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FOR QUEENSLAND

AN AUSTRALIAN PERSPECTIVE

UNITS
1 & 2

LORRAINE HUXLEY
MARGARET WALTER

SERIES CONSULTANT
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UNIVERSITY PRESS
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Published in Australia by
Oxford University Press

Level 8, 737 Bourke Street, Docklands, Victoria 3008, Australia.
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First published 1998.

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Edited by Joy Window
Typeset by Newgen KnowledgeWorks Pvt. Ltd., Chennai, India
Proofread by Jane Fitzpatrick
Indexed by Max McMaster
Printed by Sheck Wah Tong Printing Press Ltd

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Each unit begins with a unit opener that includes:

- an **overview of Topics** in the Unit
- **Unit objectives** from the syllabus.

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Each chapter begins with a chapter opener that includes course objectives from the syllabus.

Practicals
A list of mandatory and suggested practicals within the chapter that allow students to apply their knowledge to real-life activities.

Practical links
Direct links to mandatory and suggested practicals.

Key ideas
A set of clear learning objectives from the syllabus prepare students for what they will study in every section.

Science as a human endeavour
Promotes interest in topics for research investigations.

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Content is presented in clearly structured **sections**. Each section is clearly labelled and numbered to help navigation.

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Practical advice to help students improve their performance in assessment tasks.

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Check your learning
Activity boxes with questions and tasks organised using cognitive verbs according to Marzano and Kendall's taxonomy.

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Each chapter contains a range of practical activities to reinforce theoretical aspects of the syllabus. Each mandatory practical and manipulative skill from the syllabus is included in the practical manual. Suggested practicals are included via the obook assess.

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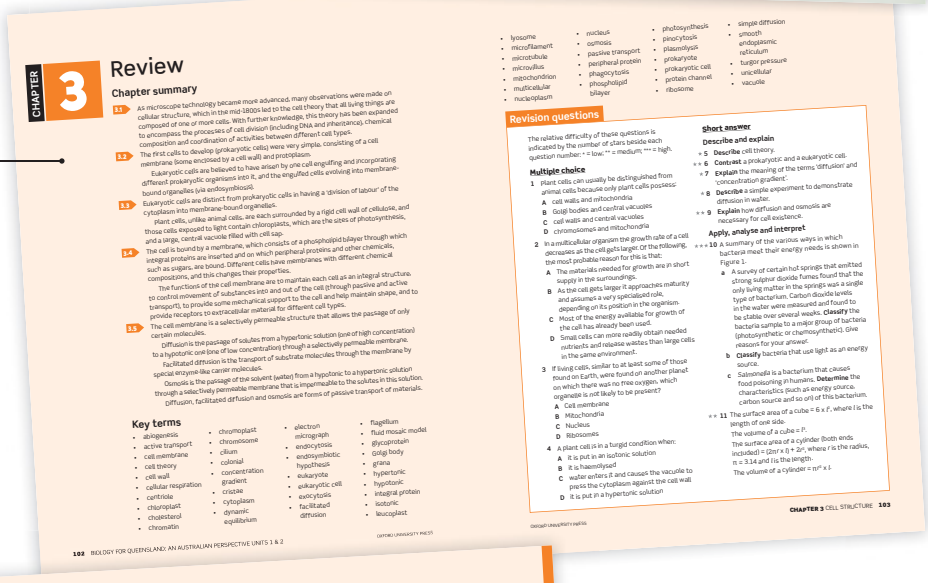

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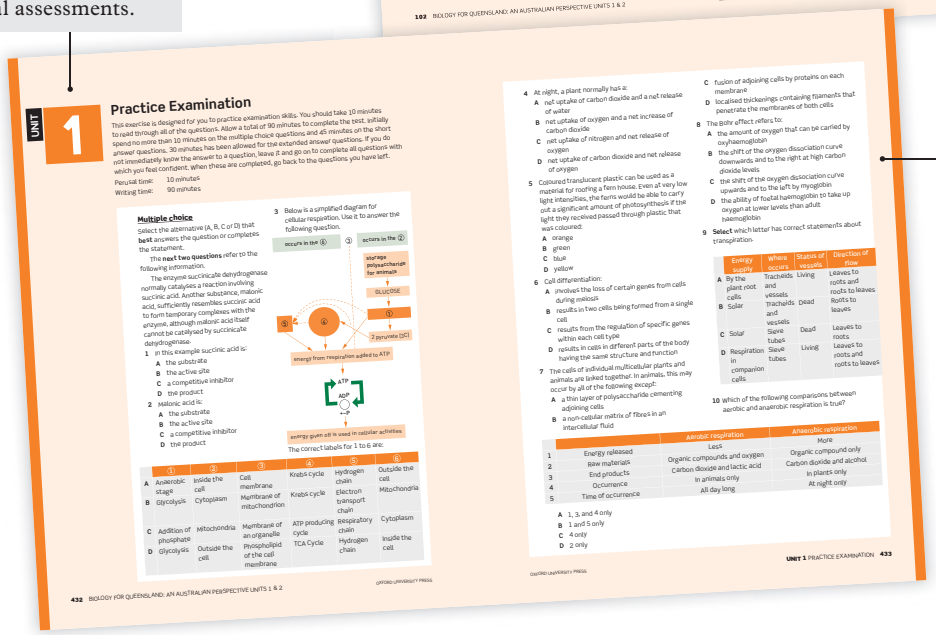
Questions can be found at the back of the book to help prepare students for their end-of-year external assessments.



