Rick Armstrong | Annie Termaat | 2nd edition

Biology 4/5

for the international student

NELSON
CENGAGE Learning

Rick Armstrong
series editor

Rick Armstrong | Annie Termaat | 2nd edition

Biology 4/5 for the international student

2nd Edition

NELSON CENGAGE Learning

Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

NELSON
CENGAGE Learning

Biology 4/5 for the international student
2nd Edition
Rick Armstrong
Annie Termaat
Jenny Sharwood
Julie Hall-Lavorgna
Katrina Mitchell
Zahara Delgado Scott

Publishing editor: Sarah Craig and Karen Lampman
Editor: Catherine Greenwood
Cover design: Aisling Gallagher
Proofreader: Jane Fitzpatrick
Text design: Aisling Gallagher
Permissions researcher: Corrina Gilbert
Production controller: Emma Roberts
Typeset by: MPS Limited

For product information and technology assistance,
in Australia call **1300 790 853**;
in New Zealand call **0800 449 725**

For permission to use material from this text or product, please email
aust.permissions@cengage.com

National Library of Australia Cataloguing-in-Publication Data
Armstrong, Rick, author.
Biology 4/5 for the international student / Rick Armstrong, Annie Termaat, Jenny Sharwood, Julie Hall-Lavorgna, Katrina Mitchell, Zahara Delgado Scott.

2nd edition
9780170353199 (paperback)
Science for the international student.
Includes index.
For secondary school age.

Biology--Textbooks.
International baccalaureate--Study guides.

Termaat, Annie, author.
Sharwood, Jenny, author.
Hall-Lavorgna, Julie, author.
Mitchell, Katrina, author.
Delgado Scott, Zahara, author.

570.712

Cengage Learning Australia
Level 7, 80 Dorcas Street
South Melbourne, Victoria Australia 3205

Cengage Learning New Zealand
Unit 4B Rosedale Office Park
331 Rosedale Road, Albany, North Shore 0632, NZ

For learning solutions, visit **cengage.com.au**

Printed in China by China Translation & Printing Services.
1 2 3 4 5 6 7 19 18 17 16 15

Contents

UNIT 4 REPRODUCTION 79

UNIT 5 DNA – THE LIFE MOLECULE 103

UNIT 6 IT'S IN YOUR GENES 129

UNIT 7 THEORIES OF CHANGE 153

UNIT 8 DISEASE AND GLOBAL HEALTH 181

About the authors

Authors

Rick Armstrong (series editor)
Freelance consultant, Madrid, Spain

Rick Armstrong has been involved with MYP sciences guide writing since 1994. He has experience with leading sciences workshops in all International Baccalaureate regions, moderation, school visits and authorisations, as an Approaches to Learning workshop leader, and as DP examiner. Rick is currently a freelance educational consultant in Madrid, Spain.

Annie Termaat
Australian Capital Territory Education and Training Directorate, Australian Capital Territory, Australia

Annie Termaat has been using inquiry methods to teach science since 1989. She was a member of writing teams for MYP Sciences guides, edited MYP Sciences teacher support materials, co-authored *MYP Interact* and has contributed to the assessment of the program as a monitor, moderator and task developer. She has taught in Turkey, Malaysia and in Australia.

How to use this series

The *Science for the international student* series provides students with a variety of engaging and stimulating formats for learning, understanding and immersion in both the Middle Years Programme (MYP) philosophy of the International Baccalaureate (IB) and the science content. The features of the student book have been specifically designed to support this and to deliver exciting content in a variety of ways.

Specific MYP features

Each unit begins with a unit opening page that specifies:
- the key concept that is covered in the unit
- the related concepts that are covered in the unit
- the Global Context of the unit
- the Statement of Inquiry
- inquiry questions, divided into factual, conceptual and debatable questions.

Key and related concepts

Each unit is based around one *key concept* of an enduring transdisciplinary nature and a small number of *related concepts* designed to help frame the unit in the minds of the students.

Global Context

Students will be encouraged to see science in diverse *global contexts*. These include historical developments in science; how scientific discoveries have affected medicine, space exploration, materials technology and nutrition; and the role of science in environmental sustainability and equitable access to resources in the developing world.

Statement of Inquiry

The *Statement of Inquiry* drives the unit and is strongly related to the units' concepts and context.

Inquiry questions

The inquiry questions are divided into factual, conceptual and debatable questions. Factual questions are related to the unit content, conceptual questions are related to the unit concepts and debatable questions are related to both and are designed to stimulate deeper thinking.

Performance assessment tasks

Opportunities for assessment tasks occur throughout each unit and these are each identified by a *performance assessment task* icon.

The *summative performance assessment task* associated with the Statement of Inquiry is identified at the beginning of each unit. The criteria assessed by the assessment task are also identified.

Approaches to Learning

Opportunities to develop and apply *Approaches to Learning* skills are identified by an 'ATL' icon. Teachers can use these prompts to discuss and reinforce learning strategies.

Investigation

Investigations challenge students to design and perform their own experiments either individually or in groups. Investigations are designed to satisfy criteria B and C.

Experiments

Experiments provide students with the opportunity to develop and practise their skills, by following processes and procedures, to discover information for themselves and to build a greater understanding of, and interest in, scientific concepts. Most experiments are designed to satisfy criterion C, but some additional important experiments are also included (and the NelsonNet teacher website has further experiments).

Taking action

Taking action suggestions are identified by a 'TA' icon and are designed to satisfy the MYP requirements for service as action.

Other features

Review

Review boxes contain questions and break the content into smaller sections, allowing students to review what they have learnt so far.

Activity

Activity boxes reinforce or develop concepts and skills through short, fun and hands-on activities.

Weblinks

Weblinks are identified by an icon and direct students to exciting websites to further explore the world of science.

Unit questions

Unit questions conclude each unit. They include review questions sorted under the MYP assessment criterion A, levels 1–8. Reflection questions are included to review the concepts underpinning the unit, to encourage further consideration of the debatable inquiry questions, and at times to consider further lines of inquiry.

NelsonNetBook

The *Science for the international student* NelsonNetBook is an interactive ebook that can be used online or offline. It is compatible with interactive whiteboards, computers and tablets, with optional Web 2.0 functionality for class groups. Students can add highlights, annotations, audio and video clips, and weblinks, and teachers can use it to share their personalised version with the class.

Visit the NelsonNet portal at www.nelsonnet.com.au to find out more, register or log in if already registered.

NelsonNet teacher website

The NelsonNet teacher website contains further valuable advice, including draft MYP unit plans covering the first two pages of the revised MYP planner, and also a curriculum overview as required by the IB. Other resources include blackline masters (BLMs) containing possible further experimental work and classroom activities, ideas for further resources, and further advice relating to teaching in a conceptual way and for the use of the Approaches to Learning framework. Answers will also be provided for all questions, as well as a list of extra resources for each unit.

Contact your sales representative for information about access codes.

Introduction

To the student

We hope you will enjoy using this exciting student book, which has been designed to provide an up-to-date science experience around the principles of the new enriched Middle Years Programme (MYP) offered by the International Baccalaureate (IB). You are likely to already be an experienced MYP student, proud of being an *internationally minded* student, and familiar with the distinctive way MYP students work in science. These revised books provide a greater emphasis on the global contexts for learning in science, ranging from the challenge to provide better and more equal access to medicines worldwide, to considering global environmental challenges such as global warming. The books emphasise investigative and experimental work and expect you to work and think like a real scientist. As you will be well aware, the MYP is also about encouraging you to develop effective learning skills that will stay with you for life, and you will see in these books many suggestions to help you with this challenge. We wish you all the success possible with MYP Science and beyond.

To the teacher

We have reviewed our original series, published in 2010–2011, to take account of the innovative developments and improvements in the MYP. In this new edition, we have deepened our coverage of MYP principles within each unit. The units are now much more contextual and more explicitly driven by the Statement of Inquiry. As you will be aware, the IB has attempted to give schools more flexibility in their delivery of the MYP and there certainly is no 'correct' model of how to put the MYP into practice. For that reason, we feel we should explain some of our approaches to constructing our units.

1 **Conceptual framework:** We have closely followed the suggested framework but have added a small number of extra related concepts that will be useful to teachers and will allow coverage of the US cross-cutting concepts. We have also used concepts from other subjects when we felt their use would enhance the unit. Importantly, we accept that the key to teaching conceptually lies in appropriate classroom practices. To help this practice, we have included activities and questions to help strengthen students' understanding of the conceptual framework as well as some further guidance in the teacher materials.
2 **Content:** We have included academically challenging content that will provide an effective transition to higher study in the Diploma Programme (DP) or in other national systems. This content should also help teachers meet the requirements of local curricula or prepare for other examinations, such as IGCSEs. We have covered all the expected content for MYP Sciences e-examination in Books 4/5. Some of this content is also covered in more detail in Books 1, 2 and 3. We have ensured that the scope and sequence of our MYP Books 1–5 is well thought out and offers a coherent framework for the development of deep understanding based on the big unifying concepts in science.
3 **Global Contexts:** The development of the Areas of interaction into the Global Contexts is very liberating and opens the door for much more creative uses of contexts in the planning of MYP units. To take advantage of this potential, we have associated the Global Context chosen for the unit with a more specific 'exploration into' statement. This 'exploration into' feeds clearly into the Statement of Inquiry for each unit. This has helped us to make the science content up to date, interesting and relevant to the real world.

4 **Statements of Inquiry:** We have written simple and clear Statements of Inquiry that are understandable to students and to teachers. We have been flexible in relation to trying to build all the chosen concepts into the Statements of Inquiry. Our priority has been to ensure that the Statement of Inquiry is easy to understand, has a conceptual feel and, importantly, relates to the chosen Global Context.

5 **Assessment tasks:** Most science units will require more than one summative performance assessment task because it is artificial to try to bring together a number of the sciences criteria in one task. Therefore, most units include assessments relating to investigation work (criteria B and C), a performance-type task relating to the impacts of science (criteria D) and end-of-unit questions to assess criterion A. At the beginning of each unit, you will see a summative performance assessment task that relates closely to the Statement of Inquiry. We have given this task the most authentic performance nature possible. Other performance assessment tasks are included in each unit that can be used summatively or formatively. We expect that not all of the assessment suggestions will be used for summative purposes.

6 **Approaches to Learning:** We are very impressed by the revised Approaches to Learning framework based on the ten clusters of ATL skills. We understand that the effective implementation of ATL is a whole-school challenge but have made suggestions for when teachers can explicitly introduce these skills and dispositions, both as part of summative assessment tasks, and also more generally in their daily teaching.

7 **Service learning:** We have suggested a possible service learning activity (labelled Taking action) for each unit.

The NelsonNet teacher website contains draft MYP unit plans, a curriculum overview, BLMs for experimental work and classroom activities, ideas for interdisciplinary tasks, further resources and advice for using the ATL framework, and answers to all questions.

We realise there may seem to be an inherent conflict between the idea of teachers working in a creative and collaborative way to produce MYP units of work and the use of a textbook. Schools will use this book in different ways. Some new schools might find it an invaluable stepping stone to getting a MYP Sciences programme up and running. Others may use it to enhance their existing courses. We encourage you not to use these books the way traditional textbooks have been used. Be creative, add to them, choose the bits you like, encourage the students to interact with them. They are there to help students in their deep learning of science, to encourage their interest and motivation. We hope the availability of materials of this kind will make your life as the teacher a little easier and give you more time to focus on the actual teaching and learning. Enjoy them.

Rick Armstrong (Series editor)

UNIT 1

THE WORLD AROUND US

KEY CONCEPT
Relationships

RELATED CONCEPTS
Interaction

Balance

Environment

Cycles

GLOBAL CONTEXT
Globalisation and sustainability: an exploration of global biodiversity and the impact of human activities on the environment

STATEMENT OF INQUIRY
Balancing global biodiversity with human needs

INQUIRY QUESTIONS

FACTUAL
1 What is meant by the term 'environment'?
2 What is the difference between an ecosystem and an environment?
3 How are nutrients cycled in ecosystems?

CONCEPTUAL
4 Why is the natural environment important for our communities?
5 What limits the numbers of organisms in ecosystems?
6 Is biodiversity important?

DEBATABLE
7 On Earth, are the changes caused by human activities bigger than those caused by past geological events?
8 Do solutions for limiting environmental problems create new challenges?
9 Is ecological sustainability possible?

COMMUNICATION
Expressing scientific ideas and argument clearly, precisely and persuasively.

Conserving biodiversity

As the human population expands across Earth, many natural landscapes are becoming fragmented by roads, agriculture and cities. Since the 1970s, ecologists have debated the best strategy for protecting biodiversity: a single large reserve or several small reserves.

What is the best way to balance the biodiversity of the species and ecosystems around us with the global impact of our needs and activities?

Write a scientific evaluation, of no more than 1200 words, of one attempt to tackle this question, with a real-world example.

1 Research an example of a local, national or global ecosystem that is currently threatened by human activity.
2 Describe the ecological value of your selected ecosystem and how human activity is likely to affect biodiversity.
3 Recommend how strategies informed by science may protect the ecosystem and its biodiversity.
4 Discuss how your recommendation will impact on at least two of the following: moral, ethical, social, economic, political or cultural factors.

Your scientific report needs to be correctly formatted, your sources documented and the work of others acknowledged.

Introduction

Our Earth is a 'Goldilocks' planet in our solar system – not too cold, not too hot, just right for water to exist in its three phases. Not too large, not too small, just the right mass for its gravity to capture and hold an atmosphere around its rocky core. There may be other planets somewhere providing the balance of conditions that support carbon-based life, but the organisms in our world are unique.

No matter where you are in the world, you can probably see the impact of humans. You may be surrounded by cars, buildings and factories. Outside cities, there are farms, roads, vapour trails from passing planes, or a satellite blinking across the night sky. Even on continents that are largely wilderness, such as Antarctica, traces of synthetic chemicals and soot in the snow provide evidence of intensive human activity elsewhere on Earth.

All human activity has consequences. This unit describes how the complex relationships in ecosystems interact and are easily unbalanced. This unit aims to help you understand which choices support life as we know it, and whether humans will be the villains or heroes of Earth's story.

Ecosystems and the environment

Earth can be divided into regional patterns called **biomes**. Major world biomes are water (fresh and salt), rainforest, savannah, grasslands and deserts. Other examples of biomes are the tundra, taiga and deciduous forests that circle the northern hemisphere. Ecosystem and biome patterns are shaped by climate, latitude and more.

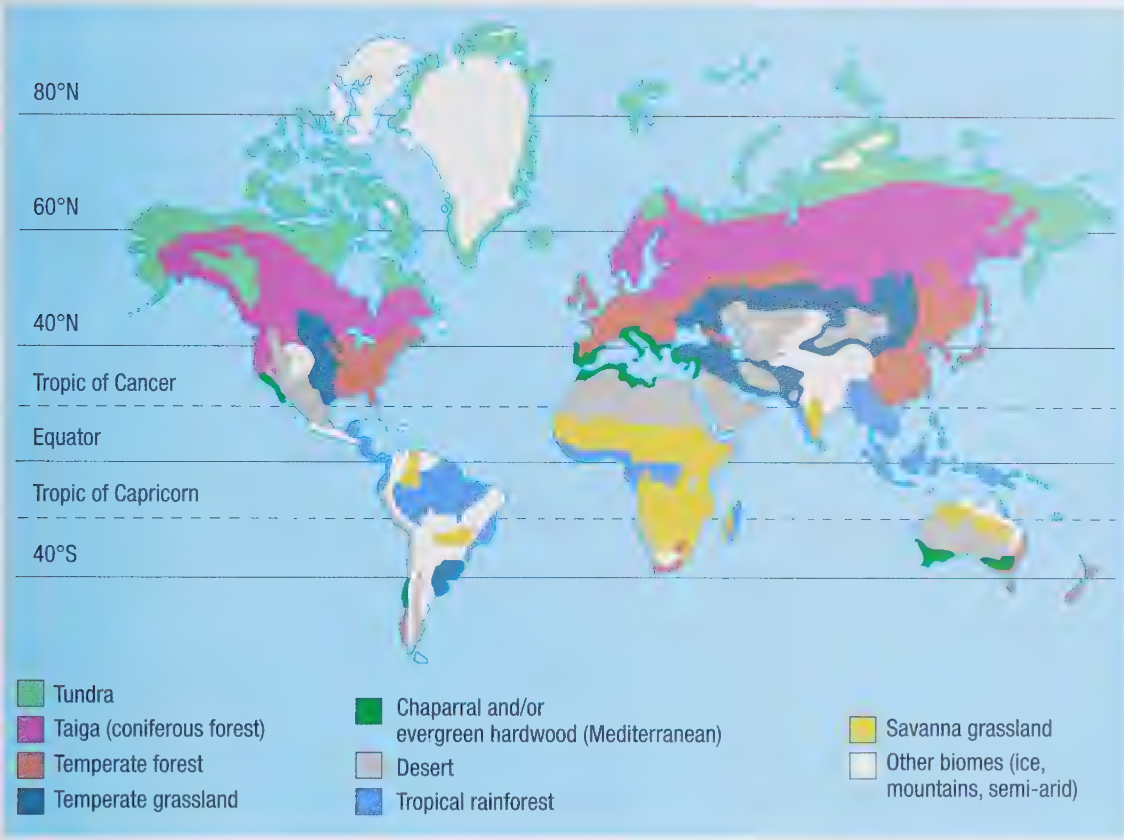


FIGURE 1.1 Distribution of the world's major biomes

Biomes can have different ecosystems within them, depending on the species present. The term **ecosystem** is used to describe the interaction between groups of organisms and their surroundings, or their **environment**. All the parts of an environment that are not living, such as temperature, light, precipitation and soil pH, are grouped as **abiotic factors**. The importance of abiotic factors can be deduced from the broad location of important types of ecosystems, which is largely determined by geography. All the living components, for example the different species, and the effects they have on other living organisms, are grouped together as **biotic factors**.

Go to http://mypbio45.nelsonnet.com.au and click on **The world's biomes**. Displayed are six different ecosystems: freshwater marine, desert, forest, grassland and tundra. Choose two ecosystems and compare their biotic and abiotic factors. How do the animals and plants differ in these ecosystems?

The distribution of **terrestrial environments**, such as tundra, deserts, open forests and temperate grasslands, depends mainly on climatic variation. Temperature, water, light and wind are the four main elements of climate. Both water and temperature significantly affect the geographic range of organisms that can live in an environment. For example, desert climates are very different from tropical rainforest climates.

Tropical rainforests generally exist between the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S), but can extend slightly outside these boundaries. Year round, temperatures range from 20°C at night to 35°C during the day. Rainfall and humidity are high, with annual rainfall typically 1500–2500 mm. However, soil in tropical rainforests is low in nutrients due to leaching of nutrients by rainfall. Organisms receive nutrients from the continual decomposition of plant debris. Although the rate of decomposition limits how quickly the forest can grow, the world's rainforests are extremely dense and home to 50% of all animal and plant life. They also accommodate numerous varieties of fungi and **bacteria**.

Abiotic factors

The nutrients in soil are essential for plant growth. Understanding soil features helps determine which plants grow best in a particular region. Soil type depends on a number of properties, including location, depth, texture, colour, porosity, pH, water-carrying capacity and nutrient status.

Looking at abiotic factors: pH of soil

EXPERIMENT 1.1

AIM

To analyse whether the pH of soil around your school varies and why this might be the case.

INTRODUCTION

Soil provides a medium in which plants can grow. It provides essential nutrients such as phosphates, nitrates and water, and supports the base of the plant and its roots. Soil pH can determine which nutrients are available to the plant and which plant diseases are present.

MATERIALS

- distilled water
- universal indicator and indicator chart
- large funnel
- 100 ml measuring cylinder
- 6 × 100 ml beakers
- stirring rod
- retort stand
- balance
- labels for the samples
- garden trowel
- 3 plastic bags
- 3 pieces of filter paper

PROCEDURE

1 On a map of your school, mark three sites where you will gather a soil sample.
2 Record the date, names of members of your group, the weather conditions, any natural and artificial features of the site and the colour of the soil. Describe the location.
3 Go to each site and use the garden trowel to remove 3 cm of topsoil. Collect approximately 20 g of the exposed soil, placing it in the bag. Secure each bag with a tie and label each bag.
4 In the laboratory, use the balance to weigh 10 g of each soil sample into separate beakers. Make sure you label each beaker.
5 To each beaker, add 20 mL of distilled water. Use the stirring rod to mix the soil and water. Allow the soil mixture to sit for 5 minutes.
6 Using the funnel and filter paper, filter the water from each soil sample into clean beakers. Be sure to change the filter paper between samples.
7 To the water, add 3 drops of universal indicator.
8 Match the resulting colour on the universal indicator chart.
9 Record your results for each of the three samples.

CONCLUSION

1 Did the soil pH vary around the school? What natural and artificial factors may contribute to any variation seen?
2 Soil pH ranges from slightly acidic (pH 6) to slightly alkaline (pH 7.5). The ‘zone of physiological stress’ is below pH 5.5 or above pH 8. Were your soil samples suitable for plant growth?

WHAT DO YOU THINK?

1 What factors do you think might contribute to the variation in soil pH?
2 Is there any correlation between soil colour and soil pH?

Biodiversity

Biodiversity refers to the variety of life in an ecosystem. Is it obvious which of the two ecosystems pictured in Figures 1.2 and 1.3 supports the greater variety?

There are many ecosystems and all have differences in their biotic and abiotic factors. The Sahara Desert in Egypt (Figure 1.2) is hot with very little water and therefore has sparse plant life. The Phetchabun mountain range in Thailand (Figure 1.3) also has high temperatures, but it has more rainfall and therefore supports a dense population of plants.

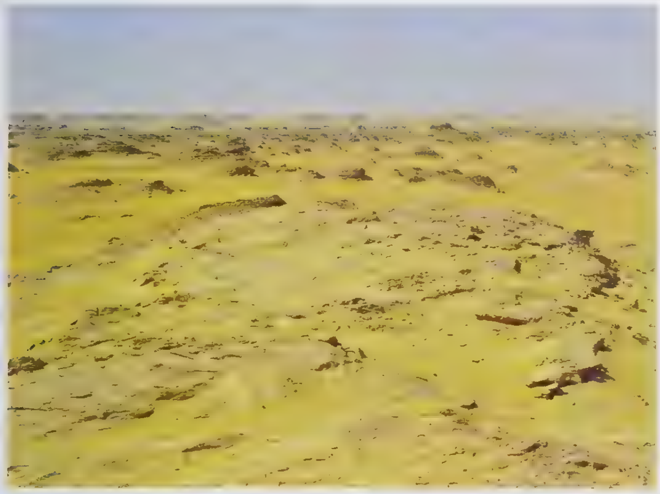


FIGURE 1.2 The Sahara Desert, Egypt, is an ecosystem with sparse plant life.

FIGURE 1.3 The Phetchabun mountain range, Thailand, is a rainforest ecosystem that supports high levels of plant life.

Identifying organisms

Classification is central to the work of environmental scientists. Examples of the classifications they make or use include the definitions of biomes, types of ecosystems, the roles of organisms within their environments, and names for organisms. Biological **taxonomy** is the science of classifying individual species. Without precise, common understandings, no two specialists can be certain they are dealing with the same species.

The first scientific system for identifying species, **binomial classification**, was developed by the Swedish botanist Carl Linnaeus (1707–1778). According to his system, which is still used today, organisms that are similar in appearance are given a common first name, the **genus** (plural genera) name, which begins with a capital letter. The second part of the name, shown in lower case, is only applied to a specific organism; for example, *Homo sapiens* belongs to the genus *Homo*. Linnaeus was an inspirational teacher whose many students explored the world to find species new to science. He recognised that sexual structures (such as flowers) held clues for understanding the relatedness of different species. He soon expanded his system to include a hierarchy of other levels.

Modern taxonomy groups closely related genera into **families**, which in turn are grouped into **orders**, **classes**, **phyla** (singular phylum), **kingdoms** and **superkingdoms**, each denoting more general similarities between the organisms they include.

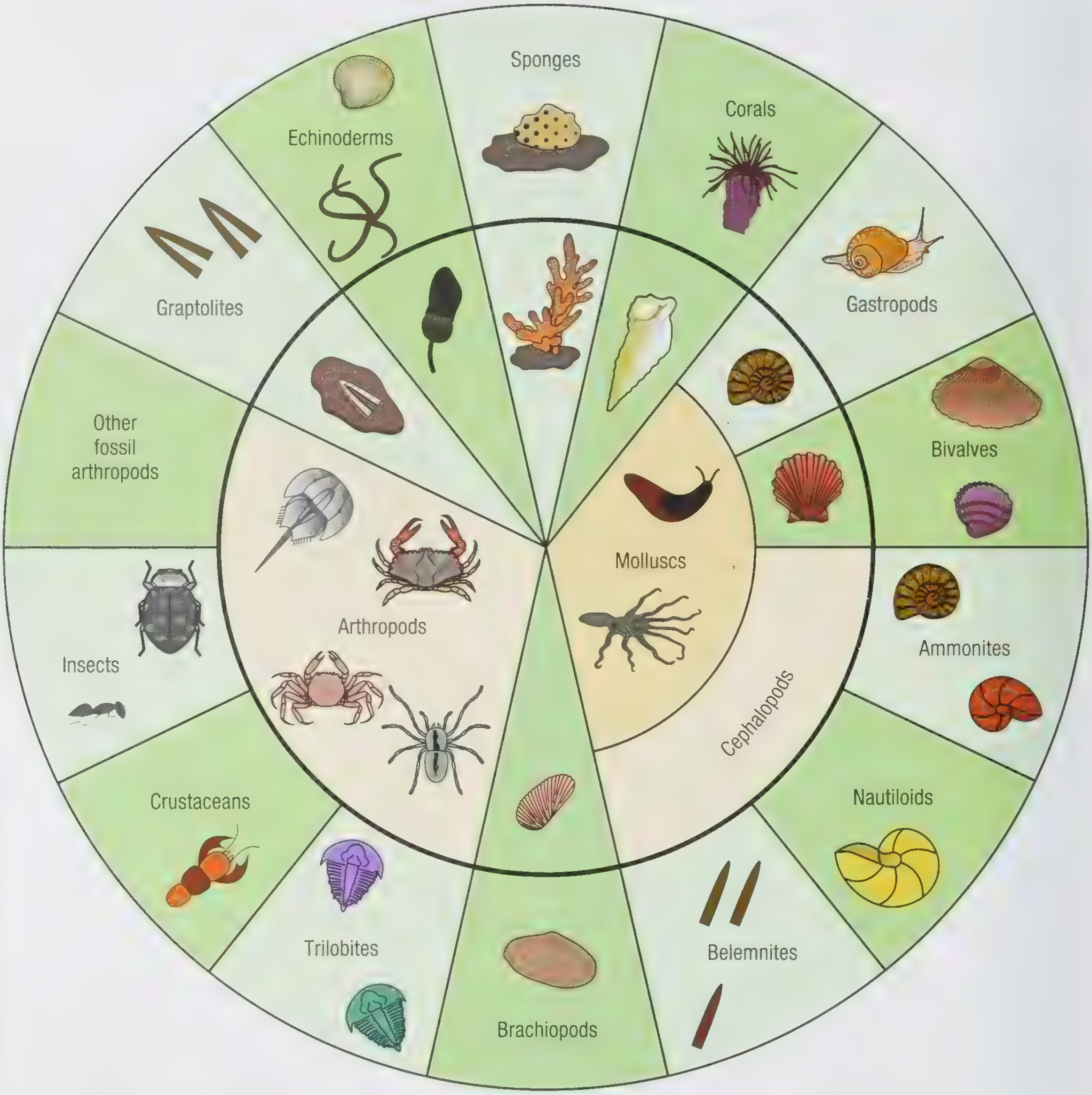


FIGURE 1.4 A circular model showing relationships between groups of invertebrates

REVIEW

1 What is meant by Earth being a 'Goldilocks' planet?
2 Define:
   a ecosystem
   b biome
   c environment
   d biodiversity.
3 Consider the following.

Homo sapiens	*Pongo pygmaeus*	*Hylobates agilis*
Nomascus nasutus	*Hoolock hoolock*	*Pongo abelii*

   a Which two species are most closely related?
   b Identify two genera.
   c Identify one species name.
4 Order the groups from the one containing the highest numbers of species to the one containing the least: genus, kingdom, species, superkingdom, order, family, class, phylum, subclass.
5 Taxonomists are divided into splitters (who prefer to see species further subdivided) and groupers (who prefer very closely related species to be given a single name). Where would the following terms be placed in the hierarchy, and which type of taxonomist would prefer to introduce it?
   a subspecies
   b subclass
6 Breeds are considered to be members of the same species; for example, different kinds of dogs are all *Canis lupus familiaris*.
   a What does the name indicate?
   b How closely are dogs related to wolves, *Canis lupus*?
   c How closely are dogs related to Australian dingos, *Canis lupus dingo*?
   d Based on the information in parts a–c, suggest a criterion for defining 'species'.
7 What do you think is the significance of Linnaeus using the structures of reproductive organs as a guide to relatedness of species?

Interactions between organisms

Ecosystems provide **habitats**, places where organisms live; for example, under the bark of a tree, in leaf litter or in a stream. Different interactions occur between the organisms in an ecosystem. These relationships impact on the biodiversity of a region. Interactions can be harmful or beneficial to other species. Many species compete with each other for resources too. Competition within and between species is a common feature of all communities.

Every living organism and its environment is profoundly affected by the presence or absence of other biotic and abiotic components. For example, organisms in a soil community are affected by the texture, mineral and water content of the soil. But the properties of the soil itself are affected by the activities of burrowing worms and **decomposers** (organisms that break down dead plants and animals). The burrows of the worms allow air and water to penetrate into the soil. Decomposers increase the fertility of soils by recycling organic material.

Understanding relationships and interactions between organisms can help us understand how an ecosystem works. Interactions can be straightforward or extremely complex.

Predator and prey

A predator–prey relationship is one in which one organism kills another or consumes part of it for its food. Although there is usually a preferred prey species, it is unusual for a predator to depend on only one species. Predation of any sort affects the biodiversity of an ecosystem. Predation includes animals preying on other animals, animals preying on plants and even plants preying on animals, such as the Venus fly trap or pitcher plants. For example, seed predators have a large effect on the plant population and their distribution throughout an ecosystem.

Symbiotic relationships

Symbiosis is the general term used to describe the relationship in which individuals of two or more different species live together and in which at least one of the species benefits. There are three main types.

1 Parasitism occurs when one organism benefits at the expense of the other.
2 Mutualism is when both species in the relationship benefit and neither is harmed, such as pollination.
3 Commensalism exists when one organism benefits and the other neither benefits nor is harmed. These relationships help shape the biodiversity of a region.

FIGURE 1.5 This remora is being carried along by the leopard shark to which it is attached. In this way, the remora does not need to expend its own energy to swim. The shark is unaffected by the remora in this commensal relationship

REVIEW

1 Define:
   a mutualism
   b commensalism
   c parasitism.
2 Using an example, explain why is it essential to have pollinators and seed dispersers in an ecosystem.
3 Using the symbols +, − and 0, create a table that summarises the three symbiotic interactions.
4 Using an example for each symbiotic relationship, explain how each shapes biodiversity.

Measuring biodiversity

To understand an ecosystem, you need to be able to determine which organisms live in it.

Generally it is easy to identify plants and **diurnal** (active during the day) animals by observation, but this is not always possible. The following techniques help ecologists investigate the species diversity in ecosystems.

Measuring biotic factors

Tree screens

Scientists use large tree screens to collect and study small invertebrates. In this method, a funnel is installed around the trunk of the tree, just below the canopy. A fast-acting natural insecticide (pyrethrin) is sprayed into the canopy. This kills the insects quickly and their bodies drop into the funnel.

FIGURE 1.6 Trapping the inhabitants of a tree

Pitfall traps

Pitfall traps are used to investigate the ground-dwelling inhabitants of a particular location, and may be combined with a low barrier that acts as a guide. A hole or series of holes is dug in the ground and a container is inserted so that the rim of the container is level with the ground. Various insects, small animals or reptiles simply fall into it. To investigate **nocturnal** (active at night) animals, the traps are opened in the evening and checked immediately in the early morning. **Fauna** (animals) inside the trap are identified, measured, sometimes photographed and then released back into their natural environment.

FIGURE 1.7 Pitfall traps being used to study animals in a reserve near Shark Bay, Western Australia. (a) Traps set [illegible] (b) [illegible] marsupial caught in the trap at dawn

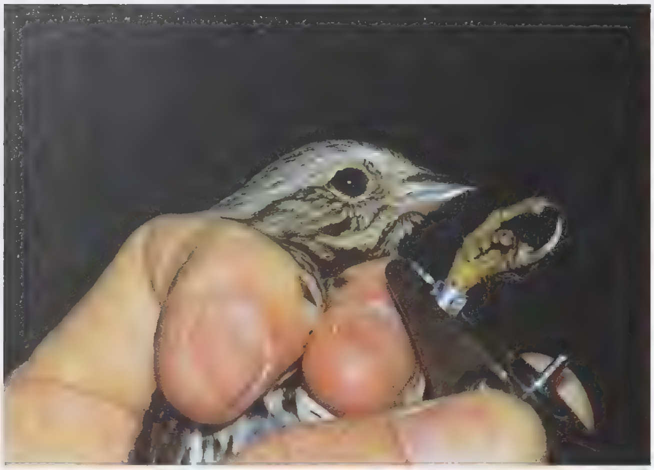


FIGURE 1.8 Bird banding

FIGURE 1.9 Collecting a water sample

Birdbanding

The movement of birds has fascinated people for hundreds of years. For example, every year 23 million short-tailed shearwaters, *Puffinus tenuirostris*, migrate from Japan to the southern coast of Australia, a 15 000 km journey that takes 6 weeks. In Australia, they breed from September to April, before returning to Japan over the Pacific Ocean in autumn.

Programs such as the Japan–Australia Migratory Bird Agreement 1981, and the South African Bird Ringing Unit (SAFRING), aim to gather important information about endangered birds. They collect information about the birds' habits, plumage, life histories, population size and movement.

Water sampling

Scientists who study invertebrates from rivers, creeks and lakes take numerous water samples from random locations at the site. In the laboratory, the samples are examined under a microscope to classify the invertebrates inhabiting the location. Abiotic factors such as temperature, pH, oxygen levels and water pollutants may also be measured.

REVIEW

1 Describe briefly two methods that could be used to determine the variety of insects in an area.
2 When scientists sample creeks or grasslands, they take numerous random samples. Why do you think this is the case?
3 Which method should be used to investigate:
   a fauna underneath the bark of a particular tree?
   b leaf litter, and foragers, such as worms and beetles?
   c migratory routes through the air?
4 What evidence is there that our knowledge of biodiversity is incomplete? Suggest some limitations of some of the trapping techniques described.

Explaining interactions

Organisms do not live in isolation: they grow, reproduce and die, and then their matter returns to their ecosystem as abiotic factors. Before considering how particular nutrients are recycled, we will review the connections between the living organisms.

How biotic factors interact

Most living organisms, including humans, survive by eating organic (complex, carbon-based) materials that were once other plants and animals. This feeding requirement makes us **heterotrophs** (*hetero* meaning 'other' or 'different'). In contrast, plants are **autotrophs**, meaning they produce their own food by converting simple inorganic molecules to complex ones. Plants are the best-known autotrophs because their reaction of **photosynthesis** converts light energy (photons) from the Sun into chemical energy of the strong chemical bonds within the glucose molecules they make (or 'synthesise').

Indirectly, all other organisms depend on plants for their energy, a concept that is modelled by a **food chain** (Figure 1.10). A food chain is a flow diagram which shows who eats whom – the arrows point to the consumer and therefore also indicate the direction of **energy flow**.

FIGURE 1.10 A common freshwater food chain

Not all of the energy or matter that was originally captured in glucose molecules by photosynthesis makes it to the end of the food chain. **Respiration** is carried out by all complex organisms, including plants. This reaction reverses the chemical reaction of photosynthesis (Table 1.1). The energy contained in the chemical bonds in glucose is used to power many other reactions in cells. Respiration is an exothermic reaction; some of the energy is radiated from organisms as heat. In respiration, glucose decomposes to carbon dioxide and water, and matter is also lost from the food chain when organisms breathe.

TABLE 1.1 Comparing chemical equations for photosynthesis and respiration

Reaction	Reactants				Products				
Photosynthesis	$6CO_2$ carbon dioxide	+	$6H_2O$ water	+ light energy → (**Chlorophyll**, found in chloroplasts)	$C_6H_{12}O_6$ glucose	+	$6O_2$ oxygen		
Respiration	$C_6H_{12}O_6$ glucose	+	$6O_2$ oxygen	→ (Mitochondria, found in all complex cells)	$6CO_2$ carbon dioxide	+	$6H_2O$ water	+	heat energy

Components of food chains

Food chains always begin with **producers**. These are autotrophs that make the complex organic molecules that are then passed along the food chain, with chemical modifications. Organisms that feed on producers are all **consumers**, the primary consumer being the one closest to the producer. If the producer is a plant, then the primary consumer may also be known as a **herbivore**; for example, a grasshopper. Secondary and tertiary consumers, such as frogs and wading birds, are animals that feed on primary consumers. Therefore, they are also known as **carnivores** (if they only eat meat) or **omnivores** (if they eat both meat and plant material). Ultimately, all the organisms in the food chain will die and become food for decomposers, such as fungi and bacteria.

Food webs

Different food chains connect to make a **food web**. Food webs can be used to analyse energy flow through an ecosystem, and can be used to model how changes to an ecosystem will affect different organisms. For example, from the food web in Figure 1.11, we can predict what might happen if a virus killed a large portion of the seed-eating birds. The foxes, hawks, owls and snakes would have to eat more of the other animals, therefore potentially reducing their numbers.

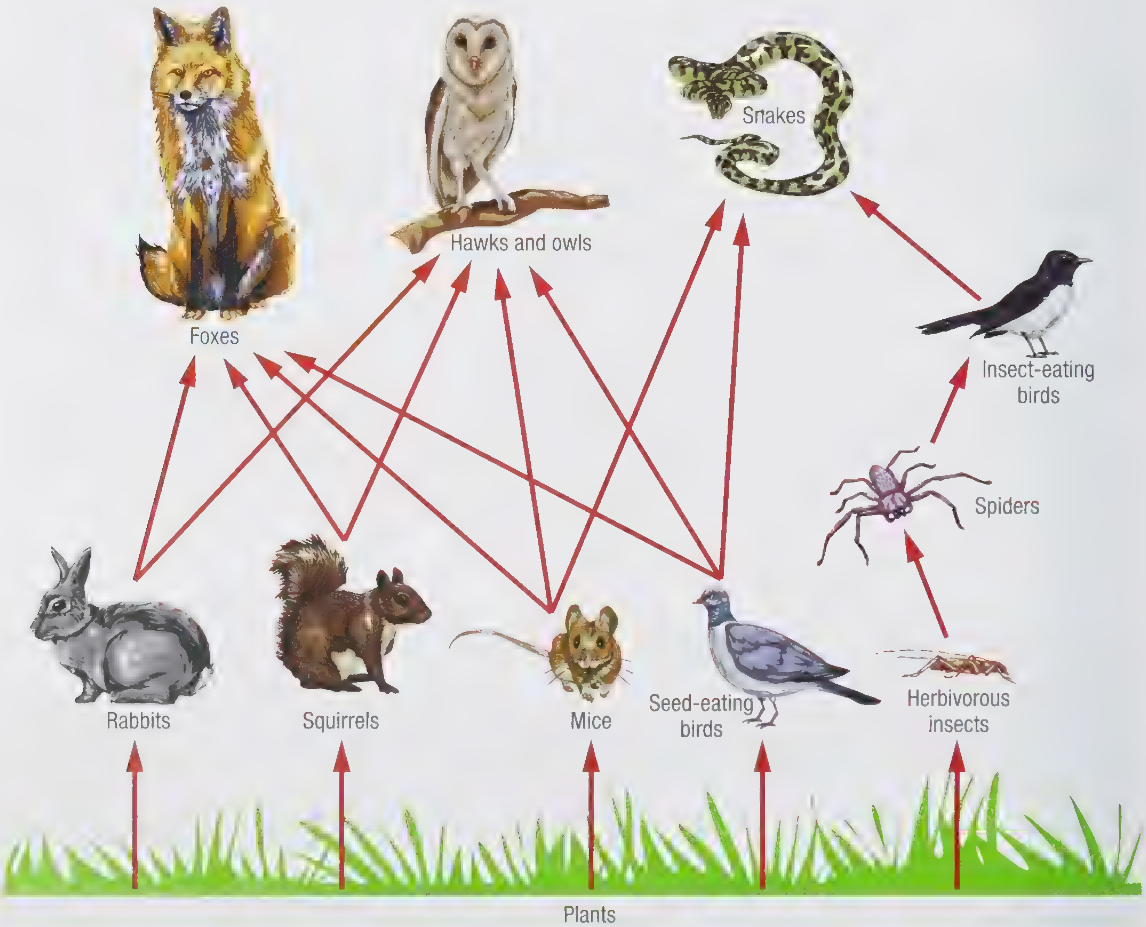


FIGURE 1.11 A common European food web

How respiration shapes ecosystems: pyramids of biomass, energy and numbers

The position of an organism in a food chain or web is known as its **trophic** (feeding) level. Primary producers (autotrophs) are at level 1, herbivores at level 2, carnivores that eat herbivores are at level 3, and so on. There are very few predators, even in the oceans, that feed exclusively on other carnivores. Very few ecosystems have more than five trophic levels.

The structure of ecosystems is closely related to the chemistry of respiration. One way to analyse ecosystems is to calculate the combined mass (**biomass**) of groups of organisms. In many ecosystems, any trophic level has about 10% of the biomass of the level below it. In a simple food chain consisting of grass, rabbits and eagles, about 100 kg of grass would support 10 kg of rabbits, which would support 1 kg of eagle. Of course, ecosystems are dynamic – the grass biomass will vary from season to season, and the rabbits may be producing offspring, and the eagle won't be able to reproduce unless there is also enough grass to indirectly support a mate and any offspring as well.

COMMUNICATION USING MODELS
A model is a diagram, a simplified physical representation or a virtual explanation that is used to clarify how concepts are related. Examples of models that describe relationships between organisms include food webs and biomass pyramids.

Biomass pyramids

The relationship between trophic levels can be shown in a diagram called a **biomass pyramid** (Figure 1.12). The reduction in biomass at each trophic level is a consequence of organisms continually requiring food in order to respire, at every stage of the food web. The levels in a biomass pyramid are connected to the biomass of the producers. A small nature reserve may not have enough grass to support, via its herbivores, a big cat family (such as a lion pride), but it may

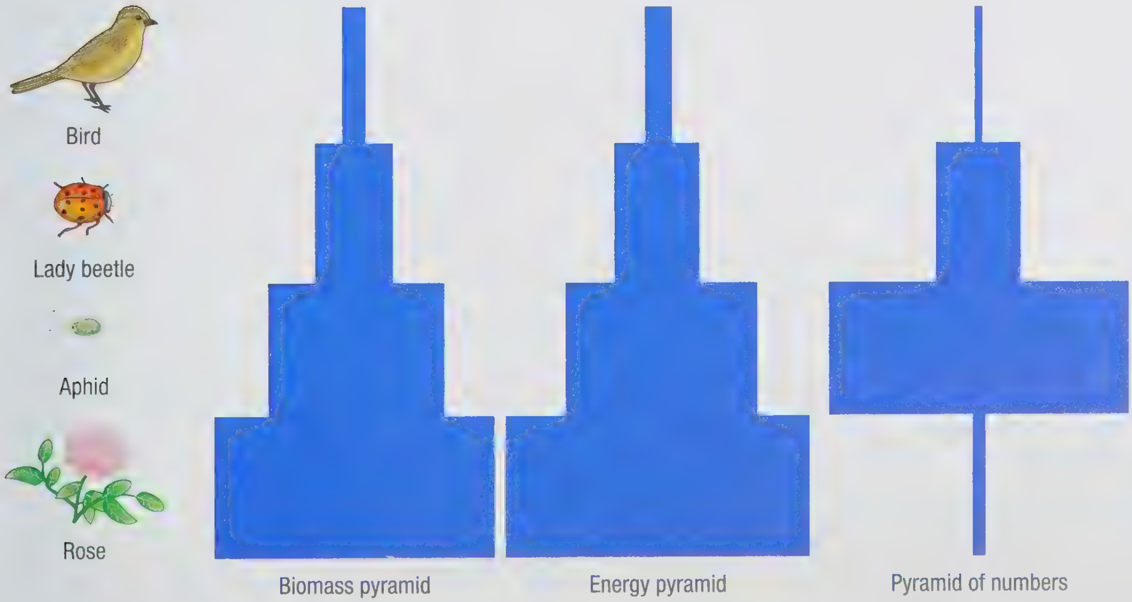


FIGURE 1.12 A comparison of a biomass pyramid, an energy pyramid and a pyramid of numbers for the same food chain. Each tier represents a trophic level

be able to support smaller carnivores at the same trophic level (such as leopards and cheetahs). The shape of biomass pyramids explains why:

- the numbers of top predators, carnivores such as eagles, big cats or crocodiles, will always be much smaller than the numbers of the animals they eat
- large nature reserves generally have more complex food webs.

It is a misconception that desert environments, which usually have low biomass, do not have high biodiversity. The organisms in desert environments tend to have little biomass.

Energy pyramids

Energy pyramids are another way to show the structure of food webs in a diagram. Biomass (measured in kilograms) contains chemical energy (measured in joules), and so most energy pyramids have similar shapes (but different units) to the biomass pyramids of the same food web or food chain (Figure 1.12).

Pyramids of numbers

Diagrams representing the numbers of organisms at different trophic levels can have a very different shape from biomass and energy pyramids. Even though there may be fewer of them, individual carnivores are often bigger than their prey. Primary producers may be even more variable. Grassland may consist of many thousands of tiny plants but a single tree or rose bush with the same biomass can also be the base of a food chain (Figure 1.12). No matter the shape of the **pyramid of numbers**, each trophic level will contain less total energy than the one below it.

Exchange of nutrients between abiotic and biotic environmental components

There are many chemical cycles within every ecosystem, but important examples are the **water**, **carbon**, **nitrogen** and **phosphorus cycles**. These substances have important uses in cells and biological molecules.

- Water (or its ions) can be a reactant in cells, it can be the medium in which cellular reactions happen, or it can form transport systems in complex organisms.
- Carbon (which can bond with up to four other atoms) forms the chemical frame for every organic compound, that is, all the complex molecules that are or were once part of living organisms.
- Nitrogen is important in proteins, nucleic acids (DNA and RNA), and some high-energy molecules that carry out important cellular reactions, such as respiration.
- Phosphorus is used in cell membranes, in high-energy molecules required for cellular reactions (especially ATP) and in the bones and teeth of vertebrates.

This will be covered in more detail in later units.

Water cycle

About 70–75% of Earth's surface is covered by water. Four processes describe the big picture of the water cycle (Figure 1.13): **evaporation**, **evapotranspiration**, **condensation** and **precipitation**.

Evaporation and evapotranspiration are similar concepts. Evaporation occurs when water changes from liquid to gas. Water in an ocean, lake, river or wet surface (including soil or plants) absorbs energy and enters the atmosphere as gaseous water vapour. Evapotranspiration refers to all water loss from vegetation, which includes the water transpired from the leaves of plants.

When water vapour in the atmosphere condenses, it forms water droplets, which we see as mist or clouds. As the tiny droplets join, their combined mass gradually becomes too great to be held up by moving air. Precipitation refers to all the forms of the water pulled to the ground by gravity, such as rain, snow and hail. The cycle continues when this water rejoins larger bodies of water or vegetation.

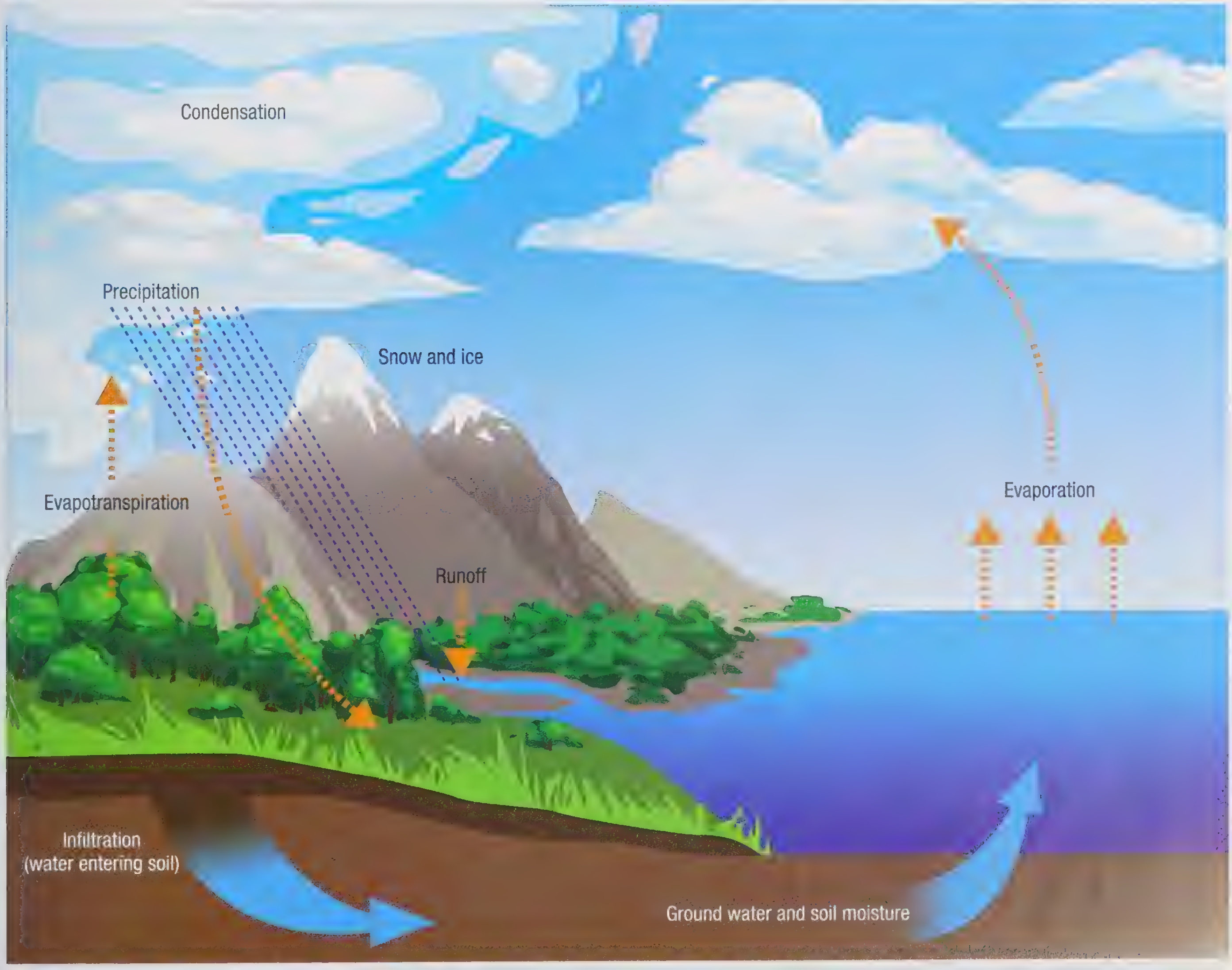


FIGURE 1.13 The water cycle

Carbon cycle

Carbon dioxide is a rare gas in the atmosphere, making up just 0.04% (or 400 ppm). The unique ability of plants to extract this gas to produce glucose makes the complex interactions between organisms possible. However, photosynthesis and respiration by living organisms form just a very short-term part of Earth's **carbon cycle** (Figure 1.14). This also applies to the carbon held in dead plant material, such as peat and compost, or frozen methane. From the perspective of Earth's long geological history, these are all short-term cycles.

Huge geological reserves, in the form of coal, oil and gas, represent carbon that was photosynthesised by plants over very long periods; many millions of years ago. When these reserves are mined as energy sources, combustion in power plants, industry and transport returns this carbon to the atmosphere as carbon dioxide.

Currently we know of only one certain way to remove these very large, extra amounts of carbon dioxide from the atmosphere: by using the photosynthesis of living plants.

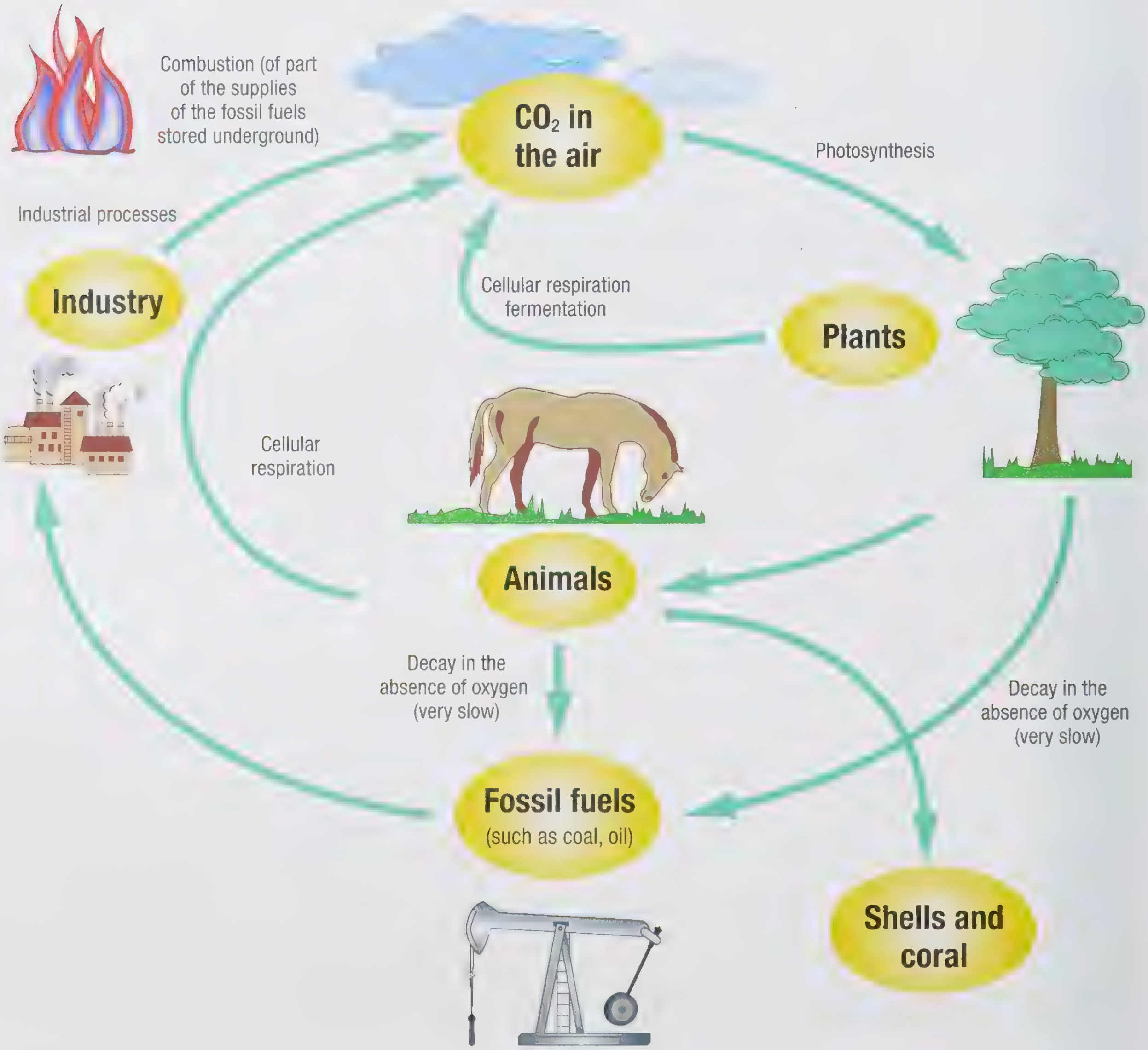


FIGURE 1.14 The carbon cycle

Nitrogen cycle

Nitrogen gas makes up a large proportion of the atmosphere (almost 80%). Plants must obtain nitrogen in the form of nitrates, which other organisms obtain via the food chain. The process of converting nitrogen gas to nitrates is called **nitrogen fixation**. Nitrogen can be oxidised to nitrates in the heat of a lightning strike, but most of the natural transfer of nitrogen between the atmosphere and living organisms relies on specialised micro-organisms. This occurs in the nitrogen cycle (Figure 1.15).

The **legume** family encompasses about 10% of known plant species, and includes food crops such as beans and pulses, and trees such as Cassias (Figure 1.16). Legumes are good sources of protein-rich food. They are able to make proteins because of their symbiotic relationship with nitrogen-fixing bacteria. The bacteria benefit by being protected inside root tissue (Figure 1.17) where they are supplied with nutrients, mainly glucose, and oxygen. The legume benefits by having a direct source of nitrates. Some marine organisms have similar symbiotic interactions with other types of nitrogen-fixing bacteria.

Another form of nitrogen found in the soil is nitrite, which is produced by the decay of plants and animals, or their wastes. Nitrifying bacteria convert nitrites to nitrates, which are then absorbed by plants.

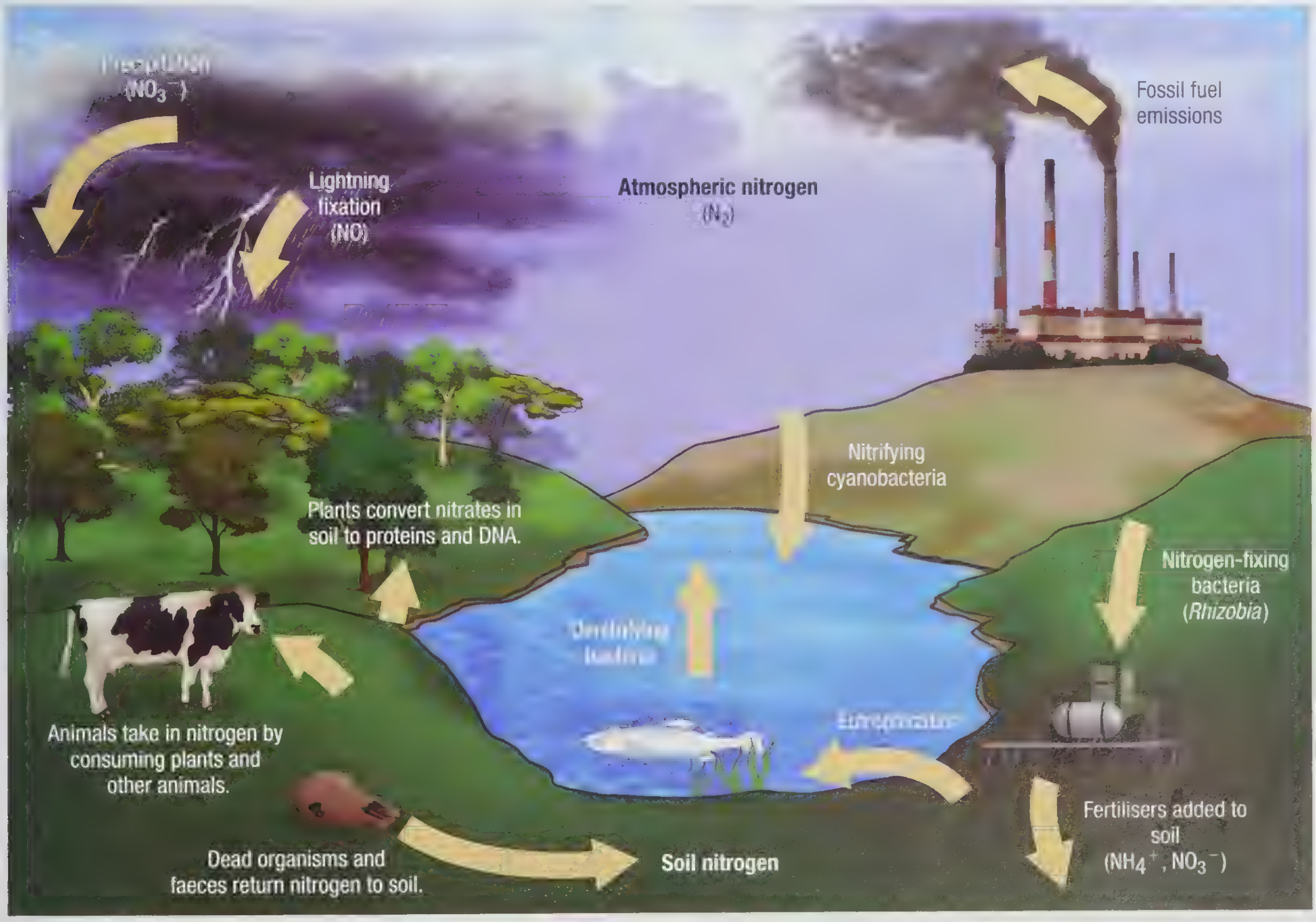


FIGURE 1.15 The nitrogen cycle

FIGURE 1.16 Plants that have pea-shaped flowers, like this Cassia tree, belong to the legume fa[illegible]

FIGURE 1.17 Legumes develop special structures on their roots (nodules) that host nitr[illegible]

Another type of bacteria, denitrifying bacteria, convert nitrates back into nitrogen gas. Denitrifying bacteria are particularly active in environments that lack oxygen, such as water-logged soils and stagnant water.

In the 20th century, human activity resulted in dramatic changes to the nitrogen cycle, almost doubling the amounts of nitrogen that now flow through ecosystems. The major source of excess nitrogen is synthetic fertilisers (which require large amounts of energy to manufacture them). Another source is air pollution. Fossil fuels are often naturally contaminated with nitrogen compounds, which after being released to the atmosphere during combustion, are then returned to the ground in rain.

Phosphorus cycle

Phosphorus enters the food chain when rocks are degraded by weathering. This process releases very small amounts, very slowly. Phosphorus is therefore often considered the **limiting nutrient** (or limiting factor) for biological productivity in all environments. Plants absorb phosphorus as phosphate, sometimes assisted through symbiotic relationships with other organisms (usually fungi).

Phosphorus returns to the environment when organisms die and decay, or as animal wastes. It is returned to the geological cycle as sediments. Animal wastes such as seabird and bat guano (droppings) are natural deposits that accumulate on barren islands or in caves over thousands of years. These processes form the phosphorus cycle (Figure 1.18).

Human activity has changed the amount of phosphorus cycling through ecosystems globally. Phosphorus is a vital nutrient for global food production. Natural deposits rich in phosphorus are mined to make synthetic fertilisers.

Cycles

FIGURE 1.18 The phosphorus cycle

REVIEW

1 Summarise your understanding of the following terms, by naming examples in the food web in Figure 1.19.
   a Autotrophs and heterotrophs
   b Producers and consumers (first, second and third)
   c Decomposers
   d Herbivores, carnivores and omnivores
   e Organisms in the first, second and third trophic levels

FIGURE 1.19 An African food web

2 Explain:
   a where the Sun's energy is stored in glucose
   b why organisms produce heat
   c why the biomass decreases as you go to higher trophic levels.
3 Refer to Figures 1.2 and 1.3 (page 5). Which environment is likely to have higher biodiversity, and why?
4 What is a limiting nutrient (or factor)?
5 List two examples of symbiosis, and the nutrients transferred by the organisms involved.
6 a List three examples where human activity has impacted on natural cycles.
   b When human activity impacts on natural cycles, is there a common cause?
7 Suggest ways in which different nutrient cycles may be interconnected.
8 Are any nutrients available in unlimited supply?

ACTIVITY Accurate pipetting

The correct way to use a pipette is to hold it vertically, fingers as shown (Figure 1.20).

Squeeze the bulb, and lower the tip into the solution you want to transfer.

Gently release the bulb, creating a vacuum that allows the solution to fill the pipette.

Continue to hold the pipette in a vertical position.

Gently squeeze the bulb to empty the pipette, controlling the flow one drop at the time.

Never allow the tip of the pipette to touch the solution to which you are adding drops. The next person using the pipette will contaminate the stock solutions and spoil the results for everyone.

If your pipette accidentally becomes contaminated, tell your teacher, who will replace the pipette with a clean one.

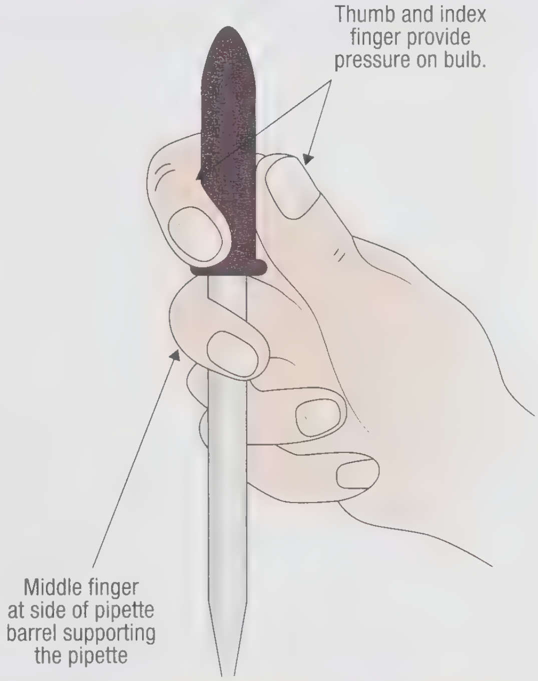


FIGURE 1.20 The correct technique for pipetting

INVESTIGATION 1.1

Investigating the effects of nutrients on plant growth

Plants are producers, so they are excellent indicators for predicting the effect of nutrient variation on ecosystems. Major nutrients for plants include the cations potassium, calcium and magnesium and the anions nitrogen, phosphorus and sulfate.

In this investigation, you will use duckweed (or another aquatic plant) to investigate how altering nutrients changes growth. Duckweed is a useful model because you can count the number of leaves as evidence of growth. It is recommended that you only use a single plant (two or three leaves) at the start of the experiment because it may grow exponentially. You will need to monitor your treatments regularly over 4–5 weeks to collect sufficient data.

Your teacher will provide de-ionised water, duckweed that has been rinsed several times in de-ionised water, and a supply of stock solutions (Table 1.2) with a labelled pipette to use with each of them.

TABLE 1.2 Stock solutions

Stock solution	Nutrients present	Ionic compound/s in stock solution	Concentration in the stock (10^{-3} mol/dm^3)	Concentration on dilution (10^{-3} mol/dm^3) as 'Growth solution'
1	Potassium, phosphate	K_2HPO_4	25	0.25
2	Calcium, nitrate	$Ca(NO_3)_2.4H_2O$	50	0.50
3	Magnesium, sulfate	$MgSO_4$	22	0.22
4	Calcium, chloride	$CaCl_2.2H_2O$	50	0.50
5	Potassium chloride	KCl	25	0.25
6	'Iron' with Na-EDTA	$FeSO_4.7H_2O$ Na-EDTA (disodium ethylenediaminetetraacetic acid) is a chelating agent (a chemical that helps metal ions such as Fe^{2+} dissolve in water).	25	0.25
7	Trace elements	For each of the following compounds, add the mass (g) shown in brackets to 100 cm^3 of de-ionised water. Then dilute a further 20 times to make 2 dm^3 of trace element stock solution. H_3BO_3 (0.3) $CuSO_4.5H_2O$ (0.01) $MnCl_2.4H_2O$ (0.4) $ZnSO_4.7H_2O$ (0.1) $Na_2MoO_4.2H_2O$ (0.01)		

1 drop of stock solution added to 100 cm^3 de-ionised water provides a nutrient concentration that optimally supports the growth of a 'typical' plant. A control treatment growing in 'full nutrients' would have 1 drop of each of stock solutions 1–4, 6 and 7 added. (Note: Solution 5 should only to be used to replace solution 1 if you wish to investigate the effects of removing phosphate.)

>

YOUR CHALLENGE

You will need to investigate the effects of various mineral nutrients on plant growth. To be able to formulate your hypothesis, you will need first to understand how the major minerals are used in plants.

You need to design an experiment that will enable you to collect sufficient data to support or refute your hypothesis

THIS MIGHT HELP

Consider whether you want to investigate the effects of one or more nutrients. A 'deficiency experiment' typically provides plants with all the nutrients except the one being studied. A 'toxicity experiment' typically provides plants with all the nutrients, but excess amounts of the nutrient being studied. A range of toxicity treatments can be investigated.

Draw up a table showing exactly how many drops of each stock solution are needed for each treatment you plan.

FIGURE 1.21 An example of a student's experiment after duckweed has been growing for several weeks

When planning replicates, it is a good idea to make up a single large volume of the solutions (the 'growth solution') in which all the stock solutions are mixed together (why?). For example, if using four replicate treatments, each requiring 100 mL, make up 400 mL of growth solution in one batch before splitting it between replicates.

Think of a way to grow your plants so evaporation does not concentrate the growth solution. Decide how to grow your plants so that light entering through the sides of the containers does not encourage the growth of algae (why?). Figure 1.21 may help.

In your discussion, you need to relate your findings to what you understand about nutrient cycles in ecosystems.

Think of a way to collect the growth information regularly, in a form that you can analyse. A spreadsheet may be useful.

Write up your investigation design following the guide in Appendix 3 on page 209 or as advised by your teacher.

CRITICAL THINKING
Control of variables in experimental design.

Adaptations to limiting factors

As well as nutrients, many other abiotic factors can be 'limiting'. Cellular reactions such as photosynthesis can be limited by light, water, temperature or carbon dioxide concentrations. Populations of many species can also be limited by biotic factors. These include competition from other members of the species, numbers of predators or prey in the area, and diseases.

Organisms adjust to their environment by having adaptive behaviour or functions (including structures). **Adaptations** help them survive under particular environmental conditions. Very cold, hot or dry environments provide particular challenges.

FIGURE 1.22 Meerkats stay in their burrows during the hottest part of the day and come out when it is cooler

FIGURE 1.23 Pelicans taking advantage of an ephemeral lake – a lake that exists for only a short time

Behavioural adaptations

Behavioural adaptations are patterns of activity that reduce energy needs or save water.

Inactivity

In some countries people take siestas – they rest during the heat of the day to improve their efficiency and productivity. Many animals, such as kangaroos, cattle and meerkats (*Suricata suricatta*), seek shade or burrows (Figure 1.22) and rest in the middle of the day. This reduces their need for water and helps maintain an optimum internal temperature.

Hibernation during cold periods is another type of inactivity (see functional adaptations, below).

Migration and long-distance travel

Birds migrate at different times of the year to take advantage of seasonal food and water availability. Nearly all Australian water birds, including pelicans (*Pelecanus conspicillatus*) travel long distances to find inland lakes after a good rain. Lake Eyre, in central South Australia, is normally dry. However, after very good rains in 2011, Lake Eyre was covered by water for only the fifth time in 200 years. Pelicans flocked to the area (Figure 1.23). It was estimated that there were 50 000 pelicans nesting on islands in the lake.

Another animal that travels long distances to find water is the camel (*Camelus dromedarius*). Camels also have a range of functional adaptations that allows them to withstand long dry periods.

Functional adaptations

Functional adaptations describe **metabolic** changes as well as an organism's physical structures that enable it to survive.

Functional changes that rely on metabolism

Metabolism refers to cellular processes. In some organisms, these processes vary throughout their life cycle or during the year. For example:

- Plant seeds are alive (they are able to germinate), but their metabolic rate is very low. This helps plants survive in the form of seeds, sometimes for many years between favourable seasons.
- Many animals, including bats and grizzly bears (*Ursus arctos horribilis*), hibernate for much of winter. These animals go into a state of **torpor**, in which their body temperature and metabolic rate lower, which reduces the amount of energy they use.
- A camel's hump is actually a fat store, which is metabolised for energy and small amounts of water, helping it survive for weeks without a drink.

FIGURE 1.24 The fennec fox (*Vulpes zerda*) of North Africa has many structural adaptations to enable it to survive in deserts. Its small body size reduces the area of the body that is exposed to the sun. The shape of the very large ears allows it to collect the faint sounds of insects and other prey moving through sand. The large ears also help it lose excess body heat, and maintain a stable body temperature.

Functional changes that rely on structures

Nearly every unique structure found in any organism is an adaptation. The bones of birds are hollow, which reduces energy use during flight. Many desert-dwelling animals are small, which means they have a high relative surface area, which helps them lose heat, and require less energy. Desert animals also frequently move by hopping, their leg tendons acting like springs that store and release energy between each bounce.

Plants obtain carbon dioxide through **stomata**, microscopic openings on their leaves. For plants, the price of carbon dioxide is **transpiration**, the loss of water that plants extract from soil, often at great metabolic cost. For example, water enters root cells by osmosis, so the cells must have a high concentration of solutes (usually glucose) to help water diffuse in. Also, root systems need to be maintained by glucose that can only be made in the upper, green parts of the plant. The larger (relatively) the root system of a plant is compared to the shoot, the less energy is available for shoot growth. Unless they are extremely old, the upper parts of desert plants are therefore nearly always small. Nearly all terrestrial plants have some structural adaptations to reduce water loss, and plants from arid areas have many. Examples are:

FIGURE 1.25 To reduce loss of water, the leaves of plants such as *Banksia quercifolia* (shown in cross-section) have sunken stomata.

