animals, there is an overlap in the size of the smallest extinct species and that of the largest present-day species.

Theory 3: Level of nutrients

A third theory accounting for the survival of smaller animals is that there were such low levels of nutrients in the soils in Australia that this may have caused a nutrient depletion throughout the food web, resulting in smaller animals. The smaller size of mammals in Australia compared with their counterparts on other continents today could provide evidence.



Megafauna extinctions

Evidence of humans and megafauna coexisting

When two species are found at a fossil site near each other, it can be inferred that they coexisted and possibly interacted with each other. Cuddie Springs is a fossil site in central New South Wales where the bones of megafauna and stone tools made by humans have been found in close proximity. There are in fact several different layers in the Cuddie Springs deposit, each with its own unique insights into different times.

Some of the specific finds include:

- a kangaroo leg bone with signs of butchering by tools (30 000 years old)
- stone tools (around 18 000 years old)
- mixtures of megafauna bones
- charcoal from camp fires (around 28 000 years old)
- a sandstone grinding stone (around 30 000 years old).

At the time of writing, further evidence has been reported of the uncovering of Aboriginal artefacts and megafauna remains at a site north of Melbourne (Lancefield Swamp).

The debate is ongoing.

KEY CONCEPTS

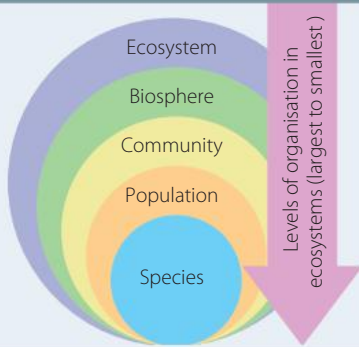
- The megafauna are a group of very large animals that were present in continents including Australia, Europe and North America.
- Most megafauna are extinct.
- Theories regarding their extinction include the influence of climate change as well as human predation and firestick farming techniques.
- Many scientists believe a combination of these factors was responsible for their extinction.
- Fossil evidence has been found of the coexistence of humans and megafauna.

- 1 Define 'extinction'.
- 2 List some of the types of animals that made up the megafauna group.
- 3 State the three theories put forward by scientists to explain the extinction of the Australian megafauna. Identify the selection pressure associated with each theory.
- 4 What evidence is there to suggest that humans and megafauna coexisted?
- 5 Why do you think scientists cannot agree as to what caused the extinction of the Australian megafauna?

CHECK YOUR UNDERSTANDING

11.2

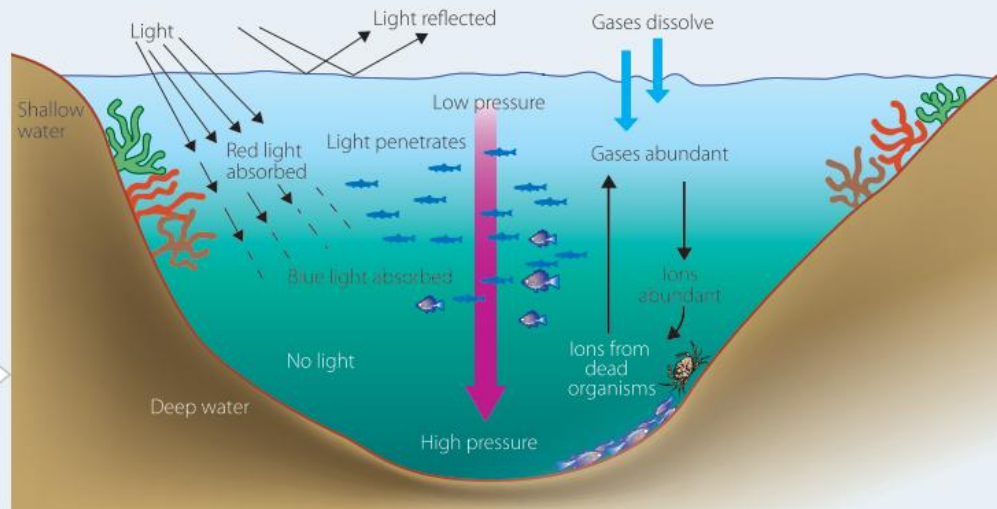
Population dynamics: What effect can one species have on another?



ABIOTIC FACTORS

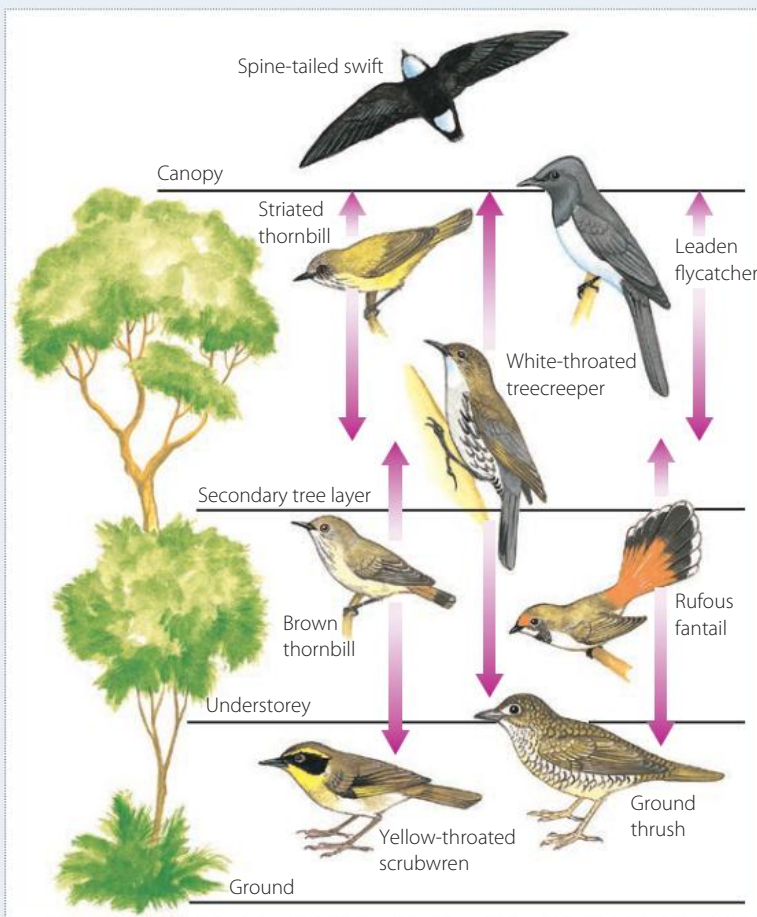
Non-living influences in an ecosystem (terrestrial and aquatic)

- Light – availability and strength
- Wind – speed and strength
- Temperature – air and water
- Water – availability
- Pressure – air and water
- Salinity – in the soil and water
- Gas – availability



Abiotic factors are *unevenly distributed* → this determines distribution and abundance of biota

A **niche** refers to all the resources that a species uses in its environment, including both biotic and abiotic factors. No two species can occupy the same niche; this is known as the *competitive exclusion principle*.



The forest provides different resources at different levels in the system. Each of these birds has access to a special set of abiotic factors.

Extinction of the megafauna

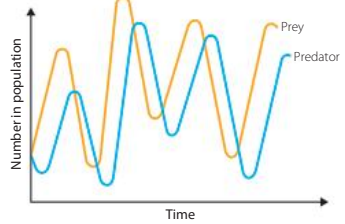
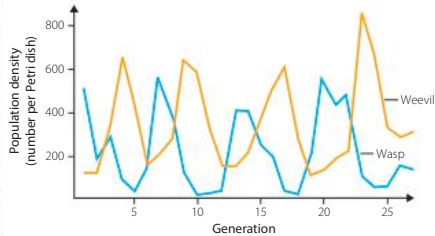


OVERHUNTING BY HUMANS?

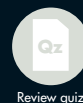
- Fossil evidence of human arrival coincides with disappearance of megafauna (both in Australia and on other continents)
- But little fossil evidence of kill sites

CLIMATE CHANGE?

- Megafauna would be less able to adapt to decreased water availability and change in vegetation
- But similar results not seen with previous ice ages

Biotic Factor		Definition	Effect
PREDATION (PREDATOR-PREY)			
Symbiosis		Feeding relationship where the predator obtains its food by killing and eating another animal e.g. the Australian bluebottle uses long stinging tentacles to capture its prey	
	COMPETITION		
		When two or more organisms use one or more resources in common such as food, shelter and mates. May be <i>intraspecific</i> or <i>interspecific</i> . They often use aggression, warning behaviours and colours. e.g. The Australian Corroboree frog uses distinct black and gold stripes as a warning. Camouflage and mimicry are other options.	
	ALLELOPATHY (a special form of plant competition)	<i>Allelopathy</i> is the production of specific biomolecules by one plant that can be beneficial or detrimental to another plant.	The plant has greater access to resources such as nutrients, sunlight and water as it creates an exclusion zone around itself.
	DISEASE		
		Disease can be defined as any process which adversely affects the normal functioning of tissues in a living organism. e.g. Devil Facial Tumour Disease (DFTD).	The effect of an emerging disease on an ecosystem is to alter the balance of food webs, sometimes dramatically. Affected species will suffer a decline in numbers, and this has consequences for their prey as well as those that predate them.
Symbiosis	COMMENSALISM	One species benefits and the other is unaffected (neither harmed nor helped) (+/0).	The advantages of symbiosis include: ■ increased evolutionary diversification – <i>biodiversity</i> ■ the development of new species from the integration of their genetic material with each other (<i>symbiogenesis</i>) ■ sources of new capabilities for <i>organisms</i>, which enhance evolutionary 'fitness'.
	PARASITISM	While one species benefits, the other suffers (usually) non-lethal damage (+/-); e.g. fleas feed on blood of their hosts but rarely kill them.	
	MUTUALISM	Where both species in the relationship benefit from the association (+/+); e.g. the clown fish shelters in the tentacles of the anemone. This lures other fish for the anemone to eat.	

11 CHAPTER REVIEW QUESTIONS



Questions 1–5 are multiple-choice questions. Select the correct response.

- 1 Abiotic characteristics are:
 - A the living components of the ecosystem.
 - B the characteristics of weather in the ecosystem.
 - C the non-living components of the ecosystem.
 - D both the living and non-living components of the ecosystem.
- 2 The concentration of oxygen in the deepest oceans is:
 - A high due to photosynthesis.
 - B high due to polar ocean currents.
 - C low due to filtering of sunlight.
 - D low due to the overgrowth of phytoplankton.
- 3 Which one of the following describes the correct conditions in aquatic and terrestrial environments?

	TERRESTRIAL ENVIRONMENT		AQUATIC ENVIRONMENT	
	TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE
A	High	High	Low	Low
B	High	Low	Low	High
C	Low	High	High	Low
D	Low	Low	High	High

- 4 When a relationship between two species results in one that benefits and the other that is not harmed, this is called:
 - A parasitism.
 - B commensalism.
 - C mutualism.
 - D allelopathy.
- 5 Which one of the following is an example of allelopathy?
 - A The growth of ferns on the sides of large trees in a coastal rainforest
 - B The cooperation of an alga and fungi to form lichen
 - C The suppression by pine trees of plant growth at their base
 - D The existence of rare species in specialised environments in Australia
- 6 Create a table to summarise the main biotic and abiotic factors affecting ecosystems.
- 7 Identify the factors that determine the number of predators and prey in an ecosystem.
- 8 Define and describe one example of each of the terms 'commensalism', 'mutualism' and 'parasitism'.
- 9 Analyse the effects of human population growth on ecosystems. Think of some products and processes that are contributing to the destruction of habitats.
- 10 Analyse the effect of a change in a population in an aquatic or terrestrial ecosystem. For example, how would the sudden disappearance of yabbies from a dam affect the population of other plants and animals in the dam?
- 11 How would the stocking of a local waterway with fish for recreational fishing affect the population of native fish?

- 12 Using an example, assess the relative contributions of climate change and human activity on the extinction of the Australian megafauna.
- 13 Analyse the effect of an outbreak of a new disease in an ecosystem. Use a current Australian example.
- 14 Define the term 'symploogenesis'. In what ways did this process allow for the development of eukaryotic cells?
- 15 Research the discoveries at Lancefield Swamp (north of Melbourne) regarding the extinct *Diprotodon*. What evidence has been found and how has this changed our understanding of the megafauna extinction in Australia?
- 16 Using specific examples, describe some positive, negative and neutral biotic interactions in ecosystems.
- 17 Some biological writers have made statements that 'humans are an introduced species'. Would you agree with this statement? Explain your answer.
- 18 Describe adaptations of a named plant or animal you have studied that helps them survive in your local environment. Explain how these adaptations help the organism survive in its environment. What could happen to this plant or animal if the environment changed suddenly?
- 19 Discuss what allelopathy is and how it helps certain plants. Provide an example.

12

Past ecosystems

INQUIRY QUESTION

How do selection pressures within an ecosystem influence evolutionary change?

Students:

- analyse palaeontological and geological evidence that can be used to provide evidence for past changes in ecosystems, including but not limited to: [CCT ICT](#)
 - Aboriginal rock paintings [ATSIHC](#)
 - geological evidence
 - ice core drilling
- investigate and analyse past and present technologies that have been used to determine evidence for past changes, for example: [\(ACSBL005\)](#)
 - radiometric dating
 - gas analysis
- analyse evidence that present-day organisms have evolved from organisms in the past by examining and interpreting a range of secondary sources to evaluate processes, claims and conclusions relating to the evolution of organisms in Australia, for example: [\(ACSBL005, ACSBL027\)](#) [CCT ICT](#)
 - small mammals
 - sclerophyll plants
- investigate the reasons for changes in past ecosystems, by:
 - interpreting a range of secondary sources to develop an understanding of the changes in biotic and abiotic factors over short and long periods of time [\(ACSBL025, ACSBL026\)](#) [ICT](#)
 - evaluating hypotheses that account for identified trends [\(ACSBL001\)](#) [CCT](#)

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How do we even begin to build an accurate account of changes in life and the environment? When forensic scientists reconstruct and analyse a crime scene, they use *Locard's principle of exchange*, which states that every contact made by a person leaves a trace – a kind of ‘silent witness’ – against the perpetrator of the deed in the form of an exchange of materials such as fingerprints, DNA or fibres (Fig. 12.1). Similarly, every change in the abiotic and biotic factors in an ecosystem leaves a trace of evidence behind. Scientists have learned over the years to recognise and collect this evidence.



FIGURE 12.1 Forensic scientists use clues to infer events at a crime scene.

Coupled with and compared to changes in the fossil record, it has been possible to link these changes in the environment, which we know as selection pressures, to changes in the abundance, distribution and types of species. It is therefore possible to see the influence that past changes in the environment have on the **evolution** of living things. This allows scientists to *infer* (come up with an explanation based on evidence and reasoning) possible future effects of environmental change on living things.

As technology has improved, so has our ability to identify and gather evidence, to more accurately analyse it and build a more complete picture of the past. In this way, scientists have been able to reconstruct a **timeline** of life on Earth and make hypotheses about the appearance and disappearance of living things in relation to major changes in the environment.

12.1

Analysing palaeontological and geological evidence

The word ‘palaeontology’ was first used in a French scientific journal in 1822 by Henri Marie Ducrotay de Blainville (Fig. 12.2). During the early 19th century, there was a growing interest in the collection and study of fossils.

Search for evidence of past ecosystems

There is great uncertainty as to when humans *first* became interested in fossils. Burial remains of Neandertals reveal that they often used jewellery to adorn their dead (Fig. 12.3), and it is possible that many of these sites were raided for their treasures. Many Egyptian tombs were raided by modern humans for the amazing treasures they contained. We can assume ancient humans probably did the same.

Even the early Greek and Roman philosophers hinted in their writings that fossils may have been evidence of previous life forms. However, Aristotle (384–322 BCE), a very famous Greek philosopher, suggested that they were ‘failed’ attempts at life, which was attempting to spontaneously generate from the soil! During the Middle Ages, many people attached great spiritual significance to the discovery of fossils, often attributing the demise



FIGURE 12.2 Henri Marie Ducrotay de Blainville



Palaeolithic jewellery

FIGURE 12.3

Both Neandertals and palaeolithic humans used elaborate burial rituals and adorned their dead with jewellery.



DK Images / Dorling Kindersley; Luigi Galante



FIGURE 12.4 A piece of an original manuscript of Leonardo da Vinci showing his drawings of local geological features

The Cainozoic era spans from 65 million years ago (mya) to the present. It is often referred to as the 'Age of Mammals'.

of the organisms to the work of evil in the world. Some even argued that fossils were the remains of creatures that perished in the great global flood depicted in the literature of many ancient cultures.

The first hints of a truly scientific interpretation came with Leonardo da Vinci (1452–1519 CE), an Italian artist and scientific thinker, who refers in his unfinished manuscripts to the **Cainozoic** mollusc fossils near his home in northern Italy (Fig. 12.4). He concluded, well ahead of his time, that these shells were buried in marine sediment that was thrown upward by some unknown process.

A breakthrough in the understanding of the fossil record came when Nicolas Steno (1638–86 CE) published his work on the principles of stratigraphy in 1669 (Fig. 12.5). His laws of superposition, original horizontality, lateral continuity and cross-

cutting relationships established the rules for relative dating that are still used today to reconstruct events in past environments.

The law of superposition states that in any sequence of rocks that is undisturbed, the oldest layers will be at the bottom and the youngest layers at the top.

The law of original horizontality states that all sedimentary strata are deposited horizontally to start with and only tilt or bend due to subsequent forces (tectonic forces that Steno had no knowledge of in his day).

The law of lateral continuity states that a stratum of rock will be continuous until something disturbs it (such as erosion or igneous intrusion).

The law of cross-cutting relationships states that in any rock sequence, the layer that crosses or intrudes another is the younger rock layer.

At this time, the great age of the Earth was not yet fully understood. Many thought it was merely thousands of years old. Yet progress had been made towards understanding the way in which changes

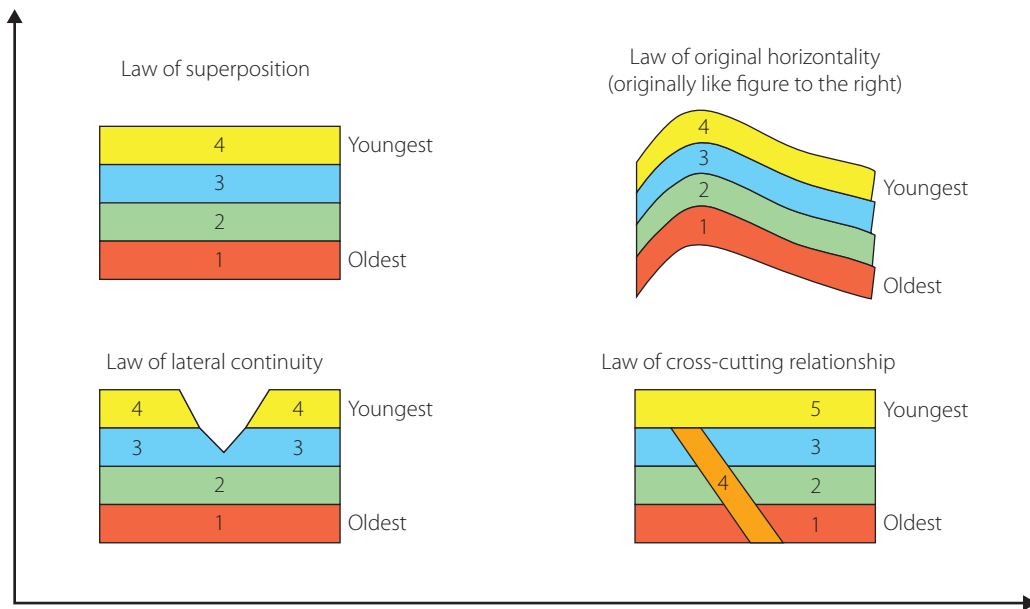


FIGURE 12.5 Steno's principles of stratigraphy help modern scientists recreate past events.

occur. Up until this time, the idea of **catastrophism** was the major ideology for explaining the way the Earth came to appear as it does. 'Catastrophists' believe that changes on Earth happened as sudden and catastrophic events such as earthquakes and floods. There was no need for long periods to explain things.

The next great wave of discovery in geology came with a new idea that changes in the Earth's crust happened because of slow and progressive causes (for example, long cycles of erosion and deposition of sediments) over long periods. This is known as **gradualism**. Scientists such as James Hutton (1726–97) and Charles Lyell (1797–1875) made major contributions to this idea and gathered much evidence in support of it. In fact, Charles Lyell's book, *Principles of Geology*, and Hutton's work, *Theory of the Earth*, had a major influence on the thinking of Charles Darwin. This gave Darwin the timescale needed for his small changes over long periods in order to establish the principle of evolution by natural selection. The first **geological timescale** was constructed in 1841 based on all this work.

The discovery of radioactivity in 1896 by Henri Becquerel (1852–1908) enabled the establishment of absolute dating methods whereby materials could be given an age in years. The invention of this technology vastly increased the accuracy of the geological timescale. By the time this technique was perfected, the age of the Earth had been estimated at 4.5 billion years old.

Palaeontology is the scientific study of fossils and all aspects of extinct life. **Geology** is the scientific study of the origin, history and structure of the Earth as recorded in the rocks. These two studies are valuable in combination to produce evidence from the past. The history of palaeontology is one in which scientists work collectively and gather data through the years to piece together a more holistic story of the journey of life on Earth. Although most organisms are not preserved, there is still a vast amount of evidence to be discovered. A thorough knowledge of the abiotic and biotic factors affecting ecosystems today is vital if we are to infer the nature of past ecosystems from the evidence they leave behind.

The evidence that scientists use to reconstruct past ecosystems is often referred to as **proxy data** (a *proxy* is one who represents or has the authority to stand in the place of another and act as their

spokesperson). This emphasises the fact that in the place of the actual organism we must make certain inferences based on evidence that these organisms leave behind. This may be geological evidence such as an imprint, a simple chemical signature or even a cast or mould of an organism (an 'impression fossil'), evidence of atmospheric changes trapped in **ice cores**, and any evidence of past ecosystems and organisms left behind by human populations, such as Aboriginal rock paintings that depict past Australian flora and fauna.

Aboriginal and Torres Strait Islander histories and cultures



Aboriginal art probably represents the longest unbroken art tradition in the world. It is yet to be confirmed if it predates the Lascaux cave art in France and Hohle Fels cave art in Germany (which are up to 40 000 years old), attributed to European palaeolithic humans. Humans are artistic by nature, driven to record details and impressions of their surroundings, how they lived with them, the climate of the time and the animals and plants they interacted with, as well as their spiritual beliefs. Ancient Aboriginal artworks are invaluable sources of primary evidence for scientists who wish to understand the change in ecosystems in Australia.

The *West Kimberley rock paintings* (Wandjina and Bradshaw paintings) are located in the remote north of Western Australia (Fig. 12.6). The Wandjina paintings (Fig. 12.7) have been conservatively dated at 50 000–60 000 years old. In this region there are thousands of individual sites where paintings are located. These paintings give scientists clues about when and how people arrived in the area, the environments at the time, how they lived and adjusted to changes in the climate and landscape, and the effect of climate change on local flora and fauna. The first European to describe the paintings was George Grey, in the 1830s. Since 2007, there has been a concerted effort to study them scientifically. Scientists at the Australian National Nuclear Research and Development Organisation are using the latest **radiometric dating** methods to give accurate dates for the paintings. Uranium/thorium dating can be applied to the underlying calcite formations to determine when they formed.

Radiometric dating is discussed on page 347.

FIGURE 12.6
Location of the
Kimberley region of
Australia



The Bradshaw paintings are distinct from the Wandjina paintings in their style. They are typically silhouettes of humans with accessories, but there are also images that appear to depict the extinct megafauna *Thylacoleo* (*Thylacoleo carnifex*), as well as the *thylacine* (*Thylacinus cynocephalus*; Fig. 12.8). The Bradshaws are believed to be up to 40 000 years old. Scientists are using the latest techniques in absolute dating to get an accurate chronology for the site. One scientific curiosity about this site is the relationship between the chemical pigments and the symbiotic fungi and bacteria that have colonised the pigment and added to the richness of the colour. Scientists are hoping to be able to use DNA sequencing of these microbes to further their knowledge of the time sequence of the artworks, as many are superimposed on one another. The types and numbers of animals depicted in the paintings changed over time. This has been interpreted by many as indicating a series of climate changes. Around 40 000 years ago, the area consisted of lush, open *tropical* forests. There is evidence that approximately 10 000 years ago there was a decrease in rainfall and a cooling period, coinciding with the most recent *glacial period*. The main ecosystems represented are scrub and open *grasslands*. With the end of the ice age, an Australian summer monsoon climate pattern emerged. Every now and then, however, there is a failure of the monsoon, which causes drought. This drought is depicted in the artwork.

The *Keep River rock art site* is a rich source of information on the types of flora and fauna that predominated. They are valuable in that they show at least four distinct changes in the types of animals that are depicted. There are over 18 000 individual paintings and 117 individual sites. In the most recent of the artworks, there is a higher percentage of reptile depictions (Fig. 12.9). Some have suggested that this represents a change in the ecology of the area. An increase in wetlands may explain the increase in reptile depictions.

KEY CONCEPTS

- Aboriginal rock art represents a record of human observations of the environment dating back as far as 40 000 years.
- The art depicts the flora and fauna of the past and changes in their abundance.
- Scientists can place these observations in context with scientific data to form a more comprehensive picture of past ecosystems and the changes that took place in them.



FIGURE 12.7 Wandjina rock art depicting insect life



FIGURE 12.8 Depiction of a thylacine in the Bradshaw rock art paintings



FIGURE 12.9 Goanna depiction, Keep River

- 1 Identify some of the discoveries that contributed to a more accurate picture of Earth's natural history.
- 2 Describe the principles by which scientists can put past natural events in order of their occurrence.
- 3 Using examples, justify the use of ancient art in the reconstruction of past environments.
- 4 Define the following terms: palaeontology, gradualism, infer.
- 5 Name an area in Australia that is rich in Aboriginal rock paintings.
- 6 State the types of animals that are depicted in Aboriginal artwork. Why do you think the Aboriginal people chose to paint these animals?
- 7 Why are Aboriginal rock paintings a valuable resource for scientists?

CHECK YOUR UNDERSTANDING

12.1a



FIGURE 12.10 The 'scene of the crime': the long bone of a large dinosaur found at Lago Barreales, Argentina. Dinosaurs were victims of a mass extinction around 65 million years ago.



FIGURE 12.11 Volcanic ash and aerosols act as selection pressures within ecosystems. They also leave a record of the chemical and physical features of past eruptions in layers of rock. Each eruption has a unique chemical 'signature'.

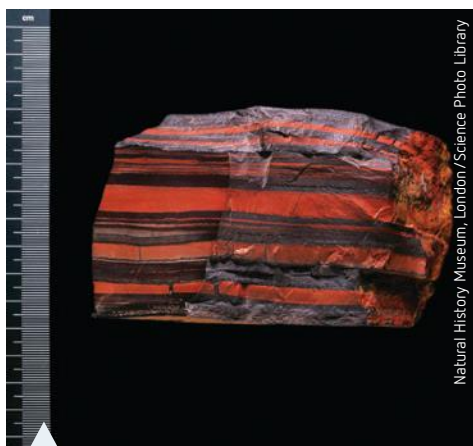


FIGURE 12.12 A banded iron formation showing alternating iron-rich and iron-poor layers

Geological evidence

The introduction to this chapter outlined the importance of gathering and analysing forensic evidence at a crime scene (Fig. 12.10). An important consequence of this is that it allows the reconstruction of a *timeline of events*. Timelines improve the ability of scientists to infer cause and effect. This is critical for managing present-day ecosystems.

The geological timescale is a scientific model that allows scientists to represent the course of changes in geological and fossil deposits and link these to evolutionary changes in ecosystems. For example, a massive deposit of volcanic ash in a rock layer may immediately precede a rapid decline in the abundance of fossil evidence for certain species. Scientists may infer that a volcanic eruption has changed the environment in such a way as to make it unfavourable for that species. One explanation could be a reduction in light intensity due to ash in the atmosphere. Also, widespread cooling due to volcanic aerosols such as sulfur dioxide may render the environment unfavourable to plant life and ectothermic organisms. Sulfur dioxide aerosol particles reflect sunlight back into space (Fig. 12.11).

Banded iron formations

Banded iron formations (Fig. 12.12) are a form of geochemical evidence found in Australia and other continents. Scientists think that Earth's atmosphere has undergone many changes, with the change from anaerobic (oxygen-poor) to aerobic (oxygen-containing) around 1.8–2.5 billion years ago being one of the most notable. Banded iron formations are geological formations consisting of alternating bands of iron-rich and iron-poor sediments. But how did they form?

The current explanation is that when the oceans first formed, they contained vast amounts of soluble iron in its reduced state (Fig. 12.13). The appearance of photosynthetic prokaryotes (such as cyanobacteria) in the oceans led to an increase in the oxygen concentration in the ocean, leading to the **precipitation** of insoluble iron oxide. This precipitate accumulated at the bottom of the ocean, forming an iron-rich layer of sediment. The build-up of oxygen in the oceans led to the large-scale death of cyanobacteria and the subsequent deposition of iron-poor sediments until the populations of cyanobacteria built up again. Periodic deposits of iron-rich and iron-poor sediments built up and **lithified** (turned to stone). Uplift and erosion exposed these sedimentary formations.

These geological formations are yet another window into the environment of the past. The Great Oxygenation Event took almost two billion years and during this time Earth's atmosphere was transformed. This type of selection pressure has important implications for living things. Scientists now think that there was probably limited aerobic respiration prior to the oxygenation event.

The increase in oxygen in the atmosphere had two consequences. It created a selection pressure for those organisms who could overcome the harmful effects of oxygen. Some oxygen **metabolites** (such as hydrogen peroxide and hydroxide radicals) are toxic, and only organisms with specific new metabolic pathways could take advantage of the benefits of oxygen without succumbing to its toxic effect. These metabolic pathways were selected for and allowed the rise of aerobic respiration. This allowed for the development of larger and more complex multicellular organisms.

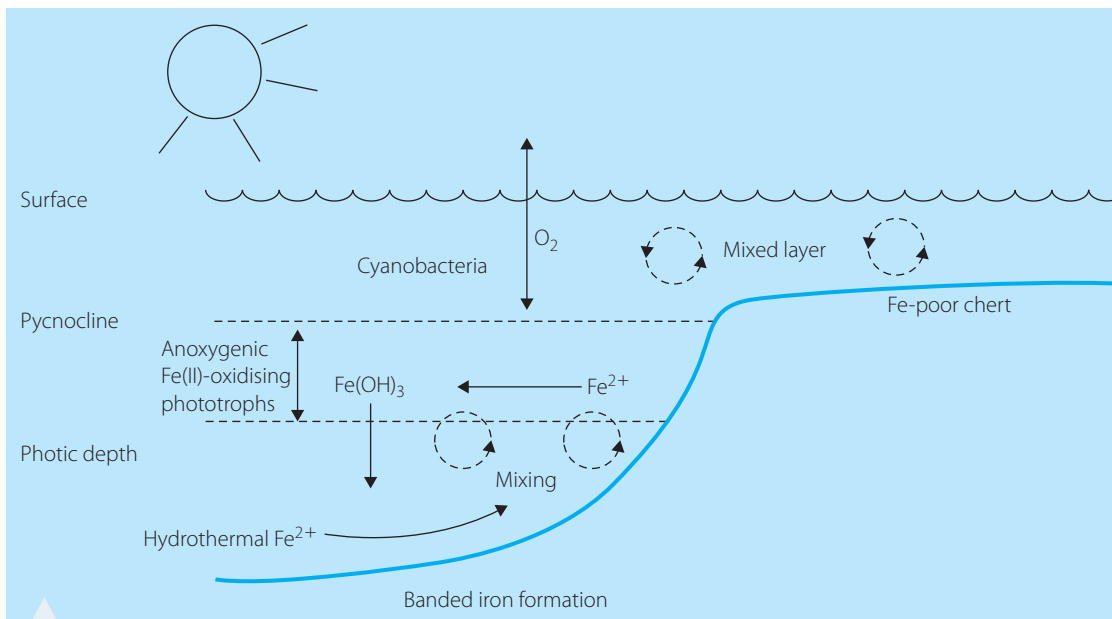


FIGURE 12.13 The chemical processes leading to the deposition of banded iron formations

Palaeontological evidence – fossils

The word ‘fossil’ comes from the Latin word *fossus*, which means ‘to be mined, dug up, buried or quarried’. Fossils are the remains of living things or evidence of their past existence. When scientists attempt to link changes in selection pressures to the evolution of living things, they look for clues in the fossils. This may vary from macroscopic (visible with the naked eye) remains, such as casts and moulds, to single molecules that are found exclusively in living things – so-called ‘geochemical remains’. Sometimes the tiniest clues, such as an impression in a rock or a tiny trail, can give clues to the past presence of a living organism.

Often these clues must be distinguished from naturally occurring patterns in rocks and minerals that may mimic the appearance of a living thing. For example, some dendritic (branching) forms of mineral crystals resemble ancient plants. Often the appearance of fossils gives us clues to the climate and environment at the time; for example, certain types of crocodile species are found only in warm, humid environments, and certain types of plankton exist only in cooler climates.

Fossils are generally found in **sedimentary rocks**. This is because the processes that create these rocks can sometimes preserve evidence rather than destroy it. Sedimentary rocks generally form in water as layer upon layer of sediment (such as sand and mud) is deposited. Igneous rocks form from lava or magma, and their heat destroys biological material. Rocks undergoing metamorphic formation are subjected to extremes of heat and pressure that are rarely compatible with preserving biological material.

There are many ways to classify fossils. Here is one useful method:

- mineralised remains such as moulds and casts (Fig. 12.14), petrified wood and opalised remains
- organic remains (for example, the preservation of soft and hard tissues in ice, amber, bogs and dry caves, as well as carbonised remains)



FIGURE 12.14 Fossil moulds and casts of extinct ammonites

- impressions – the shape of the external organism recorded in sediment
- trace fossils, which are the remnants of organic molecules or other signature atoms associated only with life. These are also known as ‘geochemical remains’ and require advanced technology to detect.

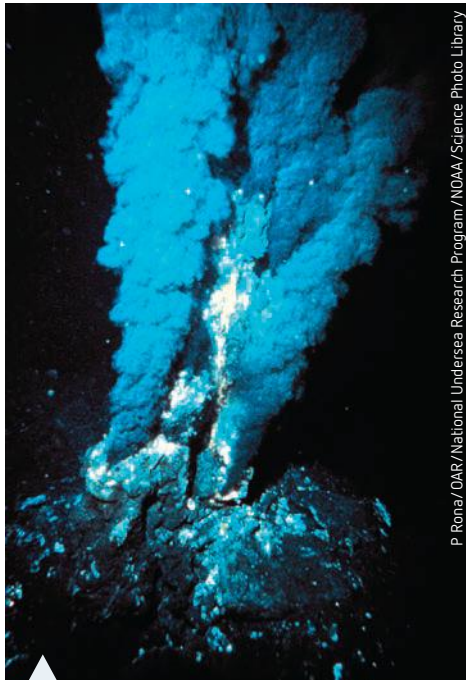


FIGURE 12.15 Hydrothermal vents occur in volcanically active areas on the ocean floor.