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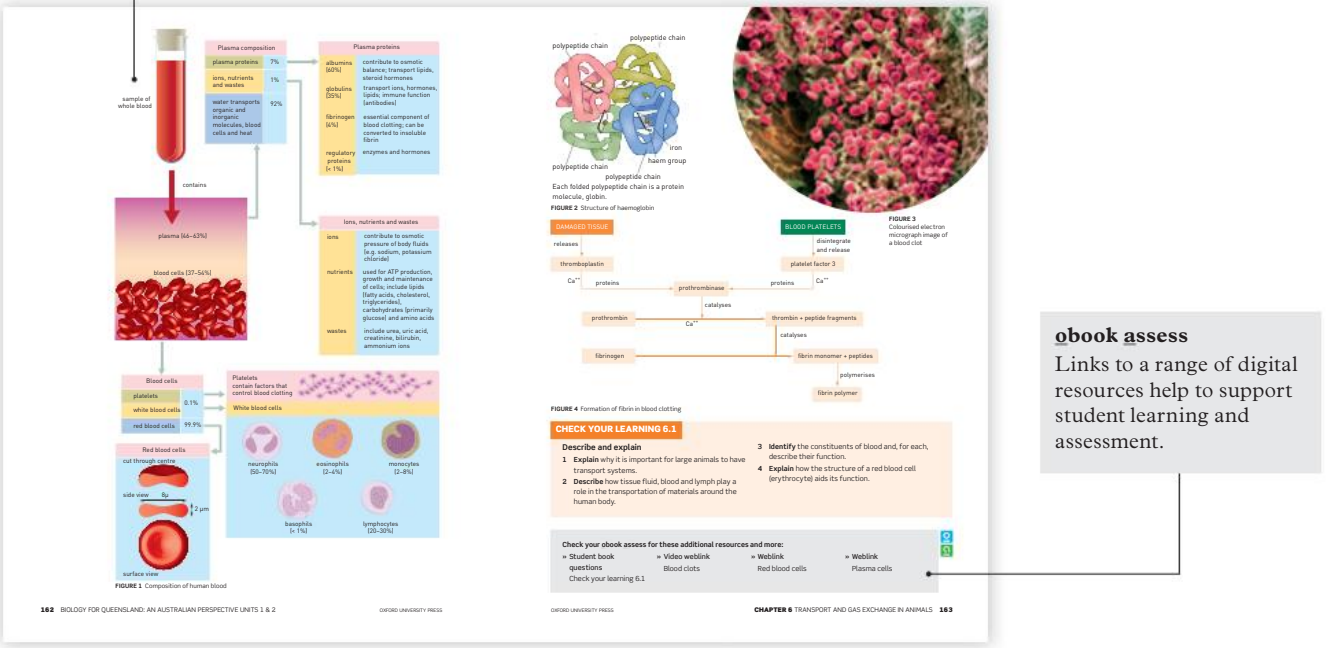

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Links to a range of digital resources help to support student learning and assessment.

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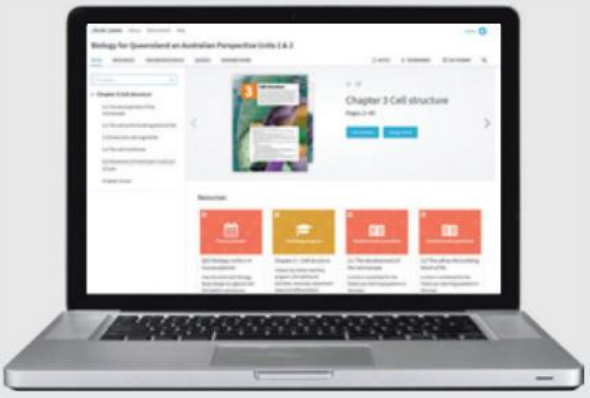

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- interactive auto-correcting multiple-choice quizzes
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- access to work assigned by their teacher: reading, homework, tests, assignments.

In addition to the student resources, teachers also receive:

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- Student book answers
- printable (and editable) sample assessments, including data tests and exams with answers
- the ability to set up classes, set assignments, monitor progress and graph results, and to view all available content and resources in one place.

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CHAPTER 1

Biology toolkit

Biology is a science which seeks to make sense of the diversity of life forms found on planet Earth – the types of organisms that exist, where they come from, and how they interact with other organisms and their non-living environment. Explanations of observations of biological processes are validated in controlled experiments. This process is called the scientific method.

In order to develop and apply biological concepts, students must first understand and then learn the course content. Study programs must take individual learning styles into account for this to be effective. Understanding and knowledge of the course content are essential components of all assessments – examinations, research reports and experimental investigations.

This chapter contains a toolkit of ideas and skills to refer to throughout Units 1 and 2 of senior biological science.

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FIGURE 1 A microscope is a laboratory tool used for closeup investigations of subjects

1.1 Biology and its branches of study

KEY IDEAS

- The different areas of biological study
- The concepts of adaptation and evolution
- The need for integration of all areas of biological research to develop a true understanding of the living world

biology
the study of life and living organisms

adaptation
a feature of an organism that enhances its ability to survive and reproduce in a particular environment

evolution
the change in organisms over time due to natural selection, resulting in changes in the gene pool of a population

Biology is the study of living organisms. Biologists are concerned with the types of organisms that occur on Earth and how they operate individually, in interactions with other organisms and with their non-living environment. Biology is such a vast field of study (see Figure 1) that individual researchers tend to specialise in only a small aspect. Further specialisation occurs within each of these broad branches.

Studying any one of these broad aspects of biology gives some knowledge of living organisms. However, a true understanding of our living world cannot be gained by simply adding up all of the known bits. For example, a biologist can cut open a body and find out the position of all of the organs and the way they are physically connected to each other, but cannot tell how they actually operate in the living organism. All parts of an organism are in dynamic relationships with each other. Each organism reacts with others around it (of both the same and different kinds), and with the non-living environment. A slight change in any one of these factors may have dramatic effects on the organism as a whole.