- more stomata on the underside of leaves, away from direct effects of the Sun's heat
- 'sunken' stomata (Figure 1.25), which create local humidity and reduce the rate of water loss
- hairy leaves, which increase the thickness of the 'boundary layer' of air humidified by transpiration.
- shiny or waxy leaves, which reflect heat away from the leaf surface

- smaller leaves or no leaves (an extreme example being cacti), which reduce the relative surface area for water loss
- leaves that roll up, or wilt during dry periods, also reducing the surface area.

REVIEW

1 Define 'adaptation' and sketch a concept map to outline, with examples, types of:
  a behavioural adaptations
  b functional adaptations.
2 Briefly explain two adaptations that help animals survive in an arid environment.
3 Unlike animals, plants cannot move around to search for water. Briefly explain two ways in which plants have adapted to conserve water, particularly in an arid environment.
4 Most species have more than one type of adaptation. Suggest why this may be the case.
5 If it were possible to find an organism that completely lacked adaptations, what would this suggest about the resources in its environment?
6 What are the advantages and disadvantages of extremely specialised adaptations? Does the specialisation of animals such as fennec foxes limit the range of environments where they can live?
7 Suggest some examples of specific adaptations of humans.

Evaluating human impact

Humans are part of the ecosystem. We interact with the natural world as heterotrophs, omnivores and consumers. In less than two centuries, our unique technological skills have changed global cycles of major nutrients, including carbon, nitrogen and phosphorus. Our growing population requires land for agriculture, fragmenting the vast natural areas that once covered the globe. Global trade exchanges more than goods: it introduces species to new continents and food webs where they never were before. The by-products of our activities are changing the atmosphere and oceans. Everywhere we look there is evidence for **anthropogenic** effects – changes caused by human activity.

Over its 4.5 billion year history, our planet has experienced many extreme climates, thousands of ecosystems and five mass extinctions. Earth has sustained life almost from the beginning.

Buying time

Compared to changes in the geological past, the scale and speed of anthropogenic change in our present are both worrying and reassuring. On the one hand, using the energy representing dozens of years of stored global sunshine every year, through our use of fossil fuels, is concerning. On the other hand, we are surrounded by organisms that seem unchanged from the first records of their existence. Somehow, through all of Earth's past cataclysms, enough survived to regenerate the diverse ecosystems we know today.

The summary of human impacts that follows identifies the choices that may make a difference.

The atmosphere

Since the Industrial Revolution in the late 18th and early 19th centuries, atmospheric carbon dioxide (CO_2) levels have increased from 280 to 400 ppm, simultaneously increasing average global temperatures.

To understand **global warming**, we must first understand the **greenhouse effect**. Inside a greenhouse is warm compared to the outside because solar energy (mainly visible radiation) enters through the glass, is absorbed by materials inside and is re-radiated as heat (infrared radiation), which cannot pass through the glass as easily. The total energy entering and leaving the greenhouse must be balanced to avoid overheating or cooling.

This is the principle of the process that sustains Earth's temperatures in the Goldilocks zone, providing the balanced conditions perfect for life. Greenhouse gases (principally, CO_2, methane (CH_4) and water) make up a small part of the total atmosphere, which acts like a blanket. The greenhouse gases absorb solar energy (mostly visible radiation, but also some UV and high-frequency infrared radiation) and re-radiate it at lower frequencies, as heat, which does eventually radiate out to space. Throughout cycles of Earth's geological history, the amounts of greenhouse gases, particularly carbon dioxide, have correlated closely with average global temperatures.

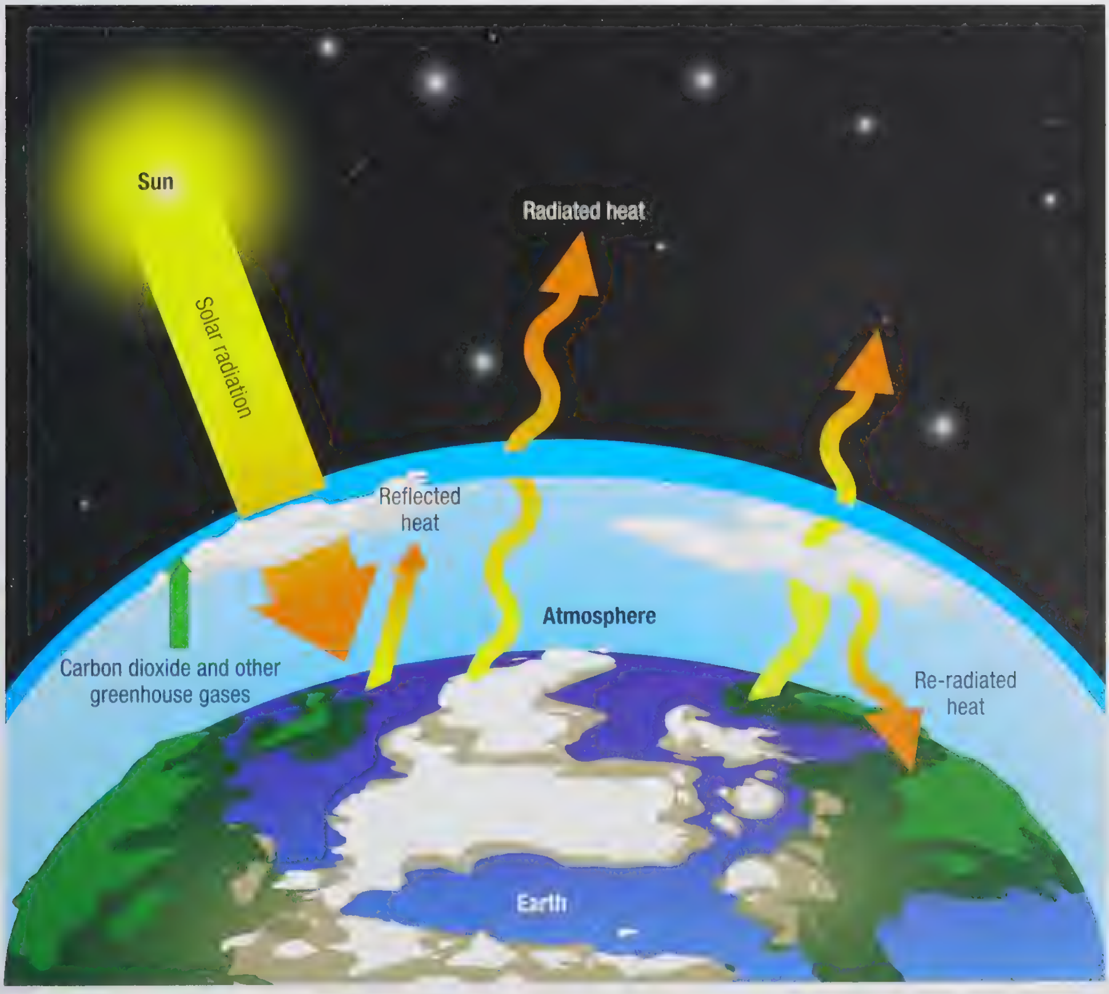


FIGURE 1.26 The greenhouse effect – radiation from the Sun is absorbed by greenhouse gases and re-radiated as heat both away from and towards the surface

Every time we use energy produced by burning fossil fuels, such as driving in a car, switching on an electric light or heater, or eating food produced with synthetic fertilisers, we are directly and indirectly adding carbon dioxide to the atmosphere. Every molecule contributes to the **enhanced greenhouse effect**. In the past decade, evidence of warming includes melting glaciers and icecaps, record average global temperatures, several exceptionally severe storms, and coral bleaching in tropical seas.

1A REDUCE YOUR CARBON EMISSIONS

Seven ways to reduce your carbon emissions.

1 Turn off lights when they are not needed.
2 Put on warm clothes instead of turning on the heater; use a fan instead of an air conditioner.
3 Ride or walk to school.
4 Turn off appliances at the wall when they are not in use.
5 Reduce 'food miles' – eat locally grown food.
6 Reuse or recycle.
7 Consider alternatives to holiday destinations that require you to fly.

Spread the word.

. to http://mvpbio45.nelsonnet.com.au and click on **Carbon footprint** ... lculate your personal carbon footprint.

The world's governments are also considering collective action to reduce carbon emissions. Previous global action against ozone-destroying pollutants has been successful.

The ozone story

Ozone (O_3) is a gas generated high in the atmosphere (stratosphere) when oxygen (O_2) reacts with free oxygen radicals (O) created when oxygen breaks up in intense light. Ozone molecules break up if they absorb UV radiation, but are also constantly regenerated. This cycle prevents dangerous levels of UV radiation reaching Earth's surface. A chance observation during the 1970s revealed 'holes' and thinning in the ozone layer, particularly over Antarctica during spring.

The cause of the holes was chemicals containing halogens from refrigeration, solvents and aerosols that entered the atmosphere. There are also natural sources of these chemicals in the environment, but human activity had upset the balance, and the long-lived chemicals were reacting with and destroying the ozone.

International collaboration resulted in global bans on their use, and the ozone hole stopped expanding. Nearly 50 years later, there is evidence that the ozone-destroying halogen pollutants are slowly breaking down. Although it may still be many decades before the stratosphere returns to the state it was in before humans invented refrigerants, within the time scale of Earth's history, this is a minor event.

Terrestrial environments

Deforestation

Deforestation is the large-scale logging and/or burning of trees in natural forests. Deforestation occurs when land is cleared for farms, agro-forestry or dams, or when the wood is required for paper, charcoal and building materials.

What effect does deforestation have on global systems? If the trees are replaced by other plants, there is little overall effect on the carbon cycle. But if forests are flooded to make dams, tree stumps decaying under water slowly release methane. When trees are burned to make charcoal, huge amounts of carbon dioxide gas are released. Both of these contribute to the enhanced greenhouse effect.

However, the most immediate effect of removing the natural vegetation is the destruction of habitats for wildlife. Thousands of species risk death, even **extinction**, when biodiversity 'hot spots' lose their forests. Large carnivores and animals that reproduce slowly are among the most threatened. Iconic examples include tigers (*Panthera tigris*) and orangutans (*Pongo pygmaeus*) in Indonesia and Malaysia, and macaws in Brazil.

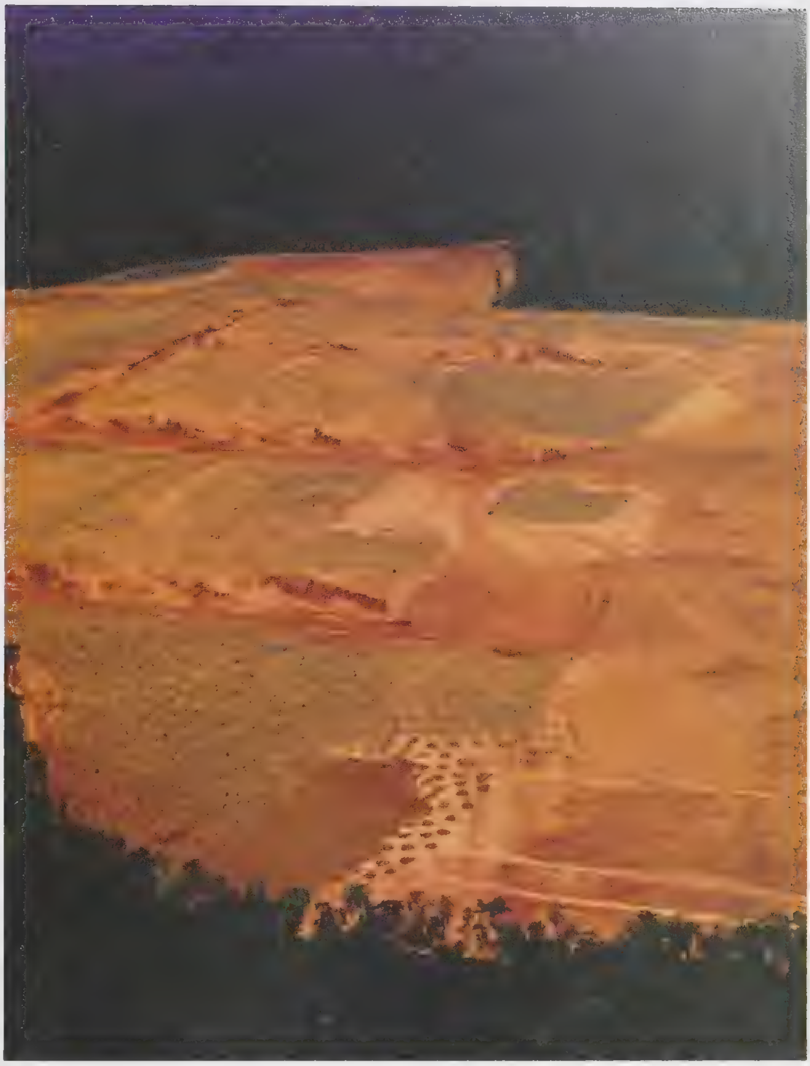


FIGURE 1.27 Deforestation of the Amazon forest is occurring mostly because the land is required for pasture for cattle

FIGURE 1.28 Agro-forestry in Sumatra: oil palm, a plant originally from Nigeria, now covers about 80% of this Indonesian island. If you have ever eaten chocolate or some other highly processed food, chances are that you will have eaten palm oil.

FIGURE 1.29 A worker harvesting palm oil in Sumatra. The trees are about 25 years old, nearing the end of their productive life, before they grow too tall for people to cut down the nuts using poles


FIGURE 1.30 Washington DC National Zoo has been involved in the captive breeding program of the golden lion tamarin, increasing its numbers from 200 to 1500 since the 1970s.

Wildlife conservation

Every animal in a zoo, every fauna box in your garden, may buffer a rare species against extinction.

By boosting their populations, captive breeding programs have successfully returned animals to environments where they had become locally extinct. Bears have been returned to the Pyrenees in France, wolves to Yellowstone National Park, USA, and European beavers to Scotland. In 2007, after 12 years of intense conservation effort, the bald eagle, the national animal symbol of the USA, was removed from the List of Endangered and Threatened Wildlife.

Captive breeding is an expensive, labour-intensive solution, but can make a difference to species (Figure 1.30). Today, the scimitar-horned oryx (*Oryx dammah*), a large North African antelope, survives only in zoos, but as long as a breeding pair or, preferably, a small population exists, there is hope that a natural ecosystem may one day be rebuilt.

TA SUPPORT LOCAL FAUNA

Ways in which you can support local fauna.

1. Discourage non-native animals. Do not use feeders or fauna boxes if they help non-native animals survive.
2. Keep pet cats indoors, particularly at night.
3. If you have a garden or planter box, grow vines, bushes or annuals to provide nectar for local birds and insects. Traditional or 'heirloom' varieties are often best for this because they are usually pollinated by natural pollinators. Consult your local garden nursery.
4. Provide water. If you can't have a pond, set up a bird bath. Refresh it daily to discourage mosquitoes breeding.

Spread the word.

Aquatic environments

During the Middle Ages (from the 11th to the 15th century), lakes, rivers and oceans near towns were often polluted with sewage, household waste and other rubbish. At the time, nearly all of the substances causing pollution were natural and **biodegradable**. Although this pollution was unsightly, smelly and often unhygienic, these problems were nearly always confined to the local area – they did not have a global effect.

Modern pollutants such as industrial waste, heavy metals, radiation, oil spills and marine dumping can persist in the environment and have global effects This section considers just two examples.

Plastic pollution

Nearly every ocean includes at least one large rotating system known as a **gyre**. Powered by wind and currents, these systems rotate very slowly, perhaps once every decade. They are essentially whirlpools, gradually drawing in plastic waste from every surrounding continent (Figure 1.31). After months of floating in the ocean, most plastics become brittle, and break down into tiny beads. These small pieces have large surface areas, which helps some types of plastic absorb and concentrate toxins, such as the polychlorinated biphenyls (PCBs). PCBs are carcinogens that are prevalent in very low concentrations.

Algae and sponges grow on the surface of the beads; this 'biofouling' makes it difficult to remove and recycle the waste. Plankton lives freely between the bits and pieces, and their predators swallow the 'plastic soup' along with the plankton. Scientists don't know what effect the tiny pieces of plastic have on their own, but they do understand the process of **bioaccumulation** – when toxins accumulate in increasing concentrations up the food chain.

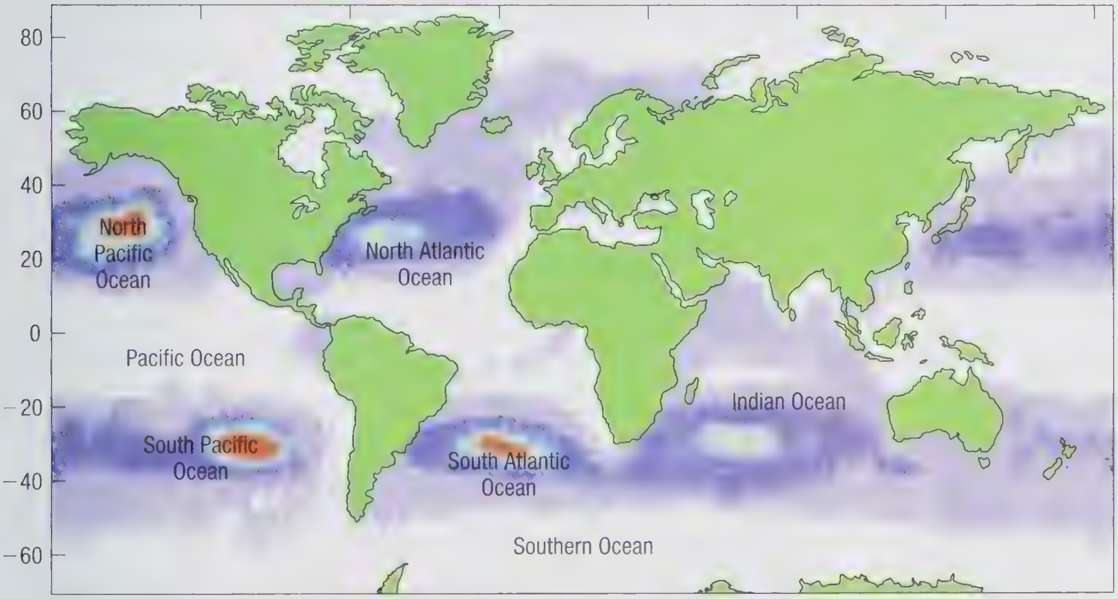


FIGURE 1.31 Location of accumulated plastic in the major ocean gyres. The centre of every gyre has a thick layer of mixed up, fragmented plastic covering an area of many thousands of square kilometres.

Eutrophication

Increasing resources may not always have positive effects. **Eutrophication** occurs when farm fertilisers enter local water bodies, in rain or as run-off after excess application. This introduces high levels of nutrients to the water bodies.

Initially, the nutrients, usually nitrate or phosphate, promote the growth of alga (producing algal blooms), which increases the growth of all the organisms that depend on these producers. But at night, when plants don't photosynthesise, oxygen soon becomes the limiting factor in this system. Organisms begin to die, and decomposers increase the demand for oxygen, starting a positive feedback loop that causes even more of the pond life to die. Eventually, only those organisms that do not require oxygen survive. These **anaerobes** include denitrifying bacteria and methanogens that produce smelly gases and methane while they digest the remains of what was once a thriving ecosystem.

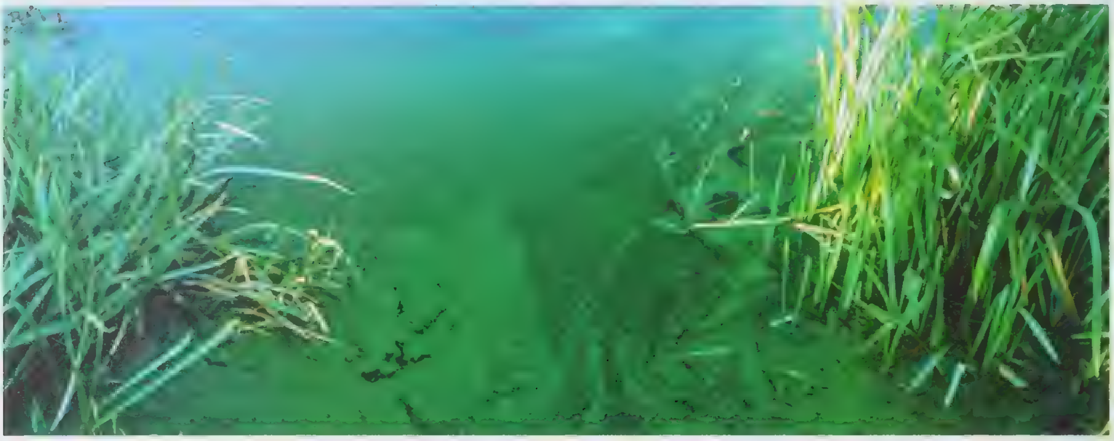


FIGURE 1.32 Eutrophication starts with an algal bloom in Lake Taihu, Wuxi, China.

TA SUPPORT CLEAN WATER

Ways in which you can support clean water.

1 Avoid single-use plastics, particularly plastic bags. Refill your water bottle.
2 Do not litter. Plastics swept into storm drains take a direct path via rivers to the ocean.
3 Avoid cosmetic products that contain abrasives. Examples are face scrubbers, soaps and toothpastes that have a rough feel. They contain microplastic beads that wash straight down the drain. Proposed legislation is likely to ban these products, but you can get a head start.
4 Form a team to clean a beach. Larger pieces of plastic that are ejected by ocean gyres often end up there. Remove the plastic before the tide takes it back to the gyre, and prevent it from strangling wildlife.
5 Limit your use of fertiliser in the garden. Consider using companion plants (intermixing legumes with other plants, such as clover and lawn grass), or use slow-release pellets.

Spread the word.

REVIEW

1 How do each of the following contribute to the enhanced greenhouse effect?
   a Using fossil fuels
   b Building dams
   c Burning charcoal
   d Eutrophication
2 What evidence is there that collective, global action is effective at conserving the environment?
3 Why do you think species such as tigers are among the first threatened by changes in land use?
4 a Construct a table and list the following water pollutants in the first column: industrial waste, plastic, heavy metals, radiation, oil spills, marine dumping (e.g. ballast water), excessive nutrients. In the next two columns, identify whether they are more likely to have global or local effects, or both.
   b Is this approach useful to help you rank the pollutants in terms of severity? Why or why not?
5 Explain the process of eutrophication.
6 Why are heirloom or traditional varieties of plants better for local wildlife than modern varieties?
7 What is the value of preserving animals in zoos?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State the difference between an ecosystem and its environment.

2 Suggest how an endangered species differs from an extinct species.

3 Explain why some people would not like to use the tree screen method.

LEVEL 3–4

4 Outline the difference between the greenhouse effect and global warming.

5 Use a diagram to show the relationship between a producer, a secondary consumer and a decomposer.

6 A scavenger is an animal that eats dead animals. How does a scavenger such as the hyena fit into a food web?

7 Create a food chain from the following information:

One afternoon, a kingfisher noticed a snake resting on a sunny rock. The bird took advantage of the situation, and caught the snake for dinner. Earlier that day, the snake had been catching his own dinner. Slithering through some high grass by the pond, he had noticed a grasshopper nibbling on some grass. Just as he was about to strike, a frog snapped it up with her long sticky tongue. Without pausing, the snake caught the frog instead!

LEVEL 5–6

8 Describe what eutrophication is and how it occurs.

9 Look at Figure 1.33. What adaptive features does this animal have to help it survive in its environment?

FIGURE 1.33 Arctic fox

10 After the eastern grey squirrel was introduced to the UK from North America, the population of native red squirrels declined dramatically. Suggest conservation approaches to help increase the numbers of red squirrels.

11 It is thought that temperature can affect the germination of certain seeds.

- **a** Design an experiment to model the effect of temperature on seed germination.
- **b** What conditions would you set for your control?
- **c** Why is a control important?
- **d** In a natural environment, what should be the limiting factor in this experiment?

12 Countries around the Equator have high biodiversity. Biodiversity decreases towards the poles. Interpret this information using a scientifically supported judgement.

LEVEL 7–8

13 Explain why photosynthesis is such an important process.

14 How does a small sample size affect the results of an experiment or investigation?

15 Rabbits were introduced to Australia in the 19th century. There were no natural predators, so the rabbit population soon grew to such levels that they interfered with habitats and food webs of native organisms. In the 1950s, myxomatosis, a viral disease that occurred naturally in South American rabbits, was released into the Australian rabbit population, which now numbered 600 million. The virus was spread by mosquitoes and fleas, and initially killed about 98% of the population.

- **a** Why do you think that Australians want to eradicate rabbits?
- **b** Why do you think not all rabbits died?

The rabbits that survived myxomatosis continued to breed and rabbits again began causing problems in Australia. In 1995, a new disease, calicivirus (also known as rabbit haemorraghic disease virus, RHDV) was accidentally introduced to rabbits. It too was initially successful at reducing numbers, which have since rebounded.

- **c** How might rabbits be adapting to their environment?
- **d** What might be another way of reducing the impact of rabbits in Australia?

16 In modern farming, a single crop is often grown over large areas, as monocultures. This makes it easy to apply fertilisers and harvest the crops. Unfortunately,

monocultures are very attractive to pests, such as insects and snails. Neonicotinoids are pesticides used to control these pests. However, run-off containing neonicotinoids kills aquatic insects, newts and wading birds.

a Make a scientifically supported judgement about whether the deaths of the species in aquatic environments are connected with modern farming processes.

Another study has linked falls in honeybee populations throughout the UK and Europe to neonicotinoids. It seems exposure to neonicotinoids damages the bees' ability to learn, and they lose their way while they are out foraging for pollen and nectar. Affected bees will die, and so will the larvae in the hive. Three-quarters of our food crops are fertilised by bees.

b Evaluate the repercussions of this observation.

More than 50 years ago, a famous book by Rachel Carson, *Silent* Spring, resulted in the world-wide banning of DDT, an insecticide that affects 'non-target' organisms, particularly birds.

c Evaluate the similarities of these two pesticides on ecosystems.

d If you were a scientific expert advisor to a committee considering the future use of neonicotinoids to improve crop productivity, what would you recommend, and why?

REFLECTION

1 Respond to the debatable questions in this unit, justifying your answers.
   a On Earth, are the changes caused by humans bigger than past geological events?
   b Do solutions for limiting environmental problems create different challenges?
   c Is ecological sustainability possible?

2 This unit was based on the key concept of relationships. Identify examples of relationships described in the text and suggest how these relationships affect ecosystems. Then, develop your own definition.

3 Interaction, balance, environment and cycles are related concepts in this unit. In 200 words, explain how each of these concepts contributes to your understanding of Earth's ecosystems.

4 The high biodiversity of rainforests and tropical coral reefs is possible because nutrients are recycled very quickly through these systems. Suggest how an understanding of recycling may be applied to improving the capacity of the planet.

5 How can we humans be the heroes of Earth's story?

UNIT 2

BODY FORMS

KEY CONCEPT
Change

RELATED CONCEPTS
Transformation

Form

Function

Scale

GLOBAL CONTEXT
Scientific and technical innovation: an exploration of how knowledge of human physiology can be used to improve health care

STATEMENT OF INQUIRY
Complex organisms need many interactive systems to work together.

INQUIRY QUESTIONS

FACTUAL
1 How are complex organisms organised?
2 What are the advantages of specialisation?
3 Can some organs be part of more than one system?

CONCEPTUAL
4 How do cells recognise and respond to change?
5 What can structure teach us about function?
6 Where can technology improve health?

DEBATABLE
7 Is form more important than function?
8 Is change possible without systems?
9 How much of our body can technology replace?

Reflective essay: Remaining human in the medical future

Pharmaceuticals, surgery and prosthetics use a modern understanding of the body. Medicines target biochemical imbalances, surgery modifies organs, and prosthetics may replace whole body parts. Almost daily, there are press reports about pioneering operations, or advances in biomechanical engineering. As these and other medical specialisations continue to develop, are we in danger of losing sight of the individual?

Respond to the question above in a 1200-word essay.

1 Use examples of emerging medical or technological interventions to explain how science addresses problems affecting cells, damaged organs or whole body parts. Generalise about the aims of these treatments, and how their effectiveness is determined.

2 Treatment choices have implications for society as a whole, the industries involved, as well as individuals. Discuss how your examples interact with two of the following factors: moral, ethical, social, economic, political, cultural and environmental.

Your information, including scientific language, needs to be correctly formatted, your sources documented and the ideas of others acknowledged.

ATL

INFORMATION LITERACY

Accessing information from a range of sources in an efficient and effective way.

Introduction

Living requires change. Matter in the external environment is transformed into organisms. Gases in the atmosphere are used in respiration and photosynthesis. Liquid water in the soil around roots or packaged inside cells used for food provides the medium for reactions in living cells. When we swallow, the food or liquid we consume meets another surface, the lining of our guts. The matter we ingest is still not quite part of us because our real insides lie beyond the gut's epithelium (skin).

How does external matter transform into organisms? Scale is important. **Diffusion**, usually across **aqueous** (watery) environments, is a common process for substances entering cells. Form is important. At every level of organisation, there are advantages when units work together. For example, as the inventors of assembly line manufacturing discovered, individual units can be simpler, easier to maintain, and specialised for their function. Several components can be built separately at the same time, to be assembled as a complex product at a later stage.

In our bodies, the simple cells that perform specialised functions are organised into **tissues**. Examples are muscle, nervous, epithelial and connective tissue. Plants have vascular tissue. **Organs** are structures made up of two or more types of tissues, such as the stomach, heart, lungs and eye. When organs work together for a single function, the relationship is described as a **system**, such as the digestive, circulatory and respiratory systems.

ACTIVITY

Engaging with body systems

Humans and other vertebrates have at least 10 different body systems. Plants also have several systems. Although there are many body parts, and they work in an integrated way, there are a smaller number of consistent patterns that will help you develop a conceptual understanding of how they function.

Let's find out what you already know about the components of some of the important body systems that connect us with the environment.

1. Create a table to categorise each organ or body part into one or more of these systems: circulatory, digestive, respiratory, excretory. The organs or body parts are artery, bladder, blood, heart, kidney, liver, lungs, mouth, pancreas, stomach, valves, vein.
2. Are any organs or parts involved in more than one system? What processes happen in these organs?
3. How did you decide when to include an organ or body part within a particular system? Discuss your ideas with your classmates to check whether you have similar opinions.

Exploring mechanisms of interaction

At a cellular level, all organisms use similar mechanisms to interact with their environments.

Single-celled pond organisms need to adapt and survive in a changing world. As well as the usual organelles, such as the **nucleus**, **mitochondria** and sometimes **chloroplasts**, they may have contractile **vacuoles** to excrete water that seeps in through their **semipermeable** membranes – membranes that allow some molecules to pass through, but not others. Some catch food by engulfing it and taking it into their **cytoplasm**, a process called **phagocytosis**. Their surface may be covered with tiny hairs called **cilia** that move back and forth or they may have a whip-like tail, or **flagellum**, that gives them mobility.

Go to http://mypbio45.nelsonnet.com.au and click on **Diversity of protists**. This site includes excellent images of single-celled and colonial organisms. Which features are familiar to cells in multicellular organisms?

The cells in multicellular organisms are surrounded by controlled environments. Specialised cells may share some of the traits found in pond organisms, which provide clues to their function. Flagella push sperm forward. Cells with cilia push dust-trapping mucus out of respiratory tracts. Patrolling immune cells consume debris from damaged tissues by phagocytosis. Groups of mitochondria power the active parts of these cells. But individual body cells of multicellular organisms are generally smaller and simpler than free-living **protists**.

Moving matter across cell membranes

Biological membranes are semipermeable because they act as gateways for materials entering or leaving. They select which molecules can pass through on the basis of the physical properties of substances. Small, uncharged molecules such as water (H_2O), and dissolved gases such as carbon dioxide (CO_2) and oxygen (O_2) move freely through the cell membrane. The molecules always move from an area of high concentration to an area of low concentration, a process called **diffusion**. The diffusion of water molecules through membranes has a special name: **osmosis**. Water always moves towards more concentrated solutions, in other words where the concentration of water molecules is lower.

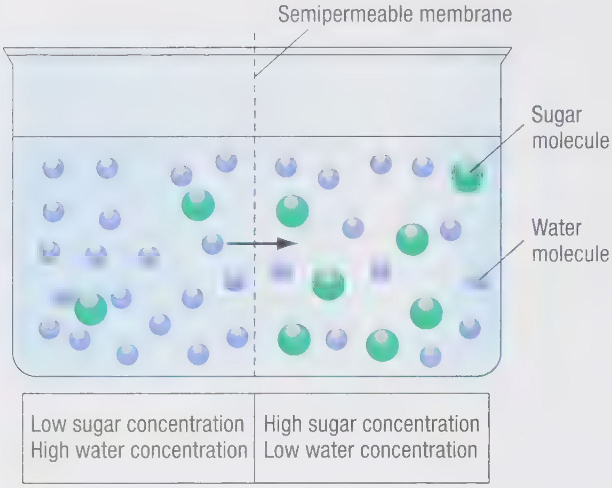


FIGURE 2.1 During osmosis, water moves by diffusion from the less concentrated sugar solution to the more concentrated sugar solution (that is sweeter), because this has fewer water molecules.

Large molecules, such as glucose ($C_6H_{12}O_6$), or electrically charged molecules, such as ions, need help to cross membranes. There may be special 'ports' or carrier proteins in the membrane, which let them through. Cells sometimes use energy from respiration (in the form of ATP (adenosine triphosphate molecules) to assist this movement in a process called **active transport**. Active transport is also used to move molecules against concentration gradients, into or out of cells.

Size and shape of the surface

Surfaces are important in biology – in cells, tissues and systems – because they are the boundary between the inner and outer environments. Figure 2.2 compares a linear section of 'surface' with a convoluted one. The straight section gives much less 'exposure' to the surrounding environment than the section with projections.

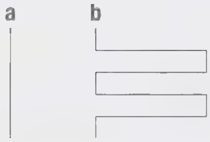


FIGURE 2.2 Schematic comparison of straight and convoluted surfaces

In animals and plants, straight structures are usually associated with transport, not exchange. For example, the **trachea** and **bronchi** bring air to or from the lungs and **xylem tissue** in plants brings water from roots to leaves. Although the processes they use may be very different, long, thin or curvy forms suggest the structures are involved in absorption. Examples are the finger-like **villi** (Figure 2.3) in the small intestine that absorb a variety of nutrients, mostly by diffusion, and the 'hairs' that extend from plant root cuticle cells to absorb water from the soil (Figure 2.4) by osmosis.

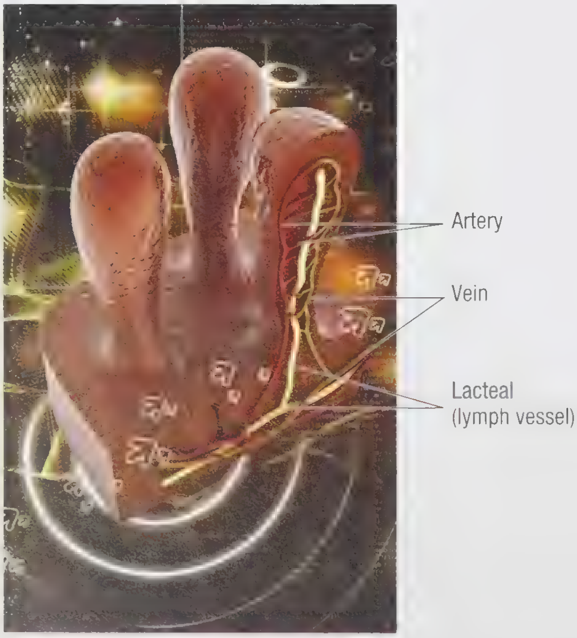


FIGURE 2.3 In the small intestine, villi increase the surface area … rption 40–60 times.

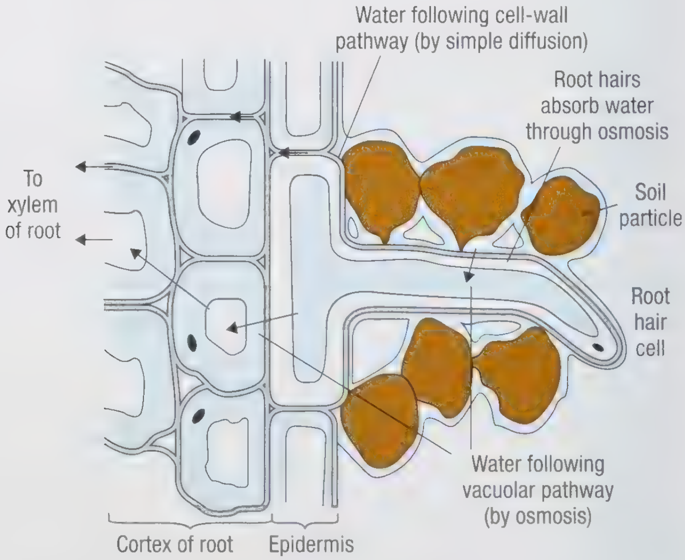


FIGURE 2.4 Water enters root hair cells by osmosis.

INVESTIGATION 2.1

Using living cells to investigate osmosis

YOUR CHALLENGE

Design and carry out an investigation into how osmosis is affected by the concentration of the surrounding solution.

Recall that plant cells are constrained by cell walls (Figure 2.6). This may affect your method.

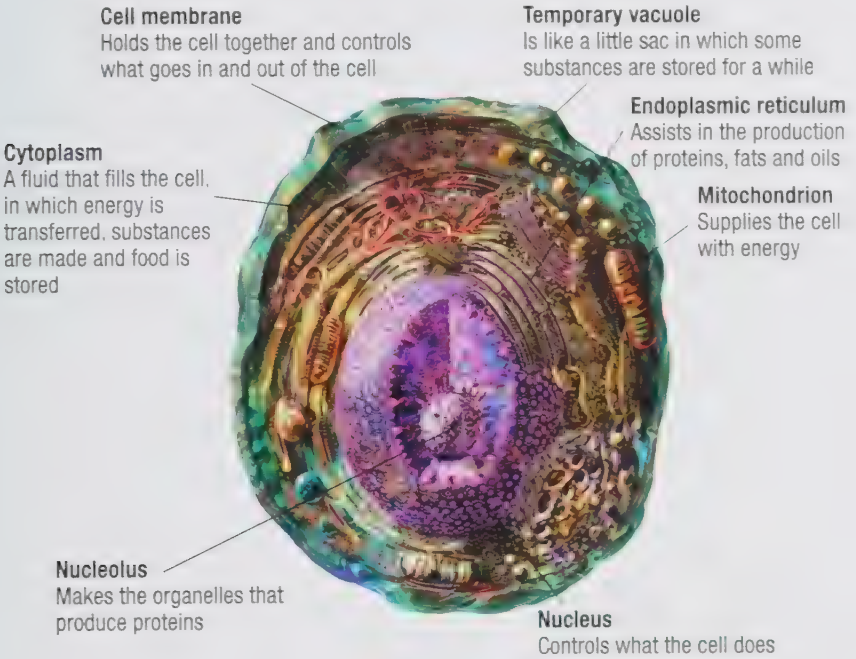


FIGURE 2.5 A typical anima

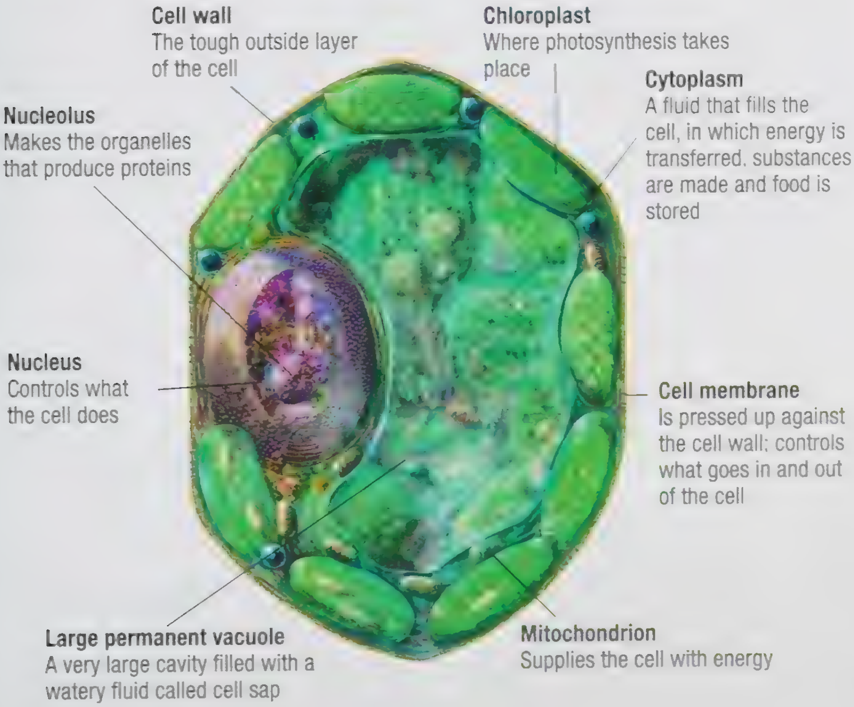


FIGURE 2.6 A typical plant ce

>

THIS MIGHT HELP

Online, you can find many demonstrations of osmosis. Research these and adapt one of these to use as a method for your investigation.

Consider whether a model for a large single cell, for example a chicken egg with its shell removed, will provide better results than a piece of uniform plant tissue. Would you expect cells in potato and apple tissue to have similar internal **solute** concentrations?

What solute will you use, and could your choice make a difference?

Before you start, provide a list of materials you need for your teacher to check.

Write up your investigation design following the guide in the Appendix 3 on page 209 or as advised by your teacher.

REVIEW

1 State the function of:
   a mitochondria
   b chloroplasts
   c semipermeable membranes
   d flagella
   e cilia.
2 Jamie was planning to make a salad but noticed the lettuce was looking a bit limp. He soaked the leaves in a bowl of water for about an hour before using them. Explain the process that made the leaves become crisp.
3 Explain why, when you plant out seedlings, it is important to be gentle, and transfer some of the potting mix along with the roots.
4 Explain why inside your intestines is 'not quite' the inside of your body.
5 Explain why free-living, single-celled organisms tend to be larger than cells in multicellular organisms.
6 How would you list the following organisational structures in order of increasing complexity: liver, epithelium, circulatory system, white blood cell, amoeba.
7 Mangroves are trees that grow in **estuaries**, and their roots are often inundated with seawater. The leaves of many mangrove species have glands that push out excess salt. How might this characteristic explain why mangrove species are slow growing?

How form affects function in systems

Nutritional input: the digestive system

The digestive system (Figure 2.7) is a good example of how form is adapted to different functions. The digestive system is basically a tube, but its shape varies in different organisms depending on their diet. For example, many herbivores have structures in their digestive systems for symbiotic bacteria that help them digest cellulose. Sheep and cattle have this structure in the first part of their stomachs; they are fore-gut fermenters. The Australian wombat, guinea pigs and rabbits are hind-gut fermenters because parts of their colon have a similar role.

In most vertebrates, the pH of the digestive system varies. The mouth, where food tends to stay a short time, is nearly neutral. The stomach, a storage organ where food spends more time, is often extremely acidic. The stomach contents are neutralised by **bile** as they enter the duodenum, the first part of the small intestine. Why should the local environments for digestion be so variable?

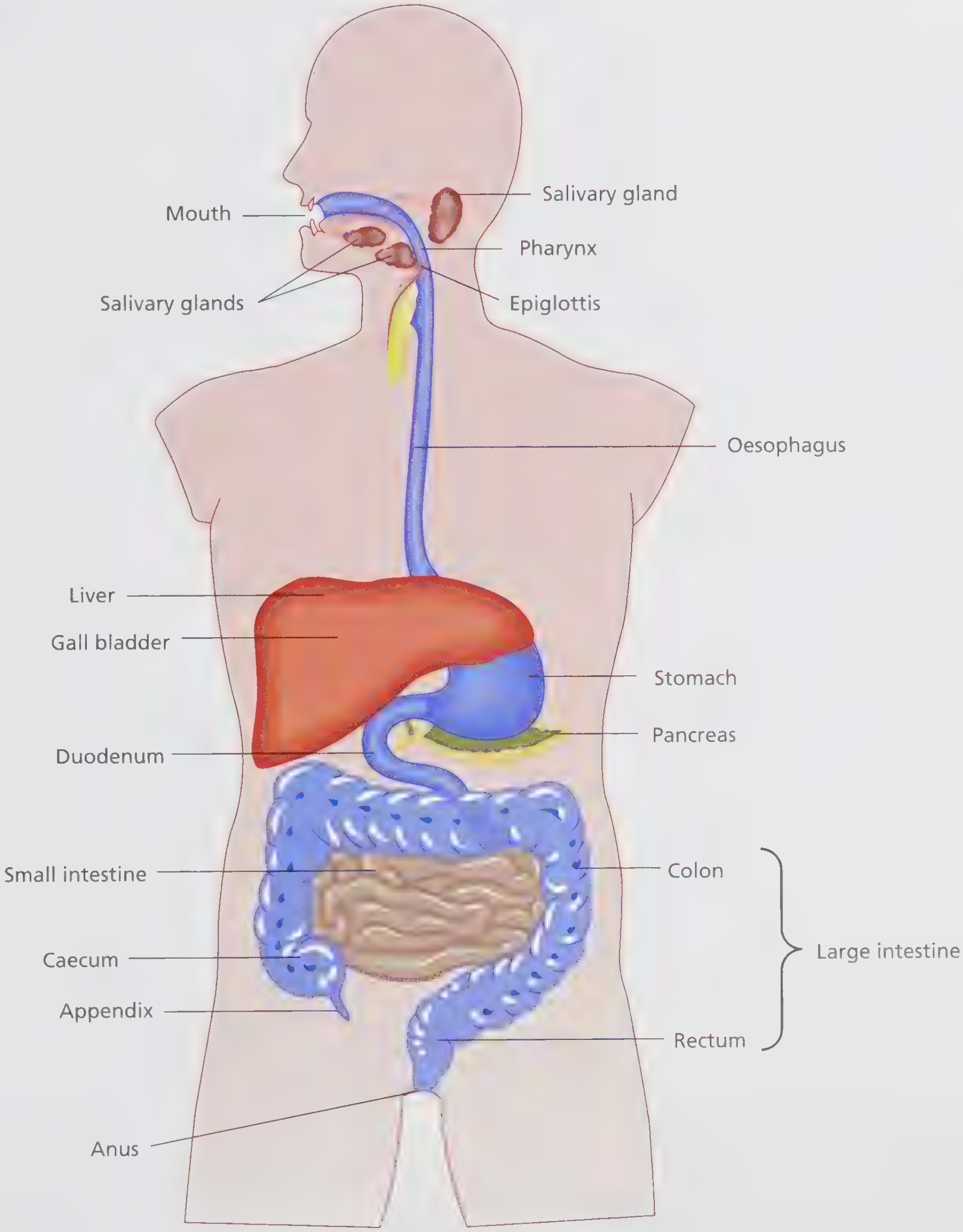
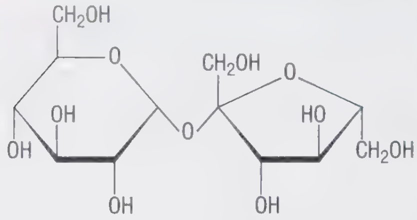
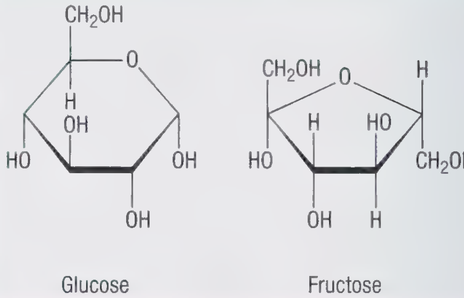
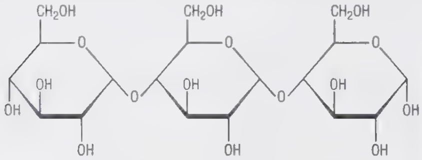
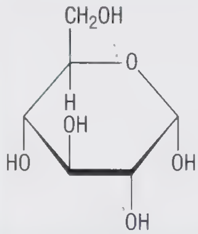
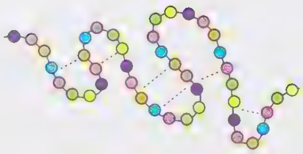
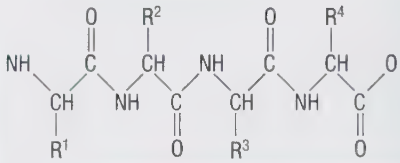
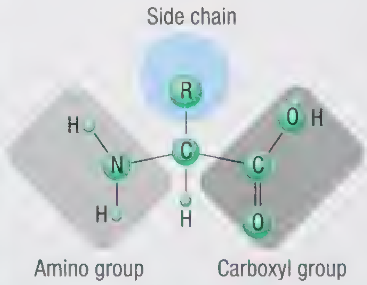
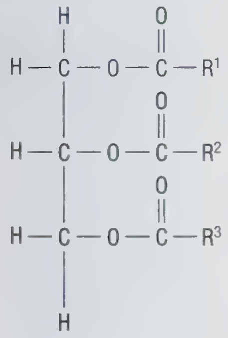
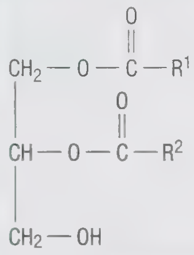
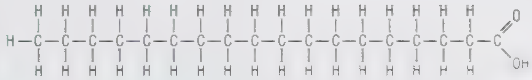
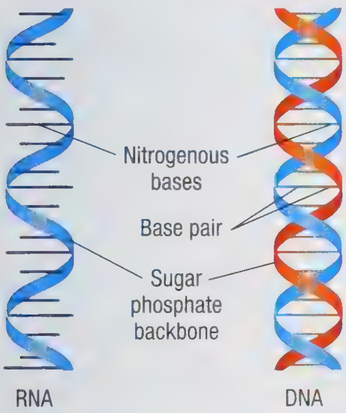
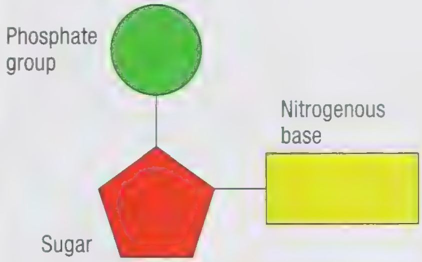


FIGURE 2.7 The human digestive system

Humans are omnivores and the food we eat is a mixture of proteins, fats and carbohydrates. Different parts of the digestive system are involved in the breakdown of these **macromolecules**, preparing them for absorption. Each of the breakdown reactions is catalysed by a different **enzyme** (Table 2.1). As with any chemical reaction, many variables may affect the rate. All along the digestive tract, the local pH is the optimum for the particular enzymes at work.

TABLE 2.1 Macromolecules in our diet, and location of major digestive enzymes

[illegible]	Location for digestion	Name and source of the enzyme	Products
Carbohydrate: sucrose 	Mouth	Amylase in saliva	Glucose + fructose 
Carbohydrate: starch (a polysaccharide) 	Mouth	Amylase in saliva	Glucose 
	Duodenum	Amylase secreted by the pancreas	
Protein  Key: Each circle represents an amino acid	Stomach	Peptin secreted by the stomach	Peptides 
	Duodenum	Trypsin and chymotrypsin, secreted by the pancreas	Amino acids 

Fats (triglycerides) 	Mouth	Lingual lipase	Diglycerides 
	Duodenum	Lipase secreted by the pancreas	Fatty acids 
Nucleic acids (DNA and RNA) 	Duodenum	Nucleases (DNAase and RNAase) secreted by the pancreas	Nucleotides 

Gas exchange in animals and plants

Surfaces for gas exchange tend to be very large. In an adult human, the combined surface area of lung **alveoli** (Figure 2.8) is estimated to be 70 m^2, approximately half the size of a tennis court. Similarly, in plants, the surface of the sub-stomatal cavities and surrounding surface of spongy mesophyll (Figure 2.9, page 44) covers a much larger area than the surface of the leaf.

These internal surfaces are all kept wet, ideal conditions for oxygen or carbon dioxide to diffuse in or out of solution, towards the location where the concentration of the particular gas is lower. What prevents these moist surfaces drying out? The concentration

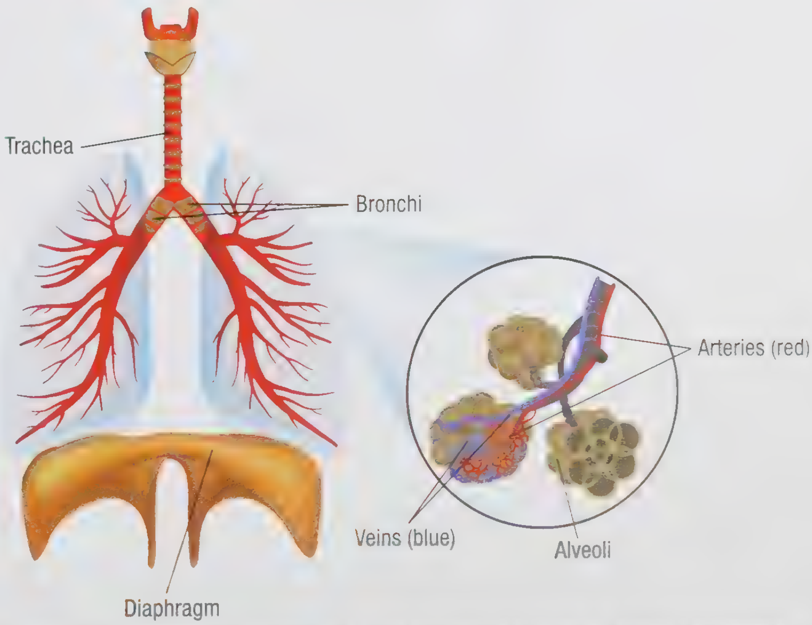


FIGURE 2.8 The respiratory system is a good example of surfaces [illegible] gas exchange.

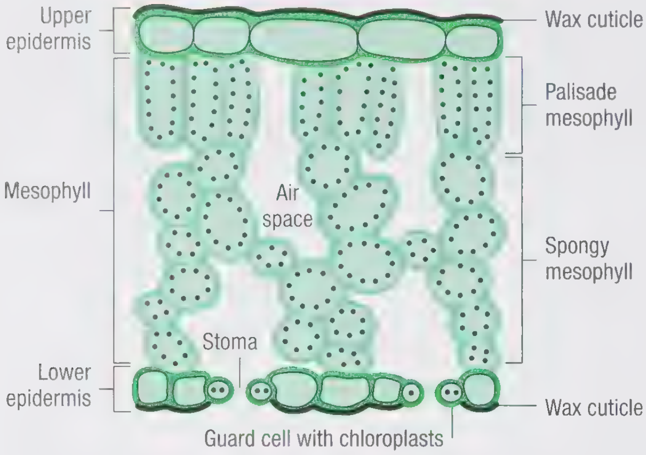


FIGURE 2.9 A cross-section of a leaf, showing the spongy mesophyll and its relationship with the stomata

of vapour of the spaces inside alveoli and leaves is kept very high. In humans, air is humidified on its way past the **nasal cavity**. In plants, the loss of water vapour to the air outside the leaf is controlled by stomata, and they close if the weather is very dry.

CRITERIA B AND C

INVESTIGATION 2.2

The role of surface area in diffusion

Diffusion is a physical process that is important for gas exchange and for absorbing nutrients. There are several published methods for demonstrating diffusion, many involving colour changes as materials move into or out of 'model' cells of different volumes.

YOUR CHALLENGE

To investigate the factors that affect the rate of diffusion into and out of a model cell.

THIS MIGHT HELP

- One possible method is based on acid diffusing into slightly alkaline gelatin containing phenolphthalein and causing it to change from pink to colourless. You teacher may demonstrate this, or another method, for you to design your investigation around.
- Will you be exploring how quickly substances move out of a structure of known dimensions, or into it?
- Which variables will best provide measurable data to extrapolate for a real cell: the total surface, the surface area to volume ratio, the distance from the surface.

Write up your investigation design following the guide in the Appendix 3 on page 209 or as advised by your teacher.

How a double circulatory system helps eliminate waste

The heart is a pump, providing pressure to blood to pulse it along thick-walled, elastic **arteries**. This pressure is gradually lost as the blood vessels divide and branch into **capillaries**, mainly because of the effects of friction between the fluid and blood vessel walls. During the slow passage of fluid in the capillaries, substances are exchanged between the blood and the cells. Then the blood carried in capillaries reunites into **veins** and returns to the heart. Now without pressure, the direction of flow is controlled by valves and the contractions of surrounding muscles.

The circulatory system brings resources to and removes wastes from every cell in a multicellular organism. Invertebrates and fish have single-loop circulatory systems involving a tube-like heart pumping blood along a route with several capillary networks, structures where exchange happens. Birds and mammals have double circulatory systems with a figure-of-eight form that alternates between lungs and the major organs.

How does double circulation help eliminate waste? You will already be familiar with the importance of the lungs as the surface separating body fluids from air. After flowing through the capillaries lining the alveoli of the lungs, where it collects oxygen and releases waste carbon dioxide, the blood returns to the heart's left **ventricle**. The next circulatory loop pushes it to one of many other organs (Figure 2.10).

Why do organisms that breathe air need oxygenated blood to be pressurised?

Figure 2.10 shows the dark colour of two organs, the liver and kidneys. Two reasons for this dark colour are haemoglobin (which implies a rich blood flow) and the presence of pink mitochondria (which implies the cells are very active and so need a lot of oxygen).

Function of liver and kidneys

The **liver** is one of the body's largest organs, weighing about 2 kg in an adult. However, it receives only about a quarter of its blood supply from the heart. Most of its blood comes from the capillaries lining the digestive system. The blood arriving by way of the **hepatic portal vein** carries varying amounts of nutrients and potential toxins from the intestines. The liver processes this blood and releases balanced, detoxified supplies of nutrients into the blood sent to the rest of the body. Over 500 different chemical reactions are involved. One of the most important detoxifying reactions is the conversion of ammonia (NH_3) to **urea** (NH_2CONH_2). Ammonia is a toxic by-product of protein metabolism, and the detoxifying process also uses up another waste, carbon dioxide ($2NH_3 + CO_2 \rightarrow NH_2CONH_2 + H_2O$). Urea is a much less reactive waste than ammonia. Although the liver is a major source of the body's waste, a need for the oxygenated blood from the heart to have high pressure is not obvious.

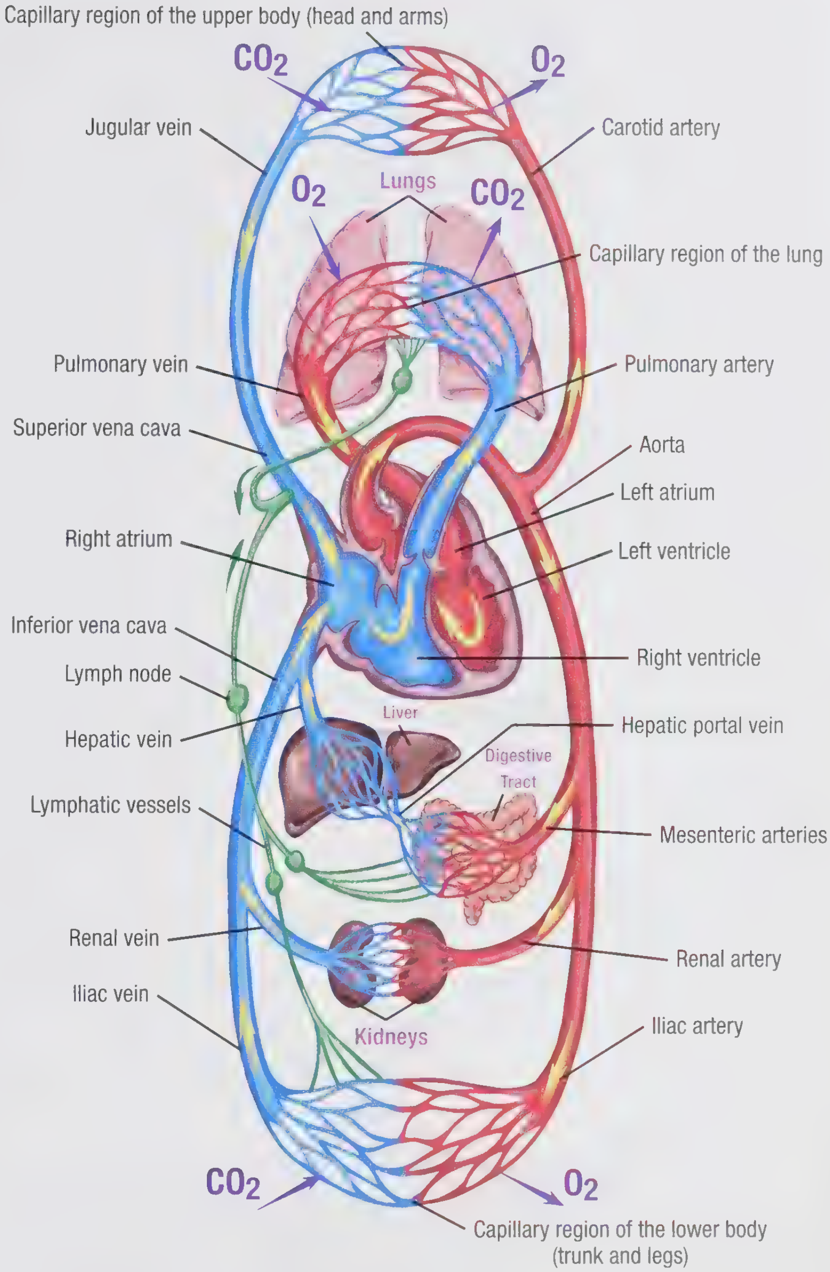


FIGURE 2.10 The human circulatory system

Compared to the liver, the **kidneys** are tiny, together weighing approximately 300 grams. However, they receive about a fifth of all the blood leaving the left ventricle. Each kidney has about a million filtration units called **nephrons** (Figure 2.11). In humans, nephrons filter about 180 litres of blood each day, at least 20 times the volume of blood in the body. High blood pressure is crucial for the first stage, filtration. Blood cells are held back in a structure called the **glomerulus**, while much of the plasma passes through to a tubular route that eventually takes the wastes to the **bladder**. Along the way, water and valuable dissolved substances, such as sugar and ions, are reabsorbed into the circulatory system. Urea is one of the most important wastes that kidneys remove from blood.

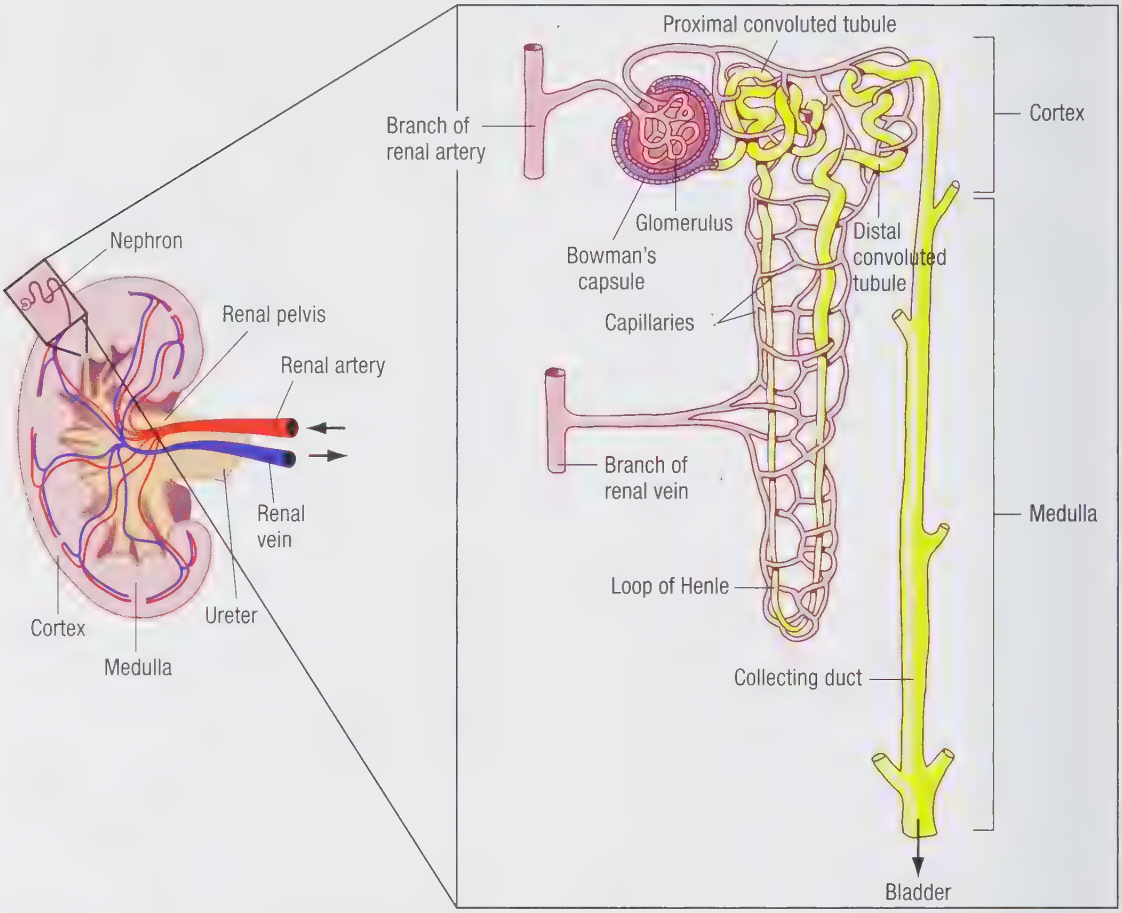


FIGURE 2.11 A kidney and close-up view of a nephron

This explains the function of the double circulation arrangement in air-breathing vertebrates. The key process occurring in the loop involving the lungs is diffusion between air and bodily fluids, leading to oxygenation. The key process occurring in the loop involving the body is kidney filtration, requiring high blood pressure. The availability of oxygen is also important, because the kidney uses active transport to reabsorb useful plasma components, often against a concentration gradient.

REVIEW

1 Construct a table with four columns. In column 1, list the organs of the digestive system in order from the mouth to the anus (see Figure 2.7, page 41).
   a In column 2, use Table 2.1 to identify digestive processes that need particular pH levels.
   b In column 3, reflect on the shape of the structure and decide whether the surface is used mainly for transport (T) or absorption (A).
   c In column 4, annotate tasks with numbers if they must be performed in sequence.
   d Explain how the structural arrangement of the digestive system supports its function; to change food into simpler chemicals that can be absorbed into the body.
2 Construct a table with two columns. In column 1, list the organs of the respiratory system in order from the mouth to the lungs.
   a In column 2, identify whether the surface of each part is used mainly for transport (T) or absorption (A).
   b How does the structure of the respiratory system limit water loss from the body?
   c Explain how the structural arrangement of the respiratory system supports its function; to exchange gases in the atmosphere with gases dissolved in body fluids.
3 Explain how the respiratory system is connected with the circulatory system.
4 Explain how the circulatory system is connected with the excretory system.
5 Explain how the excretory system is connected with the digestive system.
6 Summarise the information about body systems used as the examples in a concept map. Which organs belong to more than one system?

An alternative approach to organisation: explaining plant structures

Plants are literally rooted to the spot, and therefore need to manage their inputs and outputs in all weathers. As autotrophs, most of their nutrients and wastes are simple gases. Plants adapt to change by growing. After the rigid cell walls are formed, young growing shoots will never change their shape again. Several types of plant tissue consist of cells that died to fulfil their function.

FIGURE 2.12 Bonsai stems keep their shape once the rigid cell walls have been put down.

Plant tissues and organs

All plant tissue originates from **meristems** – tissue consisting of undifferentiated cells, or cells that have not yet developed to become specialised. Flowering plants are divided into two groups: **dicotyledons** (dicots) and **monocotyledons** (monocots), with key differences summarised in Table 2.2. In dicots, the meristems are usually located in the growing tips (roots and shoots). In monocots, the meristems are found at bases of the leaves.

TABLE 2.2 Summary of differences between dicots and monocots

	Dicotyledons (dicots)	Monocotyledons (monocots)
Examples	Oak trees, sunflowers, beans, carrots, cabbage	Palm trees, bamboo, lilies, corn, grass
Number of dicotyledons (leaves in the embryo)	2	1
Vein pattern in leaves	Networked; veins may be of different thickness	Parallel; veins all of similar thickness
Flower/seed parts	In multiples of 4 or 5	In multiples of 3
Roots	Tap roots – one main centre root with branches Xylem tissue makes an 'X' form in the centre	Many roots of similar thickness Xylem and phloem alternate in a ring
Stems	Vascular tissue makes a ring, xylem on inside, phloem on outside Often has a main trunk, tapering to an apex	Vascular system scattered Often several stems, of similar thickness

The meristem cells develop into specialised tissues organised into three main systems – the dermal tissue system, the vascular system and the ground tissue system.

Dermal tissue system

The **dermal tissue system** forms the plant's 'skin', protecting the plant by preventing water loss. Epidermal and cuticle cells, which cover leaves, are part of this system. Stomata are also part of this system.

Vascular system

The **vascular system** (Figure 2.13) is probably the most familiar because it consists of xylem vessels and **phloem tissue**.

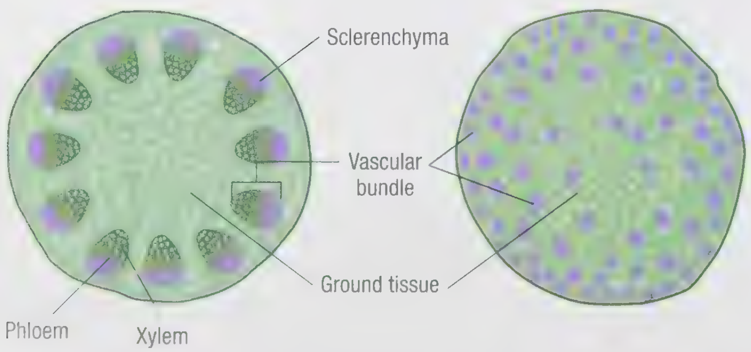


FIGURE 2.13 Cross-section of plant stems, showing arrangement of vascular bundles

Xylem transports water and dissolved minerals from the roots to the shoots. The vascular system in stems of dicots is arranged as a ring close to the dermal layer. Xylem can be seen as the 'tree rings' in a cut stump; these rings are the xylem that grew as the trunk widened during successive seasons (Figure 2.14). Xylem begins as living tissue, dividing from the inner edge of the outermost tree ring. As they mature, the cells form a hard outer layer of support tissue called secondary thickening. Then the ends of the cells digest away, and the cells die and lose their contents. Then dead xylem cells are lined up vertically, so the result is a tube or 'vessel'. In **perennial** plants, aged xylem can become blocked, but it continues to be part of the plant's support structure. The vessels are strengthened by natural polymers, and this gives wood its hardness.


FIGURE 2.14 Tree rings result from seasonal changes in how xylem grows.

Monocots do not have 'tree rings'. Instead, their vascular system is scattered as 'bundles' throughout their stems.

Phloem tissue consists of living cells that transport nutrients around the plant by a process called **translocation**. The nutrients move down a concentration gradient, from their source. Photosynthesising leaves are usually a 'source' of sugars and other carbohydrates. Two examples will help you understand how this might work.

- A growing fruit will have a much lower sugar concentration than the leaves. This makes the fruit a 'sink' in the concentration gradient, and it will attract sugar. The sugar arriving in the fruit has osmotic effects, attracting water. The water helps the fruit expand, which maintains the concentration gradient. Before it can sweeten and ripen, the fruit must stop expanding, and this happens when cells in the fruit grow secondary cell walls.
- Roots, where plants often store food energy, are also a 'sink'. In the roots, the sugar is converted to starch. Starch does not have osmotic effects, and therefore the roots will continue to attract sugar from the leaves.

Translocation is an unusual transport system because phloem tissue that transports glucose can also be translocating a completely different nutrient, perhaps an amino acid, in a different direction at the same time. This is possible because separate, parallel phloem vessels may have different sources and sinks.

TA CREATIVE USES OF PLANTS

Gardening is a common hobby, and plants are valued for their aesthetic qualities. Share the benefits of plants with others. Here are some actions to consider.

- Introduce young children to gardening by growing carrot 'ferns' (tops) on wet paper towelling, an avocado 'tree' from a seed, or a sweet potato 'vine' by suspending one just above a jar of water with a little bleach added.
- Assemble a terrarium for someone in a nursing home. Carefully placed, a terrarium will not require much attention to maintain.
- Grow a tub of herbs for a keen cook.
- If you live in a temperate part of the world, 'force' bulbs to flower early by putting them in a refrigerator for about 6 weeks in autumn, before potting them up for a friend. Tulips, hyacinths and daffodils are ideal for this.

Ground tissue system

The **ground tissue system** fills the space between the vascular tissue system and the dermal system. It forms the bulk of a plant, and functions to protect, store energy, provide support or photosynthesise. There are three types of ground tissue: **parenchyma**, **collenchyma** and **sclerenchyma**. Examples of each are outlined in Table 2.3.