FIGURE 12.16 Fossilised stromatolites from Wyoming, USA

Microfossils and stromatolitic fossils

The discovery of 3400–3500mya Precambrian fossils from Marble Bar, Western Australia, in silica-rich apex **chert** (a form of microcrystalline quartz) provided some of the first evidence of the nature of past ecosystems on Earth. **Microfossils** of single-celled, filamentous anaerobic prokaryotes were found. When scientists examined their features, they were found to closely resemble modern examples living today around deep-sea **hydrothermal vents** and volcanic hot springs. From this it can be inferred that these organisms lived in a hydrothermal environment. In fact, thermophilic (heat-loving) microbes are commonly found today in areas where volcanic hot springs exist, such as Yellowstone National Park (USA), areas in the North Island of New Zealand, and Japan. They are anaerobic and sulfur-metabolising (**chemosynthetic**) micro-organisms. Scientists can infer that chemosynthesis may have been the earliest way that organisms built organic molecules, even before the advent of photosynthesis. The discovery of these fossils was a window into ecosystems that existed on Earth billions of years ago.

Chemosynthesis is a process whereby organisms use **inorganic compounds** available to them from their environment, such as sulfur-containing compounds, to manufacture their organic molecules. This process does not require sunlight and can therefore happen in deep ocean environments, such as at hydrothermal vents where volcanic activity is high (Fig. 12.15). Absence of light is therefore a selection pressure.

Another significant discovery came in the form of unusually shaped fossils called **stromatolites** found in Archaean chert at Bitter Springs, Northern Territory. These fossils have been dated to around 3.5 billion years old. The fossilised remains of stromatolites (Fig. 12.16) provide valuable information about the structure of early organisms and the environment

in which they lived. Many of these existed in structures that were very much like present-day stromatolites. In water, colonies of photosynthetic cyanobacteria trap layers of calcium carbonate and ‘grow’ upwards in columns towards the sun. Deposits of living stromatolites can be found in Western Australia at Hamelin Pool, Shark Bay, growing at a rate of about 1 mm per year, with individual domes reaching a diameter of about 200 cm and a height of 50 cm.

Many selection pressures affected the evolution of stromatolites. Modern stromatolites (Fig. 12.17) are found in sheltered bays, which create a unique combination of abiotic conditions.

Shallow water produces increased light intensity for photosynthesis as well as warm, still water, which allows the stromatolites to grow without disturbance from grazing snails, worms and fish. The water is mineral rich and hypersaline. There are some modern examples of freshwater stromatolites in Turkey and Canada, as well as a very rare example in Jenolan Caves (Nettle Cave), south of Sydney, which grows near the light, open ends of the cave. Scientists can infer that similar conditions must have existed in areas where fossil stromatolites are currently found.

As stromatolites became more common around 2.5 billion years ago, their effect on Earth's hydrosphere and atmosphere was profound. These photosynthetic cyanobacteria produced oxygen as a by-product, eventually leading to the development of an oxygenated atmosphere (or **oxic** atmosphere). An oxygenated atmosphere allowed for the gradual development of larger and more complex aerobic life forms.

One of the selection pressures in a pre-oxygen atmosphere was the high level of **ultraviolet (UV) radiation** penetrating Earth's atmosphere. Living in water conferred some protection, but almost certainly UV radiation precluded the movement of living things onto land. UV radiation interacts with DNA to cause cell death or damage due to mutations. With the rise in free oxygen, a rise in the **ozone O_3** concentration in the **stratosphere** followed. Life was now able to move onto land without succumbing to the harmful effects of UV radiation, which was screened out by the ozone layer.

The preservation of microbial fossils depends on a range of chemical and physical conditions that ultimately determine the quality of the information preserved in the geological record.

In general, palaeontologists using the fossil evidence from different rock layers have found more primitive cells and marine organisms in lower rock layers compared to the more complex, land-dwelling organisms in the upper rock layers.

We can make inferences about extinct organisms by studying their closest modern living relatives. By examining their ecosystems today, we can make inferences about the selection pressures faced by ancient organisms and understand more clearly how their structures enabled them to compete successfully for resources.

Palaeosols

Palaeosols are 'fossilised soils'. Soils that contain unusually large concentrations of carbon compounds usually indicate the presence of life. Some of these soils have been found in South Africa. Geologists also recognise palaeosols that formed under environmental conditions that are no longer present where the fossil soils are found. For example, they may indicate the presence of a soil that formed in a tropical environment but the palaeosol may have been found in an **arid** region. Therefore, palaeosols are useful for reconstructing a timeline of past environments.

Palaeosols have also been used to reconstruct the timeline for the development of the oxic (oxygenated) atmosphere. The chemical profiles of the soils are affected by interactions with the gases in the atmosphere and with gases produced by living things.

Molecular biomarkers

Molecular biomarkers or *fossil molecules* are trace evidence of the existence of a living thing found in rocks and soils. They are produced only through biological activity. The oldest of these are generally pigments in sedimentary rocks, but may include evidence of **nucleic acids**, **carbohydrates**, **lipids** and **amino acids**.



FIGURE 12.17 Modern stromatolites, Shark Bay, Western Australia

The fragility of nucleic acids (DNA, RNA) means that they are very unlikely to be fossilised. The **polymerase chain reaction** is a technology that has helped to increase the genetic material available for analysis. The technology to analyse biomarkers was not available until relatively recently, so it is an emerging field. Biomarkers are most likely found in kerogens (precursors of petroleum; Fig. 12.18), shells and bones, rocks such as shale (Fig. 12.19), and coal samples (Fig. 12.20). Evolutionary relationships between organisms may be inferred by these biomarkers and help to build a more accurate geological timescale.

Biomarkers are also useful for identifying past human activity. Cores from peat and lake sediments (Fig. 12.21) are commonly used for this purpose.

Isotopes such as carbon-13 are biomarkers that have been found in grains of a mineral called apatite in Western Australia's oldest rocks. There is no process known to cause this accumulation other than the progressive chemical alteration of organic remains. These ancient minerals are thought to be around 3800 million years old. As scientists improve these delicate chemical techniques, **exopalaeontologists** (those who search for ancient life on other planets) will be better equipped to identify the chemical signature of ancient life in soils such as those on Mars (Fig. 12.22).



FIGURE 12.18 Kerogen



FIGURE 12.19 Shale



FIGURE 12.20 Coal



FIGURE 12.21 Lake sediment core sample showing layers that indicate depositional events



FIGURE 12.22 In the coming decades, human beings will visit Mars and continue the analysis of the soils for biomolecules that may indicate evidence of life on Mars.

INVESTIGATION 12.1

A primary- or secondary-source investigation of plant and animal fossils

BACKGROUND INFORMATION

Fossils are the remains of organisms or any evidence of their existence that is preserved over a long period. It is generally accepted that the evidence needs to be at least 10 000 years old to be called a fossil. Scientists generally consider any younger material to be 'recent'. The end of the Pleistocene period is marked by this date. The Pleistocene epoch is the period between 1.8 mya and 11 700 years ago. It covers the most recent period of glaciations. It is often referred to as 'the Ice Age'.

It is an extremely rare occurrence for an organism to be fossilised since it requires very specific conditions at the time of its death. There are four main conditions:

- 1 quick burial – rapid covering of the dead organism or evidence such as footprints or coprolites (faecal remains)
- 2 prevention of decay – reduced oxygen, low pH, low temperatures and low moisture to help prevent decay by fungi and bacteria
- 3 the organism lies undisturbed – completely covered by sediments to prevent **scavenger** organisms from breaking up and scattering body parts, little tectonic activity (earthquakes and volcanic eruptions, igneous intrusions)
- 4 the presence of hard body parts – for fossilisation to occur, organisms generally need hard parts, such as bone, exoskeleton, teeth or shells. This does not completely exclude the preservation of soft parts. The Ediacaran fauna (Figs 12.23 and 12.24) were a diverse group of organisms that existed just before the Cambrian period. They were multicellular and soft bodied. Evidence of imprints was discovered by Reginald Sprigg in the Flinders Ranges, South Australia, in 1946. The imprints were well preserved because the silt they were buried in was fine grained. They also suggest burial in sediment in a very still body of water.

AIM

- 1 To gather primary or secondary information on plant and animal fossils from printed material and online sources
- 2 To infer from fossil evidence the types of environments in which these organisms lived

METHOD

Gather primary or secondary information on a variety of plant and animal fossils. Primary sources include using actual fossil samples you may have at school, or perhaps observing collections of fossils at a local museum or fossil site. Secondary sources include printed material from your school library or online material. In your search, collect photographs or diagrams of at least four named plant and four named animal fossil specimens. Some fossil examples are provided in Figure 12.25.



FIGURE 12.23 The Ediacaran fauna – an artist’s reconstruction of a past ecosystem using the fossil record



FIGURE 12.24 An example of Ediacaran fauna – *Dickinsonia costata*, a soft-bodied multicellular organism that left an impression preserved in fine sediments

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FIGURE 12.25 Fossils: **a** trilobite – extinct organism found only in rocks dated around 500 mya; **b** fossil bones of baby diprotodont (a large, herbivorous marsupial) found at Riversleigh, Queensland (one of the richest fossil deposits in the world); **c** fossil impression of an extinct seed fern; **d** *Baragwanathia longifolia*, plant fossil found in Victoria, preserved with planktonic marine organisms (graptolites)

Some of the following observations could be made about photograph c:

- fern-like appearance
- only a sample of one fern frond or branch (not an entire plant)
- similar to present-day fern appearance
- leaflets are opposite to each other and contain vein-like structures.

You may also comment on the relative size of the organism.

Some suggested fossils to research include:

- the Wollemi pine
- *Gangamopteris* and *Glossopteris*
- *Archaeopteryx*
- coelacanth
- ammonites
- trilobites
- bivalves.

RESULTS

- 1 Create a table to summarise your findings. You should include the name of the fossil, your description, any interesting facts about the fossil, such as the site it was located, features of the organism and what type of ecosystem it is likely to have lived in, as well as your diagram or photograph.
- 2 Create a timeline to show the chronological relationship between the fossils viewed. Outline on the timeline the environment in which each existed.

DISCUSSION

- 1 Which structural features helped them to survive or withstand the selection pressures at the time before they became extinct?
- 2 What do you think were the selection pressures in the ecosystems that may have led to their extinction?

Fossils located
in the Australian
environment

INVESTIGATION 12.2

A secondary-source investigation: evolution of life timeline

There are many more divisions on the geological timescale the further forward in time you look. This is because of the difficulty of locating evidence of environmental changes or fossils in very ancient rock. Tectonic processes and meteor bombardment may have destroyed much evidence. More recent organisms are better preserved and available, so our timescale is more detailed, especially from the Phanerozoic eon onwards. In this activity, you will find that your timeline becomes much more 'crowded' the closer to the present that you come.

AIMS

- 1 To gather, process and analyse information about the types of organisms that have arisen over the past 4500 million years
- 2 To construct a timeline of the major selection pressures in ecosystems driving the evolution of living organisms, from the first organisms in anoxic environments until today

METHOD

Part A: Gather, process and analyse information

When gathering information, use a variety of secondary sources in your search, such as scientific journals, Internet sites, textbooks, library reference books, CD-ROMS, newspaper articles and experts in the field. Search engines such as EBSCOhost Research databases are invaluable for finding the latest information and may be available on your school website. Using a variety of sources increases the reliability of your information. Using recent sources, especially scientific journal articles, increases the likelihood of finding better quality information. After you have sourced the information, you need to analyse and select the information relevant to this task.

Ask yourself the following questions when researching secondary data (CRAAP method):

- What is the source of the URL (.com, .edu, .gov, .org, .net)?
- Is this website up to date (when was it published?)? → Currency
- Is the information relevant and targeted to the appropriate audience and level? → Relevance
- Who is the publisher or author and what are their qualifications? → Authority
- Is the website generally free of inaccuracies and bias? Do other sources make similar claims? → Accuracy
- What is the author intending to do – inform or persuade? → Purpose

Part B: Constructing a timeline

Once you have processed and analysed the information to obtain the dates for the evolution of different life forms over time:

- Draw a timeline to scale (for example, 1000 million years = 10 cm).
- Cover all eras and periods up to the present day.
- Use A3 or several A4 sheets joined together.
- Start adding the names of each organism type you have collected in each time interval.
- Diagrams of the organisms or their fossils may be added to enhance your timeline.
- Make sure you have covered key times in Earth's history.

RESULTS

After you have completed the timeline, confer with other members of the class to ensure that you have not left out any important points along the timeline.



Critical and creative thinking



Literacy



Information and communication technology capability

Peer review is a process whereby the work of an author, usually scholarly, is evaluated by experts in the field before it is published. This process acts ensure that published scholarly works are valid, accurate and original.



» DISCUSSION

- 1 Describe the distribution or spread of organisms throughout time.
- 2 List five of the most significant changes in organisms over time.
- 3 Discuss why there may be slight differences between your timeline and those of other members of the class.
- 4 Identify at least three times where changes in organisms can be linked directly by scientists to changes in the environment.
- 5 When gathering your information for this task, how did you ensure your information was accurate, valid and reliable?

The geological timescale

Scientists have gathered information about life in the past through varying types of fossil evidence and constructed a geological timescale. The timescale is divided into a series of eons, eras, periods and epochs (in decreasing duration). Lines are drawn across the scale where an event has occurred to represent a major event in Earth's history that has led to the appearance or extinction of species. For example, the division between the Cretaceous and Tertiary periods represents a mass extinction event occurring approximately 65 mya – the Cretaceous–Tertiary (or KT) extinction – which resulted in the disappearance of around 65 per cent of the organisms in the fossil record as well as the appearance of many new species. Geological timescales are the result of scientists gathering and analysing massive amounts of data and constructing a timeline.

Table 12.1 gives you an idea of the major stages in the evolution of living things.

TABLE 12.1 The geological timescale

STAGE OF EVOLUTION	NUMBER OF MILLION YEARS AGO	OXIC OR ANOXIC ENVIRONMENT	CHANGES THAT OCCURRED	EXAMPLES OF LIFE AND EVIDENCE
Organic molecules	4500	Anoxic	- Organic molecules (e.g. amino acids) form from inorganic molecules. - Atmosphere consists of N₂, NH₃, H₂O, CO₂, CO and CH₄; water vapour condenses to form seas; there are high levels of ultraviolet radiation, lightning and volcanic activity.	N/A
Membranes	4000–3500	Anoxic	- Membranes may have enclosed chemicals within a microstructure to control metabolic reactions. - Proteins or nucleic acids may have been able to replicate.	N/A
Prokaryotic heterotrophic cells	3500–2500	Anoxic	- Cells may have obtained their energy from the organic molecules in their environment. - Cells may not have had membrane-bound organelles.	- Evidence of microfossils - Bacteria
Prokaryotic autotrophic cells	2500–2000	Anoxic and oxic	- Ozone layer forms. - Cells may have developed the pathway to make their own nutrients (photosynthesis).	Evidence of stromatolites (cyanobacteria)



STAGE OF EVOLUTION	NUMBER OF MILLION YEARS AGO	OXIC OR ANOXIC ENVIRONMENT	CHANGES THAT OCCURRED	EXAMPLES OF LIFE AND EVIDENCE
Eukaryotic cells	2000–1500	Oxic	- Single cells may have developed from prokaryotes to increase metabolic efficiency. - First eukaryotic cells may have appeared with a nucleus, using cyanobacteria as chloroplasts and bacteria as mitochondria. - Some of the simple prokaryotic cells may have engulfed other cells, which became internal structures or organelles; the resulting organisms evolved into first eukaryotic cells. - Eukaryotic cells may have advanced to form membrane-bound organelles such as mitochondria.	- Protozoans and algae - Evidence in deposited banded iron formations (oxic environment) - Evidence to support this comes from mitochondria having their own nucleic acids
Colonial organisms	1500–1000	Oxic	Many cells may have worked in a cooperative group.	<i>Volvox</i> - Slime moulds (which can exist at times in colonies of up to 50 000 cells and search for their food supply) - Sponges and corals
Multicellular organisms	1000–500	Oxic	Cells may have been more organised to become specialised and work together as a multicellular organism (forming into tissues, then from tissues into organs).	- Evidence of multicellular animals in Ediacaran fauna around 640–680 mya - Simple organisms such as sponges, jellyfish and coral - More complex organisms such as worms, echinoderms (sea stars, urchins) and algae

KEY CONCEPTS

- Geological evidence and palaeontological evidence provide clues to past ecosystems.
- All living things can leave a trace of their existence.
- Evidence may include macroscopic clues such as impression fossils, moulds and casts, mineralised remains or whole remains.
- Geochemical remains include remnants of organic molecules or isotopic ratios only associated with living things.
- Changes in the atmosphere can leave traces in the rock record, such as banded iron formations.
- The geological timescale is a scientific model that represents past natural events in order and allows scientists to infer cause and effect.

- Define the term 'fossil'.
- Briefly summarise the main types of fossils.
- Describe how fossil casts and moulds are formed.
- Explain how banded iron formations contribute to our knowledge of past environments.
- What are stromatolites? What contribution did they make to past changes in the atmosphere?
- Describe some of the difficulties encountered when trying to interpret fossil evidence.
- Analyse the reasons why organisms must be buried quickly to be fossilised.
- Use examples to summarise the evidence provided by geochemical fossil remains.

CHECK YOUR UNDERSTANDING

12.1b



Alamy Stock Photo/Doreen Kennedy

FIGURE 12.26 Claude Lorius, the French glaciologist whose insight helped develop the science of ice core sampling

Ice core drilling

Climate refers to a sustained pattern in temperature and rainfall over an extended period in a region. **Climate change** is a statistically detectable change in the properties of atmosphere and oceans over a sustained period (usually decades). Evidence indicates that Australia's climate has warmed by approximately 1°C since 1910. Global carbon dioxide levels are steadily increasing and have been linked to climate change. It has been caused by natural processes in the past. However, scientists are concerned about the current human impacts on the climate (**anthropogenic** climate change) due to the burning of fossil fuels for energy production.

Scientists are very interested in changing climates of the past and how they affected life on Earth. It will help them to predict future effects of current climate change on Earth's ecosystems. But where do scientists gather this evidence?

Some of the most profound scientific discoveries can happen by accident or coincidence together with human curiosity. Such is the story of Claude Lorius

(born 1932; Fig. 12.26), a French **glaciologist** who was primarily responsible for the discovery and development of **palaeo-atmospherics**. This involves the interpretation of past environments from the study of gases and other materials trapped in ice.

As a young research student, Claude was sipping on a drink containing some ice cubes. He noticed the bubbles escaping from the cubes as they melted in a drink in his glass. His observation, interest and curiosity led him to realise that these bubbles would hold important information about things such as the composition of the air at the time the ice cube was formed.

Antarctic snow forms as layers just like sedimentary rocks, with the deeper layers representing ancient deposition events. This insight allowed scientists to imagine that drilling down through the ice and extracting gases could be used as a way of reconstructing the climate record, with the temperature and chemical profiles of the atmosphere dating back hundreds of thousands of years. Our understanding of the past climates of Earth, along with their effects on living things, will allow us to predict future effects of climate change on current ecosystems.

The type of ice found in places such as Antarctica has the special property that it accumulates information about the abiotic and biotic factors present at the time the ice was formed. As the snow

falls year after year, gases and particles from the atmosphere are trapped within it. In some places on Earth, it is sufficiently cold that ice forms continually in new sheets year after year. Particles such as wind-blown dust and **pollen**, volcanic ash, radioactive particles and bubbles of atmospheric gas are excellent proxy data for the past climates of ancient Earth. The best places for sampling must be where the temperature never rises above 0°C, such as Greenland, Antarctica and high mountain ranges. If the temperature rises above freezing, meltwater would trickle through the ice profile and make the samples useless for comparison.



NASA's Goddard Space Flight Center/Ludovic Brucker

FIGURE 12.27 A recently harvested ice core

INVESTIGATION 12.3

A secondary-source investigation into ice cores

Gather and analyse information from secondary sources to answer the following questions.



- 1 Describe how ice is drilled to recover ice core samples for analysis.
- 2 What properties of ice cores are analysed to reconstruct past environments?
- 3 Identify some gases that can be obtained from ice core samples.
- 4 How do scientists use these gases to reconstruct past climates?
- 5 Of what value is the reconstruction of a climate history of Earth?
- 6 What notable trends might future generations of scientists, hundreds of years in the future, note about ice core samples from the 20th century?

Scientists have developed special equipment to retrieve cylinder-shaped samples called ice cores (Fig. 12.27). A core sample can be obtained, revealing the annual changes in properties of the snow, just like reading the rings in a tree (Fig. 12.28). Radiometric dating of certain isotopes allows absolute dating of layers. Combined with the order of events, a comprehensive record of climate changes can be reconstructed. Records of human activity are also captured. The effects of industrialisation can be seen in the samples.

At the time of writing, there is much excitement in scientific circles about the possibility of retrieving the world's oldest ice, somewhere deep below the surface of Antarctica. Scientists believe this ice may contain records of past climates from as far back as a million years ago. It is considered to be at least 3km into the Antarctic ice sheet, and so new and emerging technologies will be necessary to retrieve it. At present, our oldest ice cores are approximately 800 000 years old. Million-year-old samples will give scientists a far more complete picture of past climates.

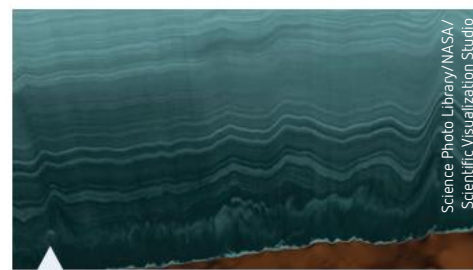


FIGURE 12.28 Layers in an ice core resemble tree rings. They are created annually from fresh snowfall.

KEY CONCEPTS

- Climate is defined as a long-term pattern of ocean and atmospheric conditions.
- Climate change alters the chemical composition of oceans and the atmosphere.
- The accumulation of ice layers in places such as Antarctica leaves an annual record of gases and dust in the atmosphere at the time.
- These chemical traces can be retrieved in ice core samples and analysed to help build a more complete record of past climates.



Using evidence for past changes in ecosystems



The Australian Antarctic Division

Read more about Australia's Antarctic program.

- 1 Distinguish between the following terms: climate, climate change, anthropogenic climate change.
- 2 What thinking process led Claude Lorius to link trapped gases and ice?
- 3 How do Antarctic ice cores reveal information about past climates?
- 4 How old is the oldest ice core that has been recovered so far?

CHECK YOUR UNDERSTANDING

12.1c

INVESTIGATION 12.4

Analysing trends in ice core data

Graphs are an excellent way to communicate vast amounts of data that is gathered in tables. A graph enables us to see any patterns in the data clearly. Patterns are very meaningful to scientists and allow them not only to make inferences about natural laws, but also to make predictions. Scatter graphs and pie charts are particular types of graph that allow us to see trends in data easily. It is important for you to learn the skill of constructing these graphs in the correct format.

Students can refer to page 22 for more information on graphing skills.

AIMS

- 1 To analyse secondary information and identify trends in evidence from ice cores
- 2 To evaluate the impact of increased understanding of climate on past and present ecosystems

METHOD

- 1 Use the table of data (Table 12.2) to construct an appropriate graph of:
 - a age of the ice (year BP is *years before present*) versus depth of the ice (m)
 - b age of the ice (year BP) versus CO₂ concentration in ppmv (*parts per million by volume* – an expression of concentration of gases).
 Plot both data sets on the same graph.
- 2 Think about which variable goes on which axis. The independent variable must lie on the horizontal (x) axis and the dependent variable on the vertical (y) axis.

TABLE 12.2 Ice core data from last 54 000 years, Vostok Station, Antarctica

DEPTH (m)	AGE OF ICE YEARS BP (YEARS BEFORE PRESENT)	CO ₂ CONCENTRATION (PPMV)
149.1	5 679	284.7
173.1	6 828	272.8
177.4	7 043	268.1
228.6	9 523	262.2
250.3	10 579	254.6
266	11 334	259.6
302.6	13 449	261.6
321.2	14 538	263.7
331.6	15 208	244.8
342.1	15 922	238.3
365.5	17 747	236.2
375.6	18 580	225.3
443.5	24 315	182.2
470.8	26 578	189.2
506.4	29 630	191.6
544.7	32 844	188.5
554.2	33 645	191.7
602.3	37 421	205.4
625.6	39 310	209.1
700.2	45 242	209.1
765	50 610	189.3
788.2	52 446	188.4
800	53 436	210.1

Critical and creative thinking

Information and communication technology capability

Trends in atmospheric carbon dioxide

CO₂ movie

» RESULTS

- 1 Your teacher may wish you to complete this exercise using digital technology such as a spreadsheet program, or by hand using a pencil, ruler and lined grid paper.
- 2 Once the graph is complete, you will analyse any trends and draw some conclusions about the links between the dependent and independent variables involved.

DISCUSSION

Analyse your graph to answer the following questions:

- 1 Describe the trend in carbon dioxide concentration over time.
- 2 Other data collected at Mauna Loa in Hawaii can be found in the weblink *Trends in atmospheric carbon dioxide*. Does this data confirm or conflict with the data gathered in Vostok?
- 3 Watch the video in the weblink *CO₂ movie*. What other process might influence the seasonal pattern of carbon dioxide concentrations in the atmosphere?
- 4 What historical events may have contributed to this pattern in atmospheric carbon dioxide concentration?
- 5 What are the direct and indirect effects of a change in carbon dioxide concentration on past and present ecosystems?
- 6 What role are Australian scientists taking in the monitoring and management of atmospheric carbon dioxide levels? Some resources you might like to refer to are in the weblinks on this page.

CONCLUSION

What is the trend in carbon dioxide concentrations in Earth's atmosphere over the past 54 000 years?



Australian
Antarctic
Division



Bureau of
Meteorology



Climate change
authority



Department of
Environment
and Energy

12.2

Using technology to investigate the past

Rapid developments in the understanding of the chemistry and physics of life have allowed the development of technologies that can detect the signatures of life. These signatures give scientists clues about past changes in environments.

Radiometric dating or geochronology

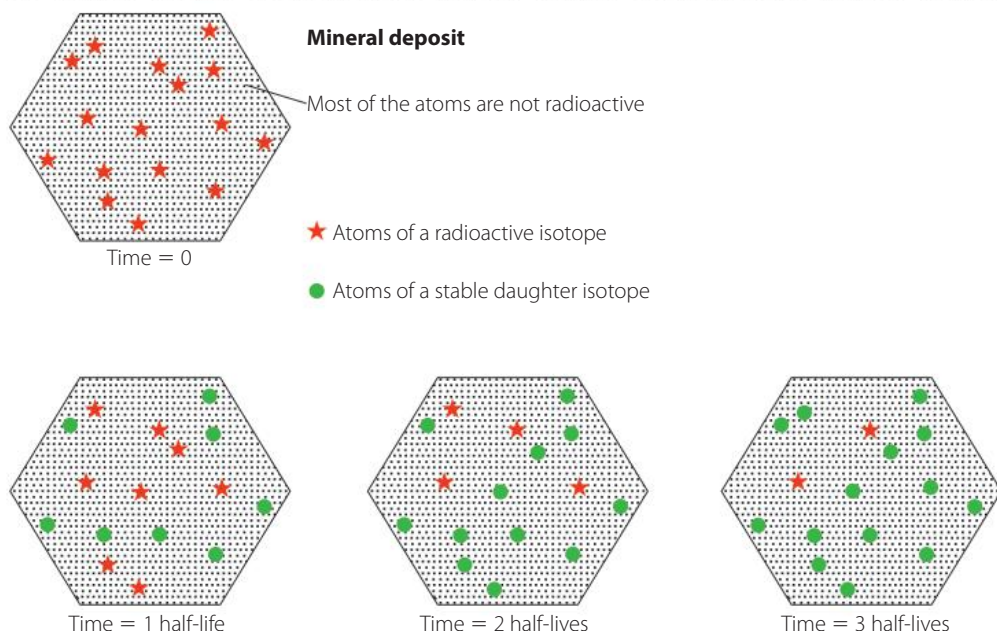
Radiometric dating is the process whereby scientists determine the age in years of a fossil, rock or mineral. Based on the content of radioactive isotopes, igneous and metamorphic rocks can be dated this way. Scientists discovered many years ago that many of the elements in the periodic table had unstable forms (isotopes) that changed over time to create more stable forms. The parent isotope undergoes radioactive decay and releases energy and/or particles to become a more stable daughter atom. The rate at which this decay process occurs is calculated using an equation (the *age equation*) that compares the abundance of the naturally occurring isotope in the rock with the abundance of the decay product. The product that accumulates is chemically different from the original atom. The decay product accumulates at a known rate as the isotope decays (Table 12.3; Fig. 12.29).

TABLE 12.3 Parent isotopes and their corresponding daughter products with decay times

PARENT ISOTOPE	STABLE DAUGHTER PRODUCT	CURRENTLY ACCEPTED HALF-LIFE* VALUES (BILLIONS OF YEARS)
Uranium-238	Lead-206	4.5
Uranium-235	Lead-207	704
Thorium-232	Lead-208	14
Rubidium-87	Strontium-87	48.8
Potassium-40	Argon-40	1.25
Samarium-147	Neodymium-143	106

* The half-life of a radioisotope is the time it takes for half of a radioactive sample to decay from the parent isotope to the daughter product. It is commonly represented by the abbreviation $t_{1/2}$.

FIGURE 12.29
Radiometric clocks – isotopes decay at predictable rates that allow scientists to estimate the age of mineral and fossil samples.



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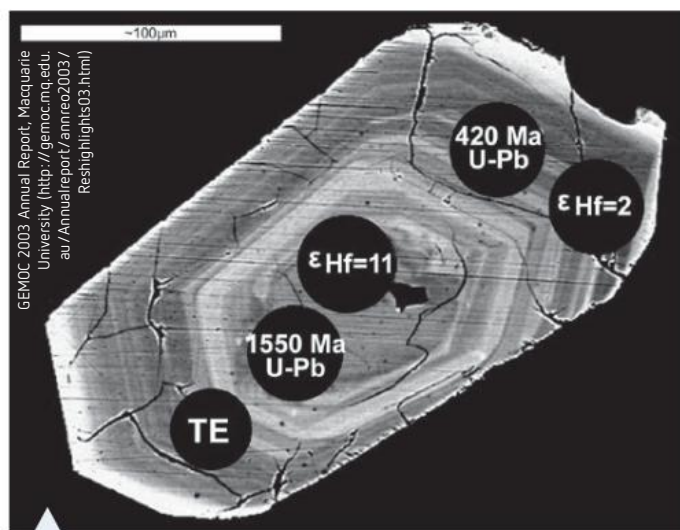


FIGURE 12.30 A zircon grain

Technologies to measure radioactivity in rocks

The radioactivity of a sample of mineral, rock or fossil is measured using a combination of technologies, including nuclear reactors, mass spectrometers, laser beams and special microscopes. One of the most significant advances in radiometric dating was the development in the 1980s of the SHRIMP (Sensitive High Resolution Ion Microprobe) technique. It was an Australian development by the Research School of Earth Sciences (Australian National University, Canberra). This method dates very resilient grains of mineral known as zircon (Fig. 12.30). This technique has allowed scientists to identify the oldest rocks on Earth (4.4 billion-year-old zircon grains from north-west Western Australia).

INVESTIGATION 12.5

A secondary-source investigation to estimate the age of fossils

Fossils themselves may contain radioisotopes such as carbon-14 that can be used for dating. However, carbon-14 has a relatively short half-life ($t_{1/2} = 5730$ years). Organisms that were fossilised more than 50 000 years ago cannot be aged using this method. To find the age of fossils, the relative timescale is combined with the atomic timescale, since radioisotopes are useful only in igneous and metamorphic rocks. Sedimentary rocks may still contain radio isotopes, but will contain mixed samples from the sediments that they accumulated from. Fossils accumulate in sedimentary rock layers. Scientists can date igneous and metamorphic formations above and below the sedimentary fossil-containing layers and estimate an age based on a combination of relative and absolute dating.



AIM

To use combined data from radiometric and relative dating to estimate the age of fossils in a stratigraphic sequence

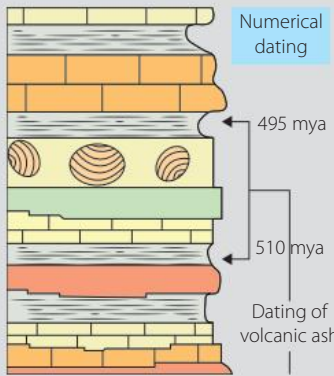
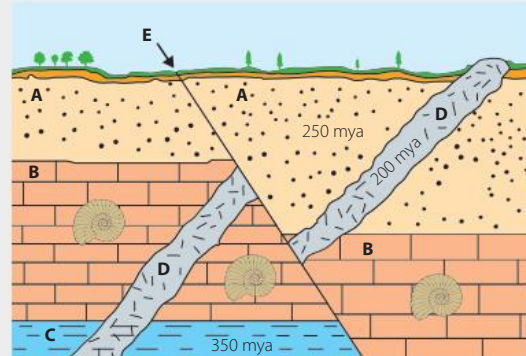
METHOD

For each of the diagrams in Table 12.4:

- 1 Estimate an age for the fossils.
- 2 Justify your choice using data from the diagram.

RESULTS

TABLE 12.4

STRATIGRAPHIC SEQUENCE	ESTIMATED AGE OF FOSSILS	JUSTIFICATION
a 		
b Rank layers A to E in order from youngest to oldest. How old are the rocks from layer B? 		



Investigation 12.5





STRATIGRAPHIC SEQUENCE	ESTIMATED AGE OF FOSSILS	JUSTIFICATION
c Estimate the age of the fossils in the box below. Adapted with permission of Jeffrey Martz		

CONCLUSION

Justify the combined use of both relative and absolute dating techniques to reconstruct the order of events in past ecosystems.

Another radiometric technology developed to improve dating methods is **fission track dating**. Decaying uranium atoms leave marks in the surface of grains as they release particles and energy (Fig. 12.31). Electron microscopes are used to see the tracks. Their density is analysed and an age can be estimated for the mineral.

One final example of a radiometric technology is luminescence dating (Fig. 12.32). All rocks contain a level of natural radiation. Scientists measure the amount of radiation trapped in mineral crystals using heat (thermoluminescence) or laser light (optically stimulated luminescence). The longer the crystal has been buried, the brighter the luminescence.