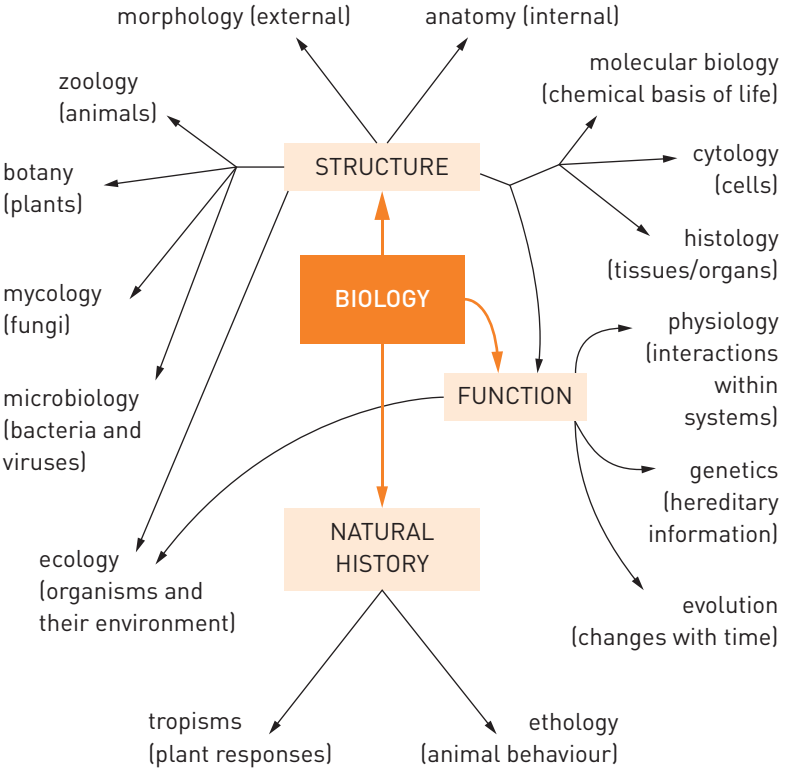


FIGURE 1 Major branches in the study of biology

Perhaps the one overriding concept of biology is survival – both of the individual and of the species. For this reason, organisms are adapted to their environment. Their structure, physiology and behaviour allow them to live successfully in a particular place. The structure of an organism is closely related to the functions it performs. **Adaptation** is not something that an organism consciously brings about. As much as a person might think another pair of hands to complete chores is needed, wishing them into existence simply does not happen! Adaptation, and thus survival, is linked with evolution. **Evolution** is the process whereby, through changes in genetic make-up over time, alterations to structure and function within groups of a particular organism come about, ultimately leading to new types of organisms. Case study 1.1 illustrates how various specialist studies can lead to a better understanding of an organism.

CASE STUDY 1.1

An Australian species – the feathertail glider

The feathertail glider, *Acrobates pygmaeus* (from *acro* = dancer, *bates* = of the summits and *pygmaeus* = pygmy), is the tiniest of the Australian marsupial gliders.

Structure

Gliders have a membrane which extends from the elbow to the ankle of each forelimb. The membranes are designed to catch an airstream, but can function only when there is an adequate air speed or when gravity causes the glider to parachute down in an almost vertical path. The animal climbs a tree to gain height and then jumps. It falls steeply down until its air speed is great enough for it to sail off in a curved path. The glider's long tail stretches out behind it and serves as a rudder to direct its flight. This type of locomotion allows gliders to move quickly from location to location to escape from predators and to increase their foraging (food-seeking) area. Since their forelimbs are not greatly specialised, they are still useful for climbing and manipulating food.

The feathertail glider is very small, measuring about 15 cm from its nose to the tip of its tail. The tail fur is arranged in two flat fringes along either side like a feather. These hairs are stiff, but the rest of its fur is soft and silky, silvery brown on the upper surface and paler underneath. It has long whiskers which are thought to help in finding its way through tiny cracks and crevices in the bark of trees in search of insects. The tail can be used to hang from branches. The toes have large, finely serrated pads which allow the animal to cling to smooth surfaces. The first toe of all four feet is large and grasping, like a thumb.

Distribution

The feathertail glider is found in forests of tall, well-watered eucalypts along the east coast of Australia and across the south-east to the border of South Australia (where it extends into the drier regions of woodland). Although it is tree-dwelling (arboreal), it also forages through thick shrub layers such as lantana. The feathertail glider feeds on nectar, small insects found on the trunks, foliage and blossoms of trees, and manna (a sugary plant sap exuded from breaks in the bark made by larger marsupials as they climb or pull away at it to feed on insects hidden beneath).

Evolutionary relationships

Researchers believe that the feathertail glider is a specialised form of pygmy possum, a very agile species found in treetops. In Papua New Guinea, there is at least one species of feathertailed pygmy possum which, apart from lacking the gliding membrane, is almost an exact copy of the feathertail glider. It is thought that this species could represent an intermediate form in the evolution of the gliding form. Pygmy possums are believed to resemble the ancestors from which all the possum family evolved. The early tree-climbing marsupials were known to be insectivorous (insect-eating), and the feathertail glider retains their characteristic arrangement of small, sharp teeth.

Behaviour and physiology

The feathertail glider is normally active at night throughout the year. It has a wide range of predators and therefore takes alarm at the slightest disturbance, often leaping so hurriedly that it may glide to the ground. There it may 'freeze' for several minutes

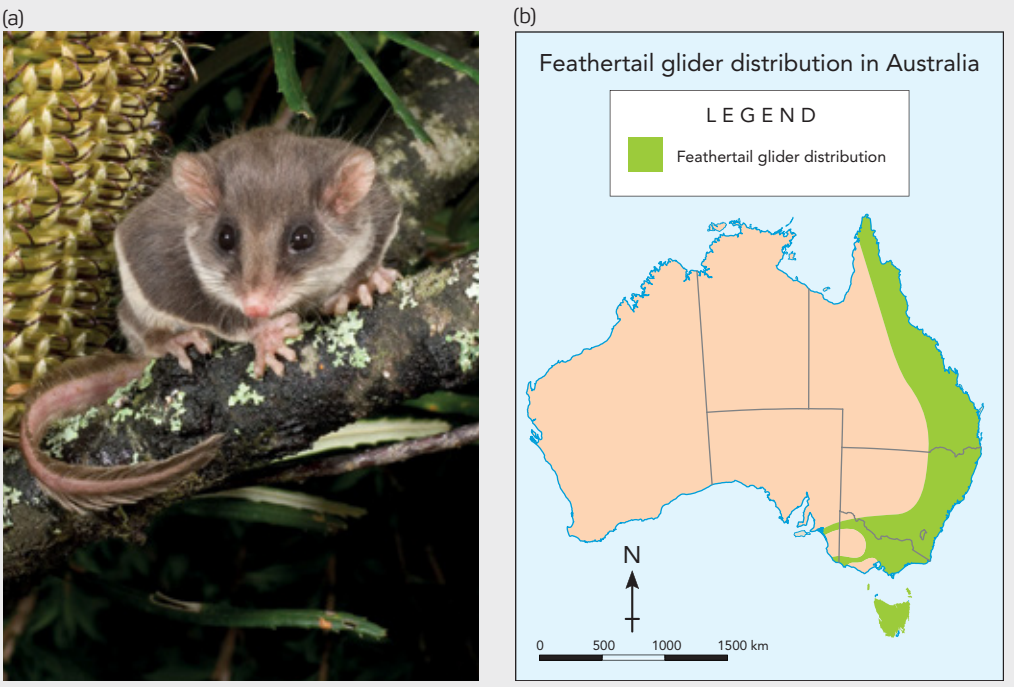


FIGURE 2 Feathertail glider (a) and its distribution (b)

(inactivity is a good way of not being seen) or take off in a leaping scamper for the nearest tree. During very cold weather these animals may become torpid (torpor = a state of inactivity) for up to 48 hours. In this state, they lower their body temperature by slowing down all body actions (blood flow and chemical reactions). This reduces their food requirements over that short period. Since feathertail gliders cannot store food, which is necessary for true hibernation, they must wake up at intervals to feed.