TABLE 2.3 Examples of ground tissue in different plant structures

	Parenchyma	Collenchyma	Sclerenchyma
Appearance and function	Thin-walled, flexible, living cells that retain the ability to divide	Thicker walled, stiffer, living cells that support growing tissue	Very thick secondary walls, consisting of dead cells. Form the strong, woody parts of plants
Examples in leaves	Photosynthesising tissue: palisade and spongy mesophyll cells	The ribs (alongside vascular tissue) that give leaves their resilience, e.g. in high wind	Fibres in leaves, e.g. flax, linen
Examples in stems	Protective tissue, e.g. pith	Strong support near developing xylem and phloem	Structural support – a major component of wood
Examples in roots	Storage tissue, e.g. tubers	Support under the epidermis of growing roots	Any woody parts
Examples in fruit	Storage tissue, e.g. pulp	Support under the epidermis	Protection, e.g. shells of nuts and hard seeds, and 'stone' cells in some fruit such as pears Fibres around fruit, e.g. cotton

REVIEW

1 In a table, list the similarities and differences between animal and plant vascular systems.
2 Would you expect the trunk of a coconut palm to have tree rings?
3 Celery is crunchy but completely edible. What type of tissue makes up the thickened ribs along the leaf petioles (the 'stems') of this salad plant?
4 Fruit such as quince have a gritty texture. What type of plant tissue is responsible for this?
5 Why can't the older parts of perennial plants change their shape as they grow?
6 What level of organisation is represented by a leaf? How does the concept of 'system' differ between animals and plants?
7 Why can you mow a lawn of grass over and over again, but not a field of sunflowers?
8 In Canada, maple syrup is made by concentrating sap from the deciduous maple trees in early spring, just before they grow new leaves. The sap is extracted by hammering a plug through the bark, and only limited amounts are drained from each tree each year.
   a What type of plant tissue transports the sugary sap?
   b Where is the 'source' of this sugar, and where is the 'sink'?
   c Why do you think maple syrup producers limit the amount of sap they take every year?

How applied technology can improve biological form and function

When people and livestock suffer accidents and disabilities, or become ill, many branches of science contribute to the search for remedies. Careers that involve researching and testing technologies that help can be exciting and rewarding. There are many ways to contribute to the welfare of others.

Applied anatomy

There are not enough organ and tissue donors in the world to supply the needs of all the people whose organs and tissues are failing, often because of cancer or autoimmune disease. **Organ printing** is an emerging technology that aims to develop a greater supply of artificial organs. The new organs can be grown to exactly match the size of the recipient's. The 'tissue-engineered' organs are grown from the patient's own cells, so they will never be rejected.

Organs consist of several types of tissues that are organised into working relationships. Currently, organ-printing technology uses a technique based on inkjet printers. Cells, bathed in nutrient gels, are dropped layer by layer onto a three-dimensional scaffold. The scaffolds are made of collagen or other biodegradable materials, which hold the arrangement in place for several months while they divide into tissues that grow together into an organ. For these artificial transplants to be used, they need to be 'vascularised' to work with a blood supply, and this remains as a technical challenge.

At least 30 artificial organs are currently being developed. Artificial bladders have been used successfully by humans since 1999, and urethras since 2004. An important goal for organ printing is to be able to supply hearts.

Go to http://mypbio45.nelsonnet.com.au and click on **3D organ printing** to look at some of the promises and challenges in this area

While organs tend to fail gradually from wear and tear, limbs are mostly lost suddenly by accident and misadventure. Traditionally, amputees have been fitted with a **prosthesis**, an artificial limb that they wear over the stump of the limb. A prosthesis can be uncomfortable and even painful to wear because it can rub and cause blisters where it connects with the soft tissues.

A new approach was inspired by the way deer antlers pierce through their hides without allowing bacterial infections to enter (Figure 2.15). The Intraosseous Transcutaneous Amputation Prosthesis (ITAP) attaches directly to the skeleton. Like antler bone, the metal under the skin is porous. Once the amputee's tissues have grown into the implant, it is naturally sealed from infections even though the attachment for the prosthesis emerges through skin. The implants have been trialled successfully on humans since 2006.

FIGURE 2.15 Why doesn't the junction between antlers and skin allow infections to enter? This question inspired a revolutionary prosthesis.

Applied physics

Some of the most successful manipulations that have improved grain yields involved changing the architecture of crop plants. Dwarfism in rice and wheat is genetically controlled. Dwarf plants have shorter stems, which give them a lower **centre of gravity**. The plants are more stable, and


FIGURE 2.16 The Intraosseous Transcutaneous Amputation Prosthesis (ITAP) attaches directly to the skeleton and was inspired by deer antlers.

less likely to fall over, particularly when carrying ripe grain during high wind and rain. This means less grain is lost before it can be harvested. The short stems also require fewer resources for the plants to grow, and therefore they grow more seed.

Physics has also provided insight into ways to improve plants at tissue level. The movement of water up xylem vessels is helped by **capillary forces**, caused by adhesion between water molecules and the inner walls of the xylem. A small number of wheat varieties have significantly narrower xylem diameters – an inheritable trait. Plants with it are more productive, being able to extract more water from the soil, particularly in areas of the world prone to dry summers. The trait has since has been widely introduced to many varieties through conventional breeding.

An emerging application of physics uses **mechanics** – the study of how forces act on bodies. Human strength and leverage can be vastly extended by wearing strap-on, external skeletons or pressurised muscle suits. It is hoped that these devices will help people stay mobile and independent as they age, or support stroke victims. They could also be used to protect nurses and carers against back problems commonly caused by lifting and turning patients confined to beds.

Design and build a model robotic arm

ACTIVITY

to http://mypbio45.nelsonnet.au and click on **Honda walking assist device** to look at an example of a mobility-assisting

In a team of three or four students, use the following everyday items to build a device capable of picking up a paper cup:

6 strips of cardboard 50 × 9 cm; 2 wire coat hangers; 6 wooden clothes pegs; 20 paper clips; 20 rubber bands; 20 paddle-pop (or craft) sticks; ball of twine/string; roll of tape; 1 m fishing line

Use your notebooks for planning, and evaluate each other's models at the end of the activity.

QUESTIONS FOR DISCUSSION

1. What have you learnt about teamwork through this process?
2. What are the advantages in different groups working towards the same ends?
3. After you have compared designs, is there a way forward that may take ideas from several models?

REVIEW

1. Explain what is meant by 'organ printing'. Is the technology already in use?
2. List the advantages of attaching a prosthetic limb directly to the skeleton.
3. Why might people need to use a strap-on skeleton or muscle suit?
4. Community service can involve indirect contributions as well as direct interventions. How can improving plant productivity make a difference to disadvantaged communities?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State the differences between a:

a free-living cell, e.g. a protist, and a cell in a multicellular organism

b plant cell and an animal cell.

2 You visit a garden centre where you see these pieces of tree trunk being recommended for use as biodegradable paving (Figure 2.17). Use this information to suggest a description of the leaves and flowers in the plant this piece of stem came from.

FIGURE 2.17 Mystery tree trunk

3 'Heartburn' is caused when the sphincter muscle in the upper part of the stomach relaxes, allowing stomach acid to squirt up into the oesophagus. Several home remedies recommend drinking a dilute solution of baking soda, which is alkaline, to relieve the sensation. Suggest how this treatment may affect the digestion of protein in the stomach.

LEVEL 3–4

4 Outline how double circulation helps a mammal's intake of oxygen and nutrients, and output of carbon dioxide and liquid wastes.

5 The digestive systems of most mammals are 'variations on a theme'. Herbivores, such as cattle, tend to have very long digestive tracts compared to their size. Carnivores, such as cats, tend to have short digestive tracts compared to their size.

a Predict where a human would fit in this pattern, explaining why.

b On a trip to a different country, you notice a dead mammal on the side of the road, one you have never seen before. Its intestines are exposed, and you notice they seem very long. What does this suggest about the animal's diet?

6 Emphysema is a disease that affects people exposed to heavily polluted air, including from cigarette smoke. The disease involves the alveoli walls breaking down. Healthy lungs look like a springy new sponge; emphysema makes the lungs look like an old used sponge with large holes, lacking elasticity. Make a scientific judgement about the likely symptoms of emphysema and its effect on life expectancy.

LEVEL 5–6

7 Describe how applying physics concepts have made a difference in the productivity of grains.

8 Figure 2.18 shows a cross-section of tissue in a leaf.

a Identify structures that support its adaptation for gas exchange.

b Identify structures that are part of the dermal, ground and vascular systems.

c How would you estimate the total internal surface area and compare it with the outer surface of the leaf? Use your method to calculate an approximate ratio.

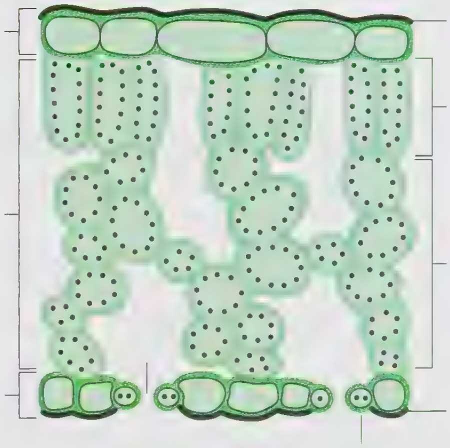


FIGURE 2.18 Cross-section of a leaf

9 Trees are sometimes killed by ring barking. A strip of bark, together with a layer of the vascular tissue beneath it, is peeled off all around the trunk. Yet ringbarked trees can remain green and apparently grow for many years before they die. Use a scientifically supported judgement to explain how this may happen.

10 One common complication for people with diabetes is that their kidneys can fail. If this happens, unless they have a kidney transplant, they need to use a dialysis machine for much of the time, as shown in

Figure 2.19. This device acts like an artificial kidney through which the patient's blood is pumped alongside a toxin-free solution with the same concentration as blood fluids. Interpret this information to explain the process that is being used to remove the toxins.

FIGURE 2.19 On dialysis

LEVEL 7–8

11 Explain how the arrangement of the digestive system separates the local environments for different, otherwise incompatible, digestive processes.

12 a Without looking at cross-sections of their roots or stems, predict the relative diameters of xylem vessels in the following species, and explain how your judgement was supported scientifically.
- **i** Cactus
- **ii** Waterlily
- **iii** Banana plants

b Deciduous plants lose their leaves during cold periods (winter deciduous) or hot dry seasons (drought deciduous). How might this adaptation for stopping their nutrient input be an advantage for the organism?

13 Table 2.4 summarises ion concentrations of the solutions found in the tubule of a nephron (the filtration units in the kidney). The parts are listed in the correct sequence from the beginning at the glomerulus to the end, the collecting duct for urine.
- **a** Analyse and evaluate the information and judge which processes are likely to be incompatible for this sequence of events to occur.
- **b** If blood cells do not pass the filtering system of the glomerulus, what is the likely nature of the protein in the first solute sample?
- **c** Why do you think glucose levels drop after the first two parts?
- **d** Why do you think the concentration of urea increases along the tubule?

TABLE 2.4 Summary of various solute concentrations along parts of a human nephron

Nephron part	Solute ($g/100 cm^3$) of solutes in the filtrate				
	Protein	Urea	Glucose	Chloride	Ammonia
Glomerulus	7.5	0.03	1.0	0.37	0.0001
Bowman's capsule	0	0.03	1.0	0.37	0.0001
Proximal convoluted tubule	0	0.03	0	0.40	0.0001
Loop of Henle	0	1.50	0	0.45	0.0001
Distal convoluted tubule	0	1.70	0	0.55	0.0001
Collecting duct	0	1.90	0	0.60	0.04

REFLECTION

1 Have your ideas about the debatable questions changed during this unit?
- **a** Is form more important than function?
- **b** Is change possible without systems?
- **c** How much of our body can technology replace?

2 This unit is based around the key concept of change.
- **a** List examples of how gases, liquids or dissolved materials from the external environment is brought into an organism.
- **b** Can you make a generalisation about how changes affect animals compared to plants?
- **c** How can technology change people's lives?

3 This unit constantly compared form with function.
- **a** What similarities are there in animals and plants?
- **b** In what ways are their forms different at cellular, tissue and system levels?

4 Another related concept was transformation.
- **a** In an animal, what levels of organisation (cells, tissues, organs etc.) capture this concept?
- **b** How does this compare with plants?

5 A third related concept was scale.
- **a** At which level – cells, tissues or systems – are animals and plants most similar?
- **b** At what scale does each of the following branches of science apply: anatomy, chemistry and physics?

6 How are the challenges of 'bringing the outside in and the inside out' different for animals and plants? How much is this related to their requirements for nutrition (i.e. as heterotrophs or autotrophs)?

UNIT 3

COORDINATED BODY SYSTEMS

KEY CONCEPT
Systems

RELATED CONCEPTS
Form and function

Movement

Balance

GLOBAL CONTEXT
Identities and relationships: an exploration of how we are made up of complex systems that work together

STATEMENT OF INQUIRY
Coordinated responses in systems require organisation and communication.

INQUIRY QUESTIONS

FACTUAL
1 How does the nervous system work?
2 What is a reflex action?
3 How do hormones regulate change?

CONCEPTUAL
4 How do the overarching systems communicate with each other?
5 How do organisms control their internal environments?
6 How are we defined by our body and its systems?

DEBATABLE
7 Is form more important than function?
8 Is there such a thing as a 'normal' body?
9 Is there a limit to complexity?

How do the endocrine and nervous systems make complex behaviour possible?

Background

Are you the sum of your parts? The behaviour of any unit within a level of organisation is determined by its local environment. This includes the other units at the same level, and the information the unit receives. For example, a cell in a tissue will be 'aware' of the cells around it, and its responses are controlled by the function of the organ they are all part of. Similarly, at the next level, organs need to receive information from the other organs around them to function together as an organ system.

ATL

INFORMATION LITERACY

Use of citations, footnotes and referencing.

Your challenge

In a formal, fully referenced 1200-word essay, discuss whether we are individuals or collections of coordinated systems of control. Who would you be if one of your systems broke down?

- Explain an example of an interaction and how it affects the lower level of organisation as well as the individual person as a whole when it functions properly and when it malfunctions. Examples involving problems with the nervous system might include the actions of neurotransmitters (perhaps blocked by drugs) or a degenerative disease of the brain or nervous tissue. Examples involving the endocrine system might include a lack or excess of a hormone, target cell or organ failure, or specific development changes. The number of examples you select will depend on the detail you provide.
- Discuss and evaluate how science has been applied to an issue or problem arising in your example; for example, how medical interventions help individuals restore balance to their systems, if possible.
- Describe how your example interacts with at least one of the following factors: moral, ethical, social, economic, political, cultural and environmental.

Introduction

Any complex **system** is more than the sum of its components, which gives it greater capabilities. For example, multicellular organisms interact with their environment in complex ways. The adaptability and movement of plants and animals enables them to take advantage of light, water, prey, shelter and other resources. The ability of sentient organisms to select suitable mates or learn useful skills makes a difference to their survival. The result of a very extreme level of awareness and consciousness explains the diversity of human culture and interests.

Whenever organisms move in unison, their interaction may result in new, unexpected behaviours. Herds of antelope, flocks of birds and shoals of fish move as single, dynamic units. The synchronised movement of human dance is a cultural phenomenon that approaches this level of complexity. All these examples of emergent systems echo complexities within organisms.

Complexity theory describes the interaction of different levels in systems, and proposes that any level in a system will only receive information from the level above or below it. Therefore, in an organism, a cell within a tissue may receive input from an organ or its organelles, organs may receive input from the system and perhaps cells making up its tissues, and organisms receive input from their physical and social environment.

FIGURE 3.1 A flock of starlings: hundreds of individuals swirl without colliding, producing an emergent level of organisati

ACTIVITY

Engaging with animal senses

Investigate some of the amazing facts about how different species of animals detect their environment with their senses. Select a story about the extraordinary abilities of one species and share it with your classmates.

Exploring discrimination of our own senses

Work collaboratively in pairs or groups of three to explore your senses in Experiment 3.1. What are you learning about your own senses and how information might be communicated in your own body? Be prepared to contribute your ideas to a class discussion at the end of each part of this experiment.

EXPERIMENT 3.1

What can we learn about our senses?

PART A DISCRIMINATION OF TEMPERATURE

Your skin is a complex organ system, with many types of receptors (Figure 3.2), including pain and pressure receptors, and at least two kinds of receptors for temperature. Some of their messages will cause the **erector papillary muscles** to make hair stand on end, which traps a layer of air and insulates you from cold. Others may instruct the blood vessels near your skin to contract so less blood is exposed to the cold. If you are really cold, other nerves will instruct certain muscles to make you shiver, which will help you warm up.

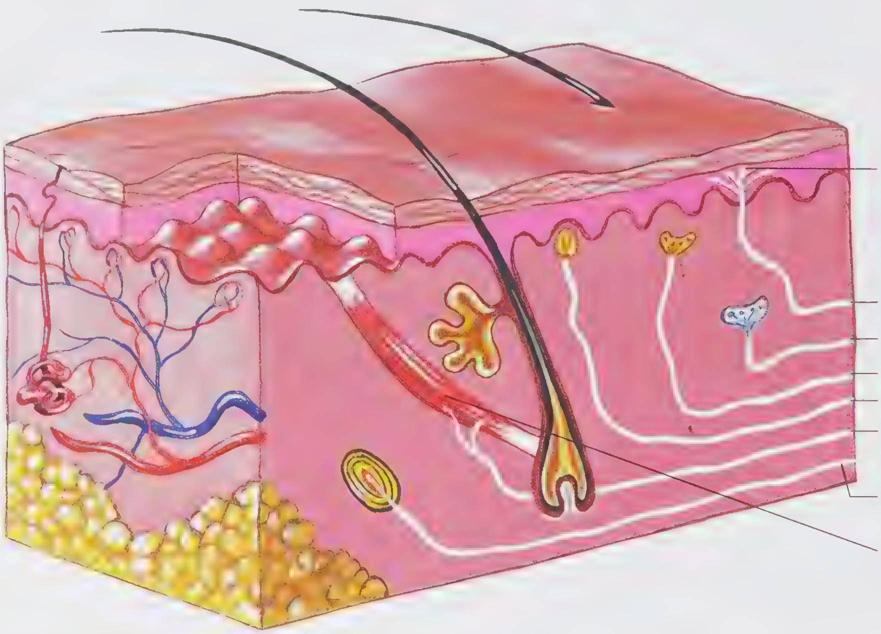


FIGURE 3.2 Sensory receptors in the skin

MATERIALS

- 1 bowl filled with warm water (about 37°C)
- 1 bowl filled with water at room temperature
- 1 bowl filled with chilled water (about 4°C)

PROCEDURE

1. Place one hand in the warm water, and the other hand in the chilled water for a few minutes.
2. Place both hands in the water at room temperature. How can you explain what you feel?

PART B DISCRIMINATION OF TOUCH

MATERIALS

- Blindfold
- 2 fine marker pens with water-soluble ink of different colours
- Disposable wipe cloths

PROCEDURE

1 Blindfold the test subject.
2 Use a marker pen to place a mark somewhere on the test subject's exposed skin.
3 The test subject then tries to mark the same place with the other pen. Experiment by repeating this test with the mark in several different places.
4 How close are the two marks? Is it easier to discriminate touch on some parts of the body than it is on others? What does this suggest?
5 Remove the ink with the disposable cloths after completing the experiment.

PART C DISCRIMINATION OF HEARING

AIM

To explore the benefits of having two ears located on the opposite side of your head, which helps you hear in stereo (Figure 3.3).

MATERIALS

- Blindfold
- Protractor
- 2 pieces string (15 m long)
- Sound generator (such as an alarm on a phone, a bell or clapping hands)
- Something with which to mark a spot and a semicircle on the ground (e.g. flour)
- Disposable foam ear protectors

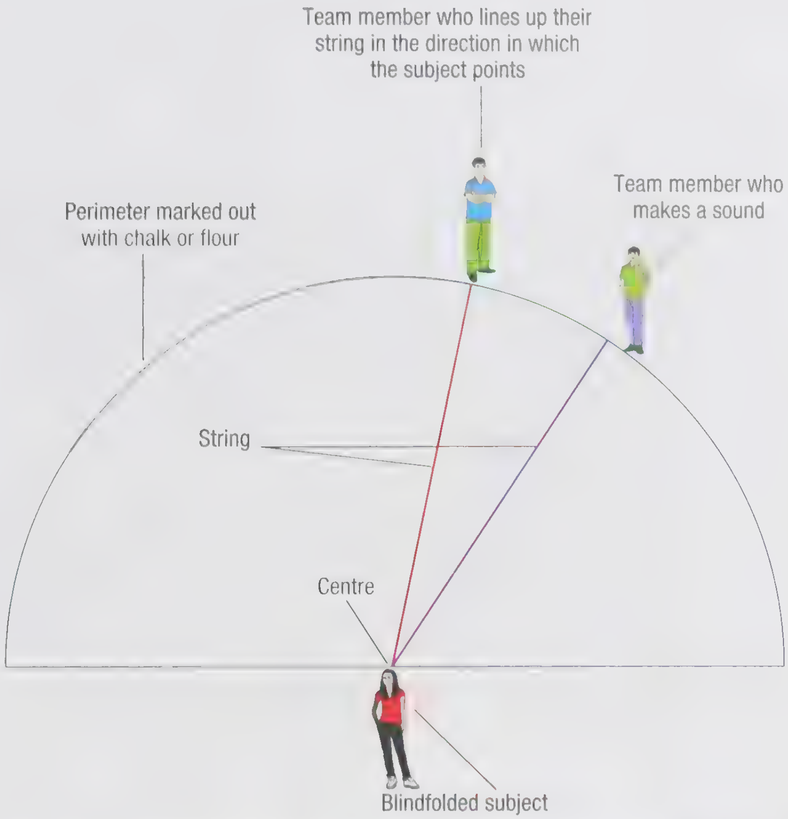


FIGURE 3.3 Suggested arrangement for mapping sound direction

PROCEDURE

It is best if two teams combine and go outside to do this activity.

1 Mark the ground, and use the string to sweep out a semicircle around this focus ('centre' in Figure 3.3).
2 Blindfold the test subject. Place the test subject at the centre, holding two pieces of string.
3 One string is held by a second team member, who stands somewhere on the semicircle and makes a sound.
4 The other string is held by a third team member, who is directed to stand where the test subject thinks the sound is coming from.
5 The fourth team member uses the protractor to measure the angle between the two strings.
6 Repeat the activity several times, from different locations on the semicircle.
7 Repeat with the subject wearing an ear protector in one ear.
8 If there is time, repeat with a different subject. Are subjects equally skilled at locating sound? Do subjects improve with practice? What is the effect of using both ears instead of using one?

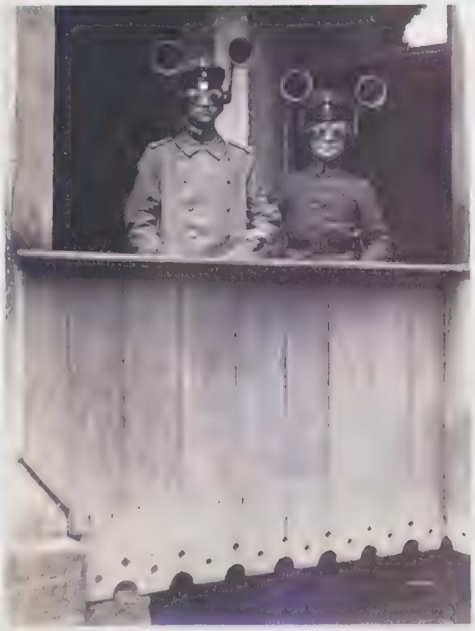


FIGURE 3.4 [illegible] incoming enemy planes. The circular detectors amplify sound, and the 'stereo' arrangement causes a phase change in the incoming sound waves as the listener turns. This helps the wearer detect the direction of the source of sound

Explaining the body's communication systems

FIGURE 3.5 Team sports require many systems of the body to communicate.

Imagine a typical scenario involving the expression of your whole body, perhaps playing in a sporting team (Figure 3.5). During intense activity, your heart needs to pump faster so that extra glucose and oxygen are delivered more quickly. The muscle cells in your legs and arms need to be supplied with glucose and oxygen at a rate that keeps up with how hard they are working; otherwise, they will not have enough energy to keep contracting and relaxing. To bring more oxygen to these cells, and to remove the extra carbon dioxide waste they are producing, your breathing rate needs to increase. To remove the extra heat generated, you will perspire more. You may also be using all your senses to detect any danger, so that your muscles can respond in time to protect you from harm. For all of this to happen at the same time, the various systems of cells must be coordinated so they work together.

u and click on **Auditory perception**. Listen to the

In humans and other mammals, coordination is achieved primarily by two systems – the **nervous system** and the **endocrine system**. The nervous and the endocrine systems work together, not independently. These specialised systems of communication enable you to respond to changes in your external environment and to maintain a stable internal environment, or **homeostasis**.

Nervous system

Your nervous system (Figure 3.6) is composed of your brain, **spinal cord** and **nerves** that reach out from your spinal cord to all the parts of your body. It is the centre of all your thinking, learning and memory, and interacts rapidly with everything that makes up your world.

Your brain and spinal cord act as the command centre, integrating information. Together they are known as the **central nervous system (CNS)**.

The **peripheral nervous system** is the set of nerves that communicate between the CNS and the rest of your body. Each nerve (Figure 3.7) consists of bundles of highly specialised cells called **neurons**, which collect and respond to information.

The nervous system can also be classified according to nerve function. **Sensory neurons** gather information from receptors and relay it to other neurons, for example, **interneurons**, found in the CNS. **Motor neurons** relay instructions, to glands or muscles, to respond.

There are two types of motor neurons. One set forms the **somatic nervous system** that connects to our skeletal muscles and involves conscious movement. The other, the **autonomic nervous system** or involuntary nervous system, controls vital glands and organs. Examples include the body's heart rate, pupil dilation, respiration and swallowing. Most of these are not under our conscious control, yet our very survival depends on the autonomic nervous system working correctly.

Neurons

The structure of neurons (Figure 3.9) provides clues about how they transmit information. Like all cells, they have a **cell body** with a nucleus, ribosomes for building proteins, and many mitochondria to provide energy. Neurons do not seem to be able to divide after you are born, which is why accidents involving the spinal cord and diseases that damage the brain can be devastating (Figure 3.10).

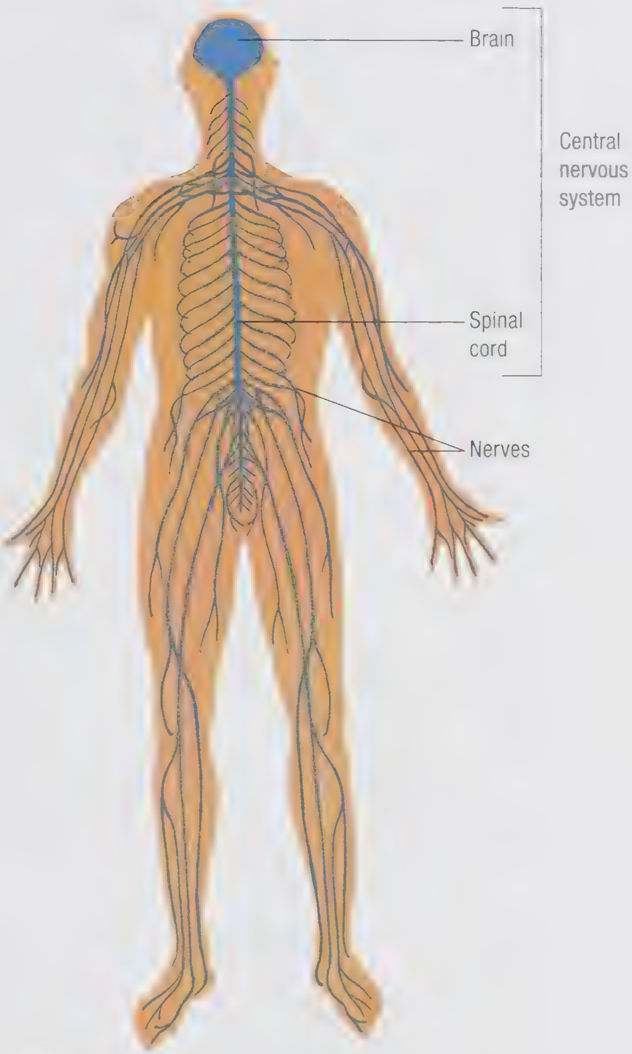


FIGURE 3.6 The human nervous system

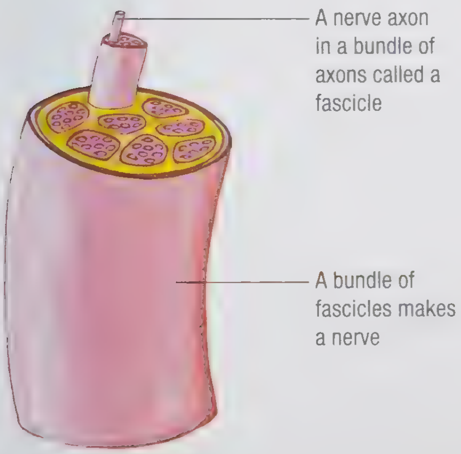


FIGURE 3.7 A nerve

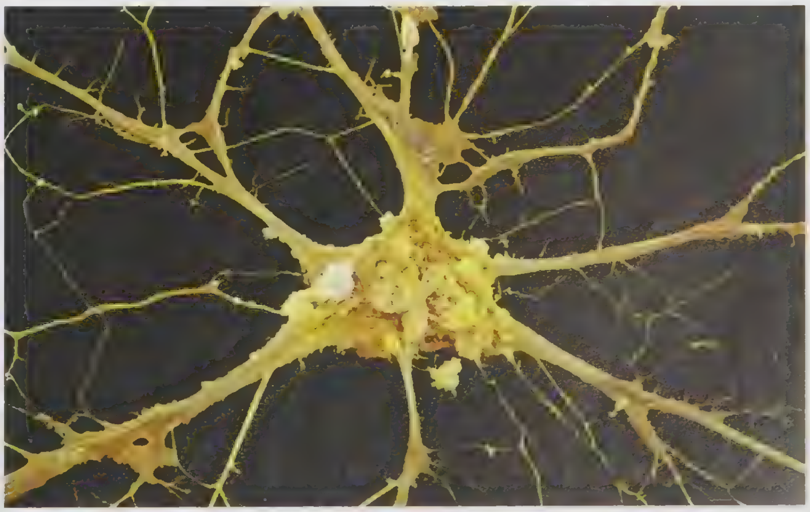


FIGURE 3.8 A neuron

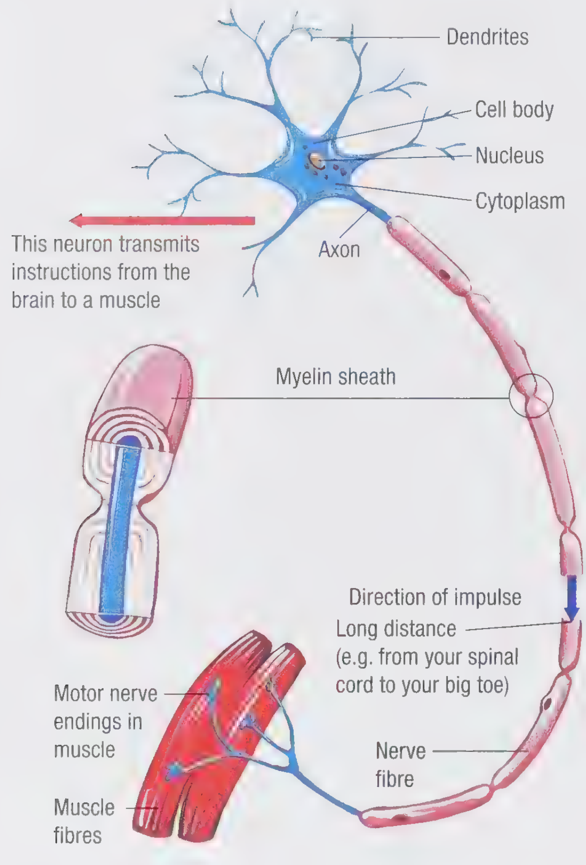


FIGURE 3.9 The parts of a neuron

Thread-like extensions called **dendrites** extend from one end of the cell, receiving information from other neurons. Individual neurons may have thousands of dendrites, particularly those in our brains. A longer and thicker extension, called an **axon**, carries messages away from the cell body to another neuron. Axons can be as long as your leg, and are often covered by a **myelin sheath**, a fatty insulating layer made of another specialised cell, a **Schwann cell**. The fatty layer results from layers of cell membranes as they roll themselves around the axon like a series of bandages, leaving tiny gaps in between. The thickness of the myelin sheath and the thickness of the axon are two variables that affect the rate of transmission of information. Information may travel along neurons at 400 km h^{-1}. Although the numbers of neurons do not change after birth, the numbers of connections between them do change, growing in complexity and thickness or 'pruned' by lack of use.

Transmission of information along a neuron

Neurons pass information as a wave of changes in membrane permeability, causing ion movements. Because ions are charged, these changes in the membrane, also known as **nerve impulses**, and can be recorded as an '**action potential**' (Figure 3.11).

FIGURE 3.10 Christopher Reeve in traction after a spinal cord injury. Well known for ... Superman in the Superman movies of the 1980s, the actor's spinal cord was ... horse-riding accident. Although he could not breathe on his own, Reeve ... to help other victims of spinal cord injury and to promote and fund ...earch into this area. Reeve died in 2004.

How does this work? Like all living cells, 'resting' neurons use active transport to maintain small differences in the ion composition of fluids on either side of their cell membranes. Inside the neuron there is a higher concentration of potassium ions (K^+) than outside, while outside has a higher concentration of sodium ions (Na^+). Subtle differences between the numbers and types of ions mean there is a small negative electrical change (voltage or potential difference) across the cell membrane in a 'resting' cell.

When a dendrite is stimulated, the cell membrane changes, and sodium ions immediately start to leak into the cell. This increases the cell membrane's leakiness further, an example of **positive feedback**. As more and more sodium ions enter the cell, the charge difference across the membrane becomes more and more positive. At a set point, the permeability of the membrane suddenly changes again. Sodium ions can no longer enter, but potassium ions leak out instead, 'resetting' the neuron's original, negative charge. This is followed by a millisecond recovery period while the ion ratio across the membrane is adjusted. During this period, the neuron is not able to respond to further stimuli.

For an action potential to occur, the dendrite needs to receive a signal that is large enough to start the process, after which the size of the signal makes no difference to the size and speed of the action potential. This is called an **all-or-none response**.

Transmission of information between neurons

The neuron pathway can only communicate information in one direction. The reason for this is that, although close, neurons never actually touch other neurons. The point of virtual contact between the dendrite and axon is the **synapse** and this tiny gap is only 20 nm wide (2×10^{-9} m). However, the impulse cannot be transmitted across the gap. Instead, a series of events called the **synaptic process** takes place (Figure 3.12).

The action potential causes chemicals called **neurotransmitters** to be released at the end of the axon. The neurotransmitters diffuse across the synapse and bind to proteins embedded in the surface of the dendrite of the next neuron. The proteins to which the neurotransmitter binds are called **receptors**. Only molecules with complementary shapes can attach to and activate them.

The binding of the neurotransmitter to the receptor triggers the generation of a new action potential, which travels down the dendrite to the cell body of the next neuron.

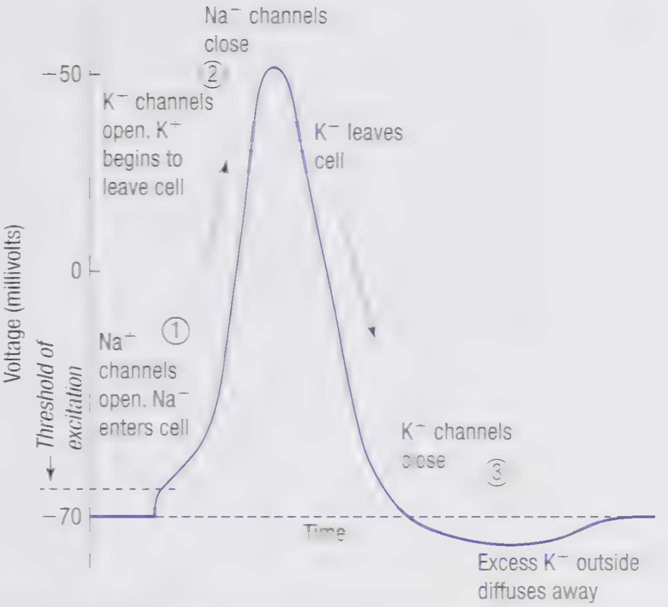


FIGURE 3.11 Changes in ion movement across the cell membrane during an action potential

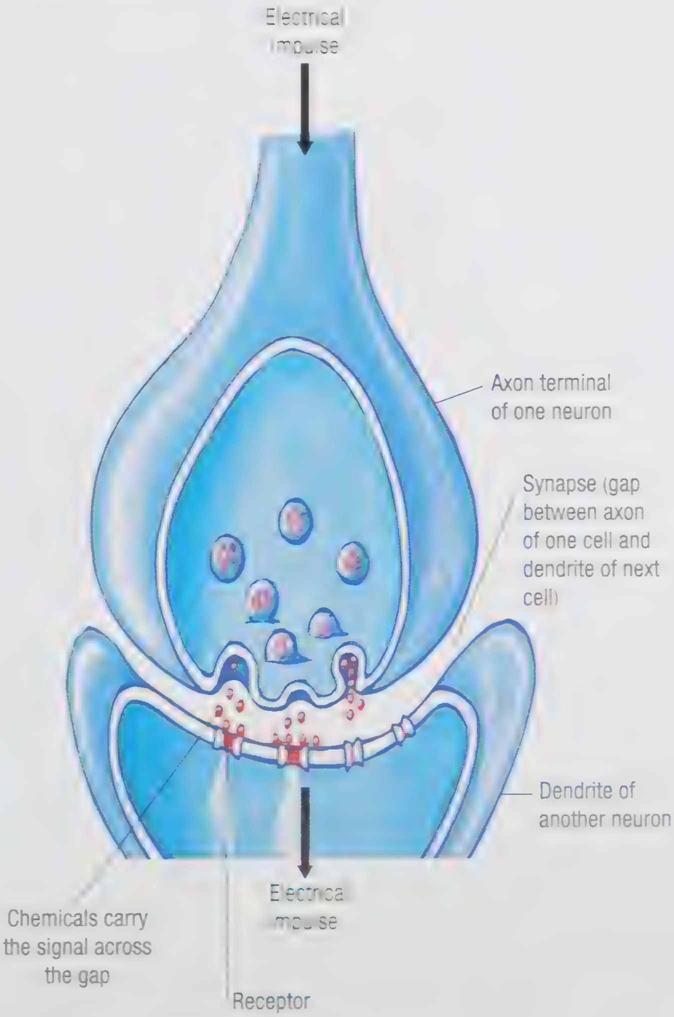


FIGURE 3.12 The synaptic process

The 'used' neurotransmitter is cut up by enzymes and diffuses back to the synaptic terminal to 'reload' the synapse.

Go to http://mypbio45.nelsonnet.au and click on **Nerve impulses** to view the animated movie that shows neurotransmitters travelling from one neuron to the next

Reflex arcs

Reflex arcs are special nerve pathways for simple, automatic responses. Have you ever accidentally burnt your hand on a hot oven or barbecue? You would have pulled your hand away almost immediately and felt the sensation of pain a little time after removing your hand. This is an example of a **reflex** action. The muscle movements are involuntary.

All nerve pathways involve the CNS, but reflex arcs do not necessarily involve the brain. You never need to 'think' about the kneejerk reflex, which is processed in the spinal cord. You use it constantly for balancing, when you stand and walk.

What really happened when you touched the barbecue? Receptors on the surface of your skin detected heat. These set off impulses up the nerve pathways. Sensory neurons relayed the message to **connector neurons** in the spinal cord. These immediately relayed an appropriate response to a motor neuron to pull your hand away. A different pathway also relayed a message to your brain, but valuable time is gained by initially bypassing the brain. Such responses to painful stimuli prevent extensive damage to tissue and so help to protect your body. The pathway of nerve cells employed in a reflex action is called a **reflex arc** (Figure 3.13).

FIGURE 3.13 A reflex arc

REVIEW

1 Outline the relationship between the central, peripheral, somatic and autonomic nervous systems.

2 a Figure 3.14 shows a typical neuron. Identify parts A–F by the appropriate terms, and explain what happens in each location.
 b How does the form of the neuron support its function?
 c How does the form of Schwann cells support their function?

3 a With the aid of a diagram, describe how neurotransmitters work.
 b How does the communication across the synapse control the direction of a nerve message?

4 Not realising where it had come from, Alice picks up a metal spoon that has just been taken out of a pot of boiling soup. Describe what you expect would happen next.

5 Humans have a central nervous system, but some organisms, such as the octopus (Figure 3.15) have a distributed nervous system. In addition to a brain, each arm also has a 'command centre'.
 a How might this affect their reflexes?
 b Octopus are among the most 'intelligent' invertebrates. For example, they can navigate mazes. What are the advantages of distributed nervous systems?
 c If you cut an arm off an octopus and introduced it to some prey, how would you expect the severed arm to behave, compared to one still attached to the animal?

6 Suggest how the following features may be advantageous for complex organisms.
 a Different types of sensory receptors in different places
 b Pain receptors in many places
 c Neurons that can transmit impulses far faster than others

7 Reflecting on your observations and explanations for Experiment 3.1, has this section changed any of your interpretations?

8 Reflecting on Unit 2, how does the nervous system interact with the digestive, respiratory and circulatory systems?

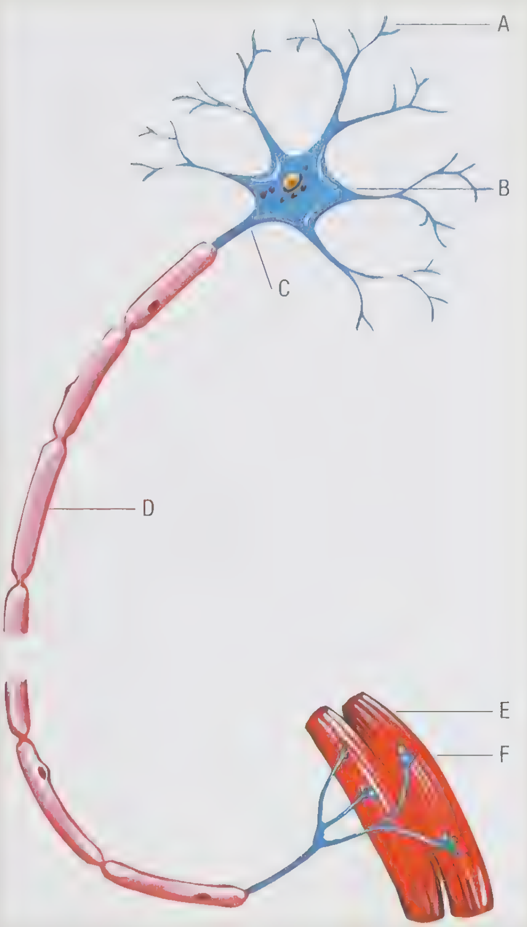


FIGURE 3.14 A neuron

FIGURE 3.15 An octopus attempting to open a jar

INVESTIGATION 3.1

Investigating nervous responses

CRITERIA B AND C

CRITICAL THINKING
Reflectively analyses and evaluates evidence.

As Experiment 3.1 suggested, there are many tests and demonstrations that can inform you about nervous responses. However, investigations require an original approach.

YOUR TASK

How can you find out whether there is a relationship between how people perform tests relating to one aspect of the nervous system, and how they perform in tests of others?

THIS MIGHT HELP

- You may want to consider methods that test and compare at least two different aspects of the nervous system.
- Consider an internet search around some the terms such as 'reflex reactions' or 'reaction times'.
- Consider investigating an unusual aspect of the nervous system (e.g. the Stroop effect).
- Adapt some of the formative tasks in Experiment 3.1.
- In general, the simpler the tests you use, the more opportunity you have to repeat the tests and use a wide number of subjects to be certain of the reliability of your results.
- After reflecting on your background reading, including your proposed method, develop a hypothesis that demonstrates your understanding of aspects of the nervous system. Check with your teacher whether the materials you need are available, and whether the tests you propose are safe. You may want to consider developing a permission slip, to show that your human subjects agreed to participate in your investigation.

Write up your investigation design following the guide in Appendix 3 on page 209 or as advised by your teacher.

Endocrine system

When a football team plays a match, the coach may send signals to the players in two ways – body language and gestures, or by sending runners out to speak to the players. Similarly, your body does not only rely on the signals from your brain, transmitted through your nervous system, to control what your cells do. It also controls what happens by sending chemical messengers through your bloodstream. These chemical messengers are called **hormones**.

Hormones are manufactured in very small quantities and secreted directly into the bloodstream by a special set of glands known as the endocrine **glands**. Unlike salivary or sweat glands, which give out their contents in a particular direction, endocrine glands lack ducts. The main glands in this system are the **pituitary gland**, thyroid gland, parathyroid glands, adrenal glands, pancreas, ovaries and testes (Figure 3.16). Together, they make up the endocrine system.

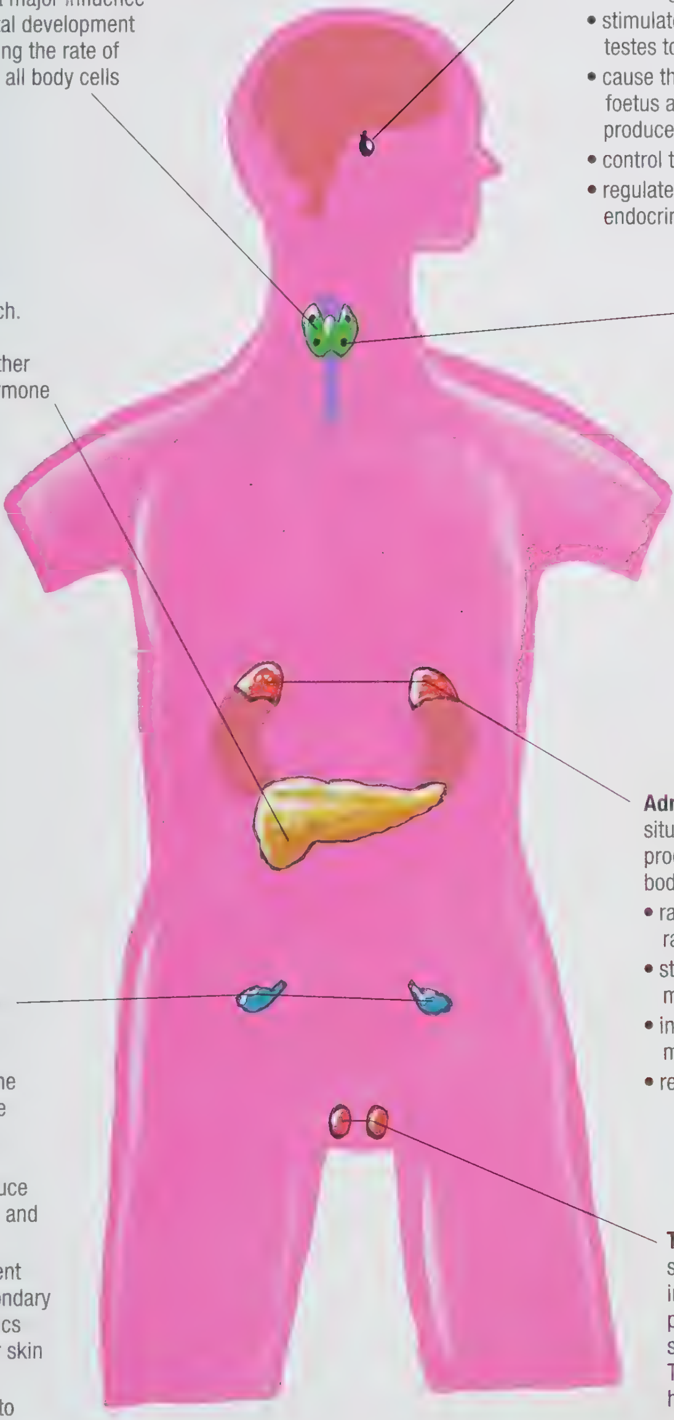
Hormones

Although the circulatory system brings hormones into contact with nearly every type of cell, they only affect a small number of those cells. These cells, called **target cells**, have a special chemical structure, or receptor, that matches up with the hormone. Any cell that contains the matching receptor for a hormone is a target cell for that hormone. Cells may have more than one kind of receptor.

Thyroid gland is situated in the neck in front of the wind-pipe. Thyroxine is the main hormone produced and it has a major influence on physical and mental development after birth by controlling the rate of chemical reactions in all body cells

Pituitary gland is situated at the base of the brain and produces hormones that:

- control growth
- stimulate ovaries to release egg and testes to produce sperm
- cause the uterus to contract and expel foetus at birth and mammary glands to produce milk
- control the amount of water in urine
- regulate the activities of other endocrine glands



Pancreas is situated just below the stomach. Part of it produces digestive enzymes, other parts produce the hormone insulin, which:

- decreases the rate at which the liver releases glucose into the bloodstream
- enables cells to absorb glucose from blood
- stimulates the body to change glucose into fat

If not enough insulin is produced, blood glucose levels are too high, leading to diabetes

Parathyroid glands are four small glands embedded in the thyroid and are sensitive to the levels of calcium in the blood. Too little calcium causes the parathyroid glands to release parathyroid hormone which:

- increases absorbtion of calcium in the intestine
- causes the release of calcium from bones
- increases reabsortion of calcium by the kidney

Adrenal glands are situated above the kidneys and produce adrenaline. This prepares body for action in:

- raising blood pressure and heart rate
- stimulating the liver to release more glucose
- increasing blood supply to muscles
- reducing blood supply to the gut

Ovaries (in females) are situated in the lower abdomen, just below the kidneys. The ovaries are part of the female reproductive system and produce eggs. They also produce hormones (oestrogen and progesterone) that:

- promote development of ovaries and secondary sexual characteristics (e.g. breasts, softer skin and voice)
- prepare the uterus to receive a fertilised egg
- regulate the menstrual cycle and pregnancy

Testes (in males) are situated in a sac (the scrotum) in the groin. The testes are part of the male reproductive system and produce sperm. They also produce the male sex hormone testosteron which:

- controls development of male secondary sexual characteristics (e.g. deeper voice, more body hair)
- is needed for maturation of sperm

FIGURE 3.16 The hormone-producing, or endocrine, glands

Balancing blood sugar levels

It is important that your internal environment is balanced. For example, your blood glucose levels must be within a certain safe range, as your body cells must be continually supplied with glucose if they are to function. Yet, you do not eat carbohydrates continually throughout the day. Often it may be hours between meals.

Your liver and pancreas are vital in controlling the levels of glucose in your blood. They do this by means of **negative feedback**. Two hormones, with opposite, or **counter regulatory** effects, are involved. For example, if your blood glucose levels are too high, negative feedback involving the hormone insulin will lower them to a safer level. If they are too low, negative feedback involving the hormone glucagon will help raise them. The possible pathways are shown in Figure 3.17.

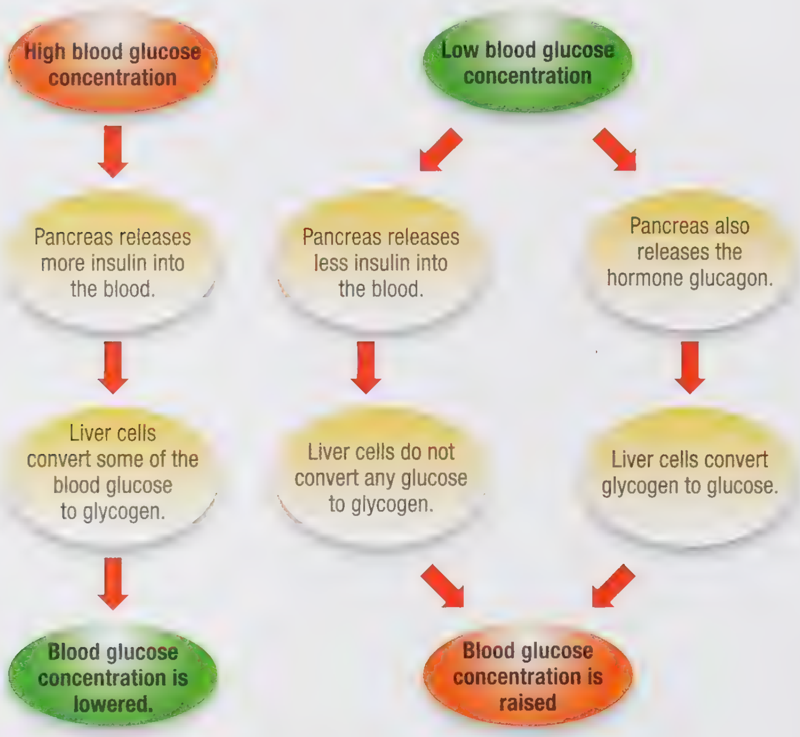


FIGURE 3.17 Negative feedback works to balance blood sugar.

Diabetes mellitus is a condition in which blood sugar levels are unregulated. This is the disease people commonly refer to as 'diabetes', and (as indicated by 'mellitis', meaning honey) the urine contains glucose. The most common reason is that the pancreas no longer produces enough insulin, so cells cannot absorb glucose from the blood. However, before this happens, there can be a period of years during which the body cells slowly become resistant to the effects of insulin, perhaps because there are changes in numbers of receptors.

Coordinating whole body change: growth

Unlike the balancing acts of insulin and glucagon, the effects of growth hormone are slow but permanent. When organisms grow, all parts of the body need to change together in a coordinated, balanced way.

Stimulated by the **hypothalamus**, human growth hormone (HGH) is produced by the pituitary and regulated by negative feedback. This hormone has many metabolic effects, stimulating protein synthesis, stimulating the breakdown of fats, and slowing the use of glucose. It also stimulates the production of another group of growth hormones (insulin-like growth factors), which promote growth and interact with the control of glucose in the body. For example, too much growth hormone over a sustained period has been linked to the development of diabetes, and similarly, too much blood glucose during childhood can suppress the production of growth hormone.

Physiological conditions directly caused by the amounts of growth hormone during childhood include gigantism and pituitary dwarfism, and people with these effects are not just unusually tall or short, but proportional and well outside the size range of their ancestors (Figure 3.18). The excess growth hormone in giants often comes from pituitary tumours. Today, children who are at risk of pituitary dwarfism can be treated using human growth hormone produced by genetically modified bacteria.

Examining the role of growth hormone also demonstrates the impact of target cell receptors. Achondroplasia is a genetic mutation that affects the distribution of target cell receptors for growth hormone in cartilage of growing bones. This affects the growth of limbs. People with the condition tend to have short legs and arms, in comparison to the rest of their bodies.

FIGURE 3.18 Robert Wadlow, the tallest man to have ever lived (2.72 m) with his father, who was tall by normal standards (1.82 m). Sadly, Robert died aged 22. His condition was due to abnormally high levels of human growth hormone.

FIGURE 3.19 The successful actor Peter Dinklage has achondroplasia.

Hormones and identity

Our appearance is very much part of our identity. However, hormonal treatments during childhood can sometimes make a huge difference. Parents of children with potential for short stature sometimes request treatments with growth hormone to give them a few more centimetres in their adult height. In a small group, discuss the following.

1 Should any person have the right to make this type of life-changing decision for another individual?
2 Is there a distinction between applying the use of extra hormones for the treatment of a pathological condition, and one that is cosmetic? Does it matter?
3 Who should pay?
4 Are individuals in your community and school treated differently if they are above or below average height? If so, why do you think this is?
5 Discuss other examples of identity that relate to hormonal control.

How the endocrine and nervous systems intersect: fight or flight response

Have you ever accidentally started to cross a road, only to realise the approaching traffic was much closer than you had estimated? How did you feel?

The 'fight or flight' response was stimulated by a nervous event, in this case seeing a potentially dangerous, stressful situation. The physiological response is controlled by the two hormones **adrenalin** and **noradrenalin**, which are secreted by the adrenal glands, located just above the kidneys.

Although most hormones are described as slow acting, within less than a minute adrenalin causes blood to be redistributed to the muscles, enlarges the pupils, and starts you sweating. Noradrenalin increases blood pressure, heart rate and glucose metabolism. All these responses are controlled by part of the autonomic nervous system known as the **sympathetic nervous system**.

Perhaps half an hour later, when the danger has passed, your heart and breathing will have slowed and your physiology returned to normal. The 'fight or flight' response was reversed by another part of the autonomic nervous system, the **parasympathetic nervous system**.

In this situation, the endocrine system and nervous system communicated in partnership. Both adrenalin and noradrenalin have other, slower effects in the body, and both can also act as neurotransmitters in some nerve pathways.

REVIEW

1 a What is a hormone?
  b State one example of a hormone produced by the pituitary and what it controls.
2 a If an 'endocrine gland' is one that lacks ducts, what do expect an 'exocrine gland' to have?
  b Refer to the text to suggest an example of an exocrine gland.
3 a Describe the role of the hormone insulin in controlling blood sugar levels.
  b In which gland is insulin made?
  c What are three possible consequences for someone whose body cannot manufacture insulin?
4 Sam eats a chocolate bar at morning recess and eats nothing else until she returns home at 4.00 p.m. Briefly describe how her body controls the glucose levels in her blood.
5 How does the nervous system work in partnership with the endocrine system?

Chemical controls in other organisms

How plant growth factors shape their growth

Because dead cells, particularly xylem, contribute to the functioning parts of flowering plants (angiosperms), plants cannot change their shape once these cells are mature (Unit 2). Only living cells that lack secondary thickening are plastic enough to be able to change their shape. However, form can be changed by pruning. 'Pinching' the tips of the leading shoots (Figure 3.20) immediately stimulates the growth of auxiliary branches, resulting in a bushier plant.

Plant growth substances are very different from animal hormones. For example, the chemicals are not secreted from identifiable structures. While tiny changes in animal hormones can have extreme effects, the concentration of plant growth substances needs to change by several orders of magnitude to affect plants. Finally, positive and negative feedback loops are difficult to detect in organisms without nervous or circulatory systems.

Nevertheless, there are compounds that increase and decrease in concentration with seasonal changes, and when applied to plants artificially, they have consistent effects. These five groups of compounds are usually called 'plant hormones' (Table 3.1).

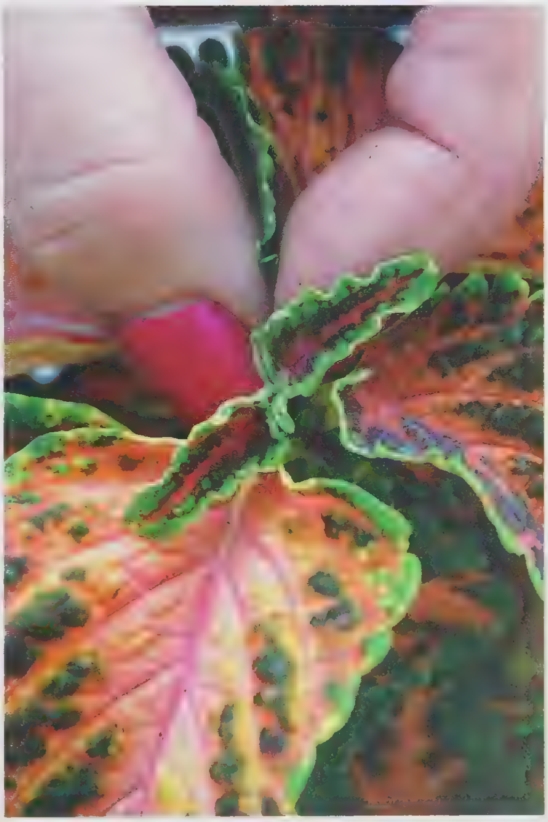


FIGURE 3.20 Gardeners often stimulate branching by pinching off growing shoots.

TABLE 3.1 Five important groups of plant growth substances

[illegible]	[illegible]		
Auxins	Cell elongation, cell wall maintenance, seasonal responses	Associated with growing	
Cytokinins	Cell division and multiplication, budding and flowering		
Gibberellins	Cell elongation and growth (particularly in dwarf varieties of plants)		
Abscissic acid	Inhibit the effects of auxins, cytokinins and gibberellins Stimulate ripening, leaf fall, dormancy	Associated with senescence, maturation	
Ethylene	Stimulates ripening and flowering		

The further away from the growing tip they are, the bigger the auxiliary (side) branches are. This is because the auxin produced by the tip inhibits their growth, and you are observing the effect of a concentration gradient. The lowest, most distant branches receive the lowest amounts. 'Pinch pruning' plants removes the apical meristem that is the source of auxins. As a result, the concentration gradient vanishes and the growth of side branches is no longer inhibited.

Tropisms

Tropisms refer to movement towards or away from a stimulus. What do you think the prefixes of these plant tropisms refer to?

- Positive *helio*tropism of sunflowers and other species (Figure 3.21)
- Positive *photo*tropism (towards light) of shoots
- Positive *geo*tropism or *gravi*tropism, positive *hydro*tropism, and negative *photo*tropism of root
- Positive *thigomo*tropism observed in the tendrils of vines such as morning glory.

FIGURE 3.21 Where is the Sun in relation to the camera?

You may have noticed plants on your windowsill leaning towards the light. How do they 'know'? The meristems in the tips of shoots produce auxins, which are translocated in the phloem. Because auxin is broken down by strong light, there will be a higher concentration in cells on the shaded side of growing stems. As a result, the shaded side of the stem will elongate more rapidly, causing the plant to bend towards light.

One explanation for geotropism is the effect of gravity on small organelles called amyloplasts, which contain starch grains. As the amyloplasts move under the influence of gravity, they somehow help the root sense the direction of the force.

CRITERIA B AND C

INVESTIGATION 3.2

Investigating tropisms

Several explanations are sometimes applied to the same observations of plant responses, particularly in the case of plant roots. Are these explanations consistent for all species? Are the effects of the mechanisms additive? Are some of the mechanisms more sensitive?

YOUR TASK

How can you design an investigation that can differentiate between at least two of the proposed mechanisms for root tropism; for example, phototropism and geotropism?

THIS MIGHT HELP

It is suggested you use roots of germinating seeds for your investigation. Why? Either use a dicot with tap roots (e.g. radish, mung bean) or consider pruning the roots of a germinating monocot (e.g. wheat or grass) down to just one root. These species all tend to germinate fairly quickly at room temperature.

How will you grow your seeds so you can observe the tropism of the roots? There are many methods, such as growing them in clear agar or in sealed plastic CD cases. Your approach needs to be consistent and replicable.

Discuss your suggestions with your teacher, to ascertain the availability of equipment and the time you need.

Write up your investigation by following the guide in the Appendix 3 on page 209 or as advised by your teacher.

Control of societies and individuals by external chemical signals

Many animals, particularly insects, communicate socially using very specific externally transmitted chemicals called **pheromones**. Moths and other insects may use pheromones to signal sexual availability over large distances, perhaps many kilometres. Some plants mimic these pheromones to attract pollinators (Figure 3.22).

FIGURE 3.22 An orchid mimics wasp pheromones to attract its pollinator.

Social insects are some of the most numerous animals on Earth. Colonies of ants, termites, bees and wasps consist of very closely related individuals that work as a unified organism. Like the organs in an organism, particular 'castes' of social insects have specialised roles. The colony is unified through the use of pheromones. For example, at a simple level, these chemicals are used to mark trails used by ants towards food. The more ants use the trail, the stronger is the signal. As the food is depleted, fewer ants visit and the signal weakens. At a more complex level, pheromones control the shape and behaviour of all the individuals in the colony.

ENVIRONMENTALLY FRIENDLY PEST CONTROL

Pheromone pest traps represent a species-specific strategy for controlling pests. Commercial pheromones need to be purchased but are cost-effective because only tiny amounts are needed. Alternatively, you could use a pest's own pheromone to good effect.

Find out if pheromone traps are used in your area. Fruit-boring moths may be lured into a blind trap or onto a sticky surface using a synthetic sex hormone. Other insects that may be controlled in this way are beetles, weevils and cockroaches in stored food. Can you offer your services to help make or assemble traps?

REVIEW

1 In a table, list the similarities and differences between the overarching communication systems of animals and plants.
2 In what way is a tropism different from a nervous or endocrine response?
3 Tomato plant gardeners usually prune the lateral buds off seedlings until they are left with just one or two main stems. Suggest how this may result in a stronger vine with fewer, bigger fruit.
4 How do plants' experiences change them?
5 Do plants have hormones?
6 In what ways do pheromones resemble hormones?
7 Why do you think scientists and mathematicians studying complexity theory are interested in social insects?

An evaluation of implications of complexity levels

You will by now be very familiar with the biological levels or organisation: cells, tissue, organs, organ systems, organisms. This unit has also suggested that there may be further levels: the social organisation of insects and the flock behaviour of birds in flight.

Emergent behaviour refers to the idea that every level of complexity has new properties. A living cell is more than a collection of biomolecules. Organs have more properties than their tissues, and societies are more than the individuals they are composed of. The whole is not just a sum of the parts that it is made of; it is different, and often has unpredictable, unprecedented properties. Just as chemistry acquires biological properties in cells, the behaviour of individuals acquires sociological properties in groups. Crowd behaviour, voting patterns and even historical cycles of war and peace have all been analysed as examples of emergent behaviours.

Systems are dynamic, and a feature of emergent behaviours is that they are adaptive. This means the system itself can feed back on the component parts, and change their behaviour. Think of the way organisms respond to their environment – light, heat, food and so on – for survival. The process of homeostasis, which keeps the conditions within the body within a narrow range, is about using feedback from the level above or below to maintain a steady state. During the 1970s James Lovelock proposed the **Gaia hypothesis**, which describes the Earth itself as a self-regulating, complex system that keeps the planet's conditions suitable for life. And it may be the case, that when the stimuli vary within a small range, complex systems are able to adapt constantly. The outcome is to keep the system in balance.

The term '**butterfly effect**' summarises how a tiny condition, such as a hypothetical insect beating its wings, contributes a ripple effect that eventually leads to a hurricane. The butterfly effect describes another type of behaviour found in complex systems: unpredictability. Sometimes, an accumulation of conditions may lead to a 'tipping point'. The resulting is **chaos**, causing the system to break down. In health science, the pathology of disease has been described as a state of chaos within an individual. If conditions drift outside the range set for homeostasis, into chaos, the organism may even die. Applied within populations, the emergence of disease epidemics are examples of chaos.

Although complexity theory is a developing system of knowledge, it is informing the way patterns are analysed in many systems, and is already providing constructive insight for management of heart disease, bipolar disease and epilepsy.

REVIEW

1. What is the relationship between complexity theory and the organisation of our bodies?
2. What is an emergent behaviour?
3. Are all human behaviours emergent?
4. Use the example of homeostasis to describe the difference between feedback that results in a system maintaining a 'steady' state and feedback that leads to 'chaos'.
5. In any of the examples listed, do the effects of one complex system interact directly with levels that are more than one level above or below?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State the differences between a:
   a plant cell and an animal cell
   b hormone and a pheromone.

2 Bakar accidentally touched the hot steel handle of a saucepan, and immediately withdrew his hand. Suggest how his nervous system protected him.

3 Reflex actions are rapid and involve movement, but planning the structure of a piece of writing like this sentence requires no movement at all. Which of these activities do you think involves more neurons, and why?

LEVEL 3–4

4 Copy and complete the following table to outline the differences between communication by the nervous system and the endocrine system.

Feature	Nervous system	Endocrine system
Means of communication		
Transmission		
Speed of transmission		
Response to a stimulus		
Relayed to		

5 Geoff put his hand on a pin that had been left on the table in his classroom. How might his response be affected if the following parts of his reflex arc were not functioning?
   a Sensory nerve
   b Motor nerve
   c Spinal cord below the entry of the sensory nerve

6 Two neighbours are competing to grow the densest hedge.
   - Roger plants his bushes 20 cm apart and lets them grow without pruning.
   - Bill plants his bushes 40 cm apart and prunes the top third every 6 months.

   Make a scientific judgement to predict which gardener will have a better hedge in:
   a 2 years' time
   b 10 years' time.

LEVEL 5–6

7 Describe the difference between positive and negative feedback. Give an example of each.

8 Your brain is encased in a rigid skull, and the spinal cord is encased within a more flexible series of backbones. The CNS is bathed in fluid that is enclosed in a waterproof membrane, the meninges.
   a Explain how these structures give maximum protection to the CNS.
   b Suggest why cyclists, motorcyclists, horse riders and canoeists are strongly encouraged to wear protective helmets.
   c Why can't all people engaged in these different sports and activities wear the same kind of helmet?

9 Figure 3.23 shows a carpal tunnel operation in progress. The carpal tunnel is like a tube that is located in each wrist. The nerves to your hands are threaded through this 'tunnel'. If this gets compressed too much, the affected hand will often get pins and needles, sometimes become numb and will not work as well. An operation can relieve this pressure and restore full use of the hand.

FIGURE 3.23 Making more room: carpal tunnel surgery

   a Describe what a nerve is.
   b Suggest why the nerves to your wrist are housed in a tunnel.
   c Make a scientifically supported judgement about the advantages of having so many different types of sensory receptors in your fingers.

LEVEL 7–8

10 Explain why:
   a complex multicellular organisms need communication systems
   b it is important that some messages from your hand bypass the brain, at least at first.

11 If someone tickles your foot, which system is responsible for your reaction? Explain the reason for your choice.

12 The role of your thyroid gland is to control your metabolism using the hormone thyroxin.
   a What do you think happens if too much or too little thyroxin is released?
   b How do you think this would affect the individual?
   c Judge whether thyroxine release is likely to be controlled by a positive or negative feedback mechanism.

13 a Predict three consequences of having the nerves to your hand cut in an accident.
   b After burning your fingertips in an accident, when they recover they first feel numb, but after about a week or two, their sensitivity returns. How do you explain this observation?

REFLECTION

1 Have your ideas about the debatable questions changed during this unit?
   a Is form more important than function?
   b Is there such a thing as a 'normal' body?
   c Is there a limit to complexity?

2 This unit is based around the key concept of systems.
   a Within organisms, in what ways is every level of organisation more than its parts?
   b List examples of how the external environment can impact on a complex system like an organism.
   c List examples of how the internal environment may help a complex system, such as an organism, maintain homeostasis in a changing environment.

3 Form and function are related concepts in this unit.
   a Explain how at the cellular level, form contributes to the coordination of animals and plants.
   b Explain how biomolecules function to contribute to the coordination in animals and plants.

4 Movement was another related concept.
   a At what levels of organisation in an animal (cells, tissues, organs etc.) does movement contribute to function?
   b How does your answer to part a compare with the levels of organisation movement contributes to in plants?

5 Balance is another related concept. List examples of how complex systems remain balanced.

6 Are complex multicellular organisms possible without coordination and communication?

UNIT 4

REPRODUCTION

KEY CONCEPT

Relationships

RELATED CONCEPTS

Patterns

Interactions

consequences

GLOBAL CONTEXT

Identities and relationships: an exploration of the human context for raising a family

STATEMENT OF INQUIRY

Nurturing the next generation sustains species.

INQUIRY QUESTIONS

FACTUAL

1. How do organisms reproduce?
2. What are the advantages of sexual reproduction?
3. What is the role of sex hormones in reproduction?

CONCEPTUAL

4. Where does reproduction fit in the cycle of life?
5. How do embryos develop?
6. Why does infertility occur?

DEBATABLE

7. Should humans control their fertility?
8. Should societies limit access to artificial reproductive technologies?

SUMMATIVE PERFORMANCE ASSESSMENT TASK

How will we deal with our infertility?

Background

Modern couples sometimes spend the early part of their married life focusing on their careers, to create a firm financial and material base for their families. However, by 40 years of age most women's fertile years are coming to an end, and the babies they have are at higher risk of having serious genetic conditions. Men's sperm quality also accumulates genetic errors. After 12 months of 'trying for a baby' without success, a couple is considered **infertile**.

Your task

Write a short play of 1200 words about how a couple approaches their experience of infertility, and how they reach a decision to accept or resolve it. The content of your play should:

1 explain how science is applied to determine the cause (if any) of infertility, and describe how at least two assisted reproductive technologies may be able to provide a solution to the condition

2 discuss and evaluate how at least one of the following factors of the technology is viewed in their community – moral, ethical, social, economic, environmental, political or cultural. Discuss how this interacts with the couple's eventual decision.

The presentation of your play should be correctly formatted, including stage directions. To keep the language appropriate, it is recommended that you avoid lengthy definitions within the dialogue and include, on a separate sheet (a) a glossary of scientific terminology, and (b) a bibliography of your sources, acknowledging the work of others.

Your teacher may ask you to perform readings with your peers of a selection of plays to demonstrate the application of a range of assisted reproductive technologies and the diversity of responses to their use by individuals and their communities.

MEDIA LITERACY
Media literacy is about your critical evaluation and interpretation of media messages. An example would be recognising how your own biases, opinions and values are affirmed in your own play about an emotional or sensitive issue.

Introduction

One of the key characteristics of life is reproduction. All organisms, from microscopic bacteria to humans and even giant trees have a limited lifetime, and develop, age and eventually die. Every cell originates from another existing cell. That is the basis of biological sciences. The continuity of successive generations is the basis of human culture.