FIGURE 12.31 Fission tracks in an apatite crystal

Gas analysis

An important part of the day-to-day work of scientists is to analyse large amounts of data, look for patterns and then make inferences about their findings. Scientists can use the data in ice cores to reconstruct atmospheric concentrations of certain gases, particularly carbon dioxide and oxygen (Fig. 12.33). Communication of scientific data such as this is generally done in the form of tables and graphs.

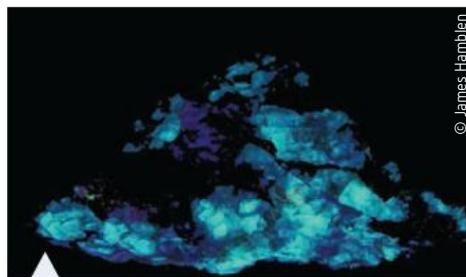
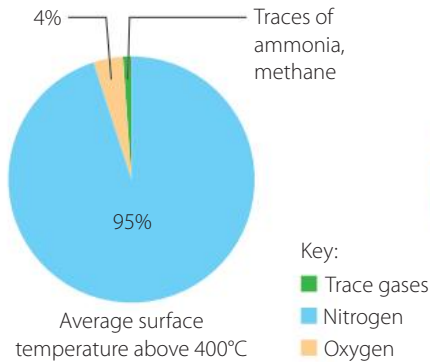


FIGURE 12.32 Some minerals release light when heated to a certain temperature.

Earth's early atmosphere



Earth's atmosphere today

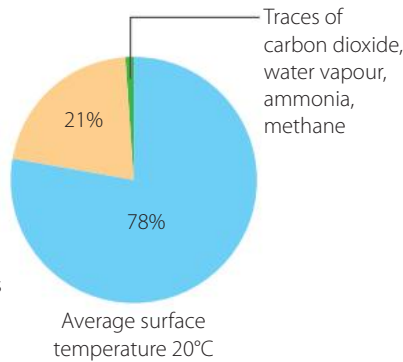


FIGURE 12.33 Gases in the early and current atmosphere of the Earth

The levels of carbon dioxide in the atmosphere have long been recognised as a key factor in the temperature of the atmosphere. Carbon dioxide is a normal part of Earth's atmosphere, along with nitrogen, oxygen, argon and other trace gases.

Carbon dioxide is also one of several so-called 'greenhouse gases' that trap solar radiation and keep Earth warm enough to sustain life. This is known as the 'greenhouse effect'. However, any large increase in greenhouse gases is likely to increase the temperature of Earth's atmosphere and subsequently the oceans. Scientists are concerned that this is happening now. This process is known as the enhanced greenhouse effect or global warming (Fig. 12.34).

Scientists use ancient carbon dioxide levels to infer past climates. Warming or cooling of the atmosphere would have a direct effect on the types of plants and animals that are suited to survive in such a climate.

Oxygen has three naturally occurring isotopes: ^{16}O , ^{17}O and ^{18}O (Fig. 12.35). These atoms are incorporated into water molecules (as H_2O). The ratio of $^{18}\text{O}/^{16}\text{O}$ gives us a record of ancient water temperatures. Scientists can analyse these ratios in ice core samples, and reconstruct water temperatures for ancient Earth.

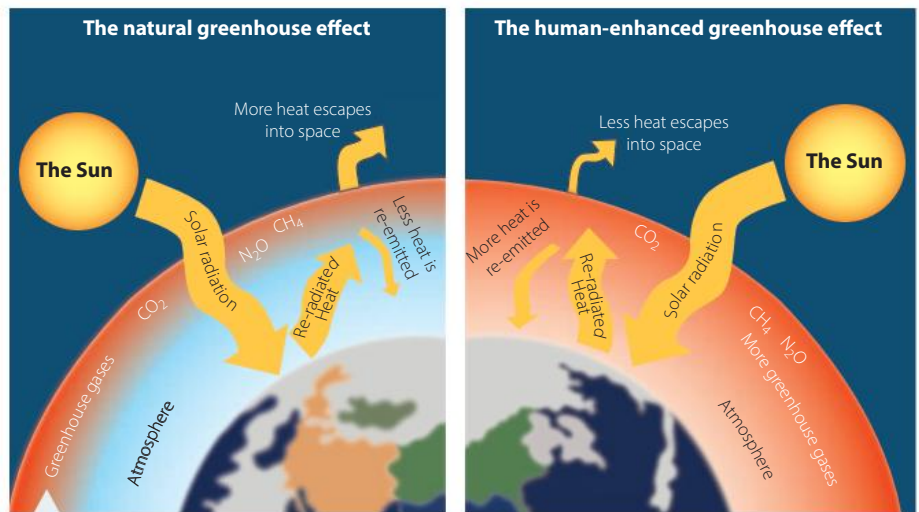


FIGURE 12.34 The greenhouse effect compared to global warming

Oxygen isotopes

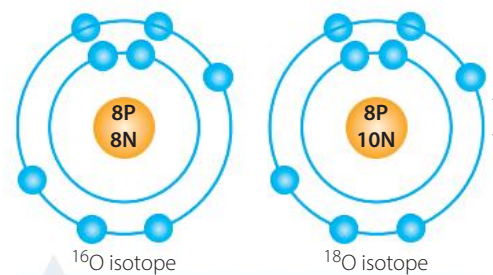


FIGURE 12.35 Proportions of oxygen isotopes in ice cores provide evidence for past global temperatures.

Edwards, A. (2016). Oxygen Isotopes [Diagram created for Climate Science Investigations]

KEY CONCEPTS

- Technologies such as radiometric dating and gas analysis are important methods for analysing evidence from past ecosystems.
- Radiometric dating is a technique that uses the natural radioisotopes found in rocks to estimate their absolute age based on known decay rates (half-lives) of these isotopes.
- Gas analysis helps scientists to infer past global temperatures based on the proportions of gases as well as ratios of isotopes of certain gases.
- Management of global warming relies on accurate estimates of temperature trends in the atmosphere and oceans.

- 1 Define the terms 'isotope' and 'half-life'.
- 2 Outline how scientists use radioisotopes to estimate the age of minerals.
- 3 Outline the significance of the different ratios of oxygen isotopes in past environments.
- 4 Explain how scientists can use a combination of relative and absolute dating to identify the sequence of rock strata and their ages.
- 5 Describe the use of fission track dating by scientists.
- 6 Why are fossils mainly found in sedimentary rock layers?
- 7 Justify the further funding for research into absolute dating technologies.

12.3 Evolution of Australian biota

Scientists analyse evidence of organisms from the past to determine if present-day organisms may have evolved from them.

Due to Australia's long history of **isolation**, Australian ecosystems consist of a unique array of flora and fauna. Fossil evidence gives scientists clues to the slow, progressive changes that have taken place in Australian species over the roughly 30 million years since Australia severed its final links with Antarctica. Australia's climate has alternated between warm/wet cycles and cold/dry cycles. This in turn has influenced the pattern of vegetation, which has gone from tropical rainforests with broad-leafed plants to predominantly open grassland and desert with **sclerophyll** plants as the dominant plant life.

The first mammals appeared on Earth around 240 mya and evolved from reptiles. The three groups, monotremes, marsupials and placental mammals, gradually evolved as branches from the common ancestor. The oldest mammals appear in Australia's fossil record around 125–110 mya. By around 110 mya, flowering plants were establishing in Australia and mammals had appeared. The mammals shared the land with dinosaurs. Australia was still linked to Antarctica, New Zealand and South America. This link was severed around 30 mya and Australia's long period of isolation began.

INVESTIGATION 12.6

A secondary-source investigation into fossil sites in Australia



Critical and creative
thinking

Australia has a series of unique fossil sites. Australian mammal fossil sites include Naracoorte in South Australia as well as Riversleigh, Queensland. The Naracoorte caves give an excellent snapshot of Pleistocene organisms and are a focal point for scientists who wish to study the link between climate change and the evolution of Australian mammals. These caves span the time from the arrival of humans and so the relationship between humans and their environment can also be understood more clearly. The Riversleigh fossil site represents the Oligo-Miocene period (15–25 mya) all the way to the Pleistocene epoch. These sites give a picture of mammal evolution for at least 20 million years, particularly that of marsupial and monotreme evolution. The evolution of Australian mammals and plants is closely linked to the evolution of the Australian climate and its tectonic setting as the continent drifts slowly north.



» AIMS

- 1 To identify and gather information on a number of Australian fossil sites
- 2 To analyse the position of the Australian continent (tectonic setting) at various stages
- 3 To evaluate evidence for the evolution of mammals in Australia

Part A: Timeline

METHOD

Study the information on the map in Figure 12.36 and then answer the questions that follow.

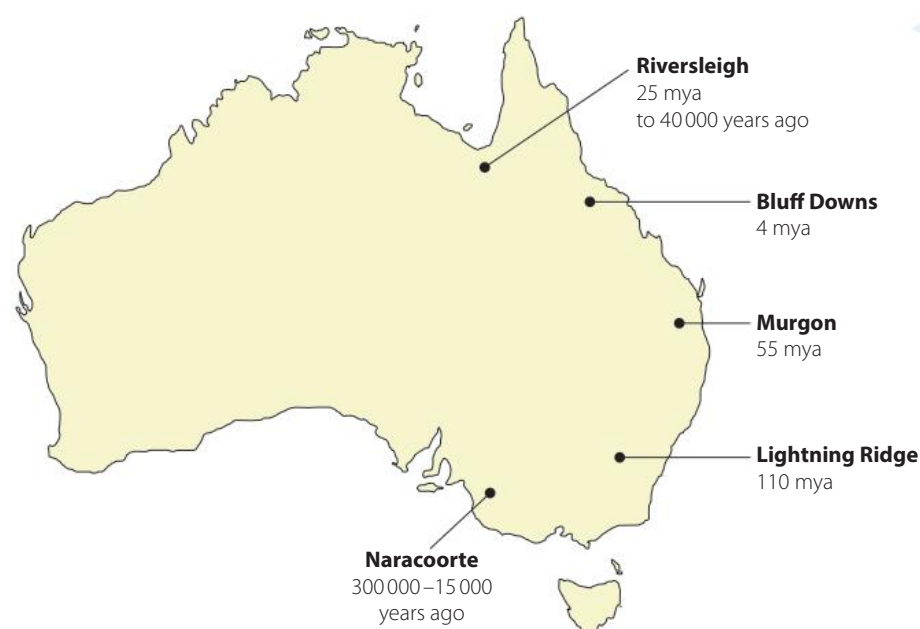


FIGURE 12.36 Main Australian fossil sites and the time frames that biota lived there

- 1 Using the information provided on Figure 12.36, draw a timeline of Australia's fossil past. Record the dates represented at each fossil site (in date order) and the name of each site on the timeline (write these above the line). Provide a suitable heading for the timeline.
- 2 Record the information listed below on your timeline. You will need to research the dates and positions of Australia to complete this.
Add this information to your timeline:
 - Australia and Antarctica attached, but New Zealand is breaking away.
 - Australia breaks away from Antarctica and begins to drift north.
 - The Australian plate moves northward and collides with the Pacific Plate and South-east Asia.

Part B: Fossil evidence

Use the information from the timeline you have drawn in Part A to answer the following questions.

- 1 Scientists have found fossil evidence of Australia's first ancestral monotremes – the platypus and echidna. Name the fossil site in Australia where these two fossils are most likely to have been found. Justify your answer.
- 2 Scientists in the past have assumed that the main reason why Australian indigenous mammals are marsupials is because there were no placental mammals present on the continent to compete with them. A discovery at Murgon (a fossil site) changed this way of thinking. Name the discovery at Murgon that changed this thinking and explain why scientists now believe that placental mammals and marsupials once co-existed in Australia.

INVESTIGATION 12.7

A secondary-source investigation to research Australia's evolving flora and fauna



Information and communication technology capability



Critical and creative thinking

Evidence suggests that present-day organisms in Australia, both plant and animal, have evolved from past organisms. The drifting of the continent northwards and the later impact of humans have created selection pressures that have influenced the evolution of flora and fauna. As the land became hotter and drier, the change in climate led to a change in the vegetation. This in turn led to a change in the fauna.

Looking at the history of fauna in Australia, we see there is a diverse range of mammals, both extinct and extant, on the continent. Most surviving mammals today are marsupials, but the coexistence of all three lines of mammals – monotremes, marsupials and placentals (eutherians) – is unique to Australasia.

Many marsupials in Australia resemble placental mammals of the northern hemisphere (Europe and North America) (Table 12.5). This is thought to be a result of convergent evolution. Besides marsupials, small Australian mammals include bats, rodents, monotremes and **marine** mammals.

TABLE 12.5 Convergent evolution: placental (eutherian) mammals in other continents show similarities to marsupials in Australia

MARSUPIAL MAMMALS	EUTHERIAN MAMMALS
a Plantigale  Getty/Tom McHugh / Science Source	a Deer mouse  Imagefolk/Shattil & Rozinski / Naturepl
b Marsupial mole  Imagefolk/Auscapse / UIG	b Mole  Shutterstock.com / Miroslav Hlavko
c Sugar glider  iStock.com/pigphoto	c Flying squirrel  Shutterstock.com / Tony Campbell
d Wombat  iStock.com/eeqmcc	d Woodchuck  Shutterstock.com/zixian



MARSUPIAL MAMMALS

e Tasmanian devil



iStock.com/CraigRJD

f Kangaroo



iStock.com/Freder

EUTHERIAN MAMMALS

e Wolverine



iStock.com/jamenpercy

f Patagonian cavy



Shutterstock.com/Foto 4440

Human impacts such as colonisation, land clearing and introduced species have put selective pressure on native flora and fauna, threatening some species, driving evolution and causing extinctions.

AIM

To evaluate the processes scientists use to reconstruct the evolution of Australia's flora and fauna, as well as their claims and conclusions based on their data

METHOD

Choose one example of a small Australian mammal and one example of an Australian sclerophyll plant and gather information on the following:

- 1 common and scientific names of your chosen species
- 2 fossil evidence for the evolution of your chosen species
- 3 a time period over which scientists have studied and collected fossil evidence for these species
- 4 major changes in the species chosen – anatomical, physiological or behavioural
- 5 corresponding changes in the biotic and abiotic factors in their environment that may have contributed to the changes you have described.

RESULTS

Summarise your findings in a table such as Table 12.6.

TABLE 12.6

Common and scientific names of organism		
Brief description of fossil evidence		
Time period involved		
Major changes in species		
Contributing environmental factors		



The past, present and future of Australia's mammals



Evolution down under



World Heritage places – Australian fossil mammal sites



Evolution of Australian flora



Investigation 12.7



Australian forests –
an introduction



Vegetation
history of
the Atherton
Tableland



DISCUSSION

Evaluate the findings and conclusions of the scientists. In this case, you will evaluate their *conclusions*.

For example:

- Was there enough fossil evidence?
- Could there be another explanation for changes observed over time?

CONCLUSION

Are scientists justified in using fossil evidence to reconstruct past environments? Give reasons for your answer.

Some resources that you may find useful to start with are provided in the weblinks.

KEY CONCEPTS

- Scientists analyse evidence of organisms from the past to determine if present-day organisms may have evolved from them.
- Fossils provide evidence of past organisms.
- The evolution of Australian mammals and plants is closely linked to the evolution of the Australian climate and its tectonic setting as the continent drifts slowly north.

CHECK YOUR UNDERSTANDING

12.3

- 1 How have Australian ecosystems changed over the last 30 million years?
- 2 State the names of the three groups of mammals.
- 3 Distinguish between the terms 'extinct' and 'extant'.
- 4 Identify the selection pressures that have influenced the evolution of Australian flora and fauna.

12.4

Changing Australian ecosystems: abiotic and biotic changes over time

If the climate in a habitat changes, the distribution and abundance of living things within that habitat also tend to change. Organisms that are better suited to the new environment survive and new species may evolve.

The distribution and abundance of present-day *plants* in Australia reflect three main origins:

- those already on the continent when it split from Gondwana
- those that dispersed from South-east Asia to Australia
- introduced species.

The origins of *animals* that led to present-day fauna are:

- 'original residents' – those that were on the continent when it split from Gondwana (for example, frogs, reptiles, monotremes, marsupials, emus and lyrebirds)
- Asian 'immigrants' that arrived when sea levels were low – 15 mya and again 40 000–30 000 years ago (poisonous snakes, back-fanged snakes, rats, mice and bats)
- those introduced by immigrant traders or late arrival Aborigines – 4000 years ago (for example, dingos)
- those introduced by European immigrants – beginning 200 years ago.

INVESTIGATION 12.8

A secondary-source investigation to assess claims made by scientists about climate and ecosystems

AIM

To assess the claims made by scientists regarding changes in the Australian climate and ecosystems



METHOD

1 Read Table 12.7 in which information has been placed in the first two columns. The column entitled 'Claim made by scientists' has been colour-coded according to the following criteria:

- claims made about climate are highlighted in yellow
- claims made about vegetation (flora) are highlighted in pink
- claims made about animals (fauna) are highlighted in blue.

RESULTS

TABLE 12.7 Claims made by scientists regarding past ecosystems in Australia

TIME	CLAIM MADE BY SCIENTISTS	SUPPORTING EVIDENCE
55 mya	Moist climates supported rainforests which formed the dominant vegetation type (before Australia separated from Gondwana). Rainforests had replaced the towering conifer forests of the previous eras. The climate was wet and warm and there was a large variety of flora and fauna. Animals included many of the early ancestors of animals we know today, such as koalas, kangaroos, bats, crocodiles and possums.	
45 mya	As Australia separated from Antarctica and began drifting north, the climate dried out and the Australian rainforests contracted, remaining mainly in the coastal regions of Australia. The inland areas which were drying out had more open forests and woodlands. Animals diversified and varieties developed that were more similar to those that we know today. Kangaroos hopped rather than walking. Large herds of animals that resembled modern-day wombats and carnivorous predators such as thylacines and marsupial lions appeared.	
8 mya	As the climate continued to dry out, gum trees and wattles became common in Australia's forests and many wildflowers bloomed. Newly developed fauna included saltwater crocodiles and budgerigars. This era formed the link between ancient and modern vegetation. Conifers and cycads were decreasing in importance as flowering plants bloomed.	



Investigation 12.8



»

TIME	CLAIM MADE BY SCIENTISTS	SUPPORTING EVIDENCE
2 mya	The climate then went through a period of fluctuation from wet to dry and the pattern of forests, grasslands and deserts kept changing. The megafauna abounded, with huge <i>Diprotodons</i> (wombat-like creatures) and giant goanna-like creatures (<i>Megalania</i>).	
60 000 years ago	Indigenous people arrived and used fire to clear vegetation for movement across the land and to burn off particular areas of bushland.	
About 5000 years ago	About 5000 years ago, Australia's climate became consistently drier and has continued to do so. The dry climate allowed lightning to start many fires, possibly influencing the selection of fire-resistant plant species, which began to flourish.	
Present day	Australia's climate is now warming due to human-induced climate change.	
The future		

- 2 The third column entitled 'Supporting evidence' will be completed by you. It is your job to:
 - research the time period in column 1
 - review the claims made by scientists in column 2
 - find some supporting evidence for their claims and place it in column 3. For example, in row 1 (55mya) find the information you need to ask the question: 'What fossil evidence supports the idea that rainforests formed the dominant vegetation at the time?'
- 3 Any diagrams and photographs that support these claims should also be placed in column 3.
- 4 Provide a complete reference list for all of your materials.
- 5 Make sure that all images are ethically sourced and copied. One easy way to ensure good digital citizenship is to use Creative Commons licensed materials. You can find information about this source at the weblink.

DISCUSSION

- 1 Evaluate the hypothesis that:
 - a the change in climate and
 - b the arrival of humans
 can account for each of the following trends:
 - i the extinction of the megafauna
 - ii the development of open forests, grasslands and deserts in Australia.
- 2 Scientists in the past assumed that the main reason why Australian indigenous mammals are marsupials is because there were never any placental mammals on the continent to compete with them. Discuss how the discovery of a fossilised tooth at Murgon in south-east Queensland changed their thinking.

CONCLUSION

Does climate change appear to influence the flora and fauna in past ecosystems? Justify your conclusion.

Good digital citizenship begins here

Changing flora and fauna

There are many hypotheses put forward to account for the changes in Australia's flora and fauna. Scientists collect evidence to account for these changes. Changes in Australian ecosystems are intimately linked with the movement of continents and the subsequent effects on climate.

Australia was originally a part of the great southern continent of Gondwana. In the early Cretaceous period, Australia lay much further south than its present location. The climate was cool and wet. Conifers, cycads and dinosaurs were abundant. And yet Australia's first mammals had already appeared (Figs 12.37–12.39). They later developed into the familiar Australian mammals we know today.

Anne Musser © Australian Museum



FIGURE 12.37 *Obdurodon dicksoni*

Anne Musser © Australian Museum



FIGURE 12.38 *Diprotodon opatum*

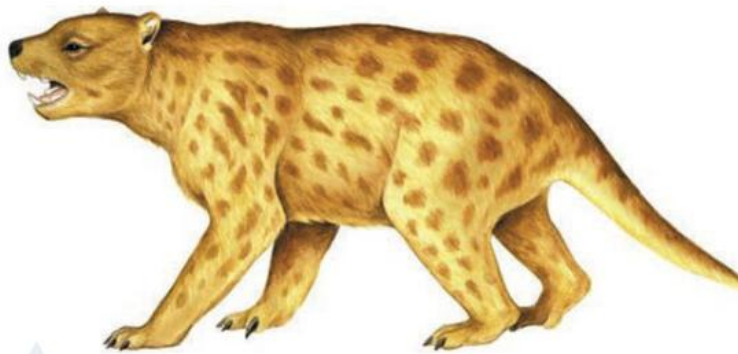


FIGURE 12.39 *Thylacoleo carnifex*

Anne Musser © Australian Museum



Reasons for evolution, survival and extinction of Australian species

KEY CONCEPTS

- If the climate in a habitat changes, the distribution and abundance of living things within that habitat also tend to change.
- Organisms that are better suited to the new environment survive and new species may evolve.
- Many hypotheses have been put forward to account for the changes in Australia's flora and fauna.

- 1 What happens to living things as the climate changes?
- 2 List the three main origins of Australian plants.
- 3 List the four main origins of Australian animals.
- 4 Explain why there are several hypotheses to explain the changes in Australian climate and ecosystems.

CHECK YOUR UNDERSTANDING

12.4

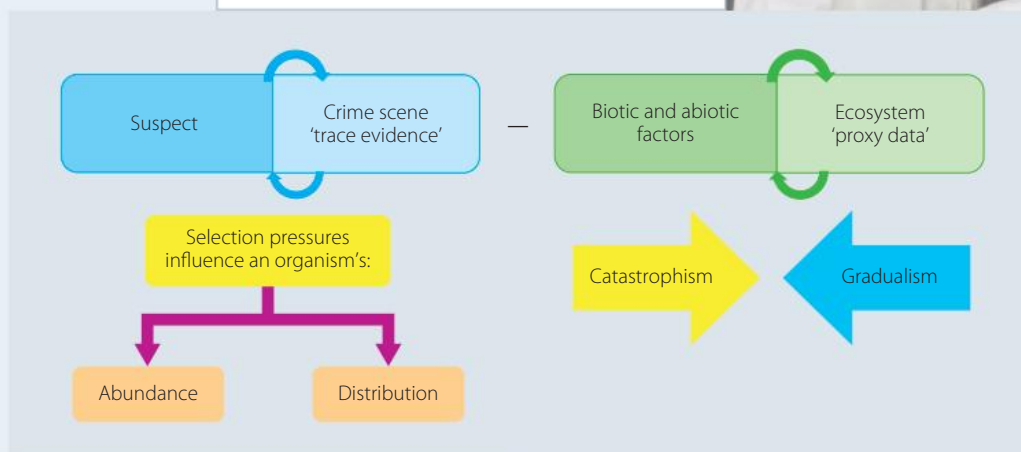
Past ecosystems: How do selection pressures within an ecosystem influence evolutionary change?

Geological and palaeontological evidence provide clues to past ecosystems.

LOCARD'S PRINCIPLE OF EXCHANGE

Every contact leaves trace evidence – what happens in a crime scene also happens within ecosystems.

The same is true for past events in Earth's history. We just need to learn to read the clues.



The *geological timescale* is a scientific model that allows scientists to represent the course of changes in geological and fossil deposits and link these to evolutionary changes in ecosystems.



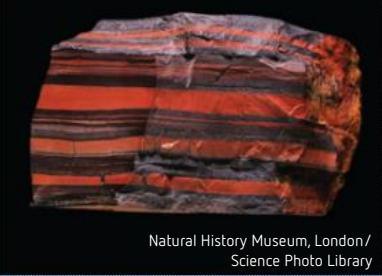
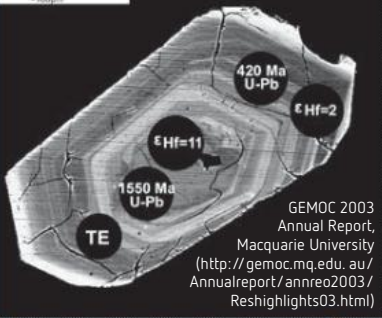
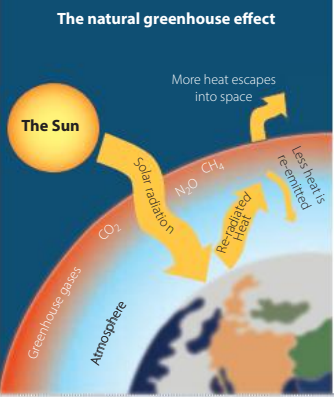
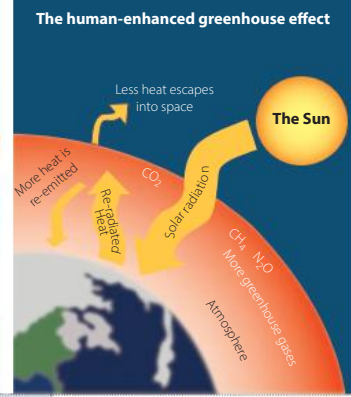
Evidence suggests that present-day organisms have evolved from organisms in the past:

SMALL MAMMALS

- Many Australian marsupials resemble placental mammals in the northern hemisphere (Europe and North America).
- This is thought to be a result of convergent evolution.
- Australian ecosystems are intimately linked with the movement of continents and the subsequent effects on climate.
- Australian mammal fossil sites include Naracoorte in South Australia as well as Riversleigh, Queensland.

SCLEROPHYLL PLANTS

- Australia's climate has alternated between warm/wet cycles and cold/dry cycles.
- This in turn has influenced the pattern of vegetation, which has gone from tropical rainforests with broad-leaved plants to predominantly open grassland and desert with sclerophyll plants as the dominant plant life.

Evidence	Features
ROCK ART  Photograph by Claire Taylor (Wandjina Rock Art) [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0/)], via Wikimedia Commons	- Longest unbroken art tradition in the world (40 000 years) - Recorded evidence of climate and organisms in their art - Changes in types and abundance of organisms observed; e.g. Keep River, West Kimberley
GEOLOGICAL  Natural History Museum, London / Science Photo Library	- Principles of Stratigraphy: - Law of Superposition - Law of Lateral Continuity - Law of Original Horizontality - Law of Cross-Cutting Relationships - Volcanic ash - Banded iron formations - Palaeosoils ('fossilised soils')
ICE CORES  NASA's Goddard Space Flight Center / Ludovic Brucker	- As the snow falls year after year, gases and particles from the atmosphere are trapped within it. - Particles such as wind-blown dust and pollen, volcanic ash, radioactive particles and bubbles of atmospheric gas provide excellent proxy data for the past climates of Earth. - Best places for sampling must be where the temperature never rises above 0°C, such as Greenland, Antarctica and high mountain ranges.
RADIOMETRIC DATING  GEMOC 2003 Annual Report, Macquarie University (http://gemoc.mq.edu.au/Annualreport/annreo2003/Reshighlights03.html)	- Process whereby scientists determine the age in years of a fossil, rock or mineral - Isotopes decay at predictable rates (half-lives) that allow scientists to estimate the age of mineral and fossil samples. - Fossils themselves may contain radioisotopes such as carbon-14 that can be used for dating. - SHRIMP technique (ANU Canberra) - Fission-track dating - Luminescence dating
GAS ANALYSIS The natural greenhouse effect  The human-enhanced greenhouse effect 	- Scientists can use the data in ice cores to reconstruct atmospheric concentrations of certain gases, particularly carbon dioxide and oxygen. - Levels of carbon dioxide in the atmosphere have long been recognised as a key factor in the temperature of the atmosphere. - Helps scientists to infer past global temperatures based on proportions of gases as well as ratios of isotopes of certain gases
PALAEONTOLOGICAL  Getty Images / Photodisc / Siele Preis	- Mineralised (moulds and casts, petrification, opalisation) - Organic remains (ice, amber, bogs, dry caves, carbonisation) - Impressions (including footprints) - Trace fossils (geochemical remains) - Microfossils - Stromatolites - Molecular biomarkers ('fossil molecules')

12 CHAPTER REVIEW QUESTIONS



Review quiz

- 1 Choose the correct alternative. The reason why it is very difficult to find evidence of the origin of life on Earth is:
 - A the earliest fossils were very similar.
 - B there are very few terrestrial fossils.
 - C the early ocean did not develop until 2000 mya.
 - D early living things were soft bodied and formed few fossils.
- 2 Define the term 'fossil'. What are the conditions necessary for fossilisation?
- 3 Briefly outline the features of the following pieces of evidence for past life and climates:
 - a palaeontological
 - b geological
 - c ice cores
- 4 What is the purpose of the geological timescale? On what basis are the major divisions in the timescale determined?
- 5 Explain the link between the geological timescale and the use of stratigraphy.
- 6 Draw a timeline of the Australian continent starting at 110 mya. Place on it the major climate changes, appearances of major plant and mammal groups as well as any major events that may have influenced the evolution of Australian flora and fauna.
- 7 Why do scientists look to Aboriginal cave paintings as a source of evidence for past environments? Outline a specific example of a named organism and the information it provides scientists.
- 8 Briefly summarise the possible origins of the animals that we see in the Australian environment today.
- 9 Why do you think there is often disagreement in scientific circles when new fossil evidence is located and an attempt is made to place it in the context of the geological timescale?
- 10 Explain how fossil evidence from areas such as Naracoorte and Riversleigh supports the theory that inland Australia once had a cool, wet climate.
- 11 This current time is often referred to as the Anthropocene epoch (*anthro* is a prefix used to mean human). What do you think will be the features of the future evidence for the presence of 21st century humanity in the geological record?
- 12 Why is it important that Australia continues to support scientific research in the areas of palaeontology and climate change?
- 13 Explain the importance of the study of past environments in predicting the impact of human activity in present environments.
- 14 Using a named example, identify a reason for the extinction of an Australian species.
- 15 Outline the ways in which eutherian mammals in North America and marsupials in Australia show similar structural features. Explain why this occurs.
- 16 Explain why some fossils have no similar living relative or modern day equivalent.
- 17 Describe three examples of Australian fossils and identify where these fossils are found.
- 18 Justify the continued research into changing past climates.
- 19 Justify the use of graphs when communicating scientific data.
- 20 Assess the ways in which palaeontology assists our understanding of the factors that may determine the distribution of flora and fauna in present and future environments.

13 Future management of ecosystems

INQUIRY QUESTION

How can human activity impact on an ecosystem?

Students:

- investigate changes in past ecosystems that may inform our approach to the management of future ecosystems, including:
 - the role of human-induced selection pressures on the extinction of species (ACBL005, ACSBL028, ACSBL095) [ATSIHC S](#)
 - models that humans can use to predict future impacts on biodiversity (ACSBL029, ACSBL071) [ATSIHC S N](#)
 - the role of changing climate on ecosystems [S](#)
- investigate practices used to restore damaged ecosystems, Country or Place, for example: [ATSIHC S](#)
 - mining sites
 - land degradation from agricultural practices

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FIGURE 13.1 A Madagascan lemur

Madagascar is an island in the Indian Ocean off the east coast of Africa. Like Australia, it has been isolated for a long time and therefore has a unique array of flora and fauna. Once covered in lush, tropical rainforest, it is now an ecological disaster in the making. The need for foreign exchange to bring some wealth into a poor country has led to over-exploitation of its natural resources. Logging to meet a global demand for tropical timbers has been conducted on such a scale that now over 80 per cent of the rainforests are gone. This has adversely affected the populations of animals such as lemurs (Fig. 13.1), which are found exclusively on this island. Many species of lemurs are extinct, and many more, such as the bamboo lemur, are critically endangered. **Poverty** in Madagascar has led to malnourishment and caused a great demand for protein in the form of animal meat and so, despite being both illegal and culturally taboo, lemurs are often hunted and eaten or sold in markets for food. The good news is that the world is starting to wake up to the effects of human practices on natural ecosystems and many situations like that in Madagascar are slowly being understood and managed.

13.1

Human-induced changes in ecosystems

Madagascar is a model for worldwide species threats from human practices. Studying ecosystems, such as those in Madagascar, and how they are changing, can enable us to understand factors that have contributed to the changes. This knowledge offers us the opportunity to prevent such changes happening in the future, both here and in other places.

One of the main factors affecting natural ecosystems is human population growth, particularly over the last century. Accurate data on human population growth is an important factor in designing mathematical models that can assess the impact of human activity on ecosystem health.

Increasing population

The population of humans worldwide is growing faster than ever before for several reasons. The 20th century saw a vastly increased efficiency of food production through **selective breeding**, the use of fertilisers, pesticides and herbicides, as well as a better understanding of the needs of plants. This has resulted in better and more efficient food production around the world. A local example of this is the CSIRO's development of self-reproducing hybrid crops of sorghum X cowpea, which could increase crop yields in sub-Saharan Africa by 30 per cent and help combat the problem of undernourishment in this region of the world.

Medical breakthroughs such as the use of antibiotics, better hygiene practices, vaccination programs and screening for common diseases have dramatically reduced the human mortality rate due to infectious and non-infectious diseases. The discovery of the antibiotic penicillin in the 1920s made a

dramatic difference to survival rates from bacterial infections, including those that arise from injury and childbirth. Vaccination programs have saved countless lives around the world. Better hygiene practices and a better understanding of the needs of the growing foetus have reduced the rate of neonatal death in many nations. When doctors and midwives started washing their hands before assisting in the delivery of a baby, the **maternal** and neonatal death rates from infections reduced significantly, except in many poorer nations where the problem persists today.

The use of **biotechnology** to produce disease-resistant, water-efficient plants and animals has reduced the impact of extremes of climate on food production. Water availability is often the most important factor limiting crop growth in many areas of the world. It takes 1 litre of water to produce 1 Calorie (4 kilojoules) of food. New crop varieties that can tolerate drought will help to reduce this water requirement. The use of antibiotics and growth hormones has also allowed intensive farming production, such as for poultry and pigs, as well as extensive production of beef and dairy cattle and sheep. This has led to increased growth rates, leaner and healthier animals. Antibiotics are an important component of the diet of beef cattle raised in feedlots. They alter the balance of fermenting bacteria in the **rumen** ('first stomach') of cattle, which break down their food and convert it to fatty acids. This increases the efficiency of feed use. They are also used **prophylactically** to control disease outbreaks, particularly when animals are densely housed, such as in poultry sheds. Human antibiotics are not used routinely in beef cattle unless under veterinary advice and there are very strict guidelines for their use. Hormonal growth promotants are used by some cattle producers to improve growth and feed conversion rates.