Feathertail gliders build round, communal nests that contain up to 16 individuals. Nests may be found in hollow trees, in old nests of other animals or in the plastic bags used to cover bunches of bananas. The whole nest is about the size of an orange. Breeding occurs throughout most of the year in the northern part of the range, but only in late winter, spring and summer in the southern areas. The female has four teats, but seldom carries more than three young, which are minute (only a few millimetres long) when born. The young then complete their development in the pouch, obtaining nourishment from milk secreted by the teats. The female can become pregnant while carrying pouched young, so litters may be reared in quick succession.

zoology
the study of animals

taxonomy
the science of classifying things

ecology
the study of the relationships between organisms and their environment

morphology
the study of external features of an organism

ethology
the study of animal behaviour under natural conditions

physiology
the study of the way in which organs and systems operate within an organism

Overview

This account is derived from several aspects in the study of biology. As an animal, the feathertail glider comes under the study of **zoology**. It has been classified with a species name to distinguish this type of animal from all others (**taxonomy**). The study of the feathertail glider's distribution and feeding relationships is part of **ecology**. Description of its external features is **morphology**. Studies of patterns of its movement, relationships with other members of its species and reactions to predators belong to **ethology** (behaviour). Studies of its reproduction and reaction to temperature are part of **physiology**. The relationships between this glider and other possums, such as the pygmy possum, are investigated in the study of evolution.

CHECK YOUR LEARNING 1.1

Describe and explain

1 **Define** the term 'marsupial'.

2 Using the paragraph letters, **identify** the following areas of biology in the account above:
   - **i** anatomy
   - **ii** ecology
   - **iii** ethology
   - **iv** morphology
   - **v** physiology.

Apply, analyse and interpret

3 **Analyse** the following accounts carefully. The paragraphs are lettered to help you answer the questions at the end.

A The red kangaroo is the largest living marsupial. It is widely distributed across inland Australia, being found in most open habitats with an annual rainfall of less than 375 mm.

B A fully grown male red kangaroo is nearly 2 m high when sitting fully upright on its large, powerful hind legs and thick, muscular tail. The thick, woolly body fur is generally a rich reddish brown with paler fur on the chest, belly and tip of the tail. Mature males weigh about 80 kg. There are conspicuous white marks on either side of the muzzle, slashed through with a black line. Females are usually blueish-grey in colour and seldom weigh more than 30 kg.

C Red kangaroos are mainly nocturnal, spending their days under shady trees (when available) and moving out in the open at night to find food (grass) and water.

D When moving slowly or feeding, the red kangaroo proceeds in a kind of crawl on all fours, using its tail as a prop. When moving at speed, the animal adopts the characteristic springy bound. A kangaroo uses less oxygen, weight for weight, than a running animal with an orthodox gait. This is in part due to the storage of energy on each bound by tensioning of the great hamstring tendons on the hind legs.

E Red kangaroos show adaptations which are linked to the fall of rain. In good seasons the red kangaroo reaches sexual maturity at between 18 and 24 months old. At any one time the female can have a large joey at heel still suckling, a smaller pouch joey and a dormant, very early embryo in reserve. The composition of the mother's milk changes with the age of the joey. When she is feeding young of two different ages, the composition of milk secreted by each nipple is different, to accommodate each joey's requirements. In drought, within the first 6–10 weeks many of the pouch young die, and after 5 months most females stop breeding totally. With the onset of rain, the females immediately resume reproduction.

F Red kangaroos can maintain body temperature at a tolerable level of 37.5°C for several hours in an air temperature of up to 44°C and average humidity, if water is available. By panting rapidly, like a dog, the red kangaroo gets rid of excess heat by evaporation of water from the lungs. Evaporative heat loss is also achieved by licking the forelimbs. (Evaporative heat loss is the removal of heat from the body by the conversion of water to vapour.) Water in the fresh green grass (their feeding preference) replaces that lost by evaporative cooling. Body water loss can be reduced by the production of very concentrated urine.

G Groups of red kangaroos from half a dozen up to a thousand can be found. Such groups are in a constant state of flux, with kangaroos almost continually joining and leaving the group. The only true social behaviour is the continued association of the offspring with the mother for a period after weaning.

Identify three adaptations of the red kangaroo to arid and semi-arid conditions.

Check your obook assess for these additional resources and more:

- **» Student book questions**
  Check your learning 1.1
- **» Video**
  Ask a scientist – Dr Misty Jenkins
- **» Video worksheet**
  Ask a scientist
- **» Weblink**
  QCAA Biology syllabus

1.2 The scientific method

KEY IDEAS

- The steps in the scientific method
- Distinguishing features of qualitative and quantitative data
- Developing hypotheses, including null and ruling hypotheses
- Types of variables
- The importance of control groups
- Developing theories and making predictions

scientific method the testing of hypotheses by controlled experimentation

data quantitative or qualitative information; facts and statistics

qualitative descriptive

quantitative measured

fact information which has been verified by observation or experimentation

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

The leaf is green.

which lead to questions:

Why is the leaf green?

and seeking answers.

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

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

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

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

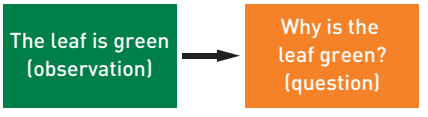


FIGURE 1 Observations lead to questions.

FIGURE 2 The golden orb spider and dewdrop spider (circled) share the same web in the illustration at left. The male and female golden orb spiders are shown in the photograph at right.