ACTIVITY

In teams of two or three, select one of the following organisms: snake, aphid (greenfly), earthworm, snail, cat, fern, frog, banana, rose, corn, titan arum lily, monitor lizard, armadillo, bird, bee.

Use a search engine to find information about its life cycle. Assemble a brief electronic slide show (no more than 3 minutes) of no more than two or three slides to share this information. Acknowledge diagrams or images by simply listing the source (URL) on the final slide.

Present the information to other members of the class.

1 Do any organisms in the list have very different life cycles compared to what we know about humans?

2 Does this information about other organisms produce the same type of emotional response that you or your peers have to human reproduction? Why is that, do you think?

3 An organism's '**reproductive capacity**' is its ability to replace its own generation. If comparing the size of the parent population with the size of the population of offspring, what do you conclude about the reproductive capacity of all the organisms listed?

Exploring patterns in asexual and sexual reproduction

The time taken to create a new generation, or **offspring**, is termed the **generation time**.

There are two ways by which living organisms reproduce: asexual and sexual reproduction. **Asexual reproduction** depends on only one parent organism, and the offspring produced are genetically the same.

The **DNA** found in the nucleus is a chemical 'instruction manual'. It determines the characteristics of an organism, including its appearance, its body structure and even the enzymes that help it digest its food. In some organisms, it is found in lengths called chromosomes (Figure 4.1), which come in pairs. In other organisms, such as bacteria, it is a found as a single loop. Units 5 and 6 discuss DNA in more detail.

Asexual reproduction produces offspring that are **clones** of their parent. Little mistakes known as **mutations** can sometimes occur when DNA is copied and these introduce variations that can then be passed on to the next generation. However, most of the time, the DNA is copied exactly, so that when the cells divide, they produce cells identical to their parents.

FIGURE 4.1 A schematic diagram of DNA

Asexual reproduction across groups of organisms

Binary fission

Single-celled organisms, such as bacteria, protozoa and amoeba, usually reproduce asexually by a process of cell division known as **binary fission**. This literally means 'splitting in two'. Two new daughter cells are made, but the parent cell no longer exists.

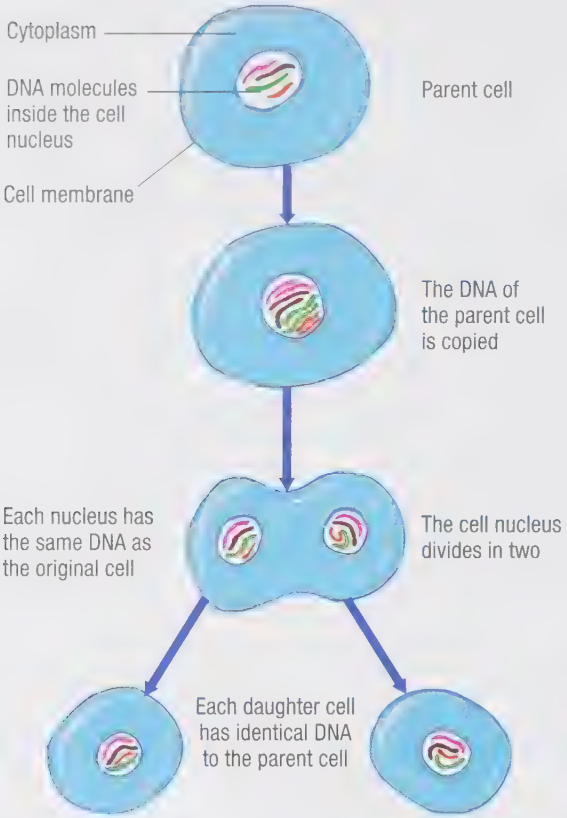


FIGURE 4.2 Binary fission in an amoeba – a schematic diagram

This is shown in Figure 4.2. This allows these organisms to reproduce quickly when environmental conditions are favourable.

Binary fission can happen very quickly. Depending on the species, in some bacteria it may take just 20 minutes. In complex cells, such as amoeba (Figure 4.3), it can take longer.

Budding

Yeasts can reproduce asexually by **budding**. Yeasts are single-celled organisms that belong to the Fungi kingdom. In yeasts, a bud forms on the wall of the parent cell. At the same time, the DNA in the nucleus makes a copy of itself. The nucleus then divides in two – one nucleus moves into the bud and the other stays in the parent. The bud may then detach from its parent or remain attached. An attached bud may grow another bud on itself. This can keep going until a long chain of yeast cells is eventually produced. Under favourable conditions, each parent cell can produce thousands of daughter cells in a very short time.

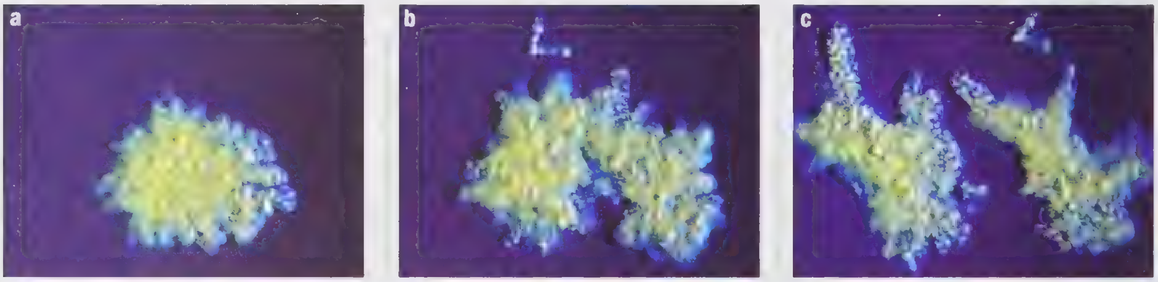


FIGURE 4.3 (a) The amoeba begins to grow (b) Cell division begins (c) Two new daughter cells are formed

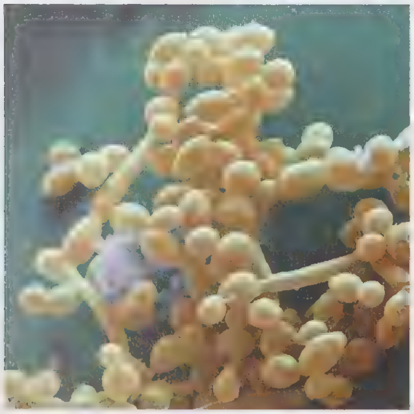


FIGURE 4.4 Budding in yeasts

Multicellular organisms and clones

Simple multicellular animals such as hydra, which are microscopic freshwater organisms, can also reproduce asexually by budding (Figure 4.5). (Hydra are also capable of **sexual reproduction** without a mate, if the environmental conditions are suitable.) When a hydra is cut in two, the pieces will regenerate as two complete hydra. **Regeneration** is the ability to replace a lost or damaged organ or part by forming new tissue. Many invertebrates and even some vertebrates can regenerate some of their parts.

Many types of plants commonly reproduce asexually. For example, the offspring produced from runners, suckers, bulbs, corms or cuttings will have cells that are identical to those of the parent and are therefore clones. These organisms can be very large and long-lived.

Cloning animals using assisted reproductive technology aims to increase the population of exceptional livestock and, very rarely, even pets. The nucleus of an **egg** from a female animal (the 'egg donor') is replaced with the nucleus from a body cell from the desirable animal (the 'genetic donor'). This cell is then transferred to a surrogate mother, who gives birth to a young animal that is genetically identical to the desirable animal. Since 2008, the US Department of Agriculture (USDA) has approved cloned animals as safe for the food supply. At least 30 different animal species have been reproduced this way.

FIGURE 4.5 This hydra has developed a bud

Regeneration

FIGURE 4.6 Rainbow left, is the genetic mother of the cloned kitten, Cc or 'Copycat'. Notice how Cc's fur pattern is not identical to Rainbow's. Cc has grown up to be a normal cat, and has had several litters of her own.

CRITERIA B AND C

INVESTIGATION 4.1

Investigating the growth of yeast

YOUR CHALLENGE

To investigate how to control the growth of yeast.

THIS MIGHT HELP

Test one variable that affects the reproduction rate of yeast. Decide how you will measure the rate of growth. Design a fair test of your variable.

Discuss your suggestions with your teacher, to ascertain the availability of equipment before you start. Conduct your investigation.

After collecting and evaluating your data, remember to consider the validity of the method, and describe improvements to the method.

Write up your investigation following the guide in Appendix 3 on page 209 or as advised by your teacher.

Sexual reproduction

Sexual reproduction requires two parents who each contribute half their DNA (detailed in Unit 5) to their offspring. This form of reproduction is used by almost all the complex organisms, particularly animals and plants (many of which can also reproduce asexually). Both parents produce sex cells, known as **gametes**, which contain half the DNA that is present in their other body cells. A gamete produced by a male is called a **sperm** and a gamete produced by a female is called an **ovum** (plural ova) or egg.

When a sperm fuses (joins) with an ovum, this is called **fertilisation**. A new cell or **zygote** is produced. The zygote contains a complete set of DNA – half from its father and half from its mother. This single cell keeps dividing, gradually developing into a **foetus** (Figure 4.7).

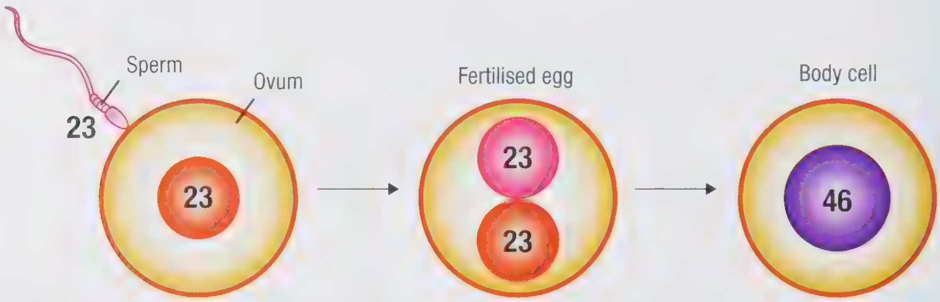


FIGURE 4.7 Fertilisation restores the total number of chromosomes. Each human gamete has 23 chromosomes. All other cells in your body have 46 chromosomes

Sexual reproduction always results in variable offspring being produced. Each gamete has a different set of possible combinations of DNA. Each zygote is the result of a chance meeting of one particular sperm and one particular ovum. Even though you may look like one or both of your parents, the set of DNA molecules in your body cells will be unique. No one in the world is the same as you, unless you are an identical twin. Identical twins occur when a fertilised ovum splits in two. Fraternal twins occur when two different ova have been fertilised by two different sperm. This means their DNA is not identical. It is like having a brother or sister who is born at the same time.

FIGURE 4.8 This three-dimensional ultrasound scan is clear enough to allow us to see possible malformations. If all goes well, in approximately 12 years this foetus will be at secondary school.

Sexual reproduction in plants

Flowers are the reproductive organs of **angiosperms**, the group to which 80% of plants belong. Flowers may contain male parts, female parts, or both. The male part of the flower is the **stamen**. It consists of an anther and a filament. The female part is the **carpel**. It consists of the ovules, the ovary, the style and the stigma (Figure 4.9). The female gametes are called **eggs** or ova. They are formed in the ovules, which are in the **ovary**. The male gametes are found in **pollen**. Pollen is produced in the pollen sacs in the anther at the top of the filament.

Plant sperm is not **motile** (able to move), and therefore plants often rely on wind or animal vectors to help the pollen reach the sticky stigmas. When pollen is transferred from the anther

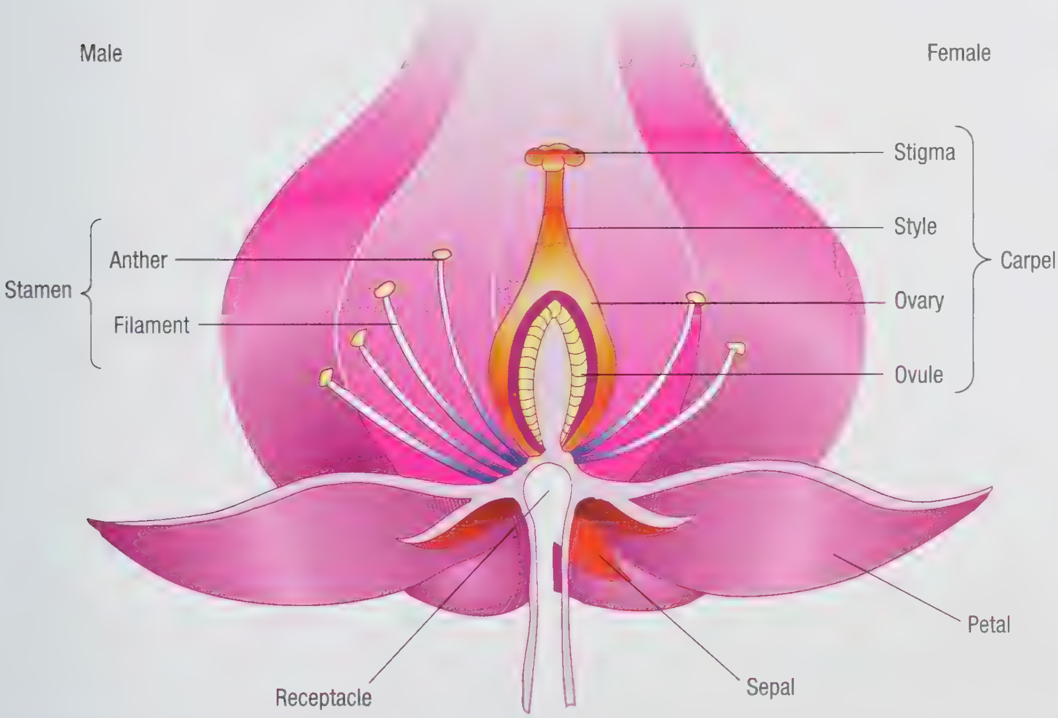


FIGURE 4.9 A generalised flower, showing both male and female parts

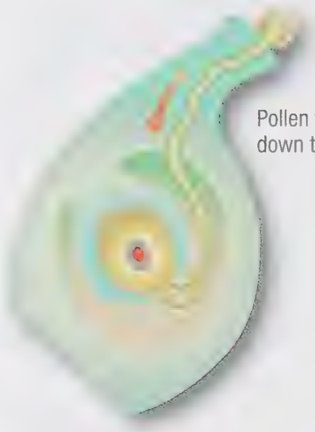


FIGURE 4.10 A pollen tube growing down into the stigma of a flower to an egg cell

to the stigma, we say **pollination** has occurred. If the pollen is from the same flower, this is described as **self-pollination**. If it is from a different flower of the same species, this is described as **cross-pollination**. In response to the sugary chemicals in the stigma, a structure called a **pollen tube** grows from the pollen grain down the stigma towards the ovary (Figure 4.10). Sperm is carried inside the tube, close to the tip. Once it reaches the ovary, the tube penetrates an ovule, where it releases its contents near an egg cell and fertilisation occurs. The tube disintegrates.

Observing the growth of pollen tubes

EXPERIMENT 4.1

Plants usually grow too slowly to observe evidence of movement, but you may actually be able to see pollen tubes germinate and elongate during a long lesson!

AIM

To observe pollen tube germination.

MATERIALS

- 10–20% sucrose solution
- fresh flowers (such as daffodils, lilies and geraniums and local examples, such as flowers from weeds)
- light microscope (100× magnification minimum)
- concave slides and cover slips
- Petri dishes

PROCEDURE

This is a good time to review the anatomy of several types of flowers as variations on the general flower in Figure 4.9.

1. Use the sugar solution to prepare a wet mount of the pollen on a concave slide. Sometimes placing a crushed, mature stigma from the same species of flower on one side of the concave sample is helpful.
2. Observe the pollen briefly at 15-minute intervals.
3. Between observations, 'store' it away from the hot microscope light in a covered Petri dish.

RESULTS

Many conditions determine whether pollen will germinate. If the pollen is the right age and the sugar solution the right concentration, you may observe germination within 15 minutes. You may even be able to calculate the rate at which the pollen tube grows.

DISCUSSION

Would you expect pollen to germinate if the sugar solution is contaminated with crushed parts of a stigma from an unrelated species? Why or why not?

REVIEW

1 What is the main purpose of reproduction?
2 What is DNA and what does it do?
3 'Binary' means consisting of two parts. 'Fission' means splitting. Explain why binary fission is a good name for the process.
4 Imagine that a single bacterium lands in an open carton of milk. After half an hour, it splits in two and becomes two bacteria. After another half an hour the two bacteria become four. Draw a graph to show how the numbers grow over 5 hours.
5 Explain why regeneration can be useful for survival.
6 Are asexually reproducing species immortal?
7 What is the main difference between the offspring from sexual reproduction and those from asexual reproduction?
8 When viewing images of parents of various species together with their offspring, which organisms really seem to 'care' about their children? Why do you think that is the case?

Explaining the cycle of life in complex organisms

When we plant a tomato seed, we do not expect to be able to harvest the fruit straight away. In complex organisms, a generation involves a predictable pattern of changes characterised by growth and development, maturation and sexual reproduction, which is followed, in nearly all species, by decline and death soon after the youngest generation can survive independently.

As a highly social species, humans have developed diverse and complex cultures, which can change the pattern. Our societies include fertile individuals who choose never to reproduce, and medical technology extends the lives of many. Can these choices we make affect our biology?

The life cycles of the two human sexes are very different. Although men can remain fertile throughout their lives, the fertility of human females declines about halfway through their lifespan. There has been much debate about the possible biological advantage of **menopause** for our species. It has been suggested that human infants need an exceptional amount of care. In our long pre-history, when human societies depended on hunter-gathering, menopausal females provided vital support for their families. Unencumbered by their own offspring, they helped supply extra food and childcare, increasing the chances of the survival of their grandchildren. Menopause has been discovered in only one other species and this is another intelligent social animal: the pilot whale.

Let's take a closer look at the human pattern of development.

From cells to baby

Embryonic stage

After fertilisation, the zygote divides and develops for a few days as a **morula**, a solid ball of cells. This then shapes itself into a hollow ball called a **blastocyst**, the structure that reaches the **uterus** and settles into the lining of the womb. The blastocyst's inner layer of cells develops

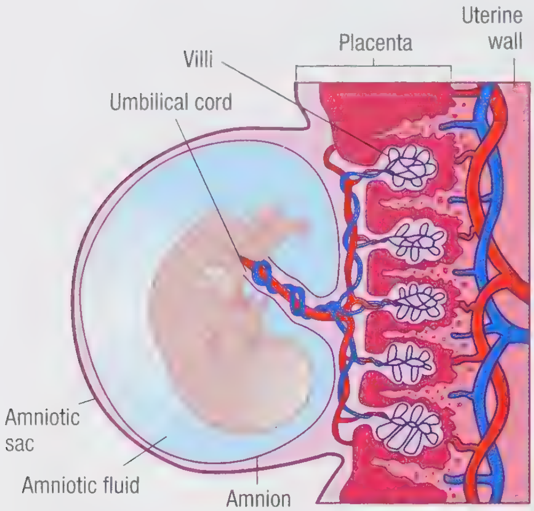


FIGURE 4.11 The organisation of an embryo, the umbilical cord, the placenta and the uterine wall

into an **embryo**. During this early stage of development these cells are already beginning to specialise, forming tissues and organs. The blastocyst's other layer of cells develops into support tissues that will nourish the embryo, including the **placenta**. When the embryo is about 4 weeks old, the **umbilical cord** that connects it to the placenta starts to form (Figure 4.11).

The **amniotic sac** forms around the embryo. It is filled with **amniotic fluid**, which helps protect the embryo from any impact or infection and keeps it at a constant temperature (Figure 4.12).

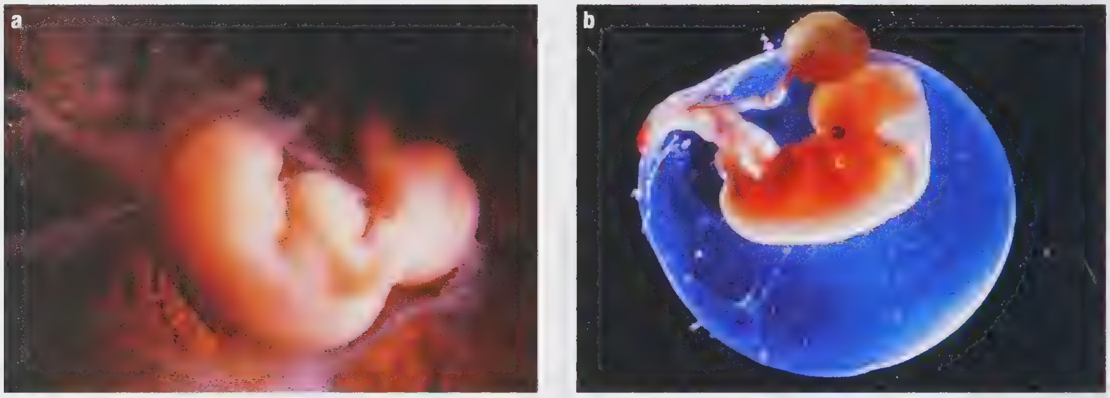


FIGURE 4.12 (a) A 28-day-old embryo. It is only about 5 mm long. A line of cells along its back will become its spinal cord. At this stage its heart starts to beat and other major organs also begin to form. (b) A 6-week-old embryo. It is about 15 mm long. Its eyes, mouth, nose and limb buds begin to form.

The placenta: a special, temporary organ

The placenta is a key feature for classifying mammals, the class of vertebrates that feeds its young milk from **mammary glands**. We belong to the subclass of placental mammals, along with dolphins, cats, dogs and other familiar mammals that give birth to quite large, well-developed offspring. Marsupials, for example Australian koalas and kangaroos and American opossums, have only very rudimentary placentas or none at all. Their offspring can only absorb nutrients by simple diffusion, and are born undeveloped, as embryos. They leave their mother's vagina and climb up to their mother's nipples in her pouch, to continue developing while being nourished by milk. Monotremes, represented by the platypus and two species of echidna, form the third subclass of mammals. Their embryos develop in eggs.

The offspring of placental mammals can develop inside the uterus because the placenta grows to support the foetus. The placenta allows the exchange of nutrients and wastes between the foetus and its mother's blood supply. The developing baby is supplied with oxygen, hormones and nutrients. Carbon dioxide and other waste products are removed. This happens in a very similar way to how gases are exchanged between air and the blood in the lungs (Unit 2), but instead involves two sets of capillaries running side by side.

The mother's blood never comes in contact with the blood of the developing offspring. This is very important because in sexually produced organisms, the baby is genetically different from the mother. There could be a risk that the mother's immune system would treat it as 'foreign', which is dangerous for the baby. The placenta also incorporates an important structural principle often found in biological systems where exchange happens – **countercurrent flow**. This means the fluids in the two systems flow in opposite directions. This maximises the difference in concentration between materials that need to diffuse between them, a condition that increases rates of exchange.

FIGURE 4.13 A 4-month-old foetus. All of its vital organs are now formed. Notice its fingers and toes. It is now about 250 mm long and its sex should be able to be determined in ultrasound pictures.

FIGURE 4.14 A 6-month-old foetus. Skin and downy body hair have now developed. Sense organs have begun to differentiate. Its face is now fully formed, although its cheeks are still hollow, making its eyes appear enormous. Now about 360 mm long, it will stretch and move around.

Gestation period

Human pregnancy is approximately 9 months long. For convenience, we divide it into **trimesters** (3-month periods). The most rapid changes occur in the first trimester. About halfway through the first trimester, the embryo starts to look human and is then called a foetus. The second and third trimesters mainly involve the growth of the foetus and preparation for birth. The time it takes for an offspring to fully mature before it is born is termed the **gestation period**.

Finding out about the offspring before birth

Boy or girl?

At about 4 months of gestation, parents can have an ultrasound to discover the sex of their baby. Usually sex cannot be visually determined until 10–12 weeks after fertilisation. Before this stage, boys and girls have the same type of simple basic sex organs, or **gonads**. The sex of the developing foetus depends on a single protein, the **H-Y antigen**. If this protein is present, the gonads turn into **testes**, and begin to secrete the hormone **testosterone**. The release of testosterone starts the formation of the penis and other male characteristics. If H-Y antigen is not present, the primitive gonads develop into female reproductive organs and begin secreting oestrogen, which starts the formation of ova.

Sex is a genetic characteristic determined by its father, not its mother (see Unit 4). Usually about half the sperm contains the DNA information for developing a boy, and the other half a girl. This is why, over the whole population, about half the babies born are girls and half are boys.

Genetic abnormalities

Amniocentesis and **chorionic villus sampling** (CVS) are tests that can identify genetic abnormities during the first trimester of pregnancy by sampling foetal tissues. Amniocentesis involves removing a small amount of amniotic fluid. CVS extracts a sample of placental tissue, the 'chorionic villi'. The foetal DNA can then be examined for known causes of abnormalities.

These tests pose risks for the foetus and are therefore not taken routinely unless the risk of a genetic abnormality is high. For example, the risk of having a child with Down syndrome is higher in mothers aged over 35.

TA VOLUNTEERING SUPPORT

All communities include children who have special needs, conditions perhaps caused by genetic or environmental conditions. Members of your family or neighbourhood may attend particular classes in your school, or may need the support of an organisation dedicated to their interests. Is there a way you can make a difference to them and their families? The experience could open a new world for you.

FIGURE 4.15 A newborn baby – the umbilical cord will be cut and the remaining part will dry and drop off

Birth: the transition to independent life

Towards the end of gestation, hormones in the placenta and baby's pituitary trigger the beginning of labour in the mother. Strong regular muscular contractions build up, resulting in the entry to the mother's womb (Figure 4.20, page 96), the **cervix**, dilating (widening), and finally push the baby out. As the baby is being born, the pressure usually causes the amniotic sac to burst. The fluid helps lubricate the baby's passage out. After the baby has emerged and taken its first breaths, the umbilical cord is tied and cut (Figure 4.15). The placenta is pushed out soon after.

The part of the umbilical cord attached to the baby dries and drops off in the next few days. The navel in the abdomen is the scar showing where the umbilical cord used to be.

Multiple births

When more than one baby is born from a single pregnancy, it is known as a multiple birth. The condition may cause the babies to be born prematurely. In humans, each additional baby seems to reduce the usual gestation period of 40 weeks by about 3 weeks. On average, twins are born 3 weeks early and triplets 6 weeks early. Of course, there can be natural variation of a week or more in these estimates. Babies from multiple births tend to be smaller than singletons, even if the pregnancy goes to term. However, the combined weight of the foetuses and their physiological demands are greater than for a single baby, and multiple pregnancies pose greater risks for the mother too.

Assisting babies born too soon

When a baby is born before it has matured sufficiently for survival without assistance it is described as **premature**. The World Health Organization describes a premature human baby as a baby born before 37 weeks.

The tiny bodies of premature babies can lose heat dangerously quickly. Incubators were one of the first technologies to make a difference to their chances of survival. Invented by Alexandre Lion in 1891, they were heated by a water boiler and had their own ventilation systems. At the time, they were considered complicated and expensive, a description that still applies to modern incubators. Incubators can predict signs of distress and organ failure in premature babies before they actually happen. Babies born at 26 weeks of gestation with immature lungs now have a good chance of survival.

ACTIVITY

Ethical issues, political decisions?

In a small group, discuss one of the following scenarios. Brainstorm all considerations and decide your group stance. After 10 minutes, report back to the class.

SCENARIO A

As well as oxygen and nutrients, the placenta allows harmful substances such as drugs, including alcohol, to reach the baby. A mother consuming alcohol during her pregnancy may have a baby with foetal alcohol syndrome. The range of birth defects includes low birth weight, heart defects, facial abnormalities, poor coordination, and even learning disabilities.

Given these risks, should it be considered a criminal offence for pregnant women to drink alcohol? What are her rights?

SCENARIO B

Babies from multiple births have lower chances of survival than babies from single births. However, fertility clinics using **in vitro fertilisation (IVF)** often implant more than one embryo to increase the chances of a successful pregnancy. Just as in natural pregnancies, very rarely an implanted blastocyst may split and result in identical twins.

In January 2009 a woman in California, USA, gave birth to octuplets after IVF.

Should there be a limit to the number of embryos IVF clinics may implant? If so, what should this number be, and why?

REVIEW

1 What is special about menopause in the human life cycle?
2 State the benefits of the foetus growing within a fluid-filled sac.
3 Outline the visible differences between the four embryonic and foetal stages shown in Figures 4.12–4.14.
4 Why is the placenta described as a temporary organ? If humans were not supported by a placenta during gestation, what size would you predict they would need to be at birth?
5 Why do most premature babies need an incubator to survive?

Development to sexual maturity

FIGURE 4.16 The human growth pattern

Growth is the result of asexual cell divisions, but not all parts of the body grow at the same rate. Shape, or body proportion, changes throughout life (Figure 4.16). For example, a newborn baby's head is about a 20–25% the length of its body at birth, and initially grows quickly. Arms and legs grow quite slowly at first and their growth speeds up in later childhood, towards **puberty**. Most humans stop growing in height by their late teens.

ATL

COMMUNICATION

Use and interpretation of graphs for effective communication

on Growth charts

Human diversity

ACTIVITY

Have you ever wondered where you fit in the incredible spectrum of human diversity? The Centre of Disease Control presents population growth data collated by the World Health Organization (WHO) and the USA, including electronic slide shows, graphs and spreadsheets. Many tens of thousands of individuals contributed their personal measurements to this data.

Explore the website to find biodata summaries for people in your age group (2–20 years).

- What is the difference between a percentage and percentile?
- How different are boys from girls?
- How do you explain the different shapes of growth curves for each sex?
- With a trusted friend, measure each other's personal biodata (e.g. height and mass) and find out which percentile you are on.

Puberty and the reproductive system

Although babies and children have complete sex organs, these are not sexually mature until after puberty. As with all aspects of growth, these developments are orchestrated by a cascade of hormones (see Unit 2).

The human male

In males, the journey through puberty takes about 6 years and is controlled by a 'dialogue' of hormones between the brain and the gonads (testes). Stimulated by a message from the hypothalamus, the pituitary gland in the brain produces two hormones that stimulate the development of the testes, which respond by producing testosterone. Testosterone is responsible for male secondary sexual characteristics: chest and facial hair, deeper voices and **libido** (emotional interest in sexual activity).

Producing sperm

Sperm are small, **motile** specialised cells that are made during **spermatogenesis**. After puberty, a man makes approximately 120 million sperm every day. Sperm is made and develops in the testes, located in the sac-like **scrotum** (Figure 4.17). The testes are mainly bundles of thin tubes called the **seminiferous tubules**, which would be more than 500 metres long if unravelled. In the tubules, the **flagella** (tails) are added to the immature sperm. The immature sperm are released into the **lumen** (the hollow centre of the tubules), along with fluid to help keep them nourished. At first they are unable to swim, but as they move towards the **epididymis**, the organ in which sperm are stored, they gradually mature and begin to move their flagella and swim for themselves. The mature sperm are stored in the epididymis until they are released from the body. Sperm can last a few months in this storage before they are re-absorbed by the body.

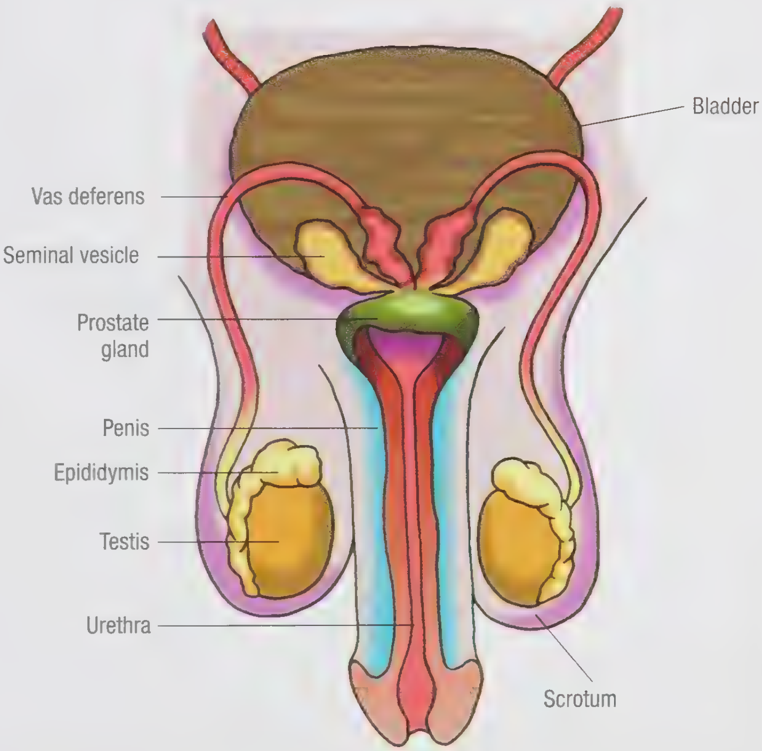


FIGURE 4.17 The reproductive organs of a male (front view in cross section)

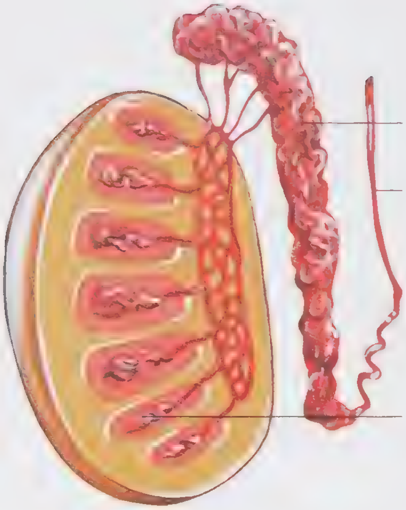


FIGURE 4.18 Close-up view of inside the testes

Releasing sperm

Sperm are released in a process called **ejaculation**. During this process, sperm are first released into the **vas deferens**, a tube that leads up into the main part of the body (Figure 4.18). The **seminal vesicles** and the **prostate gland** then add fluid. The mixture of sperm and fluid is called **semen**. The semen is then released through the **urethra**. In human males, the urethra serves as a channel for the ejaculation of sperm as well as for the excretion of urine. However, a valve ensures only semen or urine can be passed at any one time.

To enable the ejaculated semen to be passed into a female, blood enters specialised tissue in the penis known as **erectile tissue**. This makes the penis become enlarged and firm, which is described as having an **erection**. In this erect state, the penis can be inserted in a female's vagina during **sexual intercourse**. In this way, sperm can be transferred without being exposed to the external environment where they could become **dehydrated**.

Sexual behaviour in other animals

Animals that live in dry environments need to fertilise their eggs internally. Reptiles and most mammals use a penis to mate. Fish and amphibians rely on their watery environments for their gametes to meet in a process called **external fertilisation**. The females tend to **spawn** large numbers of eggs, which are fertilised by males who deposit their sperm into the water nearby.

The human female

In females, the journey through puberty takes about 4 years and is also controlled by a 'dialogue' of hormones between the brain and the gonads (**ovaries**). Stimulated by a message from the hypothalamus, the pituitary gland in the brain produces two hormones, **follicle stimulating hormone (FSH)** and **luteinising hormone (LH)**, which work cyclically to stimulate the ovaries to produce two other hormones, **oestrogen** and **progesterone**. Both these hormones coordinate the development of the female secondary sexual characteristics: smooth skin, hips and breasts, and menstruation. The underlying pattern of communication between these four hormones resembles the pattern seen in males, with elaborations because the female reproductive system plays different and far more involved roles in the formation and early development of a human baby.

FSH stimulates the development of the **follicles** where the ova are. It also causes the release of oestrogen from the ovary, which stimulates the lining of the uterus to thicken. Oestrogen has two feedback effects. First, it inhibits the production of FSH (therefore preventing too many eggs ripening at once). Second, it stimulates the production of LH, which causes an ovum to be released, a process called **ovulation**. After ovulation, the follicle becomes a new structure – the **corpus luteum**. The presence of LH causes the corpus luteum to release the second hormone, progesterone. Progesterone maintains the lining of the uterus, and inhibits the production of FSH, to prevent further ovulation.

What happens next depends on whether the egg becomes fertilised.

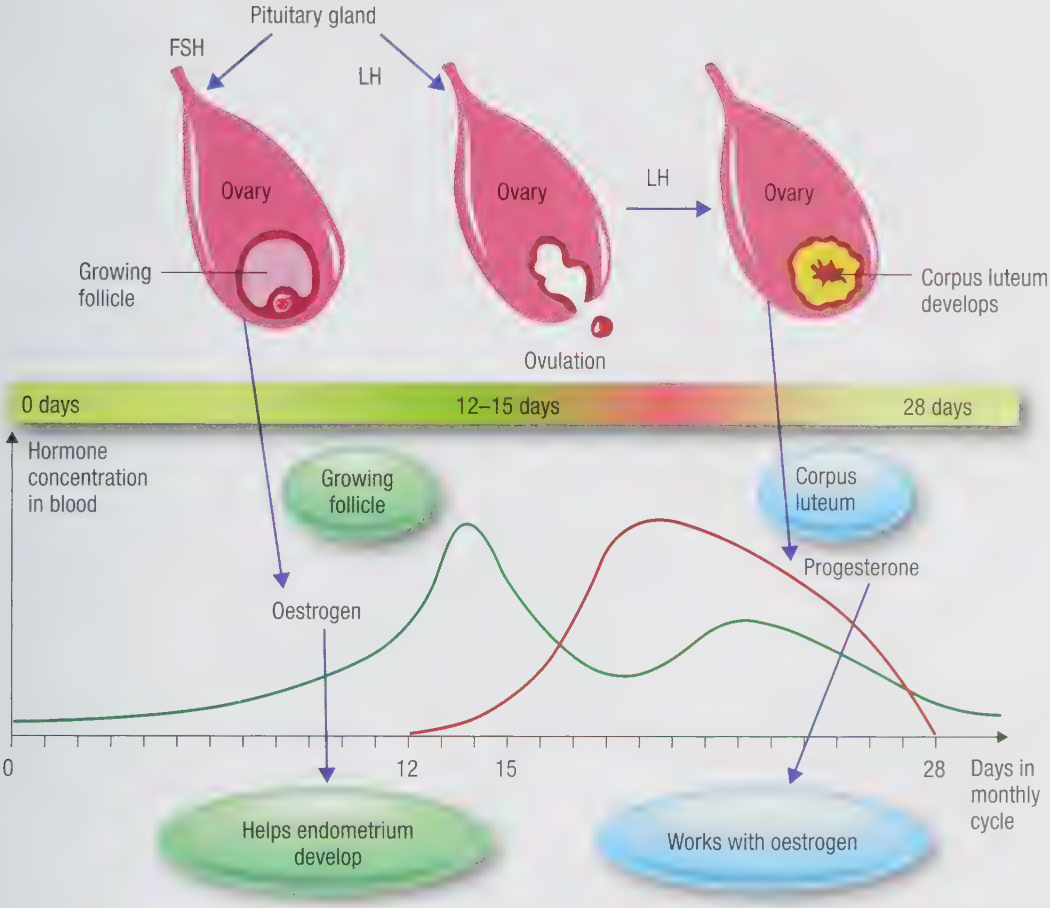


FIGURE 4.19 A visual representation of the hormonal control cycle

Producing ova

A human ovum is smaller than the size of a printed full stop. It is produced and stored in the ovary. At birth, a female has several hundred thousand partly formed ova. Most of these disintegrate over time. The remainder continue forming until the girl reaches puberty, usually between 8 and 15 years of age. At puberty, the mature ova begin to be released, usually one a time. This process stops when the woman reaches about 50 years of age – a phase known as menopause.

How the fate of the ovum determines the menstrual cycle

The menstrual cycle lasts approximately 28 days. By convention, we begin counting the cycle with the breakdown of the lining of the uterus, the **endometrium**. This is easily observed as a flow of blood from the vagina, a process is called **menstruation**. The bleeding can last about a week and is commonly called a '**period**'.

The ovum is released 14 days before the end of the cycle, or halfway through a 28-day cycle. The released ovum travels slowly down the **oviduct** (Figure 4.20) towards the uterus. An ovum can wait at the end of the oviduct for about 3 days for sperm to reach it before it is 'swept' down into the uterus.

If the ovum is unfertilised during a cycle, it will not **implant** in the endometrium. The corpus luteum in the ovaries breaks down and, therefore, the progesterone levels decline. As a result, the endometrium is no longer maintained. Instead it also breaks down to become menstrual blood.

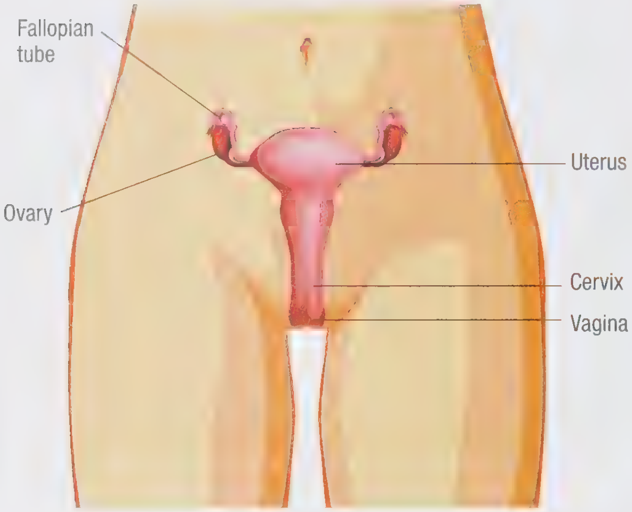


FIGURE 4.20 The reproductive organs of a female (front view in cross section)

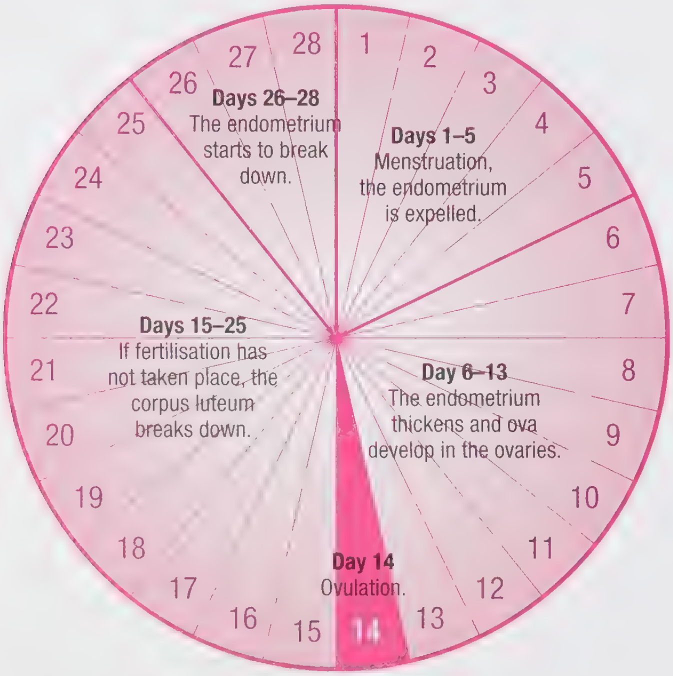


FIGURE 4.21 The menstrual cycle

After ovulation

If an ovum is fertilised by a sperm, it will develop into a zygote and implant in the endometrium. Immediately it will begin producing a hormone that maintains the corpus luteum. As a result, progesterone levels stay high enough to maintain the endometrium. After about 8 weeks, the baby's placenta will also start producing progesterone, and this is sustained throughout the pregnancy.

Cycles in other animals

Menstruation only occurs in a few species, such as humans, apes and some other primates. Other mammals mostly undergo an oestrous cycle, in which the females are only able to become pregnant during certain times of the year. This is called being 'on heat'. During this time, some animals (e.g. dogs) produce a bloody vaginal discharge, but this is not the shedding of the endometrium. The endometrium is not shed at the end of an oestrus cycle but changes back to its former state.

Birth control

If a man and a woman choose to have sex and do not want the woman to become pregnant, they should practise some method of **birth control** or **contraception**. Birth control methods have been used for thousands of years. There are three main strategies:

- preventing sperm from meeting the ovum (barrier methods)
- creating local environments that are unfavourable to sperm or eggs
- manipulating hormonal cycles.

Many of these techniques are inspired by the many causes of infertility. For example, in women the oviducts can be blocked or damaged, and in men the vas deferens or epididymis can also be blocked or damaged. If the testes get too warm, this can damage sperm. Tiny hormonal imbalances can sometimes cause problems with endometrium growth or ova quality, or follicles may not mature. Some men and women produce antibodies that kill sperm.

ACTIVITY The contribution of birth control to a sustainable future

BACKGROUND

Demographics is the branch of statistics that studies populations. For example, knowing the numbers of people of different sexes in particular age groups is important on a local level when planning education and aged care facilities. Nationally, it is important for planning resource development, and globally, it is important for world trade and environmental sustainability.

A demographic study estimates that the world's population will grow to approximately 11 billion people by 2100, and will keep rising. The United Nations Population Fund estimates an important contributing factor to this rise is that 220 million women worldwide are not currently able to access contraception.

Go to http://mypbio45.nelsonnet.com.au and click on **Demographics**

YOUR TASK

Prepare a report of no more than 1200 words on how science is contributing to solutions to the need for greater access to contraception.

1 Explain several modern scientific approaches to controlling fertility. Include a description of research into side effects and what happens if a method fails. How much attention is required by individuals (men or women) applying these methods for them to be effective? For example, if relying on condoms to prevent pregnancy, couples need to remember to use them every time they have sexual intercourse. The contraceptive pill needs to be taken daily. Which member of the couple should be responsible for birth control?
2 Discuss and evaluate how introducing contraception in an overpopulated country may by affected by a factor that is important in their society (moral, ethical, social, economic, environmental, political or cultural).
3 Use appropriate language and presentation style in your report and document your sources fully and correctly.

REVIEW

1 Name the organ that stores mature sperm.
2 Fish use external fertilisation. Why don't fish need a penis to reproduce?
3 Platypus belong to the subclass of mammals called monotremes. What do you think 'mono' refers to?
4 List the structures through which mature sperm move, starting with the testes and ending with the oviduct.
5 Give reasons why only one large ovum is released every month yet several million microscopic sperm are released in one ejaculation?
6 Considering growth patterns of different human body parts, what might be the advantages of:
   a a baby's head growing quickly early in its lifespan?
   b puberty happening later during the growth cycle, just before adulthood?
7 a Outline the differences in the hormones involved in the development of men compared to women.
   b What mechanisms prevent the release of further eggs:
      i after ovulation?
      ii during pregnancy?
   c Why do you think the interaction of reproductive hormones is complex, compared to the case studies listed in Unit 3 (page 69)?

>

8 Compared to many other mammals, humans have several very unusual characteristics. Suggest whether there are possible advantages for human societies for:
  a infants having very long childhoods
  b women not obviously showing when they are in oestrous
  c menstruation
  d menopause at 50 years, when life expectancies of women are longer than for men.

How might your ideas be tested scientifically?

FIGURE 4.22 Parenting is a highly important shared task in primate families. These are olive baboons with their young.

Living and ageing

A traditional African proverb states 'It takes a village to raise a child.'

In general, the fewer offspring an organism produces, the more time and energy the parents need to spend rearing them. Many large social species support the pattern seen in human cultures. Whales, elephants and most primates have long gestation times, and at birth their offspring are usually unable to survive without intensive care. Living in their communities requires complex routines, including knowing how to find suitable food, how to find shelter and how to communicate appropriately with all the other members of their community. It takes time for offspring to learn these skills.

A very large part of the human reproductive cycle is involved with parenting. Besides the biological parents, many other people help offspring develop as a person. Examples are through education and all kinds of social and cultural activities, formal and informal. Because humans are 'lifelong learners', in a sense our growth and development is never ending.

Why would a species spend so much time raising offspring to replace adults with knowledge and experience? If you've ever had a small accident such as a cut, you will have noticed that the scar was less elastic than the original skin. When you eat a sugary diet, acid-producing bacteria in your mouth begin to damage your tooth enamel within a few minutes. Already as teenagers, the exposed skin on your body will have accumulated some damage from the sun. Although our bodies constantly repair damage, the 'replacement parts' are never quite like the 'originals'. We are also constantly exposed to diseases, and some will damage our health permanently.

The wear and tear of ageing affects cell components as well as tissues, organs and organ systems. On average, the cells of our bodies are replaced every 7 years, but there is a limit to how often that can happen. Every cell division shortens the ends of the chromosomes slightly, until they can divide no more. Some cells, particularly in the nervous system, seem to lose the ability to divide at birth. One of the reasons older people have less energy is that their mitochondria have accumulated damage, and no longer produce as many ATP molecules as their younger body cells once did during respiration.

Countering the effects of ageing

Just as knowledge of our reproductive systems can be applied to resolve infertility or develop new forms of contraception, **hormone replacement therapy (HRT)** can alleviate symptoms some women experience during menopause. A positive side effect of HRT is to reduce loss of bone density that can occur at this time. A negative side effect is that long exposure to some of these hormones is correlated with increased rates of certain cancers.

Sexually transmitted infections

The sexual behaviour of adult organisms provides a niche that can be used by microbes and viruses. **Sexually transmitted diseases (STDs)** affect most organisms, even insects. A broader, more accurate term to use is **sexually transmitted infections (STIs)**, because not all infections lead to **disease**. All STDs are STIs, although the reverse is not true.

Human STIs include gonorrhoea, chlamydia, genital herpes, syphilis and human papillomavirus (HPV). AIDS is a disease caused by the human immunodeficiency virus (HIV) that became prevalent in human populations only quite recently, during the 1980s. Several STIs affect fertility and some of them cause babies to be born with **congenital** infections. The spread of STIs is helped when people feel embarrassed about discussing their sexual activity openly and so do not seek medical advice. People who contract these diseases may not experience symptoms, or experience symptoms immediately.

A person in a **monogamous relationship** only has sexual intercourse with one partner. Someone in a monogamous relationship has a lower risk of exposure to STIs than someone who has several partners. The most effective method of preventing STIs is to use a barrier method, such as a condom.

ACTIVITY How do STIs persist in communities?

PERFORMANCE ASSESSMENT TASK CRITERION D

BACKGROUND

All STIs are opportunistic infections that take advantage of human behaviour. Syphilis first became prevalent in Europe in the 15th century, with devastating consequences. HIV/AIDS first came to global attention in 1981. Since then, more than 40 million people have died and at least the same number is living with the infection.

YOUR TASK

Design a booklet for use in medical clinics, to inform men or women on strategies to avoid infection by a bacterial and a viral STI. Your 1200-word booklet will differ from the usual manuals and leaflets in that it provides a biological perspective about why these infections are so persistent in society.

1. Briefly describe two STIs, and the consequences of an infection. For a while after becoming infected, people with many STIs do not show symptoms – they appear '**asymptomatic**' – although they are contagious. What advantage does this have for the organism causing the STI? What human behaviours would limit its spread?
2. Explain how the selected STI infections are tracked through a population. For example, how can scientists determine whether everyone with the disease is equally infectious? How can they determine the source of the disease?
3. Describe how a moral, ethical, social, economic, environmental, political or cultural factor interacts with the spread of the selected STIs.

Use language and presentation style appropriate for the booklet's audience. Document your sources fully and correctly, for example by listing them separately from the design you use to present the rest of your booklet.

FIGURE 4.23 [illegible]

Renewal

A new life represents a fresh beginning. During the process of egg formation, enzymes test DNA and other cell components. Only the cells with good-quality components develop further, excluding many defective cells. Competition between sperm will also exclude defects. Weak and damaged sperm do not reach the ovum. Some miscarriages are caused by errors in the baby's development. Miscarriage rates in the first months of pregnancy vary between 20% and 50%, depending on the age of the mother.

In sexually reproducing organisms, the variation between offspring is not necessarily advantageous for individuals. However, it provides species with the diversity to be resilient in the face of change. These themes will be explored in the next units.

REVIEW

1 Explain why organisms that do not care for their young usually have large numbers of offspring.
2 Suggest why more complex species, such as primates, tend to parent their offspring, while simpler organisms do not.
3 Should a natural event such as menopause be treated as a medical problem?
4 Why is having a monogamous relationship and using condoms currently the best way to stop transmission of STIs?
5 Why can't we live forever?
6 In what ways are offspring produced by sex a new beginning for the species?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State two differences between asexual and sexual reproduction.

2 What is the difference between a morula and a blastocyst?

3 **a** Use Figure 4.21 to explain what is happening during the menstrual cycle on:
- **i** days 1–5
- **ii** days 6–13
- **iii** day 14
- **iv** days 15–28.

b If a woman wants to become pregnant, what is the best time for her to have sexual intercourse?

4 Strawberries plants can be clones (genetically identical), even though they may not look like it. How can you tell that they are clones?

LEVEL 3–4

5 Use a labelled diagram to explain how identical twins occur.

6 What could cause identical twins not to look identical as they get older?

7 If a species that reproduces asexually were to encounter a disease to which it was susceptible, what may happen, and why?

8 Some flowers have stigmas that are taller than stamens. Interpret this information to judge a possible biological advantage of this.

9 Copy and complete the following table to classify birth control methods.

Contraceptive method and description	Barrier	Locally unfavourable environment	Hormonal
Female condoms are placed inside the vagina and collect semen.			
An intrauterine device (IUD) placed in the womb alters the lining of the uterus.			
A diaphragm blocks the opening to the uterus and is used with a chemical that kills sperm (a **spermicide**)			
Implants, pills, injections, patches or vaginal rings can prevent ovaries from ovulating and releasing ova.			
A condom is placed over a penis during intercourse.			

LEVEL 5–6

10 Describe the role of the placenta.

11 British researchers found that although more than half the babies born at 23 weeks were admitted to intensive care, there was no improvement in survival rate in this group over the 12 years of a study. Only 18% of these premature babies survived long enough to leave hospital. Premature babies' survival rates have stopped increasing. Explain why this is by referring to foetal stages.

12 Use the descriptions of animals A–C to make scientifically supported judgements about their relationships with the next generation.

Animal A: The males court mates with mating calls at night. Females approach the loudest, biggest caller and he grips her back. She releases hundreds of eggs, and he squirts his sperm on top.

Animal B: The males court with mating calls and a colourful display. Females approach the most elaborate song, and he grips her back. He transfers sperm from the opening under his tail to hers, and they begin to build a structure to support their three or four offspring.

Animal C: The males need to demonstrate their superiority over other males to earn the right to mate with every female. All the females in his harem groom him, in return for his protection while they each raise a baby.

13 Explain the hormonal changes that cause the endometrium to develop and disintegrate during a menstrual cycle.

14 It is often argued that the 'purpose' of sexual reproduction is to enable species to respond to change. However, organisms that reproduce asexually also have variation, caused by mutation. And not every variation is an advantage. How can you explain the prevalence of sexual reproduction in larger, more complex species?

15 A seed contains an embryo (Figure 4.24). The plant embryo consists of a shoot (plumule), a root (radicle) and one or two seed leaves (cotyledons). The endosperm, which arises from a separate fertilisation involving a second gamete in the pollen tube, is rich in carbohydrates. The hard seed coat covers and protects the seed. Analyse and evaluate this information and make scientifically supported judgements about similarities in the seed structures and structures found around a developing human embryo.

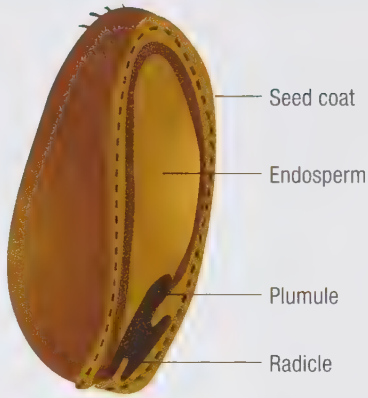


FIGURE 4.24 A schematic diagram of a seed

REFLECTION

1 Have your ideas about the debatable questions changed during this unit?
   a Should humans control their fertility?
   b Should societies limit the scope of artificial reproductive technologies?

2 This unit is based around the key concept of relationships.
   How important are relationships for:
   a organisms that reproduce asexually?
   b plants?
   c animals with external fertilisation?
   d animals with internal fertilisation?

3 A related concept is patterns. What patterns did you note as organisms develop in complexity?

4 What are the consequences of the following interactions, and how do they support the development of a baby?
   a Countercurrent flow between the baby's circulatory and the mother's circulatory systems, in the placenta
   b Hormones that maintain the endometrium
   c Relationships between the mother and her community

5 In what way does nurturing the next generation sustain a species?

UNIT 5

DNA – THE LIFE MOLECULE

KEY CONCEPT
Systems

RELATED CONCEPTS
Models

Form

Function

Transformation

GLOBAL CONTEXT
Scientific and technical innovation: an exploration of the way a model is transforming our understanding of life

STATEMENT OF INQUIRY
Understanding DNA empowers humans to shape food, health products and even the species we share our planet with – if we choose.

INQUIRY QUESTIONS

FACTUAL

1 What is DNA?
2 How was the structure of DNA discovered?
3 How is the code used to build proteins?

CONCEPTUAL

4 Was the discovery of the structure of DNA inevitable?
5 What does DNA tell us about relationships between species?
6 How can DNA technology be used to probe the world?

DEBATABLE

7 Is genetic information beneficial?
8 Should limits be placed on the use of DNA technology?
9 Is it possible to limit the reach of scientific knowledge?

Introduction

Bacteria are **microscopic**, single-celled organisms. They are very different from us, yet we share part of a biochemical code with them. This code dictates the many characteristics of living things and is commonly known as **DNA** (**deoxyribonucleic acid**). The discovery of the structure of the DNA molecule is thought by some to be the most important scientific achievement in history. This unit explores the players involved in solving the puzzle surrounding this mysterious molecule. Since unravelling the secrets of the form of DNA, scientists have been exploring the function of DNA's code and have transformed it into a tool for tackling a range of biological challenges.

Has the Human Genome Project opened 'Pandora's Box'?

The aim of the Human Genome Project (HGP) was to produce the first complete map of human genes, a goal achieved in June 2000 after a decade of international research collaboration and rivalry.

Write a feature article of no more than 1200 words for a newspaper supplement aimed at stimulating interest in science as a human endeavour. Remember to include topics of human interest.

1 Explain how science was applied to achieve the HGP's outcome within a decade, much earlier than originally planned.
2 With reference to the myth of Pandora's Box, discuss and evaluate both the positive and negative implications of the HGP's findings. Help your readers focus on the science through one of the following lenses: moral, ethical, social, economic, political, cultural or environmental.
3 Use appropriate scientific terminology and submit a separate, complete reference list for the newspaper's legal team should your article prove controversial.

INFORMATION LITERACY
Effective scientific research requires correct use of referencing and well constructed bibliographies

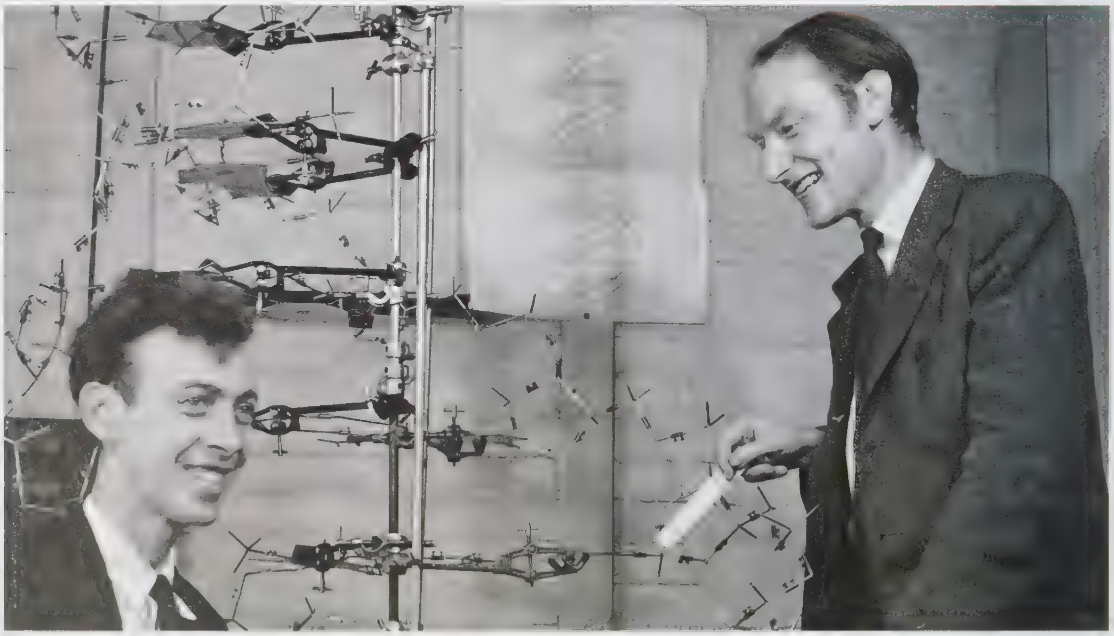


FIGURE 5.1 Ja[illegible] Watson (left) and Francis [illegible]

Discovery of DNA

More than 60 years ago, in 1953, two young men burst into a bar in Cambridge, England, shouting that they had discovered 'the meaning of life!' Why did James Watson and Francis Crick think that their work on the structure of DNA was so important?

Timelines in history are often represented like stepping stones, each event logically leading to another important discovery. The reality of Crick and Watson's discovery is more complex. The separate findings of a range of scientists needed to be considered to get them onto the right path.

The findings of others

Swiss biochemist Johann Friedrich Miescher was the first (1869) to describe the unknown substance he found inside the nucleus of cells. He named it nuclein and was convinced it was essential for life. German biochemist Albrecht Kossel built on the work of Miescher, isolating the **protein** and non-protein components in nuclein, and dubbing it **nucleic acid**. He then showed that nucleic acids were **polymers** of **nucleotides**, which were constructed from sugar groups, phosphate groups and several different **bases**. He isolated all of the bases within the polymers using highly accomplished **chemistry**. Although the physiological role of the cell nucleus was not understood at this time, his structural groundwork is an essential part of the story of this incredible molecule. Albrecht Kossel was awarded the Nobel Prize in Physiology or Medicine in 1910.

Biological role of nucleus

In 1900, three European botanists publicly declared the importance of an obscure scientific paper published 35 years earlier in 1865. Gregor Mendel, an Austrian monk, had concluded that parent plants transmit definite information ('factors') to their offspring in particular patterns.

Dutch scientist Hugo de Vries realised that the results of his own plant-breeding experiments, completed during the 1890s, duplicated Mendel's discoveries. De Vries initially tried to avoid acknowledging Mendel's work in his reports because it would have made his own work appear less original.

Meanwhile, Carl Correns was working independently in Germany, making close observations of the nucleus during cell divisions. He realised the mechanism he observed explained the laws of inheritance Mendel had first observed.

The third scientist was Erich von Tschermak, an Austrian agronomist. Also working independently, he too re-discovered the patterns of inheritance through his own plant-breeding experiments. Tschermak was delighted his research matched the results of earlier published scientific work. Inheritance really did follow clear rules, and the key was to be found in the cell nucleus.

Suddenly, a connection could be made between the macroscopic observations on plant varieties by Mendel, de Vries and Tschermak, and the microscopic observations on cell nuclei by Correns, and Kossel's chemical research.

Lethal transformation

Frederick Griffiths was a British Army medical officer who was trying to develop a **vaccine** against strains of bacteria that cause pneumonia. The standard technique for developing vaccines in 1928 involved injecting mice with different strains of bacteria. One bacterial strain was lethal, and the other was benign (harmless). If the lethal strain had been heated, it did not make the mice ill. Griffith assumed heating had killed the lethal bacteria.

When Griffiths injected mice with a mixture of living benign bacteria and killed lethal bacteria, the injected mice all became ill. He was also able to show that their blood swarmed with the lethal strain of bacteria. Griffiths said his benign bacteria had 'transformed' themselves. His results provided strong evidence that there was a **hereditary** chemical present in bacteria that could be passed from one strain of bacteria to another.

Investigating DNA with chemistry: paired bases

Fascinated by this, Oswald Avery, an American scientist, investigated further. In 1944, he showed that the hereditary material in the bacteria was made up of nucleic acids, possibly deoxyribonucleic acid, which we now simply call DNA.

Soon many scientists were directly exploring the chemistry of the DNA. Erwin Chargaff was an Austrian who had emigrated to the USA in the 1930s. In 1950, he found that the amount of the base **guanine** is always the same as the amount of the base **cytosine**, and the amount of the base **adenine** is always the same as the amount of the base **thymine**. This important discovery led to the realisation that the bases always occurred in pairs.

Investigating DNA with physics: it's a helix

At King's College, London, Maurice Wilkins and research student Raymond Gosling pioneered X-ray diffraction techniques to study the structure of DNA. Rosalind Franklin (Figure 5.2a), a brilliant chemist and **X-ray** crystallographer, joined Wilkins' laboratory in 1951. Along with Gosling, Franklin improved on previous techniques to achieve clearer images. In 1952, she and

(a) (b)

FIGURE 5.2 (a) Rosalind Franklin and (b) Photo 51 – Franklin and Raymond Gosling's famous X-ray image of DNA (looking

Gosling managed to obtain clear X-ray images of the DNA molecule. One of these, Photo 51 (Figure 5.2b) is an iconic photograph in science history. It was a great achievement because this complex molecule was very hard to isolate in a form suitable for taking X-rays.

Franklin was aware the USA-based chemist Linus Pauling had used X-ray crystallography to discover that many protein molecules have a **helical** (spiral) shape. When Franklin analysed her X-ray results, she realised that DNA also has a helical shape.

Go to http://mybio45.nelsonn[illegible] [illegible] on **Rosalind Franklin** [illegible] story. Name two of her other ac[illegible] Describe the relationship [illegible] Franklin and Wilkins.

End game: modelling

Meanwhile, at Cambridge University, James Watson and Francis Crick developed a very different approach to the problem. They gathered the evidence from a number of sources and produced a series of physical models. These models were refined until they could completely account for all the results.

The year after Franklin took her X-ray images of DNA, Watson and Crick used her results and other evidence discovered by scientists across the world to build their now-famous three-dimensional model of DNA. Watson and Crick used simple things such as retort stands, clamps and cardboard to build their model. Their breakthrough model also immediately and directly suggested a hypothesis to explain how the DNA molecule could pass on instructions to other molecules. It was to this Watson and Crick were referring when they exclaimed in the bar about finding 'the meaning of life'.

Nine years later, in 1962, Watson and Crick, together with Franklin's colleague Maurice Wilkins, received a Nobel Prize. By this time Franklin had died from cancer, most probably the result of her regular occupational exposure to radiation. She was only 37. Not during her lifetime and not even after her death was Franklin given the credit due to her for the crucial role she played in determining the structure of DNA.

INVESTIGATION 5.1 Improving a simple technique

Only 20 years ago, extracting DNA from tissue was considered a state-of-the-art technique in university biochemistry labs. Now you can do it in your kitchen. If you do a quick internet search for 'DNA extraction' you will find an abundance of material about possible methods you could use. Scientists like Kossel, Chargaff and Franklin moved our understanding of DNA forward by improving on previous knowledge using pioneering techniques.

YOUR CHALLENGE

You are asked to investigate at least one variable that could affect the yield of DNA from a extraction method you choose.

THIS MIGHT HELP

- First carry out some research to choose a possible simple method of extracting DNA. Check your choice of method with your teacher.
- What is the purpose of each step in the method you are researching? Why does it work? How are you going to measure the amount of DNA you extract? Do different methods make a difference?
- When discussing your results, consider whether the material you extract is pure DNA or something else. Which approach gave the best results? What could be an application of your selected method? How does your method compare with strategies used in scientific research?

Write up your investigation design as advised by your teacher.

Explaining DNA

Structure of DNA

As you can see from Figure 5.3, DNA is a very long molecule that looks like a twisted ladder or spiral staircase. It consists of two chains (or strands) of atoms twisted around each other. This structure is called a double helix.

The atoms within each strand are held together by **covalent bonding**, in which atoms form a strong connection by sharing electrons. The result is that the individual strands of the helix are difficult to break along their length. The two strands in the spiral are held together with **hydrogen bonds**, in which the atoms are attracted by electrostatic forces. This type of chemical bonding is much weaker, and is an important feature of DNA chemistry. The two strands of the helix need to be separated or 'unzipped' whenever the DNA molecule is copied and when it is used to instruct the cell how to make proteins. You will learn about this later in this unit.

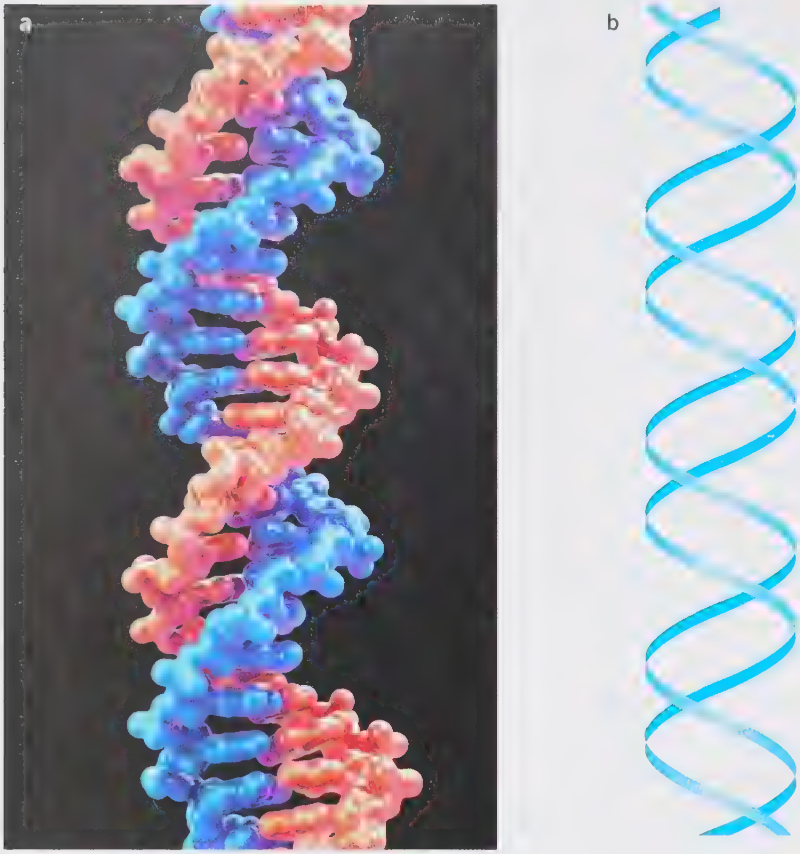


FIGURE 5.3 (a) A model of a DNA molecule and (b) a simplified diagram of a double helix

Repeating unit pattern

DNA is a polymer, a giant molecule made of repeating units (monomers). Its monomers are called nucleotides. Therefore, DNA is a **polynucleotide**. Covalent bonds join one nucleotide to the next.

As shown in Figure 5.4, each nucleotide is made up of three components: a base, a sugar and a phosphate group.

Each strand of the DNA molecule consists of alternating sugar and phosphate groups. This is termed the **sugar–phosphate backbone** of DNA. The bases, which are attached to the sugar groups, hang off the backbone like the 'rungs' on a ladder.

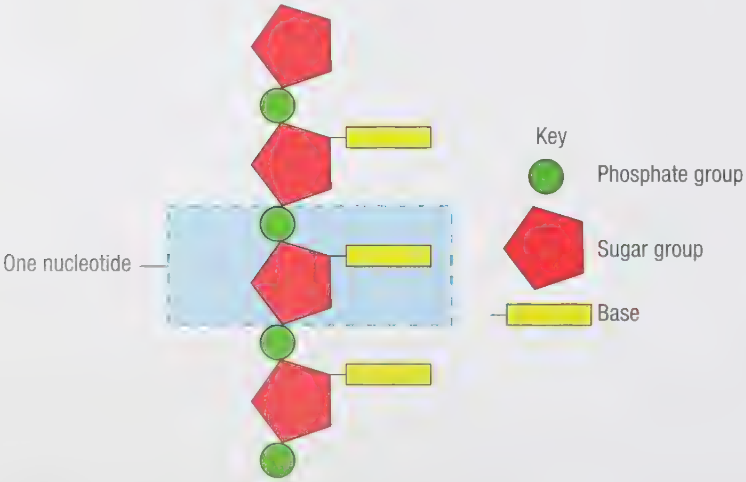


FIGURE 5.4 A schematic diagram of a DNA strand

The sugar, the base and the phosphate group each consist of a group of atoms in a particular arrangement. For example, the sugar group has at its centre a ring of five atoms (hence the shape shown in Figure 5.4). As indicated by its name, the phosphate group contains a phosphorus atom that is bonded to oxygen atoms.

Base pairs

The base on each nucleotide is the key to the way DNA works. There are four different bases, so there are four possible nucleotides. These nucleotides are repeated over and over again along each strand, in all kinds of sequences. This is like making a giant necklace when you only have four kinds of beads to choose from. You can make many different arrangements, even with this restricted range of beads.

The four bases present in a DNA molecule are guanine, cytosine, adenine and thymine, and they are usually represented as G, C, A and T. While they have many similarities, the structures of these four bases also have important differences. Due to their chemical structure, the bases can only form the 'rungs' of the ladder in two possible combinations. The only pairs that bond together are G with C, and A with T. These two combinations are known as **base pairs** (Figure 5.5).