Because more people are living longer and healthier lives, this puts a demand on the environment for space and resources such as food, materials for construction of infrastructure and fresh water, and increases the need for waste disposal. Fortunately, solutions are becoming available as technology improves and as human creativity and ingenuity are employed with greater effectiveness.

Future projections for world population growth are startling. Scientific modelling now alerts us to the future trends in population growth (Fig. 13.2).

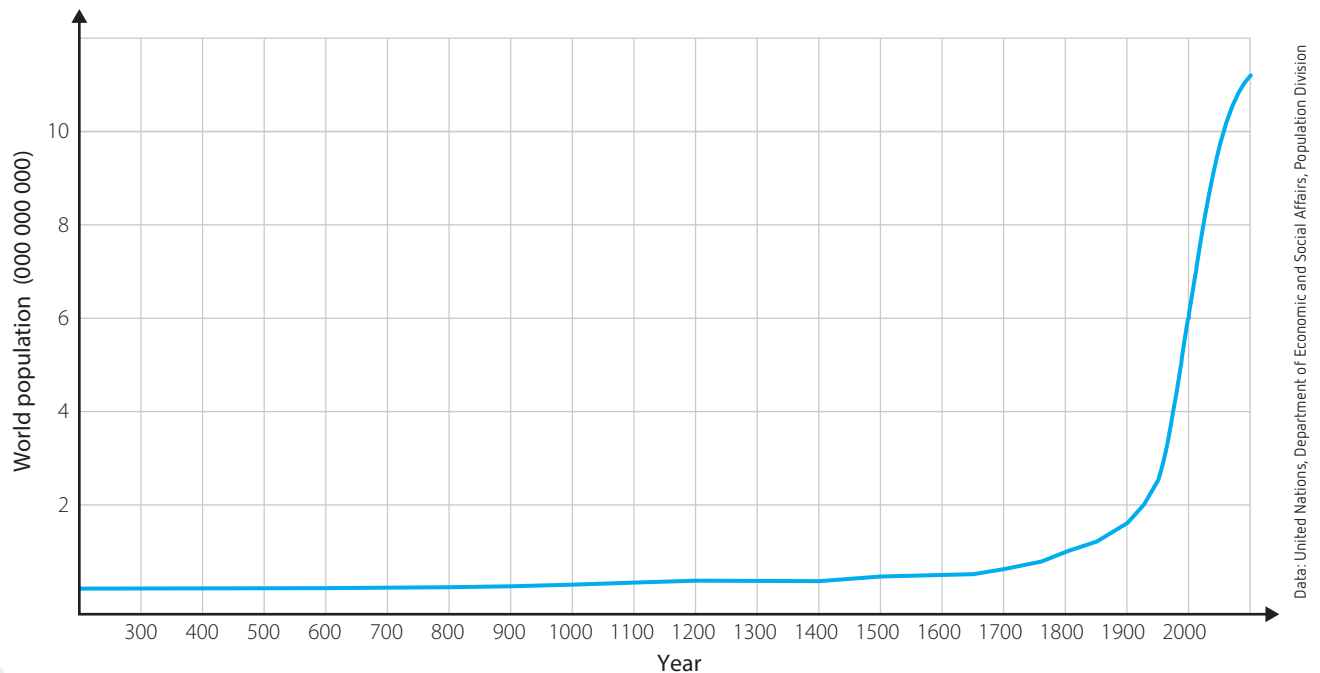


FIGURE 13.2 World population: past and present

The population of Australia has increased steadily since the mid-20th century as a result of both migration and increased lifespans. According to the Australian Bureau of Statistics website, as at 19 February 2017 the resident population of Australia was projected to be 24 366 269 people. It is estimated that the Australian population increases, through birth and immigration, by one person every 1 minute and 24 seconds.

INVESTIGATION 13.1

A secondary-source investigation into trends in human population growth and its impact on ecosystems

Human population trends are closely linked to the fate of natural ecosystems. In this activity you will examine the trends in human populations both in Australia and around the world.

AIMS

- 1 To gather and process data on human population trends over the last 200 years
- 2 To analyse the main factors contributing to this growth
- 3 To analyse impacts of this trend on biodiversity
- 4 To communicate this information to peers in a suitable format

METHOD

- 1 Use secondary sources and Figure 13.2 to explore the reasons for the dramatic increase in world population since the year 1800.
- 2 Find out in which countries an ageing population is becoming a trend.
- 3 Remember to use sources that are *accurate*, *reliable* and *valid*. Refer to the CRAAP test on page 10. Keep a record of your sources in an appropriate format. Your school library website may be able to provide a suitable template for references gathered.

RESULTS

Present your findings to your class in an appropriate format. Include graphs, statistics and images to make your presentation more engaging and informative.

DISCUSSION

Now that you have examined factors affecting human population growth, design an aim and hypothesis to test the effect of increasing human populations on one factor in the environment. You do not need to carry out the experiment; simply design it as if it could be carried out by someone else.

CONCLUSION

Write a summary statement of what you have learned from your research.

EXTENSION

Explore the use of satellite images from NASA to measure urban sprawl and green space and how this 'big data' may be used in the future to determine different types of land use.

- Human activities act as a selection pressure on ecosystems.
- Increasing populations of humans lead to increased demands on the resources provided by ecosystems.

- 1 Identify the trend in world population growth.
- 2 Why is it important that we have accurate data on human population growth?
- 3 List the reasons for the dramatic increase in world population during last century.
- 4 What is the daily increase in Australia's population?
- 5 What are the major factors leading to the increase in the Australian population?

Agriculture

The trend in human population growth can be traced to the very beginnings of agriculture. There have been many agricultural 'revolutions' throughout human history. The first occurred approximately 10 000 years ago, when humans transitioned from a hunter-gatherer lifestyle and started to cultivate crops and domesticate animals. This is often called the **Neolithic** revolution.

The immediate effect was an increase in human populations. Villages and towns emerged from this as humans started to radically transform their natural environment to produce food and other goods. It is widely accepted that this process began in many areas of the world within a short space of time and spread out from these centres (Fig. 13.3). Even at this early stage, the local landscape was being transformed. **Irrigation** was developed alongside the domestication of plants as a means of producing a surplus, and so water was diverted away from its natural courses. Selective breeding of crops and livestock radically altered their features to favour large yields.

By Joe Roe (Own work) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0>) via Wikimedia Commons]

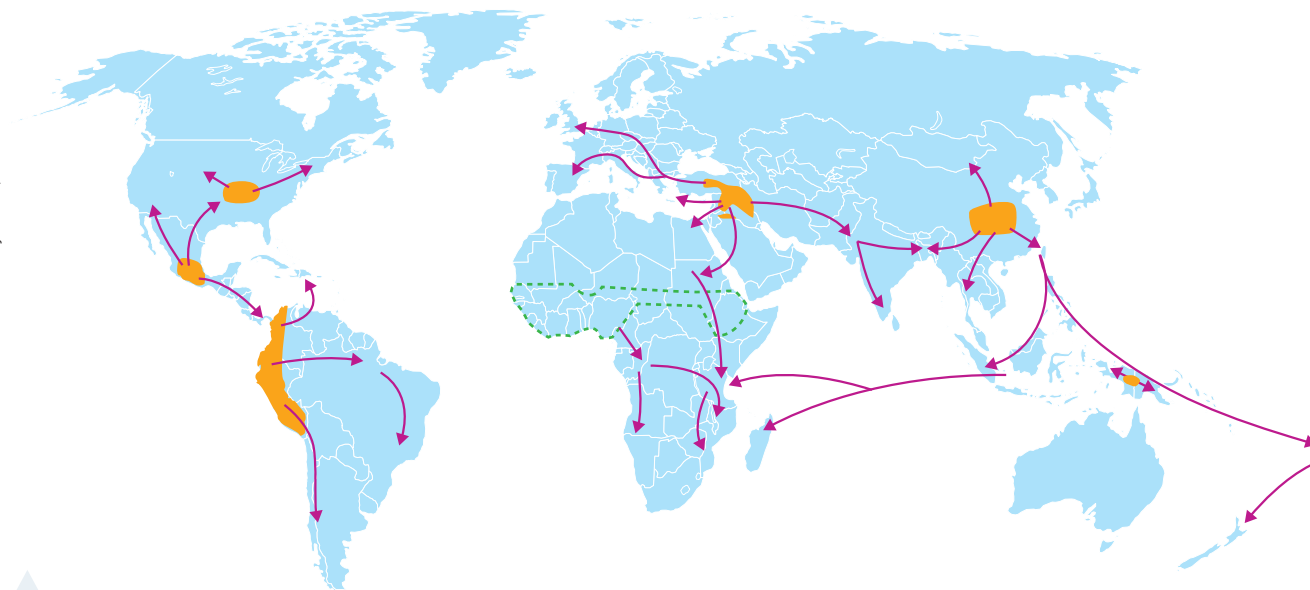


FIGURE 13.3 Centres of origin of agriculture. Map of the world showing approximate centres of origin of agriculture and its spread in prehistory: the Fertile Crescent (11 000 BCE), the Yangtze and Yellow River basins (9000 BCE) and the New Guinea Highlands (9000–6000 BCE), Central Mexico (5000–4000 BCE), Northern South America (5000–4000 BCE), sub-Saharan Africa (5000–4000 BCE, exact location unknown), eastern North America (4000–3000 BCE).

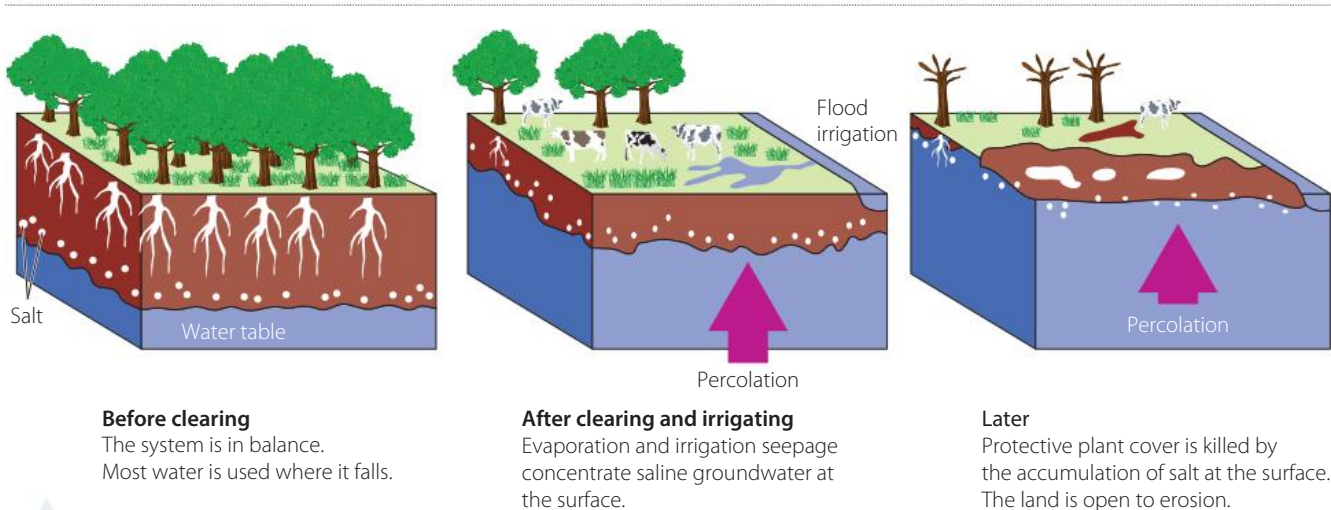
As human access to a reliable food and water source improved life expectancies, agricultural practices began to alter critical processes in ecosystems.

One of the immediate effects of agriculture on ecosystems was a disruption of natural soil structures and processes. Soil **erosion** refers to the removal of topsoil to distant areas by wind and water. The main causes are:

- ▶ removal of vegetation/leaving land **fallow**
- ▶ soil cultivation practices that break up the **soil structure**
- ▶ increased stocking rates of hard-hooved animals such as horses, cows and sheep grazing on land, leading to the break-up of the soil
- ▶ compaction of the soil by heavy machinery with loss of rain **infiltration** and increased water pooling on the surface
- ▶ salinisation of soils, which changes soil structure.

Disturbance of the soil during agricultural or urban development destroys the mechanisms that hold soil particles together and maintain soil structure. Removal of deep-rooted vegetation such as tall trees also leaves the soil vulnerable to erosion. Erosion represents a loss of valuable minerals for an ecosystem, as the **topsoil** is a rich source of nutrients and contains the vast bulk of organic matter. This has consequences for every level of the food web, from plants that use soil to anchor and sustain themselves to **detritivores** that break down organic waste and make it available for other organisms. **Tilling** the soil is one way that farmers break up the soil for ease of planting. Traditionally, methods of tilling destroyed the superficial soil structure. Another consequence of soil erosion is **siltation** of waterways from loose soil that is washed away into waterways by wind and rain. This leads to an increase in the **turbidity** of waterways and a reduction in light availability for aquatic plants, and adverse consequences for other aquatic organisms whose gills become clogged with silt and subsequently are unable to process dissolved oxygen in the water.

The disruption of soil processes often interferes with natural flows of water through them. **Salinity** refers to salt concentration. **Salinisation** is the process of increasing the salinity of soils and waterways. Australian soils contain high levels of salt as a leftover from the inland sea as well as from ocean salt blowing inland and being deposited in soils. Salt concentrations in soil and water are critical for living things because high concentrations of salt exert an osmotic drag on their tissues. Salinisation of soils occurs when humans remove deep-rooted trees (dryland salinity; Fig. 13.4) and when humans irrigate crops to increase yields (irrigation salinity). Both have the effect of raising the water table, which solubilises and



Original image sourced from: 'Managing Salinity: Ensuring a Farming Future'. Department of Agriculture and Rural Affairs (1980), State of Victoria.

FIGURE 13.4 Dryland and irrigation salinity

drags salts (mainly sodium chloride) from deeper soil layers to the surface of the soil. Severely affected soils often exhibit deposits of white crusts on the surface (Fig. 13.5). Salinised soil destroys the soil **biota**. Salinised waterways represent a danger to freshwater vertebrates and invertebrates as the high salt concentration puts higher demands on their **osmoregulatory** mechanisms.

Another effect of both agriculture and urbanisation is the introduction of unwanted substances into the environment. Pollution refers to the presence in the environment of any unwanted substance that causes harm. It is a problem on land, in waterways, in the atmosphere and in the ocean. The main concern is the effect of agricultural chemicals on **non-target species**. Pollution may come in the form of:

- **fertilisers** – fertilisers are used widely in Australia due to the generally low nutrient status of the soils. The Australian continent has been tectonically stable for millions of years and this has contributed to the poor nutrient load in the soil. European farming methods require fertilisation of the soil to achieve the yields expected to sustain crops for human consumption, animal pastures and fodder. Common fertilisers contain compounds containing the elements nitrogen and phosphorus.
- pesticides (insecticides, **anthelmintics** and herbicides) – weeds and insects threaten to reduce the quality and quantity of plant and animal produce. Insecticides are applied to plants to reduce crop loss from insects. They destroy or interfere with the development of many stages of the insect life cycle. Insecticides are also a threat to non-target organisms, and must be transported and handled with care. Any residues in crops represent a health threat to humans. Insects targeted include aphids, locusts, fruit flies, leaf miners and mealy bugs (Fig. 13.6). Insecticides are administered to animals in the control of ticks, lice, flystrike in sheep and bot flies in horses. Herbicides are applied to crops and pastures to reduce weed populations. They may be washed into waterways and persist in the soil. Anthelmintics are administered to animals to control parasitic worms such as roundworms, tapeworms, flukes and hookworms. These substances are shed in faeces and represent a residue in the soil, and there have been reports of some effects on native arthropod populations from exposure to certain chemicals in cattle dung. The chemicals pose a threat to native species because many agricultural chemicals persist in soil and waterways for decades.

One particular form of pollution is **eutrophication** (Fig. 13.7). Eutrophication refers to the overgrowth of cyanobacteria in waterways due to an increase in the availability of phosphorus-containing compounds such as those in fertilisers and detergents. Often referred to (inappropriately) as ‘algal bloom’, this poses a threat to native plants and animals in waterways through both loss of light and the presence of cyanide-containing toxins in many species of cyanobacteria.



FIGURE 13.5 Salinisation and its devastating effects



FIGURE 13.6 The citrus mealy bug

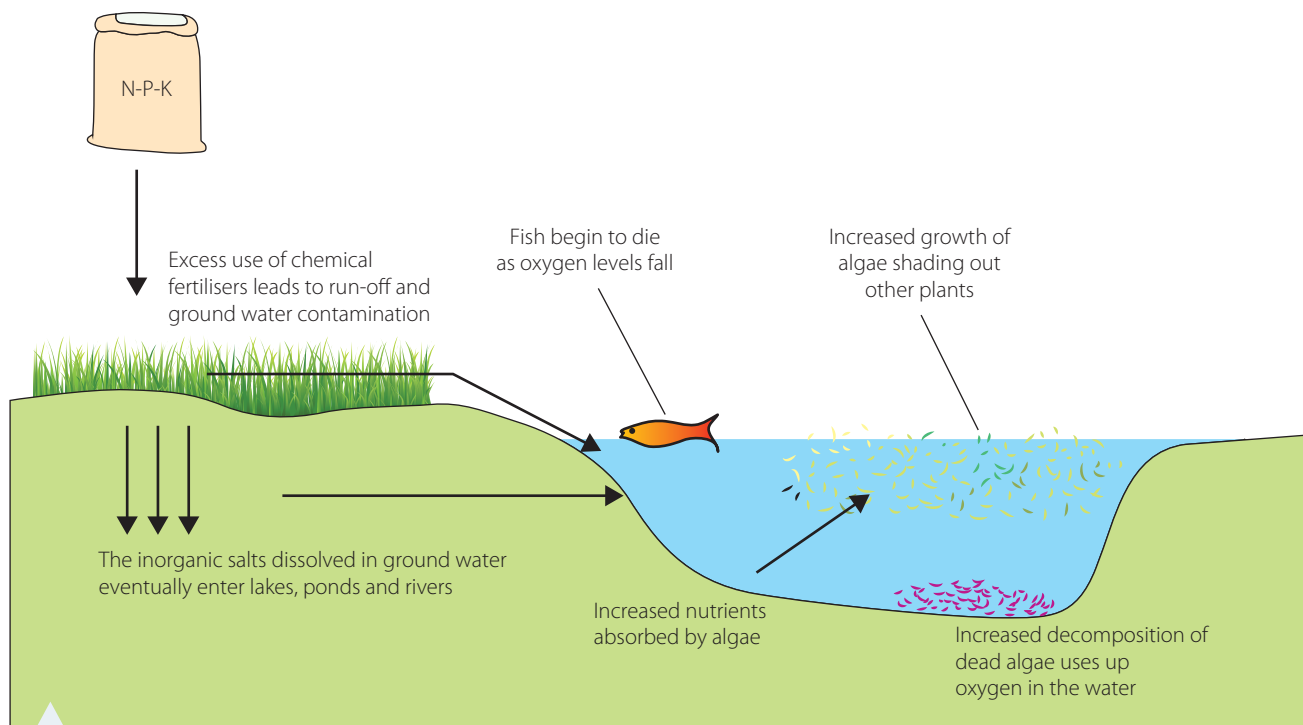


FIGURE 13.7 Eutrophication

KEY CONCEPTS

- Agriculture was developed to improve human access to resources.
- When not well managed, agriculture has severe consequences on ecosystems, including soil and water degradation, loss of habitats for organisms and chemical pollution.

CHECK YOUR UNDERSTANDING

13.1b

- 1 What is meant by the Neolithic revolution?
- 2 What was the effect of the Neolithic revolution?
- 3 Outline some of the main contributing factors to soil degradation.
- 4 List the consequences of soil disturbance.
- 5 What are the main causes of pollution in an agricultural setting?
- 6 How can native species be affected by pollution?



FIGURE 13.8 European red fox (*Vulpes vulpes*)

Introduced species

As human populations expanded, new species of animals and plants were brought from overseas for many reasons. **Introduced species** of plants and animals are a major problem in Australia. Since European colonisation of Australia, many species of plants and animals have been either deliberately or accidentally introduced into Australian environments. Examples of deliberate introductions include the European rabbit, the European red fox (*Vulpes vulpes*; Fig. 13.8) and many ornamental garden plants. Many of these European species out-competed native species for water, light, habitats and nutrients. They have also changed the environment in such a way as to alter the **microclimate** of the area to favour their own growth and development.

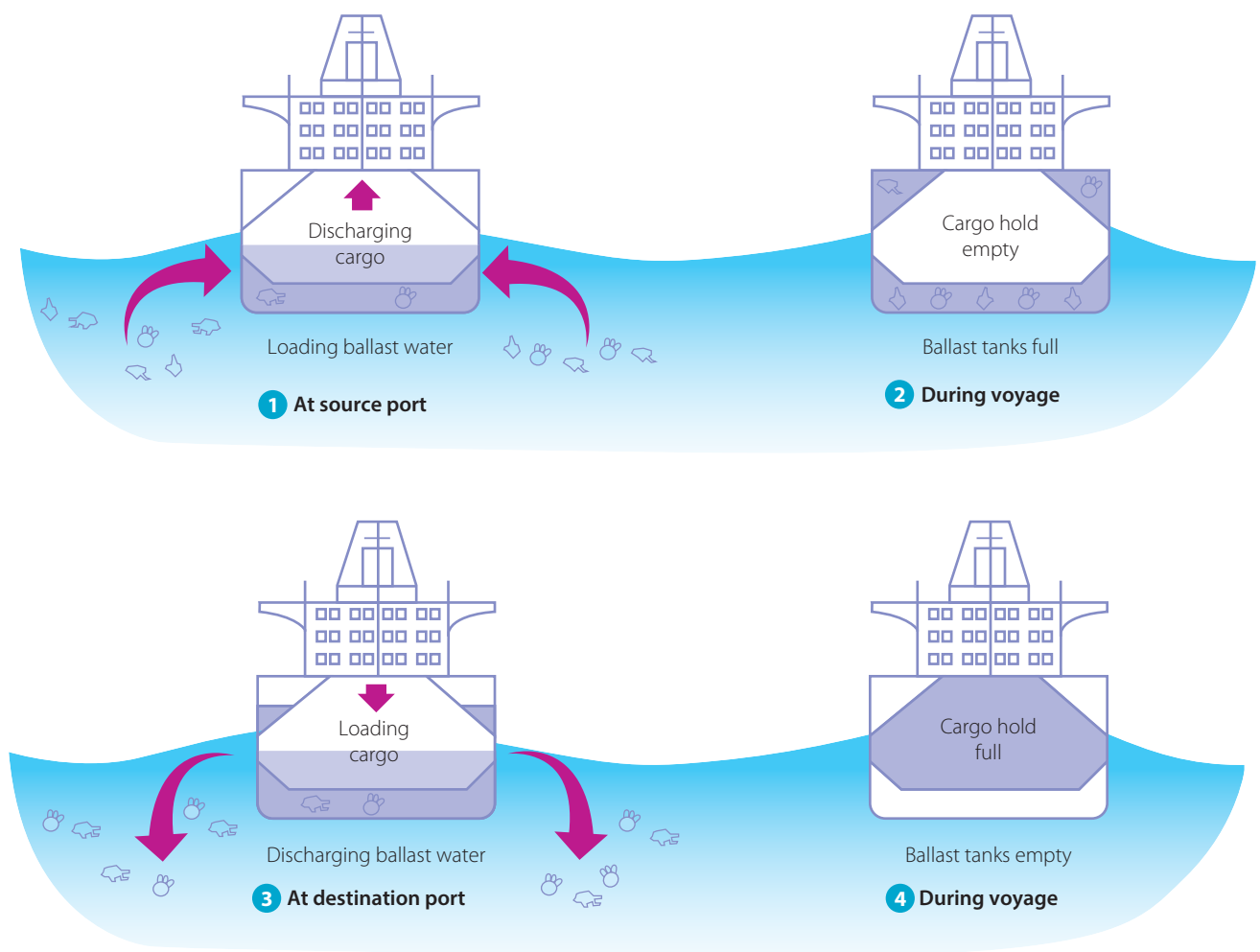


FIGURE 13.9 Ballast water

Marine life is also susceptible to threats from introduced species. **Ballast** water (Fig. 13.9) is used by ships to improve their stability on long ocean voyages. It is picked up when cargo is loaded and discharged upon arrival at the destination. When ballast water is picked up, marine species are picked up also and transported across the oceans to distant sites. The Northern Pacific seastar (*Asterias amurensis*) is an aggressive predator that has had major impacts on native shellfish, small invertebrates, aquaculture and fisheries in Victorian and Tasmanian waters (Fig. 13.10).



FIGURE 13.10 The Northern Pacific seastar

Land clearing

To sustain growing populations and create space to grow food, trees need to be removed. **Land clearing** (Fig. 13.11) refers to the removal of native vegetation for urban or agricultural development. As well as contributing to soil salinisation and erosion, land clearing removes the nesting sites and habitats of native animals. Many of these animals are territorial and are not able to re-establish themselves elsewhere.



FIGURE 13.11 Land clearing for urban development



FIGURE 13.12 Effects of acid rain on vegetation in Queenstown, Tasmania

 Mt Lyell mine, Queenstown

As the demand for water increased for consumption and agriculture, waterways began to be altered. **Dams** and **weirs** are features of the Australian environment. Australia is a very dry continent and European farming methods have traditionally had a high demand for water for crops and livestock maintenance. Extraction of water from surface waterways has led to a drop in water levels in rivers as well as the loss of some **wetlands**. Water is often diverted into dams and weirs for irrigation. Some crops, such as cotton, have a high demand for irrigation water. The amount of water extracted by landowners is tightly regulated by the government to make irrigation a more **sustainable** practice in the long term. Water flows in Australian rivers often occur in pulses because rain is periodic. The breeding cycles of fish and invertebrates living downstream are adapted to these seasonal pulses, but dams and weirs disrupt the pattern.

The Snowy River was dammed in 1967 to produce hydroelectricity. Only 1 per cent of the natural water flows remained after damming. There was a severe reduction in biodiversity to such an extent that the Victorian and New South Wales governments legislated for **environmental flows** to occur to restore the biodiversity of aquatic systems in the region.

As technology improved and infrastructure increased to cope with higher human populations, more of Earth's mineral resources were needed. **Mining** represents a rich source of income for Australia. **Ores** such as lead, iron ore, silver, aluminium, gold, copper, uranium and zinc are extracted from the ground. Some ores are processed and refined in Australia before they are exported and others are exported overseas for processing and manufacturing purposes. Some resources, such as coal, are used locally for electricity generation. In 1851 gold was discovered in New South Wales and Victoria. Soon after, almost 40 per cent of all the gold produced in the world was found in Australia.

Mining is carried out in all states and territories of Australia. It contributes to land degradation in the following ways:

- Extraction and refining of ores leaves behind chemical pollutants, which accumulate in soil and local waterways.
- Acid wastes are produced, which change the acidity of waterways.
- The **topography** of the land is altered by the removal of topsoil and vegetation, leading to soil erosion and siltation of local waterways.
- Old buildings and machinery may be left behind once mining operations cease.
- Air pollution with oxides of sulfur and nitrogen may lead to the production of **acid rain** (Fig. 13.12), which destroys vegetation and soil invertebrates.

Extinction

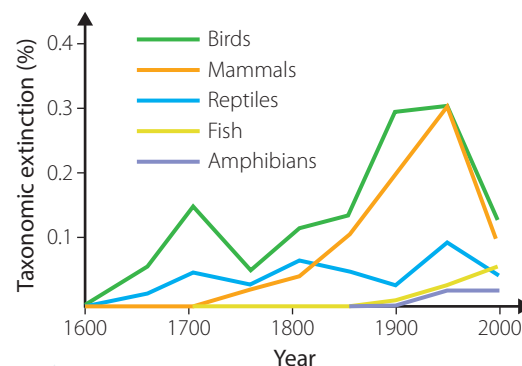
Habitat loss is the leading cause of **extinction** around the world. Most historic extinctions have occurred on islands because even small losses of habitat have devastating effects there. Island populations are often relatively small, and thus particularly vulnerable to extinction. Of the 90 species of mammals that have gone extinct in the world in the last 500 years, 73 per cent lived on islands. Another 19 per cent lived in Australia (Table 13.1).

TABLE 13.1 Australian contribution to the global status of major animal, fungus and plant groups

SPECIES	AUSTRALIAN DIVERSITY
Marine fish	One of the most diverse fish faunas in the world, with more than 4500 species
Sharks and rays	54% of the entire chondrichthyan fauna is endemic to Australia
Ectomycorrhizal fungi	95% endemic (22 genera and three endemic families)
Terrestrial vertebrates	1350 endemic terrestrial vertebrates, far more than the next highest country (Indonesia, with 850 species)
Terrestrial mammals	305 species, of which 258 (85%) are endemic; more than 50% of the world's marsupial taxa occur only in Australia
Birds	17% of the world's parrots occur in Australia – more than 50 species (second highest level of endemism after Brazil and the same as Colombia)
Reptiles	89% endemic; some groups such as front-fanged snakes (family Elapidae), pythons and goannas are more diverse than elsewhere in the world; Australian deserts have the world's highest diversity of lizard species
Frogs	94% endemic; around 230 total species of amphibians in Australia (highest level of endemism of any vertebrate group in Australia)
Marine invertebrates	17.8% of the world's crustaceans, 22% of bryozoans and 29.4% of sea squirts occur in Australian waters
Vascular plants	91% of flowering plants are endemic; 17 580 species of flowering plants, 16 endemic plant families (the highest in the world) and 57% of the world's mangrove species
Butterflies and moths	Many groups are unique to Australia

Source: Australia State of the Environment 2016. © Commonwealth of Australia 2017, released under a CCBY licence.

Recently, the extinction crisis has moved from islands to continents. Most modern species threatened with extinction now occur on continents. We can now predict that these areas will be affected the most from the extinction crisis in the next 100 years (Fig. 13.13 and Table 13.2).

**FIGURE 13.13** Trends in species loss. The graph presents data on recorded animal extinctions since 1600.**TABLE 13.2** Extinctions recorded since 1600

TAXON	RECORDED EXTINCTIONS				APPROXIMATE NUMBER OF SPECIES	PERCENT OF TAXON EXTINCT
	MAINLAND	ISLAND	OCEAN	TOTAL		
Mammals	30	51	4	85	4000	2.1
Birds	21	92	0	113	9000	1.3
Reptiles	1	20	0	21	6300	0.3
Amphibians	2	0	0	2	4200	0.05
Fish	22	1	0	23	19 100	0.1
Invertebrates	49	48	1	98	1 000 000+	0.01
Flowering plants	245	139	0	384	250 000	0.2

Source: Reid, W. V. and Miller, K. R. (1989). Keeping Options Alive: The Scientific Basis for Conserving Biological Diversity. World Resources Institute, Washington DC www.wri.org

Australia has a very diverse collection of plant and animal species. Our continent hosts approximately one million species of known plants and animals. Many are **endemic** to Australia (that is, they are found only here).

According to the Australian Government Department of the Environment and Energy website:

Between 7 and 10% of all species on earth occur in Australia. More than 4500 species of marine fishes – the greatest number of red and brown algae, crustaceans, sea squirts, and bryozoans in the world – live in Australian inshore waters. Fifty-seven per cent of all mangrove species are found in Australian intercoastal zones. There are more than twice as many species of reptiles in Australia as there are in the United States, and Australian deserts support more lizard species than any other comparable environment.

Source: Steffen, W., Burbidge, A., Hughes, L., Kitching, R., Lindenmayer, D., Musgrave, W., Stafford Smith, M. and Werner, P. (2009). Australia's Biodiversity and Climate Change. Australian Government Department of Climate Change, Canberra. © Commonwealth of Australia 2016. 8 Biodiversity. <https://www.environment.gov.au/science/soe/2011-report/8-biodiversity/1-introduction/1-1-importance>

So we need to ask ourselves the question: are extinction and habitat loss normal processes or is there a genuine crisis going on now? Some people have argued that we should not be concerned because extinctions are a natural event and extinctions have occurred in the past. Indeed, at least five mass extinctions have occurred during the last one billion years (see page 257). Mass extinctions are a special category of extinction where not just many species disappear, but entire families and orders of organisms are wiped out at the same time. This usually occurs in multiple places around the world simultaneously. This is distinct from species extinctions such as the extinction of the thylacine (Tasmanian tiger) during the 20th century.

Two mass extinctions that have offered scientists detailed insights into the effects of climate on ecosystems include the Permian-Triassic (end-Permian) extinction and the Cretaceous-Tertiary (K-T) extinction.

The end-Permian extinction was responsible for the loss of over 90 per cent of species on Earth. It occurred approximately 245 mya. Scientists have used clues in the geological record to infer that massive volcanic activity in an area known as the Siberian Traps led to huge changes in the composition of the atmosphere and oceans. Outpourings of carbon dioxide and sulfur dioxide from volcanic activity had significant effects on the global climate. Marine-based organisms were particularly affected. Multiple selection pressures led to massive extinction but also to adaptive radiation into new niches by those species that already possessed the traits that enabled them to thrive in the new conditions. Biodiversity rebounded.

The K-T **mass extinction** occurred around 65 mya and was responsible for the loss of the dinosaurs as well as approximately 65 per cent of all other species. There are several theories about the cause, but the most generally accepted explanation is an asteroid strike in shallow waters in the present-day Gulf of Mexico. This asteroid caused an explosion big enough to alter the atmosphere and oceans, blocked the sun and caused massive global cooling. Photosynthetic organisms suffered from reduced light penetration from the sun. The most dramatically affected organisms were large terrestrial vertebrates such as the dinosaurs, which gradually disappeared, probably due to starvation. This extinction opened niches for surviving organisms to expand into. Rapid development of new species followed. Biodiversity rebounded.

A look at the past to inform the future

Biologists can estimate rates of extinction by studying recorded extinction events, examining the fossil record and by analysing modern trends in habitat loss and disruption.

Studying a wide array of recorded extinctions and many species currently threatened with extinction, conservation biologists have identified human-induced selection pressures that seem to play an important role in many recent extinctions (Table 13.3):

- 1 Over-exploitation of resources – this refers to the harvesting of resources in a way that is not sustainable over time. The ability of nature to ‘rebound’ is stretched beyond its limit. An example is the unsustainable removal of tropical rainforests for timber and agricultural purposes in South America, South-east Asia and central Africa.