TABLE 1 Types of data

Data	Definition	Example
Quantitative	Numerical data that are measured	Leaf length
Qualitative	Description of a characteristic	Leaf colour
Objective	Measured according to an identified criterion	Leaf colour using defined special charts, reproducible by others
Subjective	Based on a researcher's opinion	Leaf colour on researcher's judgement

Questions and hypotheses

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

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

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

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

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

This detailed hypothesis:

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

Note that the hypothesis given was written in the negative – the introduced spiders will not be eaten by the golden orb spiders. A hypothesis written in this form is termed a **null hypothesis**. Scientists use this form because it is easier to provide evidence that something will not occur than to provide evidence that the hypothesis will always be correct in these conditions.

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

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

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

null hypothesis
a hypothesis written in the negative form

ruling hypothesis
the most successful hypothesis of a particular investigation

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

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

experimental variable (independent variable)
the single factor under investigation in a controlled experiment

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

dependent variable
a variable whose value is dependent on another variable

extraneous variable
some factor in an experiment which was unaccounted for and thus was not controlled

repeatability
the ability to get the same measurement as in the original experiment when using the same method and equipment

reproducibility
the ability of an entire experiment or study to be duplicated

valid
describes an experiment which provides data that refers directly to the hypothesis

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

prediction
forecast of a future event based on similar known events

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

Variables

A variable is a quantity or quality that can be different at different times or places. Two variables are found in each experiment – the **independent variable** is deliberately changed by the researcher and the **dependent variable** is the property being measured (i.e. changes observed *depend* upon the deliberately altered condition of the experiment). Sometimes, however, changes may be due to outside influences not originally considered by the experimenter (**extraneous variables**). For instance, in testing the effects of nutrients on plant growth, the investigator may attempt to grow all of the plants at the incorrect temperature for the best growth of that species. If the experimenter has not taken this into account, an incorrect conclusion could be drawn. Care must therefore be taken to work out all possible extraneous variables.

Reliability

The experiment must be repeated many times to ensure that the results are not due to chance. This is particularly important when using living organisms in experiments, since some individuals may respond to the experimental variable on the basis of their individual characteristics rather than those of the species. Reliability is based on the concepts of repeatability and reproducibility. **Repeatability** refers to the ability of the same scientist to obtain the same results with the same equipment. **Reproducibility** is a measure of the ability of a different scientist being able to obtain the same results with different equipment.

Validity

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

Development of theories

Repetition of the sequence (observation – hypothesis – experiment), in a number of situations, gradually allows broad generalisations to be drawn. It is important, therefore, that scientists report the details of their experiments fully, so that others may repeat them and so validate their findings. Based on accumulated generalisations about an unknown, a **scientific law** is developed – a description of the supported observations made, but does not explain the causes of why or how they occur. On the basis of a law, **predictions** (or forecast) about an *unknown* can be made. A **scientific theory** provides an explanation for the observed, reproducible law. Theories in science are never considered absolute since further discoveries can lead to more accurate ways of observing, testing or interpreting information.

This account of the steps in the scientific method should not be taken as a rigid formula. Other factors do enter into scientific discoveries. Accident, the inference leap (an idea without absolute basis), prejudice and emotions all play a part in science and should not be overlooked. The fact remains, however, that science is a logical method of considering problems, following a pattern of reasoning characterised by observation, questions, formation of hypotheses, controlled experiments and prediction.

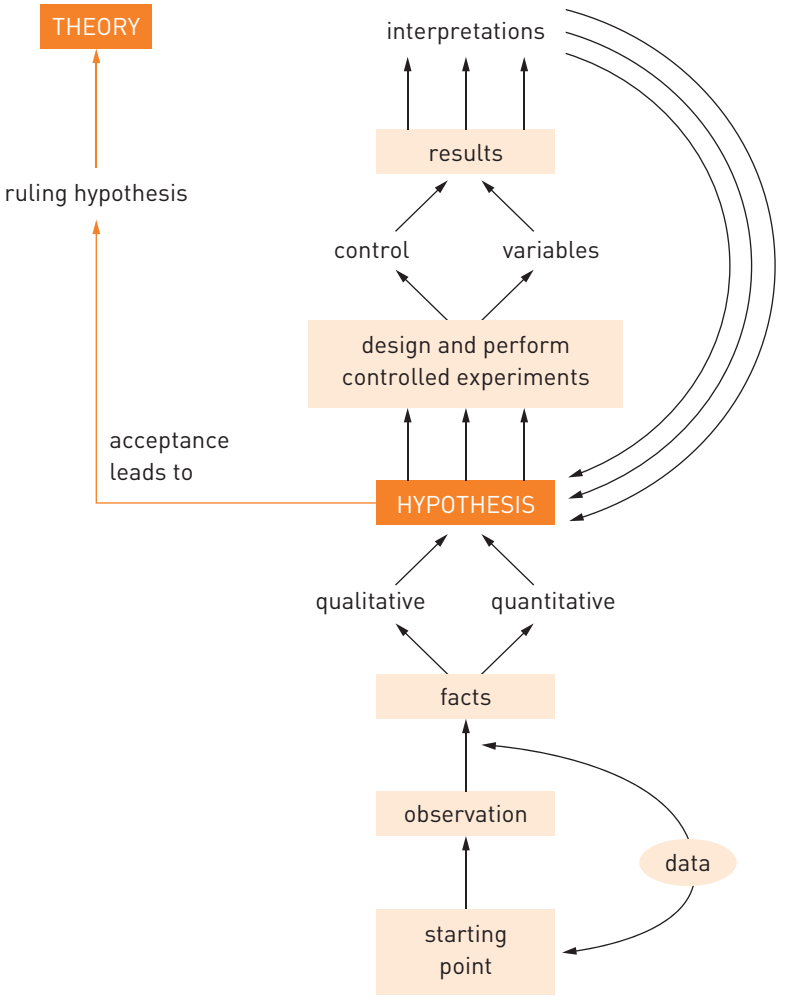


FIGURE 3 Steps of the scientific method

CHECK YOUR LEARNING 1.2

Describe and explain

1 **Explain** the difference between quantitative and qualitative data.
2 **Construct** a simple concept map that explains the scientific method.
3 **Explain** why scientists prefer not to use the word 'proof'.
4 **Describe** an extraneous variable. Explain how it can influence the outcome of an experiment.
5 **Describe** how scientists use the terms 'hypothesis', 'ruling hypothesis' and 'theory'.