Notice the base pairs in Figures 5.5 and 5.6. The weak electrostatic forces that hold the base pairs together are called hydrogen bonds. These bonds occur between and within molecules, and consist of the attraction between a hydrogen atom and an **electronegative** atom such as oxygen or nitrogen. The bonds are easily disrupted if the DNA is exposed to acidic or basic solutions, or heat. In Figures 5.5 and 5.6, three dotted lines are shown between each C and G, but only two dotted lines between each A and T. This means A–T separates more easily than C–G, and is the basis for an important technique for comparing species.

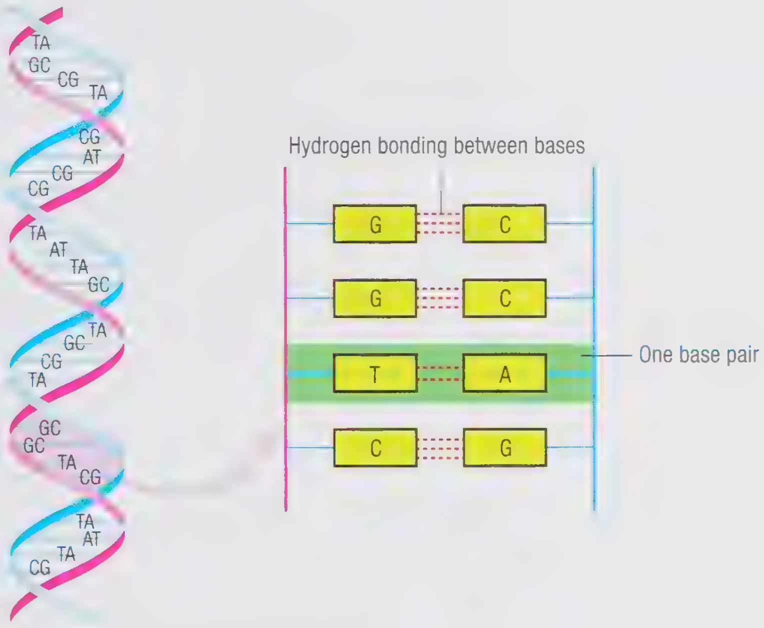


FIGURE 5.5 The four bases at work

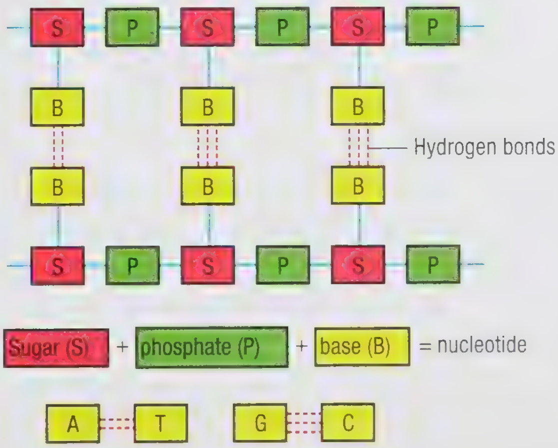


FIGURE 5.6 DNA structure as a polymer

[illegible] DNA [illegible]

In this activity, you will work in pairs to create a three-dimensional model of a section of a DNA molecule.

Your teacher will provide you with a range of materials from which to construct your model. Negotiate how you will make your model and then build it. Ensure that you also include a key to explain what each item represents.

Display your model and key to the class.

1 Examine all the models built by the class. Which features most helped the models to work?
2 All models have their limitations. Identify one limitation of the model you constructed.

FIGURE 5.7 A student reflects on pairing of nucleotides.

REVIEW

1 DNA is a giant molecule that is the shape of a double helix.
   a What is DNA an abbreviation for?
   b What role does DNA play in the body?
   c Name the monomer from which DNA molecules are made.
   d What does the term 'double helix' mean? You may use a sketch to assist your answer.
2 How many bases are there in DNA?
3 What are the possible base pair combinations in DNA?
4 How are the bases in DNA held together?
5 Where is DNA found in a cell?
6 Many scientists contributed to our knowledge of DNA. Which work would you consider the most important, and why, in determining the result: the first discovery, or the last? Does it matter?
7 Was the simultaneous re-discovery of Mendel's work in the late 19th century truly a coincidence? Why was Mendel's work 'lost'? Is science really just about discovering how the world works, so the same understandings will always emerge in time, or does the personal interpretation that scientists bring to their results change the outcome?

The power of DNA

DNA and relationships

What makes DNA such a special molecule? The hydrogen bonds holding the two bases together provide the clue about how the molecule replicates itself. If you have a single strand of nucleotides, you can determine the order of nucleotides in the second strand. For example, a particular segment with base sequence AATGCCGGTAA will have a **complementary sequence** of TTACGGCCATT on the other strand. This arrangement provides a kind of insurance for the information the molecule carries. To change the sequence, an entire base pair would need to be inserted or deleted.

Whenever a cell divides, the DNA molecule splits and each strand is copied. This results in two identical DNA molecules that will end up in one of the two daughter cells (Unit 6). Generally, each cell in an organism contains the same DNA, which ultimately controls the processes that occur in each cell. Differences between cells can generally be explained by cells using different parts of a DNA molecule, much like different users of a computer may use different software or files stored on its hard disk.

DNA can also explain bigger differences within and between organisms. Changes called **mutations** can involve the replacement of nucleotides or sections of a DNA strand. In an individual, this type of change may result in differences in cells, for example, a cancer developing. Within a species, bigger differences that are common to groups can explain breeds (Figure 5.8, page 112). Differences between species can also be explained by comparing DNA (Figure 5.9, page 112). It may surprise you to learn that there is only a 1.6% difference between the DNA sequences of a

FIGURE 5.8 [illegible]

FIGURE 5.9 [illegible] DNA.

human and a chimpanzee, and a 5.5% difference between those of a human and a rhesus monkey.

Comparing DNA of different species has become a powerful tool for understanding how organisms are related to one another. The weak electrostatic hydrogen bonds between the complementary bases can be broken by gentle heating. On cooling, the DNA will re-form into double helixes. This is called **DNA–DNA hybridisation**. If the DNA is in short pieces and from the same organism, you could expect this hybridisation to be almost perfect.

If you mixed the DNA from two closely related species and tried the same technique, the amount of hybridisation that you would see is a strong indicator of the similarity of the DNA, and how closely the two species might be related.

Human Genome Project

The Human Genome Project revealed that only 5% of the entire genome holds useful genes, and there are only about 21 000 of them. The other 95% is sometimes called 'genetic junk'. More than 70% of this 'junk' consists of degraded viral genomes. It must have come from very ancient infections because we share it with the related primates the great apes. All this material has been copied, sometimes with benign errors, for tens of thousands of generations.

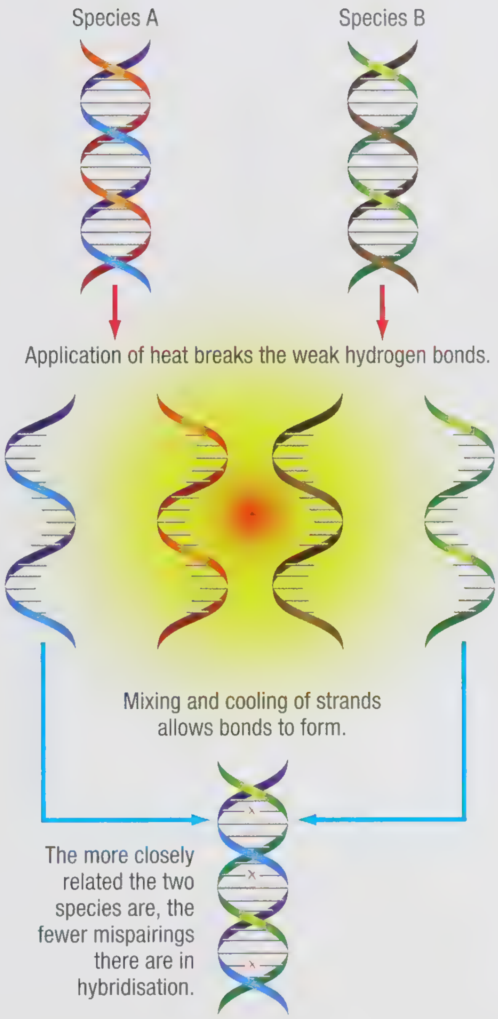


FIGURE 5.10 DNA–DNA hybridisation – a technique used to measure the degree of similarity between the DNA of two species

INVESTIGATION

Modelling DNA change over time

Have you ever made two copies of a Word file, edited both, and then copied and edited each file again? You now have four files, in two 'generations'. If you forgot to label them, it may be difficult to work out what the original document said. This is particularly the case if you not only added information or words, but also deleted sections, phrases or sentences. It becomes more difficult if the document is very long, for example a book, and the changes you made were small, perhaps single words or even letters.

Working out the sequence of changes is similar to the problem faced by scientists who study evolutionary relationships using DNA–DNA hybridisation, or the sophisticated statistical techniques that directly analyse DNA sequences, base by base. DNA mutations can include **insertions**, **deletions**, **repetitions**, **inversions** (flipping a section over so it is backwards) and **transpositions** (moving a section from one part of a strand to another). Some of these changes may have happened more than once, and have overlapped in the same region of the molecule.

YOUR CHALLENGE

This is an investigation into the process of modelling as a tool for understanding a theory. You are to model the effects of processes of evolutionary change using a piece of text, over approximately 10 'generations'.

THIS MIGHT HELP

- When developing your method, consider the advantages and disadvantages of using an actual text, an original text, or a nonsense text. Does every individual in each generation need to 'reproduce'? What effect does the length of your text have when considering how you are going to keep track of changes to test the relationships you later infer from your final collection of documents? How will you describe the change in each generation diagrammatically? How will you analyse variation between samples?
- What assumptions are you making about the rate of change in DNA base pairs over time? Is this rate constant? And if not, what might change the rate of mutations? Will this have made a difference in the real changes between species?
- When developing your hypothesis, what results do you predict using your model, and why?

In your write-up, make sure you report your results and evaluate your method. Identify any problems with your method, and suggest improvements.

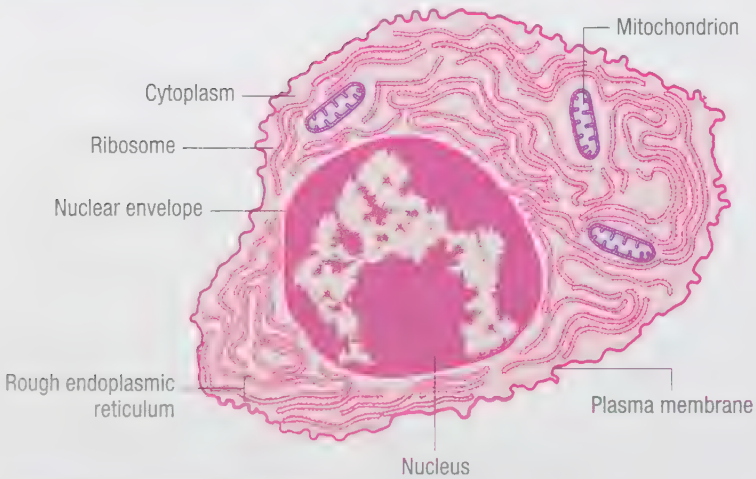


FIGURE 5.11 Schematic diagram of a cell

What DNA tells us about the origin of complex cells

For a molecule that carries such a huge amount of information, DNA takes up amazingly little space. The nucleus makes up only 10% of the volume of **eukaryotic** cells (cells with 'true' nuclei) (Figure 5.11). Only 0.3% of the volume of the nucleus is DNA. The rest of the nucleus is water, and a collection of proteins.

The cytoplasm around the nucleus is filled with almost invisible membranes, which greatly increase the surface area on which chemical reactions take place, and organise the space in much the same way that walls divide a house. Throughout the cytoplasm there are smaller structures, called **organelles**. You probably know about two examples: **mitochondria**, which are responsible for making molecules that store energy for the cell; and **chloroplasts**, which are found in plant cells and are responsible for photosynthesis. As early as the 1880s, scientists hypothesised that mitochondria and chloroplasts may have originated from free-living bacteria that entered into a cell as **parasites** and gradually become **symbiotic**. Refined microscopy developed in the 1960s eventually supported the idea.

By the 1980s, it was possible to extract and compare DNA from organelles and confirm its similarity to the DNA in groups of wild, free-living bacteria and cyanobacteria. This was the work of Lynn Margulis (Figure 5.12), a scientist whose ideas about the origin of eukaryotic cells steadily gained acceptance as a result of DNA analysis.

FIGURE 5.12 Professor Lynn Margulis (1938–2011) was a scientist whose radical ideas about the origin of eukaryotic cells became mainstream as a result of DNA analysis.

REVIEW

1. Explain why the sequence on one strand of DNA determines the sequence on the other.
2. What is a mutation? What are some of the different types of mutations that can occur in DNA?
3. Suppose an error occurred in the DNA sequence in an individual cell, perhaps by radiation deleting a short sequence of base pairs.
   a. If this happened in part of the DNA strand that the cell was not actually using, would it be detectable?
   b. If the cell then divided by binary fission (dividing into two) would you expect the two daughter cells to have identical DNA, with exactly the same deletion?
4. Does 'junk' DNA do any harm?
5. If there is a 1.6% difference between the DNA sequences of a human and a chimpanzee, would that distinction be found in junk DNA or the other genetic material, such as genes? Explain your reasoning.
6. Explain how DNA hybridisation works.
7. a. Put the pairs of organisms in order of how closely they are related to each other: cat and lion, poodle and great dane, identical twins, cat and tree.
   b. Why should closely related species have more DNA in common?
8. In vertebrates, mitochondria are inherited down the maternal line – you received yours from your mother's egg. Which of these hypothetical relatives would definitely have the same mitochondria as you? Explain your answers.
   a. Your brother
   b. Your cousin
   c. Your maternal grandmother
   d. Your grandfather

Making proteins

Every cell in your body contains the same DNA, but the cells can look very different. For example, compare a cell in your eyeball with one in a muscle. The differences are due to the cells having different proteins, or different amounts of the same proteins.

Proteins are classified as giant molecules, although protein molecules are not nearly as big as a human DNA molecule. Because of their size and complexity, protein molecules and DNA molecules are also termed biological **macromolecules**. Proteins perform many different functions in cells. Examples are:

- 'gatekeepers' to the cell, embedded in **cell membranes** and controlling what comes in and out
- 'messengers' between cells; for example, the hormone insulin is a protein that controls blood sugar levels
- 'biological catalysts' called **enzymes**, which speed up reactions without being consumed in the process. Each of the thousands of reaction in our cells requires its own particular enzyme
- 'structural proteins', which make up the 'building material' of our body, such as muscles, hair and fingernails
- 'transport proteins', which include important molecules such as haemoglobin, the molecule that transports oxygen to our cells.

Given the diverse range of protein functions, it is not difficult to understand why specialised cells in the same organism can appear so different.

FIGURE 5.13 [illegible]s and fingernails are all made from proteins.

Protein structure

Like DNA, proteins are polymers. The monomers of a protein are small molecules called **amino acids**, held together by strong covalent bonds. Unlike DNA, these only form a single strand. Proteins generally contain more than 100 amino acids (those with fewer amino acids are called peptides), but the total number varies for each protein.

Up to 20 different amino acids can be used to make proteins, although any one protein generally does not contain all of them. In humans, cells can manufacture some amino acids from other sources, but others, the 'essential amino acids', need to come directly from the diet.

The sequence of amino acids in a protein is termed its **primary structure** (Figure 5.14). It is the primary structure that determines what happens next. Some amino acids are bulky, some repel water molecules, and some carry weak electrostatic charges. These **intramolecular** effects cause parts of the entire protein molecule to be pulled into a spiral shape, or a shape that resembles stairs, by weak hydrogen bonding between parts of the molecule. This bonding further pulls the protein into coils or even round 'balls' (Figure 5.15). The shape of the protein determines its properties and hence its function.

FIGURE 5.14 A schematic diagram of a section of a protein when it is stretched out (primary structure)

Genes: linking the two living codes

DNA and protein are two very different polymers. DNA is found in the nucleus and stores its information using a 'code' of hundreds of thousands of just four bases – A, T, G and C. Proteins are found mainly in the cytoplasm and stores its information using a 'code' of 20 amino acids. Immediately after the structure of the DNA molecule was understood, many scientists, including James Watson, began speculating how the sequence of bases might **translate** to the 20 amino acids known in proteins. Researchers began to look at how a particular section of DNA, consisting of a particular sequence and number of bases, might provide the information to instruct the primary sequence of amino acids.

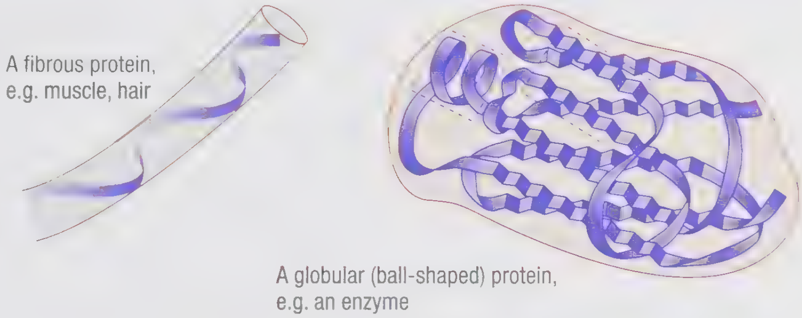


FIGURE 5.15 The different shapes of proteins determine their properties and functions.

We now call these segments of DNA **genes**. Genes carry the information for making all the proteins required by all organisms. The principal role of DNA is to instruct cells to make specific proteins. Proteins determine the characteristics of the organism, including what it looks like, how well it fights infection and sometimes how it behaves. The entire collection of genes in an organism is called its **genome**. In the human genome, there are approximately 21 000 genes and 3 billion pairs of bases altogether.

Switching genes on and off

When cells specialise, many instructions in the DNA are not used. For example, our hair cells do not need to use instructions about building muscle or bone. But they do need instructions for making hair. So only necessary instructions are active, or switched on, and irrelevant instructions are made inactive, or switched off. Interestingly, if cells are transplanted so that they have to perform a new function, they can adapt and alter which instructions are active.

[illegible]

Before you read on, consider how you would go about answering the following questions. Perhaps your teacher will organise a class discussion.

1 How many combinations of DNA bases is a likely 'code' for each amino acid? Copy and complete the following table by finding patterns to help you estimate.

[illegible]	[illegible]	[illegible]	[illegible]
2	4 (i.e. 2 × 2)	8 (i.e. 2 × 2 × 2)	
3	9 (i.e. 3 × 3)	27 (i.e. 3 × 3 × 3)	
4			

a Which sequence totals give sufficient combinations for 21 amino acids?
b Which sequence totals give sufficient combinations for 21 amino acids if some amino acids use more than one combination?
c What if some sequences act as signals to 'start' and 'stop' reading a section of DNA?

2 How does the information get from the nucleus to the cytoplasm? The DNA can unzip. What form might a messenger take?

3 How does the messenger's information get used to assemble the protein? Is there a structure that acts as a 'workbench'?

CREATIVE THINKING
Intelligence has been defined as 'knowing what to do when you don't know what to do'. An effective student knows how to handle different or demanding situations or questions. In fact, they enjoy such a challenge. What do you think about the questions Watson's team asked to unravel the link between the two codes?

How genes make proteins

Transcription: DNA to mRNA

Crick and his team reasoned that if four bases are combined in **triplets**, this would give 64 (4 × 4 × 4) possibilities – not too many if some combinations are used more than once, and other sequences act as signals to start or stop 'reading' the information from the DNA template. This reasoning was eventually shown to be correct.

A single-stranded polymer called **messenger RNA (mRNA)** acts as the go-between for the nucleus and cytoplasm. RNA is also a nucleic acid, but uses a different sugar, ribose, and a base called uracil instead of thymine. Table 5.1 summarises the differences between DNA and mRNA.

TABLE 5.1 A comparison of DNA and mRNA

[illegible]	[illegible]
A nucleic acid	A nucleic acid
Nucleotides form a very long double strand	Nucleotides form a much shorter single strand (about the size of a gene)
Contains the sugar deoxyribose (hence the name deoxyribonucleic acid)	Contains the sugar ribose (hence the name ribonucleic acid)
Contains the bases adenine (A), cytosine (C), guanine (G) and thymine (T)	Contains the bases adenine (A), cytosine (C), guanine (G) and uracil (U)

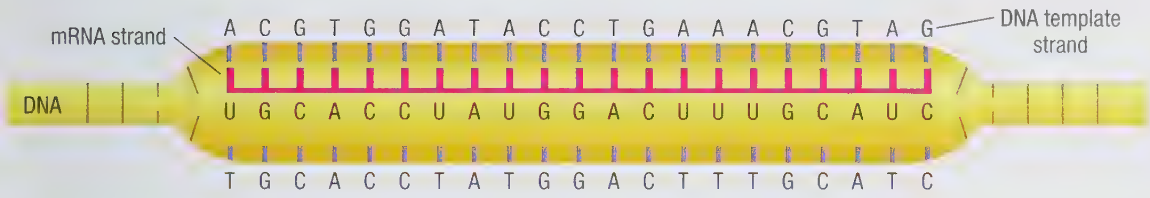


FIGURE 5.16 The formation of mRNA

The production of mRNA from a DNA strand is called **transcription**. The DNA molecule unwinds and then 'unzips' in the region of the gene for the protein. This exposes the DNA bases along both strands, but only one of these, the **template strand**, is copied (Figure 5.16). The mRNA molecule is formed when free-floating RNA nucleotides in the nucleus pair up with the complementary DNA nucleotide on the template strand. Notice that in mRNA, the base **uracil** replaces thymine (Table 5.1) to pair up with adenine.

Before mRNA leaves the nucleus and enters the cytoplasm, it is modified. A little 'cap' is added to the front of the chain and a 'tail' to the other end. Also, some bits (**introns**) are snipped out and the remainder (**exons**) spliced together.

Translation: mRNA to protein

The production of a peptide or a protein from mRNA is called **translation**. Each step in the process is assisted by one or more specialised proteins, or enzymes.

The mature mRNA leaves the nucleus and enters the cytoplasm, where it binds with an organelle called a **ribosome**. The ribosome consists of two units that 'munch' along the mRNA strand like a clamp opening and closing along a rope. This process exposes sets of three bases on the mRNA, called **codons.** Codons are the templates for molecules of another type of RNA found in the cytoplasm, **transfer RNA** (**tRNA**).

There is at least one type of tRNA molecule for each of the 21 amino acids. In the cytoplasm, one end of a tRNA molecule temporarily connects to its free-floating amino acid and brings it to the ribosome. The other end of the tRNA has a set of three exposed bases, called an **anticodon**, which complements the exposed mRNA codon. This is how the right amino acid is matched to the right spot on the mRNA.

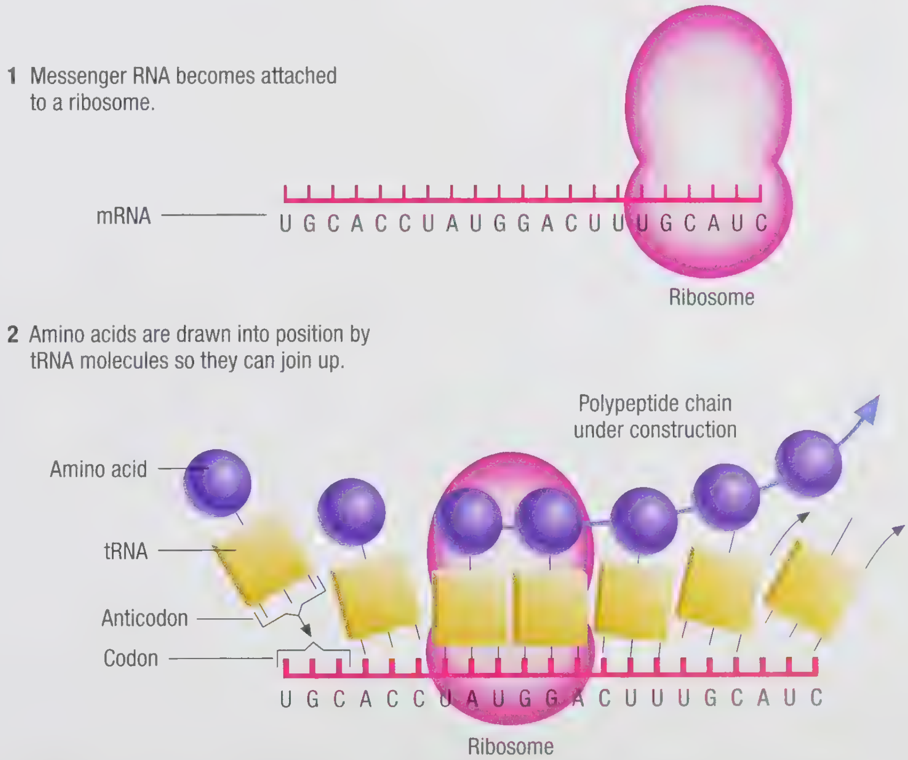


FIGURE 5.17 Proteins are synthesised in the cell in a process called translation, which involves mRNA and tRNA and occurs at the ribosomes.

DNA-protein

As soon as two tRNAs have assembled side by side on the mRNA, the amino acids they carry join by reacting together. Then the first tRNA detaches from its mRNA codon. The whole assembly moves along the ribosome, ready for the next tRNA, and so on. The primary sequence of the protein grows as the amino acids gradually join one by one. This process is shown schematically in Figure 5.17 (page 119).

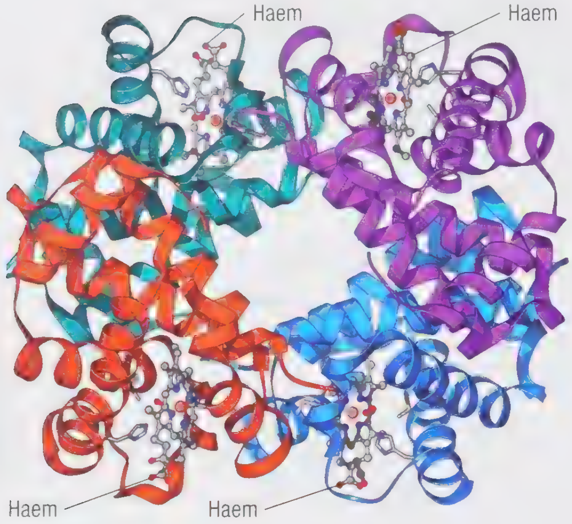


FIGURE 5.18 Haemoglobin, the carrier protein found in red blood cells, consists of two pairs of proteins and four haem locations

Gene partnerships

Not all proteins are coded for by one gene. Complex proteins often require two or more genes to work in partnership in order to build them.

An example of this is haemoglobin (Figure 5.18), found in red blood cells. Haemoglobin molecules transport oxygen to body cells. These molecules are made up of two alpha-globin proteins and two beta-globin proteins, each of which is a very long protein. They also contain iron ions, which give the red blood cells their colour.

There are two genes that code for haemoglobin. One is the alpha-globin gene, which is about 1500 nucleotides long; the other is the beta-globin gene, and is about 1600 nucleotides long. With very few exceptions, the order of nucleotides that makes up these two genes is the same in every human.

REVIEW

1 Why are specialised cells so different in appearance, if they carry the same DNA?
2 List five different functions carried out by proteins.
3 What are the parts of a DNA 'code'? What are the parts of a protein 'code'?
4 What determines the three-dimensional shape of a working protein?
5 Reflect on the Watson team's thinking about how protein might form from information carried in DNA. What terms now replace these ideas?
   a The DNA base combination
   b The messenger between nucleus and cytoplasm
   c The workbench
6 Outline all the examples of 'complementary pairing' in:
   a DNA replication
   b protein synthesis.
7 a Why do you think the formation of mRNA is called 'transcription'? Where else is this term used, and what does it suggest?
   b Why do you think the formation of a protein is called 'translation'? Where else is this term used, and what does it suggest?
   c Given the primary sequence of amino acids in a protein, can you determine the original DNA nucleotide sequence? Explain your answer.
8 Where do you think the amino acids in the cytoplasm originally come from?

Genetic disorders

Occasionally, errors (mutations) occur in the sequence of bases in a gene. These mutations can be harmful or beneficial, or have no effect. Genes that are very big tend to mutate more than others, and sometimes a tiny change can lead to disastrous consequences.

A very positive outcome of the research undertaken for the Human Genome Project is that we can now screen for about 1500 genetic disorders. Obviously, we would all wish to avoid passing on faulty genes that can lead to serious health problems in our children. This is why many people with a particular family health history undertake genetic screening (testing the DNA of people for the presence of the particular genes that cause these conditions) and genetic counselling before starting a family.

REFLECTIVE

A characteristic of effective learners is that they reflect and consider the ethical implications and personal relevance of what they are learning. In this section, think about how knowledge of having a genetic disorder would affect you. Would you want to be tested if one of the possible outcomes was to learn that your life expectancy was shorter? What ethical implications do you see here?

Cystic fibrosis

One gene found in all humans is called the CFTR gene (cystic fibrosis transmembrane regulator gene). This gene codes for a very large protein (about 1500 amino acids long) that controls the salt balance on either side of the cells that line the lungs, the vas deferens (the tube along which sperm travel from the testes) and the pancreatic duct. The pancreas produces digestive enzymes as well as the hormone insulin.

People who suffer from cystic fibrosis (Figure 5.19) get blockages in these parts of their body, have trouble breathing and digesting food, and experience infertility. Their life expectancy is usually only about 20–30 years unless they can have a heart–lung transplant.

What has gone wrong? Cystic fibrosis sufferers have inherited a faulty CFTR gene. In about 70% of cases the gene only has one tiny mistake – three bases are missing out of the 4500 or so needed to code for the protein. This means a CFTR protein is made, but it has one less amino acid and doesn't work properly.

FIGURE 5.19 Cystic fibrosis sufferers require frequent physiotherapy to help them breathe.

FIGURE 5.20 Haemophilia is a bleeding disorder in which one of the essential clotting factors is missing. It is a lifelong condition, but recombinant DNA technology has made safe amounts of the clotting factor available, so the condition is now manageable.

Huntington's disease

Sometimes parts of the genome have repeat codons ('stutters'). In this genetic disease, a section of the genome coding for the amino acid glutamine (CAG) is repeated more than 35 extra times. The disorder causes premature senility when the brain cells fail in response to this different protein. The severity of the disease, and the age of onset, is closely related to the number of repeats. The number of repeats increases with each generation in families that carry the disease.

Haemophilia

Haemophilia is a group of hereditary genetic disorders that impair the control of blood clotting. Blood clotting requires a number of reactions, each controlled by a different protein, or 'factor'. One of these is factor VIII, a protein coded by a gene 186 000 nucleotides long. Errors result in a faulty factor VIII protein that contains more or fewer amino acids than normal. In people with haemophilia (Figure 5.20), bleeding is mostly internal, usually into the joints or muscles. These 'bleeds' can occur spontaneously or as the result of an injury, causing pain, swelling and tissue damage.

LIVING WITH GENETIC DISEASES

What are the implications of living with or having a family member living with a genetic disorder? Look at the weblink to consider the active support you may need to provide.

Go to http://mypbio45.nelsonnet.com.au and click on **Living with a genetic disorder**

Genetic modification using biotechnology

Genetic modification is the manipulation of genes for a particular purpose, such as improving a plant's resistance to a particular disease. Modification can be the result of conventional breeding and selection (Unit 6) or **genetic engineering**, in which genes in organisms are altered directly. Genetic engineers may cut, paste, purify, amplify and manipulate DNA. Modern techniques can even target individual nucleotides for change.

Recombinant DNA technology

Recombinant DNA technology often relies on special proteins called **restriction enzymes**, isolated from bacteria, to recognise and cut specific short sequences of DNA. Another enzyme – DNA **ligase** (as in 'ligature') – joins sections of DNA together.

Recombinant DNA technology is used to produce **transgenic** organisms, organisms that contain foreign genetic material, usually a useful gene selected from another completely unrelated species. Although many hundreds of transgenic organisms exist, it takes at least a decade for the original concept to be developed into a commercially useful product. Examples are listed in Table 5.2.

No transgenic vertebrate animal has yet been approved for human consumption.

TABLE 5.2 Transgenic organisms

Transgenic organism	Transformation caused by gene transfer
Bt cotton	*Bacillus thuringiensis* is a bacterium that produces many types of proteins that are toxic to insects. Inserting the relevant genes into cotton means less insecticide needs to be sprayed, saving costs and reducing the impact on the environment.
Golden rice	Genes for beta-carotene, which humans convert to vitamin A, have been transferred to a variety of rice popular in developing countries, where blindness as a result of vitamin A deficiency is common.
Insulin-producing bacteria	Human insulin is now produced by transgenic bacteria grown in vats, which has eliminated allergic responses.
Glofish	Originally developed to detect water pollution, these aquarium fish species are now part of the pet trade in some countries. Fluorescing proteins of different colours from corals and other marine species have been inserted into a variety of aquarium fish, including tetras, barbs and danios.

ACTIVITY

DNA: always a useful tool?

Consider one of the following scenarios, which illustrate some DNA applications.

SCENARIO A – THE PREMATURE DESIGNER BABY

A couple's first child has a rare, incurable heritable disorder and requires frequent, painful medical intervention to survive. Although they are both fertile, they choose to have an assisted reproductive therapy, IVF, so that the embryo can be tested before implantation, and their next child can avoid the disease. However, they know IVF pregnancies may carry other, different risks, including premature birth.

They choose the therapy, and their next child is born free of the disease, but 7 weeks early.

Discuss your opinion of the morality of this couple choosing IVF.

>

SCENARIO B – GENETIC DATABASES AND PRIVACY

Forensic scientists have long used DNA tests to find if suspects can be linked to violent crime scenes. The DNA profile is destroyed if the person is later deemed innocent, but filed for all convicted criminals. Most countries have accumulated substantial databases of genetic information.

After a night of drinking and fighting, two drunken youths stone a passing car. The driver loses control and is killed. Forensic scientists find traces of blood from an unknown person on the rock.

A technique called **familial DNA searching** identifies more than two dozen partial matches from their database, one of whom has a relative in the area where the driver died. This man is later convicted of manslaughter.

Should forensic databases be used to identify genetic relatives of suspects?

RNA interference

RNA interference or RNAi is an emerging field of genetic modification that involves the use of injected, double-stranded RNA. In this technology, the mRNA is degraded when it binds to a complementary strand of RNA. The result is that the mRNA cannot be translated into a protein. It is a process that also seems to occur naturally in cells to regulate gene expression and to defend against attack by certain viruses. It is also used by a group of viruses, the double-stranded RNA viruses, to control the genomes of host cells.

RNAi technology is extremely selective, as it will only target mRNA for enzymes that are involved in unwanted processes. Only tiny amounts of double-stranded RNA are needed to achieve an effect. The interference seems to spread to other cells and can be inherited.

Applications of RNAi technology include silencing enzymes involved in the production of allergens. This will benefit people with life-threatening allergies. Enzymes involved in competing alternative metabolic pathways that consume energy or amino acids can also be silenced, increasing the amounts of the desired product. This technology is particularly promising for improving and fine-tuning agricultural yields in parts of the world where malnourishment occurs.

REVIEW

1 Complete the following table to summarise the information about genetic diseases.

Disease	Effect	No. of base pairs in gene	No. of amino acids in protein
Cystic fibrosis			
Haemophilia			

2 Consider a group of neurological diseases affecting humans.
- CAG stutters of more than 39 in a gene on chromosome 4 cause Huntington's disease.
- CAG stutters of more than 20 in a gene on chromosome 6 cause spinocerebellar ataxia type 1, affecting balance and speech.
- CCG or CGG of more than 200 cause a slight mental retardation, Fragile-X syndrome.
- CTG stutters of between 50 and 1000 times in a gene on chromosome 9 cause myotonic dystrophy.

   a Based on what you know of Huntington's disease, suggest a prognosis (disease prediction) for people born with the gene over successive generations.
   b Can you see any common patterns in the triplets involved in these four conditions?
   c Why do you think these diseases are collectively known as 'polyglutamine diseases'? (Hint: What is a glutamine?)

3 **a** What is a restriction enzyme?
   b What function do you think restriction enzymes have in bacteria, where they were first discovered?
   c What is a ligase?

4 Some DNA technologies also increase the amount of DNA in organisms. For example:
- transgenic organisms (such as insulin-producing bacteria) contain an artificial human gene to make human insulin used by diabetics
- genetically engineered salmon have extra promoter genes for growth hormone, generating high yields.

   Based on what you know of Huntington's disease, suggest why multiple copies of DNA triplets may sometimes cause harm, but multiple copies of whole genes do not seem to.

5 These open-ended questions have no right answers. They will require some creative thinking, and some open-mindedness in listening to the perspectives of others.
   a Suppose a pig is genetically engineered to produce a vital blood factor for use in humans. Would the use of this medical product have limitations in certain cultures? Explain.
   b Suppose a rose is genetically engineered to express the gene from blue petunias. Predict whether the availability of deep blue roses could change the economy.

6 Genetic modification by conventional breeding techniques is rarely considered controversial. Do some responses by students to Question 5 help you understand why recombinant DNA technologies are different?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State how the following cell components were linked to DNA in this unit.
   - **a** Nucleus
   - **b** Mitochondria, chloroplasts
   - **c** Ribosomes
   - **d** Cell membranes
   - **e** Cytoplasm

2 Erwin Chargaff observed that bases always occurred in pairs. There was always the same amount of guanine as cytosine, and the same amount of adenine as thymine. Why was his observation important?

3 Interpret the information about the nucleotide sequence AUCCGAUAGAUAUGG to judge the:
   - **a** type of nucleic acid it is
   - **b** part of the cell where you would expect to find it
   - **c** molecule it might be part of.

LEVEL 3–4

4 Outline differences between the nucleic acids by completing the following table.

[illegible]	[illegible]	[illegible]	[illegible]
Sugar present			
Bases present			
Complementary pairings			
Location in the cell			
Function			
Process			

5 Part of the base sequence on a template strand is CCCCCTGTAATACAAGAC.
   - **a** What will be the complementary sequence on the mRNA molecule?
   - **b** How many codons is this?

6 If a sequence of three bases is missing in a gene (which means three nucleotides are missing in the structure), one amino acid will be missing from the protein that gene codes for. But if only one base is missing, then nearly every amino acid could be different. Interpret this information to support your judgement about why a deletion of three base pairs, or the substitution of one base pair, is likely to be less damaging than the deletion of one or two base pairs.

LEVEL 5–6

7 Describe how the weaker bonding between the DNA strands contributes to its function during replication (copying the DNA) and transcription (copying to mRNA).

8 Consider the genetically controlled pathway in a plant shown in Figure 5.21.

   The series of enzymes A, B and C (each coded by their respective genes) controls the biochemical conversion of a flower pigment molecule, P.

   Gene D is responsible for an inhibitor protein that renders enzyme C inactive. Assume faulty genes result in inactive proteins.

   Explain what the final flower colour would be if:
   - **a** gene A is faulty
   - **b** gene B is faulty
   - **c** gene C is faulty
   - **d** gene D is faulty
   - **e** genes A–D are all functional.

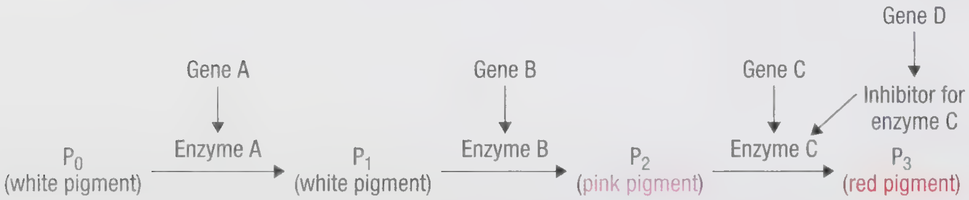


FIGURE 5.21

9 Many viruses do not carry their genetic information as DNA. Instead, they have a single strand of RNA. An accidental change in the base sequence of a single strand cannot be detected, so RNA organisms can change their sequences at about 10 000 times the rate of organisms that have DNA for their genetic code. Using this information, deduce why you may catch a different cold every year.

10 Explain why:

a the manufacture of proteins is so vital to living organisms

b your diet should include a range of different sources of protein.

11 Figure 5.22 shows the 'DNA code'. This is a near-universal code used by all living organisms to translate the codon sequence into amino acids.

a Determine the amino acid sequence coded for by the mRNA section you transcribed in Question 5.

b The DNA code is said to be 'redundant'. Look carefully at the base-pair sequences of amino acids that are translated from more than one codon, and decide what the term 'redundant' means.

Second letter

First letter	U	C	A	G	Third letter
U	UUU, UUC **Phe**nylalanine UUA, UUG **Leu**cine	UCU, UCC, UCA, UCG **Ser**ine	UAU, UAC **Tyr**osine UAA, UAG **STOP**	UGU, UGC **Cys**teine UGA **STOP** UGG **Trp**tophan	U C A G
C	CUU, CUC, CUA, CUG **Leu**cine	CCU, CCC, CCA, CCG **Pro**line	CAU, CAC **His**tidine CAA, CAG **Glu**tamine	CGU, CGC, CGA, CGG **Arg**inine	U C A G
A	AUU, AUC, AUA **Ile**ucine AUG **Met**hionine	ACU, ACC, ACA, ACG **Thr**eonine	AAU, AAC **Asp**aragine AAA, AAG **Lys**ine	AGU, AGC **Ser**ine AGA, AGG **Arg**inine	U C A G
G	GUU, GUC, GUA, GUG **Val**ine	GCU, GCC, GCA, GCG **Ala**nine	GAU, GAC **Asp**artic acid GAA, GAG **Glu**tamic acid	GGU, GGC, GGA, GGG **Gly**cine	U C A G

FIGURE 5.22 The genetic code – the first letter of the codon is listed in the left-hand column, the second is listed along the top of the table and the third is listed in the right-hand column. The amino acid the tRNA will deliver is named next to the combinations. The three-letter code for each amino acid is indicated by the letters in bold: for example, Leu represents leucine, Gln is glutamine and Trp is tryptophan.

12 In 2008, the platypus genome was completely sequenced. A platypus is an Australian animal that belongs to a primitive class of mammals that lays eggs. The research revealed the following.

- The platypus genome carries both reptilian and mammalian genes associated with egg fertilisation.
- Like the genomes of other mammals, the platypus genome contains a tightly clustered set of genes that produce the casein proteins in milk.
- The platypus shares more than 80% of its genes with other mammals whose genomes have been sequenced.
- Chickens and lizards have a relatively few odorant receptor genes responsible for their ability to detect smells. Interestingly, the platypus has about half as many odour receptors as other mammals.
- Venom produced by the male platypus arose from duplications in certain genes that are similar to ancestral reptile genomes.

Make scientifically supported judgements about what the platypus genome suggests about the evolution of mammals.

REFLECTION

1 Respond to the debatable questions in this unit.
  a Is genetic information always beneficial?
  b Should limits be placed on the use of DNA technology?
  c Is it possible to limit the reach of scientific knowledge?

2 Systems, the key concept, are sets of interacting components. Explain how DNA, the body code, unifies our understanding of components biology, including as:
  a the basis of cellular specialisation
  b the mechanism for genetic disorders
  c classification between organisms.

3 Models are a related concept in this unit. How did Watson and Crick's design inspire future understanding of genetics and protein synthesis?

4 Transformation, another related concept, refers to a dramatic change from one state or form to another. What makes the following examples of transformation?
  a Mutations
  b Specialisation of an undifferentiated cell
  c Using recombinant DNA technology to create transgenic organisms
  d The emergence of eukaryotes

5 How does the form of DNA support its function for conserving genetic information?

6 What new technologies have emerged as a result of discovering DNA?

7 Do you feel that learning to control DNA is a positive or a negative outcome of human ingenuity?

UNIT 6

IT'S IN YOUR GENES

KEY CONCEPT

Change

RELATED CONCEPTS

Patterns

Transformation

Consequences

GLOBAL CONTEXT

Personal and cultural expression: an exploration of a modern understanding of genetics, as a source of conserving identity or generating variation

STATEMENT OF INQUIRY

Genetics shows us who we, and all other life, once were, are and might become.

INQUIRY QUESTIONS

FACTUAL

1 How do we inherit our characteristics from our parents?
2 What happens to information during mitosis and meiosis?
3 What are some useful applications of genetic information?

CONCEPTUAL

4 What are the advantages of sexual reproduction?
5 Where does life's diversity come from?
6 How predictable are the outcomes of a mating?

DEBATABLE

7 Can undesirable genes ever be eliminated from populations?
8 How important is the DNA in our organelles?
9 Are we the sum of our genes?

Introduction

Unless you are an identical twin, your genome is unique. Yet every cell in your body contains the same information, recorded in its DNA. When your body repairs wear and tear, the DNA information in each new replacement cell is identical. There are great advantages to this: your body cells can recognise 'self', and organisms that reproduce by cloning can quickly conquer new terrain. In the first part of this unit, you will explore the mechanism of asexual reproduction.

The DNA within each of your cells was contributed by your biological parents and theirs by your grandparents and so on, back in time. In this unit, you will learn how this information is passed down the generations, and about the unpredictable outcome of sexual reproduction. Finally, you will investigate how the DNA information presents itself. Nuclear DNA genes shuffle to dramatically predictable rules. Organelle DNA tells a different story. Together, they tell us which characteristics we inherited from our parents, and identify our familial relationships worldwide.

SUMMATIVE PERFORMANCE ASSESSMENT
CRITERION D

Who is at risk?

Some groups of parents are more at risk of having children with severe genetic disorders than others. Which groups are they?

Your task

Create a pamphlet of up to 1200 words in a format appropriate for a community health facility, informing prospective parents of how, when and where they can find assistance, locally and nationally, for a syndrome of your choice.

Describe parents' options for diagnosis, and the risks of using these tools. Are there any technologies that can improve the chances of having a genetically healthy child? How do they work? Does their use carry risks?

Parents of children who are different often find themselves joining new communities that advocate for their children's needs. What are the implications of having a child with the syndrome? How does one of the following factors for the parent – moral, ethical, social, economic, political, cultural or environmental – interact with the concerns a child might have?

Your clear scientific communication should include photographs and correctly formatted pedigree diagrams (as shown later in this unit). You should use referenced printed and electronic media and interview specialists in the field, support groups and/or sufferers.

ATL

AFFECTIVE-EMOTIONAL INTELLIGENCE

People working in the field of advising parents of children with severe genetic disorders will need to be able to control their own emotions and be able to show empathy for the situation of the parents. Consider which of these attributes are also important in learning and in all aspects of life.

The genetics of asexual reproduction

Species that reproduce asexually rely on one kind of cell division – mitosis. Only cells can make new cells. To reproduce, most of the cells of your body go through a two-phase (stage) cell cycle. In rapidly growing organisms, the complete cycle takes about 10–30 hours in plant cells and 18–24 hours in animal cells. However, this rate varies in different tissues.

Most of a cell's life is spent in the growth phase; the reproduction phase only takes about one-twentieth of the cell's life (see Figure 6.1).

Growth phase

During the growth phase, cells typically synthesise proteins and double their size. This phase is called **interphase**, since it is the period between the cell divisions. During interphase, proteins are manufactured and the cell organelles multiply. Just before the cell divides, its DNA makes a duplicate copy of itself.

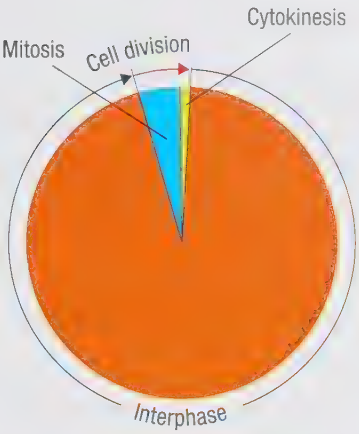


FIGURE 6.1 This circle represents the entire life of a cell

Reproduction phase

This phase consists of two stages. In the first stage, the DNA becomes visible, divides and forms two nuclei. Movement of the DNA in the cell is controlled by thread-like proteins called **spindle fibres**. This process is termed **mitosis** (from the Greek word *mitos*, meaning 'fibre'). In the second stage, the cell divides, halving the contents of the cytoplasm, including the organelles. This process is called **cytokinesis** (from the Greek words *kytos*, meaning 'a vessel', and *kineein*, meaning 'to move').

The two cells that result from this division are commonly called **daughter cells**. The original cell, of course, no longer exists. It has reached the end of its cycle.

ATL

TRANSFER

How scientific root words build understanding across sciences. Many scientific terms are based on Greek or Latin. A basic knowledge of these prefixes will also support you in all future studies of science.

... au and click on **Prefixes** ...

Go to http://mvbb... com.au and click on **Twin studies**. Twins volunteering ...

Advantages of asexual reproduction

Asexual reproduction requires only one parent. The only kind of cellular division that asexual species have is mitosis. Organisms that reproduce asexually can quickly take advantage of empty terrain, such as land that has been cleared or devastated by wild fires or on volcanic islands that emerge from the ocean.

Mutation – a source of variation

It is sometimes argued that the lack of variation in cloned organisms makes them vulnerable to threats such as new diseases or climate change. But cloned organisms do have an important source of variation: mutation. Mutations happen as a result of damage to the cell's DNA. Our environment has many potential sources of damage, including ultraviolet radiation from the Sun and the carcinogens found in cigarette smoke (Figure 6.2).

We all know of people with cancer. Many cancers affect genes that control cell division. The damaged cell keeps dividing in the same uncontrolled way, resulting in the growth of a tumour.

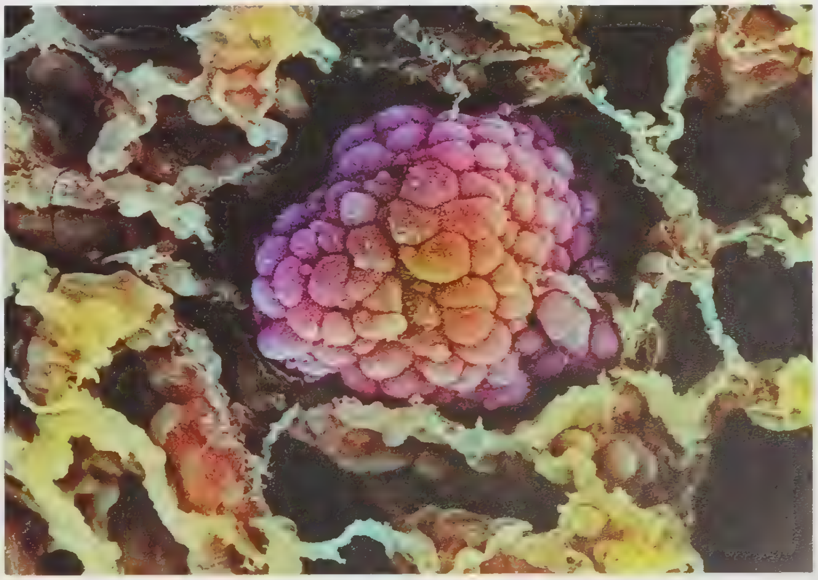


FIGURE 6.2 The tar in cigarettes can cause cancer of the throat and lungs. This scanning electron image shows a small cancerous tumour (pink) in a lung. A few cancer cells can also be seen separated from the main tumour.

Advantageous mutations may only become apparent if the environment begins to select against organisms that do not have it. For example, bacteria (which reproduce asexually, although not by mitosis) sometimes acquire antibiotic resistance by swapping genes. This will be of no advantage to an individual bacterium unless its environment is suddenly flooded with antibiotics. In hospitals all over the world, the rise of antibiotic-resistant bacteria demonstrates how effective asexual reproduction is as a means of adaptation to change (see Unit 8).

INVESTIGATION 6.1

What makes a species?

All varieties of commercial fruit or edible tubers are clones reproduced asexually from an original individual that had desirable traits. The DNA in all the cells of fruit of the same variety should be identical.

FIGURE 6.3 Apples and pears are considered to be different species, although both are pome fruit.

YOUR CHALLENGE

Develop a series of tests to determine when the traits or characteristics of an organism are sufficiently different to define it as a species. You should study at least two varieties of a species (e.g. two varieties of potato or apple) and a related, but different edible species (e.g. sweet potato, quince or pear).

THIS MIGHT HELP

You will need to design test methods that compare the two types of tubers or fruit, to identify traits that are common to the species, and traits that are variations. Traits in your specimens include firmness, juiciness, size, mass, taste and colour. They may include chemical properties such as the levels of starches, sugars and acidity. Which characteristics are best to measure, and why? Which tubers or fruit do you predict will have the greatest similarity, and why? How many replicate samples will you need to be confident of your knowledge of each species?

After collecting your data, evaluate whether there is any overlap between the characteristics that are properties of the variety and those of the species. Relate your results to how scientists classify new species, and how agronomists develop new varieties.

Carry out and write up your investigation following the guide in the Appendix 3 on page 209 or as advised by your teacher.

The mechanics of mitosis

Imagine you had a string about 100 000 times longer than a room. The string is extremely fine, and you need to move it across the room diagonally. How could you do this? You might cut it up into shorter lengths. You might roll each length up into a tight ball. This effectively is how the 10^{-5} metre diameter human cell solves the problem of moving a 1.7-m long DNA polymer through its semifluid interior.

The DNA lengths are called **chromosomes**. As suggested by their name (from the Greek word *chroma*, meaning 'colour') these structures can be stained. An average human chromosome contains about 130 million pairs of nucleotides.

During interphase, each chromosome is thin and not visible through a microscope. A single DNA double helix runs down its length. Before cell division begins, the DNA 'unzips' in sections and copies itself. To make a copy, nucleotides present in the nucleus assemble on each of the two complementary strands. This results in two identical DNA molecules, each consisting of half of the original molecule and a newly synthesised complementary strand (Figure 6.4). The two identical DNA molecules will separate during mitosis. While they remain together, they are called **sister chromatids** of the chromosome (Figure 6.5, page 134). The entire 'assembly' is still described as a chromosome.

Notice in Figure 6.5 that the duplicated chromosome resembles an X. The part where the paired chromatids are joined is the **centromere**. This region of the chromosome is very important, as this is where the chromosomes attach to the spindle fibres that move the chromosomes during cell division.

FIGURE 6.4 Semiconservative replication. The DNA molecules split during replication and each 'daughter' cell will receive a molecule that is half an original strand (blue) and half newly synthesised DNA (orange).

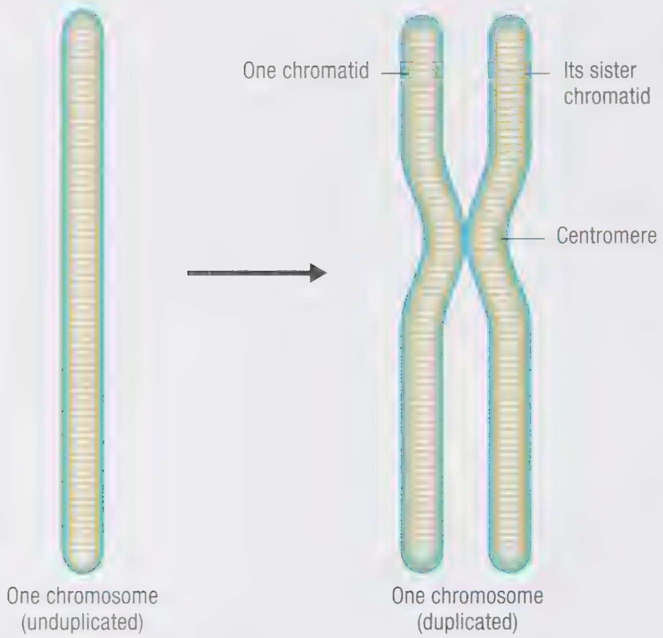


FIGURE 6.5 The formation of sister chromatids

TRANSFER

Developing memory skills – a mnemonic is a device to help memory. For example, the first letter of each word of a term may be easier to remember than 'prophase, metaphase, anaphase and telophase' – P, M, A, T. Or create a mnemonic using the letters. Consider why this helps memory. How are memory and learning related?

The main stages of mitosis are shown schematically in Figure 6.6. However, these events are actually occurring dynamically in three dimensions, in the spherical cell.

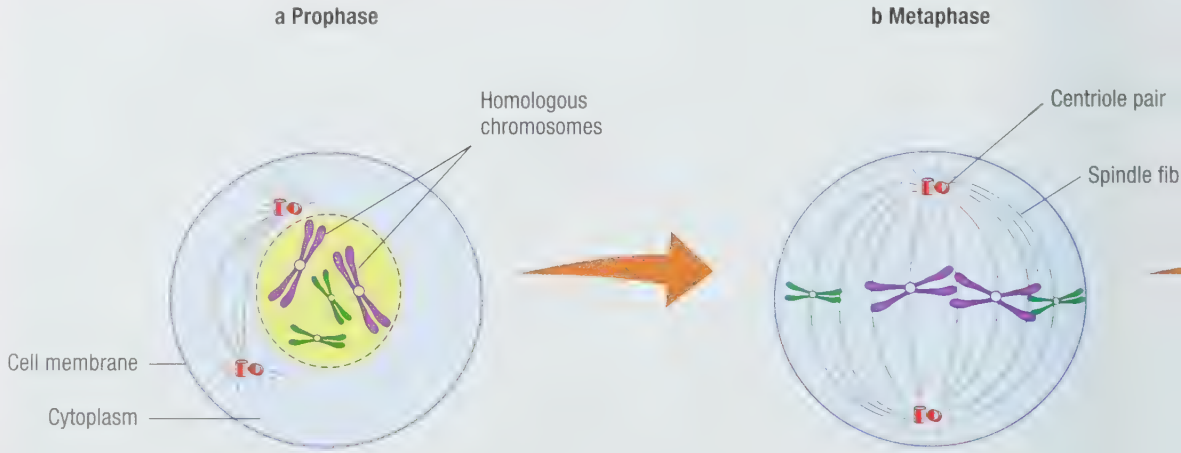
Stages of mitosis

Prophase

In a non-dividing cell, the nucleus is divided into compartments by a nuclear membrane that extends in folds throughout the cytoplasm.

During **prophase**, the beginning of mitosis, the duplicated chromosomes coil up and become much shorter and, consequently, thicker. This is analogous to rolling a fine string into a tight ball, and has the effect of protecting the delicate molecule. The chromosomes are now visible under a microscope. At the same time, the nuclear membrane is broken down and becomes less visible.

Figure 6.6a shows four chromosomes. The spindle fibres, which are controlled by structures called **centrioles**, attach to the centromeres. Spindle fibres are chemically nearly identical to the fibres found in muscle tissue and use the same mechanism to contract. All controlled movements of organelles within cells use these chemicals.



• Chromosomes coil and become visible. • Nuclear membrane disappears. • The centrioles divide and move to opposite poles. • Spindle forms.	• Chromosomes line up along the middle of the cell. • The spindle fibres attach to each chromatid of each chromosome.

FIGURE 6.6 The stages of mitosis

Metaphase

The second stage is **metaphase** (from the Greek *meta*, meaning 'after'). The spindle fibres have pulled the chromosomes onto a circular 'plate' across the centre of the cell. This positioning is very important, as it will ensure that each daughter cell receives one copy of each chromosome.

Anaphase

The third stage, **anaphase**, often happens very quickly. The centromere divides and the spindle fibres pull the structures, now called **sister chromosomes**, to opposite ends of the cell. The V-shape of the chromatids indicates they are limp, and that it is the centromeres that are actually being pulled.

Telophase

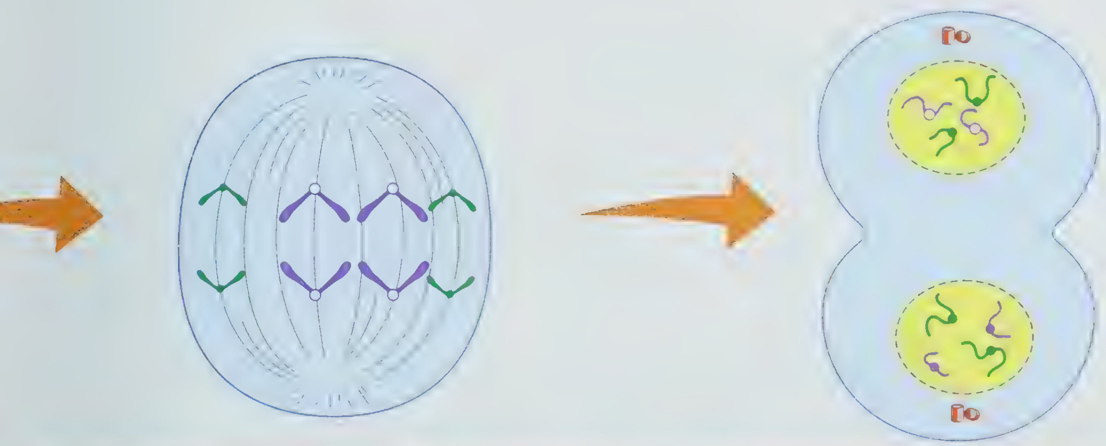
During **telophase** (from the Greek *telos*, meaning 'end'), the separated sister chromosomes group together at opposite ends of the cell. A new nuclear membrane forms around them, and they become invisible, even under a microscope. Meanwhile, the cytoplasm begins to undergo cytokinesis. Notice (Figure 6.6d) that there are now four chromosomes in each daughter cell.

In plant cells, which are rigid because of the plant cell wall, cytokinesis involves building new cell membranes and a cell wall between the sister nuclei.

Each daughter cell will have an exact copy of the original DNA, and half of each molecule will be from the parent cell.

Mitosis ... to see how the cell cy... dividing and 'resting'. Wh... doing while it ...

c Anaphase **d Telophase**



Anaphase	Telophase
• Centromeres split. • Sister chromatids move apart to opposite ends of spindle.	• Chromosomes reach the opposite poles of the cell. • Nuclear membrane re-forms, and the chromosomes become less visible. • Cytokinesis begins. Animal cells 'pinch in', and plant cells grow new membranes and cell walls between the two nuclei.

REVIEW

1 Describe how asexual reproduction is an advantage when:
   a new land emerges in the ocean as a result of a submarine volcanic eruption
   b an apple seedling is discovered with an unusually flavourful fruit.
2 Summarise this section by outlining the connections between the following terms in a concept map: interphase, reproductive phase, mitosis, cytokinesis, prophase, metaphase, anaphase, telophase, daughter cells.
3 Suggest why most of the cell cycle is spent in interphase.
4 Use a diagram to show how the cell cycle changes in a fast-growing cancer cell.
5 If a cell of a growing fruit has 16 chromosomes, how many chromosomes will there be in its daughter cells?
6 Write down a four-word mnemonic to remember the stages of mitosis.

Chromosomes: our parents' legacy

In Figure 6.6 you may have noticed that the four chromosomes are shown in two pairs, two large ones and two short ones. Most eukaryotic organisms have paired chromosomes in their normal body cells. The pairs are known as **homologous** chromosomes. They are homologous because they look alike and they also carry matching genes – genes for the same traits (characteristics). The number of pairs is the **diploid** number. (This name comes from the word *ploid*, meaning 'sets'.) The diploid number in these **somatic** (body) cells is symbolised as $2n$.

The number of pairs is a characteristic of the species (Table 6.1).

TABLE 6.1 The diploid numbers of several organisms

[illegible]	[illegible]
Pig	38
Cat	38
Rabbit	44
Human	46
Chimpanzee	48
Potato	48
Chicken	78
Bracken fern	116

Notice that bracken fern has more chromosomes than we do. In addition, chimpanzees and potatoes have the same diploid number but are obviously very different organisms. The reason for this is that the number and kind of genes on a chromosome varies from species to species. Clearly, the genes along the chromosomes are more important for characteristics than the total number of inherited chromosomes.

Karyotypes

The typical number of chromosomes in an organism's body cells is called its **karyotype**. When whole chromosomes are studied, they are often stained and show bands. The bands correspond to large groups of genes. The different chromosomes can then be individually recognised by their size, the position of their centromeres and their banding pattern. The chromosomes can be rearranged (from a microphotograph) in pairs for comparison. Figure 6.7 shows a schematic **karyogram** of the 23 different chromosome pairs found in humans.

In Figure 6.7, you can see that there are two copies of each chromosome. One is inherited from the mother (**maternal chromosomes**) and one from the father (**paternal chromosomes**). This principle is shown schematically in Figure 6.8.

FIGURE 6.7 The karyogram of human chromosomes. The convention for identifying chromosomes is to number them according to their size, with chromosome number 1 being the largest.

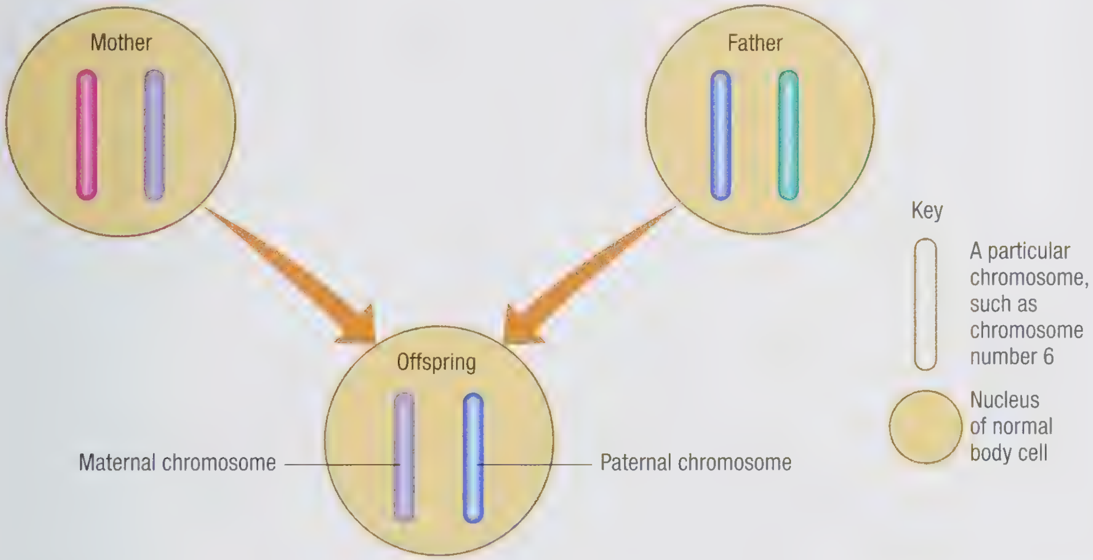


FIGURE 6.8 Our parents' legacy

Although homologous chromosomes carry genes for the same traits, the details of their genetic information, such as for nose shape or hair colour, are not necessarily identical.

The only cells that do not have two copies of each chromosome are the gametes (sperm and ova). They only have one copy of each chromosome set. This means they are **haploid**, and carry half the genetic information found in normal body cells. The chromosome number in these **sex cells** is symbolised as n.

When a sperm and an ovum unite during fertilisation, the resulting cell, the zygote, has the **diploid** number of chromosomes ($n + n = 2n$).

This applies to all organisms that reproduce sexually. The only difference is in the number of chromosomes they have.

FIGURE 6.9 At fertilisation, the chromosomes of each gamete are added together, forming a single cell with 23 pairs of chromosomes.

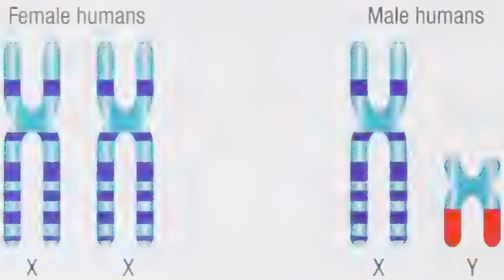


FIGURE 6.10 The chromosomal difference between male and female humans

The difference between males and females

What determines our sex? In Figure 6.7 the karyogram shows 22 pairs of matching chromosomes. These chromosome pairs are called **autosomes**. The 23rd pair is dissimilar. It consists of the sex chromosomes. For simplicity, the sex chromosomes in mammals are called the X and Y chromosomes. The Y chromosome is smaller than the X chromosome and contains fewer genes. Because they are different, the X and Y chromosomes are termed **heterosomes**. Figure 6.10 shows that female mammals have two X chromosomes, symbolised XX. Males have one of each, symbolised XY.

How karyotypes can diagnose genetic errors

Examples of genetic disorders that resulted from faulty proteins, ultimately traced to errors in the nucleotide sequence of the DNA, were given in Unit 5. Other errors are possible.

If homologous chromosomes do not separate properly during the cell divisions that generate gametes, the result is a **non-disjunction**. After fertilisation, there will be an imbalance of chromosomes in the zygote. When only one copy of a pair is present, it is known as a **monosomy**. When three copies are present, it is a **trisomy**. Partial effects are also possible if parts of a chromosome break off (partial monosomy) and, more rarely, re-attach to others (partial trisomy).

None of these effects is trivial. Many are lethal and result in miscarriage, particularly if the chromosome involved is large. Fortunately these errors are extremely rare.

The schematic karyograms in Figure 6.11 all show evidence of non-disjunction. These karyotypes are consistently associated with a set of symptoms and are medically known as syndromes.

Y-chromosomal Adam and Mitochondrial Eve

Down every human line of descent, there are two kinds of reproduction that do not involve genetic exchange: in the Y-chromosome and in the organelles.

The male line

Because only men have Y chromosomes, the Y chromosome passes only from father to son. In generations that do not produce sons, the father's particular Y chromosome becomes extinct. However, every male on Earth must be directly connected, through his Y chromosome, to his first male ancestor.

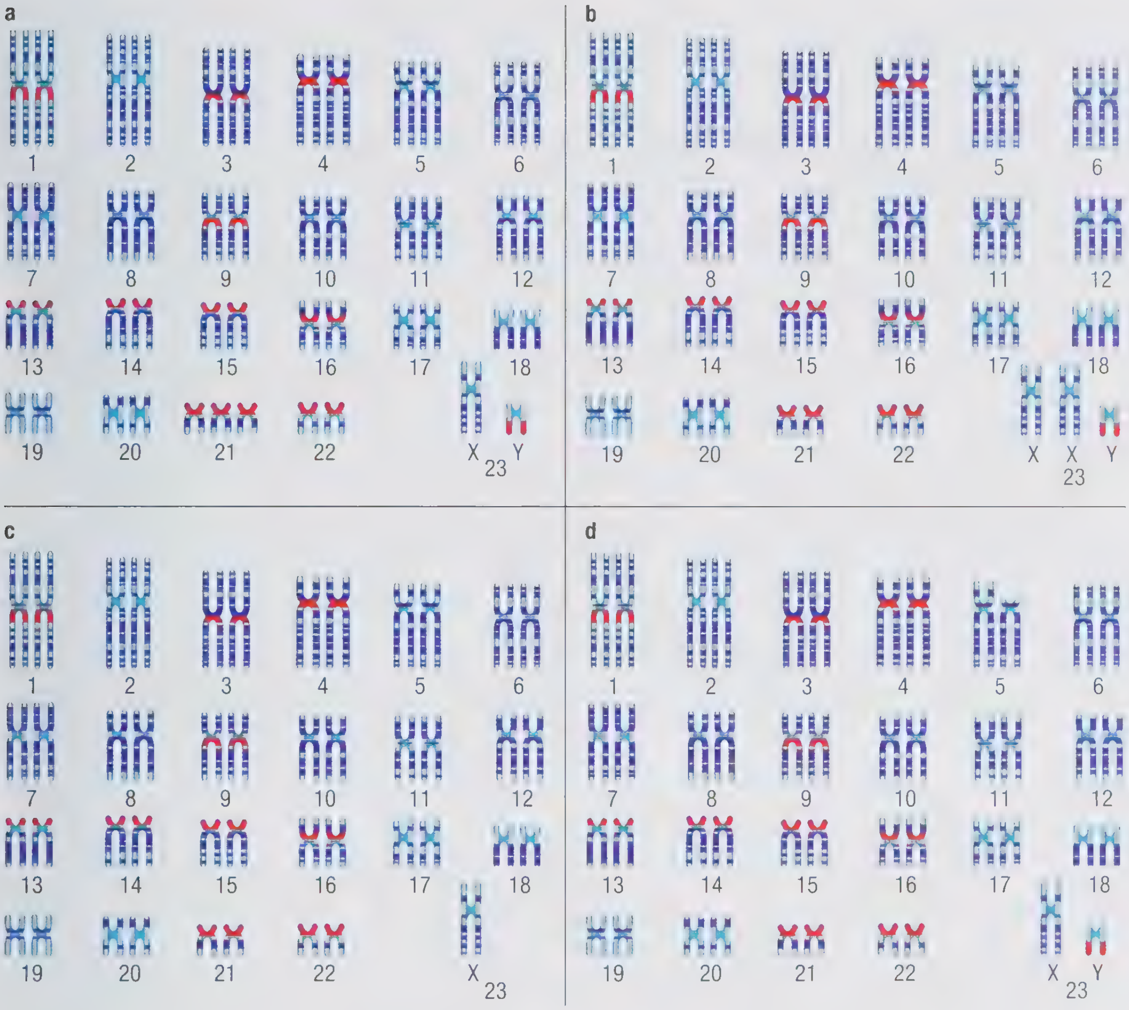


FIGURE 6.11 What conditions do the people with these karyograms have?

Over time, as with all genetic information that is reproduced without crossing over, the Y chromosome has collected mutations. This makes it possible to trace the patrilineal line of descent of people of all ethnicities back to a single man who probably lived in Africa about 60 000 years ago.