- 2 Introduced species – the introduction of new species into an ecosystem causes changes in relationships due to competition, predation and disease. An example is the devastating effects of the cane toad on populations of small mammals and native toads and frogs (see pp. 221, 294).
- 3 Disruption of ecological relationships – established food webs are disrupted due to the loss of available niches, with alterations in the abundance and distribution of populations. This may involve loss of genetic variability, habitat loss and/or fragmentation of populations with subsequent effects on genetic diversity.



Role of humans in extinction of species

TABLE 13.3 Percentage of species influenced by the given factor

GROUP	PERCENTAGE OF SPECIES INFLUENCED BY THE GIVEN FACTOR ^a					
	HABITAT LOSS	OVER-EXPLOITATION	SPECIES INTRODUCTION	PREDATORS	OTHER	UNKNOWN
<i>Extinctions</i>						
Mammals	19	23	20	1	1	36
Birds	20	11	22	0	2	37
Reptiles	5	32	42	0	0	21
Fish	35	4	30	0	4	48
<i>Threatened extinctions</i>						
Mammals	68	54	6	8	12	–
Birds	58	30	28	1	1	–
Reptiles	53	63	17	3	6	–
Amphibians	77	29	14	–	3	–
Fish	78	12	28	–	2	–

a Some species may be influenced by more than one factor, so some rows may exceed 100 per cent.

Source: Reid, W. V. and Miller, K. R. (1989). Keeping Options Alive: The Scientific Basis for Conserving Biological Diversity. World Resources Institute, Washington DC

Biodiversity

Habitat loss can affect biodiversity. There are three recognised levels of biodiversity:

- 1 Genetic diversity refers to the **intraspecies diversity** in traits that makes a population more resilient to environmental changes. For example, cheetahs experienced a genetic bottleneck around 10000 years ago and subsequently demonstrate a very low diversity in their genetic make-up. This has led to some reduction in their reproductive success.
- 2 Species diversity is the variety of different species available in an ecosystem. It is sometimes referred to as 'species richness'. Food chains rely on many species interacting to pass on nutrients and energy from one to another. Plants supply food for **herbivores**, which in turn are a food source for carnivores.
- 3 Ecosystem diversity is the variety of ecosystems available in a broader area such as continents or globally. For example, wetland ecosystems provide a home for a range of animals and plants and are important for flood control, water purification, shoreline stabilisation and storm protection.

The Australian Government is responsible for managing biodiversity and key threats to ecological communities.

The value and benefits of maintaining biodiversity fall into four main categories. First, there is the direct economic value of products we obtain from species of plants and animals, and from **bioresources** for food, fibres, timber and medicines. For example, colchicine, used to treat gout, comes from a small flower called the colchicum. Quinine for the prevention and treatment of malaria comes from



Biodiversity

Find some examples of how the Australian Government is managing biodiversity.



Convention on biological diversity
Use the information presented to find out the goals of the convention.

the cinchona tree in the rainforests of South America. The potential for finding more bioresources is significant (for example, ants possess specialised glands for producing antibiotics to reduce disease in their colonies). These discoveries hold great potential for therapeutic use. Second, there is an indirect economic value of benefits produced by species without consuming them. For example, ecosystems underpin many of our natural resources and provide services such as healthy soil, clean water and crop **pollination**. Bees pollinate many of our fruit and vegetable crops. Their extinction would threaten the human food supply chain. Third, all species have an ethical right to exist, just as humans do. We all share this planet together! Last, living organisms have an **aesthetic** value. Humans enjoy the beauty of the natural environment, and nations like to conserve their heritage for future generations to enjoy. For example, the stunning beauty of the Great Barrier Reef would be lost without the variety of coral, fish and invertebrate species that make it their home.

At an international level, biologists are working together to discover and record all the types of organisms on Earth – the world’s biodiversity – so that it can be synthesised into a classification system that will reflect our knowledge of all of life. The 1992 *Convention on Biological Diversity* sets out its goals as the conservation and sustainable use of biological diversity for present and future generations.

The Australian Government’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) was created to meet Australia’s obligations as a signatory to the *Convention on Biological Diversity*. This Act protects all native fauna and provides for the identification and protection of threatened species. In each Australian state and territory there is a **statutory** listing of threatened species. At present, 380 animal species are classified as either endangered or threatened under the EPBC Act. A complete cataloguing of all the species within Australia has been undertaken; it is a significant step in the conservation of Australian fauna and biodiversity. In 1973, the federal government established the *Australian Biological Resources Study*, which coordinates research in the taxonomy, identification, classification and distribution of Australian flora and fauna.

Monitoring is essential to any action plan to conserve biodiversity. It provides information on how the management plan for conserving biodiversity is performing. If species continue to decline in population numbers, then it shows that the current management plan is not effective and requires change. Changing management involves assessing human-related activities such as mining, forestry and recreation, as well as conservation-related activities such as those existing in reserves and national parks. Ideally, all species in existence would benefit from having their populations monitored; however, this would be a very time-consuming and costly process, and funding is limited.

So, at present, monitoring programs tend to focus on threatened species or ecosystems, or ecosystems that provide economic value through industry (for example, mining, logging and tourism).

Amphibians have been identified as good indicators of environmental health because they are very sensitive to changes in their environment (their skin is permeable to both liquids and gases). Because of this sensitivity their decline within an ecosystem may indicate that other components of the ecosystem are also in a state of decline or bad health. Information can also alert us to the nature of the population decline and the potential threats causing the decline.

The EPBC Act allows for the identification of key threatening processes. These include anything that directly or indirectly affects the:

- survival of a species
- abundance of a species
- evolutionary development of a species.

Australian extinctions

By looking at the evidence for changes between past and present climate, and observing the changes in the distribution of organisms that formed fossils over time, we can understand more about the factors that may determine the distribution of flora and fauna in present-day environments. We can use this to predict the movement and distribution of organisms in the future.



Key threats
Key threatening processes are listed on the Australian Government’s environment website.



Human-induced selection pressures on the Baw Baw frog

South American marsupials have been dominated by placental mammals over time. This could happen in Australia given the same conditions. To find out exactly what those conditions were is the role of the palaeontologist. Palaeontologists can compare past life to modern groups of organisms to discover genetic relationships and the ages of different groups. The fossil record for kangaroo-like marsupials in Australia extends back 45 million years to a time when rainforests were widespread. Figure 13.14 shows how scientists have been able to reconstruct a simple ‘family tree’ of kangaroos based on fossil evidence.

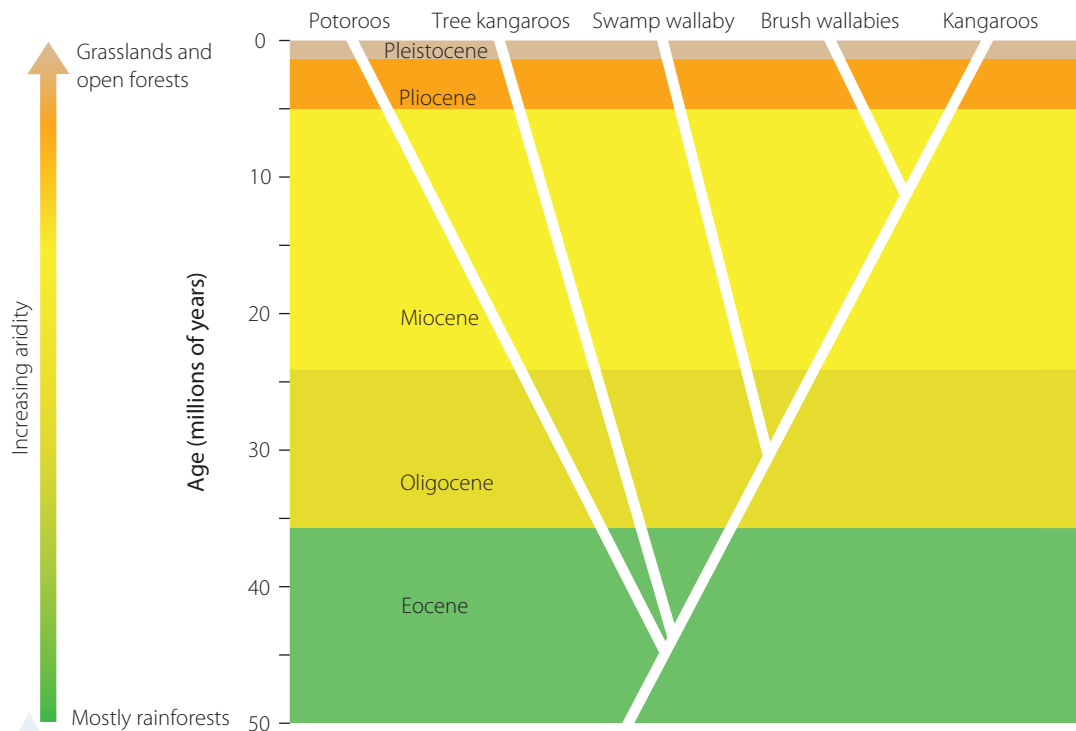


FIGURE 13.14 Relationships of kangaroos: a phylogenetic tree representing a simplified view of the relationships of kangaroos throughout the past 50 mya

As the Australian plate drifted north, the availability of water decreased and the aridity of the land increased, with grasslands and open forests becoming more common. The number of living species of grazing macropod kangaroos that adapted to a diet of grasses reflects success in the drying environments, while the once common browsing (leaf-cutting) *sthenurine* kangaroos have declined, possibly due to reduced availability of low-leaf foliage. The living kangaroo most like the ancestor of all kangaroos is the musky rat-kangaroo, *Hypsiprymnodon moschatus* (Fig. 13.15), which lives in rainforests and eats a variety of foods. It has simple, rounded molars for crushing soft food items. Species of *Macropus*, such as the red kangaroo (*Macropus rufus*), have high-crested molar teeth that efficiently shear and grind food into a paste (Fig. 13.16). This allows a high proportion of nutrients to be extracted from relatively poor-quality grasses.

Hypsiprymnodon, which retains many ancestral kangaroo features, does not hop bipedally and has a less specialised foot structure, differing from all other kangaroos in retaining the first toe. Kangaroos such as *Macropus* species have a hopping form of locomotion and can achieve speeds greater than 50 km/h because of the reduction of the number of toes. This speed is an advantage in grasslands. The modern varieties of musky rat-kangaroo are found in a tiny area of north-east Queensland, where rainforests dominate. The distribution of rainforests is very likely to be affected by climate change (see page 207).



FIGURE 13.15 **a** The first digit ('thumb') has been retained in the foot of the musky rat-kangaroo; **b** the red kangaroo does not possess a first digit.

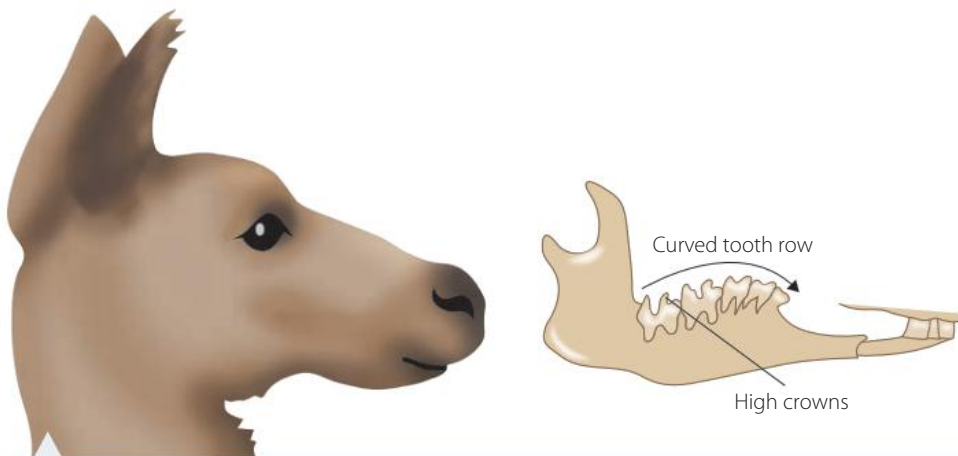


FIGURE 13.16 Kangaroo molars have high crowns that are adapted to shearing and grinding grass.

INVESTIGATION 13.2

A secondary-source investigation into the conservation status of animals and plants

The conservation status of a species refers to the likelihood of its remaining alive in the near future. Several systems categorise the conservation status of species:

- global systems such as the IUCN Red List of Threatened Species, which has nine categories
- CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), which regulates international trade in species
- Australian state and federal systems, such as the *EPBC Act 1999*, which categorise species as:
 - extinct
 - extinct in the wild
 - critically endangered
 - vulnerable
 - conservation dependent.



» AIMS

- 1 To use secondary sources to collect and organise data on the conservation status of a named animal and plant in Australia
- 2 To justify the value of record keeping of this data by the Australian Government

METHOD

- 1 Working in groups of five, gather data and communicate the definitions of the above Australian state and federal conservation status categories.
- 2 Formulate a research question for this task. To do this, analyse the information in tables 13.1, 13.2 and 13.3 as well as the graph in Figure 13.13. As a group, brainstorm questions into two categories: 'answerable now' and 'needs further research'.
- 3 As a group, select one question as the research focus for the data you gather on conservation and the significance of this data for Australia.
- 4 To help you answer your research question, collect data on one animal and one plant that fall into each of the five categories listed on the previous page. Divide this research among the members of your group.
- 5 Search secondary sources such as the Internet, books and journals for photos or diagrams of your species and include them in your table.
- 6 Enter your group results into a table that you create in a shared Google doc.
- 7 Discuss the discussion questions as a group. Write the answers to the discussion questions individually.

RESULTS

- 1 Present your group results in a carefully planned table in a shared Google doc.
- 2 Individually write your own answers to the discussion questions below.

DISCUSSION

- 1 Justify the value of the Australian Government keeping records of the conservation status of its flora and fauna.
- 2 Outline some of the difficulties encountered when researching secondary sources.
- 3 Summarise your views on the value of tracking population health to decide the conservation status of native species in Australia.

CONCLUSION

Write a summary statement to outline what you have learned in relation to the research question that you formulated as a group.

KEY CONCEPTS

- Introduced species are animals and plants that have been brought in from overseas.
- Land clearing is the removal of native vegetation for development.
- Habitat loss due to introduced species and land clearing is leading to the extinction of some species.
- Habitat loss is affecting biodiversity.
- Monitoring is essential to conserving biodiversity.
- Palaeontological evidence can be used to predict future distribution of organisms.

CHECK YOUR UNDERSTANDING

13.1c

- 1 Define the term 'introduced species'. Provide examples.
- 2 Provide one example of how an introduced species has affected a native species.
- 3 List the effect of land clearing on Australian ecosystems.
- 4 List the effect of mining on Australian ecosystems.
- 5 Define extinction.
- 6 List the major factors that lead to extinction.
- 7 State the benefits of maintaining biodiversity.
- 8 Explain why monitoring is essential to conserving biodiversity. Which ecosystems tend to be monitored?

Changing climate



Sustainability

Earth's climate systems are complex and rely on the exchange of energy and matter between the four spheres of the Earth:

- the **hydrosphere** – all water on Earth in all three states (ice, liquid and vapour)
- the **lithosphere** – the outer rigid crust of the Earth
- the **atmosphere** – all the gases surrounding the Earth
- the **biosphere** – all living things on Earth.

Life on Earth is made possible by the presence and nature of our atmosphere and hydrosphere (mainly oceans). The atmosphere and oceans act as mechanisms to trap solar radiation throughout the day, storing it at night and preventing catastrophic temperature differences between day and night. Atmospheric gases, including water vapour and carbon dioxide, keep the atmosphere warmer than it would otherwise be. The Moon, which has no atmosphere, experiences temperature swings of almost 300°C between day and night.

This phenomenon is called the **greenhouse effect**. It is a normal part of Earth's climate system and happens as follows:

- 1 Solar radiation reaches and penetrates Earth's atmosphere – some of this is reflected out into space.
- 2 Some of the radiation is trapped by the greenhouse gases in the atmosphere, and this energy is absorbed by the land and the oceans in the form of heat energy.
- 3 This keeps the Earth warm enough to sustain life (Fig. 13.17).

The *enhanced* greenhouse effect occurs when there is an increase in the concentration of greenhouse gases in the atmosphere. This results in more heat energy being absorbed by the land and oceans.

Scientists have been collecting scientific data about Australian climate for a little over a hundred years and are able to analyse proxy data in the geological record to infer past climate changes from before records were kept. Australia's climate has always undergone periods of cooler or warmer, wetter or drier conditions, but the general trend over the last century is one of warming (Fig. 13.18).

Throughout geological history, there have been many influences, both internal and external, on Earth's climate (Fig. 13.19).

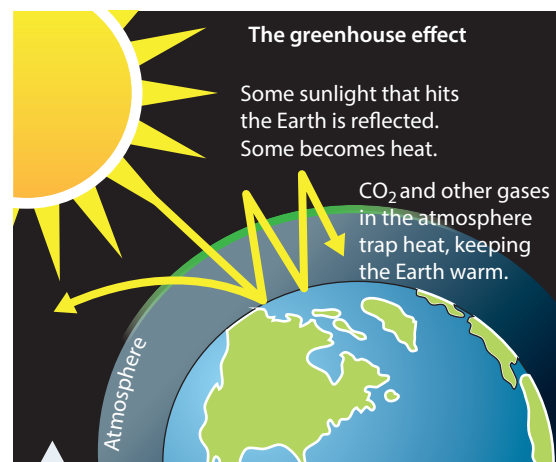


FIGURE 13.17 The greenhouse effect makes life on Earth possible.

Department of Ecology, State of Washington



Animated greenhouse effect

Use the animation to familiarise yourself with the greenhouse effect.

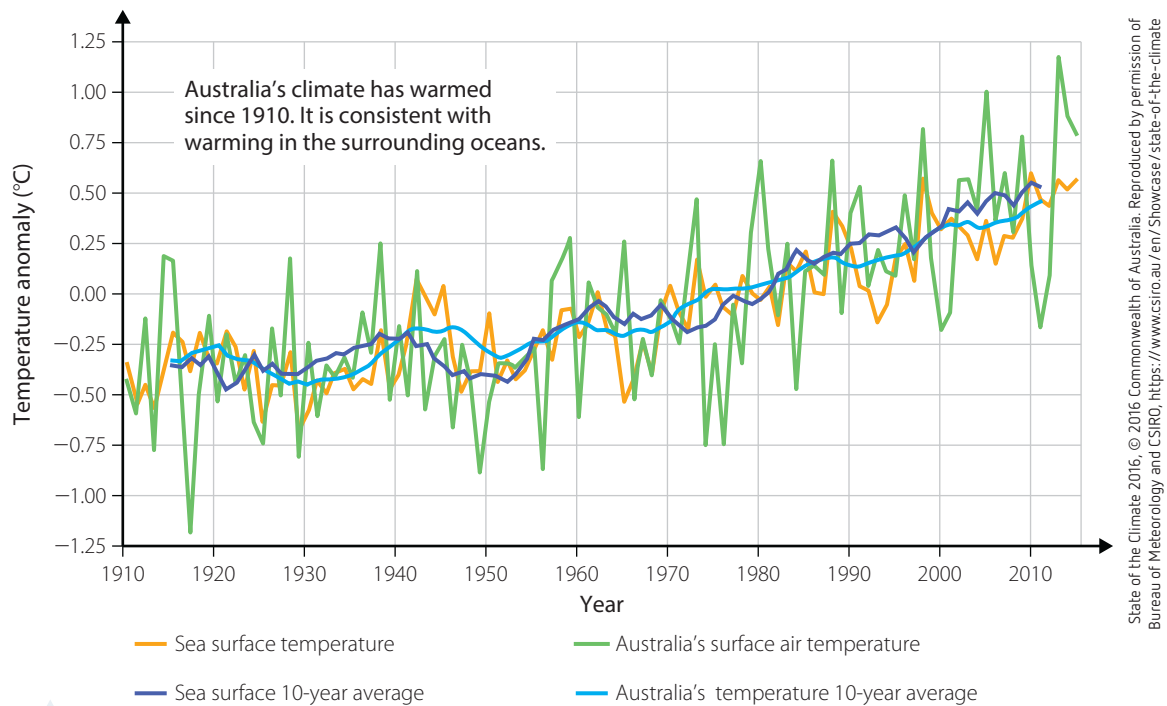


FIGURE 13.18 Variations in sea surface and surface air temperatures over the last century

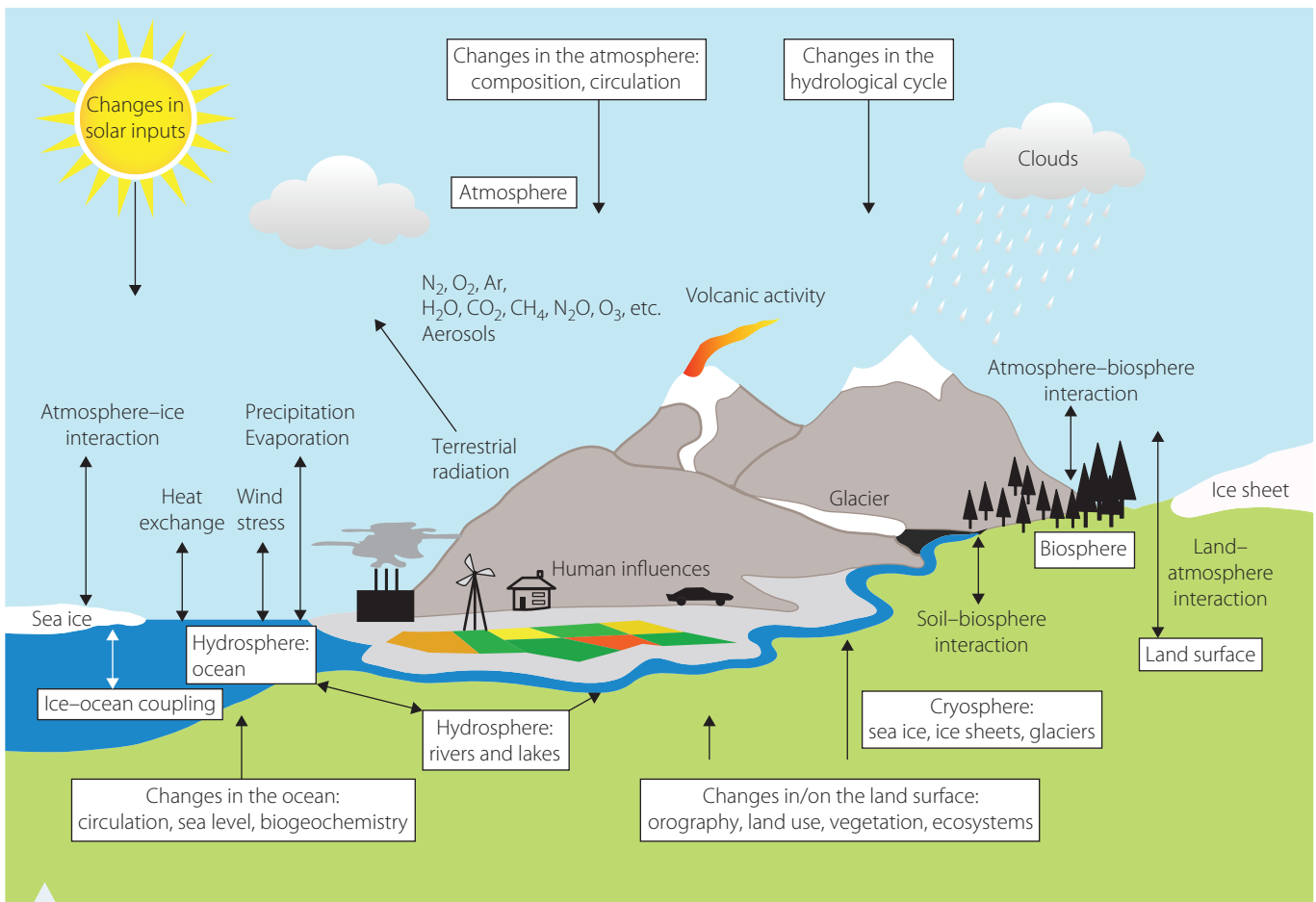


FIGURE 13.19 Factors affecting climate change

External factors include:

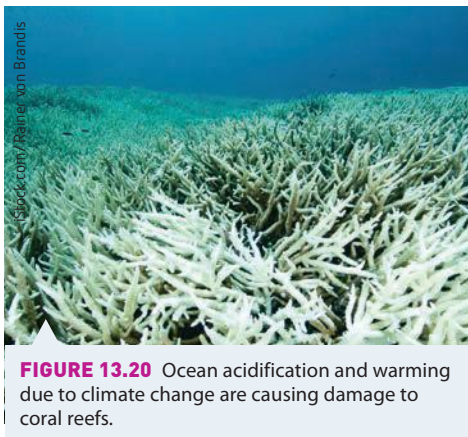
- solar energy output from the Sun
- variations in Earth's orbit around the Sun.

Internal factors include the:

- activity of volcanoes – release of carbon dioxide gas into the atmosphere
- temperature of the oceans – oceans are a sink for carbon dioxide, but as ocean temperatures rise, the solubility of carbon dioxide decreases; it diffuses back into the atmosphere
- amount of ice cover on the continents – ice reflects a lot of sunlight back into space due to its high reflectivity (**albedo**). Loss of ice cover reduces Earth's albedo and therefore more solar radiation is absorbed by Earth's surface.

The three main human factors contributing to climate change are:

- 1 increased carbon dioxide from the burning of fossil fuels such as coal, petroleum and natural gas
- 2 the impact of modern agricultural practices
- 3 widespread land clearing.



The impacts on Australia are both environmental (Fig. 13.20) and economic. There are issues surrounding water security, agricultural viability, the effects on coastal communities of changing sea levels and species distribution, as well as infrastructure considerations (for example, dams, desalination plants, erosion control in coastal communities, and building flood-resilient communities).

In Australia, CSIRO and the Bureau of Meteorology are involved in analysing future projections for climate change and its effects in Australia. Globally, the Intergovernmental Panel on Climate Change is the regulatory body that oversees research and strategy for climate change across the world.

The problem with seemingly small changes in average temperatures is that they can have marked effects on weather patterns. For example, scientists predict that there will be more days over 35°C, and so more intense heatwaves leading to more fires. Droughts have always occurred, but they may last longer and be more severe. Similarly, floods have always occurred, but the rain could become more intense, which will lead to more severe flooding.

Throughout geological time, there have been many instances where climate change was responsible for drastic effects on ecosystems.

Some of the major effects are summarised in Figure 13.21.

Ecosystems are generally very resilient. The problem with climate change is that multiple changes are being imposed on ecosystems at the same time, putting greater stress on their resilience.

The extent of the effect of climate change is best illustrated by the number of large animals that have become extinct during the period in which people have been in Australia. Most extinctions occurred between 35 000 and 15 000 years ago, at a time when conditions were driest during the last glacial period. Although climate has been considered to be the main cause of these extinctions, there is no evidence to suggest that climatic conditions at this time were more extreme than during the previous glacial phases. However, increased environmental instability resulting from burning by humans and the associated vegetation changes may have sufficiently altered stream flow and lake levels to produce a more drought-prone environment. A generalised summary of the development of the present vegetation and environment in south-eastern Australia is shown in Figure 13.22.

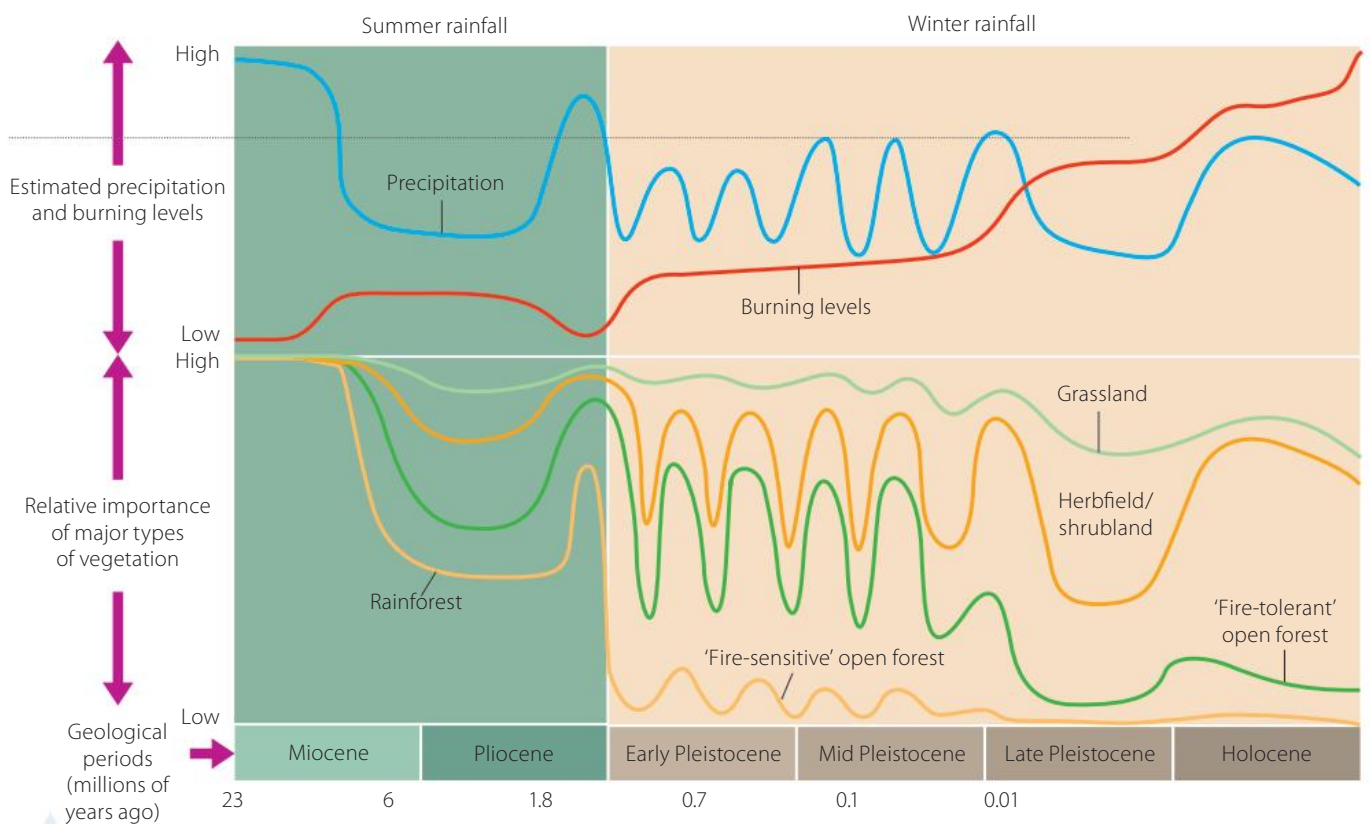
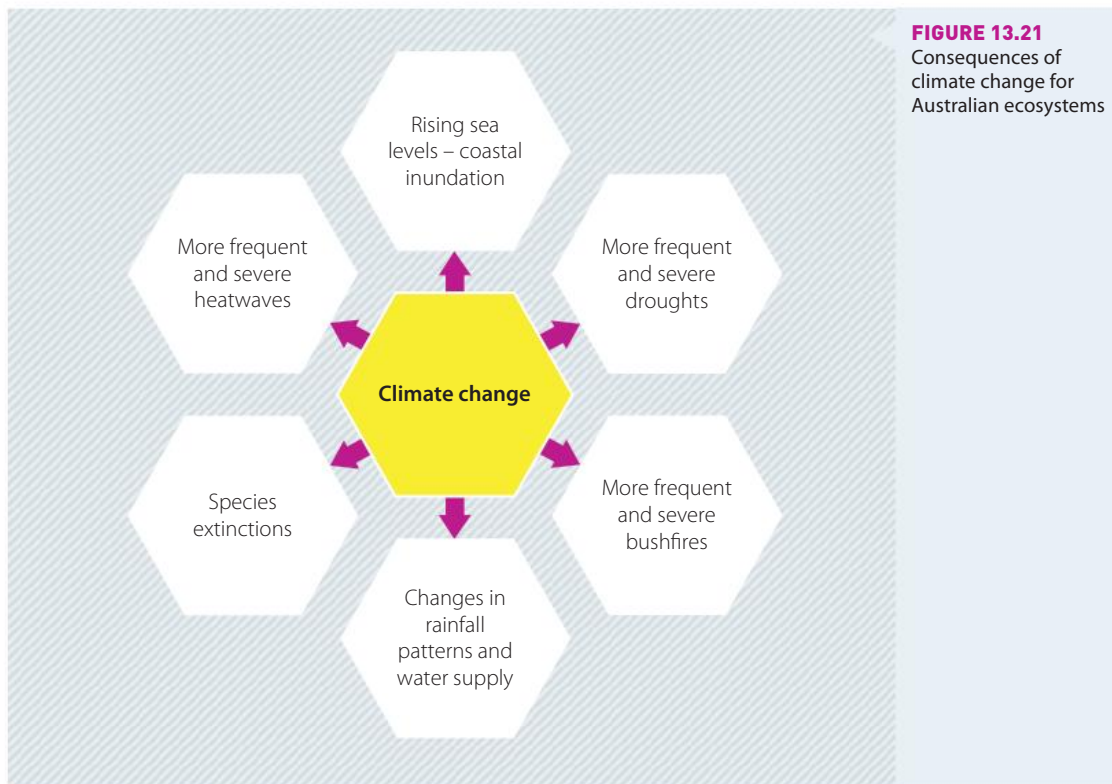


FIGURE 13.22 Vegetation and rainfall changes in south-eastern Australia

INVESTIGATION 13.3

A secondary-source investigation to analyse data from a graph on climate change and its impact on ecosystems

Use the data in Figure 13.22 to answer the following questions:

- 1 What is measured on the x- and y-axes of the graph in Figure 13.22?
- 2 Construct a key to the major vegetation types shown and for the precipitation and burning.
- 3 Comment on the trends over the last 23 million years for south-eastern Australia for each of the following:
 - a type of rainfall pattern
 - b burning levels
 - c dominant plant life.
- 4 Describe the relationship (if any) between precipitation levels and the populations of herbfield/shrubland species. What evidence is there for such a link?
- 5 Describe the relationship (if any) between burning levels and the dominance of fire-sensitive and fire-dominant species from the late Pleistocene period onwards. Justify using data from the graph.

KEY CONCEPTS

- The atmosphere traps solar radiation throughout the day, storing it at night and preventing catastrophic temperature differences between day and night.
- The greenhouse effect is a normal part of Earth's climate system.
- The enhanced greenhouse effect occurs when there is an increase in the concentration of greenhouse gases in the atmosphere.
- The burning of fossil fuels for energy has led to an increase in greenhouse gases.
- Changes in the composition of the atmosphere affect the temperature of the atmosphere and the oceans, and disrupt natural physical and biological cycles.