Apply, analyse and interpret

6 **Contrast** the scientific method with other methods of explaining observations.

Investigate, evaluate and communicate

7 **Devise** an experiment to test a new dog food for 'dog appeal'.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 1.2

» Weblink
The Scientific Theory

» Weblink
Controlled experiments

» Weblink
Hypotheses

1.3 Student experiments

KEY IDEAS

- Bioethical approval required for animal (including human) experimentation
- Initial steps in a student experiment
- Determining the data to be collected and methods of collection
- Experimental design
- Presenting qualitative and quantitative data
- Measures of central tendency
- Graphical representation of data
- Writing an experimental report

The student experiment offers the opportunity to experience the development of new science knowledge based on existing knowledge built up during Units 1 and 2 Biology. It requires students to complete a range of tasks including developing a research question and hypothesis, designing an experiment, collecting and interpreting data, and writing a scientific report.

The use of animals and humans in student investigations

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

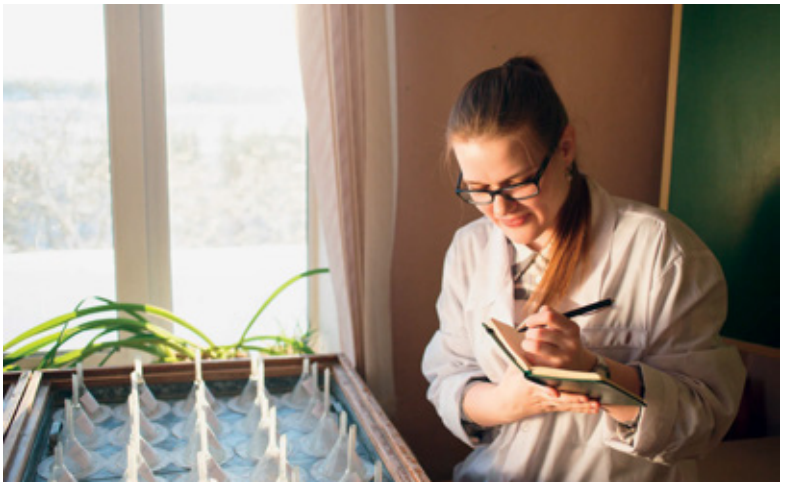


FIGURE 1 Logbooks are a useful tool for recording information that will later be crucial to writing the experimental report.

The use of a logbook

It is a highly recommended to keep a logbook (in either a physical book or as a digital file) for all stages of the experiment. It should include the following information: lists of ideas (with advantages and disadvantages); library and internet research (including full references); notes on the experimental process; possible means of collecting data; raw data or results; and possible interpretations of data.

All information, therefore, is in one place when it comes time to write the report.

Time management

It is important to note the due dates for the task, which may include progress reports, draft report and final date. Setting aside adequate time each week for each is critical to good results in each subject. Research has shown that evenly spaced effort of short durations during the week is better than a long time spent once a week.

Developing a research question and hypothesis

Student experiments are usually carried out over a limited time, for example four weeks. The type of question posed must therefore be succinct and provide rapid results that can be easily analysed in the time frame.

The research is usually restricted to the general area of study that is currently being undertaken – for example, cell function, physiology, ecology or genetics. It is best if the actual investigation is of personal interest. Some aspect of the course topic might instigate a desire for further exploration, or an observation might be cause for reflection. For example, as an athlete a person may notice that some of the squad members recover their normal heart rate more quickly after a hard training session than others. This may lead the student to question the factors that determine rapid recovery time.

This example has been chosen as an illustration only to show the steps required in a student experiment, as bioethical permission for this experiment would take a long time.

Gathering background information

Once the research question has been determined, library and internet research needs to be conducted to determine the types of investigations that have already been carried out in this area and their findings. It is important that such findings are both valid (the process of collecting data relates to the research question and the data supports the conclusion) and **reliable** (several independent investigations reach the same conclusion). This points to possible means of determining an answer to the question.

reliable
the degree to which an investigation produces stable and consistent results

Further ideas need to be explored in order to develop the hypothesis and method. Using the research question 'Does level of fitness determine recovery time after heavy exercise?', the following points could be considered:

- Will the experimental participants be of the same age group and gender?
- How is level of fitness to be determined? A sample of students from three different categories – minimal exercise (e.g. walking to and from class only); moderate exercise (approximately 2 hours per week); and high level of exercise (2 to 3 hours per day most days of the week) – might be selected.
- How many participants in each category will be tested? (Usually 25 participants in each category are considered to give reliable results.)
- What equipment is available to perform the experiment? An example is an exercise bike that can be set at a particular tension and shows speed so that each participant will cycle at that tension at a specified speed for a set time to ensure consistent effort.
- What is to be measured and how? The same Fitbit, for example, could be used on each participant to measure resting, maximum and recovery heart rates. In different types of investigations, the data collected may be qualitative (e.g. comparison of leaf colour when plants are treated with different nutrients) or observational, and may require descriptions, drawings or photographs.

- Will the conditions for measuring resting heart rate be the same for each participant initially and for recovery?
- Will the time of testing be the same for each participant? Could this influence the results?
- How will the raw data be recorded?
- How can the raw data be converted to provide meaningful results (graphs, tables, statistical tests, etc.)?

In this case the independent variable will be level of fitness and the dependent variable will be the time taken for resting heart rate to be restored.

Having decided on these points, the hypothesis can be developed – for example, 'The level of individual fitness does not influence the recovery heart rate of 20-year-old urban women after the same intensity and time of exercise.' Note that this has been written in the negative form since it is easier to disprove a hypothesis than to show that the independent variable is the only factor causing the results. It is a statement of the relationship between the independent and dependent variables under specified conditions and time frame.

Experimental design

The hypothesis determines the experimental design. This is because the experiment performed must yield results that relate to the hypothesis.

The experimental design must clearly state:

- the procedure for testing
- controls (factors that remain constant throughout the experiment)
- independent and dependent variables
- how measurement and recording of data is to occur.