The female line

The mitochondria also contain DNA (Unit 5). The mitochondria in your cells originally came from your mother, as organelles in her ovum. Every person on Earth must be directly connected, through the inheritance of the mitochondria, to the first woman on Earth.

Mitochondrial DNA has also collected mutations over time. This has made it possible to trace the matrilineal line of descent of all people back to a single woman who probably lived in Africa about 170 000 years ago.

The dates for the male and female lines differ because, first, the rates of mutation of DNA in chromosomes and organelles may be different. Second, 'Y-chromosomal Adam' and 'Mitochondrial Eve' were just individuals who lived within large populations at different times. These estimates simply give the most recent common ancestor, using different means.

REVIEW

1 The diploid number of a rabbit is 44.
   a What is the haploid number ?
   b How many autosomes are there in its somatic cells?
   c How many sex chromosomes are there in a rabbit's gamete?
   d If you were making a karyogram of the rabbit's genome, how many pairs of chromosomes would it show?
   e In a rabbit, what is *n*?
2 From the schematic human karyograms in Figure 6.11, diagnose the errors and research the name given to the syndromes. Is there any other information you may learn from these karyotypes?
3 a What is meant by the 'patrilineal' line of descent?
   b Why is the Y chromosome an example of an asexual line of descent?
   c Explain how asexual lines can be useful for determining ancestry.
4 a What is meant by the 'matrilineal' line of descent?
   b Where do the organelles in our cells come from?
   c Explain how organelles, like mitochondria, can be useful for determining ancestry.
5 Explain why 'Mitochondrial Eve' and 'Y-chromosomal Adam' never met, but both are ancestors of us all.

The origins of sex

Although many species reproduce successfully by asexual means, most eukaryotes are diploid. Diploid genomes hint that sexual cycles are possible or sometimes required. Sexual reproduction provides a greater range of variation in the offspring (Unit 4). A lack of variation could make a species or population much more vulnerable to extinction if a major environmental change or disease occurred. This is the reason most commonly given as the advantage of sexual reproduction. However, the advantage is for the species as a whole, not all the individuals experiencing the selection processes.

For an individual, variation is not an obvious advantage because there is a chance of being less well adapted than its parents. Also, in many species, the male and female gametes come from two individuals (plants being frequent exceptions). There are risks in finding a suitable mate, and no certainty that fertilisation will be successful. Given that there were already successful mechanisms for asexual reproduction in early species, why did sexual reproduction evolve at all?

Advantages of sexual reproduction

There is evidence supporting many ideas about the origin of sexual reproduction and it remains an active discussion in evolutionary biology. Here is a brief look at some hypotheses.

In asexually reproducing species, parasites are well adapted to their hosts, which gradually become weaker. Sexually produced offspring provide new combinations of resistance. Evidence supporting this hypothesis is that the genes for the immune system seem to evolve much faster than other genes in several species.

Sexual reproduction is about deleting damaged genes. The haploid part of the sexual reproductive cycle exposes damaged genes. Competition between healthy genomes prevents the damaged genes passing to the next generation. This is true for the gametes and can also apply to whole organisms. In many social insects, one sex is haploid. The virgin queen bee will mate only on her maiden flight. She will use the sperm from the 12–15 drones for the rest of her life. Because drones are haploid, the effects of defective genes will become obvious when the drones compete with hundreds of others to mate. The genes of a defective male will be excluded from the new hive.

FIGURE 6.12 In a hive. The diploid queen bee (marked) has already mated with haploid drones

Sexual reproduction is about improving the health of the organelles. During a lifetime, the DNA in organelles such as mitochondria gradually becomes damaged (which is why elderly people often lack the energy of youth). In most species, the female is defined as the individual with the bigger gamete, and this cell provides the offspring's cytoplasm and organelles. During the formation of the ovum, organelles are carefully vetted by enzymes and only a small number, perhaps less than a dozen from many tens of thousands, will then generate new populations of perfect organelles in the cell that will eventually contribute to the new organism.

Making sex cells by meiosis

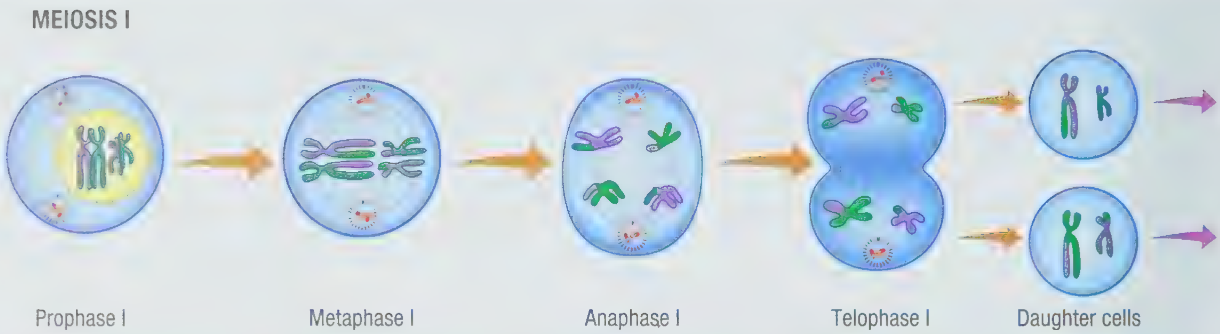
You have already seen that each cell contains a maternal and a paternal copy of each chromosome. A special kind of cell division is needed to produce the haploid genomes found in the gametes. This process is called **meiosis** (a Greek word meaning 'diminishing or reducing') and takes place in the testes of males and the ovaries of females. These organs are collectively termed gonads.

Figure 6.13 shows that in meiosis, there are two sets of divisions in succession. Compare this diagram, and the short descriptions of events during each phase, to Figure 6.6. From your knowledge of mitosis, you will already be familiar with the key stages: prophase, metaphase, anaphase and telophase. In meiosis, these words are followed by I or II, signifying the set of divisions within the cycle in which they occur.

You may wonder why the cell doesn't just simply separate the homologous pairs of chromosomes. If the maternal and paternal chromosomes separate completely randomly, 2^{23} (or more than 8 million) possible combinations can result from a human cell with 23 pairs of chromosomes. This process is called **random assortment** and it is a very important source of variation in sexual reproduction.

However, there is another important source of variation – **crossing over**. Crossing over swaps DNA sequences between homologous chromosomes. The chromatids of two homologous chromosomes are cut in the same location, and rejoined to the corresponding homologue. Typically, this will occur about three times along the length of a human chromosome. Crossing over results in a mixing of paternal and maternal genes along each of the four homologous chromatids. Each chromatid will end up with different combinations of maternal and paternal genes. If every chromosome had just one crossing-over event between its homologues, this would increase the variation fourfold. No wonder we are all unique!

You already know the key processes of cell division stages. This summary, which needs to be read together with the descriptions in Figure 6.13, focuses only on the major differences between meiosis and mitosis.



Prophase I	Metaphase I	Anaphase I	Telophase I	Daughter cells
• Chromosomes coil and become visible. • Nuclear membrane disappears. • Spindle forms. • Homologous chromosomes move towards each other. • Crossing over occurs (pieces of homologous chromosomes are exchanged).	• Homologous chromosomes align in the middle of the cell.	• Homologous chromosomes move apart. Maternal and paternal chromosomes randomly move to a side. • In each chromosome, sister chromatids are still attached.	• Paired chromatids reach the opposite poles of the cell. • In some organisms the nuclear membrane may re-form, and the chromosomes become less visible. • Cell begins the reduction division, in which the number of chromosomes will be halved.	• The two daughter cells are haploid. • Sister chromatids each have some material from the homologous pair.

FIGURE 6.13 The stages of meiosis

Prophase I

The chromosomes of a homologous pair move next to each other. For example, the maternal and paternal copies of chromosome number 1 move until they are side by side. Crossing over takes place during this stage.

Anaphase I

The spindle fibres separate the homologous pairs of chromosomes. This is called the reduction division, as the daughter cells after this step are haploid.

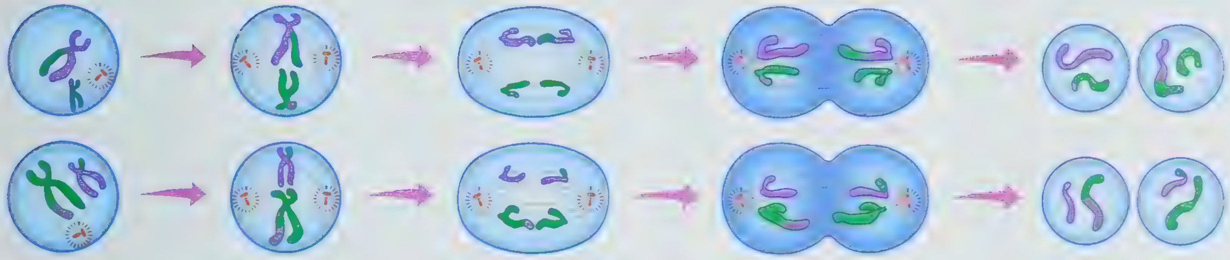
Prophase II

There is no need to replicate the DNA before this stage and, in most species, the chromosomes remain condensed.

Anaphase II

This division separates the sister chromatids. After meiosis, the original diploid cell has formed four haploid cells, each with a unique genome, shown in the two colours in Figure 6.13. In the testes, the four new cells all develop into sperm. But in the ovaries, only one of the four haploid cells develops into an ovum. The remaining three cells soon disintegrate.

MEIOSIS II



Prophase II	Metaphase II	Anaphase II	Telophase II	Daughter cells
• Chromosomes condense. • Spindle forms. • Nuclear membrane disappears.	• Chromosomes align in the middle of the cell.	• Sister chromatids separate and move to opposite poles of the cell.	• Chromatids reach opposite poles of the cell. • Cytokinesis begins.	• After the second division there are four daughter cells. • Each cell is unique because: – paternal and maternal chromosomes are sorted – each chromatid has unique combinations of genes.

REVIEW

1 Draw a table outlining the differences between asexual and sexual reproduction with the following rows.
  a Number of cell divisions
  b Number of daughter cells
  c Number of chromosomes (*n*) in daughter cells
  d Genetic composition of daughter cells compared to parent cells
  e Parts of the body where these cell divisions happen

2 Why might the size of its gamete be considered a good way to define an organism's sex?

3 Explain how the following contribute to the variation in organisms produced by sexual reproduction.
  a Random assortment
  b Crossing over

4 In 1938, a young museum curator in South Africa, Marjorie Courtenay-Latimer, was given a dead coelacanth. She was able to recognise it immediately because of her unusual knowledge of 400-million-year-old fossil fish. In 1994, a species of pine, *Wollemia nobilis*, was discovered growing in a gorge 150 km north of Sydney, Australia. It, too, was previously known only from 200-million-year-old fossils, from organisms that lived when dinosaurs roamed the Earth. Both these organisms reproduce sexually.
  a Would they be genetically similar to their immediate parents? Explain your reasoning.
  b Are they really the same as their ancient fossil relatives? Explain your reasoning.

FIGURE 6.14 Gregor Mendel (1822–1884)

Explaining patterns: Mendel's gift for statistics

Gregor Mendel (Figure 6.14) came from a peasant family with high ambitions for their children's education. When an industrial accident prevented his father from earning a living, his two sisters financially supported Gregor through his university studies. After graduating, he looked to the local monastery for a secure vocation.

At that time, monasteries were much more than religious institutions. The St Thomas Monastery at Brno (now in the Czech Republic), where Mendel returned to teach and work, was deeply concerned with scientific research to improve crop productivity.

Mendel was educated in statistics and physics, which prepared him to look at the world in terms of ratios, in contrast to the other great naturalist biologists of the time. He found that the laws of probability could be applied to working out inheritance.

All Mendel's experiments were completed during an 8-year period. When he was promoted to abbot, his increased workload prevented further experiments. The terms he created to explain his observations are the same terms you, too, will be using. So significant and consistent are the patterns he described that he is now known as the 'father of genetics'. However, when Mendel published his results in 1865, they were ignored. It was not until three other scientists independently produced similar data in 1900 (see Unit 5) that their importance was recognised, 16 years after his death.

Mendel

Patterns of inheritance

Pure breeding traits

Mendel's most famous breeding experiments involved seven characteristics (or **traits**) in the garden pea, *Pisum sativum*. The species has a diploid number of 14 ($n = 7$) and the genes for the seven traits are all located on different chromosomes. Mendel's choice of traits to investigate may have been a lucky chance or it may have been the result of astute observation.

Garden peas are normally self-fertilising. The seedlings of peas with yellow unripe seeds always produce yellow unripe seeds, and the seedlings of peas with green unripe seeds always produced green unripe seeds. When characteristics are continued like this, generation after generation, the organism is described as **pure-breeding** for that trait.

Keeping track of generations

Mendel's pea experiments always deliberately crossed two varieties. He called this the **parental generation (P)**. By carefully cutting off the anthers of flowers as they opened, he ensured the flowers could not pollinate themselves. Using a fine brush, he then brushed pollen collected from flowers of one variety onto the stigmas of the other. The resulting seeds were allowed to ripen. Then they were collected and grown the following summer. You can imagine how carefully the dozens of plants needed to be labelled and how patiently he needed to await the results.

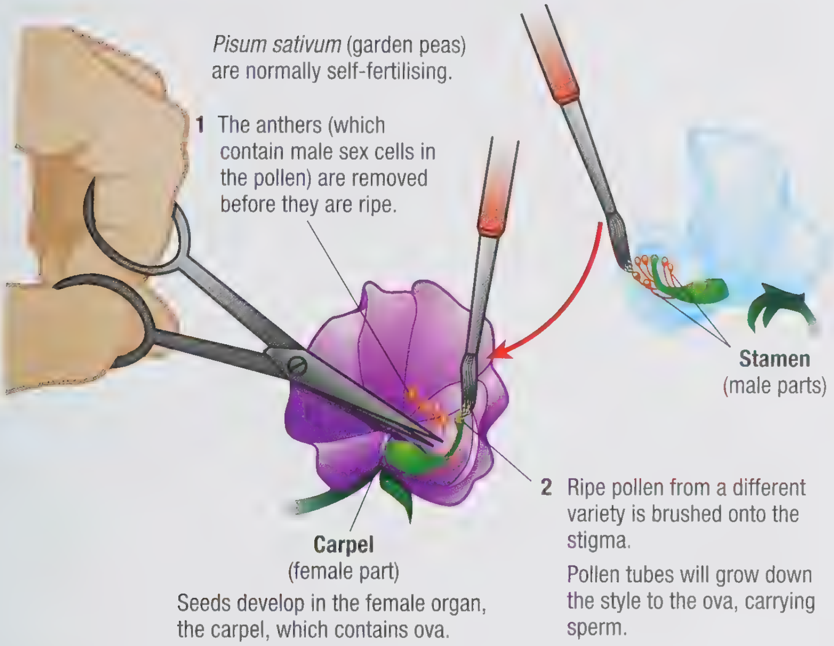


FIGURE 6.15 Cross-pollinating peas

What result might you expect? In this experiment, the unripe seeds of the next generation (which Mendel called the first filial or **F_1 generation**) were all yellow.

Mendel let these plants self-fertilise. The following year, the second filial or **F_2 generation** consisted of 6022 plants with yellow unripe seeds and 2001 plants with green unripe seeds.

Explaining the patterns caused by dominant and recessive traits

How did Mendel explain these results? First, he realised that the F_1 generation must have always had information for the green seed coat, even though he could not observe it. He called this a **recessive** trait. The other trait, yellow seed coat, was therefore **dominant**.

Second, he noticed that 6022:2001 was an approximate ratio of 3:1. This ratio is known as the Mendelian ratio and all other crosses can be explained by it. Mendel explained the result by suggesting hereditary information was stored in pairs in the adult plant, but only half this information was passed on from each parent to the offspring. This was a remarkable insight, considering no one at the time had observed chromosomes, let alone meiosis.

Third, Mendel developed a notation to explain the pure-breeding parents, which he described as **homozygous**. Homozygous parents only provide information of one type to the zygote. The F_1 generation contained two types of information, and this he called **heterozygous**. The heterozygous F_1 carried information for two traits, green and yellow seeds.

Predicting Mendel's ratios

Alleles

As you have learned, organisms inherit half their chromosomes from each parent. This means they inherit two copies of each gene. However, not all genes on chromosomes are exactly the same for everyone. For example, people have different eye colours and Mendel's unripe peas had different coat colours. Different versions of a gene are termed **alleles**. Although many alleles may exist for particular genes, no individual organism can carry more than two different alleles, because chromosomes only come in pairs.

FIGURE 6.16 The alleles of genes – a schematic representation. These are alleles for just one gene on one homologous pair of chromosomes. Thousands of other genes will also be located on these chromosomes.

Allele notation – genotypes and phenotypes

An organism's **genotype** for a trait describes the alleles it actually carries.

Homozygous dominant traits

The original parent plant used by Mendel produced yellow unripe seeds. The plants were pure-breeding, so the symbol we use to show each allele is the same. The trait is also dominant, so by convention we use a capital letter. Therefore, we could show the plant's homozygous dominant genotype as YY. This plant can only donate the Y allele to its offspring.

Homozygous recessive traits

Let's now consider Mendel's original homozygous, recessive parent plant that produced green unripe seed. By convention, we use the same letter for the gene, but in lower case to indicate it is a recessive characteristic, yy. This plant can only donate the y allele to its offspring.

Heterozygous traits

The F_1 plants are heterozygous, and have two different alleles. Their genotype is therefore Yy. However, the appearance of their seeds is the same as for the homozygous parent with yellow unripe seeds. The appearance is known as the **phenotype**. Without breeding the plants, it is not possible to tell whether their genotypes are different.

Using a Punnett square to predict the outcomes of a genetic cross

Alleles from F_1 male parent \ Alleles from F_1 female parent	Y	y
Y	YY	Yy
y	Yy	yy

FIGURE 6.17 Punnett square of F

A **Punnett square** (Figure 6.17) is a table that predicts the results of all possible combinations of alleles for a particular trait in a cross of parents whose alleles are known. It is named after their creator, English geneticist Reginald Punnett.

In a Punnett square, each allele from the genome of each parent is shown separately in a column or row in the table. The alleles are combined where the columns and rows intersect. All the possible genotype combinations for crossing two F_1 plants are shown: 1 × YY; 2 × Yy; 1 × yy.

Inferring the phenotypes from these genotypes, you can see YY and Yy have the same phenotype, so the phenotypic ratio is 3 × Y– : 1 × yy. The '–' indicates that the second allele is not significant. Notice how the Punnett square explains the 3:1 pattern of the 'Mendelian ratio'.

and click on Eye colour

Blue eyes – brown eyes

Eye colour inheritance is much more complicated than the simple case of pea seeds. People can have a large variety of eye colours, because more than one gene is responsible. One pair of alleles controls the amount of brown pigmentation (melanin) on the iris. Blue eyes do not have any of this pigment deposited, but dark brown eyes have a lot of the pigment.

REVIEW

1 The allele for a tongue that can curl is dominant, so we can represent this by C. Suppose a female had the genotype cc and her partner had the genotype Cc. Use a Punnett square to determine the probability that their first child will be able to curl its tongue.

2 Another characteristic of peas that Mendel studied was whether they had round or wrinkled seeds. We now know that the allele for a round seed is dominant over the allele for a wrinkled seed. We can use R to represent the allele for a round seed, and r to represent the allele for a wrinkled seed.
   - a State the genotype of a pea plant that produces wrinkled seeds.
   - b State the phenotype of a pea plant of genotype Rr and justify your answer.
   - c Suppose Mendel crossbred a pea plant of genotype RR with a pea plant of genotype rr. Draw a Punnett square to show the possible outcomes for their offspring.
   - d Use your Punnett square to determine the probability of the offspring having wrinkled seeds.
   - e If 20 offspring were produced, about how many, if any, will have wrinkled seeds? Would this always be the exact number?

3 In Question 1, a homozygous recessive organism was crossed with a heterozygous organism. This technique is often used to determine whether a dominant phenotype is homozygous or heterozygous. It is known as a **back-cross** or test-cross. How would the ratios of offspring phenotypes change if the dominant phenotype were homozygous?

4 Use two Punnett squares to explain the following examples of **incomplete dominance**.
   - a A red and a white carnation are crossed to produce pink carnations.
   - b The pink carnations are crossed with each other and the offspring are red, pink and white. What ratio do you predict for these F_2 phenotypes?
   - c Having worked through this example, what do you think is meant by incomplete dominance?

Other examples of inheritance

All of the information on inheritance patterns discussed so far is the same in both males and females. These are called autosomal patterns of inheritance, as they arise from genes that are on the chromosomes of all humans. These are chromosomes numbered 1 to 22.

Sex-linked inheritance

Human chromosome number 23 is classified as XX in females and XY in males (page 138). These chromosomes are inherited like all the others. The set of sex chromosomes we inherit not only determines whether we are biologically male or female, but also whether we may be prone to certain genetic diseases.

Sperm \ Eggs	X	X
X	XX Girl	XX Girl
Y	XY Boy	XY Boy

FIGURE 6.18 Punnett square for determining sex

Determining sex

Figure 6.18 shows the different possibilities for the sex of a child. It shows the father provides the Y chromosome that creates a male child. This is why males and females are born in approximately the 1 : 1 ratio.

However, other factors affect this ratio. The pH of the vagina may affect the outcome slightly. There is also evidence suggesting that daughters are more likely to be conceived around the time of ovulation. Sperm carrying Y chromosomes are lighter, so slightly faster. The 'winner' of the sperm 'race' may not entirely be a simple matter of chance.

In addition, baby girls tend to be more resilient if born with health problems, and so have a slightly better survival rate than boys.

DESIGN A GAME TO HELP OTHERS UNDERSTAND PUNNETT SQUARES

Simple games like Tic-tac-toe, which are usually played with pen and paper, are sometimes available in wood or cardboard. Could you make something similar using Punnett squares for use as a study device?

Missing back-ups

Females carry two X chromosomes and so they have two copies of each of the genes found on them. Males only have one X chromosome so only have one copy of the genes found on it. Males are haploid for these genes. If their allele is faulty, they do not have a back-up version to help. This explains why males suffer more genetic diseases than females. A trait that is carried on the X (usually) or Y (rarely) chromosome is said to be sex-linked.

Pedigrees

A **pedigree** chart is a flow chart that shows the relationships within a family over several generations. Males are shown as squares, females as circles. Offspring are shown in order of birth from left to right. Drawing a family pedigree chart can be very important in families in which genetic disorders such as cystic fibrosis (Unit 5, page 121) are prevalent. Figure 6.19 shows a pedigree in which the red shaded individuals have cystic fibrosis. A person who does not have cystic fibrosis but passes it on to their child is called a **carrier**. Such a person must be heterozygous for that gene. Some pedigree charts show the carriers as half solid.

From this pedigree chart, we can tell that cystic fibrosis is autosomal, because males and females are equally likely to suffer from it. We also can deduce that it is recessive because the mother and father do not have cystic fibrosis but one of their children does. This means that both parents must be **carriers** to have a child with this disorder.

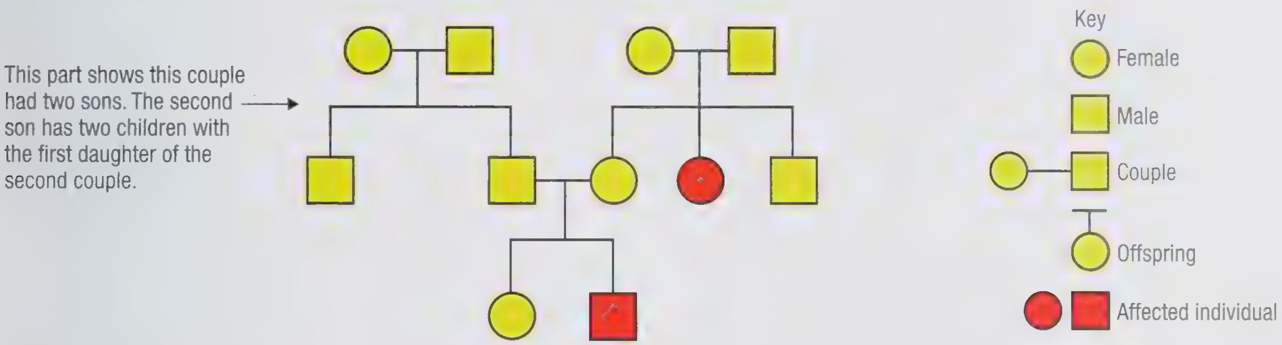


FIGURE 6.19 Pedigree chart of cystic fibrosis

Non-Mendelian genetics: organelle inheritance

Carl Correns was the microscopist who first observed chromosomes migrating to opposite ends of the cell. Correns' other famous work was on cellular organelles. He identified strains of plants that had more than one type of chloroplast, and noted that these were not inherited in a predictable manner.

Approximately one in eight human genetic disorders is carried on the mitochondrial DNA. Because the organelles are inherited in an unpredictable manner in the mother's ovum, it is not possible to predict the severity with which children will inherit any condition. It depends on the relative numbers of affected mitochondria passed to the ovum.

REVIEW

1 The gene for hairy pinnae (hairy ear lobes; Figure 6.20) is thought to occur on the Y chromosome.
   - **a** What is the sex of the person in the image?
   - **b** Would it be possible to have this phenotype and be a woman? Explain.
   - **c** What is the probability of a father giving his son the allele?

FIGURE 6.20 A hairy pinna

2 Draw the pedigree chart of a family you know (for example, your own family, or neighbours) using the key shown in Figure 6.19. Identify one or more characteristics that vary between family members; for example, eye colour, attached ear lobes, ability to roll the tongue, handedness, or whether the right or left thumb is on top when the hands are naturally clasped.
   - **a** By comparing the presence of each characteristic in successive generations or between siblings, suggest whether:
     - **i** the characteristic is likely to be dominant or recessive
     - **ii** the parents are heterozygous or homozygous.
   - **b** What else would you need to know if you cannot determine the answers to part a?

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State the difference between a 'chromatid' and 'chromosome'.

2 The cell cycle describes the proportion of time a cell spends in interphase, and the proportion of time spent dividing. Suggest what happens to these relative amounts (proportions) from the time a zygote grows to when it becomes an adult.

3 Which of the pedigrees in Figure 6.21 show a recessive pattern of inheritance? Note the red shaded individuals express the characteristic in question.

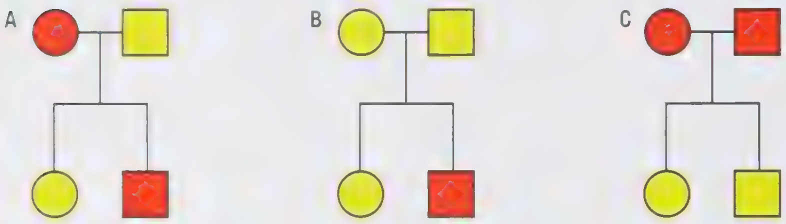


FIGURE 6.21

LEVEL 3–4

4 In a table, outline the key similarities and differences between mitosis and meiosis for an organism of diploid number 40 that reproduces sexually, in terms of the following.

- a In what types of cells do they occur?
- b What must happen in the cell before these processes start?
- c What moves the chromosomes into position?
- d How many main stages are involved altogether?
- e What other process must occur before cell division takes place?
- f How many cells result?
- g What is the genetic composition of the cells formed as a result of the process?
- h Does this lead to variation in the species?
- i What is the definition of the process?

5 Two alternative forms of one gene determine coat colour in mice: the dominant brown allele and the recessive white allele.

- a Give appropriate symbols for the two forms of the gene.
- b State the genotype for a white mouse.
- c State the genotype for a heterozygous brown mouse.
- d Draw a Punnett square to represent the possible offspring of a female white mouse and a heterozygous brown male mouse. Hence, state the predicted ratio of the phenotypes of their offspring.

6 Suppose that you deduce that the probability of someone inheriting blond hair is ¼. Do you interpret this to mean that exactly one-quarter of the children of a family will be blond?

LEVEL 5–6

7 Describe the importance of genetic variation between groups of individuals within a given population.

8 Yellow mice (all with exactly the same genotype) are crossed, and the following offspring are born: 101 yellow, 48 grey.

Assume this is an example of a Mendelian F_1 cross. Draw a Punnett square to predict possible genotypes. How can you explain this ratio?

9 A third trait studied by Gregor Mendel was the height of plants. He crossbred tall pea plants that were homozygous for this trait with short pea plants that were homozygous for this trait. All their offspring were tall plants, very slightly taller than the homozygous tall parents. Mendel described this as 'hybrid vigour'.

- a What does this term suggest to you?
- b What can you conclude about the alleles for the gene for plant height?
- c Draw a Punnett square to show the genotypes and phenotypes for the F_1, the offspring of the original parent plants.
- d Suppose the F_1 plants are now crossbred to produce more plants. What genotypes, phenotypes and ratios would you expect in the resulting F_2 plants?

10 Genes influence how tall a person grows. Identify one environmental factor that might also influence height.

LEVEL 7–8

11 Explain how a back-cross works to reveal recessive alleles.

12 Sometimes a gene has more than two alleles. When this occurs, there are more combinations of genotypes and hence more possible phenotypes. A very good example of multiple alleles is ABO blood typing. The gene for blood types has three different alleles represented by A, B and o. This means that A and B are both dominant over o and **co-dominant** with each other. This means that both phenotypes are expressed (there is no blending, unlike in incomplete dominance). The following table shows the possible genotypes for each blood type.

Blood type	Genotype(s)
A	AA or Ao
B	BB or Bo
O	oo
AB	AB

In 1944, Charlie Chaplin (a famous silent-screen movie star) was taken to court by Joan Barry (a starlet), who claimed he was the father of her child. Blood group evidence was not admissible at this time. **Chaplin** lost and supported the child. The baby was blood group B, the mother A and Chaplin was blood group O.

Apply your knowledge and understanding to explain whether there may have been a different outcome today.

13 Thomas Morgan was a geneticist who studied a species of fruit fly, *Drosophila melanogaster* (Figure 6.22). He found that these fruit flies were an ideal species to study. As in pea plants, the connections between the traits of the parents and those of their offspring were easy to track. But the flies had the added advantage of breeding very rapidly and producing large numbers of offspring. Consequently, Morgan achieved similar results to Mendel but much more quickly.

Using X-rays, Morgan induced mutations (such as changes in eye colour) in his flies. In this way he discovered many genes, far more than there are fruit fly chromosomes. Genes located on the same chromosome are often inherited together, unless there is a crossing-over event on the chromosome sequence between them. Using many breeding events, he was able to map the relative location of these genes.

FIGURE 6.22 *Drosophila melanogaster*

Evaluate how Mendel's results might have been changed if the genes for his pea traits were not all on different chromosomes.

REFLECTION

1 Respond to the debatable questions in this unit.
   - a Can undesirable genes ever be eliminated from populations?
   - b How important is the DNA in our organelles?
   - c Are we the sum of our genes?

2 This unit is based on the key concept of change. Change causes shifts in systems.
   - a What changes occur when organisms reproduce asexually or sexually?
   - b In a large, randomly mating population, would you expect changes to happen in the frequencies of alleles?
   - c Why is the variation caused by sexual reproduction considered an advantage for species?
   - d What would need to happen for species to change?

3 A related concept was patterns.
   - a How important are Mendel's insights in helping us understand the sources of variation?
   - b If Mendel hadn't completed his experiments, would these patterns have emerged anyway?
   - c Are the patterns of inheritance an example of constructed knowledge, or are they real? Explain the reasons for your choice.

4 Transformation, another related concept, refers to change over time.
   a What is the source of transformation in asexually-produced organisms?
   b How is sexual reproduction important for providing diverse populations for selection?
   c Are all sexually produced individuals as suited to their environments as their parents?
   d What types of selection affect:
      i sperm?
      ii social insects?
      iii individuals?
   e Do you think it is possible to be aware of all the beneficial or damaging alleles a person may be carrying?

5 The third concept, consequences, refers to the effects of earlier events. What, in cells or organisms, are the consequences of:
   a mitosis?
   b random assortment and crossing over?
   c failing to produce a son or a daughter in a family?
   d inheriting an X chromosome with a faulty allele?
   e inheriting many damaged mitochondria?

6 In older times in England, people used to say someone's behaviour was 'in the blood'. In those days 'upper class' parents arranged their children's marriages, partly for financial reasons but also partly to keep their blood 'pure'.
   a What do you think they meant by 'in the blood'?
   b On what evidence, if any, do you think they might have reached conclusions such as this?
   c To what extent might they have been correct? Given all that we know now, what is your opinion of the practice of arranged marriage?

UNIT 7

THEORIES OF CHANGE

KEY CONCEPT

Change

RELATED CONCEPTS

Evidence

Movement

Transformation

GLOBAL CONTEXT

Orientation in space and time: an exploration of how world views change in the light of new interpretations of evidence.

STATEMENT OF INQUIRY

A synthesis of evidence has led to dramatic unifying theories of the history of the Earth and how life evolved its diversity.

INQUIRY QUESTIONS

FACTUAL

1 What causes an earthquake?
2 What can we learn from fossils?
3 What caused the formation of the Himalayan mountains?

CONCEPTUAL

4 In what way is our understanding of plate tectonics a unifying theory?
5 How does the theory of evolution unify ideas in biology?
6 Why were theories relating to evolution and plate tectonics controversial when they were first proposed?

DEBATABLE

7 Are extinction events inevitable?
8 Have all the great unifying controversial ideas in science now been discovered?
9 What is the role of humans in the history of the Earth?

Introduction

As you sit there quietly reading these words, it is hard to imagine that the ground beneath your feet is on the move. The landscapes around you seem so permanent, but they are relatively new in comparison with the age of the Earth. Ever since its outside layer was cool enough to form the Earth's first solid rock, mountains and islands have risen up and then disappeared, to be replaced by others.

Similarly, it is difficult to imagine that the plants and animals around us have not always been in their present form. How could it be that horses and mice have common ancestors? This unit introduces you to these two crucial aspects of understanding how the Earth appears today. We refer to these as the theories of plate tectonics and evolution.

Create a museum exhibit

Background

This exhibition focuses on how Darwin and Wallace's theory of evolution and Wegener's theory on plate tectonics have radically changed how we see the world around us.

Your task

You task is to produce an item of work suitable for a museum exhibition on the theme of 'How the world never seemed the same again'. You can choose any format you think would be suitable for such an exhibition. Your exhibit should include:

- an explanation of how science is applied to understand the example you have selected
- a discussion that invites viewers of your exhibit to evaluate the interaction of one of the 'big ideas' with one of the following factors in your example: moral, ethical, social, economic, political, cultural or environmental.

Your clear scientific communication should not exceed 1200 words. Submit a correctly formatted reference list separately, or link it with an electronic presentation under 'Further information'.

COMMUNICATION
Appropriate forms of communication for different purposes. Data visualisation: scientific information, particularly through measurement, is frequently collated in tables and spreadsheets. Visit the 'Science is beautiful' link. How important is presentation in supporting understanding, in graphs, tables and the dynamic display of ocean currents?

b.o45 nelsonnet
k on **Science is beautiful**.

How old is the Earth?

Scientists once thought molten and **semimolten** rocks under the Earth's crust were evidence that the Earth had not finished cooling since it first formed as a giant molten ball. Lord William Kelvin (1824–1907) was a brilliant Scottish mathematician and physicist. He used the fact of molten rock beneath the surface (Figure 7.1) to calculate the age of the Earth to be about 15–20 million years. Kelvin used his expert knowledge of cooling rates, and because his work was so greatly respected, his theory was accepted for a long time. However, we now have evidence that the Earth is around 4.5 billion years old.

How can the Earth be this old and still have molten rock inside? The answer is that the Earth has a 'nuclear reactor' in its core. The immense amount of heat that results in a core temperature of about 4300°C is produced by the decay of radioactive **isotopes** such as those of uranium,

FIGURE 7.1 An explosive volcano erupting. Where did the heat come from?

thorium and potassium. These have very long **half-lives**, which explain why the reactor is still active. For example, the half-life of thorium-232 is 14 billion years. It is thought that the early core also was kept hot by the radioactive decay of isotopes with shorter half-lives.

Radioactivity is the source of the massive amounts of energy that drives the most dramatic geological events around us – earthquakes and volcanoes.

Evidence of a changing Earth

When slabs of rocks or landmasses move, are pushed towards one another or pulled apart, or slide past each other, the forces exerted cause enormous stress. This results in the formation of huge fractures in the rocks – **faults**. Faults are evidence the rocks are not strong enough to withstand all the forces on them. As the massive blocks of rock on either side of the fracture are pressed tight against each other, a great deal of friction occurs. For a while, this can lock the two blocks together, but eventually the pressure will build up so much that the massive blocks will snap apart and suddenly start to move in different directions. The vast amount of energy released as the blocks suddenly slip causes the solid rock to vibrate. This triggers an earthquake. The vibrations, which are called **seismic waves**, are transmitted rapidly through the rocks. The shockwave travels out in all directions from the source – the **focus** – causing the ground to shake violently. The maximum disturbance occurs at the **epicentre**, the point on the Earth's surface above the focus of the earthquake.

Along the huge fracture, movement can go on intermittently, with periods in which the blocks are pressed tight against each other and periods in which they yield to the pressure and move again. This triggers more earthquakes.

Tectonic plates

When **geologists** (scientists who study the structure and composition of the Earth) mapped where volcanoes and earthquakes occurred on Earth, they found that the activity was clustered in certain areas. This was one of the major pieces of evidence that led them to realise that the Earth's crust must be broken up into sections they called plates. There are seven major **tectonic plates**, shown in Figure 7.2. More than 90% of earthquakes occur along these boundaries. The most intense earthquakes occur at the edges of plates that are pushing together. It is these earthquakes that have created massive devastation and loss of life.

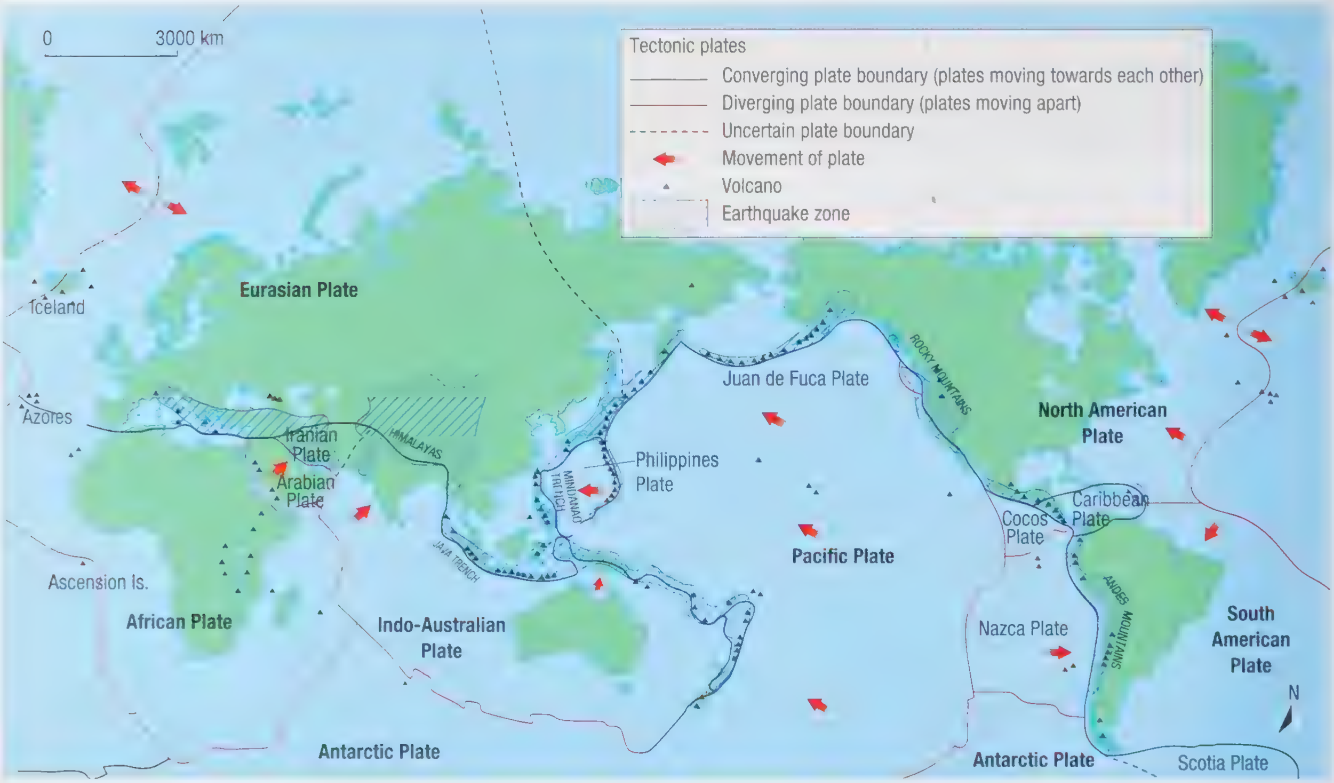


FIGURE 7.2 The major tectonic plates

The tectonic plates 'float' on the layer of semimolten rocks below the Earth's crust, in the **mantle**. Geologists call this material **magma**, and believe it is continually heated by the much hotter radioactive core below. This causes convection currents that move the continental plates that float on top.

FIGURE 7.3 Magma

What's happening at the cracks?

When rocks break, the kind of fault that forms depends on whether the slabs of rocks or even continental plates are being pulled apart, being pushed together, or sliding past one another (Figure 7.4). The San Andreas Fault in California, USA, formed where two plates are slipping past each other. The Alpine Fault in the South Island of New Zealand formed where two plates are pushing against each other. In both these cases, the blocks have slipped sideways.

In some areas, one plate is being pushed under another. Called **subduction zones**, part of the seafloor that is connected to the lighter plate can suddenly be thrust upwards by the heavier sinking plate As the huge block of the seafloor is thrust upwards, it can violently push the water above and cause a **tsunami**.

Seismic waves can leave the focus of the earthquake at a speed of about $14\,km\,s^{-1}$. If the wave carries enough energy, it can break apart huge concrete and steel buildings, and open deep fissures in the ground and even close them again. The focus can be as deep as 700 km, although most earthquakes at plate boundaries have a shallow focus of less than 7 km. Over Earth's history, such events have led to change.

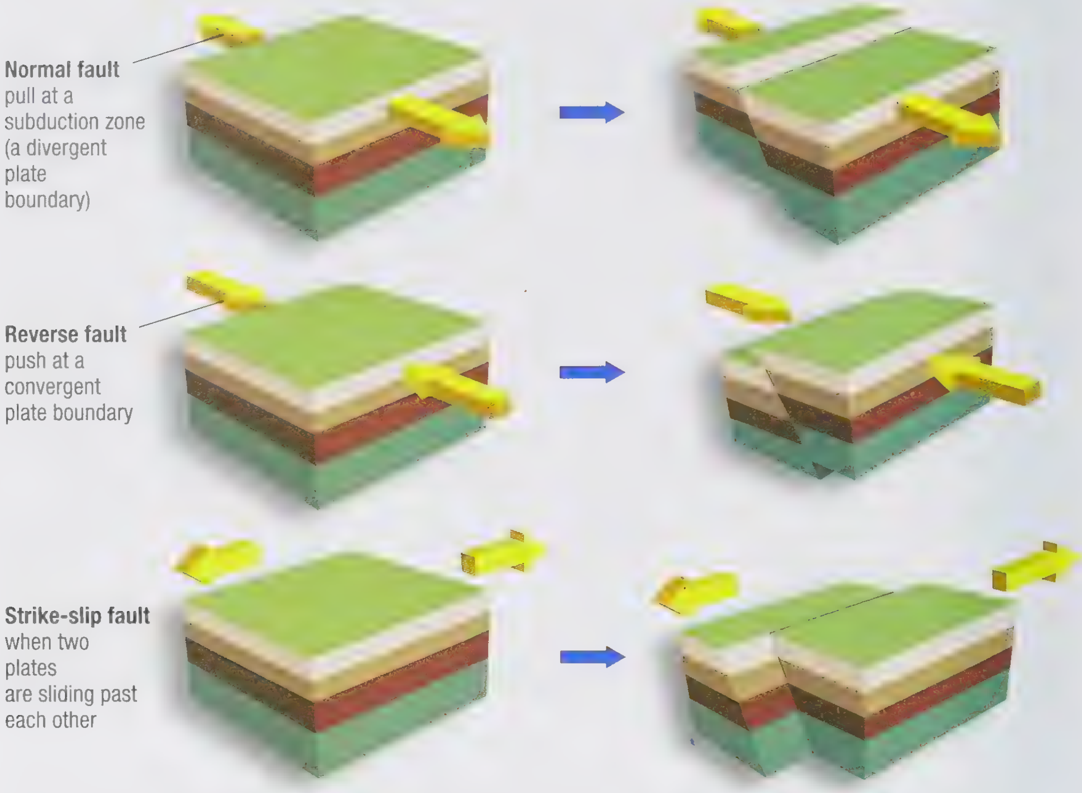


FIGURE 7.4 Examples of types of faults

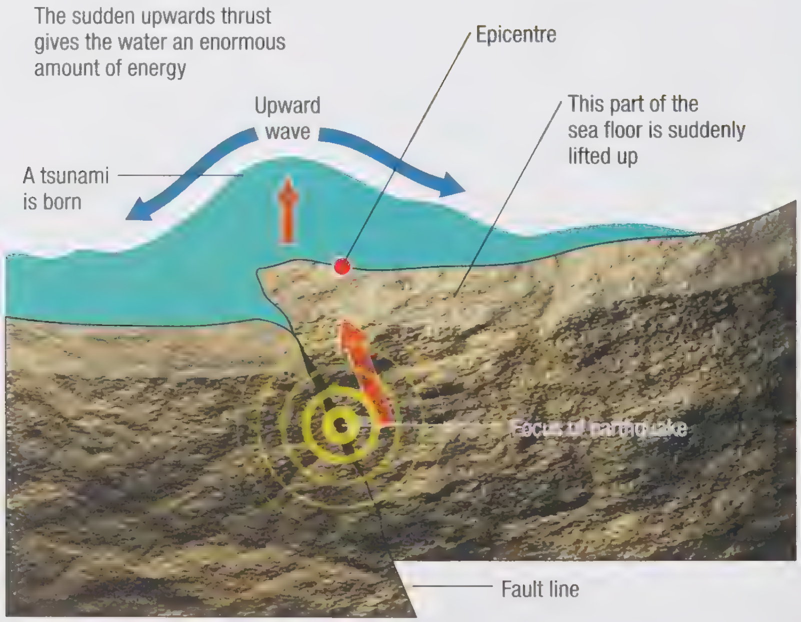


FIGURE 7.5 The formation of a tsunami

1A SUPPORTING COMMUNITIES WHO HAVE EXPERIENCED NATURAL DISASTERS

In which parts of the world are communities regularly severely affected by movement of the tectonic plates causing earthquakes or tsunamis?

Search the internet for information on recent large earthquakes. What did they measure on the Richter scale? What damage did they cause? How do local people protect themselves in high-risk areas? How does the international community respond to these sorts of disasters?

What help can you contribute to the most recently affected community?

Faulting and folding

Different rocks respond differently to huge forces. Brittle rocks fracture when pressed together; more pliable rocks ('ductile' rocks) will buckle and fold.

The formation of a fold is rather like what happens when two people push a tablecloth from different directions.

When brittle and ductile rocks occur in the same area, the ductile rocks may bend or fold over the fault (Figure 7.6). If the pressure on these ductile rocks is intense and comes from different directions, the folds can close up. A series of folds can form, alternating between upwards folds, known as **anticlines**, and downwards folds, known as **synclines** (Figure 7.7). Broad, step-like folds are known as **monoclines**. Monoclines occur when sedimentary layers are folded over underlying rock or a faulted block. Folds can range in size from 1 cm to many kilometres across.

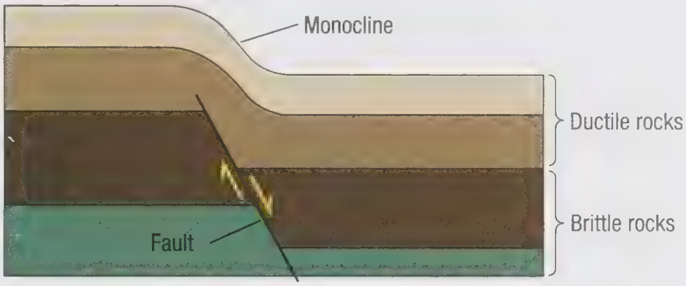


FIGURE 7.6 Forming a fold

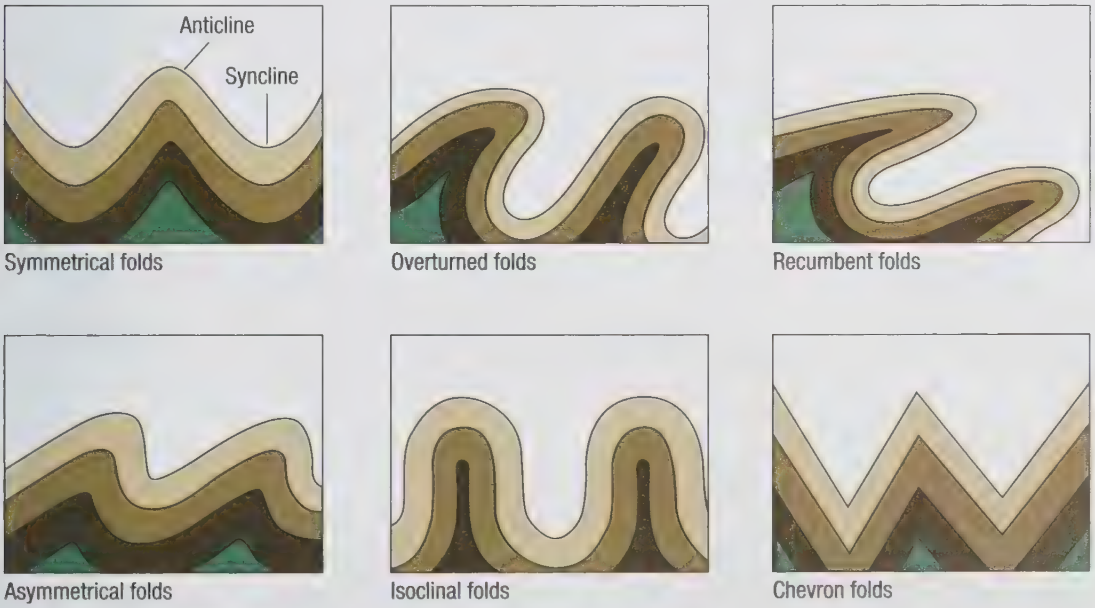


FIGURE 7.7 Some types of folds

INVESTIGATION 7.1

CRITERIA B AND C

How can we build safely in an earthquake zone?

BACKGROUND

Earthquakes generate many different kinds of waves (S, P and Love waves) all of which can have variable effects. When earthquakes occur, the damaged buildings are usually of a similar height. One hypothesis is that the damage is due to resonance of buildings with the wave frequency of the earthquake. 'Resonance' is a term musicians might understand: it is the natural frequency of an object that will vibrate in harmony with other vibrations.

For example, Mexico City was 400 km from the epicentre of the 1985 earthquake. Most of the damage was observed in high buildings that had a period (T, or the complete oscillation time) of about 2 seconds. Frequency is the inverse of the period, so $\frac{1}{T} = \frac{1}{2}$ or 0.5 Hz. In other words, they were resonating back and forth 30 times a minute.

YOUR TASK

To investigate the relationship between a building's height and the potential damage caused by an earthquake.

THIS MIGHT HELP

- Explain how the oscillation of 'buildings' might vary with fast and slow shakes (representing different earthquake frequencies), and develop a testable hypothesis that will generate quantitative data.
- When designing your investigation, consider whether building height is the only parameter to be involved in its behaviour when an earthquake occurs. What else might you test?
- How might you construct a model that can consistently compare the effects of shaking, and how can you standardise your 'earthquake' vibration?

Carry out and write up your investigation, following the guide in Appendix 3 on page 209 or as advised by your teacher.

REVIEW

1 You may have used the absolute temperature scale, measured in degrees kelvin (K). What is the connection between this and Lord William Kelvin?

2 a Explain the source of heat in our planet's core.

b How do you think it contributes to earthquakes and volcanoes?

3 What type of force would cause a 'reverse' fault?

4 Many of the most populated areas of the world are located along coastlines and areas where there are major faults. Do you think that we should continue to allow new developments along the coastline or should they be built further inland? How can the people already living on the coast be better protected? Investigate this issue and present your opinion.

Paradigm shifts in geology

There have been certain key periods in science when existing theories have been shown to be inadequate or wrong and have been replaced by new theories. One example is how the Sun-centred theory of the solar system proposed by different thinkers took hundreds of years to finally replace the more commonly believed theory that Earth was the centre of our solar system. The theories of continental drift/plate tectonics and evolution are further examples. Scientists and many other people often resist such changes. Sometimes, as in Kelvin's estimation about the age of the Earth, this is because of a sense of respect. Sometimes, it is for emotional reasons. Quite often, people tend to brush away exceptions to general theories, not realising their significance.

According to Thomas Kuhn in his book *The Structure of Scientific Revolutions,* a paradigm shift will only occur when there are enough exceptions that cannot be explained by the previous theory. In accepting the new theory, people need to change their entire world view. They can never again go back to the previous way of thinking.

How Wegener made the Earth move

In 1915, Alfred Wegener proposed a theory that over time the continents have drifted apart, forming the continents we know now. He said the continents were once joined to form a supercontinent called Pangaea. From the time the outside shell of the Earth was cool enough for water to condense on its surface, the oceans and lakes have formed then re-formed in different places. Continents have changed shape and are in very different locations from where they once were. This very slow movement of the continents is called **continental drift**.

This drift continues to this day. Presently, the Pacific Ocean is getting narrower, the Atlantic Ocean is getting wider, the Mediterranean is likely to become a lake and the Red Sea may become an ocean.

Unless there is an earthquake, this rearrangement of the Earth's crust generally occurs so slowly that you cannot feel it. What is interesting about the movement of the Earth's crust is why it happens and why it will keep on happening for millions of years.

FIGURE 7.8 The way our world may look, about 250 million years from now. The dark regions indicate mountain ranges

How continental drift theory changed the paradigm

Wegener's ideas seemed impossible. He could not explain how or why the continents moved apart.

The existing theories, which seemed to have worked for a long time before, suggested that the Earth had contracted and become smaller as it cooled down. This caused the Earth's crust to wrinkle, thus forming mountains and valleys. The hard, solid rocks in the Earth's crust prevented any movement of the continents.

FIGURE 7.9 Wegener's evidence for movement of South America and Africa

Wegener's evidence

Wegener had noticed that the continents looked like pieces of a giant jigsaw that could fit together. You can see how South America fits into the coastline of West Africa in Figure 7.9.

He also noticed that similar fossils of plants and animals and mountains with similar rocks were found in South America and Africa.

Mid-Atlantic Ridge patterns

In about 1930, scientists started to realise that convection currents in the mantle of the Earth could be responsible for the movement of the continents.

But it wasn't until the 1950s and 1960s that clearer evidence was found after surveys of the centre of the Atlantic Ocean. A submarine mountain ridge with volcanoes runs down the centre of the Atlantic Ocean. On either side of the ridge there are similar patterns of humps and hollows (Figure 7.10). The further away from the ridge, the older the rocks are. Geologists studying the magnetism of the rocks found that every half-million years, the Earth's magnetic field flips. More importantly, they found that the pattern of change in magnetism of rocks was exactly the same on either side of the ridge of mountains. These discoveries made scientists think that convection currents in the mantle of the Earth were causing lava to spew out from the volcanoes, forcing the two halves of the seabed apart.

Go to http://mypbio45.nelsonnet com.au and click on **Great Rift Valley**. Explore this website, see some images of this extraordinary area of Africa and find out about the giant rift (or tear) that is likely to split Africa apart. How long is the valley? Why are the tallest [illegible] here? What evidence is there that this area is geologically active? What amazing discovery was made at Serengeti?

Go to http://mypbio45.nelsonnet com.au and click on **Mid-Atlantic Ridge**. Read the introduction and find out what [illegible] set out to do and [illegible] going to collect [illegible]ata. Who were the chief [illegible]? What was the name of [illegible] submersible? Go on [illegible] voyage with them by reading their diary.

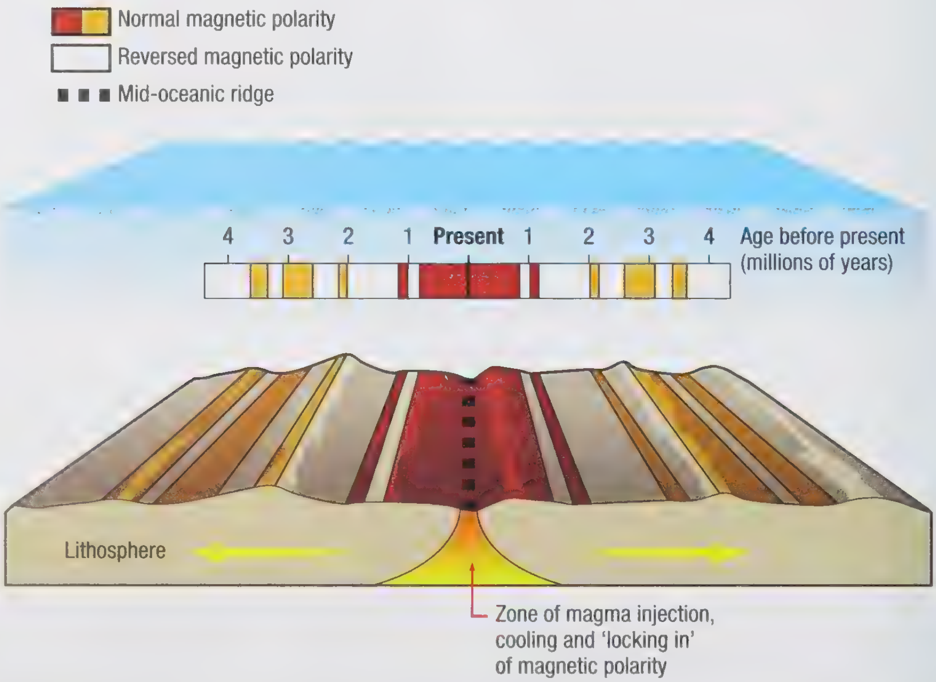


FIGURE 7.10 Magnetic patterns in the rocks on each side of the Mid-Atlantic Ridge

Seafloor spreading evidence

Where two adjacent plates are being pulled in opposite directions, magma keeps oozing up through the gaps between them onto the seafloor, causing the plates to move further apart. The magma then cools and solidifies, adding to the size of the plates. This process is termed **seafloor spreading**, and where it occurs is known as a **spreading centre** (Figure 7.11).

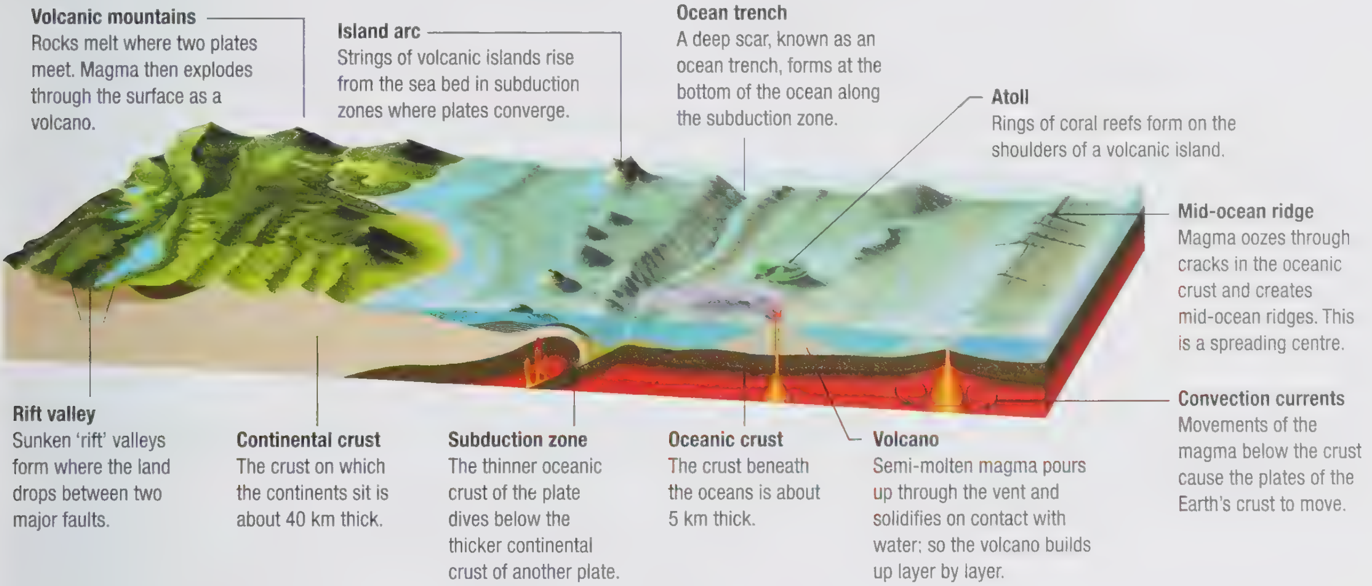


FIGURE 7.11 Moving and changing

Seafloor spreading is occurring at places such as the Mid-Atlantic Ridge. Along this ridge is one of the Earth's largest undersea mountain ranges, which is nearly 10 000 km in length. The seafloor spreading occurring along this ridge is pushing Africa and Europe away from North and South America, and is the reason why the Atlantic Ocean is widening. However, you will not see any noticeable difference in your lifetime – the rate of spread is only about 24 mm per year.

As the seafloor spreads, volcanic islands are pushed up out of the water. The plate on which a volcanic island sits moves away from the spreading centre, and the constant movement of the sea wears the material in the island away, until it disappears altogether from view. But, as shown in Figure 7.12, coral can sometimes grow on the remaining part, forming a ring of coral known as a coral atoll.

FIGURE 7.12 A coral atoll around an extinct marine volcano

Evidence for subduction

If seafloor spreading were the only process that occurred, the crust would be getting bigger and bigger. This does not happen because in other regions one plate is slowly being pushed beneath another. This process is termed **subduction** and these regions are known as subduction zones (Figure 7.11).

As it is pushed down into the mantle, the rocks in the sinking plate re-melt and are reabsorbed into the mantle. As this plate sinks, the other is pushed upwards. This can cause mountain ranges on the elevated plate to rise even higher.

Where plates meet

The reason our world is slowly changing is that the tectonic plates are gradually sliding over the mantle. Convection currents are set up as the semimolten rocks come in contact with the much hotter core of the Earth, and absorb some of its heat. As a result, their density decreases and they start to rise. Cooler, denser material higher up in the mantle sinks to take their place, because the gravitational attraction on this material is stronger.

When the rising magma reaches the underneath of the solid layer of a continental plate, it has to turn sideways (Figure 7.11). Because the magma is so viscous, frictional forces act between the magma and the plate. As the magma moves, it drags the plate along with it.

Incredibly, most of the geological processes that occur on Earth result from this movement of the tectonic plates. These processes include the recycling of rocks and the formation of mountains. Many of the Earth's natural energy and rich mineral resources are concentrated along the boundaries of the plates or where they met in the more recent past.

REVIEW

1. **a** Explain Wegener's theory of continental drift.
   b What evidence did Wegener have for his ideas?
   c What initial response did Wegener have to his ideas?
   d When did scientists begin to accept Wegener's theory?
2. Explain the structure of the Earth's outer shell.
3. What causes the tectonic plates to move?
4. Explain why the Atlantic Ocean is becoming wider at a rate of 24 mm per year.
5. If material is being constantly added to the tectonic plates, why are they not just getting bigger and bigger?
6. Why are volcanoes usually located along the boundaries of plates?

Paradigm shifts in understanding the origin of species

The **theory of evolution** proposes that there is connection between all forms of life, because they have a common ancestor. Living organisms differ because over a long period of time they have adapted to new environments and to changes within their environment, such as changes of climate. This means that significant changes in traits that can be inherited (that is, passed on through genes) occur over a period of time. Although Charles Darwin was not the first scientist to think that evolution happens, his publication *On the Origin of Species* in 1856 was the defining moment in the slow acceptance of the idea of evolution.

Table 7.1 summarises and compares the different evolutionary hypotheses and theories that have been proposed over time. The modern view of biologists is that the novel views put forward by Darwin and Wallace were largely correct. Modern genetic discoveries have caused the original theories to be modified to some extent and have led to the theories of Neo-Darwinism.

TABLE 7.1 Hypotheses and theories of evolution

Scientist/philosopher	Background	Hypothesis/theory
Thales (~640–546 BCE) 	He was a Greek philosopher and possibly the first to use scientific enquiry to study natural phenomena. He studied organisms from the Aegean Sea.	All life originated in the sea and arose out of the sea.
Aristotle (384–322 BCE) 	He was a Greek naturalist and philosopher who collected all the zoological facts known at the time. He tried to classify animals on the basis of their anatomy.	There has been a natural evolutionary progression from plants to plant–animals to animals to humans.
Carl Linnaeus (1707–1778) 	He was a Swedish botanist who developed a system for classifying all living things in his book *Systema Naturae*, published in 1735. Linnaeus' description of plants and animals was based on their physical appearance and method of reproduction. The Linnean Society of botanists and zoologists was named in his honour. His system of classification for plants and naming system for species are still used today (Unit 1).	Organisms can be grouped together according to their degree of similarity.

TABLE 7.1 *Continued*

[illegible]	[illegible]	Hypothesis/theory
Georges Louis Leclerc, Comte de Buffon (1707–1788) 	He was a French naturalist who studied law at a Jesuit college in Dijon, France, and then devoted himself to science. He was the author of *Histoire Naturelle*. in which he discussed all the known facts of natural science in very eloquent language, and translated some of the work of Sir Isaac Newton into French while on a visit to England.	Similar organisms may have a common ancestor, and living things do change over time.
James Hutton (1726–1797) 	This Scottish geologist proposed the theory of uniformitarianism. Evidence to support this theory was later found by a European geologist named Charles Lyell.	The natural forces that currently shape the Earth's surface were operating in the past in much the same way as they do today.
Jean-Baptiste Lamarck (1744–1829) 	He was a French naturalist who gave lectures for 25 years on invertebrates (animals with backbones) and he invented the dichotomous key. He authored a number of books, including his famous *Philosophie Zoologique* and was the first to fully state a theory of evolution that involved descent by modification.	For a species to survive, it must be able to adapt to changing environmental conditions. There have been natural evolutionary changes in species as a result. Acquired adaptations or changes could be passed on from one generation to the next, so species are not static.
Dr Erasmus Darwin (1731–1802) 	This English physician, naturalist, poet, author of *Zoonomia – or the Laws of Organic Life* and other books was the grandfather of Charles Darwin. He kept an extensive botanical garden.	All warm-blooded animals have a common origin.

Scientist/philosopher	Background	Hypothesis/theory
Charles Darwin (1809–1882) 	He was an English naturalist who studied zoology, botany and geology at Cambridge University. He then sailed the world for a number of years in a ship called the *Beagle*, having been commissioned to collect specimens of rocks, minerals, plants and animals, which he brought back to England for analysis. He was the author of books including the famous *The Voyage of the Beagle*, *On the Origin of Species by Means of Natural Selection* and *The Descent of Man*. He also developed theories about how coral reefs and volcanic islands formed. He was greatly influenced by his grandfather's work and that of the Scottish geologist Sir Charles Lyell, who later became a great supporter of his work.	Species evolve and change by a process of natural selection. Many more offspring are born than can survive and reproduce. This means there will be intense competition between them. Those that have more favourable variations are more likely to survive any particular environmental conditions to which they are exposed. For example, giraffes born with longer necks were able to obtain more food and so their survival rate was better. In the end the short-necked variety would have died out.
Alfred Wallace (1823–1913) 	This Welsh naturalist also travelled extensively to study flora and fauna. He was the author of many books, including *Contribution to the Theory of Natural Selection and Darwinism.*	He independently proposed the theory of natural selection at the same time as Charles Darwin, sending him an essay on his theory. Darwin and Wallace's papers were presented together at a meeting of the Linnean Society in 1858. Neither scientist was present, and the minutes record the papers as unremarkable. Their theory is now known as the Darwin–Wallace **theory of natural selection**. This proposed that populations of one species living in different places could evolve in different directions over time. Evolution occurs by natural selection acting on chance variations present in each population. Over many generations, the populations could become increasingly different from each other in structure, physiology and behaviour. Eventually, they could become so different that they would form two different species, and so no longer breed together and form fertile offspring.
Gregor Mendel (1822–1884) 	This Austrian monk carried out plant breeding experiments and discovered there is a recombination of parental traits in offspring.	Research into genetic inheritance provides an insight into the patterns in which heritable traits are passed from one generation to the next, including the mixing of maternal and paternal traits.

Ideas that preceded current evolutionary theory

Opposing the idea that species had changed over time, the **theory of spontaneous generation**, which had a long history, proposed that all organisms were specially and spontaneously created out of non-living materials. Its supporters believed that:

- the Earth and the natural surroundings had changed very little since they formed
- fossils of species that no longer existed were the result of local catastrophes that had caused widespread extinctions and new species had been spontaneously generated to take their place.

Evidence for the theory of evolution

By the 19th century, the scientific community had sufficient evidence to show that the Earth was very old and that life forms on the Earth were changing over time. Fossils from different layers of rock showed that species were becoming increasingly complex over time.

Eons to epoch – change over time

Geological time line Explore this geological time line by clicking … periods?

The study of the structure and composition of rocks has led geologists to propose that the Earth's geological history can be divided into major periods of time. Fossils have enabled scientists to piece together what kinds of organisms lived in these times. The principle of fossil succession states that fossil organisms succeed each other in a definite, consistent and determinable order. Once younger rocks no longer record fossils of an animal, the animal is assumed to have become extinct, and will never reappear. The results of the combined research are shown in Figure 7.13.

Sedimentary rocks

Sedimentary rocks are rocks that form as a result of the physical and chemical breakdown, or weathering, of rocks that already exist. The rate at which this breakdown occurs depends on the climate, the vegetation and the topography (physical structure) of the area, as well as the chemical composition of the rocks. The original rocks are broken down into particles (**sediments**) that can range from fine mud and silt to gravel and even boulders.

These sediments are then carried along by wind and water in a process called **erosion** and, as a result of gravitational forces, always travel down any slope in their path. Eventually, they will reach a large depression (hollow), where they settle. Sometimes these depressions are at the bottom of a lake, but generally the sediments make their way to the sea, where they settle on the seafloor. As they slowly sink through the water, they form horizontal layers called **beds**.

After they are deposited, sediments can be covered by younger sediments. The weight of the newer sediments squeezes the water out and the sediments are pressed into rock and preserved. The depression becomes known as a **sedimentary basin**.

As more and more sediment is deposited, the basin subsides from the weight of all the material, and becomes larger. Most of the sedimentary sequences that have been preserved in this way are formed as a result of catastrophic events such as floods, mudslides, rockslides and the melting of glaciers.