CHECK YOUR UNDERSTANDING

13.1d

- 1 List the four spheres of Earth.
- 2 Define 'greenhouse effect' and 'enhanced greenhouse effect'. Identify the main difference between them.
- 3 List the influences on Earth's climate.
- 4 Use Figure 13.19 to describe the trends in surface sea temperature and surface air temperature over the last century.
- 5 What are the predicted effects of climate change?
- 6 Justify the scientific concern for changing global average temperatures in terms of the consequences for climate change.
- 7 What is the link between burning fossil fuels and climate change?

13.2

Models to predict impacts on biodiversity

Thomas Malthus (1766–1834) (Fig. 13.23) was an English author, demographer, cleric and political economist who wrote prolifically on the relationship between human populations and the strain on natural resources. Although Malthus was concerned mainly with human populations, his arguments can be extended to the interaction between selection pressures and population numbers of any species. In fact, Charles Darwin based much of his development of the Theory of Evolution by Natural Selection on the writings of Malthus. Malthus based his work *An Essay on the Principle of Population as it affects the Future Improvement of Society* on the following arguments:

- Resources increase slowly.
- Human populations grow quickly.
- Human populations will outgrow their own ability to feed themselves.
- Great fertility will eventually lead to starvation, war and disease.
- These will reduce population numbers and keep the population in check (within the limits of the environment to sustain it) – this is a natural negative feedback loop.

The work of Malthus contributed to the introduction in Great Britain of the *Census Act 1800*, which enables the holding of the national census every 10 years to gather information on population trends. Malthus developed a simple mathematical model (the Malthusian or exponential growth model) to show that human populations grow exponentially where resources are unlimited:

$$P(t) = P_0 e^{rt}$$

where

P_0 = the initial size of the population

r = the population growth rate

t = time

Malthus was one of the first people to use the concept of a *model* to predict future trends. His research was detailed and his data was quantitative.



FIGURE 13.23 Thomas Malthus

Models to predict future population changes

To assess whether a particular species is vulnerable to extinction, conservation biologists look for changes in population size and habitat availability. Species whose populations are shrinking rapidly, whose habitats are being destroyed or which are endemic to small areas can be considered endangered.

Historical information is critical in explaining the present state of the environment and therefore also in predicting the future. In environmental management, this usually involves two aspects:

- 1 Baseline information for some point in the past that has relevance to the ecosystem being managed. In Australia, this has most often been taken to be the moment of first European settlement, as representing the state of the environment prior to the impacts and changes brought by that settlement. This is known as an **equilibrium model**. It is assumed that biological communities were stable at this point.
- 2 Measurements of change since that point of time are then examined. This is the non-equilibrium model. Disturbances are factored into the model. Disturbances may include an event such as a storm, fire, flood, drought, overgrazing, land clearing or other human activity. These disturbances may remove organisms from the community or change the availability of resources. Disturbances may be:
 - high level (high frequency or high intensity)
 - low level (low frequency or low intensity).



The Australian ecosystems models framework

Recognition of different rates and types of change in the past is a crucial foundation to understanding change in the present and to managing human activity into the future. By gathering data from specific communities over several years, scientists can piece together the variables that most influence ecological communities. It is important to note that not all disturbances are negative and some may lead to a positive impact on the ecosystem. New opportunities may become available for some species. In fact, as seen in mass extinction events of the past, greater ecosystem diversity may result.

Scientists can use models of biological communities to predict the effects of human impacts on their populations. Models are simply a representation of a concept that is too complicated to study *in situ* (in place). Often modelling is in the form of mathematical calculations which include the input and output variables for the community in numerical form. For example, numerical values for species numbers from sampling as well as values for the different abiotic features in an environment can be entered into the equation. Trends in populations mapped along with trends in abiotic factors can help scientists make mathematical links between a steady rise in atmospheric temperature and the features of a species.



Case study: the mysterious Australian ringneck parrot



FIGURE 13.24 Barnard's parrot's increased wingspans may be due to climate change.

A report has been written on the effect of increased average temperature on the wingspan of the Australian ringneck parrot (Barnard's parrot, *Barnardius zonarius*; Fig. 13.24) in Western Australia. Scientists have been surprised to find during routine surveillance of the population of parrots that the population average wingspan of the birds has been increasing. They hypothesise that an increased wing length leads to an increase in the surface area of the bird's skin for radiative heat loss from surface capillaries (birds do not sweat). Increased average temperatures have acted as a selection pressure for increased wing length. Birds that can thermoregulate more efficiently have a reproductive advantage and so the species has slowly changed. Computer modelling has made this research possible.

There are two ways that scientists can approach the question of constructing cause and effect models for biological communities:

- 1 Some models examine the effects of changes to the top of the food chain. This is called the *top-down model*. It examines the effect of loss of top-order predators on the numbers of organisms in the other trophic levels. For example, a scientist may want to know the effect of **biomagnification** of a pesticide and loss of predatory eagle numbers on the populations of other lower order predators and herbivores in the community.
- 2 Other models examine the effect from the opposite direction. Scientists use the *bottom-up model* to predict what might happen if the producers in food chains such as plants, algae and certain bacteria were removed from ecosystems. For example, what effect does a reduction in phytoplankton in the ocean due to climate change have on populations of zooplankton, filter-feeding invertebrates and whales?

Population growth models

Scientists recognise three main models used to predict population growth in organisms: geometric growth, exponential growth and logistic growth.

Geometric growth

When the environment is ideal and there are no factors that limit expansion of the population, populations grow at either a *geometric rate* or an *exponential rate*. Geometric growth is *evenly distributed throughout the year*.

In geometric growth:

- there is a fixed rate of population increase within a given time
- population sizes are compared to the previous year at the same time.

The equation to calculate the population N at any time t in the future is:
 $N(t) = N(0)\lambda^t$

where

λ = geometric growth rate

t = time in years

$N(0)$ = the initial population size ($t = 0$)

$N(t)$ = the population size at time t

▶ WORKED EXAMPLE 13.1

A grassland area contains an initial population of 20 female kangaroos. The females give birth to 12 joeys in the next 12 months but four kangaroos die in that year due to drought and disease.

If the growth rate is geometric, what will the kangaroo population be in:



a 2 years?

b 8 years?

ANSWER	LOGIC
a $N(t+1) = 20 + 12 - 4 = 28$ $\lambda = \frac{N(t+1)}{N(t)} = \frac{28}{20} = 1.4$ $N(t) = N(0)\lambda^t$ $N(2) = 20 \times (1.4)^2$ $N(2) = 39.2$ Therefore there will be 39 kangaroos in 2 years' time. b $N(t) = N(0)\lambda^t$ $N(8) = 20 \times (1.4)^8$ $N(8) = 20 \times (14.7)$ $= 295.2$ Therefore there will be 295 kangaroos in 8 years' time.	- Calculate the size of the population after year 1. - Rearrange the above equation to make λ the subject and then apply the equation. - Calculate the population in 2 years' time. - Use the same logic to calculate the kangaroo population in 8 years' time.

TRY THESE YOURSELF

A population of yabbies was studied in a dam in western New South Wales. There was a starting population of 45 yabbies. During the next year, 300 yabbies hatched and grew, but 150 yabbies died.

a What is the growth rate for this population?

b If the growth rate stays the same, how many yabbies will be in the dam in 5 years' time?

Exponential growth

When growth is *intermittent* during the year, but resources are still unrestricted, the growth rate is exponential. The shape of the growth rate curve is always 'J-shaped' (Fig. 13.25).

Bacteria in a Petri dish grow exponentially. The calculations for this type of growth are beyond the scope of this course, but can be easily investigated online for those who wish to pursue a depth study in the mathematical modelling of population growth.

Logistic growth

This is the most common way in nature that populations grow. There is an initial growth in the population, but this slows down because there is competition for limited resources. The graph is a *sigmoid (s-shaped) curve* (Fig. 13.26).

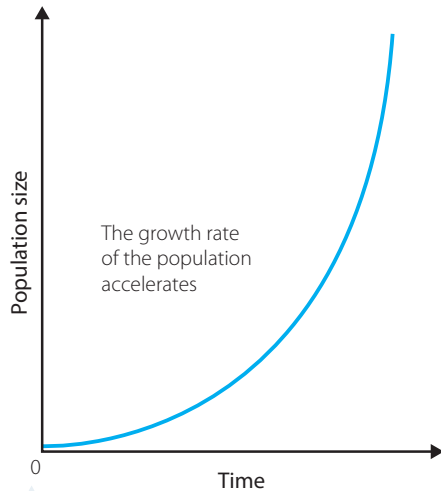


FIGURE 13.25 Exponential growth curve

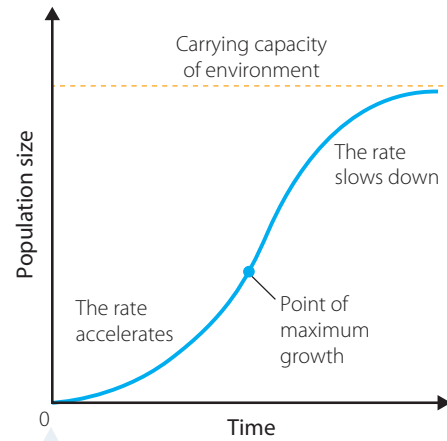


FIGURE 13.26 Logistic growth curve. The logistic growth model predicts that as a population of a species approaches the carrying capacity, its growth rate will slow down because resources become more limited. In other words, organisms start to die.

State of the Climate 2016, © 2016 Commonwealth of Australia. Reproduced by permission of Bureau of Meteorology and CSIRO, <https://www.csiro.au/en/Showcase/state-of-the-climate>

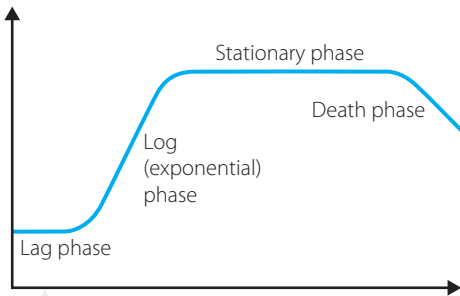


FIGURE 13.27 Phases in the logistic growth model

Once again, the calculations for this type of growth are beyond the scope of this course, but can be easily investigated online for those who wish to pursue a depth study in the mathematical modelling of population growth.

The *logistic model* introduces the concept of *carrying capacity* (K) for any ecosystem. The carrying capacity is the largest population size of any species that an ecosystem can support without negative effects on that ecosystem. This is a dynamic variable that changes with rainfall patterns, abundance of resources and other variables.

Therefore, there are usually three distinct time phases during logistic growth (Fig. 13.27).

Computer modelling

An example of a current computer model being used by scientists is the Western Australian Rangeland Monitoring System (WARMS). Its purpose is to predict the future possible impacts of climate change on ecosystems.

Case study: Parramatta River mangroves

Mangroves in the Parramatta River provide an example of the application of data modelling to environmental management. It had been assumed that the mangroves along the banks of the Parramatta River (the central river flowing into Sydney Harbour) are remnants of former, more extensive growth, destroyed in the course of the city's European history. This assumption, based on the present distribution of mangroves, has been overturned by research conducted by L. C. McLoughlin in 1987 and 2000, exploring historical sources back to initial settlement and finding major changes in the vegetation from the early 1800s up to 2000. The earliest data showed mangroves confined to patches only in lower areas of the river, and other prominent vegetation such as saltmarsh. The latest data showed increased mangrove growth to eventually line all available sections of the riverbanks, and invade and replace saltmarshes. The earlier, incorrect, assumptions had a significant influence on foreshore planning, management and restoration activity. Fortunately, this study has now provided more accurate information about the human impact on vegetation such as mangroves along the Parramatta River. Models created by scientists are only as accurate as the data they are based on.



Computer modelling of the environment

Using models to manage human impacts on future ecosystems

The past is the key to the future, and the more scientists learn about past ecosystems, the better able they will be to manage them in the future.

Palaeontology provides excellent data for building models to help guide future ecosystem management. Fossils are the remains of once living things that were uniquely suited to their environments. They provide invaluable information about what past environments were like. Through the study of fossils, we can construct models of the environmental requirements of organisms in the past and predict changes to those present species that are closely related to them. Such predictions will be most reliable in the case of younger rock strata that contain fossils that have representatives alive today. As we go further back in geological time, the predictions become less reliable because we encounter fossils of extinct groups about whose environmental requirements nothing is directly known.

Palaeontologists can use the fossil record to:

- determine how the organisms have changed over time
- understand how the organisms may be related
- understand why the organisms have become extinct
- see the effects of species extinction on other organisms
- recognise changes in past distribution of organisms in order to provide information about how the distribution may be currently changing.

The environmental information obtained from fossils may be as simple as whether the rocks in which they occur were deposited in the sea, in a brackish **estuary**, in fresh water, or on land. For example, rocks containing fossils of corals, brachiopods or echinoderms must have been deposited in the sea because living representatives of those groups are found only in the sea today. Similarly, fossils of land-dwelling animals such as kangaroos indicate deposition on land or in an adjacent body of fresh water.

Fossils of reef-building corals indicate that the rocks in which they occur were deposited in warm, shallow seas. At the present day, reef-forming corals are found in tropical seas and only at depths of less than 200 m where sunlight can penetrate the water to reach the photosynthetic algae within them. Limestone deposits that are remnants of former coral reefs give clues as to where and when these shallow seas occurred as well as the life forms contained within them. Examining the strata directly above may give clues as to the environmental causes of stress on coral reefs.

Fossil evidence may provide clues about the interactions of organisms with each other, biotic and abiotic factors of past ecosystems, and evidence of climate change in past environments. This fossil evidence therefore provides us with the factors that may have determined the distribution of fauna and flora in the past and hence distribution in present and future environments.

Many sites around Australia (Fig. 13.28) are rich in fossil samples and provide information about the species and environment in that area in the past. Table 13.4 summarises the fossil findings at each site, which in turn can provide evidence about factors that may have influenced them and help to indicate possible factors that may determine distribution of plants and animals currently and in the future.

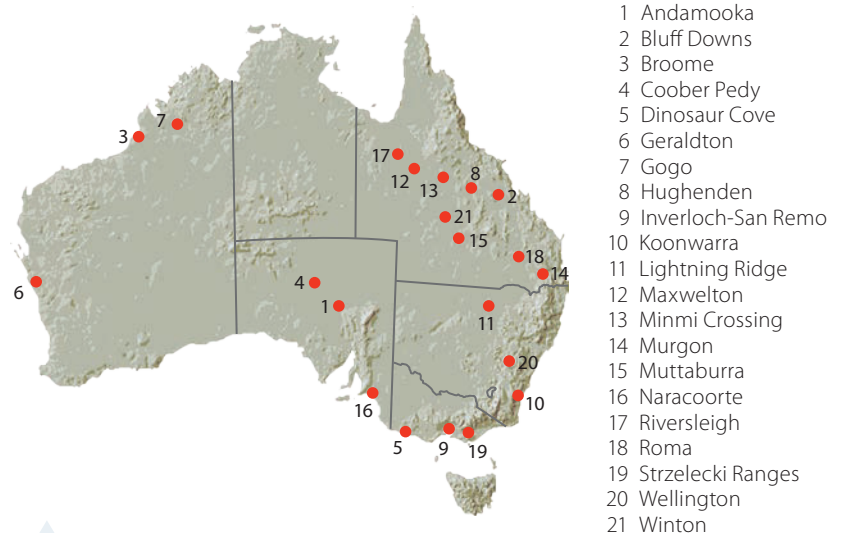


FIGURE 13.28 Fossil sites in Australia


Computer
modelling of
ecological
systems

Fossils are
discussed on
pp. 329–331.

TABLE 13.4 Australian fossil sites and their findings

FOSSIL SITE	AGE OF FOSSILS (YEARS AGO)	EXAMPLES OF FOSSIL SPECIMENS	PAST FLORA AND FAUNA PROPOSED FROM EVIDENCE
Lightning Ridge	110 million	• <i>Steropodon galmani</i> (small monotreme) • <i>Tachyglossus aculeatus</i> (short-beaked echidna) • <i>Ornithorhynchus anatinus</i> (platypus) • <i>Muttaborrasaurus langdoni</i> (herbivorous dinosaur) • <i>Rapator ornitholestoides</i> (carnivorous dinosaur)	Forests of ferns and pines and the beginnings of flowering plants, herbivorous and carnivorous dinosaurs, and monotremes
Murgon	55 million	• Placental mammals (condylarths) • Crocodiles • Snakes • Frogs • Salamanders • Marsupial mammals • Rainforest plants	Rainforests, no dinosaurs, but reptiles, songbirds, large numbers of marsupial mammals, few placental mammals, and amphibians lived near the streams
Koonwarra	115–118 million	• <i>Australurus plexus</i> (mayfly nymph) • <i>Tarwinina australis</i> (flea) • <i>Ginkgoites australis</i> (ginkgo leaf)	Large freshwater lake with fish, plants, insects, crustaceans, spiders, birds and crabs
Inverloch	115 million	• <i>Ausktribosphenos nyktos</i> (placental mammal) • <i>Koolasuchus cleelandi</i> (large amphibian)	Dinosaurs and mammals
Riversleigh	25 million–40 000	• Parrots • <i>Emuarius</i> (ancestor of emus and cassowaries) • Marsupials • Crocodiles • Snakes • Lizards • Turtles • <i>Yalkaparidon</i>, dasyurids, thingodontans (marsupial mammals)	Rainforests with high diversity of animals such as birds, reptiles, large numbers of marsupials, kangaroos, possums, wombats and monotreme mammals
Bluff Downs	5 million	• Bluff Downs giant python (<i>Liasis</i> sp.) • Koala-like mammal (<i>Koobor jimbarretti</i>) • Ancestral dasyurids	Lakes and streams, wetland area with rich diversity of animals such as birds, reptiles and mammals, many very large animals (e.g. giant python 8 m long)
Wellington Caves	5 million–30 000	• Diprotodon (giant marsupial wombat) • <i>Thylacoleo</i> (marsupial lions)	Leaf-browsing decreasing and grass-grazing marsupials increasing (kangaroos, wallabies and tree-kangaroos) over time, and grasslands expanding
Naracoorte	300 000	• <i>Macropus giganteus</i> (eastern grey kangaroo) • <i>Wallabia bicolor</i> (swamp wallaby) • <i>Sthenurus browni</i> • <i>Protemnodon brehus</i>	Large range of vertebrates: megafauna – large animals, marsupials, birds, reptiles and frogs

INVESTIGATION 13.4

A secondary-source investigation into the evolution, survival and extinction of species

The history of life on Earth over the past 3500 million years has been characterised by a dramatic increase in biological diversity. This increase in diversity did not occur in a gradual way over time, but it is the collective result of a number of rapid evolutionary spurts followed by occurrences of mass extinction. This rise of species numbers and fall through extinctions over time has resulted in an overall increase in biological diversity. Mass extinctions are often followed by occurrences of diversification, during which biological diversity is restored and eventually increased. This occurs by the rapid evolution of the survivors of the extinction, which adapt to repopulate the ecological space left by the extinct organisms.



AIMS

- 1 To gather, process and analyse information from secondary sources and use available evidence
- 2 To propose reasons for the evolution, survival and extinction of species, regarding specific Australian examples

METHOD

Part A

Select two Australian examples for each of the following categories:

- species that have evolved and changed over time
- species that have survived unchanged over time
- species that have become extinct over time.

Start your search using online or other secondary sources, selecting examples from the most recent periods such as the Holocene (10 000 years ago to the present) and Pleistocene (1.6 million to 10 000 years ago) for those organisms that may have survived and evolved over time, and the less recent periods for organisms that became extinct.

Once you have gathered information from secondary sources and processed and analysed the relevant information for your six selected examples, use the evidence available to attempt Part 2.

Part B

Propose reasons for the evolution, survival and extinction of species, with reference to specific Australian examples.

Complete Table 13.5 by proposing reasons why each of your six selected Australian species examples evolved, survived or became extinct over time. Four examples have been provided: two extinct examples, the thylacine (Tasmanian tiger, which became extinct in 1936) and the *Diprotodon* (which became extinct 50 000 years ago, coinciding with the arrival of humans into Australia); one survival example, the spotted cuscus (*Phalanger maculatus*); and one evolution example, the kangaroo (*Macropus* species).

RESULTS

TABLE 13.5 Reasons for evolution and extinction of some Australian species. Some examples have been provided for you as a guide.

AUSTRALIAN EXAMPLE	SPECIES EVOLVED, SURVIVED OR BECAME EXTINCT	PROPOSED REASONS
<i>Thylacine</i> (Tasmanian tiger)	Extinct	• Introduction of the dingo 3500 years ago • Hunted by farmers in Tasmania (seen as a predator to sheep and chickens) • Tasmanian Government bounty for threat to farming • Disease • Possibly all of the above reasons in succession



Investigation 13.4





AUSTRALIAN EXAMPLE	SPECIES EVOLVED, SURVIVED OR BECAME EXTINCT	PROPOSED REASONS
<i>Diprotodon optatum</i> (marsupial mammal – megafauna)	Extinct	- Human hunting - Climate change - A combination of both
	Extinct	
	Extinct	
<i>Phalanger maculatus</i> (spotted cuscus)	Survived	Retreated with the rainforest as the climate changed
	Survived	
	Survived	
<i>Macropus</i> species (kangaroo)	Evolved	- Developed adaptations to the changes that occurred in the environment (such as change from forests to grasslands with increasing aridity) - Reduced number of toes and can hop bipedally at high speeds away from predators in open grassland, unlike earlier ancestors - Also a change from those with leaf-browsing diet to those that were grass-grazers
	Evolved	
	Evolved	

KEY CONCEPTS

- Models can be used to predict impacts on biodiversity.
- Palaeontology can be used to provide data for building models.

CHECK YOUR UNDERSTANDING

13.2

- List the conclusions of Malthus's work. Do you think these conclusions still apply today?
- Explain why it is necessary to be able to make predictions about population changes.
- Distinguish between the top-down model and the bottom-up model of population growth.
- Explain how palaeontology can be used to model future ecosystems.

13.3 Restoring damaged ecosystems

Although the rate of species loss worldwide is alarming, there are many examples of endangered populations of species being restored. Some of the recovery is due to natural cycles of population change, but many are the result of careful management and legal protection of species.

Whale species, for example, are staging extraordinary recoveries after being hunted to the verge of extinction. It is predicted that by 2050 the population of southern right whales in Australian waters will approach their pre-whaling numbers. Populations of humpback whales are expanding in the north Atlantic and north Pacific oceans, and off the Western Australian coast.

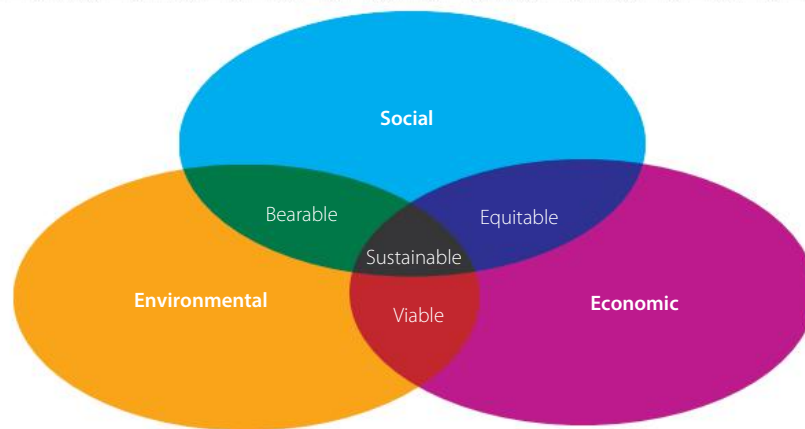
Mining sites

When a mining operation is being proposed in Australia, mining companies are required by law to follow very strict guidelines, which include submitting information on how they intend to ensure minimal harm to the environment. The *Mining Act 1992* establishes definitions of harm and the subsequent management of mine sites to minimise harm. It is unrealistic to expect absolutely no long-term damage from mining operations, but careful planning can keep the possible effects to a minimum. These effects include not only the physical disruption to the earth, but also the potential harm from the processing of the ores. All mining companies must complete an environmental impact statement (EIS) as a part of their mining license application. Companies with mining sites in areas that are sacred to Indigenous Australians have to be particularly mindful of the sensitivities of the traditional owners of the land. An example is the Ranger Uranium Mine, located in Kakadu National Park in the Northern Territory.

All Australian state governments encourage the safe and sustainable exploitation of Earth's natural resources. Mining companies must complete a report that details how they are going to restore the mine site after mining operations have ceased. They operate on the principles of sustainable development (Fig. 13.29), which state:

- The next generation should not be left with a less healthy and diverse environment (intergenerational equity).
- Biodiversity and environmental integrity must be conserved.
- The precautionary principle – decisions should err on the side of caution. The burden of proof needs to be on the company to convince that their plan is ecologically sustainable.
- Limits should apply according to the ability of the environment to supply what is required.
- Human efficiency and ecological resilience are extremely important factors.

FIGURE 13.29
Principles of sustainable development



Strategies for environmental control and rehabilitation of mine sites include:

- removal of any infrastructure, including machinery and buildings
- making sure that mine entrances and shafts are sealed and secure
- removal of contaminated soil – any chemical contamination is managed
- revegetation and landscaping of the environment – when a mine is being developed, topsoil and samples of native flora and fauna are removed and kept to be returned when mining operations cease
- regular testing of local waterways for signs of chemical contamination from run-off, especially of acids
- control of gas emissions
- control of dust generated at the mine site

Aboriginal and
Torres Strait
Islander histories
and cultures

Ranger
Uranium Mine

- scheduling of truck movements to limit noise pollution
- stabilising all underground tunnels
- treatment of tailings and other chemical waste
- fencing of the site to protect it while it re-establishes
- control of weeds and feral pests such as rabbits while vegetation re-establishes.

INVESTIGATION 13.5



Sustainability



Sunnyside Coal Mine



Practices used to restore mining sites

A secondary-source investigation into rehabilitation of mine sites

During the 1980s there was much attention given to the effects on the environment from disused mine sites. Increased awareness led to state and federal governments changing the laws that regulate mining operations and rehabilitation.

AIM

To complete a case study on the rehabilitation of a mine site in Australia

METHOD

Use secondary sources to locate information on the rehabilitation of a mining site in Australia.

RESULTS

Present your information in a suitable format. Make sure to include:

- maps of the site (showing location and site layout)
- the type of resources being mined (such as copper or coal)
- documents relating to the preparation of the mine site before mining operations commenced (for example, environmental impact statement, plans to manage local plant and animal species, and plans to protect and manage local waterways)
- documents relating to the rehabilitation of the mine site once operations ceased.

DISCUSSION

Is it possible for mining and environmental sustainability to coexist? Use specific examples to support your justification.



Landcare Australia



Environment and energy



Salinity

Land degradation from agriculture

With increased awareness of the science of soil and water management, and better access for land owners to this information via the Internet and computer modelling, there has been a marked improvement in the management of Australian soils and waterways. Farm owners can have their land evaluated by scientists and personalised management strategies created for their farms. The management of salinity and erosion are high priorities in most areas of Australia.

Some of the strategies available to restore damaged ecosystems are listed in Table 13.6.

TABLE 13.6 Managing land degradation due to agriculture

PROBLEM	CONTROL MEASURES
Soil erosion	• Use minimum till/direct drilling techniques. • Do not leave soil fallow for long periods. • Reduce stocking rates for livestock and employ rotational grazing. • Retain stubble after harvest. • Grow crops on slopes. • Use channels and terraces to store and redirect water. • Leave riparian buffer strips to reduce riverbank erosion. • Make windbreaks. • Use drip irrigation instead of flood irrigation.
Salinisation	• Replant deep-rooted perennial plants. • Use drip irrigation instead of flood irrigation. • Mulch garden beds. • Plant salt-tolerant plant species. • Time sprinkler systems.
Eutrophication	• Reduce run-off into streams of nitrogen and phosphorus-containing fertilisers and detergents.
Introduced species	• Use quarantine and border control methods. • Use methods of control such as biological and chemical. • Manage weeds by physical removal in appropriate situations.
Land clearing	• Replant deep rooted native vegetation. • Re-establish ground cover.
Pesticide residues	• Use integrated pest management systems that incorporate several strategies besides chemicals (for example, traps, barriers and genetic engineering).

Pesticides

Invasive species

Eutrophication

INVESTIGATION 13.6

A secondary source investigation into land management strategies for agriculture

AIM

To gather information on a specific land management issue on Australian farms and some of the solutions to this problem

METHOD

- 1 Choose an issue from column 1 of Table 13.6 (for example, pesticide residues).
- 2 Use the Internet and other resources to gather information on the problem and its causes.
- 3 Gather information on at least two management strategies that are being put in place on Australian farms to combat this problem.
- 4 Find one recent innovation (in the last 2 years) that has improved the management of this issue.

RESULTS

Record your findings in an appropriate format.

DISCUSSION

Why do strategies such as the one you have researched offer hope for the future management of Australian ecosystems?



Literacy



Information and communication technology capability



Land and soil degradation

Case studies of land management: biological control

There is a certain point at which a living thing becomes a pest. This depends on its ability to reproduce quickly as well as its effect on the environment and other living things. Some introduced species that were brought in for sport, recreation or other purposes could exploit the conditions in their new environment and establish themselves quickly in the Australian environment.

The *Galaxias* fish (Fig. 13.30) is a native freshwater fish whose populations decreased when mosquitofish were introduced.

Other species suffering similar decreases in numbers, due largely to predation by introduced pest species, face the same issues. They can sometimes be bred in captivity. For land animals, such as bandicoots, wallabies, quolls and marsupial mice, the threat is from feral cats, dogs and foxes. Their successful reintroduction requires safe release areas such as those with pest-proof fencing, which is an expense that affects the success of any such captive-breeding program.

Australian crops have succumbed to an assortment of fungi, bacteria, insects and herbivores that are introduced species. Paterson's curse, or Salvation Jane, is a hardy European annual plant with a tap root that enables it to survive drought conditions. Throughout late spring, these plants produce thousands of seeds. Germination results in thousands of fast-growing plants that take over whole pastures very quickly. The term 'Salvation Jane' was given to the plant for its ability to sustain cattle and horses throughout long droughts. But this plant unfortunately contains toxic alkaloids that lead to liver damage in stock when ingested long term.

The use of chemical pesticides (chemical control) is a quick and effective method of getting rid of pests. However, pesticides can cause problems in ecosystems due to **bioaccumulation** (where toxins are accumulated in individual organisms) and biomagnification (where top predators receive a larger dose of the toxin). Scientists now favour the use of biological control agents, using their knowledge of the relationships between organisms. The best strategy involves integrated pest management, where a combination of strategies is used to control the organism. This involves the use of biological measures to control pests and limits the use of chemicals to narrow-spectrum agents that target specific species. Biological control is not always successful. The cane toad is a perfect example of what occurs when biological control is not well planned.

There are four kinds of biological control agents:

- 1 *General predators* are organisms that consume a great variety of pest species (for example, ladybirds target aphids, caterpillars, mites and small beetles; Fig. 13.31). Recent research has shown that green ants are a cost-effective method of controlling most pests that attack mangoes. Growers are being encouraged to introduce these into their orchards.

Almost all ecological disasters resulting from biological control have been due to the introduction of general predators.

- 2 *Specialised predators* are organisms that target one pest species or group of species.

Introduced weeds, some escaped from gardens or dumped from aquariums, choke many waterways. The plants grow freely, without any environmental control, and affect the local animal and plant populations negatively. Too many weeds limits the populations of other species that native animals require for food and shelter. A small South American weevil, the natural predator of the



FIGURE 13.30 The *Galaxias* fish is a freshwater fish whose populations decreased when mosquitofish were introduced.



FIGURE 13.31 A ladybird feeding on citrus aphids

For more information on cane toads see pp. 221 and 294.

water weed *Salvinia*, was released in 1980 with great success in many areas. Moths and flea beetles, introduced in 1977, are reducing the impact of alligator weed. Another beetle from South America is controlling water hyacinth. There now tends to be a balanced relationship between the control agents and the plants.

- 3 **Parasites** are organisms such as wasps or flies that lay their eggs in the bodies of hosts. When the eggs hatch, the larvae feed on the body of the host (scale insects, aphids, moths and caterpillars), causing the host's death.

Wasps are being used to control the native stem-girdler moths that can decimate macadamia and pecan crops in Queensland. The wasps lay their eggs in the moth eggs, which are then consumed by the wasp larvae. Many other wasps have been harnessed to control a range of pests, such as the *Heliothis* moth that feeds on cotton plants.

- 4 **Microbial diseases** are caused by bacteria, fungi and viruses that target species and cause death through illness. Examples include the myxomatosis virus and calicivirus, which were introduced to control rabbit populations.

'Myco-insecticides' (*myco* = fungus) are showing promise as control agents. Many species of fungi in the soil attack grubs (larvae) that gnaw the roots of plants, including pasture grasses, sugar cane, potatoes and other crops. Selected fungi are now being used as biological control agents of scarab beetles and other target insects. Dutch elm disease is a fungal infection that leads to the death of the tree, most commonly elm trees. The fungus is carried by beetles that infect each tree on which they feed. One way of combating the infection in the trees is to target the beetles. This is achieved by the action of another fungus that infects the beetle's digestive system and prevents it from gaining adequate nutrition, thus killing it.

KEY
CONCEPTS

- Land degraded by mining must be rehabilitated by the mine owner.
- Farm owners have increased access to information on how to manage soils and waterways.
- Biological controls are being used to manage pest species.

- 1 Explain the responsibility of a mine owner to the surrounding environment.
- 2 Explain two problems caused by agriculture and how they can be controlled.
- 3 Distinguish between the following pairs of terms:
 - a bioaccumulation and biomagnification
 - b general predators and specialised predators.
- 4 Provide one example of how microbes are being used as biological control agents.

CHECK YOUR
UNDERSTANDING

13.3

Future management of ecosystems: How can human activity impact on an ecosystem?