Once the method has been established, **it is important to consider any safety measures that may apply**. An audit on all chemicals and equipment needs to be undertaken to ensure there are no hazards associated with the experiment. Decisions need to be made to avoid potentially dangerous situations or deal with them should they arise.

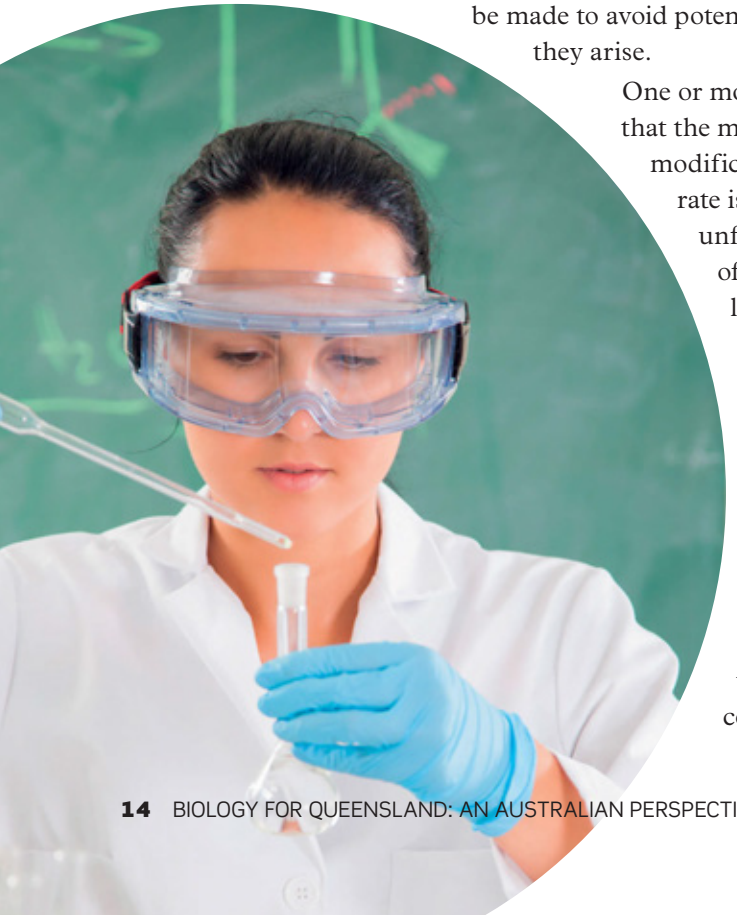


FIGURE 2 Students need to determine how they are going to test their hypothesis, as well as how they will control the experiment and record results.

One or more trials of the experiment should be performed to ensure that the method is providing the required data or, if not, what modifications are needed. In the given example where the heart rate is expected to rise with exercise, tests need to be made with unfit individuals to determine the strength and length of time of exercise so that the heart rate does not increase to an unsafe level. This then determines the maximum effort to be used by all test subjects.

Once the data have been collected, they must be analysed and presented so that they can be communicated to others.

Presentation and analysis of data

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

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

Quantitative data presentation consists of columns displaying the values of related variables, but they may not give an immediate or clear indication of the relationship between the variables. It is usually the first step in recording information and forms the basis for selecting the most appropriate graphical presentation. Various mathematical applications can be readily applied once the data are in tabular form. For example, 10 participants in the medium fitness group recorded the following times for heart rate to return to resting rate after exercise (see Table 1).

TABLE 1 Time taken for heart rate to return to resting level after exercise in participants of medium fitness

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

Measures of central tendency

Two sets of calculation – that of **central tendency** (how the data are clustered towards the central point of the dataset) and that of **variability** (how the scores are spread out) – are useful in analysing the effects of independent variables. Measures of central tendency include mean, median and mode:

- The **mean** is the average of all of the scores divided by the total number of scores.

  In the above example the addition of scores is:

  $6.4 + 5.2 + 1.5 + 2.1 + 4.2 + 7.5 + 2.4 + 2.6 + 2.4 + 3 = 37.3$

  The total number of scores is 10.

  Thus the mean recovery time is:

  $\frac{37.3}{10} = 3.7$ minutes
- The **median** is the score that occurs in the centre of the numbers when they are arranged from lowest to highest.

  For example: 1.5, 2.1, 2.4, 2.4, 2.6, 3.0, 4.2, 5.2, 6.4, 7.5

  Therefore, the median recovery time is half-way between 2.6 and 3:

  $\frac{2.6+3.0}{2} = 2.8$ minutes
- The **mode** is the most commonly occurring score. In this example, two of the scores are exactly the same (2.4 minutes – participants 7 and 9) and so the mode could be given as 2.4 minutes.

Since the mean, median and mode have quite different values in this example, the data suggest there is no central tendency. However, comparison of these calculations between the different groups of participants could yield some valuable conclusions and provide further questions of cause and effect if all groups show a similar spread of results.

Measures of variability

Measures of variability include variance and standard deviation.

Variance determines how much, on average, each score differs from the mean. Because some scores are higher than the mean (and have a positive difference) and some are lower than the mean (and have a negative difference), they will cancel out when calculating a 'mean difference'. By squaring the difference from the mean of each score, a **mean variance** can be determined (a negative value squared results in a positive value: $-A \times -A = +A^2$)

table
a display of information in named rows and/or columns

central tendency
the tendency for the values of a random variable to cluster around its mean, mode or median

variability
the extent to which data points in a data set diverge from the average, or mean, value as well as the extent to which these data points differ from each other

mean
the average of a set of arithmetic values

median
the value lying at the midpoint of a frequency distribution of observed values

mode
the value that occurs most often

variance
a measure of how far each value in the data set is from the mean

mean variance
the average of the sum of the squared differences of a set of values from the mean

The sum of the squared differences from the mean is 36.25 and since there are 10 scores the mean variance = 3.63 minutes.