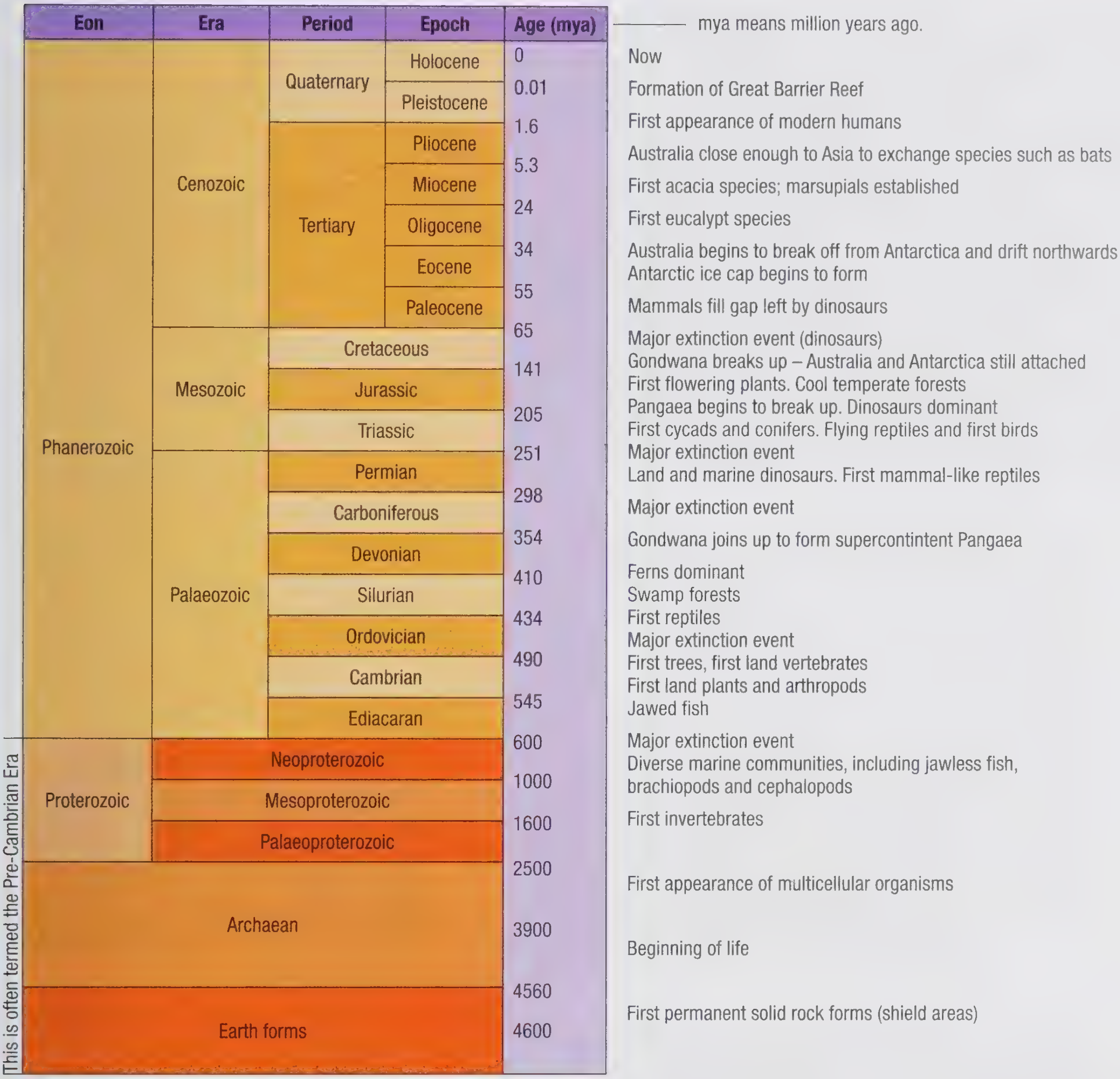


FIGURE 7.13 The Earth's geological time line

All sedimentary rocks are formed in horizontal beds, but not many stay that way for long due to the pressures on them. Generally you will see folding or faults. One exception is the very large Kombolgie sandstone block in Australia's north, which is still horizontal after 1.8 billion years. This forms the spectacular cliffs of the Arnhem Land escarpment and has given rise to many beautiful waterfalls in the Kakadu and Litchfield National Parks.

FIGURE 7.14 Horizontal sedimentary rock at Mt Brockman in Kakadu National Park, Northern Territory, Australia

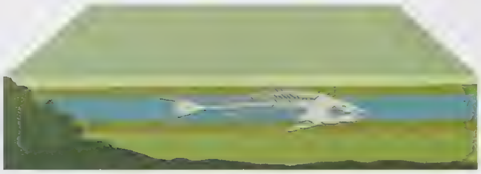
The process of sedimentation ensures that in any **stratified** (layered) sedimentary rock the oldest rock is at the bottom of the pile. As you work your way up through the layers, the sediments must be more and more recent. Therefore, if you dig through the layers (**strata**), you will see a timeline of events that have occurred in the past. Amazingly, geologists can determine many things from the 'clues' left behind in these sediments – even the climate in which the sediments formed.

Fossils

Often, the bodies of living organisms are caught up in the mud and silt and then become embedded in the rock, forming **fossils**. A fossil is any preserved remains of an organism or trace of an organism or its activity. The conditions needed for forming a fossil are rarely met. The dead organism needs to be covered quickly, must not be completely decomposed or weathered, and must remain relatively undisturbed. If it is decomposed completely by micro-organisms, such as bacteria and fungi, and exposed to weathering by rain, wind or sand, there often remains no trace.

a Dead organism

b Organism is buried and compressed under many layers of sediment



c Under high pressure, deposits harden to form sedimentary rock and the fossil remains become mineralised

d Erosion or excavation of sedimentary rock exposes fossil remains on the surface

FIGURE 7.15 The preservation of a fossil in sedimentary rock

Many fossils consist of hardened body parts, such as teeth, bones and shells. The soft parts have usually been consumed or have decomposed. But fossils can also be in the form of impressions of burrows, footprints and even chemical remains. Sometimes, minerals have taken the place of cells, or soak into the pores and cavities of organisms that have decomposed very slowly, showing their shape in the finest detail. These fossils are often petrified or 'turned to stone'. The fossils are then exposed when the rock is partly eroded away or when the Earth has moved, such as during an earthquake.

Fossils preserved in sedimentary rock only show parts of the original organism, so **palaeontologists** (scientists who study fossils) often have to be super sleuths to work out what they have found. For example, when they find the fossil of a vertebrate (animal with a backbone), they need to piece many bones together to deduce what the skeleton of the original organism might have looked like. This is like solving a very complex jigsaw puzzle, often with vital pieces missing. Once the skeleton has been assembled, anatomists can deduce what the original animal might have looked like, how it moved and even what it ate.

Fossils are not only preserved in sedimentary rock. Some are preserved intact in tar pits (reservoirs of thick tar that has welled up from underground) and peat bogs, permanently frozen in the ground and even trapped in amber (hardened tree sap) that happened to drip down on them. For example, complete skeletons of sabre-toothed tigers and other extinct mammals have been obtained from the tar pits of Rancho La Brea in Southern California, USA.

FIGURE 7.16 This 10-million-year-old rhinoceros fossil was found at a dig in Nebraska, USA.

FIGURE 7.17 This is a fossil of a dragonfly that lived between 110 and 114 million years ago in Brazil, South America.

FIGURE 7.18 Solving the puzzle: by piecing together the fossil skeleton, scientists can deduce much about the original animal.

FIGURE 7.19 Fossil of a mycetophilid (fungus gnat) preserved in amber from the Dominican Republic, one of the world's main sources of amber

The fossil record

The **fossil record** is a very comprehensive catalogue of all the fossils that have been discovered. The fossils of more than 250 000 species have been identified so far, with more being discovered each year. Organisms with hard shells or bones, or organisms that lived in or near aquatic environments, were the most likely to be preserved. Fossils of large land animals such as dinosaurs are rare. The most common kind of fossils are microfossils, fossils of microscopic organisms or their remains, such as fossils of pollens and magneto bacteria.

The fossil record represents only a tiny fraction of all the species that have lived on the Earth. Less than 1% of fossils represent organisms that are still living today. However, the similarity between fossils and modern animals, and with other fossils of the same age, has helped scientists reconstruct the pattern of evolution of life on the Earth.

'Missing links' are organisms that have features in common with two very different groups of organism. These are always very important finds. In 2006, scientists discovered a fossil link between fish and land animals. Tiktaalik is a crocodile-like animal. The name Tiktaalik is from an Inuit dialect and means 'large, shallow-water fish', which accurately describes the habitat this animal probably occupied. Well-preserved and complete, this fossil discovery provides evidence to support the theory that there were animals that made the transition from water to land.

Go to http://mypbio45.nelsonnet.com.au and click on **Tiktaalik** to learn more about this important find

Dating fossils and rocks

Geologists have now determined that virtually every meteorite is about 4.6 million years old and the oldest solid rock on the Earth, found in the Canadian Shield area, is about 3.9 billion years old. How do they know this?

When rocks formed long ago, they contained a certain amount of radioactive isotopes. The older the rocks are, the lower the concentration of the original radioactive isotopes in them. For example, potassium-40 is a very common isotope found in a variety of rocks and is often used to date them.

Similarly, the radioactive carbon-14 isotope can be used to determine the age of relatively young fossils (up to about 12 000 years old), provided they still contain some organic material. Dating fossils by this means depends on the fact that the concentration of carbon-14 in the environment has been stable over a very long period. (It is produced by the steady bombardment of our atmosphere by cosmic rays from space.)

In the atmosphere, some of the carbon in carbon dioxide will be the carbon-14 isotope, which enters the food chain via photosynthesis. While an organism is alive, the carbon it absorbs continually in its food includes this carbon-14. As a result, the ratio of carbon-14 to carbon-12 in its body will be the same as in the environment. But when it dies, carbon exchange with the environment ceases and any decayed carbon-14 will no longer be replaced.

This means that the ratio of carbon-14 to carbon-12 atoms will keep decreasing over time (Figure 7.20). By using a complex mathematical formula that compares the ratio of carbon-14 to carbon-12 for a fossil to that of a living organism, together with the half-life of carbon-14 (5700 years), scientists can obtain a fairly accurate estimate of the fossil's age.

For older fossils, isotopes with a longer half-life are used (Table 7.2), such as potassium-40, since it has a half-life of 1.25 billion years. If the isotope is not present in the fossil, then isotopes in the rocks of the same stratum (layer) are tested. Sometimes several different isotopes are tested to improve accuracy.

Table 7.2 lists the half-lives of other isotopes sometimes used to date rocks.

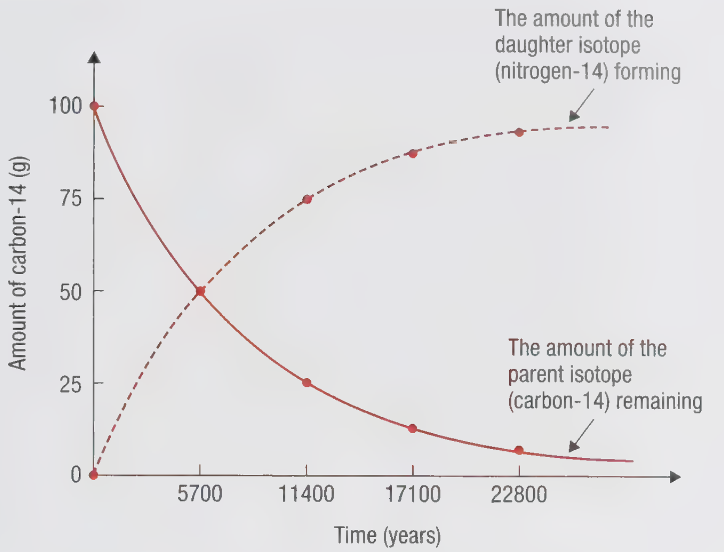


FIGURE 7.20 The decay of carbon-14: after 5700 years, half the original mass is present.

TABLE 7.2 Some isotopes and their half-lives

Original isotope	Decay product	Half-life (years)
Potassium-40 (^{40}K)	Argon-40 (^{40}Ar)	1.25×10^9
Rubidium-87 (^{87}Rb)	Strontium-87 (^{87}Sr)	4.88×10^{10}
Uranium-235 (^{235}U)	Lead-207 (^{207}Pb)	7.04×10^8
Uranium-238 (^{238}U)	Lead-206 (^{206}Pb)	4.47×10^9
Thorium-232 (^{232}Th)	Lead-208 (^{208}Pb)	1.40×10^{10}

Classification

The journey that changed Charles Darwin's life was the voyage of the *Beagle*. The original purpose of the voyage was to map the coastline of South America and the islands near it, including the Galapagos Islands. Darwin left the ship to explore the regions near the coast while this mapping was being carried out. Once, in Chile, he witnessed a bed of shells being raised up several metres in an earthquake, and so was able to explain an early observation by Leonardo da Vinci (1452–1519) that seashells are sometimes found high up on mountains.

He also noticed that many fossils were larger versions of modern-day species. He concluded that they were ancestral forms of the living species. For example, a *Glyptodon* bore a remarkable resemblance to the armadillos he had seen (Figure 7.21). Russel Wallace, who was 14 years younger than Darwin, was to make similar observations between fossil species and living organisms during his travels in what is now south-east Asia.

Darwin saw giant tortoises, cacti, iguanas and finches and other fascinating species that inhabited the Galapagos Islands, and he wondered how these animals and plants came to be there. He was fascinated by the comparison between the finches on the South American mainland and the slightly different finch species on the islands (Figure 7.22). This led him to believe that these bird species were originally carried to the islands and then, over time, underwent small changes in their beaks and other features that made them more suited to the island environment and their way of life.

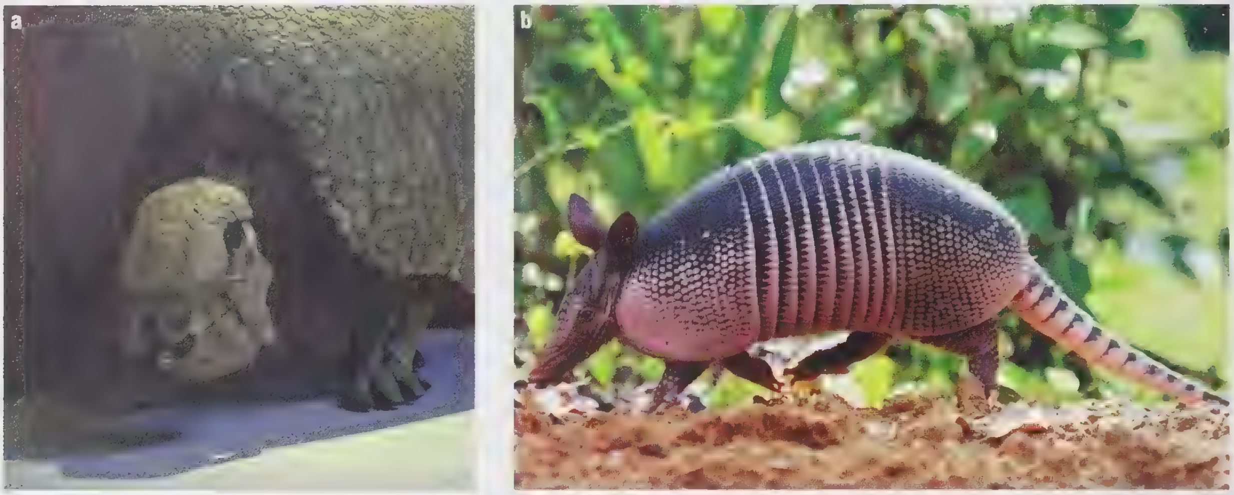


FIGURE 7.21 (a) The *Glyptodon* was a large armoured mammal that was an ancestor of (b) living armadillos

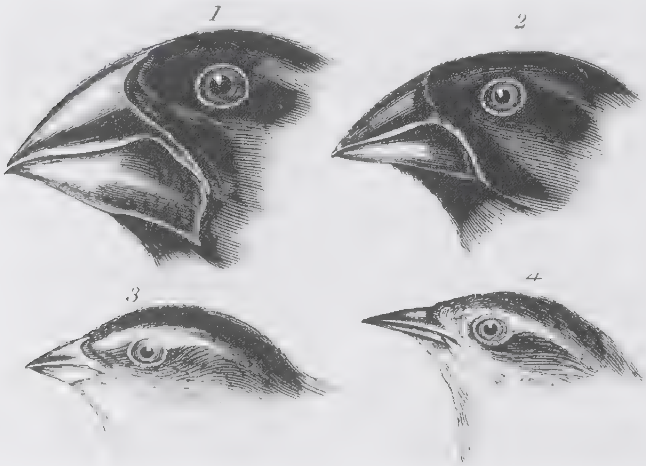


FIGURE 7.22 Different species of Galapagos island finches

Again, Wallace was to have an identical insight based on observations of butterfly species throughout islands now part of Indonesia and Malaysia.

The unifying idea of evolution

Darwin and Wallace's mechanism to explain change over time was inspired by Thomas Malthus' (1766–1834) 'Essay On the Principle of Population', which noted all species can produce vastly more numbers of offspring than the parent generation. The scientists linked this idea to species' adaptations ('fitness', or suitability) for their environments. They recognised that if resources became limiting, then the least well-adapted would be excluded, and if not dying of starvation outright, then they would not reproduce.

There were initial weaknesses in Darwin and Wallace's ideas.

1 The fossil records of the day were incomplete and it was difficult to track changes from one species to another. Recent fossil finds, such as Tiktaalik, continue to emerge, strengthening the evidence with each discovery.
2 In the mid-19th century, the Earth was thought to be only 6000 years old, based on information in the Bible. So there didn't seem to have been enough time for evolution to take place. Improvements in dating technology now provide evidence that the Earth's age is approximately 4500 million years.

3 Neither Darwin nor Wallace could explain why all living organisms in one species were not the same, or how living organisms passed on features from one generation to the next. Our modern knowledge of genetics, and the links between organelle DNA and the archaebacteria, explain this perfectly.

Although there have been gaps in knowledge, to date the unifying theory of evolution that connects all of the Earth's life has not been countered with scientific evidence.

REVIEW

1 What is a sedimentary rock?
2 With the aid of a sketch, explain how sedimentary rocks are formed.
3 Explain why sedimentary rocks are found in layers, and how we know the bottom layers are the oldest.

FIGURE 7.23

4 Identify the type of rock shown in Figure 7.23.
5 What is a fossil? Explain why most dead organisms do not form fossils.
6 Under what circumstances would a complete organism be fossilised?
7 What is the fossil record? Is this a complete record of all the organisms that have lived on the Earth?
8 How have fossils provided us with information about the formation of the Earth?
9 It is believed that today's lizards and even our mammals descended from the first vertebrates that colonised dry land. These were primitive reptiles that had four legs and laid eggs.
   a What were the earliest life forms on the Earth and in what geological period did they exist?
   b What kind of evidence would show that these primitive reptiles existed, had four legs and laid eggs?
   c Outline the process by which this evidence might have been preserved.
   d Describe how scientists have been able to calculate when these early lizards existed.
10 Compare the two main theories of evolution, proposed by Lamarck and by Charles Darwin and Alfred Wallace. In what respect were they similar and in what respect were they different? How would each theory explain why giraffes have long necks? Which theory is better supported by scientific evidence (be sure to support your answer as well)?
11 Working independently, Darwin and Wallace reached identical conclusions. Does this
   a strengthen the evidence for the theory?
   b suggest their explanation is real, or is just a construction?

Elaborating on the evolution of ideas

On his return to England, Darwin tested many of his ideas experimentally from field observations. He realised that if his results did not demonstrate evidence to the scientific community, then the only other possible explanation would have been that the species had come to the Galapagos Islands by spontaneous generation, as argued by the churches of his day.

PERFORMANCE ASSESSMENT TASK
CRITERIA B AND C

Travelling seeds

INVESTIGATION 7.2

Darwin thought seeds must have been carried by long sea journeys to new lands, such as the Galapagos islands, which began as submarine volcanoes. If so, how long could plant seeds survive immersion in salt water?

YOUR CHALLENGE

Investigate how long a variety of seeds can float on, or survive immersion in, salt water.

THIS MIGHT HELP

Note: Seawater is approximately 0.5 mol/dm^3 NaCl. It may take several weeks for seeds of some species to germinate.

- Consider the species you will select to test. Perhaps reflect on the environments of islands and the types of adaptations plants on them have. What controls would you need for your hypothesis?
- How will you determine how 'viable' seeds are before you expose them to your treatment? How will you determine their viability afterwards?
- How will the seeds be carried? Will they be part of flotsam, floating plants, or will they be submersed?

Carry out and write up your investigation following the guide in Appendix 3 on page 209 or as advised by your teacher.

Books that changed the nature of scientific thinking

While travelling on the *Beagle*, Charles Darwin read Sir Charles Lyell's book *Principles of Geology*. In this book, Lyell (1797–1875) argued that the greatest geological changes that have occurred might have been produced by forces still at work. The same book had separately inspired Russel Wallace and his naturalist friend Henry Bates (1825–1892) to visit South America as very young men. While funding their explorations by collecting specimens to sell, both were searching constantly for insight into the important question of 'the origin of species'.

It was Wallace's correspondence with Darwin that alerted him to the importance of Malthus' 'Essay on the Principle of Population', and you have already seen how this work, published in 1798 before both scientists were born, contributed the idea for the mechanism driving evolutionary change.

The famous *On the Origin of Species* was published in November 1859. The book caused one of the greatest controversies in the history of science. When the British Association for the Advancement of Science met in 1860, many argued against Darwin's ideas. However, two of his scientist friends, Thomas Huxley and Joseph Hooker, defended the ideas. Thomas Huxley was reported to have said after reading the book: 'How stupid of me not to have thought of this first!'

Thomas Kuhn's book about the nature of paradigm shifts, *The Structure of Scientific Revolutions,* published in 1962, is a socio-historical approach to changes in thinking about scientific knowledge. It claims that changes also depend on consensus within communities of researchers, and this may explain why, sometimes, important discoveries, such as Mendel's, are ignored.

There is another school of thought about the nature of scientific knowledge, dating from about the same period. Karl Popper (1902–1994) places great emphasis on the logic of falsification. In his publication, *The Logic of Scientific Discovery* (1959), he defined a scientific theory as one that is compatible with observable evidence, which would need modification whenever it was shown to be false.

Popper argued the growth of human knowledge emerged from the need to solve problems, not from observations of 'bare facts'. Now that you have been introduced to the unifying theories of plate tectonics to describe the Earth's dynamic geology, and of evolution, what do you think?

REVIEW

1 Why did Darwin believe it was important to test his ideas experimentally?
2 How significant are reading and discussion for driving thinking? What has made some books famous, but not others?
3 What is meant by 'a theory'? Can scientists prove theories to be correct? When does a theory become 'true'? What happens if a theory can't explain something adequately?
4 How has the original theory of evolution proposed by Darwin developed over the past 200 years? (This is a demanding question, and you are likely to need help from your teacher or to do extra research.)
5 Many native peoples have their own 'stories' or 'legends' about how humans and animals have appeared or developed on the Earth. Sometimes these stories illustrate moral dilemmas.
   a Can the knowledge of mythology be useful?
   b Can the knowledge of mythology be falsifiable?
   c How can people believe two apparently contradictory theories at the same time?
6 There was great excitement across the world when the discovery of a 'lost race of human hobbits' (Figure 7.24) in Indonesia was announced. This sparked considerable debate among palaeontologists. One argument is that the fossils are genuinely of other human species, like Neanderthal man and *Homo habilis*. The other suggests that the skeleton is different because the individuals had a genetic disorder.
   a Does this knowledge challenge our current paradigm of thinking about evolution?
   b What would need to happen to resolve the arguments?

FIGURE 7.24 An artist's impression of the 'lost race of hobbits'

CRITERION A

1 State why is there still molten rock in the core of the Earth.

2 Some people liken the Earth to a broken raw egg, with pieces of broken eggshell sliding over thick, glue-like egg white that is slowly being stirred.
   - a In this analogy, what do the pieces of broken shell and the stirred egg white represent?
   - b Discuss how geologists worked out how the Earth's crust was broken up and where the boundaries of the broken bits were located.
   - c List three geological processes that occur as a result of the movement of the Earth's broken crust.

3 When plates move, there is a build-up and release of energy. Predict where the build-up of energy would occur for each fault and how it would be released.

4 Outline some of the consequences of the release of energy from the movement of the plates.

5 With the aid of diagrams, distinguish between:
   - a a fault and a fold
   - b an anticline and a syncline.

6 Give explanations for the following.
   - a Some types of rock are prone to faulting, whereas others tend to fold.
   - b The Southern Alps on the South Island of New Zealand are slowly getting higher.
   - c The Atlantic Ocean is slowly getting wider.

7 Use Figure 7.25 to answer these questions.
   - a Distinguish between a spreading centre and a subduction zone and identify them on Figure 7.25.
   - b Identify and name the layer of the Earth in which the magma is rising and sinking.
   - c What term do we use for the physical state of this magma?
   - d State the name of the currents this movement creates. Where else do you see these types of currents in your everyday life?
   - e Identify the region in the diagram where volcanic eruptions are least likely to occur and justify your answer.

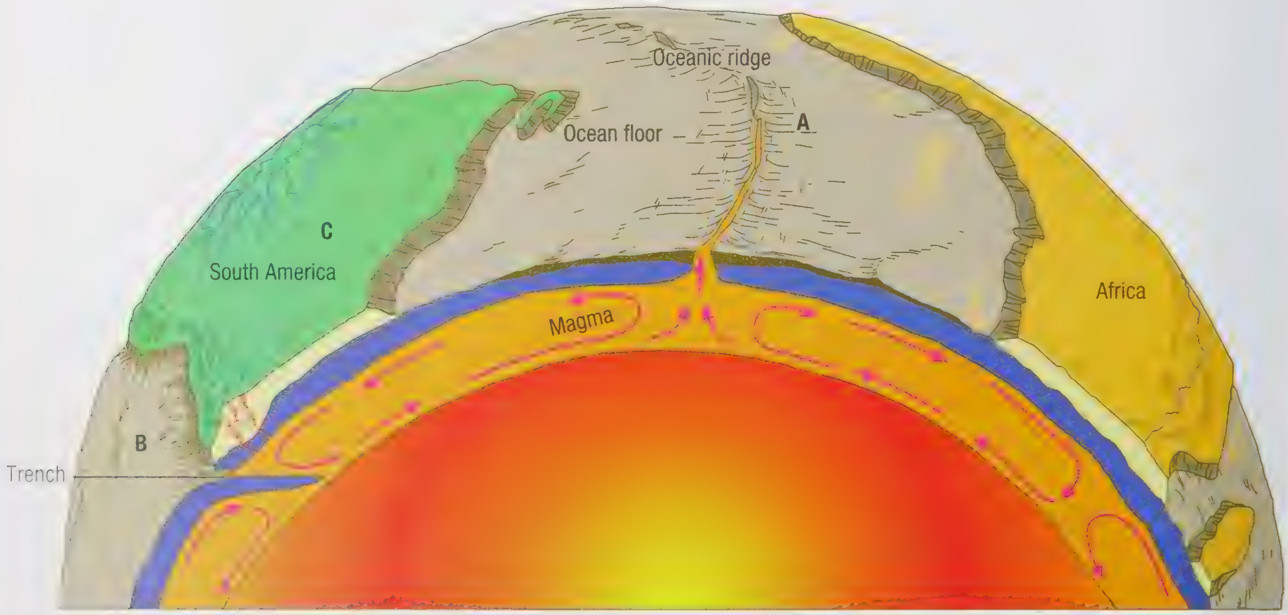


FIGURE 7.25

LEVEL 5–6

8 With the aid of diagrams, describe how the following phenomena can occur.
- **a** An earthquake
- **b** A tsunami
- **c** A fault

9 Describe how the temperature of rock affects its ability to break or bend.

10 Describe how an earthquake is caused. In your description, include the difference between the focus and epicentre of the earthquake.

11 There are three main types of mountains:
- fault block mountains, such as the Sierra Nevada mountains of California, USA
- fold and thrust mountains, such as the Himalayas, which are currently the highest on Earth (though dwarfed by the highest mountain on Mars)
- volcanic mountains, such as the mountains of the Hawaiian Islands.

What determines the kind of mountain range that forms in a particular area?

12 How can the different ages of the Hawaiian Island chain be accounted for using the plate tectonics theory?

13 The photograph in Figure 7.26 shows a fold. Which rocks are the oldest – those in the centre layer or those on the outside? Or would they all be the same age? Justify your answer.

FIGURE 7.26

LEVEL 7–8

14 In terms of the forces involved, explain why magma rises and sinks.

15 With the aid of diagrams, explain how fossils are formed.

16 How might you explain the extinction of a species using the theory of natural selection?

17 The world that dinosaurs inhabited was very different from ours. Apart from different animals and vegetation, the world 'map' was very different.
- **a** Describe how the landforms were different then.
- **b** Which processes have occurred to change the world map since then?
- **c** Will current world maps be correct one thousand years from now? Discuss.
- **d** Did humans and dinosaurs roam the Earth at the same time?
- **e** About how old must the rocks be in which dinosaur skeletons have been uncovered? How was their age worked out?

18 Analyse and evaluate the information below to make scientifically supported judgements to explain them.
- **a** One of the two types of tortoise found on the Galapagos Islands has a shell that flares at the front so it can lift up its long neck (Figure 7.27). There are also two main types of prickly pear, a

FIGURE 7.27 Galapagos tortoise

kind of cactus. The variety that grows on islands not inhabited by tortoises spreads low across the ground and has soft spines. But the prickly pear on the island the long-necked tortoises inhabit is tall and has hard spines. Suggest an explanation for the difference in the two types of prickly pear.

b Organisms that live in fresh water or the sea are relatively common in the fossil record, whereas fossils of desert organisms are quite rare. Propose a hypothesis to explain why this might be so.

c Palaeontologists can deduce whether an animal was a herbivore or a carnivore simply by examining its skeleton. Some palaeontologists have even estimated the walking and running speed of dinosaurs from their fossilised footprints. How do you think they could do this?

REFLECTION

1 Transformation, the third related concept, can apply to:
   a the change of species over time and space. Suggest examples from the text to support this definition.
   b changes in thinking. For example, how might your world-view be different if you lived in the UK in 1800? Has your thinking about ideas changed as a result of understanding some of the core ideas in famous works about the nature of scientific knowledge, such as those of Kuhn and Popper?

2 Respond to the debatable questions in this unit.
   a Are extinction events inevitable?
   b Have all the great unifying controversial ideas in science now been discovered?
   c What is the role of humans in the history of the Earth?

3 Change, the key concept, causes shifts in thinking.
   a How did ideas about the nature age of the Earth change?
   b How did ideas about the connectedness of living organisms change?

4 Evidence is an important related concept in this unit.
   a What observable evidence supports the theory of plate tectonics?
   b What observable evidence supports the theory of evolution?
   c What connects the two types of evidence?

5 Another related concept is movement. How does movement refer to:
   a the physical movement of continents?
   b paradigm shifts in thinking?

6 Why do you think some people are initially unwilling to accept new ideas?

UNIT 8

DISEASE AND GLOBAL HEALTH

KEY CONCEPT

Relationships

RELATED CONCEPTS

Environment

Interaction

Consequences

GLOBAL CONTEXT

Fairness and development: an exploration into the inequalities surrounding the impact of diseases on different societies

STATEMENT OF INQUIRY

Health, history and global relationships are all transformed by infectious disease.

INQUIRY QUESTIONS

FACTUAL

1 What types of infectious diseases exist?
2 How are different types of infectious diseases transmitted?
3 How can human body systems work together to combat disease?

CONCEPTUAL

4 Are microbial encounters always harmful?
5 What properties enable a disease to be eradicated forever?
6 How did transmissible human diseases originate?

DEBATABLE

7 Why do some diseases attract more research effort?
8 What rights do individuals have in preventing diseases that affect global communities?
9 How can the intellectual property of Indigenous peoples be used fairly?

Introduction

A disease is any condition that impairs the normal functioning of the body. There are many different types of diseases, including those that are caused by our lifestyle and by dietary deficiencies, and those that are inherited genetically. This unit will focus on diseases that are caused by other organisms, known broadly as **pathogens**. Diseases caused by pathogens are also termed **infectious diseases**.

In this unit, you will begin to develop an overview of diseases, including how different types of diseases have transformed human history, and attract different levels of research interest. The scale of impact ranges from a few individuals who become ill, to whole populations and societies being affected. Significant medical research is directed at finding ways to control pathogens, and prevent and treat diseases. Each of these efforts is loaded with a range of issues and opinions; and some prevention or treatment regimes may cause other problems. Understanding pathogens and their forms of transmission helps us predict and combat emerging health issues around the world.

SUMMATIVE PERFORMANCE ASSESSMENT TASK
CRITERION D

Write an article for a popular science journal on the topic 'The challenges of eradicating infectious diseases in the modern world of global relationships'.

Your article may refer to the examples mentioned in this unit or another infectious disease of your choice. You may want to select an emerging disease.

Your article should cover the following content.

- A description of the type, symptoms and **prognosis** of the disease (treated or untreated)
- A discussion of societies where the disease occurs, and whether it has changed the course of human history
- An explanation of scientific approaches to treating the disease, including how the disease spreads through populations
- An analysis of how the scientific solution for eliminating the disease interacts with one of the following contexts in which it is applied: moral, ethical, social, economic, political, cultural or environmental

As with all communication, the language, format and presentation must be appropriate for the task.

ATL

INFORMATION LITERACY

Quality academic writing requires accurate note-taking, respects academic honesty when referencing sources, and evaluates information critically, identifying points of view and bias. This task is your opportunity to demonstrate mature scholarship.

Origins of infectious diseases

Humans were all originally hunter–gatherers, but as their populations expanded, hunting no longer provided enough resources and agriculture slowly took over. By chance, the natural grains in the Fertile Crescent, a region that stretches in an arc from the Nile to the Tigris and Euphrates rivers and east to the Persian Gulf, were edible and gave high yields in the wild. Also, the grain could be harvested within a season, a big advantage for farmers who were still somewhere between being nomadic hunters and settled villagers.

Unlike later crops, including fruit and vegetables, grain was easy to store. These ancestral food species needed very little genetic change to become useful crops. The farming culture soon spread to nearby Europe and Asia, and human populations grew in response. Equivalent natural plant resources did not exist on land areas such as Australia (home to Aborigines), Arizona (Native

Americans) and Cape of South Africa (Khoisan). Their climates were less reliable, so their human populations consequently remained sparse. Different diseases began to evolve in the different human circumstances.

Animal husbandry developed alongside crop production, perhaps because wild herbivores were attracted to the crops. By chance, many of the suitable animals also occurred in the Fertile Crescent. Domestic sheep, goats and cattle all had wild relatives in Asian or Mediterranean regions. From them, humans first contracted measles (Figure 8.1), pox **viruses** and tuberculosis. Initially, these diseases were very deadly, or **virulent,** in their new **hosts**. These diseases were also extremely **contagious**, or easily transferred, just as many of the newly emerging diseases are in human populations today. These diseases from animals that naturally live in herds needed to be transmitted directly from one host to another. They also thrived in relatively high-density human populations. Gradually, over the next 10 000 years, the original diseases became less virulent and their human hosts evolved some genetic immunity.

Origins of parasitic diseases

In hunter–gatherer societies, population densities were never high enough for easy transmission of micro-organisms from one human host to another. Instead, successful micro-organisms, or **microbes**, exploited other animals in addition to humans to complete their life cycles. Parasitic diseases such as malaria, yellow fever and sleeping sickness thrived in ecosystems with a variety of host species.

FIGURE 8.1 Measles was once a common childhood illness. It is caused by a highly contagious virus

How pathogens transformed human history

The explosion of European exploration in the 16th century followed the enormous social upheavals caused by the Black Death. The Black Death may have been spread along the Silk Road (a trading route) from Asia by the Mongols. Spanish conquistadores may owe some of their conquering success in the Americas to their inadvertent exposure of new diseases to local Indigenous people. We will never know how many died in the smallpox **epidemics** that followed their invasion.

A genetic blood disorder that happens to protect many West Africans from malarial infection unfortunately made them the slave workers of choice on Caribbean sugar plantations. Ironically, it seems that the spread of the malaria parasite around the world was likely helped by the infected mosquito larvae carried in the bilges of European explorers' ships.

CRITICAL THINKING
Three Level Guides provide a strategy to help you learn to interpret challenging text in this activity.

Interpreting text

ACTIVITY

After reading the previous section, decide whether you agree with the following statements. Prepare to discuss and justify your answers with a partner.

LEVEL 1: LITERAL STATEMENTS – DO YOU THINK THE TEXT ACTUALLY SAYS THIS?

1 All humans were once hunter–gatherers.
2 Infectious human diseases were caught from the first domestic animals.
3 Dense human societies support parasites well.
4 Over time, diseases and their human host populations are both transformed.
5 Sheep, goats and cattle are examples of herbivores.

LEVEL 2: INTERPRETATIVE STATEMENTS – DO YOU THINK THE TEXT SUPPORTS THIS OPINION?

6 Humans are part of the ecosystem, which includes microbes.
7 Humans domesticated animals because natural hunting resources ran out.
8 Without disease, European conquests of much of the world would have been unsuccessful.
9 Whenever new food resources become available, population explosions follow.
10 Parasitic diseases can be introduced together with their host species.

LEVEL 3: APPLIED STATEMENTS – DO YOU THINK THIS IS A 'TAKE HOME' MESSAGE FROM THE TEXT?

Be prepared to justify your opinion using scientific argument.

11 Infectious diseases contributed more to human history than parasites.
12 To avoid catching a disease completely new to humans, keep away from wild animals.
13 Parasitic diseases are more ancient than infectious diseases.
14 When a disease organism adapts to living in a new host, it is there forever.
15 Microbes will always have an important, unexpected role in human history.

Useful micro-organisms

Although some microbes cause disease, the majority of microbes are incredibly useful. For example, in the ecosystem around us are microbes that purify water, recycle important elements such as nitrogen, fix carbon dioxide and decompose wastes (Unit 1). Microbes can indicate the presence of oil-bearing rocks. Some are so useful that we grow them and use them in large quantities. They are used to tan animal skins and manufacture linen; clean up oil spills; and produce genetically engineered **antibiotics**, amino acids, enzymes and some hormones. More than 90% of our processed foods involve microbes, including pickles, cured meats, soy sauce, cheeses, vinegar, wine and beer.

Types of pathogens

A pathogen is any organism that causes disease. Categories of pathogens include parasites, fungi, bacteria, viruses and prions. Each of these types of pathogen has caused disease that has had devastating effects on human populations, either directly or indirectly. Understanding the biology of these pathogens can inform our efforts to tackle them when they get out of control.

Parasites

Parasites are organisms that require another living organism to provide nutrients or protection for them to survive. Parasites are more numerous than non-parasites. On average every 'free living' species supports seven parasitic species. Although all viruses and infectious bacteria are parasites, as they need living hosts to multiply, the word 'parasite' usually applies to eukaryotic organisms.

Parasites of vertebrates are usually divided into two major groups.

- **Ectoparasites**, such as ticks and fleas, are found on the surface of the body. They depend on their host for food and shelter, and are often **vectors** for other parasites.
- **Endoparasites** live inside the body and are further divided into two other groups.
  - **Protozoans** are all single-celled organisms. Malaria is an example.
  - **Helminths**, or worms, that infest humans fall in three major groups: flukes, roundworms and tapeworms.

Ectoparasites are a temporary nuisance, although some can spread disease. Endoparasites are a major health concern because millions of people worldwide, mainly children, are infected. An estimated 700 million are infected with hookworm and up to 1.2 billion with *Ascaris* roundworm (Figure 8.2). Those infected tend to harbour many worms at a time and suffer ill health from malnutrition and other concerns.

FIGURE 8.2 Roundworms such as this one infect more than a billion people worldwide

Fungi

Fungi are very diverse eukaryotic organisms, of which about 1.5 million species are known. Many fungi are important in the food industry and for making antibiotics. About 300 species of fungi are human pathogens and others cause diseases in plants. Pathogenic plant fungi are responsible for the destruction of important food crops around the world. The potato blight fungus in Ireland in the mid-19th century caused mass starvation of approximately 1 million people. The rice blast fungus occurs in over 85 countries, wherever rice is grown. It continues to cause an estimated annual loss of enough rice to feed 60 million people.

.com.au and click on **Parasites**
Find out the reasons for the

Bread-making uses a fungus, yeast, mixed with a little sugar in the dough. There are a number of different yeasts, but they all feed on sugar. Yeast is an example of a useful microbe. It can respire either aerobically:

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

glucose + oxygen → water + carbon dioxide

or **anaerobically**, by fermentation:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

glucose → ethanol + carbon dioxide

As this equation shows, fermentation breaks down glucose to form ethanol and carbon dioxide. Notice how both reactions produce carbon dioxide gas. This forms little bubbles inside the dough but cannot escape, and so as more and more gas is produced, the dough swells up. This is called 'letting the dough rise' and takes about half an hour to an hour, when the dough is left in a warm place. Once the dough has risen, it is baked in an oven until the outside is brown and the inside is well cooked. The baking process also causes any alcohol that may have been produced through anaerobic respiration to evaporate.

Bacteria

Bacteria are unicellular micro-organisms that lack a cell nucleus. They are found in every habitat on Earth and there are thought to be somewhere between 10^7 and 10^9 different species. The vast majority of these bacteria are not **pathogenic** (disease-causing). Of those that can live in and on humans, most actually help you. For example, your large intestine is home to over 500 bacterial species, without which you could not synthesise vitamins such as folic acid, vitamin K and biotin, and which also help you by fermenting otherwise indigestible complex carbohydrates. These bacteria also help to control potentially pathogenic bacteria. Many bacteria that are pathogenic cause disease because they produce **toxins** that damage your body's cells.

FIGURE 8.3 An influenza virus seen under an electron microscope

Viruses

Viruses were first seen when the electron microscope was invented. Viruses do not neatly fit the biological definition of a living thing because they are not cellular and cannot reproduce independently. Instead, a virus particle is made up of a protein coat encapsulating the viral nucleic acid (a fragment of DNA or RNA). Unlike bacteria, all viruses are pathogenic – that is, they all cause some type of disease in the organism that acts as their host. Examples are HIV, Ebola and influenza (Figure 8.3).

Working with microbes: visualising relative scale

ACTIVITY

Medieval monks famously argued about how many angels might dance on the head of a pin. You will use this analogy to help you understand the relative sizes of groups of micro-organisms.

Imagine a 1 mm pin head magnified 100 000 times. Use the 100 m running track or mark out this distance on the oval using two pieces of dowel.

Read through Table 8.1 and notice there is a large range of sizes for the groups of organisms.

Cut out cardboard or newspaper models of the relative shapes and sizes suggested, or use chalk to draw them on the ground.

TABLE 8.1

[illegible]	[illegible]	[illegible]	[illegible]
Virus	10^{-8}–10^{-7}	Square	1 mm^2
Bacterium (e.g. bacillus)	10^{-7}–10^{-6}	Rectangle	1 cm × 3 cm
Yeast – single-celled type of fungus	10^{-5}	Ovoid	10 cm in length
Protozoans	10^{-5}–10^{-3}	Circle	1 m diameter

Place the models inside the marked 'pin head' 100 m length.

1 How realistic are textbook cell diagrams marked 'not to scale'?

2 In what ways can the accuracy of this model be further improved?

Be aware that even a tiny virus particle can dramatically change the health of a cell.

Prions

Prions do not contain nucleic acids. **Prion** diseases are caused by changes in the shapes of proteins, when they fold in a different way. They generally affect the brain, where damage appears as plaques and tangles of the protein. They can affect animals and humans and can be acquired from food or inoculation, inherited or appear sporadically. Prions cause several diseases, including Creutzfeldt–Jacob's disease, Kuru and bovine spongiform encephalitis.

Diseases caused by pathogens

Table 8.2 lists some diseases caused by the pathogens discussed in this unit.

TABLE 8.2 Diseases affecting humans and their causes

Parasite	Protozoa	Fungus	Bacterium	Virus	Prion
Scabies	Malaria	Tinea	Tetanus	Human papilloma virus (HPV)	Bovine spongiform encephalitis
Lice	Sleeping sickness	Candidiasis	Diphtheria	Chickenpox	Parkinson's disease
Schistosomiasis (blood flukes)	Toxoplasmosis	Histoplasmosis	Whooping cough	Rubella	Kuru
Taeniasis (tapeworms)	Cryptosporidiosis	Aspergillosis	Cholera	Herpes	Creutzfeldt–Jacob's disease
Fascioliasis (liver fluke disease)			Syphilis	HIV	Lou Gehrig's disease (ALS)
Elephantiasis			Gonorrhoea	Glandular fever	
			Legionnaire's disease		

REVIEW

1 List examples of each type of pathogen.

- a Ectoparasite
- b Endoparasite
  - i Protozoan
  - ii Helminth
- c Fungus
- d Bacterium
- e Virus
- f Prion

2 Which of the examples in Question 1 are parasites, and why?

3 Which of these groups include useful, harmless and harmful organisms?

Disease transmission

Epidemiology is the study of disease, where it occurs and who it affects. **Epidemiologists** study patterns of disease. Whether the disease is new or old, they study who becomes ill, and what activities and practices seem associated with risk.

Humans do not develop enough new contagion to contribute to the transmission cycle, so we are often dead-end hosts for new diseases. Lyme disease, common in the USA and parts of Europe, is caused by bacteria that usually live in rodents, are amplified in deer and transmitted by ticks. Every one of the tens of thousands of infections annually is **zoonotic**. Ross River virus, which occurs in Australia and Oceania, is probably transmitted from vertebrates by mosquitoes, but no human has ever infected another.

Each of the following examples provides clues to help you understand how diseases may emerge, may re-emerge or are spread.

Ebola

The '**index patient**', the first person to be infected with Ebola, was identified in 1976 in West Africa. Ebola is very contagious and virulent, placing family and carers at great risk of infection. Since then, outbreaks often claimed hundreds of lives. The 2014–2015 outbreak claimed over 10 000 lives. Eating 'bush meat', monkeys or apes, seemed to be the source of infection in humans. However, these animals are not natural hosts for the virus, but are intermediate hosts that caught the disease from a species of fruit bat. Intermediate hosts for outbreaks may act as disease amplifiers, and carry far higher amounts of virus than the natural host.

Middle Eastern Respiratory Syndrome (MERS)

MERS is the most recent serious zoonotic disease to infect many hundreds of people, who may pass it to others directly. It was first identified in the Middle East in 2012. MERS claims the lives of approximately a third of those it infects. The intermediate hosts seem to be domestic camels, which may also have caught it from bats. Three-quarters of the local camels have **antibodies** to the disease, evidence they have come in contact with the virus in the past. Global trade and travel are the potential disease amplifiers of MERS. Every year, thousands of camels are imported to Saudi Arabia, and up to 2 million international pilgrims make the spiritual journey to Mecca during the hajj.

Influenza

Influenza viruses are named after the combinations of RNA substrands that make up their **genomes**, which code for various proteins (for example, hemagglutinan or the enzyme neuraminidase). H5N1 ('bird flu') is found in many migratory water birds, and is becoming more common. Sharing ponds or food with domestic fowl can provide the contact to spread the virus. Domestic birds, chickens and ducks, are the source of bird flu in humans. Since 2003, it has caused nearly 400 deaths, mostly in China, Indonesia, Pakistan and Vietnam. The disease has never passed directly from one human to another.

FIGURE 8.4 A medical ward during the Spanish flu, which may have killed as many as 20 million people globally

The danger of any cross-species viral infection is that some cells may become infected with more than one strain of influenza. During viral replication, new deadly combinations of RNA substrands may result. The 1918 Spanish flu (Figure 8.4) **pandemic** was caused by a strain of H1N1, as was the 2009 swine flu.

Dengue fever

The most deadly mosquito-borne disease after malaria, dengue does not require an animal reservoir for transmission. Mosquitoes transmit the virus from one human to the next. Urbanisation over the past 50 years has helped it spread globally, from South-East Asia, to India, tropical Australia, the USA and parts of Africa. Despite much greater scientific knowledge about the virus, there are now 30 times as many infections as in 1960. There are four types of dengue fever and surviving one type increases the risks of very serious side effects during an infection with a second type.

Polio

The polio virus is hosted by human gut bacteria, which are also capable of living wild in sewers. Polio can kill or cause paralysis. A few drops of **attenuated** virus, Sabin's OPV, or oral polio vaccine, are enough to protect a person for life. Unfortunately, immunisation is not yet universal. Older generations who can remember the terrible effects of polio are dying out and the importance of vaccinating children can be overlooked. Simply by going to the toilet, an individual carrier from a country that has not yet eliminated the disease can put hundreds of thousands of unimmunised people at risk.

Modelling how a disease spreads

EXPERIMENT 6.1

There are many different ways in which a disease can be spread throughout a population, including by transfer through a vector, objects touching each other, body fluid contact and blood contact. In this activity, one of your classmates will be 'infected' with a disease and you will model how the disease can spread around the classroom.

MATERIALS

- Phenolphthalein indicator
- 1 test tube containing 3 cm of an unknown clear solution
- Pipette

PROCEDURE

1 Your teacher will hand you a test tube containing 3 cm of clear solution. One student in the class will have a test tube containing 0.1 M sodium hydroxide – they are the 'infected' individual. The rest of the class will have water.
2 Within a 30-second time frame you are to walk around the room and place 6 drops of your solution into as many other people's test tubes as you can.
3 After 30 seconds, place 1 drop of phenolphthalein indicator into your test tube. Infected individuals should see a purple coloured solution.
4 Record the class results.
5 Repeat the activity three more times but allowing 1, 1½ and 2 minutes to 'infect' other individuals.
6 Record the class results for each session.

RESULTS

1 What relationship did you discover between the number of infected individuals and time?
2 Does this activity accurately represent the spread of disease? What could you change to make it more accurate?
3 What are the ways in which you are able to stop the spread of disease?

DISCUSSION

1 Did all the test tubes of the 'infected' individuals show the same intensity of colour on addition of phenolphthalein? If not, why might this be the case and what would it mean in this model?
2 Do you think it is possible to determine who was the first infected person?

Spreading the message

Human effort can eliminate disease from the world. Smallpox was the first disease to be made extinct in the natural environment, although small amounts are held in secure laboratories. Humans were its only host. A universal immunisation program eradicated opportunities for humans to host the virus, and nearly all of the laboratory stocks were destroyed about 30 years ago.

Guinea worm may be eliminated in the next decade. Fresh water copepods (water 'fleas') host the parasite for part of its life cycle, but not for longer than 3 months. The nematode spends up to a year in its human hosts. Low-technology solutions, by the community action of not bathing in natural water bodies, and by providing clean drinking water, have broken a disease cycle that not long ago debilitated millions of people every year.

IMMUNISATION SCARES

Consider the following scenario.

An HPV immunisation team will soon be visiting your school, but many students are afraid of the injection. Their anxious behaviour is now persuading other students to resist immunisation. How can you convince the school community to help slow or stop the spread of this disease?

ACTIVITY

Sterile technique – an important practical study skill

Everything around you – even the dust in the air – is covered with micro-organisms. A **sterile** environment or object is free from any living things, including micro-organisms. Sterile technique aims to minimise the opportunity for these unwanted microbes to contaminate your cultures. Here are some of the principles of the sterile technique.

- Keep a lit Bunsen burner on your bench and work near it. The heat from the flame is used to kill any micro-organisms on objects you use to manipulate cultures, such as metal loops. Be very careful and use all the precautions necessary for working with Bunsen burners.

FIGURE 8.5 Sterile technique

- Wash your hands with an antiseptic handwash before working with sterile items.
- Minimise exposure of sterile items to air. For example, keep swabs covered and keep the lids on Petri dishes.
- When you open a Petri dish, do not completely remove the lid. Just open the lid a little and insert your loop or swab through the gap. Do not touch the surface of the medium with your fingers. Seal the Petri dish immediately. Remember that it is not safe to open any Petri dish that has bacteria growing on it, unless your teacher gives you permission.
- Avoid handling sterilised items. Do not touch the end of a sterilised swab onto anything other than the surface from which you are collecting micro-organisms or onto which you are swabbing them. Sterilise the loop every time you finish using it to prevent spreading bacteria.
- Avoid coughing or breathing onto anything. Wash your hands again before leaving the laboratory.

CRITERIA B AND C

Can you catch it from a coin? Vectors and fomites

INVESTIGATION 8.1

A vector is a living organism that does not cause a disease but can transmit it. Domestic and wild mammals, birds and insects may carry pathogens between hosts. Even viruses used in genetic engineering to transmit pieces of DNA can be categorised as vectors.

A **fomite** is an object that may transmit pathogens. All frequently handled objects are potential fomites. For example, clothing worn by recently deceased smallpox victims could transmit the disease. Infected clothing may have been used as a form of biological warfare to oppress Indigenous peoples during the 19th century.

YOUR CHALLENGE

You will design and conduct an experimental investigation to find out how effective vectors and fomites are as potential sources of bacteria.

THIS MIGHT HELP

Consider human activities where hygiene is deemed particularly important; for example, near food preparation and toilet activities. Which particular vectors and fomites raise concerns? What controls will be needed? How will you represent your data, and show variation between replicate samples? Are all the bacteria you identify likely to be pathogenic?

Your teacher will provide you with sterile agar plates. Refer to the Activity box on 'Sterile technique' to limit the exposure of the plates to only the vectors and fomites you are investigating.

Carry out and write up your investigation following the guide in Appendix 3 on page 209 or as advised by your teacher.

SAFETY

Petri dishes must *never* be opened after cultures are grown in them. They must be disposed of by autoclaving to destroy all the microbes.

REVIEW

1 Name and describe three examples of how the spread of disease may be amplified.

2 Design a table to summarise which diseases have recently emerged, which are re-emerging and which are spreading in the world.

3 Are any continents exempt from disease? Why do you think this is the case?

4 What do the letters H and N in flu virus strains represent?

5 A laboratory recently recreated the 1918 Spanish flu in order to study why this H1N1 virus was particularly deadly. Although the research had been approved and funded by a national medical organisation, others thought this experiment was too dangerous to go ahead. What do you think?

6 Do you think all smallpox virus laboratory stocks should be destroyed? Why do you think some has been kept?

7 List examples of zoonotic diseases mentioned in the previous section.

8 Do you think shrinking wilderness areas increase or decrease opportunities for zoonotic infections?

9 Imagine someone close to you is the index patient for a new disease.
   - a How would you feel?
   - b If you were the medical research scientist meeting this patient, how might your feelings differ?

10 International funds for understanding and eliminating pathogens are large, but not infinite. If you controlled this budget, what criteria would you suggest to help you prioritise the research effort?

11 The world was unprepared for the severity of the 2014 Ebola outbreak. Why do you think WHO and similar international health organisations had not given this extremely virulent disease the same priority as vaccines for influenza?

How our bodies respond to disease

If pathogens are passed around as easily as suggested and are as prevalent as suggested in Investigation 8.1, why aren't we constantly sick?

Your body has an arsenal of chemical and biological 'weapons' to fight off pathogens. These weapons form part of the **immune system**. The immune system effectively has two separate, but interrelated, strategies that operate on different scales.

Non-specific defences

First line of defence: preventing entry

Your body's external and internal surfaces resist entry by pathogens. At a fundamental scale, skin is an effective barrier, because it is quite acidic, and because perspiration contains an enzyme called **lysozyme** that destroys the cell walls of bacteria. Most bacteria and fungal spores that land on your skin will die very quickly. However, if your body surfaces were completely impenetrable, you would never be able to ingest food or excrete wastes. Our internal surfaces often also use these and other ways to resist pathogens (Table 8.3).

FIGURE 8.6 The mucous membranes that line your airways trap most of the pathogens you breathe.

TABLE 8.3 How internal surfaces resist pathogens

Internal surface	First line of defence
Mouth, leading to digestive system	Saliva contains lysozyme and stomach contains **mucus**, protein-digesting enzymes and hydrochloric acid
Nostrils, leading to the respiratory system	Hairs trap microbes along with other undesirables such as dust. Past that point, special cells in the respiratory tract produce lysozyme-rich mucus to trap and destroy foreign bodies. **Mucous membranes** are also lined with cilia (Figure 8.6), tiny beating hairs that sweep mucus up to the throat, where it is either coughed out or swallowed and dealt with by the acid in the stomach.
Ears	Sticky wax (cerumen) with antibacterial and antifungal properties traps microbes and is gradually pushed out as the jaws move.
Eyes	Tears contain lysozyme and salt, which also has antiseptic properties.

FIGURE 8.7 When we sneeze, each of the droplets expelled into the air may contain thousands of pathogens.

But how would pathogens get into your mouth, nose or eyes? Physical contact with an infected person is one way, but it isn't the only way. For instance, a simple sneeze from an infected person can expel droplets (Figure 8.7), each of which can contain thousands of pathogens. You might breathe in these droplets.

Second line of defence: the non-specific immune system

Barriers sometimes break, leaving a gap for pathogens to enter. For example, you may get a scratch or cut. The non-specific immune system provides the next level on the scale of defence, the second line, resulting in **inflammation**, a complex response involving proteins and white blood cells. The flowchart in Figure 8.8 summarises how inflammation prevents pathogens from spreading to nearby tissues, destroys and removes pathogens and damaged cells, and prepares your body for healing. You know that your immune system is using inflammation when you notice heat, redness, pain and swelling at the site of an injury.

Invaded tissue quickly attracts white blood cells called **monocytes**, which enlarge and develop into **macrophages** (*macro* means 'large', *phage* means 'eat'). Macrophages surround and engulf the foreign material (Figure 8.9), in a process known as **phagocytosis** (*phago* means 'eat', *cyto* means 'cell'). The ingested material is chemically destroyed with enzymes.

Another type of macrophage is found in the lymph nodes, and constantly cleans up foreign material in the lymph fluid.

Neutrophils are the second major group of non-specific white blood cells. Although white blood cells generally make up only a few per cent of all cells in the blood, neutrophils are by far the most common. Neutrophils are attracted to bacteria and infected cells, then phagocytise them, and die in the process. Pus developing in an infected wound is a sign that your immune system is working to fight off the infection, because pus is largely made up of dead neutrophils.

Specific defences

Third line of defence: the adaptive immune system

How can your body protect itself from pathogens that are not cleaned up by inflammation? The third line of defence involves a transformation of your own cells.

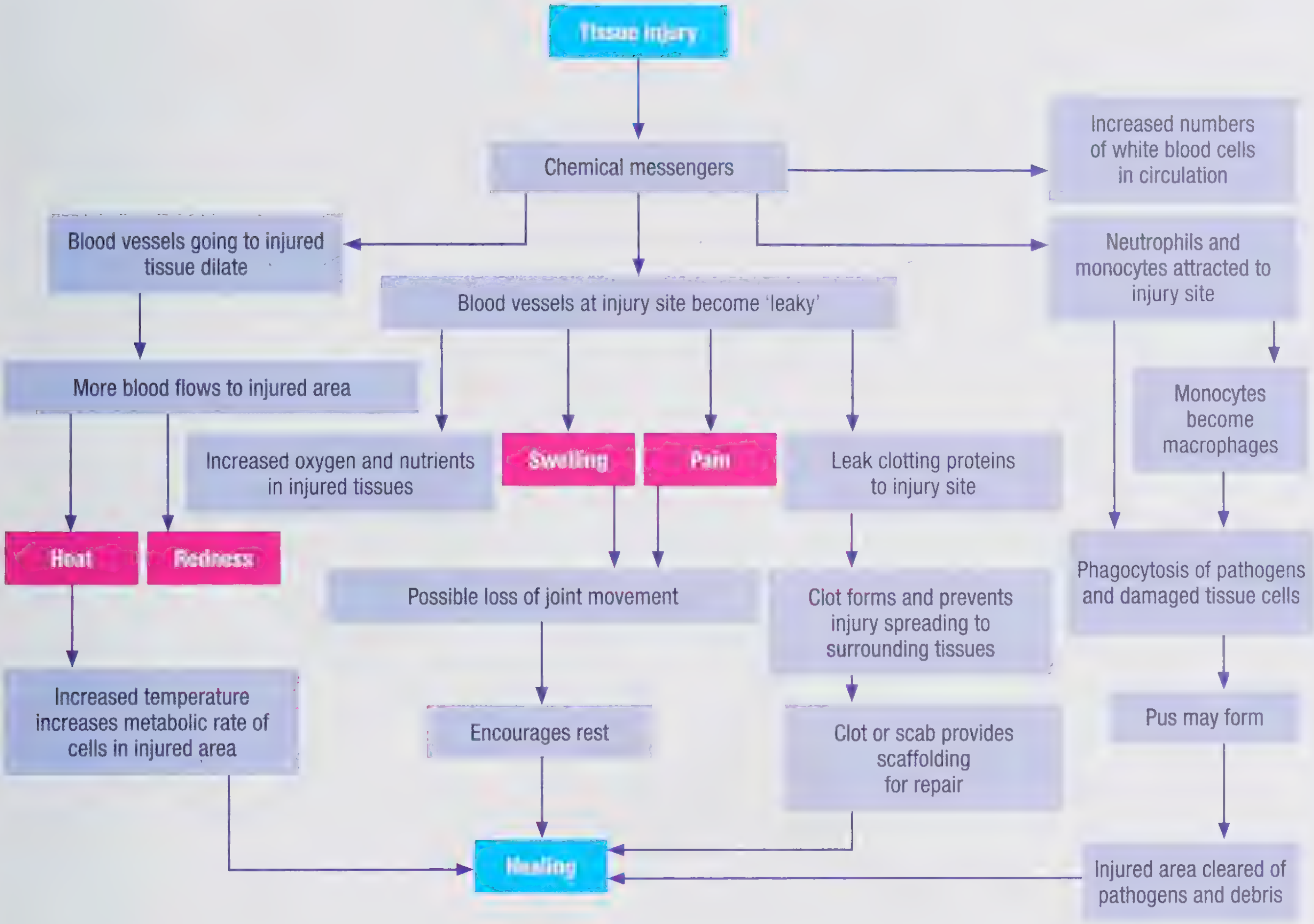


FIGURE 8.8 Inflammation – a schematic diagram

Your body cells, as well as all organisms and substances that may enter your body (including viruses, bacteria and some parasites), are covered with unique chemical 'markers' known as **antigens**. Specialised white blood cells interpret these antigens and recognise whether they are your own cells (self) or invading materials or cells (foreign). If a foreign invader is detected, the adaptive immune system can start to fight it. Your immune system can also recognise whether this is a new pathogen or one that has been fought in the past.

FIGURE 8.9 A schematic diagram of a macrophage engulfing an invading yeast cell

The white blood cells involved in recognising and responding to antigens are called **B lymphocytes** (or **B cells**, for short). B cells originate in bone marrow and are extremely diverse. For any particular antigen, only a tiny number out of millions will be capable of producing the specialised proteins, or antibodies, to neutralise it (Figure 8.10). The specific B cells are stimulated to divide after a process called clonal selection (Figure 8.11), triggered by the antigen itself and other specialised proteins and helper cells. The identical daughter cells can flood the body with thousands of antibodies capable of attaching specifically to the pathogen.

While all this is happening, the immune system becomes prepared for the future. It is very 'expensive' for your body to respond to a pathogen. So if you were to meet the same pathogen in the future, it is better for your immune system to be ready.

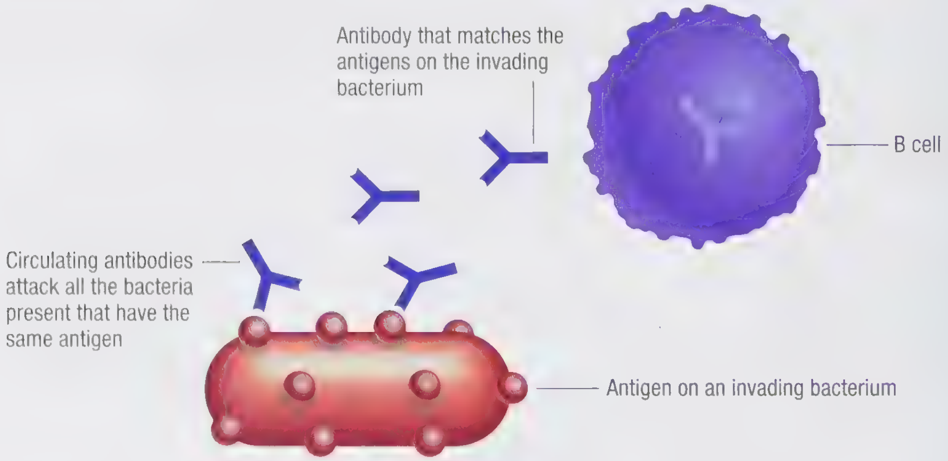


FIGURE 8.10 Making antibodies – a schematic diagram

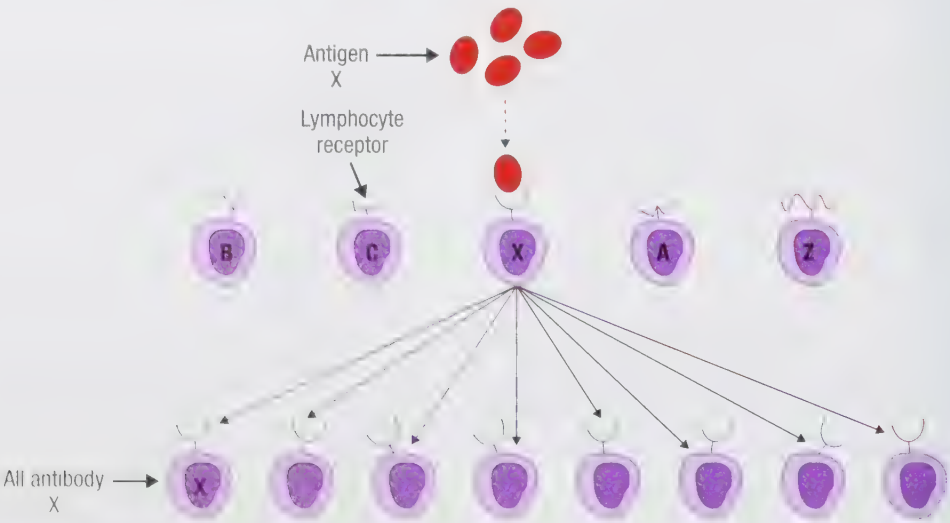


FIGURE 8.11 Clonal selection requires an antigen to stimulate one of hundreds of thousands of B cells, which then multiply (clone). The daughter cells then flood the body with antibodies specific to the antigen

Another type of specialised white blood cell is responsible for this. After the infection has passed, most B cells die, and antibody numbers also fall off, but a small number become **memory B cells**. These are ready to respond to the pathogen quickly if you meet it again and usually stop the infection in its tracks, without you even being aware of the threat (Figure 8.12). The adaptive immune system results in **naturally acquired immunity**, and is why most people contract illnesses, such as chickenpox, only once.

There are many dozens of types of specialised lymphocytes because different pathogens trigger slightly different antibody responses. An important group are T lymphocytes (or **T cells**, which mature in the thymus). Examples are killer T cells (also known as null-killers), which destroy bacteria that have become coated with antibodies, and helper T cells, which prompt B cells to start making antibodies.

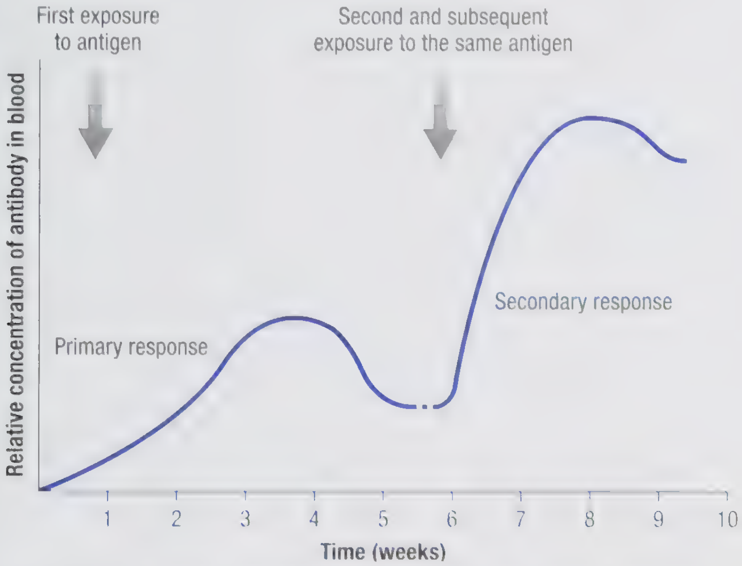


FIGURE 8.12 The second exposure to an antigen activates memory B cells and massively increases the numbers of available antibodies

When your immune system turns on you

Sometimes the immune system loses its ability to tell the difference between 'self' and 'foreign'. When this happens, the full immune response is turned on the body's own cells. For reasons that are not well understood, the immune system begins to make antibodies (autoantibodies; *auto* means 'self') and killer T cells that attack the person's own tissues. This phenomenon is called **autoimmune disease**. For example, type 1 diabetes is an autoimmune disease in which cells in the pancreas are destroyed, making the person unable to produce enough of the hormone insulin. Without enough insulin, the person is not able to control their blood sugar levels effectively and must rely on insulin injections.

Allergies are another example of the immune system working against you. When you are allergic to something, you experience an abnormally strong immune response to it. For instance, we all inhale pollen and, for most people, it just gets trapped in the nasal passages and is later sneezed out. For a person allergic to pollen, the immune system detects the foreign particles and launches an attack as if they were a dangerous threat. The result is not life-threatening, but it is very annoying: constant sneezing, a runny nose, blocked sinuses and watering eyes. Other common **allergens** are dust and animal hair.

More rarely, some people experience a very severe and life-threatening allergic reaction known as **anaphylactic shock**. The process is quite similar to a less serious allergic reaction, but it happens throughout the entire body. The airways in the lungs constrict, making it difficult to breathe; the capillaries suddenly become very leaky, so that blood may no longer circulate effectively. Without urgent medical help, a person experiencing anaphylactic shock may die. Allergens that cause this type of reaction include bee venom and nuts.

REVIEW

1 Divide a page into three columns and label them 'First line of defence', 'Second line of defence' and 'Third line of defence'.
   a List examples of each type of defence.
   b Next to each example, state whether it is a non-specific or a specific defence.
   c Classify whether the defence is physical, involves cells or depends on chemical messengers.
   d Were any of the categories difficult to classify? If so, why?
2 What is the significance of this statement? 'Three-quarters of the camels in the Middle East have antibodies to the MERS'.
3 Diseases such as measles were not considered particularly serious to 19th century European explorers, but were often fatal to peoples of the Pacific Islands. How can your knowledge of the immune system explain this observation?
4 Today, most babies are immunised against measles, because natural infections often have very serious outcomes, including brain damage and death. What do you think would happen if a large percentage of the community chooses not to be vaccinated?
5 If there is no medical reason not to, do individuals have a right to refuse to be immunised? What might be the consequences of this choice for:
   a the individual?
   b their local, national and global communities?

Disease control

Vaccines and immunisation programs

Scientists have long thought about ways to prevent people from contracting various infectious diseases. Antiviral drugs specifically target viruses and work in one of three ways: to stop viruses from entering cells; to inactivate the viral genetic material and stop the construction of new virus particles; or to prevent infected cells from releasing new virus particles.

Vaccination is the process in which a person is deliberately exposed to a pathogen, with the aim of creating **artificially acquired immunity**.

Most vaccines contain weakened or killed pathogens, so they should not cause symptoms of the disease; however, their antigens are still present. Your immune system can respond to these antigens by producing antibodies and, more importantly, memory B cells. The ongoing presence of memory B cells is more likely if you also have booster shots to repeat the process. Therefore, if you are exposed to the actual disease at a later date, your body will have memory B cells ready to immediately make antibodies and fight off the infection without you getting sick.

Access to vaccines

For various reasons, some people choose not to have vaccinations. Very rarely, a vaccination can cause the disease that it should have prevented. This may happen if the pathogen in the vaccine was not weakened enough. For every 2.7 million infants given the attenuated virus in Sabin's oral polio vaccine, one will develop the disease. Also extremely rarely, people may have a severe allergic reaction to some vaccines. Other people perceive that being un-vaccinated does not have any risks.

FIGURE 8.13 Doctors must choose the best option from many different medicines available.

Fighting bacteria and creating superbugs

Some types of pathogens are so dangerous that there is not time for your body to fight the disease naturally. Antibiotics are a group of drugs that attack bacteria. Some kill bacteria directly; others stop them from multiplying, allowing your immune system to attack the infection. Since antibiotics attack cells (for example, by disrupting their reproduction or damaging the cell wall), they only work on cellular pathogens. This means they don't work on viruses, because viruses are not made of cells.

Why pathogens may change over time

Overuse or misuse of any medication against pathogens can allow resistant strains to multiply. In a normal infection, a small number of the pathogens may have a mutation that protects them from the medication for at least a short while. Your immune system could effectively clean up these remaining pathogens, or you could keep taking the medicine long enough to kill off virtually all of the pathogens. However, if a small group of surviving pathogens is allowed to multiply, they will pass on this resistance to the next generation. Over time, this process may result in less effective medicines.

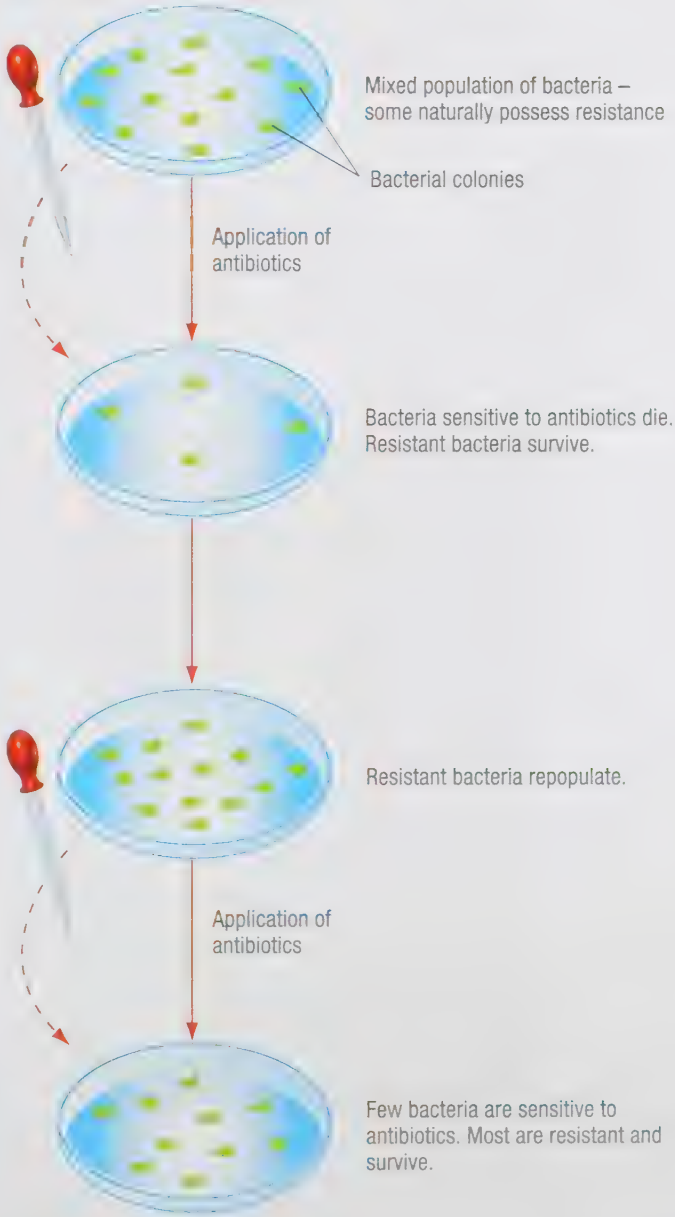


FIGURE 8.14 The development of antibiotic resistance – a schematic representation

This is why it is very important to:

- follow your doctor's prescription for medicines (and not use someone else's prescription)
- only take antibiotics for illnesses that they can treat (and not use them for viral illnesses, such as a cold and flu)
- always take the full course of a medicine, even though you might feel much better before you finish.