Improved medicine
and food production

Increases in human
population

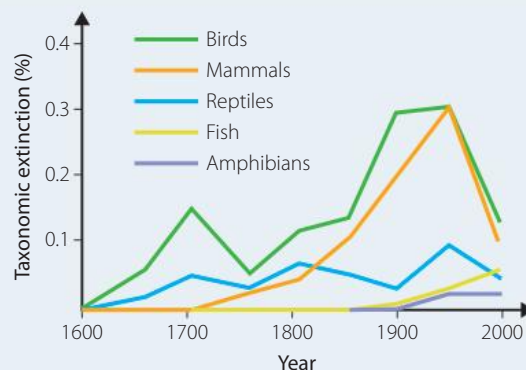
Increased demand on
environment for space
and resources

Environmental
damage and reduced
biodiversity

EXTINCTION

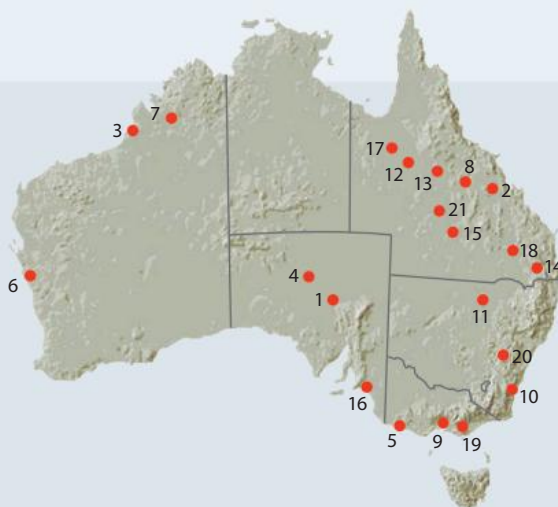
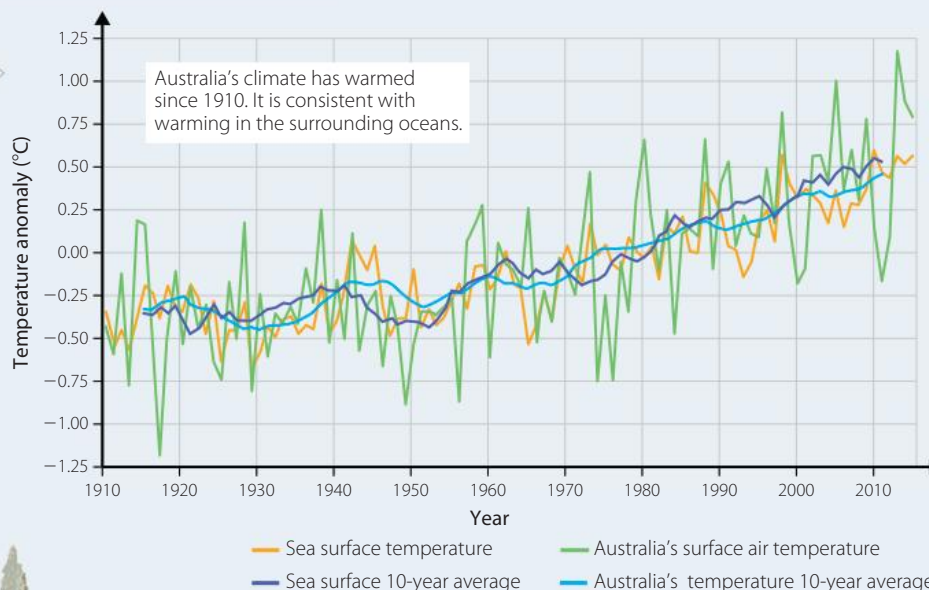
Habitat loss is the leading cause of *extinction* around the world. Most historic extinctions have occurred on islands because even small losses of habitat have devastating effects there. Island populations are often relatively small, and thus particularly vulnerable to extinction. Of the 90 species of mammals that have gone extinct in the world in the last 500 years, 73 per cent lived on islands (and another 19 per cent lived in Australia).

Trends in species loss: the graph presents data on recorded animal extinctions since 1600.



AUSTRALIA'S CLIMATE TREND

Scientists have been collecting scientific data about Australian climate for a little over a hundred years and are able to analyse *proxy data* in the geological record to infer past climate changes before records were kept. Australia's climate has always undergone periods of cooler or warmer, wetter or dryer periods, but the general trend over the last century is one of warming.

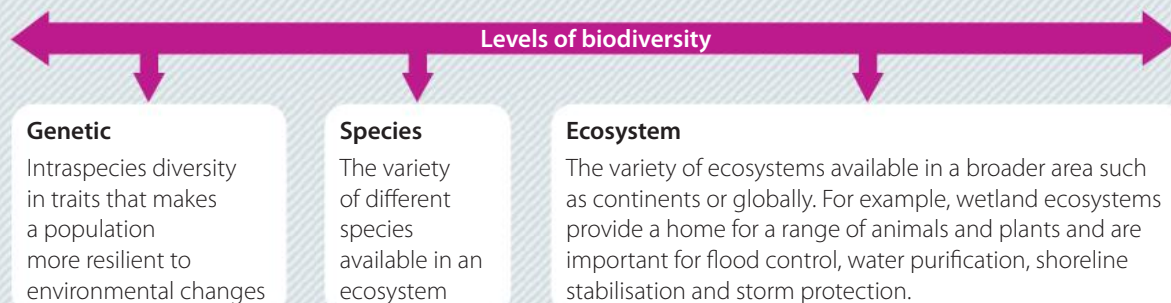


- 1 Andamooka
- 2 Bluff Downs
- 3 Broome
- 4 Coober Pedy
- 5 Dinosaur Cove
- 6 Geraldton
- 7 Gogo
- 8 Hughenden
- 9 Inverloch-San Remo
- 10 Koonwarra
- 11 Lightning Ridge
- 12 Maxwellton
- 13 Minmi Crossing
- 14 Murgon
- 15 Muttaborra
- 16 Naracoorte
- 17 Riversleigh
- 18 Roma
- 19 Strzelecki Ranges
- 20 Wellington
- 21 Winton

FOSSILS

By looking at the evidence for changes between past and present climate, and observing the changes in the distribution of organisms that formed fossils over time, we can understand more about the factors that may determine the distribution of flora and fauna in present-day environments. We can use this to predict the movement and distribution of organisms in the future.

State of the Climate 2016, © 2016 Commonwealth of Australia. Reproduced by permission of Bureau of Meteorology and CSIRO. <https://www.csiro.au/en/Showcase/state-of-the-climate>



Problem	Issues	Control measures
SOIL EROSION	- Clearing of vegetation - Cultivating the soil - Saline soil - Flood irrigation - Introduced species - Soil compaction by machinery and hard hooves	- Use minimum till/direct drilling techniques - Don't leave soil fallow for long periods - Reduce stocking rates for livestock and employ rotational grazing - Retain stubble after harvest - Grow crops on slopes - Channels and terraces to store and redirect water - Repair buffer strips to reduce riverbank erosion - Make windbreaks - Use drip irrigation instead of flood irrigation
SALINISATION	- Removal of deep rooted vegetation - Irrigation - Water table rises - Destroys soil biota	- Replant deep-rooted perennial plants - Use drip irrigation instead of flood irrigation - Mulch garden beds - Plant salt-tolerant plant species - Time sprinkler systems
EUTROPHICATION	Run-off of fertilisers, detergents and organic waste (manure) into waterways	Reduce run-off into streams of nitrogen and phosphorus-containing detergents
INTRODUCED SPECIES	Accidental and deliberate introductions	- Quarantine and border control methods - Use methods of control such as biological
LAND CLEARING	- Urban development - Agriculture	- Replant deep-rooted native vegetation - Re-establish ground cover
PESTICIDE RESIDUES	Management of weeds, insects and other plant and animal pests	Integrated pest management systems that incorporate several strategies besides chemicals (for example, traps, barriers and genetic engineering)

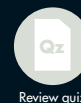
Maintenance of biodiversity – managed by all levels of government

Direct economic/
scientific/medical value
from bio-resources

Ethical considerations –
all species have a right
to exist

Aesthetic considerations –
humans enjoy the beauty of
the natural environment.

13 CHAPTER REVIEW QUESTIONS



- 1 Identify three of the main effects of humans on ecosystems.
- 2 Explain why human populations are increasing so quickly around the world.
- 3 Explain why increased populations of humans put stress on ecosystems.
- 4 Outline how the study of past environments enables us to make decisions about managing current ecosystems.
- 5 Outline some of the factors responsible for extinctions in the past.
- 6 Define 'biodiversity'. Outline the three levels of biodiversity.
- 7 Outline some of the benefits of biodiversity.
- 8 What are some of the key threatening processes that lead to species loss?
- 9 Justify the following statement: 'Climate change has occurred in the past but the current change in climate is likely to be more devastating than all previous ones.'
- 10 Draw a simple diagram to summarise the causes of global warming.
- 11 Assess the use of modelling to predict changes in populations of organisms.
- 12 Justify the reason why scientists use different models of growth for different populations.
- 13 Choose one fossil site covered in this chapter. Outline the evidence found and how it helps scientists manage future ecosystems.
- 14 Why do governments put threatened species into different categories? Give an example of a organism that is endangered or threatened and the factors leading to this. How is the situation being managed and how will scientists know if they are successful?
- 15 Create a table to summarise the methods used to minimise the effects of mining on land degradation.
- 16 Define 'salinisation'. Draw a flow chart to summarise the steps leading to irrigation and dryland salinity on properties.
- 17 Research a case study of a successful program to rehabilitate a salinised soil. Identify the area studied and the scientific basis for the strategy.
- 18 Discuss the reasons why soil erosion is a major issue in agriculture.
- 19 Justify the use of a land management strategy to restore damaged agricultural land.
- 20 Copy and complete Table 13.7 to compare the advantages and disadvantages of three strategies to manage pesticide residues in soils. Use the Internet and other resources to find information on the three strategies.

TABLE 13.7 Managing pesticide contamination in agricultural soils

STRATEGY	ADVANTAGES	DISADVANTAGES
Traps		
Barriers		
Genetic engineering		

Answer the following questions.

- 1 Scientists have recognised for a long time the importance of symbiotic relationships between organisms and how they have influenced the course of evolution. When viewed under a microscope, the root nodules of legumes such as alfalfa and clover possess a special bacterium (*Rhizobium*), which is able to extract nitrogen gas from the atmosphere and convert it into useable nitrogen (nitrogen fixation) for the plant to use. In turn, the bacterium has access to sugars and other nutrients from the plant. However, it has been observed that, in some cases, the bacterium is not providing any benefit to the plant in the form of nitrogen fixation and is simply taking the nutrients from the plant.
 - a Identify the original relationship between the bacterium and the plant.
 - b How has the relationship changed in terms of the form of symbiosis now developing?
 - c Predict a possible consequence of this changing relationship in terms of evolutionary processes in the plant.
- 2 Paterson's curse is a plant introduced into Australia from the Mediterranean region. Because of its prolific growth, it smothers large areas of pasture.
 - a Explain in terms of competition how Paterson's curse is a pest in Australia, but not in Mediterranean regions.
 - b One control method that has been attempted is the use of herbicides; however, this was unsuccessful as it leaves large areas of bare soil susceptible to erosion. Suggest an alternative approach to regulating the spread of this plant.
- 3 It is often difficult to predict what has occurred in past environments. Scientists rely heavily on evidence to make predictions about possible future environmental changes.
 - a Using two pieces of evidence, explain how ice cores and gas analysis can be used to provide information about past environments.
 - b Discuss the use of these two methods in terms of their usefulness.
- 4 Examine the data in the Figure M4.1 and answer the following questions:
 - a Suggest how scientists gathered this data.
 - b Describe the relationship between tree ring growth and temperature.
 - c Predict what you would expect to see in the year 2020.
- 5 A fossilised Australian mammal was unearthed at a fossil site and analysed by palaeontologists. It was found to be an extinct species of megafauna known as *Diprotodon*. These animals were known to have become extinct around 15 000 years ago.

Table M4.1 shows the half-lives of four radioactive elements that can be used by scientists when dating fossils.

TABLE M4.1 Half-lives of useful isotopes

RADIOACTIVE ISOTOPE	HALF-LIFE
Uranium-235	700 million years
Potassium-40	1.25 million years
Carbon-14	5500 years
Argon-39	269 years

- a Identify the most appropriate isotope to date the *Diprotodon* fossil.

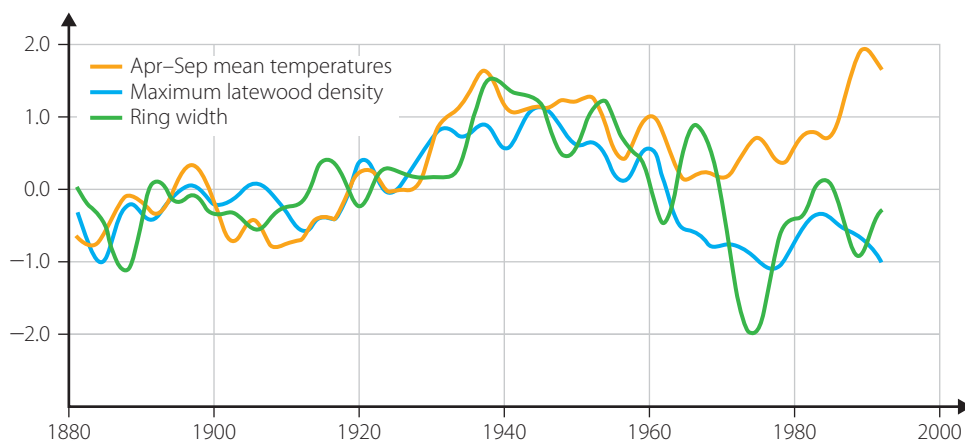


FIGURE M4.1 Divergence between tree growth and temperature

By SUV (Own work) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)] via Wikimedia Commons

- b** Justify your answer in terms of the half-life of the material.
 - c** Suggest reasons why the *Diprotodon* became extinct.
 - d** Justify the use of absolute dating techniques for this fossil.
- 6** Scientists recognise that life on Earth has changed dramatically over millions of years. This is usually linked to a change in ecosystems. For example, during the end of the Permian period, there was an increase in toxic gases in the atmosphere due to volcanism in the Siberian Traps. Approximately 90 per cent of all organisms became extinct at this time.
- a** How do scientists know that volcanic eruptions were a major feature of this period?
 - b** How do scientists know the extent of the devastation on living things?
 - c** Explain why some organisms survived the end-Permian extinction.
 - d** Suggest a possible consequence of a mass extinction on the availability of new niches.
- 7** The introduction of European farming methods into Australia in the 1800s has significantly influenced the productivity of soils in farming areas.
- a** Outline the effect of land clearing on soil salinity.
 - b** What strategies have farmers put in place to manage soil degradation such as salinity, erosion and loss of nutrients?
 - c** If these problems are not managed well in the future, predict the effect on the productivity of Australian soils.

- 8** The European carp was accidentally released into Australian waterways in the 1800s and its numbers have grown significantly. It is classified as a pest due to its effect on waterways. One current way to regulate its numbers is to release a herpes virus into waterways in the hope that this will reduce its population.
- a** What is one possible consequence for non-target species of this form of biological control?
 - b** Why did the carp become a pest at all?
 - c** Carp are bottom feeders and stir up the mud in creeks and streams to look for food. Suggest how this would affect any plants growing in these waterways.
- 9**
- a** Describe some of the key proxy data that is used to reconstruct past climates.
 - b** Outline some of the major causes of past climate changes.
 - c** How can we use evidence from past climate changes to manage current ecosystems more successfully?
- 10**
- a** Given our understanding of the mechanisms involved in global climate change, how can we apply this to the possible predictions of future climate change?
 - b** What are the consequences of global warming for current ecosystems? Use specific examples to support your understanding.
 - c** What recommendations would you make to current governments in terms of managing the use of fossil fuels for their energy needs?

DEPTH STUDY SUGGESTIONS

- Look into fossil evidence for the extinction of the Australian megafauna.
- Find out about computer modelling for monitoring the distributions and abundances of species.
- Investigate developments in the management of facial tumour disease in Tasmanian devils.
- Find out about the use of technology (for example, GPS or drones) in assessing animal and plant populations.
- Look into a specific group of Aboriginal cave paintings and their use by palaeontologists to reconstruct past environments.
- Investigate the evolution of Australian sclerophylls and effects of current bushfire management strategies on their distribution and abundance.
- Find out about a specific fossil site and its contribution to the reconstruction of a past ecosystem.
- Investigate the contribution of your local museum to the understanding and preservation of evidence for past environments.
- Construct a case study of a land management issue on a farm with specific reference to the scientific explanation for the causes, including solutions to the issue.

APPENDIX

TIMELINE: a short history of biology

MICROSCOPE BEGINNINGS	THE CELL THEORY	1590	Hans and Zacharias Jansen made the first compound microscope by placing two convex lenses in a tube.
		1628	William Harvey discovered that blood circulates, identifying the central role of the heart, arteries and veins in producing blood movement in a circuit.
		1634	Jan Baptist van Helmont experimented to determine if plants got their increased mass from water and/or soil, leading to the rejection of the <i>humus theory</i> and to the start of understanding photosynthesis.
		1663	Robert Hooke introduced the term 'cell' after observing cork under a light microscope. He also worked at improving a number of scientific devices, including the microscope, telescope and barometer.
		1668	Francesco Redi conducted an experiment to challenge the theory of spontaneous generation.
		1669	Nicolas Steno formulated the principles of stratigraphy that allowed the reconstruction of past climate and biological events in the fossil record.
		1674–1683	Anton van Leeuwenhoek , a Dutch lens maker: - produced lenses of higher quality, which allowed for greater magnification (up to 200 times) - described 'animacules' (unicells) - discovered bacteria.
THE SCIENTIFIC REVOLUTION	THE CELL THEORY	1758	John and Peter Dollard (father and son), spectacle makers, produced the first achromatic (colour-free) lenses, making microscopes superior to hand lenses.
		1779	Jan Ingenhousz demonstrated that light and the green sections of the plant are required for the plant to produce the gas oxygen. He is credited with discovering photosynthesis.
		1796	Edward Jenner used cowpox in the first successful vaccine against the disease smallpox.
		1801	Robert Brown , a botanist and naturalist, first described the cell nucleus while observing plant cells in an orchid. He also noticed the random movement of pollen grains (Brownian motion).
		1836	Charles Darwin arrived in Sydney Harbour aboard HMS <i>Beagle</i> .
		1838	Matthias Schleiden , a botanist, stated that parts of plants are made of cells (not visible to the unaided eye).
		1839	Theodor Schwann , a zoologist, stated that parts of animals are made of cells; he agreed with Schleiden and they published the cell theory in a book, stating that the cell is the basis of the structure of all living things.
		1841	Charles Lyell and James Hutton 's work led to the publishing of the first geological timescale.
		1843	Robert Koch studied the cause of the disease anthrax.
		1855	Rudolph Virchow introduced the idea that cells reproduce by dividing, stating that all living cells can only arise from other living cells, further challenging the theory of spontaneous generation.
	EVOLUTIONARY THOUGHT	1856–1858	Gregor Mendel began a series of controlled experiments with garden peas to carry out a statistical study of heredity.
		1858	Charles Darwin and Alfred Wallace presented the paper <i>A Theory of Evolution by Natural Selection</i> .
		1859	Charles Darwin 's book <i>On the Origin of Species</i> is published.
		1860	The Huxley–Wilberforce debate takes place. This debate occurred during a series of lectures about the scientific evidence for evolution and whether it could coexist with a literal interpretation of the Bible.

THE SCIENTIFIC REVOLUTION (CONTINUED)	GERM THEORY OF DISEASE	1861	Louis Pasteur published his experiments showing that fermentation was caused by something in the air, finally disproving spontaneous generation.
		1862	Louis Pasteur's experiments with bacteria showed that infectious diseases are caused by micro-organisms, leading to the <i>germ theory of disease</i> .
		1863	Louis Pasteur introduced pasteurisation, a practical application of what he had learned through his fermentation experiments.
		1866	Gregor Mendel published his work on studying plant hybrids.
		1867	Joseph Lister made the connection between Pasteur's work and infection and introduced antiseptic surgery (published paper).
		1880	Charles Louis Alphonse Laveran first identified the cause of malaria: a microscopic organism.
		1881	Louis Pasteur developed a vaccine against anthrax.
CLASSICAL SCIENCE	GERM THEORY OF DISEASE	1882	Walther Flemming discovered nuclear material – termed 'chromatin material'.
		1882–1893	Koch proposed postulates: 'rules of engagement' for bacteriologists.
		1885	Louis Pasteur used a vaccine against rabies on humans for the first time, saving the life of a young boy who had been bitten by a dog.
		1891	Robert Koch concluded that malaria was transmitted by mosquitoes.
		1897	Ronald Ross demonstrated that female <i>Anopheles</i> mosquitoes were the vectors (carriers) of malaria, by showing that these mosquitoes carried malarial oocysts in their gut tissue.
		1900	Significance of Mendel's experiments in terms of heredity is noticed after three other scientists get similar results.
		1902	Walter Sutton and Theodore Boveri independently proposed and demonstrated a connection between chromosomes and inheritance. Sutton studied meiosis in grasshoppers. Boveri studied chromosome behaviour and inheritance in sea urchins.
		1911	Thomas Hunt Morgan studied sex-linked inheritance (Nobel Prize in 1933 for life's work).
		1909	Wilhelm Johannsen introduced the term gene.
		1928	Alexander Fleming noticed that the mould <i>Penicillium</i> killed bacteria in a Petri dish.
		1933	Ernst Ruska built the first electron microscope.
		1935	Howard Florey began to search for a useful medicine to kill germs.
		1938	Fritz Zernike invented the phase contrast microscope, which can be used to observe living, unstained cells.
		1939	Howard Florey extracted stable penicillin (the first antibiotic).

CONTEMPORARY SCIENCE	MOLECULAR TECHNOLOGY, GENETICS AND BIOTECHNOLOGY	1941	George Beadle and Edward Tatum published the results of their experiments with bread mould, in which they proposed the one-gene-one-enzyme (protein) hypothesis.
		1942	Viruses first seen under the electron microscope.
		1945	Frank Macfarlane Burnet isolated influenza A virus (in Australia) and developed a vaccine.
		1945	Howard Florey and Alexander Fleming received the Nobel Prize for Physiology and Medicine for their work on penicillin.
		1946	Reginald Sprigg discovered first fossils of soft-bodied, multicellular life in the Ediacaran Hills, Flinders Ranges, South Australia.
		1950	Rosalind Franklin and Maurice Wilkins made a crystal of DNA to study its structure.
		1952	Stanley Miller and Harold Urey conducted their famous experiment investigating the origins of organic compounds
		1953	James Watson and Francis Crick put together a model of DNA.
		1955	Marvin Minsky invented the scanning electron microscope.
		1960	Frank Macfarlane Burnet and Peter Medawar received the Nobel Prize for Physiology and Medicine for their work in immunology and organ transplants.
		1961	Melvin Calvin received the Nobel Prize for determining the process by which carbon dioxide is converted into carbohydrates in the process of photosynthesis.
		1962	Vernon Ingram did further work on genes and proteins, leading to the change to the one-gene-one-polypeptide hypothesis.
		1962	Watson, Crick and Wilkins received the Nobel Prize for Chemistry for their discovery of DNA. (Rosalind Franklin died in 1958; her work was acknowledged but the Nobel Prize cannot be awarded posthumously.)
		1967	Graeme Clark began researching the possibility of an electronic implantable hearing device.
		1972	Singer and Nicholson proposed the fluid mosaic model of cell membranes.
		1972	Niles Eldridge and Stephen Jay Gould put forward the theory of evolution by punctuated equilibrium.
		1972	Paul Berg created the first recombinant DNA molecules using restriction enzymes and DNA ligases.
		1974	Rudolf Jaenisch created the world's first transgenic animal, a transgenic mouse, by introducing foreign DNA from a virus into its embryo (however, the mice did not pass the transgene to their offspring).
		1980	WHO declared the disease smallpox eradicated worldwide.
		1981	Frank Ruddle, Frank Constantini and Elizabeth Lacy created the first transgenic mouse that showed transmission of the inserted genetic material to subsequent generations.
		1982	Graham Carrick was the recipient of the first cochlear implant, which allowed him to hear for the first time in 17 years.
		1983	Kary Mullis develops the polymerase chain reaction (PCR) technique, which opened up a variety of new applications in genetics including DNA sequencing and the analysis of genes.
		1996	First cloning of a mammal, Dolly the sheep.
		2001	The Human Genome Project releases the first draft of the human genome sequence.
		To present	Genetic and reproductive revolution: in-vitro fertilisation, genetic engineering, cloning and advanced biotechnology.

Note: As a result of inconsistent record-keeping, dates may show slight inconsistencies when different timelines are compared. The sequence of events is more important than absolute dates in reflecting the historical developments in science.

ANSWERS

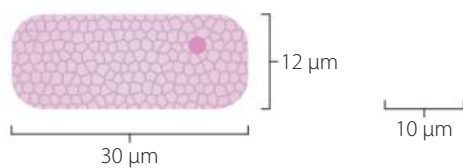
TRY THESE YOURSELF

WORKED EXAMPLE 2.1

OCULAR LENS MAGNIFICATION	OBJECTIVE LENS MAGNIFICATION	TOTAL MAGNIFICATION
10	20	200
10	40	400
12	40	480

WORKED EXAMPLE 2.2

Onion cell



Red blood cell



WORKED EXAMPLE 3.1

- a 3:1
- b 2:1

WORKED EXAMPLE 7.1

- 1 9600
- 2 22 165

WORKED EXAMPLE 7.2

- 1 150
- 2 40 000

WORKED EXAMPLE 13.1

- a 4.3
- b 66 150

GLOSSARY

A

abdomen the section of the body of an insect located just behind the thorax

abiotic pertaining to the physical and non-living components

abiotic factor non-living features; physical and chemical factors (for example, temperature, rainfall, salinity)

abscission the detachment of leaves or fruit from a plant

absolute dating a process determining the age of a fossil or rock strata

abundance the number of individuals in a population

accurate having the true value

acid rain any form of rain that has a pH less than 7

activation energy the minimum amount of energy required to start a reaction

active site that part of the surface of the enzyme with a specific shape that the substrate binds to

active transport the movement of substances from a region of low concentration to a region of high concentration (against the concentration gradient), which requires the input of energy

adaptation an inherited characteristic (could be structural, physiological or behavioural) that allows an organism to be better suited to surviving in its natural environment

adaptive radiation the diversification of organisms into different forms to occupy many different niches

adenosine triphosphate (ATP) an energy storage molecule

adhesion protein a protein that links cells together

adhesive able to stick two surfaces together (for example, water and the walls of the xylem)

adipose tissue a type of connective tissue (for example, fat storage cells)

aerobic oxygen-containing

aesthetic concerned with beauty or the appreciation of beauty

aestivation the dormancy of certain species during hot and dry conditions

albedo the proportion of light reflected by a surface (for example, ice or the Moon)

alcohol fermentation the breakdown of glucose in the absence of oxygen to form ethanol (an alcohol) and carbon dioxide; two molecules of ATP are also produced

algae a group of photosynthetic organisms that lack true stems, roots and leaves (for example, seaweed)

allelochemical a chemical released by an allelopathic organism

allelopathic having characteristics of allelopathy

allelopathy the inhibition of growth in one species of plants by chemicals produced by another species

allopatric speciation also known as geographic speciation; it occurs when biological populations of the same species become isolated from each other to an extent that prevents them from exchanging genetic material

alveoli air sacs in the lungs through which oxygen and carbon dioxide are exchanged between the blood and the air (singular: alveolus)

ambient relating to the surrounding environment

amino acid an organic molecule that is the building block (monomer) of polypeptides. It contains the elements carbon, hydrogen, oxygen, nitrogen and at times sulfur, phosphorus and other elements

amylase an enzyme that catalyses the breakdown of starches

anaerobic oxygen-poor

analogous having different structures but the same function

anthelmintic something that destroys parasitic worms

anthropogenic originating in human activity (for example, climate change)

antibiotic a medication used in the treatment of bacterial infections

antigen a marker molecule

anus the external opening of the rectum from which faeces are eliminated or egested

apoptosis programmed cell death

aquaporin a 'water pore' or channel in the cell membrane through which water moves in and out of the cell

Archaea one of the two domains of prokaryotes, often living in extreme environments. They are structurally similar to bacteria, but have genes and metabolic pathways closer to those of eukaryotes

arid describing a place or climate having little or no rain

artefact something introduced into the image in the preparation of samples for use in an electron microscope

arteriole a small branch of an artery that leads into a capillary

artery a type of blood vessel that carries blood away from the heart; it has thick, elastic walls to assist in the movement of blood pumped by the heart

atmosphere the layer of gases surrounding the Earth

atrium a blood collection chamber in the top part of each side of the heart (plural: atria)

autotroph 'auto' self; 'troph' feeding; an organism that produces its own nutrition, through either photosynthesis (a plant) or chemosynthesis (bacteria)

autotrophic organism an organism that produces its own nutrition through either photosynthesis or chemosynthesis

axon a long extension of the neuron (nerve cell) along which the electrical impulses move to be passed onto other neurons

B

Bacteria one of the two domains of prokaryotes, living in a wide variety of environments. They are structurally similar to Archaea, but have circular chromosomes and unique genes and metabolic pathways. Sometimes called Eubacteria

ballast material used to provide stability to something (for example, a boat or ship)

banded iron formation a layer of sedimentary rock containing iron oxide deposits

behavioural adaptation a certain behaviour of an organism that allows the organism to be better suited to surviving in its natural environment

benthic relating to the lowest level of the water column near the bottom of an ocean or lake

bile a fluid produced by the liver and stored in the gall bladder until its release into the duodenum where it emulsifies fats

bioaccumulation the accumulation of a substance such as a pesticide within an organism

biochemistry the study of the chemicals and chemical reactions that occur in the body

biodiversity the number, relative abundance and genetic diversity of organisms in an area or on Earth

biofilm a group of micro-organisms that exist as a colony on a surface

biogeography a branch of biology that looks at the distribution of plants and animals

biological control the introduction of a known predator species to control the numbers of a prey species

biomacromolecule a naturally occurring substance having a large molecular weight

biomagnification the increasing concentration of a substance as it moves upwards through the food chain (for example, a pesticide)

bioresource a resource from agriculture, forestry and biological waste

biosphere those parts of the Earth that contain living things

biostratigraphy a tool used in geology to determine the age of rock strata using fossils

biota the flora and fauna of a given habitat or region; the sum total of all living things on Earth

biotechnology technology that involves the use of cells or parts of cells to develop products to improve life and health

biotic relating to living features (for example, organism abundance, distribution or interactions)

biotic factor a factor that relates to a living thing (for example, number, distribution and interactions)

blood the fluid transport medium in the cardiovascular system of a mammal that contains blood cells and plasma

blood vessel a vessel that carries blood around the body, transporting nutrients, gases and wastes

bolus chewed food that has been mixed with saliva and formed into a ball shape by the tongue

brumation a hibernation-like state in endotherms in response to very cold weather

C

Cainozoic the current geological era starting 65 million years ago; means 'recent life'

capillary a tiny blood vessel that has a wall only one cell thick and makes a network through the tissues to bring blood into close contact for the exchange of substances

capsule the outer layer of a bacterial cell, composed of complex carbohydrates

carbohydrate a biological molecule containing carbon, hydrogen and oxygen; includes sugars and starches

carbon-14 a radioactive isotope of carbon

cardiac muscle a muscle fibre with striations, present in the heart

cardiovascular system the transport system in mammals composed of the heart, blood and blood vessels

carnivorous meat-eating

carrier protein a protein that carries out facilitated diffusion of large molecules by binding to the molecule to be transported, changing shape and then releasing the molecule on the other side of the membrane

cartilage a type of connective tissue that is composed of dense fibres with lots of collagen fibres for strength and providing flexibility and cushioning (for example, at the end of a bone)

catalyst a chemical that controls the rate of reactions

catastrophism a theory that states that the changes in Earth's crust have resulted from a series of sudden, violent events rather than slow, progressive changes

cell membrane a structure that surrounds and encloses a cell

cell sap the watery solution in a vacuole

cellular respiration the series of chemical reactions that occur in the mitochondria, in which oxygen and glucose are combined to produce energy and the waste products carbon dioxide and water

cellulose a large molecule made up of many glucose molecules joined together

cell wall the rigid outer layer of a cell that gives the cell support and structure

centrifuge to spin at very high speed to separate materials of different densities

channel protein a protein that facilitates the diffusion of charged ions of a particular shape and size by forming a narrow passageway through the cell membrane

chemosynthetic relating to the biological conversion of carbon-containing molecules into organic matter

chert a microcrystalline quartz-containing sedimentary rock

chlorophyll a green pigment that traps sunlight and enables its use in the process of photosynthesis

chloroplast an organelle containing chlorophyll

chromatin the material in the nucleus made up of proteins and nucleic acid

chromosome a rod-shaped structure made up of DNA and protein

chyme a thick semifluid composed of partly digested food and digestive juices that moves from the stomach to the duodenum

cladode a flattened leaf-like stem

cladogram a diagram to show the relationships between organisms

climate a sustained pattern in temperature and rainfall over an extended period in a region

climate change change in long-term weather patterns

closed circulatory system a circulatory system in which the transport medium remains enclosed in a system of vessels at all times

cohesion sticking together

collagen the main structural protein found in connective tissue

colon the region of the large intestine from which water and some salts are absorbed back into the bloodstream

colonial relating to cells that are able to form together into a group to survive in a cooperative manner, but can also survive on their own

colonial organism a group of single-celled organisms that live in a colony

colony a group of identical single-celled organisms living together

column or bar graph a type of graph used when items have been counted into unrelated categories; the columns do not touch

commensalism a symbiotic interaction between two species where one benefits and the other is unaffected

community the combination of groups of different populations in an area or habitat

companion cell a type of cell found alongside the sieve tubes in the phloem; it has a cell nucleus and other cell organelles and is thought to assist neighbouring sieve tube cells

comparative anatomy the study of the similarities and differences in structures of different organisms

comparative embryology the study of the developmental stages of different species; used to determine relatedness

competition an interaction between organisms where both are harmed by requiring the same types of resources

complementary base pairing the pairing of bases in DNA where A always pairs with T and G always pairs with C

complementary strand the chains of a double helix strand that correspond to a specific sequence of bases which follow the base pairing rule

concentrated solution a solution that contains a large amount of solute in relation to the amount of solvent

concentration gradient the difference in the concentration of a substance from one area to the next; substances move from where they are in high concentration to where they are in low concentration

conjugation the transfer of genetic material between bacterial cells

connective tissue tissue that provides support and holds various parts of the body together

controlled kept constant

controlled variable a variable that is kept constant so that it does not interfere with the outcome of the experiment

convergent evolution the process by which organisms that do not have a recent common ancestor develop similar features in response to similar selection pressures in their environments

crista a fold in the inner membrane of the mitochondrion

cuticle a waxy coating over the epidermal layer of the leaf

cyanobacteria photosynthetic eubacteria

cytoplasm the fluid part of the cell outside of the nucleus that contains dissolved chemical substances, insoluble substances and suspended organelles; the chemical reactions that allow the cell to live are carried out here

cytoplasmic streaming the process whereby organelles and cytosol flow through the cell in a circular movement in order to maintain a steeper concentration gradient

cytosol the gel-like substance enclosed within the cell membrane and outside the nucleus

D

dam a barrier designed to hold back water for the purpose of forming a reservoir to control flooding, create a water supply or for hydroelectricity generation

deciduous losing leaves in a particular season

deep vein thrombosis a condition that occurs when a blood clot forms in a vein, usually in a leg

denature to irreversibly change shape and structure due to heat or change in pH; in a protein the active site is changed and so an enzyme will not function as it should

dendrite the short, branched extension of the neuron that receives electrical impulses from other neurons

deoxygenated describing blood that is lacking in oxygen

dependent variable a factor that changes during an experiment as a result of the experiment; it is the observed or measured outcome that depends on other factors that have been changed in the experiment

depth study an investigation or an activity completed by a student or students to explore more deeply a topic from the Year 11 Biology course that they find interesting

derived data data that is deduced from raw data by mathematical manipulation, such as graphs, algebraic equations and geometric constructions

dermal tissue tissue found on the outer layers of the stems, roots and leaves; it protects plant tissues

detritivore an animal that eats organic litter or detritus (a type of degrader)

differentially permeable see *selectively permeable*

differentiate when cells develop structures that allow them to carry out their specific function

diffusion the movement of *any* molecules from a region of high concentration to a region of low concentration of that substance, until equilibrium (the same concentrations in both regions) is reached

digestion the breaking down of large and complex food particles into much smaller and simpler chemical substances that are small enough to be absorbed through the walls of the small intestine

dilute solution a solution that contains a small amount of solute in relation to the solvent

disaccharide a complex sugar consisting of two sugar units (for example, maltose)

disease a disorder of structure or function in a living thing

distribution where the population of a species is spread within an ecosystem

diurnal most active during the day

divergent evolution the process by which organisms that are related look different due to exposure to different selection pressures

DNA deoxyribonucleic acid, a nucleic acid that contains genetic information

DNA–DNA hybridisation a quantitative biochemical process used to determine relatedness

dormancy a period of time when an organism reduces activity and growth in order to conserve energy

duodenum the first section of the small intestine

E

ecology study of the relationships that living organisms have with each other and their environment

ecosystem a community together with its environment; any environment containing organisms interacting with each other and with the non-living parts of the environment (for example, a rainforest or a freshwater pond)

ecosystem diversity the variation of ecosystems found in a region

ectoparasite a parasite that lives on the surface of its host

ectotherm an animal that relies on an external source of heat energy to regulate its body temperature

egest to removal undigested waste material from the body

elastin a protein that contributes to the elasticity of the skin

embryonic cell a young cell that has not become specialised

empirical able to be verified by gaining evidence through observation and experimentation

emulsifies breaks down large fat globules into smaller particles, thus increasing the surface area for the action of digestive enzymes

endemic unique to a specific geographic region; if a species is endemic, it is assumed to have evolved there

endocytosis 'endo' into, inside; 'cyto' cell; the process of changing shape of the cell membrane to surround a particle and engulf it

endoparasite a parasite that lives within its host

endoplasmic reticulum the network of flattened, interconnected membranes that provides transport within the cell

environment the non-living (abiotic) surroundings of an organism

environmental flow an adjustment to the pattern of water flow in a river or stream to maintain healthy ecosystems

enzyme a protein molecule that controls all metabolic reactions in living cells; enzymes are biological catalysts

ephemeral having a very short life cycle

epidermal relating to the outermost layers

epiglottis the flap of skin that closes over the entrance to the trachea to prevent the entry of food into the respiratory system

epiphyte a plant that grows on another plant for support (not parasitic)

epithelial tissue a covering that lines body surfaces and cavities

equilibrium the state that occurs when concentrations are the same and there is no net movement of molecules in either direction; the same number of molecules move in each direction

equilibrium model a mathematical model that attempts to explain changes in populations

erosion the action of wind, gravity or water to transport material from one location to another

estuary where the mouth of a river meets the sea

eukaryote an organism composed of eukaryotic cells

eukaryotic relating to a cell containing a membrane-bound nucleus and membrane-bound organelles

eukaryotic cell a cell with a membrane-bound nucleus and membrane-bound organelles

Eustachian tube a narrow passage leading from the pharynx to the middle ear

eutrophication a form of water pollution where an overgrowth of algae occurs due to increased nutrients such as phosphorus and nitrogen in the water

evidence information, gained by the scientific method, that serves to either support or disprove a scientific hypothesis or theory

evolution the change in a population over a period of time; it implies that organisms were not created independently of each other, but may have arisen from a common form that changed over time in response to selection pressures

exocytosis the process by which a membrane-bound vesicle moves to the plasma membrane, fuses with it and releases its contents to the external environment

exopalaentologist a scientist who searches for fossilised life forms on other planets

extant presently living

external environment the environment surrounding a cell outside the cell membrane

extinct no longer in existence; there are no remaining members of the species (species has died out)

extinction occurs when a species or group of organisms has died out or been wiped out of existence

extracellular matrix connective tissue with a web of the protein fibres collagen (for strength) and elastin (for flexibility) and cells scattered through it

exudate cells and fluid that weep out of tissue, usually from a wound

F

facilitated diffusion the diffusion of charged or large molecules across the cell membrane, assisted by proteins

facultative capable of existing in a variety of environmental conditions

fallow when the soil in a field is left bare after a crop is harvested; unploughed or uncultivated

falsifiable able to be disproved

fauna animal life

fecundity the ability to produce an abundance of offspring

fertiliser a substance added to the soil to increase its fertility and plant growth; may be natural or synthetic

fertility the ability to conceive and have offspring

fibrous connective tissue a type of connective tissue that holds the body together (for example, forming a tendon)

fission track dating a technique for establishing the age of a mineral sample by examining uranium fission tracks

flagellum a whip-like tail that provides a cell with locomotion (plural: flagella)

flora plant life

fluid mosaic model a model of the structure of the cell membrane, which is flexible and has a phospholipid bilayer studded with proteins

fluorescent giving off visible light

fossil the preserved or mineralised remains of prehistoric organisms or traces of prehistoric organisms (for example, footprints)

fossil record the total number of fossils that have been discovered and the information that they provide about past life on Earth

fundamental niche the total range of possible environmental conditions suitable for the existence of a species

fungi eukaryotic, single-celled or multicellular organisms that decompose and absorb organic matter (for example, mushrooms, moulds, rusts and yeasts)

fungicides chemicals designed to kill fungi

G

gall bladder the storage organ for bile

gene pool the stock of genes in a breeding population

genetic diversity the total number of genetic characteristics in the genetic make-up of a population of organisms

genome the complete set of genes present in an organism

genotype the genetic make-up of the individual

geological timescale the timescale illustrating the different periods of time when different organisms existed, constructed from fossil evidence

geology the scientific study of the origin, history and structure of the Earth as recorded in rocks

gill a respiratory organ found in many aquatic organisms; it extracts dissolved oxygen from the water and excretes carbon dioxide

gill slit the individual opening to the gills

glacial period a period in Earth's history when ice sheets covered much of the Earth and the temperature was lower

glaciologist a scientist who studies glaciers and ice formations

glycolysis the first step in cellular respiration; the series of reactions that occur in the cytosol, involving the splitting of 6-C glucose molecules into two 3-C pyruvate molecules; accompanied by the release of two molecules of ATP

glycoprotein a type of recognition protein that combines with a sugar molecule and acts as a marker molecule to identify a cell as 'self'

Golgi body an organelle involved in the secretion and transport of materials

gradualism a type of evolutionary change proposed by Darwin that is slow and proceeds by the accumulation of gradual changes

grassland habitat where the dominant vegetation is grass and there are very few shrubs and trees, typically in a low or sporadic rainfall area

greenhouse effect the trapping of the sun's warmth by a planet's lower atmosphere

ground tissue all the internal cells of a plant other than vascular tissue

guard cell a bean-shaped, specialised cell that controls the opening and closing of the pores (stomata) of leaves

H

habitat the place where an organism lives

haemoglobin the oxygen-carrying protein present in the red blood cells

haemolymph the transport fluid in an open circulatory system; it is a mixture of blood and tissue fluid

halophyte a plant that has adapted to living in high-salt environments

heart the driving mechanism in a circulatory system

herbicide a chemical designed to kill plants

herbivore an organism that eats or consumes only plants

herbivorous relating to organisms that consume plants

heterotroph 'hetero' different; that is, 'feeding on something different'; an organism that cannot produce its own food and has to take in all of its nutrients (for example, animals)

histogram a graph similar to a column graph but which has columns that do touch each other because they represent continuous numerical data

homologous having the same or similar structure, corresponding in origin but not necessarily in function

host an organism that harbours a parasite

hydrophilic able to absorb water or dissolve in water ('water loving')

hydrophilic molecule a molecule able to absorb water or dissolve in water, otherwise known as 'water loving'

hydrophobic water avoiding or unable to dissolve in water ('water hating')

hydrophobic molecule a molecule that is water avoiding or unable to dissolve in water, otherwise known as 'water hating'

hydrosphere all the water on Earth, including the water vapour in the atmosphere

hydrothermal vent a crack in the Earth's surface that releases water at high temperatures; caused by magma under the Earth's crust

hypertonic relating to fluid outside the cell that has a higher solute concentration than the cytoplasm; water diffuses out of the cell by osmosis

hypotonic relating to fluid outside the cell that has a lower solute concentration than the cytoplasm; water diffuses into the cell by osmosis

hypothesis a tentative prediction, usually based on an existing model or theory; also a tentative explanation of an observation based on an existing model or theory

I

ice core sample of ice removed from an ice sheet that contain clues to past climates and ecosystems

ileum the end region of the small intestine

immune system the system in the body that is responsible for the defence of the body against foreign particles

independent variable the variable that is controlled or manipulated by the experimenter

index fossil remains of an organism that lived in a particular geological age that are used to identify or date the rock or rock layer in which they are found

induced-fit model the model that describes enzyme action where the shape of the active site is not rigid; when the substrate binds to the active site, it induces the enzyme to change its shape to fit more tightly around the substrate

inferior vena cava the large vein that returns blood to the heart from the lower and middle part of the body

infiltration where water enters soils by moving into and through pore spaces

ingested when things such as food are taken into the body by the mouth

inorganic relating to nutrients that are part of the non-living world and do not contain carbon and hydrogen in long chains (for example, carbon dioxide, water and sodium ions)

inorganic compound a chemical compound that is part of the inanimate, non-living world, is not produced by living organisms and does not contain hydrocarbon chains (the combined elements of carbon with hydrogen)

insecticide a chemical designed to kill insects

interglacial period a period between ice ages (glacial periods) where the temperature is warmer than in the ice ages

intermediate form a transitional organism that shows characteristics of more than one group

internal environment the environment inside the cell membrane

interspecific competition competition that occurs when individuals of different species strive for the same resource that is in limited supply

interstitial fluid also known as tissue fluid; a solution that surrounds the tissue cells of multicellular animals

intraspecific diversity those variations in traits that occur within organisms of the same species

intraspecific competition competition that occurs when individuals of one species strive for the same resource that is in limited supply

introduced species a species that is not endemic to a certain location

irrigation supplying water to pastures and crops by means of channels or pipes

isolation the effects of separation that prevent individuals from interbreeding

isotonic when fluids inside and outside the cell are of equal concentrations; there is no net movement of water

isotope one of two or more forms of a chemical element that have the same number of protons but a different number of neutrons

J

jejunum the middle section of the small intestine

L

lacteal the lymphatic vessel in the villi of the small intestine that absorbs digested fats

lactic acid fermentation fermentation that is carried out by animals when the body cannot produce enough energy by aerobic cellular respiration; one molecule of glucose is broken down in the absence of oxygen to produce two molecules of lactic acid as well as two molecules of ATP

land clearing the removal of native vegetation from an area for the purposes of agriculture or urban development

large intestine the last part of the digestive tract, consisting of the colon and the rectum

laser a device that produces a narrow, intense beam of light

lenticel a raised pore in the stem of a woody plant that allows gas exchange between the atmosphere and the internal structures of the plant

lichen an organism arising from a symbiotic relationship between two or more fungi and an alga or cyanobacterium

light-dependent stage (photolysis) stage 1 of photosynthesis, which occurs in the grana of chloroplasts and involves the use of light energy to split the water molecule, releasing oxygen as a waste product, hydrogen ions and ATP

light-independent stage (carbon fixation) stage 2 of photosynthesis, which occurs in the stroma of the chloroplast, using the ATP to combine carbon dioxide and hydrogen ions to form glucose; no light is required

lignin an organic compound that adds strength to plant tissues by binding to cellulose fibres

limit of reading the smallest unit of measurement on a measuring instrument

line graph a type of graph used to show the relationship between continuous variables

line of best fit a straight line that is fitted to a graph of data points

lipase an enzyme that catalyses the breakdown of fats

lipid a large hydrocarbon molecule, such as in fats, oils and waxes; an important component of cell membranes and certain hormones

lipid bilayer a double layer of lipids

literature review a report and evaluation of information from secondary sources on a topic of interest

lithified turned into stone

lithosphere the crust and upper rigid mantle; the outer rigid part of the Earth (sections of this are also called 'plate')

lock-and-key model a model that describes enzyme action; the active site is a rigid shape that exactly fits the shape of the substrate

logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

loose connective tissue a type of connective tissue that holds the body together (for example, it is found under the skin)

lymph the fluid that circulates throughout the lymphatic system; it is composed of tissue fluid, white blood cells and the end products of lipid digestion

lymphatic system the part of the transport system in mammals through which lymph drains from tissues back into the blood

lymph system a part of the circulatory system that transports a number of substances around the body including tissue fluid; it also plays a major role in the immune system

lymph vessel a thin-walled vessel with valves that transports the lymph

lysosome an organelle within a cell that contains digestive enzymes

M

macroevolution major evolutionary change over a long period of time

macroparasite a parasite that is visible to the naked eye (for example, a tick)

magnification the degree to which the size of an image is larger than the image itself

marine relating to saltwater environments (the ocean or sea)

marsupial a type of mammal that is born at an undeveloped stage and then is suckled and carried in a pouch

mass extinction an extinction that has occurred on a large scale (for example, that of the dinosaurs)

maternal derived from the mother (female parent)

matrix the central fluid-filled space in mitochondria

measurand the quantity being measured

megafauna extremely large animals, most of which are extinct today

meristematic tissue tissue with undifferentiated cells in the young, growing regions of the root and shoot tips of a plant

mesophyll cells in the middle layer of the leaf that are responsible for photosynthesis

metabolism the sum total of all chemical reactions occurring within a living organism

metabolite a small molecule made during metabolic reactions, having various functions in the body

microclimate the climate of a very restricted, small area (for example, under a tree)

microevolution small changes within a species over a short period of time

microfossil fossil of single-celled anaerobic prokaryotes

microparasite a parasite that is invisible to the naked eye

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

midrib the central main vein of the leaf that runs along the length of the leaf

mimicry the resemblance of an organism to another organism or its surroundings for the purpose of concealment

mining the process of obtaining minerals and ores from the crust

mitosis the process of cell division where identical copies of the original cell are produced

model a representation of a system or phenomenon that explains the system or phenomenon; a model may be mathematical equations, a computer simulation, a physical object, words or another form

monomer a small, repeating molecule that makes up a polymer

monosaccharide a simple sugar composed of one sugar unit (for example, glucose)

monotreme an egg-laying mammal

MRI magnetic resonance imaging; this method uses strong magnetic fields and radio waves to generate images of structures

MRSA methicillin-resistant *Staphylococcus aureus*

multicellular relating to organisms composed of many specialised cells organised into different levels; these cells cannot live independently of each other

multicellular organism an organism made up of many eukaryotic cells

muscle tissue tissue composed of muscle cells called muscle fibres that are highly specialised for contraction

mutation change in the genetic material that results in new heritable characteristics

mutualism the symbiotic interaction between two species where both benefit from the association (for example, lichen)

N

natural selection the process by which certain members of a population that are more suited than others to prevailing environmental conditions survive and reproduce (their chances of survival are influenced by how successfully their genetic make-up enables them to withstand changes in the environment)

Neolithic literally 'new stone age'; when stone weapons and implements were abundant (approximately 10 000–2000 years ago)

nervous tissue nerve cells that are highly specialised for communication between all parts of the body

neuron a nerve cell that makes up nervous tissue

niche the place of a species within a community, involving relationships with other species

nitrogen fixation the process by which nitrogen from the air (N_2) is converted into other nitrogen-containing molecules that can be used by living things

non-target a species that is not intended to be a target of pesticides or a component of trapping/sampling

non-vascular a plant that does not have a transport system

NT neutron tomography; this method creates a three-dimensional image by reconstructing a series of two-dimensional photos as the object is rotated 180°

nuclear membrane the structure that surrounds and encloses the nucleus

nucleic acid a large organic molecule such as DNA and RNA; it allows the transfer of genetic information from parents to offspring

nucleolus the structure in the centre of the nucleus, made up of mostly RNA; manufactures ribosomes

nucleoplasm the liquid material in the nucleus that contains the chromatin

nucleotide the monomer that makes up nucleic acids; each contains a simple sugar, a base and a phosphate group

nucleus the membrane-bound structure in a cell that contains the genetic material of an organism

O

obligate describes species that are compelled or restricted to a single mode of life

oesophagus the soft-walled, muscle-ringed tube that leads from the mouth to the stomach

open circulatory system a circulatory system in which the transport fluid leaves the vessels, enters cavities in the body and comes in direct contact with the organs

ore a naturally occurring rock or mineral that has economic value

organ a group of different types of tissues that perform a particular function

organelle an internal structure or part of the cell that is enclosed by a membrane and has a particular function

organic relating to substances that are synthesised by living things and contain carbon and hydrogen atoms in chains (for example, glucose and amino acids)

organism a thing that is or once was alive and can carry out most of the functions that characterise being alive; plants, animals, microbes and fungi are all organisms

organ system a system of different organs grouped together that are responsible for a particular bodily function

osmoregulatory relating to osmoregulation, which is the maintenance of the salt and water content of the body, within certain limits, to protect cells from too much water entering or leaving them

osmosis movement of a solvent from a region of high concentration of the solvent to a region of low concentration of the solvent through a selectively permeable membrane

osmotic pressure the pressure created by water moving across the cell membrane; the more water moving across the membrane the higher the osmotic pressure

ostia tiny holes in the side of the heart chamber in an open circulatory system

outlier a data point that is distant from the other data points in the sample

oxic having oxygen

oxygenated blood that contains oxygen

ozone a molecule consisting of three oxygen atoms. Ozone is generated and accumulated in the stratosphere

P

palaeo-atmospherics the use of evidence in ice, rocks and fossils to reconstruct past climates and infer the composition of the atmosphere before written records began

palaeomagnetism a branch of geophysics concerned with the magnetism in rocks that was induced by Earth's magnetic field during the formation of the rocks

palaeontology the scientific study of fossils and all aspects of extinct life

palisade cell a type of mesophyll cell that is elongate in structure and contains many chloroplasts; it is the main photosynthetic cell in the plant and is located just below the upper epidermal layer of the leaf

pancreas an organ that produces pancreatic juices containing digestive enzymes that are released into the duodenum

parasite an organism that lives and feeds on or in another organism (the host), which is usually larger than the parasite

parasitic characteristic of a parasite

parasitism the symbiotic relationship between two species where one benefits (parasite) and the other is harmed (host)

passive movement movement that requires no input of energy

pathogen a disease-causing organism such as a bacterium or virus

pelagic that part of the ocean that is neither near the bottom nor close to shore

pentadactyl a vertebrate limb containing five fingers or toes

peptide a polymer containing up to 10 amino acid monomers

peristalsis muscular contractions that move the food through the digestive tract

perennial a plant that lives for 2 or more years as opposed to an annual, which lives for a year

permeable allowing liquids or gases to pass through

PET positron emission tomography; an imaging technique that uses radioactive tracers to follow the pathway of substances in an organism

phagocytosis endocytosis of a solid particle
pharyngeal slit also known as a gill slit; used in embryology to determine relatedness

phenotype the detectable physical or behavioural characteristics or traits of an organism

phloem vascular tissue that transports the products of photosynthesis

phospholipid part of the structure of the cell membrane; each molecule has a 'head' with two fatty acid chains connected to it

photic zone the surface layer of the ocean that receives sunlight

photosynthesis 'photo', light; 'synthesis', manufacture; a series of reactions occurring in the chloroplast by which plants, some bacteria and some protists use light energy trapped by the chlorophyll to produce glucose from carbon dioxide and water

phylogenetic tree an evolutionary tree showing inferred relationships

phylogeny a branch of biology that deals with evolutionary relationships

physiological to do with the functioning of an organism

physiological adaptation a functional feature (how the organism works) of an organism that allows an organism to be better suited to surviving in its natural environment

phytoplankton photosynthetic prokaryotes that grow abundantly in the oceans

pili hair-like structures on the surface of a cell

pilus a structure used by bacteria to exchange genetic material

pinocytosis endocytosis of a liquid

placental relating to a type of mammal that has a placenta and develops internally

planTIS a PET scanner for plants

plasma the yellow, watery, fluid part of blood consisting of about 90 per cent water and 10 per cent proteins; carries many substances in either dissolved or suspended form

plasmid the circular ring of genetic material in a prokaryotic cell

plasmolysis the process by which cells lose water in a hypertonic solution, causing the cytoplasm to shrink away from the cell wall

plastid a small organelle in the cytoplasm of plant cells; it contains either pigment or dissolved nutrients

platelet (thrombocyte) a crescent-shaped fragment of cells produced in the bone marrow; has a function in the clotting of the blood

polar relates to molecules that have a slightly different charge, positive or negative, on each end

pollen the collective term for pollen grains

pollination the transfer of pollen from the male to female reproductive organs of a flowering plant

polymerase chain reaction (PCR) a technique used to multiply a small number of copies of a DNA segment to generate thousands or millions of copies of that DNA segment

polypeptide a polymer containing more than 10 amino acid monomers

polysaccharide a complex polymer composed of many single sugar monomer units joined together (for example, starch)

population a group of organisms of the same species living in the same area at a particular time

pore hole

poverty severe deprivation and need at the family level

precipitation rain, hail and snow that falls to the ground or condenses on the ground

precise what measurements are called when they are close to each other

predator an organism that catches and kills another organism for food

predator-prey relationship the relationship between a predator and its prey

prey something that is hunted or caught for food

primary data data that you have measured or collected yourself

principle of uniformitarianism the scientific understanding that the geological processes and natural laws that currently modify the Earth's crust have behaved in the same manner and with the same intensity throughout geological time

producer a plant that makes its own nutrients through the process of photosynthesis (an autotroph); constitutes the first trophic level in a food chain

prokaryote unicellular organism that lacks membrane-bound organelles such as a nucleus, mitochondria or chloroplasts

prokaryotic relating to cells with no membrane-bound nuclei or membrane-bound organelles

prokaryotic autotrophic cell a cell lacking a membrane-bound nucleus and that produces its own nutrients

prokaryotic cell a cell that neither has its DNA enclosed by a membrane nor forms a proper nucleus; it has no membrane-bound organelles within the cell; prokaryotic organisms are usually unicellular (for example, bacteria)

prokaryotic heterotrophic cell a cell lacking a membrane-bound nucleus and that obtains its energy from organic molecules in its environment (for example, bacteria)

prophylactically by any measure used to prevent or protect from infection by a pathogen

protoplasm the living content of a cell that is surrounded by the cell membrane; composed of the nucleus and the cytoplasm

proxy data the data that palaeoclimatologists use to interpret past climates, such as fossil pollen, ice core gas readings, ocean sediments and tree rings

pulmonary artery the blood vessel through which blood is pumped from the right ventricle to the lungs

pulmonary circulation the pathway of blood from the heart to the lungs and back to the heart

pulmonary vein the blood vessel through which blood is transferred from the lungs to the left atrium

punctuated equilibrium a type of evolutionary change that is marked by isolated episodes of rapid speciation between long periods of stability and no change

pyloric sphincter a valve composed of a ring of smooth muscle that regulates the passage of chyme from the stomach to the duodenum

Q

quadrat a frame of known dimensions used to estimate populations of a species in a given area

qualitative descriptive data; the quality of results can be described or drawn (non-numerical)

quantitative relating to results that are measured and recorded as numbers (quantities)

quarantine the separation and isolation of living things to prevent the spread of infectious disease

R

radiation (adaptive) the rapid diversification of an ancestral species into many new forms

radiation (from radioactive materials) energy emitted in the form of waves or particles

radioactive unstable; emitting particles (known as radioactive decay)

radioactive tracer a chemical compound in which one or more atoms have been replaced by a radioisotope

radioisotope unstable form of an atom that emits radiation

radiometric dating a method of estimating the age of objects or material using the decay rates of radioactive components

rainforest a type of ecosystem characterised by a dense canopy of trees, ferns and other plants in enormous variety; found in a high rainfall area

raw data original data taken directly from a measurement system

realised niche that part of the fundamental niche that the species actually occupies at a certain time

real-time radioactive imaging system (RRIS) a non-destructive imaging system using radioisotopes; can be used to visualise the movement of substances in the phloem

receptor protein a membrane protein that binds hormones and other substances

recognition protein a membrane protein that allows the body to recognise it as 'self'

rectum the region of the large intestine where the remaining waste material, known as faeces, is stored before it is removed from the body

red blood cell (erythrocyte) a very small biconcave cell containing haemoglobin that is formed in the bone marrow

relative dating determining the relative order or chronology of past events

reliable giving the same results within experimental uncertainty

reproducibility able to give the same result, within uncertainty, when repeated measurements are made

reproducible giving the same result, within uncertainty, when repeated measurements are made

research question the specific question that a particular experiment or investigation is designed to answer

resistant able to withstand the effects

resolution the degree to which it is possible to distinguish *between* two objects that are very close to each other

respiration a chemical reaction in the mitochondria of cells whereby energy is released from organic compounds (especially carbohydrates)

respiratory system the system involved in the exchange of gases between an organism and its environment

rhizobia soil bacteria that fix nitrogen

ribosome a very small, spherical structure found in the cytoplasm that contains both RNA and proteins; its function is to manufacture the proteins required by the cell

riparian relating to the banks of a river

root hair the extension of a root epidermal cell to increase absorption of water and mineral ions

root pressure pressure caused by water entering the roots by osmosis; causes the water in the xylem to flow in an upward direction

rumen the 'first stomach' of an animal such as a cow or sheep (ruminant) where fermentation of grass takes place by bacteria

S

salinisation increasing salt content within soils or waterways

salinity the amount or concentration of dissolved salt

sampling technique an ecological technique used to estimate species populations by the collection and/or counting samples of the population

saturation point the point at which all available enzymes are being used to catalyse reactions

scatter plot a graphical representation of the relationship between the individual data points of two variables

scavenger an animal that feeds on dead organisms

scientific method a systematic process of observation, experimentation, measurement and analysis to either support or disprove a hypothesis

sclerophyll a type of vegetation typically found in Australia, consisting of plants with spiky, hard leaves with an orientation parallel to direct sunlight, hence reducing moisture loss

secondary data data or information that has been collected by someone other than you

secrete produce or discharge

sector or pie graph a circular graph that shows fractions of a whole

sedimentary rock rock formed from the accumulation of sediments (for example, sandstone, shale, conglomerate)

selection pressure a factor, often in the environment, that affects the survival and reproduction of an individual within a population (usually by acting on a variation)

selective breeding breeding where humans choose particular animals or plants for their favourable traits to mate and have offspring

selectively permeable describing a membrane that will let certain substances through and not others

semipermeable describing a membrane (usually synthetic) that allows material to pass across it, but is unable to select which material

septum the muscular wall that separates the left- and right-hand sides of the heart

sieve plate the perforated cell wall on the end of a sieve tube cell

sieve tube cell a long, thin phloem cell that has large pores through the cell walls at each end; it has no nuclei, mitochondria or vacuoles and is arranged end-to-end into sieve tubes

siltation when water becomes dirty because of fine particles of mud or silt

sink 1: the low-pressure region where the glucose is required in the plant; 2: a natural or artificial reservoir (for example, the ocean is a carbon dioxide sink)

sinus a space in the body cavity of an insect

skeletal muscle muscle with long fibres and striations (light and dark areas); attached to bones; contraction causes movement in the organism

smooth muscle muscle with fibres without striations that contracts and pushes substances through specialised organs, such as the gastrointestinal tract

soil structure the arrangement of the solid parts of a soil into units called aggregates, allowing for pore spaces between them

solute a substance that dissolves in a solution

solution the product formed when a solute dissolves in a solvent

solvent the substance that the solute dissolves in (usually water)

source where something is produced

specialised cell a cell that has structures that allow it to carry out a particular function

speciation the formation of a new and distinct species in evolution

species a group of organisms of similar appearance within a population, the members of which can interbreed to produce fertile offspring

species diversity a measure of the diversity of species in an ecological community

spiracle a small pore in the body of an insect that is connected to internal air tubes called tracheae through which gases are exchanged

spongy cell a type of mesophyll cell that is located between the palisade cells and the lower epidermis; they carry out photosynthesis and are loosely packed to allow gases to move between them

statutory written into law (for example, legal restrictions on air pollution by cars)

stem cell an undifferentiated cell that divides and develops structures that allow it to become specialised

stoma a pore in a leaf through which gases are exchanged and water is lost by evaporation (plural: stomata)

stratigraphy a branch of geology concerned with the chronological order of fossils

stratosphere a layer of Earth's atmosphere above the troposphere; contains the ozone layer

striations light and dark areas in muscle tissue

stroma the liquid part of the chloroplast

stromatolite a concentrically layered rock, the layers being formed by the successive growth of thin mats of cyanobacteria

structural adaptation a physical feature of an organism that allows the organism to be better suited to surviving in its natural environment

stubble the cut stalks of plants such as cereals in the ground after the grain is harvested

substrate the reactant that binds to the active site

substrate–enzyme complex the complex formed when the substrate binds to the active site of the enzyme and the reaction proceeds

succulent one of a group of plants that store water in their leaves

sucrose the form in which the glucose produced in photosynthesis is carried around the plant in the phloem

superior vena cava the large vein that returns blood to the heart from the head, neck and upper limbs

sustainable (in ecosystems) able to remain diverse and productive in the future

symbiogenesis the evolutionary theory that eukaryotic cells evolved from prokaryotic organisms

symbiosis the group of interactions in which two organisms live together in a close relationship that is beneficial to at least one of them

symbiotic interaction see *symbiosis*

sympatric relating to a process through which species evolve in the same geographic region

systematic error an error that results in a consistent, predictable offset from the 'true value' (for example, a zero error)

systemic circulation the pumping of oxygenated blood to all parts of the body and the return of deoxygenated blood to the heart

T

terrace a form of landscaping used to reduce soil erosion and surface run-off of water

terrestrial on the land

theory a substantiated explanation based on a body of facts and evidence

therian belonging to a group of mammals that comprises marsupials and placental mammals

thorax the middle section of the body of an insect between the head and the abdomen

thromboplastin an enzyme released by platelets that starts the process of blood clotting

thylacine a large, carnivorous Australian marsupial now thought to be extinct

Thylacoleo an extinct genus of carnivorous marsupial lions, including *Thylacoleo carnifex*

thylakoid a membrane in the chloroplast that has chlorophyll on it; each stack of thylakoids forms a granum

tilling (the soil) to prepare the soil for growing crops or pastures

timeline a linear representation of important events in the sequence in which they occurred, whereby each event is drawn on the line to a scale that reflects the time that has elapsed between successive events

tissue a group of specialised cells that perform a similar function

topography the shape and features of the land (often called 'relief')

topsoil the upper layer of soil with the highest concentration of organic matter; where plants generally concentrate their roots

tracheal system the system in insects where the gases oxygen and carbon dioxide are exchanged by a system of tubes (called tracheae) that open to the outside through small holes (called spiracles)

tracheal tubes branching air tubes that carry gases to and from the cells of an insect; part of the tracheal system

tracheole a small air tube branching from the tracheal tubes

transect a method used in population sampling in which observations are made across a narrow strip that crosses the entire area being studied

transitional form an organism or fossil that shows characteristics intermediate between its ancestral form and its descendants

translocation the movement of the products of photosynthesis from the leaves to all parts of the plant

transpiration the evaporation of water from the leaf to create a 'pull' that assists the movement of water in the xylem tissue

transpiration stream the movement of water from the roots of a plant to the leaves, caused mostly by the evaporative pull of transpiration

transport protein a protein embedded in the cell membrane to allow movement of certain substances through it

triglyceride a lipid molecule composed of three fatty acid chains attached to a glycerol molecule

tropical referring to an area of hot and humid climate

trypsin an enzyme produced by the pancreas that catalyses the breakdown of protein in the duodenum

turbidity cloudiness of a fluid (for example, a river) caused by particles such as mud

turgid firm, full of fluid

U

ultraviolet (UV) radiation a type of radiation produced by the Sun

uncertainty an estimate of the range of values within which the 'true value' of a measurement or derived quantity lies

unicellular made up of a single cell

V

vaccine a serum or plasma that is administered to people or other animals to produce an immune reaction to disease-causing organisms

vacuole a large, fluid-filled storage sac in the cytoplasm of a cell

valid relating to results that are affected by a single independent variable and hence are reproducible

valve a structure lining the internal surfaces of the lymph vessels and veins preventing the backward movement of lymph and blood

vascular plant a plant that has a transport system to move substances around the plant and provide support

vascular tissue transport tissue which is organised into vessels (such as xylem and phloem in plants)

vector an organism that carries parasites and transmits them from one host to another

vein a type of blood vessel that returns the blood to the heart; it has thin walls, and valves to prevent the backward flow of blood

ventricle the bottom chamber on each side of the heart that pumps to expel blood out of the heart

venule a small branch of a vein that leads from a capillary to a vein

vernalisation the exposure of seeds or bulbs to low temperature to initiate germination or flowering

vestigial relating to a structure that has degenerated or is functionless due to evolution

villus a small projection lining the surface of the small intestine that provides a large surface area for the absorption of food (plural: villi)

W

weir a barrier across a river designed to alter flow

wetland an area saturated by water during certain seasons or all the time; a type of ecosystem

white blood cell (leucocyte) an irregularly shaped cell, produced in the bone marrow, that carries out the role of defending the body

woodland a habitat with a sparse canopy of trees, usually with less rainfall than that of a rainforest

X

xerophyte a plant that is adapted to survive in dry environments

X-ray computed microtomography a technique that uses X-rays to create cross-sections of a physical object that can be used to recreate a visual model without destroying the original object

xylem vascular tissue in plants that transports water and dissolved mineral ions up the plant as ascending sap

xylem tracheid non-living xylem elements formed from a single cell, with strong, tapered, elongated ends and pitted walls thickened with lignin (also see *xylem*)

xylem vessel continuous tube of xylem, originally formed by cells stacked end to end that lost their end walls (also see *xylem*)

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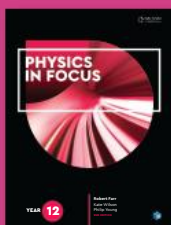
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OVERVIEW

- Meets the complete requirements of the NESA Stage 6 Biology syllabus in intent, content and sequence
- Accessible language and clear explanation of concepts throughout
- Scenario-style questions to apply, analyse and evaluate content
- Review quizzes at the end of each chapter to test students' understanding
- Learning across the curriculum areas, as detailed in the syllabus, embedded within the content
- Working Scientifically processes developed within each investigation
- Includes both primary and secondary-sourced investigations, including modelling
- Contains a dedicated chapter on how to approach and carry out the depth study at Years 11 and 12
- Depth study suggestions for each module are provided