Antibiotic resistance has become a major problem, particularly in areas where antibiotics are used frequently, such as hospitals and in animal agriculture, where low doses may routinely be added to feed. For example, the bacterium *Staphylococcus aureus* (also known as golden staph) could be effectively treated 50 years ago; however, there are strains of the bacteria today that are resistant to all known antibiotics. This superbug is sometimes called multidrug-resistant *Staphylococcus aureus* (or **MRSA** for short). It is very difficult to treat a person with this type of infection.

Other types of pathogens are also developing resistance to the environment humans have imposed on them. Malaria, spread by mosquitoes, is caused by a parasitic protozoan. One strategy to counter the disease involved the use of DDT and other insecticides against the vector. However, this has selected for resistant mosquitoes. A second strategy involved attacking the protozoan. Over time, resistance has emerged against each new group of these drugs: chloroquine in the 1950s, sulfadoxine-pyrimethamine at the end of the 20th century, and now artemisinin, which first became globally available in 2006. A third strategy involves preventing opportunities for the mosquito to bite and breed, by using mosquito nets and draining swamps. When we interact with other living organisms, transformations constantly upset the balance.

FIGURE 8.15 Sweet wormwood had a long tradition as an antimalarial drug in China, and is the source of the modern antimalarial drug artemisinin

Natural bactericides

Where will we obtain our next generation of antibiotics?

Indigenous people used a wide variety of plants, animals and minerals to treat ailments or relieve symptoms. The range of treatments known to a group is called a **pharmacopoeia** (pronounced farm-a-ko-pee-a).

The person or people who discover something are said to own that knowledge. It is called their **intellectual property**. If someone else uses that knowledge without permission or without acknowledging it appropriately, they are breaching the owner's intellectual property rights – their copyright.

Sadly, this has sometimes been the case for Indigenous people. For instance, pharmaceutical companies are interested in finding out about bush medicines. They try to find out what part of the treatment works so that they can make a medicine from it. They may then **patent** the medicine, which means they own the intellectual property and are the only people allowed to produce the medicine and profit from it. This is sometimes done without acknowledging the Indigenous knowledge that led to the discovery. In cases where the pharmaceutical company goes on to make money from selling such medicines, Indigenous people feel they should share in that profit. Pharmaceutical companies may disagree because they invested in developing the medicine without really knowing if it would ever be profitable. Do you agree with them? How might this problem be resolved?

Indigenous people gained their pharmacopoeial knowledge as a result of their traditional close relationship with their natural environment. However, similar chemicals surround us all, in our gardens, at the local markets, and at the seaside.

Plants that have bactericidal effects, including spices and seasonings used in cooking, often have strong aromas. Onions and garlic contain allicin, leafy herbs contain terpenes and chillies contain capsaicin (Figure 8.16). Cooks may have used these ingredients originally to cover the smells and tastes of rotting food, but the chemicals themselves may also have prevented food poisoning.

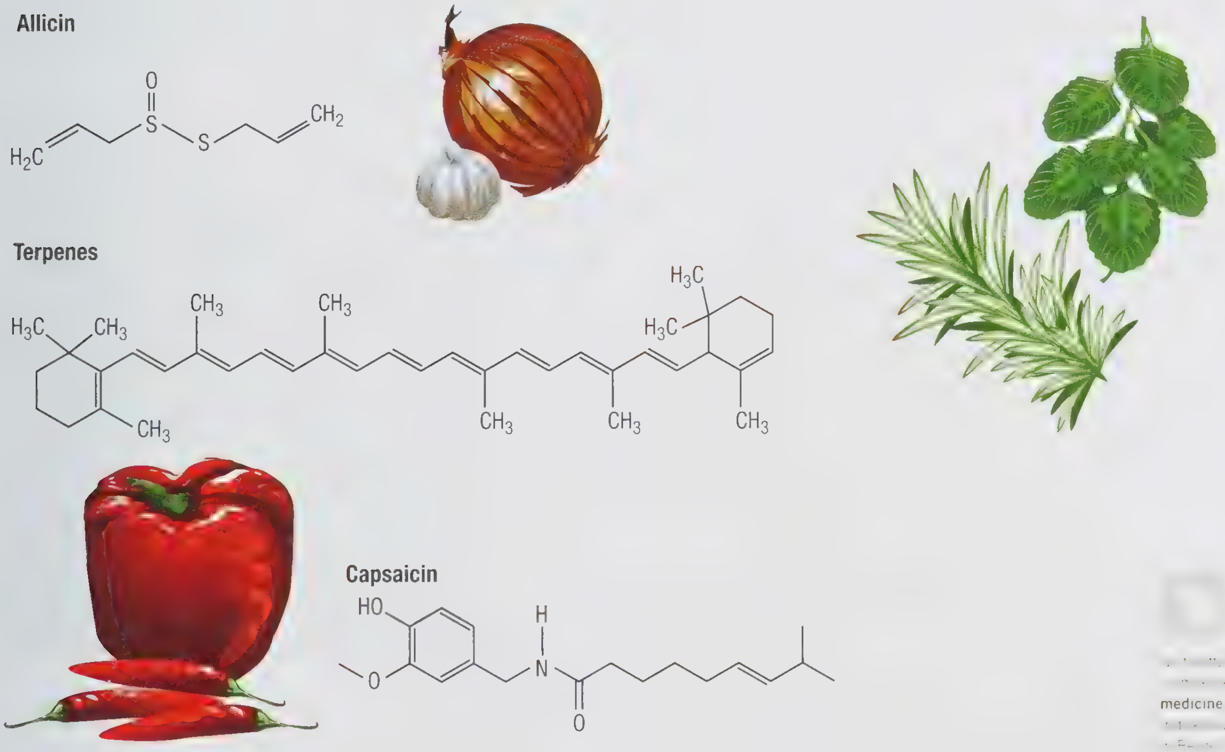


FIGURE 8.16 Many herbs and plants contain natural bactericides

Marine organisms are another potential source of natural **bactericides**. Coloured algae from the intertidal zone, invertebrates such as jellyfish, sponges and ascidians (also known as sea squirts) are constantly bathed in the microbial 'soup' of the ocean. Many of these organisms are **sessile** (anchored) or have little control over their movement for much of their lifespan. It is likely they use chemicals to protect themselves from disease.

CRITERIA B AND C

Natural bactericides

INVESTIGATION 8.2

YOUR CHALLENGE

Your teacher will give you prepared plates covered with a 'lawn' of benign bacteria (*Staphylococcus albans*).

Conduct an investigation into natural bactericides in your local environment.

THIS MIGHT HELP

- Explain how you will identify the organisms and plants you are using. Do you need permission from fisheries or environmental authorities to collect material from a marine site?
- In your hypothesis, explain how potential **bioactive** compounds may function in the original organism. (Generally these compounds are produced at high metabolic 'cost', and there will be strong selection pressure against organisms that produce them.)
- Explain how you plan to extract any potential chemicals to be able to compare effects consistently. How will you check that the extraction method you design (for example, using a solvent such as ethanol) does not interfere with the bioactive properties of materials in the chemicals present in your organism? If samples are to be stored frozen to avoid decay, what assumptions are you making about the potentially active chemicals?
- A method for testing the extracted chemicals on the lawn may be inferred from Figure 8.17. How many measurements would you take of the clear ring around the filter paper that was embedded with a potential bactericide?
- If your data suggests a bioactive compound is present, does this mean it is feasible to collect it from the wild, or it is suitable for human use? What further extraction processes and tests might be required?
- Bactericides use a variety of mechanisms. Some stop binary fission, some prevent the building of bacterial cell walls, and some **lyse** bacteria. How could you find out which mechanism produced the **antimicrobial** zone (zone of inhibition) in your assays?

SAFETY/OTHER CONSIDERATIONS

- Refer to the activity on sterile technique. This is one example where the Petri dish can be opened briefly.

Carry out and write up your investigation following the guide in Appendix 3 on page 209 or as advised by your teacher.

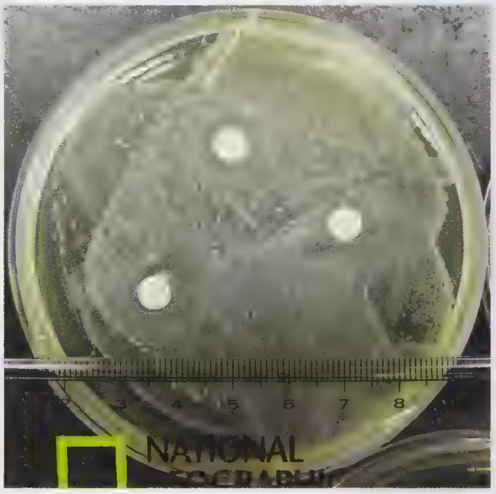


FIGURE 8.17 Lawn of *Staphylococcus albus* being tested by a student

REVIEW

1 Name examples of autoimmune diseases.
2 Describe two mechanisms by which antibiotics stop bacterial pathogens.
3 Name two low-cost, low-technology strategies that counter malaria effectively through community action.
4 Low doses of antibiotics are sometimes added to food for severely malnourished children, for example in refugee camps, because they will gain weight more quickly. Outline the risks and benefits of this practice.

UNIT QUESTIONS

CRITERION A

LEVEL 1–2

1 State the difference between the terms in each part.
   a Antibodies and antigens
   b Allergen and antigen
   c Allergy and anaphylactic shock
   d Naturally acquired immunity and artificially acquired immunity
   e Disease, epidemic, pandemic

2 Copy and complete the following table, summarising immune cells involved in the second line of defence.

Cell type	Function in immune system
B cell	
	Special type of B cell that remembers antigens and their matching antibodies long after an infection
Helper T cell	
	Specialised white blood cells that destroy pathogens

3 Suggest three specific ways in which pathogens could enter your body. For example, one way could be by drinking from the water bottle of an infected person.

4 Interpret Figure 8.18 to identify which of the antibodies shown would be effective against the pathogen.

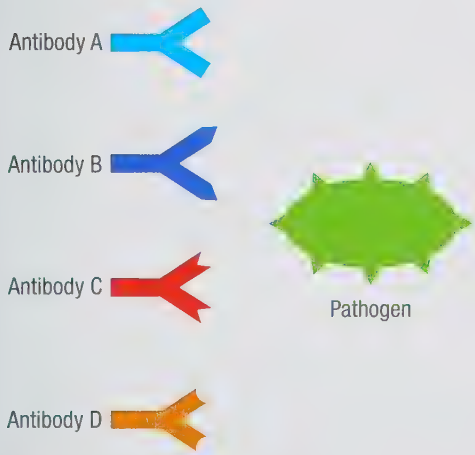


FIGURE 8.18

5 Viruses have been described as 'the living dead'. Suggest what this expression refers to.

LEVEL 3–4

6 Outline all the components of the immune system's first line of defence.

7 Apply your scientific knowledge to show why it is important to:
   a follow your doctor's advice and only take medicines prescribed to you (and not use someone else's prescription)
   b only take antibiotics for illnesses that they can treat (not viral illnesses, such as a cold or flu)
   c always take the full course of a medicine even though you might feel much better before you finish.

8 Sometimes doctors advise people planning to travel to have extra vaccinations. Make a scientifically supported judgement why is this necessary.

9 Analyse this information to make scientifically supported judgements.
   In April 2009, a new illness named 'swine flu' appeared in Mexico. Within a week, cases were reported throughout the world. Within months, the disease was declared a pandemic.
   a What distinguishes a pandemic?
   b What relationship is there between the outbreaks in pigs and in humans?
   c How might swine flu move around the world so quickly?

10 Use your knowledge of science to judge how pathogens could be spread:
   a at a football game
   b in a childcare centre
   c in a restaurant kitchen.

LEVEL 5–6

11 Describe strategies to try to prevent the spread of infectious diseases in each of the situations in Question **10**.

12 Suggest reasons for the following observations.
   a Most people will only catch chickenpox once.
   b The flu vaccine is different each flu season.
   c Antibiotics are useless if you have a cold.

13 A person with tonsillitis is given a prescription for antibiotics by their doctor. They take the medicine for 3 days and feel much better. Although they have a few days of medicine left, they decide to save it for next time, since they are already better.
   a Is this a safe idea? Why?

A few weeks later, the same person goes to the doctor with another illness. The doctor tells them that they have a virus and sends them home to rest. The person asks the doctor for some antibiotics and the doctor says it isn't necessary.

b Explain the doctor's reasoning.

14 Parasitic diseases offer several options to prevent transmission. Suggest how transmission could be prevented in a hypothetical parasitic disease, spread to humans by snails only during wet seasons, and surviving in fish during the dry seasons.

15 Under good conditions, some bacteria will divide in 20 minutes.

a How many offspring will be produced in:

i 1 hour?

ii 24 hours?

b What volume would they occupy? (Assume bacteria are spheres, 10^{-7} m in diameter.)

c Do bacteria actually ever die?

d Why aren't we knee deep in bacteria?

LEVEL 7–8

16 Acquired Immune Deficiency Syndrome (AIDS) is a disease caused by a virus that attacks a person's null killer cells. How would this affect the infected person? Predict what you think would ultimately lead to their death?

17 Perspiration is odourless, but the bacteria that naturally live on your skin break it down, producing smelly by-products in the process. A person with body odour knows this and has therefore decided to shower with an antibacterial wash several times a day. Will this fix their body odour problem in the long term? Could it make it worse? Explain.

18 Counterfeit artemisinin and similar new drugs are increasingly available in local markets in Burma and other developing countries.

a Explain the medical risks this drug poses to the patient.

b Explain the consequences of this drug on the transformation of the bacteria causing the problem.

19 Trypanosomes are parasites that cause African sleeping sickness. They coat themselves with new antigens every week, just after their human host has successfully cloned a new set of antibodies and killed off most of the protozoa in the blood. Trypanosomes have an arsenal of many thousands of antigens and the disease can progress for years.

a What effect will this disease have on their host's immune system?

b People with sleeping sickness have recurrent fevers that last about a week, and often succumb to opportunistic infections, much as AIDS patients do. What do you think is the real cause of death?

20 Relenza and Tamiflu are known as neuraminidase inhibitors (NIs). Many governments have invested millions in stockpiles of these recently developed antiviral drugs, in preparation of a potential influenza pandemic.

a Make scientifically supported judgements about their effectiveness in the light of the following information.

i They may mitigate (lessen) the development of severe disease if taken within 48 hours of symptoms starting.

ii The World Health Organisation (WHO) has now recommended that the drugs should be used against seasonal flu – the usual forms of flu that strike every winter.

b Suggest alternative, low-technology responses that may also be effective for a community.

REFLECTION

1 The key concept of this unit is relationships. Because of diseases, how have relationships changed between:

a human communities?

b human communities and the natural world?

2 A related concept is environment. How might the course of human history have been different if:

a the useful grains of the fertile crescent were instead part of the natural flora of Australia, an island continent with an unreliable climate?

b animals such as cattle, which were the likely source of measles and smallpox, were instead domesticated in the Americas?

3 Another related concept is interactions. What are some of the intellectual property conflicts between the owners of Indigenous pharmacopoeial knowledge and the companies that develop commercial applications? How can the conflict be resolved fairly?

4 The third related concept is consequences. Diseases have been transformed through the process of interacting with their hosts. How is the consequence of becoming less virulent a result of the relationships between hosts?

5 Do you believe everyone should have access to medication to counter infectious diseases? Who would benefit from an arrangement of universal access to this medication, and who should pay?

Appendices

Appendix 1: Approaches to Learning (ATL) framework in MYP Sciences

One of the main reasons the IB is so respected worldwide is that it places Approaches to Learning (ATL) in a central role in all IB programmes, thus encouraging the skills, habits and dispositions necessary to succeed in learning, both at school and for the rest of your life. Whenever you are learning in the MYP, you should remember that there are two things happening.

1 You are learning about the subject you are studying.
2 You are learning about learning.

The key attribute you need is to believe that you can continue improving as a learner over your life. Throughout the *Science for the International Student* books, you will see reminders of ATL skills (from the list below) that are involved in the tasks we have set.

ATL skill categories and clusters	ATL skills
COMMUNICATION	
I Communication	**1** Express ideas clearly, precisely and persuasively. **2** Use effective and correct scientific language. **3** Use appropriately a variety of media for communication, including 21st century technologies. **4** Use appropriate forms and modes of communication for different purposes and audiences. **5** Use strategies skillfully for speaking in public, reading for meaning, and structured writing.
SOCIAL	
II Collaboration	**1** Show empathy to others when working in diverse teams, be aware of cultural differences, encourage and support all members of a team. **2** Show flexibility and willingness to make necessary compromises to accomplish a common goal when working in groups. **3** Carry out a variety of roles and accept responsibility when working in groups/teams; show negotiating, advocacy, consensus-making and leadership skills. **4** Listen effectively and use non-verbal communication/body language. **5** Use social networking to build relationships effectively.
SELF-MANAGEMENT	
III Organisation	**1** Understand the importance of setting personal goals, both long term and short term. **2** Manage time well, establish priorities, using a daily and longer term planner, and meet deadlines. **3** Prepare for and sit examinations, prepare a study program, make summaries, revise actively and control emotions. **4** Be organised for learning, including materials, books, notes, online resources and necessary equipment for class. **5** Establish good support systems through family and friends, and create a pleasant place to study.
IV Affective	**1** Be self-motivated, have a positive attitude, and believe you can improve as a learner. **2** Be mindful of mental distractions and how to improve focus. **3** Be resilient, cope well with failure and unexpected challenges. **4** Persevere in achieving long-term goals (grit). **5** Be emotionally intelligent, control emotions and stress.

V Reflection

1. Be self-aware as a learner; be able to discuss your strengths and weaknesses and make goals for improvement.
2. Be able to give and respond well to feedback.
3. Show self-awareness of your learning, including being able to strategically plan how to carry out the task.
4. Monitor your work to review the progress being made, the areas of difficulty and the need for revised strategies.
5. Be knowledgeable about aspects of learning such as multiple intelligences and learning styles.

RESEARCH

VI Information literacy

1. Access information from a range of sources in an efficient and effective way; be skilled in summarising information and note-taking.
2. Evaluate information critically, be able to identify primary and secondary sources, identifying points of view and bias.
3. Use information selectively, accurately and creatively for the task at hand.
4. Understand the legal and ethical implications around the use of information, academic honesty and intellectual property rights; use citations, footnotes, referencing and bibliographies.
5. Develop the skills to function in a knowledge economy, using digital technologies such as networking tools and social networks.

VII Media literacy

1. Think critically about media to analyse; evaluate and understand how and why media messages are constructed and any bias, spin or misinformation that may be present.
2. Appreciate how individuals interpret messages differently.
3. Understand how media can influence our beliefs and behaviours, and culture and society generally.
4. Show an understanding of the ethical and legal issues surrounding the access and use of media.
5. Understand and utilise the most appropriate media creation tools, characteristics and conventions to communicate information and ideas.

THINKING

VIII Critical thinking

1. Use various types of reasoning, such as deduction and induction, as appropriate to the situation.
2. Be able to logically design scientific investigations to explore research questions, to develop an appropriate hypothesis and to control variables.
3. Reflectively analyse and evaluate evidence, data, arguments, alternative points of view, and claims and beliefs, to make valid judgments, conclusions, interpretations and decisions.
4. Synthesise and make connections between information and arguments to create new understandings.
5. Solve problems effectively, including in non-familiar situations; ask penetrating questions to clarify the problem.

IX Creative thinking

1. Show curiosity, a desire to dig deeper; enjoy novelty and uncertainty, and coming up with new ideas, products and solutions.
2. Be creative and imaginative, play with ideas; show divergent thinking, and be willing to let go and take risks; tolerate ambiguity; see mistakes as opportunities for learning.
3. Reason through metaphor and analogy; elaborate ideas, synthesise disparate bits of information; utilise knowledge in new contexts; formulate general concepts by abstracting common properties.
4. Design new products and technologies; be innovative and show entrepreneurial skills.
5. Create original works and ideas.

X Transfer (of skills and knowledge)

1. Show the motivation and meta-cognitive ability to support possible transfer of skills and knowledge within a discipline or across disciplines.
2. Be able to apply conceptual understandings and skills to new situations and across disciplines.
3. Appreciate the importance of interdisciplinary challenges and authentic problems, in which transfer of skills and knowledge is so important.
4. Be knowledgeable about recent developments in neuroscience and use information about the functioning of the brain to discuss learning (including the value of active, inquiry-based, contextual, collaborative and conceptual learning).
5. Understand how memory works and use techniques to improve memory.

Appendix 2: MYP Sciences 4/5 assessment criteria

	Achievement level			
	1–2	3–4	5–6	7–8
Criterion A Knowing and understanding	i **State** scientific knowledge.	i **Outline** scientific knowledge.	i **Describe** scientific knowledge.	i **Explain** scientific knowledge.
	ii **Apply** scientific knowledge and understanding to **suggest solutions** to problems set in **familiar situations**.	ii **Apply** scientific knowledge and understanding to **solve problems** set in **familiar situations**.	ii **Apply** scientific knowledge and understanding to **solve problems** set in **familiar situations** and **suggest solutions** to problems set in **unfamiliar situations**.	ii **Apply** scientific knowledge and understanding to **solve problems** set in **familiar and unfamiliar situations**.
	iii **Interpret** information to make **judgments**.	iii **Interpret** information to make **scientifically supported judgments**.	iii **Analyse** information to make **scientifically supported judgments**.	iii **Analyse** and **evaluate** information to make **scientifically supported judgment**.
Criterion B Inquiring and designing	i **State** a problem or question to be tested by a scientific investigation.	i **Outline** a problem or question to be tested by a scientific investigation.	i **Describe** a problem or question to be tested by a scientific investigation.	i **Explain** a problem or question to be tested by a scientific investigation.
	ii **Outline** a testable hypothesis.	ii **Formulate** a testable hypothesis **using scientific reasoning**.	ii **Formulate and explain** a testable hypothesis **using scientific reasoning**.	ii **Formulate and explain** a testable hypothesis **using correct scientific reasoning**.
	iii **Outline** the variables.	iii **Outline** how to manipulate the variables, and **outline** how **relevant data** will be collected.	iii **Describe** how to manipulate the variables, and **describe** how **sufficient, relevant data** will be collected.	iii **Explain** how to manipulate the variables, and **explain** how **sufficient, relevant data** will be collected.
	iv **Design** a method, **with limited success**.	iv **Design** a **safe method** in which he or she **selects materials and equipment**.	iv **Design** a **complete and safe method** in which he or she selects **appropriate materials and equipment**.	iv **Design** a **logical, complete and safe method** in which he or she **selects appropriate materials and equipment**.
Criterion C Processing and evaluating	i **Collect and present** data in numerical and/or visual forms.	i **Correctly collect and present** data in numerical and/or visual forms.	i **Correctly collect, organise and present** data in numerical and/or visual forms.	i **Correctly collect, organise, transform and present** data in numerical and/or visual forms.
	ii **Interpret** data.	ii **Accurately interpret** data and **explain** results.	ii **Accurately interpret** data and **explain** results **using scientific reasoning**.	ii **Accurately interpret** data and **explain** results using **correct scientific reasoning**.
	iii **State** the validity of a hypothesis based on the outcome of a scientific investigation.	iii **Outline** the validity of a hypothesis based on the outcome of a scientific investigation.	iii **Discuss** the validity of a hypothesis based on the outcome of a scientific investigation.	iii **Evaluate** the validity of a hypothesis based on the outcome of a scientific investigation.

	Achievement level			
	1–2	3–4	5–6	7–8
	iv **State** the validity of the method based on the outcome of a scientific investigation.	iv **Outline** the validity of the method based on the outcome of a scientific investigation.	iv **Discuss** the validity of the method based on the outcome of a scientific investigation.	iv **Evaluate** the validity of the method based on the outcome of a scientific investigation.
	v **State** improvements or extensions to the method.	v **Outline** improvements or extensions to the method that would benefit the scientific investigation.	v **Describe** improvements or extensions to the method that would benefit the scientific investigation.	v **Explain** improvements or extensions to the method that would benefit the scientific investigation.
Criterion D **Reflecting on the impacts of science**	i **Outline** the ways in which science is used to address a specific problem or issue.	i **Summarise** the ways in which science is applied and used to address a specific problem or issue.	i **Describe** the ways in which science is applied and used to address a specific problem or issue.	i **Explain** the ways in which science is applied and used to address a specific problem or issue.
	ii **Outline** the implications of using science to solve a specific problem or issue, interacting with a factor.*	ii **Describe** the implications of using science and its application to solve a specific problem or issue, interacting with a factor.*	ii **Discuss** the implications of using science and its application to solve a specific problem or issue, interacting with a factor.*	ii **Discuss and evaluate** the implications of using science and its application to solve a specific problem or issue, interacting with a factor.*
	iii **Apply** scientific language to communicate understanding but does so **with limited success**.	iii **Sometimes apply** scientific language to communicate understanding.	iii **Usually apply** scientific language to communicate understanding **clearly and precisely**.	iii **Consistently apply** scientific language to communicate understanding **clearly and precisely**.
	iv Document sources, with **limited success**.	iv **Sometimes** document sources **correctly**.	iv **Usually** document sources **correctly**.	iv Document sources **completely**.

*Factors include moral, ethical, social, economic, political, cultural and environmental.

Appendix 3: Guidance on carrying out and writing up MYP scientific investigations (criteria B and C)

Title

- Give the investigation a title, e.g. 'Properties of Springs'.

Problem/Research question (criterion B I)

- Write down and explain what you are trying to find out, e.g. 'How does the weight on a spring affect its length? I am interested in the relationship between the weight added to a spring and the length it stretches to.

Hypothesis (criterion B II)

- Formulate and explain what you think is going to happen in your investigation, e.g. 'My hypothesis is that the spring will stretch as I put more weights on it'.
- Use your scientific knowledge to explain why you think this will happen, e.g. 'I think it will stretch because a force will cause the particles of the spring to separate'.

Variables (criterion B III)

- To do a **fair test** you must only change one variable at a time.
- Write down the variable that you will measure (dependent variable), e.g. length of spring.
- Write down the variables that you will change (independent variables), e.g. weights put on the spring.
- Write down the variables that you will keep the same while doing your investigation (control variables), e.g. use the same spring.

Experimental method (criterion B III and IV)

- List all the materials and equipment you will use.
- Design a logical, complete and safe method which shows how to use the materials and equipment you have selected. Include a special section on the safety issues. Drawing a diagram will often help you explain what you want to do.
- Include the **range** of measurements you will take and/or the size of the sample and how often you will repeat readings.
- Your plan also needs to include an explanation of how you will control and manipulate the variables and how you will collect sufficient and relevant data. Describe how you will process the data.
- Sometimes you might need to carry out a preliminary experiment to check that your plan works. You might need to alter some aspects of your initial plan.

Results (criterion C I)

- Collect, organise and present all your observations or measurements (data) carefully and fully. Use a well labelled table, including correct column headings and units. In some experiments, you will be asked to express and justify the uncertainties in your numerical data.
- Carry out any necessary transformation of your data, e.g. numerical calculations such as averaging. Present this as well.
- Draw an appropriate graph of your results if you have numbers. If you are drawing a line graph, then draw a smooth curve or **line of best fit** through your points. In some experiments, you will be asked to add uncertainty bars and to calculate minimum and maximum gradients based on these uncertainty bars.

Conclusion and explanation (criterion C II and III)

- Accurately interpret your data; that is, i.e. explain what your data tells you about your original research question. Comment on any patterns in your result. If you have numbers and a graph, discuss the shape of the line and the relationship it shows between the variables. This is your conclusion. Make sure you explain your conclusion, showing good scientific understanding.
- When writing your conclusion, construct a well thought out and reflective argument based on a careful consideration of your evidence. Is your evidence good enough? If you feel your results don't really provide enough evidence to make a firm conclusion, then say so.
- Evaluate your hypothesis – did it prove to be valid based on your results?
- Note: Where a result seems to be out of place and does not conform to the pattern, it is called an **anomaly**. (Perhaps a mistake was made in the reading.) You should discuss any such results and suggest reasons for their presence, but don't use them in making your conclusion.

Evaluation (criterion C IV and V)

- How well do you think your method worked? Did you have any problems you dealt with while carrying out the experiment?
- Validity: Did you collect sufficient valid data to answer the question? Did the instruments measure what they were meant to? What errors were in your measurements? Was the experiment a fair test? Did you repeat your readings enough times? Was your sample well chosen and large enough?
- Improvements: Write down how you might make your investigation better, especially to improve the validity or to obtain more reliable evidence. Write down any further experiments you could carry out to get more evidence or to extend this investigation.

Appendix 4: Articulating the conceptual framework in MYP Sciences

The MYP Science conceptual framework is defined by the key concepts of change, systems and relationships. These key concepts are further articulated via the use of related concepts. This conceptual framework will then be articulated in the curriculum via a series of integrating conceptual statements.

In MYP Science, students develop their understandings about scientific **systems** and the **changes** that take place within these systems via the investigation of causal **relationships**.

The conceptual framework

Systems

Scientists use a systems approach to study the world. There are different kinds of systems, including the universe itself, Earth, ecosystems, closed systems in physics, and many others.

Related concepts	Integrating conceptual statements	Examples
Environment (biology)	The form, development and survival of an organism or a community is influenced by its surrounding **environment**, i.e. a combination of both abiotic and biotic factors.	In **biology**, we study the reasons for the changing populations in animals. In chemistry, we consider how pollution has affected fish life in lakes. In physics, we consider the impact of energy policies on the environment.
Interaction	Often there are **interactions** in science when two objects or more come together in a way that affects both of them.	In **biology**, we could study the interaction between flowers and bees. In chemistry, we consider the interactions between water molecules. In physics, we study the interactions between electrostatic charges.
Models	Scientists use **models** to help them understand and to study some aspects of the world.	In **biology**, we can use a model of the lungs to understand how breathing happens. In chemistry, we use models of chemical structures to understand the properties of salt (sodium chloride). In physics, we could use a model that is a simulation of how particles move in a gas.
Cycles	To understand many systems we need to consider **cycles** of energy and matter.	In **biology**, we consider cycles such as menstruation. In chemistry, we study cycles of elements in nature, such as carbon and nitrogen. In physics, we study cycles in the appearance of sunspots.
Scales	Different systems work at different **scales**, usually in relation to size, energy and speed. Scientists have developed the SI system of units to aid communication.	In chemistry and **biology**, we learn that different scales in sizes of particles of matter have an enormous effect on their properties. In physics, we consider speeds that range from moving tectonic plates to the speed of light.

Change

In sciences, change is viewed as the difference in a system's state when observed at different times. This change could be qualitative (such as differences in structure, behaviour or level) or quantitative (such as a numerical variable or a rate).

Related concept	Integrating conceptual statements	Examples
Energy	**Energy** can be transformed from one form to another. Energy flows can be tracked through a system. The total amount of energy is conserved in closed systems.	In **biology**, we track energy flows through an ecosystem. In chemistry, we study how we can relate the heat given out in reactions to bond energies. In physics, we study how solar energy can be converted to electrical energy.
Transformation	Molecules, organisms, materials and energy can be **transformed** from one form to another.	In **biology**, we learn about genetic transformations in cells or the transformation as caterpillars change into butterflies. In chemistry, we learn about sand being transformed into glass. In physics, we study how energy can be transformed from one form to another.
Movement	Change and **movement** are at the heart of all natural systems, from the universe itself to the smallest cell.	The study of **biology** and chemistry depends on understanding the movement of particles. In physics, Newton's laws are used to explain the movement of objects.
Balance	Achieving a **balanced** state or equilibrium is an important idea in many sciences. Feedback loops are an important aspect of understanding many stable systems.	In **biology**, we consider how the body regulates its temperature. In chemistry, we learn about how reversible chemical reactions reach equilibrium. In physics, we consider how the forces on an object can be balanced.
Evolution	The natural world can be understood by considering **evolutionary** changes, some gradual and continuous, others sporadic.	We study the theory of biological evolution, which examines the changes in all forms of life over generations. We can also consider how technology evolves over time.
Conditions	Physical **conditions** influence chemical reactions and physical properties of materials.	In chemistry, we learn about the influence of factors such as temperature on the speed of reactions and how erosion of rocks is affected by changes in physical conditions.

Relationships

Relationships in sciences indicate the connections found among variables through observation or experimentation. These relationships also can be tested through experimentation. Scientists often search for the connections between form and function. Modelling is also used to represent relationships where factors such as scale, volume of data, or time make other methods impractical.

Related concepts	Integrating conceptual statements	Examples
Patterns	Recognising and seeking explanations for **patterns** in nature or collected data is the first step in scientific inquiry.	In **biology**, we could consider the patterns in fossil records. In chemistry, we study patterns in the reactions of elements. In physics, we consider the patterns we see in the movement of the planets.
Cause and effect	The search for underlying causes of scientific phenomenon is based upon establishing **cause and effect** relationships. We must always remember 'correlation does not necessarily imply causation'.	In **biology**, we could look for cause and effect relationships to help us learn how to reduce certain diseases. In chemistry, we consider the causes of increased erosion. In physics, we look for cause and effect relationships between force and changes in motion.
Evidence	Scientists use observations and data to develop **evidence** to support their claims, conclusions or answers to research questions. Scientists need to make careful arguments to justify their evidence.	In scientific investigations, we need to carefully consider the evidence when making conclusions, e.g. did the results show that a heavier weight on the pendulum made it swing faster, slower or did it make no change?
Consequences	Understanding that making changes to systems (especially ecosystems) sometimes has significant **consequences**; sometimes these can be predicted, other times they can be unexpected.	We consider the consequences of global warming, the possible consequences of nanotechnology, the consequences of increased air traffic.
Form and function	The **function** (purpose, role, way of behaving) of a system or a structure is related to its **form** (the shape, relationships between the parts, composition and properties).	In **biology** this is a crucial concept, with applications ranging from studying the arrangement of legs on an animal, to the shape of seeds, to the form and function of different cells. In chemistry, we consider how the structure at the ionic or molecular level results in the properties of substances. In physics, we can discuss how to alter the design of a bike to improve its performance.
Development	Scientific understanding is being continuously **developed** via a continuous process of scientific investigation.	In **biology**, we consider how ideas about the cause and spread of diseases developed, and the theory of biological evolution. In physics and chemistry, we study how ideas about the atom developed, especially in the late 19th and early 20th centuries.

Related concept	Integrating conceptual statement	Example
Creativity	The scientific endeavour is associated with a high level of **creativity**.	We experience the importance of creativity by studying the contributions of many truly creative scientists, such as Rutherford, Darwin and Mendeleev; through designing and carrying out our own experiments and in the way we use our ideas in science to develop higher level understandings.

Conceptual framework diagram

The conceptual framework can be shown visually. Note: The following diagram has limitations. There are many other relations between key and related concepts, and between different related concepts, not shown in this diagram. However, we feel it could help teachers and students start developing a mental map of how the conceptual framework for MYP Sciences links together.

Glossary

abiotic factor a non-living factor
abort to terminate a pregnancy
action potential the generation of a new impulse in a neuron
active transport transport of a substance across a cell membrane that requires the expenditure of energy, e.g. transport against a concentration gradient
adaptation a characteristic of an organism that improves the organism's chance of survival
adenine (abbreviation A) one of the bases in DNA and RNA
adrenalin a hormone produced by the adrenal glands, in response to a stimulus from the sympathetic nervous system
alleles different versions of a particular gene
allergen a normally harmless antigen that causes an immune reaction in sensitive people
allergies an overreaction of the immune system to a normally harmless antigen
all-or-none response a response that requires a threshold amount of stimulus to start, and cannot vary its intensity
alveoli (singular: alveolus) small balloon-like structures in the lungs, where gas exchange takes place
amino acid the monomer that makes up proteins
amniocentesis a technique that samples part of the amniotic fluid, which contains cells shed from the baby; tests for some types of abnormalities.
amniotic fluid the fluid present in the amniotic sac
amniotic sac the fluid-filled sac in which a developing foetus or embryo is sealed inside the uterus; this bursts during or before birth
anaerobe an organism that does not require oxygen to survive
anaphase the phase (stage) in cell divisions when the separated chromosomes are being pulled to opposite ends of the cell by the spindle
anaphylactic shock a life-threatening, whole-body immune response to an allergen
angiosperm a flowering plant
anomaly a result that seems to be out of place and does not conform to the pattern
anthropogenic caused by human activity
antibiotic resistance the ability of micro-organisms, such as bacteria, to withstand antibiotic treatment
antibiotic a drug used to treat an infection caused by bacteria
antibody a special protein produced by white blood cells, commonly known as B cells, that is shaped to complement the antigen on an invading pathogen, and can therefore attach to the antigen like a key in a lock
anticline an upward fold of rock, forming a 'crest'; formed when pressure is placed on ductile (not brittle) rocks
anticodon a sequence of three bases found on tRNA
antigen a uniquely shaped 'marker molecule', usually a protein, embedded in the surface of cells or viruses, by which they can be recognised
antimicrobial a substance that kills or inhibits the growth of microbes
artery a blood vessel flowing away from the heart, thick-walled and elastic
artificially acquired immunity immunity produced by deliberate exposure to a pathogen, as in vaccination
asexual reproduction the process by which a single organism reproduces itself, producing offspring with identical DNA to their parent
asymptomatic without symptoms
attenuated (virus) weakened, but living viruses that can stimulate an immune response
autoimmune disease a disease caused when the immune system attacks the organism's cells by mistake
autonomic (involuntary) nervous system the system that involves the functioning of certain organs over which you have no conscious control, such as the heart
autosomes the pairs of chromosomes that are the same for males and females (numbers 1–22 in humans)
autotroph an organism that can produce its own organic food from inorganic substances
axon long hair-like extension to a nerve cell that relays electric impulses away from the cell body to another nerve cell

B cell (B lymphocyte) a white blood cell that responds to antigens by making antibodies
back-cross a technique in which a homozygous recessive organism is crossed with a heterozygous organism; used to determine whether a dominant phenotype is homozygous or heterozygous
bacteria (singular: bacterium) unicellular micro-organisms of which a few are pathogenic (cause disease)
bactericide a substance that kills bacteria

base one of three components in a DNA or RNA nucleotide
base pairs the possible combinations of bases that can weakly bond to one another by hydrogen bonding to form the 'rungs' of the DNA molecule
bed a horizontal layer of sediments that has settled into a depression
bile a yellow-greenish alkaline fluid produced by the liver and stored in the gallbladder, which helps the mechanical digestion of fat by breaking it up into droplets
binary fission a process in which a living cell splits in two
binomial classification a scientific system of naming organisms using a two-part name
bioaccumulation (or biomagnification) when toxins are not excreted by organisms at the rate they are ingested, organisms higher up the food chain will have higher concentrations than the organisms below them
bioactive any chemical that has an effect on a living organism
biodegradable can be broken down by micro-organisms or natural physical processes, such as the effects of UV light
biodiversity the variety of different living things found in a particular area
biomass the mass of living organisms in a given area
biomass pyramid a way of representing the mass of organisms in food chains or trophic levels
biome a distinct community of plants and the organisms they support in a particular geographical region
biotic factor a living factor
birth control mechanisms used to prevent pregnancy
bladder a hollow organ that stores urine excreted by the kidneys
blastocyst a hollow ball of cells that has developed from a morula and which implants itself into the endometrium
bronchi a branch from the trachea in the respiratory system, dividing into bronchioles
budding a form of asexual reproduction in which a new individual starts life as an outgrowth of its parent
butterfly effect the phenomenon in chaos theory whereby a tiny localised change in a complex system can have large unpredictable effects elsewhere

capillary a thin, fragile blood vessel that is only one epithelial cell thick, which delivers nutrients and oxygen to all cells in tissue, and removes wastes
capillary force the interaction between a liquid and a solid inside a narrow tube, which causes the liquid to rise or fall
carbon cycle the recycling of carbon through the environment
carnivore an organism that only consumes meat
carpel the female part of a flower, consisting of the ovules, ovary, style and stigma
carrier someone who does not express a genetic disorder but who passes it on to their children
cell body the main part of a neuron that contains all the necessary components of the cell, including the nucleus
cell membrane the outer surface of a cell
central nervous system (CNS) the part of the nervous system made up of the brain and the spinal cord
centre of gravity the place in a system or body where the weight is evenly balanced in all directions
centriole a structure that organises the spindle fibres during cell division in animal cells
centromere the part of a duplicated chromosome where the two chromatids are joined and the spindle fibres attach
cervix the ring of muscles at the entrance to the uterus
chaos a completely unpredictable set of responses that leads to system breakdown
chemistry the study of substances and how atoms are exchanged between them
chlorophyll the green pigment within leaves where photosynthesis occurs
chloroplast an organelle found in plant cells where photosynthesis occurs
chorionic villus sampling (CVH) a technique that samples part of the embryo, which is genetically identical to the baby, to test for some types of abnormalities
chromosomes tiny structures, made of protein and DNA, found in the cell nucleus that contain the entire set of genes of the organism
cilia (singular: cilium) hairlike organelles, identical in structure to flagella, that beat in rhythmic waves, providing movement
class a category of biological classification between phylum and order
clones organisms that have identical DNA
co-dominant phenotype that shows traits of both parents for a particular characteristic; AB blood types are an example
codon a three-base sequence on DNA or mRNA that is translated to an amino acid in a protein
collenchyma a tissue consisting of thickened, living cells that provide support

complementary sequence the sequence of matching base pairs on a second DNA strand, when the order of base pairs of one strand is known
condensation the process in which water vapour (gas) changes to liquid water in the form of clouds, usually as a result of cooling
congenital present at birth
connector neuron a neuron that makes links between other neurons
consumer a heterotrophic organism in a food chain
contagious infectious
continental drift the very slow movement of continents relative to one another due to the movement of the tectonic plates on which they sit
contraception prevention of conception
corpus luteum the remains of a burst ovarian follicle after the release of a mature egg
counter regulatory effect an opposing effect, related to hormones
countercurrent flow fluids in two systems flowing in opposite directions; increases rates of exchange because it maximises the difference in concentration between materials that need to diffuse between them
covalent bonding a form of bonding between atoms that involves sharing electrons
crossing over an event in prophase I in meiosis in which sections of maternal and paternal chromatids swap
cross-pollination the transfer of pollen from one plant to a carpel of another plant of the same species
cytokinesis the process towards the end of each major stage of cell reproduction in which the cell divides
cytoplasm the fluid and dissolved substances between the plasma membrane and the nucleus
cytosine (abbreviation C) one of the bases in DNA and RNA

daughter cells the cells that result when cell division occurs
decomposer an organism that breaks down dead animal and plant litter
deforestation the large-scale logging or burning of naturally occurring forest
dehydrated lacking in, or without, water
deletion when one or more base pairs is removed from a DNA sequence
demographics the branch of statistics that studies populations, e.g. by income, age or sex
dendrite thread-like extension to a nerve cell that relays electric impulses to the cell body
deoxyribonucleic acid, see **DNA**
dermal tissue system (plants) the protective outer surface of plants, e.g. the epidermis in leaves
dicotyledon a flowering plant that has two embryonic seed leaves and leaves with netlike veins
diffusion movement of molecules from an area of higher concentration to an area of lower concentration
diploid (2n) having two complete sets of chromosomes, one from each parent, e.g. in somatic (body) cells
disease amplifier a condition that hastens the spread of a disease. Examples include war, global travel and intermediate hosts which can magnify the amount of contagion (virus particles or bacteria) and bring it in contact with new host species
diurnal active during the day
DNA (deoxyribonucleic acid) a molecule present in chromosomes in the cell nucleus that determines the characteristics of the organism
DNA–DNA hybridisation a technique for recombining single DNA strands from two species, to determine their similarity
dominant (gene) a gene that 'overrides' another gene for the same characteristic and so is expressed; usually symbolised by a capital letter

ecosystem all the organisms interacting with each other and with their environment
ectoparasite a parasite found on the surface of the body, e.g. ticks and fleas
eggs the female gametes produced by flowering plants
ejaculation the process by which sperm are released from a male's body
electronegative how powerfully an atom attracts electrons to itself
embryo an unborn, developing organism, at the stage when its cells begin to specialise and some organs start to form
emergent behaviour the new behaviour of a 'whole' entity, which will have different properties from the sum of its parts
endocrine system the set of glands that produce hormones and secrete the hormones directly into the bloodstream
endometrium the mucous membrane that temporarily lines the uterus
endoparasite a parasite that lives inside the body; categorised as either protozoans or helminths
endosymbiotic theory the theory that organelles in eukaryotic cells originated from bacteria
energy flow how energy is moved through an ecosystem
enhanced greenhouse effect the trapping and re-radiating of more radiant heat to Earth's surface due to increased levels of CO_2 in the atmosphere

environment the conditions under which an organism lives; terrestrial environments are land based, aquatic environments are water based, and the atmosphere is a gaseous environment
enzyme a biological catalyst that speeds up a reaction without being consumed in the process
epicentre the point on the surface above the focus of an earthquake
epidemic a higher than expected incidence of a disease in a particular area
epidemiology the study of factors affecting the health and illness of populations
epididymis the organ in which sperm are stored
epithelium a tissue type that covers the surface of an animal
erectile tissue specialised tissue inside the penis that can fill with blood, causing the penis to stiffen
erection a state in which the penis becomes enlarged and firm
erector papillary muscles muscles in the skin that make hairs stand up straight
erosion the removal of soil due to wind or water (in all states)
estuary the tidal mouth of a river, where seawater and river water mix
eukaryotic a cell with a nucleus, a nuclear membrane and organelles; *eu-* means 'true' cells
eutrophication when excess nutrients in a body of water promote the growth of algae to the point when oxygen concentrations at night becomes critically low, causing death of aerobic organisms
evaporation the process in which liquid water changes to water vapour (gas), usually as a result of heating
evapotranspiration the net loss of water to the atmosphere from plant and soil surfaces
exon the parts of a gene that are used to make a mature mRNA molecule
external fertilisation the process in which sperm fuses with an ovum outside the body
extinction when there are no living representatives of a species, all have died

F_1 generation first filial generation; the result of a genetic cross between parents
F_2 generation second filial generation; the result of crossing two F_1 siblings
fair test when you only change one variable and keep all others constant
familial DNA searching a database search of relatives of a suspect
family a category of biological classification that includes one or more genera (e.g. the cat family, the legume family)
fault a huge fracture that is produced in brittle rocks when a large force is exerted on them
fauna animals
fertilisation (conception) the process in which a sperm fuses with an ovum, producing a new single cell (a zygote) that contains the DNA of both gametes
flagellum a whip-like appendage that enables many protozoa, bacteria and sperm cells to swim
focus the point at which rocks snap apart, i.e. the source of an earthquake
foetus the name given to an unborn human after about 6–8 weeks, when it resembles a human being
follicle a sac-like structure in the ovary that contains the maturing ovum
follicle-stimulating hormone (FSH) the hormone produced by the pituitary gland that stimulates the growth of follicles in the ovary in females and induces the formation of sperm in the testis in males
fomite any object or substance that may carry infectious organisms
food chain a diagram that represents the way in which energy flows between organisms in a simple 'line' (producer, primary consumer, secondary consumer)
food web a diagram that shows how food chains link together
fossil any preserved remains of an organism or traces of an organism or its activity
fossil record a comprehensive catalogue of all the fossils that have been found
fungi a taxonomic kingdom of eukaryotes that includes mushrooms, toadstools, yeasts, rusts

Gaia hypothesis the hypothesis that states the Earth is a self-regulating, life-sustaining complex system
gamete a sex cell; contains only half the DNA present in other body cells
gene a section in the genome that provides information for a particular protein
generation time the time taken for a species to reproduce itself
genetic engineering altering the DNA of a cell, including moving genes from one species to another
genetic modification manipulating genomes by amplifying, knocking out or changing genes; can involve traditional processes such as breeding
genome genetic information in the form of DNA or RNA
genotype the combination of two genes (pair of alleles) inherited for a particular characteristic
genus (plural: genera) a taxonomic group consisting of one or more closely related species
geologist a scientist who studies the structure and composition of the Earth

gestation period the period of time taken for the offspring of a placental mammal to mature inside its mother's uterus
gland a group of specialised cells whose function is to produce specific chemical compounds
global warming an increase in the average temperature of Earth's atmosphere
glomerulus a cluster of capillaries around the end of a kidney tubule, where waste products are filtered from the blood
gonads the organs in which gametes are produced
greenhouse effect the way in which Earth maintains a stable temperature
ground tissue system (plants) a system that makes up all the tissues between the vascular bundles (xylem and phloem) and the dermal tissue; it is made up of parenchyma, collenchyma and sclerenchyma, and makes up the bulk of the plant
guanine (abbreviation G) one of the bases in DNA and RNA
gyre a large rotating ocean current

habitat the place where an organism lives
half-life the time it takes for a quantity of a radioactive substance to decrease by half
haploid (n) having a single set of unpaired chromosomes, e.g. in gametes
helical coiled in a continuous series around a shape with a constant distance from the centre
helminth a taxonomic group, worms
hepatic portal vein a vein conveying blood to the liver from the capillaries around the spleen, stomach, pancreas and intestines
herbivore an organism that only consumes plants
hereditary passed on from one generation to another
heterosomes pairs of chromosomes that are different, e.g. the X and Y chromosomes
heterotroph an organism that must consume organic matter for energy
heterozygous when the two alleles inherited for a particular characteristic are different, such as Bb
homeostasis the process for maintaining the internal 'steady state' in an organism
homologous a pair of chromosomes that carry matching genes; one is inherited from the mother and one from the father
homozygous when the two alleles inherited for a particular characteristic are the same, such as bb or BB
hormone replacement therapy (HRT) the administration of synthetic or natural female hormones, usually oestrogen, to a woman during menopause to treat symptoms produced by reduced levels of natural hormones
hormone a chemical messenger released in small quantities directly into the blood by the endocrine glands; has a unique chemical structure and will act only in target cells
host any organism that carries a disease
H-Y antigen the protein that causes the primitive gonads of a foetus to develop into male reproductive organs; if absent, the primitive gonads of the foetus develop into female reproductive organs
hydrogen bond a weak electrostatic bond between hydrogen and an electronegative atom, such as oxygen, nitrogen or fluorine, in a molecule
hypothalamus part of the brain that controls the autonomic nervous system, which relays messages to the 'master gland', the pituitary, to secrete many different hormones

immune system the body system that is involved in fighting off infectious diseases
implant an event that occurs in early pregnancy in which the embryo adheres to the wall of the uterus
in vitro fertilisation (IVF) fertilisation that takes place outside the body, in a glass dish. The embryo is inserted into the mother's uterus
incomplete dominance the pattern of inheritance in which both genes are expressed, forming an intermediate, blended phenotype, e.g. pink carnations from red and white parents
index patient the first person identified with a new disease
infectious disease a disease caused by pathogens; can be passed from one person to another
infertile unable to reproduce
inflammation a non-specific immune response to injury that causes redness, heat, swelling and pain
insertion when one or more base pairs is added to a DNA sequence
intellectual property a product of the mind, such as an idea or thought
interneuron also called association neuron; makes links between neurons within the brain and spinal cord
interphase the period of the cell cycle in which the cell takes in raw materials, manufactures proteins and additional organelles, grows and synthesises new DNA
intramolecular occurring within the molecule
intron a section of the gene, usually consisting of DNA that is not translated into a protein
inversion when a section of the genome is reversed
isotopes atoms of the same element with different numbers of neutrons

karyogram a table or diagram showing all the chromosome sets from a cell lined up in pairs in order of size

karyotype the chromosome set in a cell of an organism
kidneys bean-shaped organs that filter the blood and balance its composition
kingdom one of five very large taxonomic groups (prokaryotes, protists, fungi, plants and animals), below which organisms are grouped into phyla

legume a plant family that includes peas and beans, which produces seeds in pods
libido interest in sexual activity
ligase enzyme that can catalyse the joining of two DNA molecules by forming a new chemical bond
limiting factor an environmental factor that controls a process, particularly the growth, abundance or distribution of a population of organisms in an ecosystem
line of best fit a line drawn through points on a graph that goes roughly through the middle of all the point
liver a large reddish organ that has a major role in metabolism, digestion, detoxification and elimination of toxins
lumen the hollow centre of a vessel, for example, the seminiferous tubules
luteinising hormone (LH) the hormone produced by the pituitary gland that stimulates ovulation and the development of the corpus luteum in females and the production of testosterone to aid sperm maturation in males
lyse to dissolve, decompose, break open
lysozyme an enzyme that destroys the cell walls of bacteria

macromolecule a large molecule, often a polymer found in biological systems, e.g. proteins, carbohydrates, fats, nucleic acids
macrophage a large white blood cell that attaches to invading microbes, surrounding and engulfing them, and then chemically destroying them using enzymes
macroscopic can be seen without technological aids
magma the semimolten rock found in the mantle
mammary glands glands in a female mammal's breasts that develop when she becomes pregnant and produce and excrete milk for the newborn baby
mantle a layer of semimolten rocks below the Earth's crust
maternal chromosome a chromosome inherited from the mother
mechanics a branch of physics that deals with the action of forces on bodies and with motion
meiosis the type of cellular division that produces four haploid cells
memory B cell a specialised white blood cell that 'remembers' antigens and their matching antibodies long after an infection
menopause the period over which a woman's menstrual cycle gradually stops occurring
menstruation the flow of blood from the uterus, resulting from the breakdown of the endometrium
meristem a dividing, undifferentiated plant tissue
messenger RNA (mRNA) an intermediary molecule between DNA and protein; it copies the base-pair sequence from the DNA template in the nucleus, and moves into the cytoplasm where it translates to a protein
metabolic reactions involving chemical changes in cells
metaphase a stage in cell division where all the chromosomes are lined up on a 'plate' across the centre of the cell
microbe an organism of microscopic or submicroscopic size, including bacteria and fungi
microscopic very small object that can only be seen with a lens or microscope
mitochondria small structures within the cytoplasm that release energy for the cell
mitosis the type of cellular division that produces two diploid cells, or somatic (body) cells
monocline broad, step-like folds in which there is a horizontal sedimentary stratum
monocotyledon a flowering plant that has one embryonic seed leaf and leaves with parallel veins
monocyte a white blood cell
monogamous relationship one in which a couple only have sexual relations with one another
monosomy a condition in which only one of a pair of a particular chromosome is present in a diploid cell
morula a solid ball of cells formed when a zygote has undergone a series of cell divisions
motile able to move
motor neuron a neuron that carries instructions from the central nervous system to the muscles and glands
MRSA multidrug-resistant *Staphylococcus aureus*; also known as golden staph; is resistant to most antibiotics
mucous a thick fluid produced by various tissues in the body
mucous membrane the lining of body cavities that open to the outside, such as the airways and digestive tract
mutation a mistake that occurs in DNA that can be passed on to the next generation and that may cause harmful, harmless or beneficial change in the phenotype
myelin sheath a fatty insulating cover over the axon of certain neurons

nasal cavity the respiratory passage between the nostrils and the pharynx
natural acquired immunity immunity produced when a person is exposed to a pathogen naturally (not intentionally, as in vaccination)
negative feedback the sequence of responses of the body that results in changing the stimulus
nephron the functional unit of the kidney; there are about a million in each kidney
nerve a bundles of nerve fibres
nerve impulse an action potential, a message transmitted by the movement of ions
nervous system the system of brain, spinal cord and nerves that communicates with body cells and controls (regulates) what happens in the body by means of impulses; enables humans to interact with the external environment and to think, learn and remember
neuron (or neurone) scientific name for a nerve cell
neurotransmitter a chemical 'messenger' that enables nerve impulses to be transmitted across the gap from one neuron to the next
neutrophil the most numerous type of white blood cell whose job is to phagocytise pathogens
nitrogen cycle the recycling of nitrogen through the environment
nitrogen fixation a major component of the nitrogen cycle; the process of converting nitrogen gas to nitrates
nocturnal active only at night
non-disjunction an error in cell division in which the chromatids do not separate properly
noradrenalin a hormone with similar effects to adrenalin, also produced in the adrenal cortex
nucleic acid a polymer of nucleotides, e.g. DNA or RNA
nucleotide a monomer in a nucleic acid, consisting of a phosphate, a sugar and a base
nucleus (plural: nuclei) the part of the cell that contains the cellular DNA

oestrogen the hormone released by the ovaries; it controls puberty and the menstrual cycle in females; stimulates production of luteinising hormone and suppresses the production of follicle-stimulating hormone in the pituitary gland
offspring the immediate descendants of an organism
omnivore an organism that eats both plants and animals
order a taxonomic group that includes one or more families (e.g. 'carnivores' is an order within the class of mammals)
organ a group of tissues that performs a specific function or group of functions
organ printing a technology that aims to create living replacement organs
organelle a specialised subunit in a cell, with a specific function
osmosis a special case of diffusion by water through a semipermeable membrane
ovary the organ in which the female's ova are stored
oviduct (fallopian tube) the tube down which an ovum travels towards the uterus after it is released from a follicle
ovulation the release of an ovum from an ovary
ovum (plural: ova) an egg or female gamete

palaeontologist a scientist who studies fossils
pandemic an epidemic that occurs in multiple parts of the world
parasite an organism that lives on or in another living organism for part of its life cycle
parasympathetic nervous system the part of the nervous system not under conscious control, that counters the effects of the 'fight or flight' response
parenchyma a type of ground tissue in plants, composed of thin-walled cells that are able to divide
parental (P) generation parents
patent the exclusive right of an inventor or discoverer to their invention or discovery
paternal chromosome a chromosome inherited from the father
pathogen a disease-causing organism, such as a virus, bacterium or fungus
pathogenic disease causing
pedigree a chart that shows relationships in a family over several generations; usually used to track the occurrence of a genetic disorder
perennial a plant with a life cycle lasting more than 2 years
period bleeding during the menstrual cycle; scientifically known as menstruation
peripheral nervous system the set of nerves that reach out from the spinal cord to the rest of the body
phagocytosis the process by which an invading pathogen is destroyed by a macrophage
pharmacopoeia a list of treatments for restoring people's health
phenotype a characteristic (trait), such as ability to roll the tongue or free ear lobes
pheromone a chemical signal that triggers a natural response in a member of the same species
phloem the tissues of a plant that transport sugars
phosphorus cycle the recycling of phosphorus through the environment
photosynthesis the chemical reaction in which plants convert light energy into usable chemical energy

phylum (plural: phyla) a taxonomic group that includes one or more classes

pituitary gland a gland associated with the hypothalamus, regarded as the master gland of the endocrine system because of the numbers of hormones it releases that regulate growth and metabolism

placenta an organ that provides the embryo with nutrients and oxygen and removes wastes; is attached to the wall of the uterus and is connected to the mother's blood supply

plant growth substance a chemical that regulates plant growth; also called a plant hormone

pollen the male gamete produced by flowering plants

pollen tube a tube that grows from a pollen grain down into the stigma towards the ovary; once it penetrates an ovule, it releases its contents near an egg, and then disintegrates

pollination the transfer of pollen from a stamen to a carpel, (which may lead to the fertilisation of the plant's eggs)

polymer a large molecule made by covalently linking smaller units together

polynucleotide a polymer of nucleotides, e.g. DNA or RNA

positive feedback when a response acts as a further stimulus

precipitation the falling of water to Earth's surface as rain, hail or snow

premature when an offspring is born before the natural gestation period has been completed

primary structure the amino acid sequence of a protein

prion a type of protein that can fold in multiple ways and cause plaques and is associated with neurological disease

producer an autotrophic organism in a food chain

progesterone the female hormone released by the ovaries; it works with oestrogen to continue the thickening of the endometrium

prognosis the probable course of a disease and the chances of recovery in an individual

prophase a stage of cell division in which the chromosomes first become visible

prostate gland a gland surrounding the bladder and urethra in the male; it adds fluid to semen

prosthesis a device that replaces a body part, usually a limb

protein a polymer of amino acids

protists a kingdom of free-living single-celled or colonial organisms

protozoan a single-celled eukaryote

puberty the stage of adolescence in which an individual becomes physiologically capable of sexual reproduction

Punnett square a table that shows or predicts all possible allele combinations for a particular trait in a cross of parents whose genes are known

pure breeding when offspring in every generation are the same for that trait

pyramid of numbers a way of representing organisms in food chains that takes into account the size of individuals

random assortment the random allocation of maternal and paternal chromosomes to daughter cells at the end of the first meiotic division

range the distance between highest and lowest values

receptor a protein gateway in the surface of a dendrite terminal to which neurotransmitters bind

recessive (gene) a gene that is overridden by a dominant gene for the same characteristic; usually symbolised by a lower case letter

recombinant DNA technology technology that enables genetic engineers to cut, paste, purify, amplify and manipulate DNA from one or more sources

reflex an automatic response to a stimulus

reflex arc the pathway of nerve cells involved in a reflex action

regeneration the regrowth or replacement of tissue of a lost or damaged organ or part

repetition when one or more base pairs is repeated and added to a DNA sequence

reproductive capacity the potential to replace the numbers of organisms in the current generation; in all species it far exceeds the two parents involved in creating offspring

respiration the cellular process of obtaining energy from organic compounds; aerobic respiration uses oxygen

restriction enzyme an enzyme that cuts double- or single-stranded DNA at a specific sequence of nucleotides

ribosome a cell organelle involved in protein synthesis

schlerenchyma a type of ground tissue in plants, composed of very thick walled cells that have died, but continue to support and protect the plant

Schwann cell a specialised cell that rolls around a nerve axon forming a 'sheath'

scrotum a sac-like organ that contains the testes; hangs outside the male body not in kangaroos, it is above the penis

seafloor spreading the process in which tectonic plates are moving apart; magma moves up in the gap between the plates on the seafloor and solidifies, adding to the size of the plates
sediment a particle formed from the weathering of rocks; sediments are carried along by wind and water and form deposits in a depression
sedimentary basin a depression in which sedimentary rock has formed
sedimentary rock rock that forms as a result of particles produced by the physical and chemical breakdown (weathering) of rocks that already exist
seismic wave a vibration that travels outwards through rocks and other materials in its path when massive blocks of rock suddenly snap apart
self-pollination pollination that occurs between flowers or in a single flower on the one plant
semen the mixture of sperm and fluid that is ejaculated by a male
semimolten a very viscous (flows very slowly) state between solid and liquid
seminal vesicles a pair of glands that secrete seminal fluid to nourish and help the movement of sperm through the urethra
seminiferous tubules the thin tubes inside the testes in which sperm are produced
semipermeable selectively permeable; only allows some molecules through
sensory neuron a neuron that carries messages from the body to the central nervous system
sensory receptor a part of a highly specialised nerve cell that is capable of detecting and relaying information
sessile not free-moving, permanently attached, e.g. a barnacle
sex cells haploid cells, gametes
sexual intercourse when a male places his penis inside a female's vagina
sexual reproduction the process by which two organisms produce an offspring that receives half its DNA from each parent
sexually transmitted diseases (STDs) infectious diseases that are spread through sexual contact
sexually transmitted infections (STIs) infections that are spread through sexual contact and could lead to disease
sister chromatids two identical chromosomes present in a duplicated chromosome that are joined together by a centromere
sister chromosomes two genetically identical chromosomes that arise from either the maternal or paternal homologue, in mitosis
solute the part of a solution that is dissolved in the liquid (solvent)
somatic (cells) normal body cells
somatic nervous system the part of the nervous system that controls conscious movements
spawn the release of eggs of aquatic animals such as fish and amphibians
sperm a male gamete
spermatogenesis the process of producing sperm
spermicide a chemical that kills sperm
spinal cord the main information pathway between the brain and the rest of the body. It is housed inside the bones of the spinal column
spindle fibres protein fibres within the cytoplasm that control chromosome movement
spreading centre the plate boundary at which seafloor spreading occurs
stamen the male part of the flower; consists of an anther and a filament
sterile free from living organisms, including microbes
stimulus anything that activates a sensory cell in the nervous system or causes a response in the endocrine system
stomata (singular: stomate) microscopic pores mainly on the under surface of a leaf through which gas exchange occurs
strata layers of rock
stratified formed in layers
subduction the process in which one tectonic plate is slowly pushed beneath another
subduction zone plate boundary at which subduction occurs
sugar–phosphate backbone the 'struts' of the DNA ladder (if it is imagined unwound)
superkingdom (or super domain) a classification system dating from 1990 that divides all living organisms into three main groups – Archaea, Bacteria (formerly grouped together as the kingdom Prokaryotes) and Eukaryotes
symbiosis a close relationship between different species for mutual benefit
symbiotic a physically close and mutually beneficial relationship between two organisms
sympathetic nervous system the part of the nervous system not under conscious control, that stimulates the 'fight or flight' response
synapse the point of virtual contact between the axon of one neuron and the dendrite of another
synaptic process a set of events at a synapse in which neurotransmitters are released from the terminal of an axon and migrate to receptors on the terminal of the dendrite, enabling an impulse to be generated in the dendrite
syncline a downward fold of rock, forming a 'valley'; formed when pressure is placed on ductile (not brittle) rocks
system a group of organs that serve a common function

T cell a specialised white blood cell that destroys pathogens and matures in the thymus; can be either a null-killer or a helper
target cell a cell that will only respond to the presence of a particular hormone
taxonomy the branch of science involved with identifying, describing, grouping and naming organisms
tectonic plate a section of the Earth's crust
telophase the fourth phase of a cell division, just before cytokinesis
template strand the strand on the gene that is transcribed to mRNA
terrestrial environment a land-based environment
testes (singular: testis) the organs in a male in which sperm are produced
testosterone the male hormone that causes the development of the penis and other male characteristics in the foetus
theory of evolution the proposal that all forms of life have evolved over a long period of time from a common ancestor; they differ because over a long period of time they have adapted to the environments they moved to and to changes within their environment
theory of natural selection the proposal that many more offspring of a species are born than can survive and reproduce. This means there will be intense competition between them; those that have more favourable variations are more likely to survive in the particular environmental conditions to which the organism is exposed
theory of spontaneous generation the proposal that all creatures were specially and spontaneously created out of non-living materials
thymine (abbreviation T) one of the bases in DNA; replaced by uracil in RNA
tissue an organised group of similar cells, working together
torpor a state through hibernation in which the metabolic rate of an organism is lowered in order to reduce its energy consumption
toxin a poisonous substance
trachea the part of the respiratory system between the larynx and the bronchi
trait a characteristic, or feature, of an organism
transcription the process of copying coded information from the DNA molecule to mRNA
transfer RNA (tRNA) a molecule that transfers amino acids to mRNA in the cytoplasm; one end of the molecule has an anticodon on the ribosome, which recognises the codon on the mRNA; each codon has its own tRNA
transgenic an organism that contains foreign genetic material
translate when something is changed from one language to another, e.g. when the mRNA nucleotide sequence is translated to an amino acid sequence
translation the production of a peptide or a protein from mRNA
translocation the movement of sugars in phloem tissue, driven by a concentration gradient
transpiration loss of water vapour from a plant via the stomata in the leaf
transposition when a section of the genome (or even an entire gene) is removed and inserted in a random place
trimester a 3-month stage within a human pregnancy
triplet a series of three nucleotide bases that form the genetic code
trisomy a condition in which three copies of a particular chromosome are present in a diploid cell
trophic level the position of an organism in a food chain, food pyramid or food web
tropism a movement (positive or negative) in response to a stimulus, e.g. heliotropism involves the Sun, thigmotropism involves touch, or contact
tsunami a giant wave caused by an earthquake

umbilical cord the cord that connects the embryo or foetus to the placenta; blood flows along it, carrying nutrients and oxygen to and wastes away from the foetus
uracil (abbreviation U) one of the bases in RNA; replaced by thymine in DNA
urea a waste product of protein metabolism, converted from reacting ammonia with carbon dioxide
urethra a channel that is used for the ejaculation of sperm as well as for the excretion of urine
uterus (womb) the mammalian organ in which offspring are conceived and develop before birth

vaccination the process by which a person is deliberately exposed to a pathogen with the aim of creating artificially acquired immunity
vaccine a preparation to make a person immune to disease
vacuole a membrane-bound organelle that is very noticeable in plant cells, where it helps cells keep turgid, pushing cytoplasm against cell walls
vas deferens the duct that carries sperm from the epididymis to the urethra
vascular system (plants) a transport system that consists of xylem and phloem
vector an organism that carries pathogens between hosts
vein a blood vessel that returns blood towards the heart (except the hepatic portal vein); have thin walls and valves

ventricle the part of the heart that pumps blood to the lungs (right ventricle) or the body (left ventricle)
villi (singular: villus) finger-like projections that increase surface area, particularly in the small intestine
virulent extremely harmful or deadly
virus an extremely small, non-cellular pathogen, consisting only of a nucleic acid (a fragment of DNA or RNA) surrounded by a protein coat

water cycle the recycling of water through the environment

X-ray high-energy radiation of wavelength 0.1–10 nanometres (10^{-9} m)
xylem tissue the vascular tissue of plants that transports water and minerals and provides structural support

zoonotic any infectious disease that is transmitted, directly or by a vector, from other animals
zygote the new cell that is produced when a sperm fertilises an ovum

Index

A

B

C

D

E

F

G

H

I

K

L

M

N

U

V

W

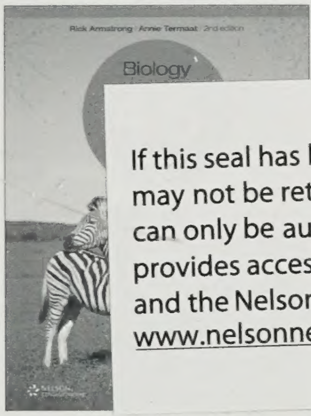
X

Y

Z

nelsonnet

1 access code



If this seal has been broke
may not be returned. Eacl
can only be authenticatec
provides access to the Nel
and the NelsonNetBook. V
www.nelsonnet.com.au – c

Student Access Code Card

Hannah Korn

nelsonnet

Register online at:
www.nelsonnet.com.au
to access digital resources to support improved learning & teaching*

Biology 4/5 for the international student has been developed for the world student. This six book series has been written by an experienced international author team and will benefit students studying the International Baccalaureate MYP Next Chapter. The series has been carefully crafted to ensure students develop a global view of science.

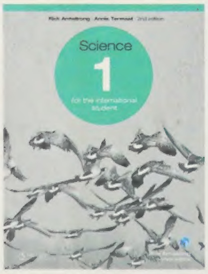
Biology 4/5 for the international student presents eight biology units. The key concept, related concepts, global context and statement of inquiry are identified at the beginning of each unit.

Each unit features:

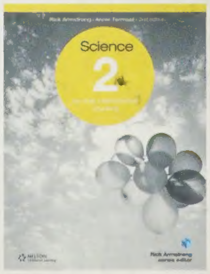
- content ensuring progression to the IB Diploma programme
- clear, well-explained text
- flexibility that allows schools to develop a programme suitable for their needs
- summative assessment task identified
- student reflection built into each unit
- progressive development of scientific inquiry through experiments and investigations addressing Criteria B and C
- icons indicating the development of Approaches To Learning and Taking Action
- Review question sets throughout each unit
- highlighted new terms and full glossary
- hands-on learning activities suitable for class or home
- end-of-unit review questions incorporating a range of question types suitable for assessment of Criterion A

Each course book comes with a code to access the electronic version of the book. Go to www.nelsonnet.com.au to create your account.

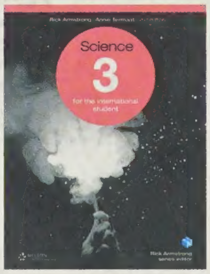
This book is supported by a Teacher NelsonNet website.*



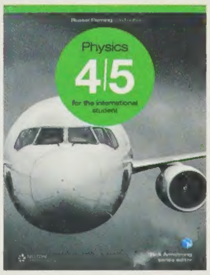
Science 1
Student book
9780170353403



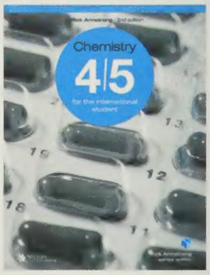
Science 2
Student book
9780170353472



Science 3
Student book
9780170353540



Physics 4/5
Student book
9780170353335



Chemistry 4/5
Student book
9780170353267

ISBN: 978-0170353199
9 780170 353199

NELSON
CENGAGE Learning
For learning solutions, visit **cengage.com.au**

* Please note that complimentary access to NelsonNet and the NelsonNetBook is only available to teachers who use the accompanying student textbook as a core educational resource in their classroom. Contact your sales representative for information about access codes and conditions.