TABLE 2 Calculation of variance for the median fitness group with a mean recovery time of 3.8 minutes

Recovery time (min)	Difference from mean	Squared difference from mean (variance)
6.4	+2.7	7.2
5.2	+1.5	2.25
1.5	−2.2	4.84
2.1	−1.6	2.56
4.2	+0.4	0.16
7.5	+3.8	14.44
2.4	−1.3	1.69
2.6	−1.1	1.21
2.4	−1.3	1.69
3.0	−0.7	0.49

$$\text{Mean variance} = \frac{\text{the sum of the squared differences from the mean}}{\text{quantity of numbers}}$$

$$= \frac{7.28 + 2.25 + 4.48 + 2.56 + 0.16 + 14.44 + 1.69 + 1.21 + 1.69 + 0.49}{10}$$

$$= \frac{36.25}{10}$$

$$= 3.63 \text{ minutes}$$

Since the recovery time is only recorded to one decimal place, then the answer should be expressed in the same number of decimals (3.6 minutes) so as not to give a false impression of higher accuracy.

standard deviation
a measure of the dispersion or variation in a distribution

The mean variance gives an indication of the spread of the data, but since it is a squared value, it is difficult to compare with the mean score. **Standard deviation**, however, determines how different the scores are from the mean. It is calculated from the square root of the mean variance. In this case the standard deviation is $\sqrt{3.6} = 1.9$. The closer the standard deviation is to zero, the less the data are spread (variability) and the more reliable they are (i.e. they are clustered around the mean). As the value of the standard deviation increases away from zero, the data become more variable and so less and less reliable.

graph
a diagram that exhibits a relationship between two sets of numbers as a set of points having coordinates

Graphical representations of data

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

1 the **horizontal *x*-axis** which carries values called **abscissae** which show the magnitude of the **independent** variable. This is the **known** quantity and is the variable whose value is chosen by the experimenter.

2 the **vertical *y*-axis** that carries values called **ordinates** that show the magnitude of the **dependent** variable. This is the '**unknown** quantity' and is the variable whose values are not chosen by the experimenter.

Graphing features

All scientific graphs have features in common:

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

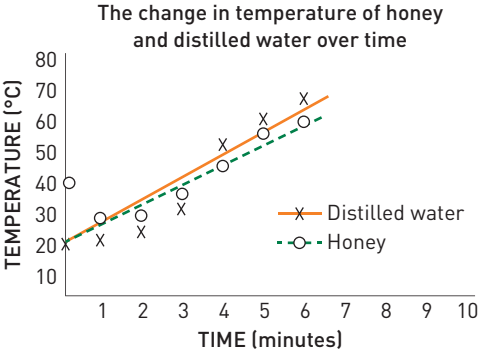


FIGURE 3 This graph demonstrates the key features of a scientific graph. (These are lines of best fit to the data.)

Graphing continuous data

The type of graph presented is determined by the type of data. If, for example, measurements can be made on a continuum or scale where the numbers can be subdivided into smaller and smaller parts, the data are said to be **continuous data**. A **scatterplot** or **line graph** is drawn when the data are continuous.

continuous data
values that are not restricted to defined separate values, but can occupy any value over a continuous range

scatterplot
a graph of plotted points that show the relationship between two sets of data

line graph
a pictorial representation of data in which specific values of a function are plotted as dots on a coordinate plane. Adjacent pairs of dots are connected by straight lines

Line graphs

The resulting graph might form a straight line in which there is a direct relationship between the independent and dependent variables (correlation). If the slope of the line increases (Figure 4a), the conclusion drawn is that as the independent variable increases, so too does the dependent (positive correlation). If the slope of the line decreases (Figure 4b), as the independent variable increases, the dependent variable decreases (negative correlation).

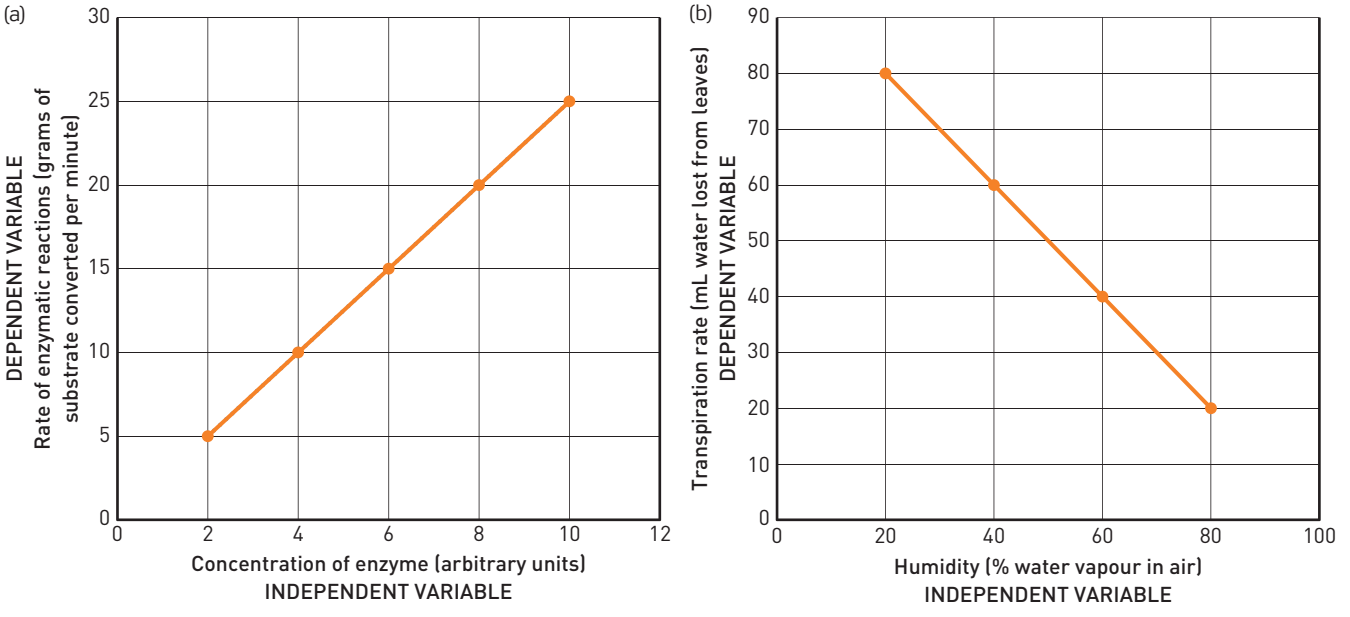


FIGURE 4 (a) The effect of enzyme concentration on the rate of conversion of a substrate (a positive correlation); (b) the effect of humidity on plant transpiration (a negative correlation)

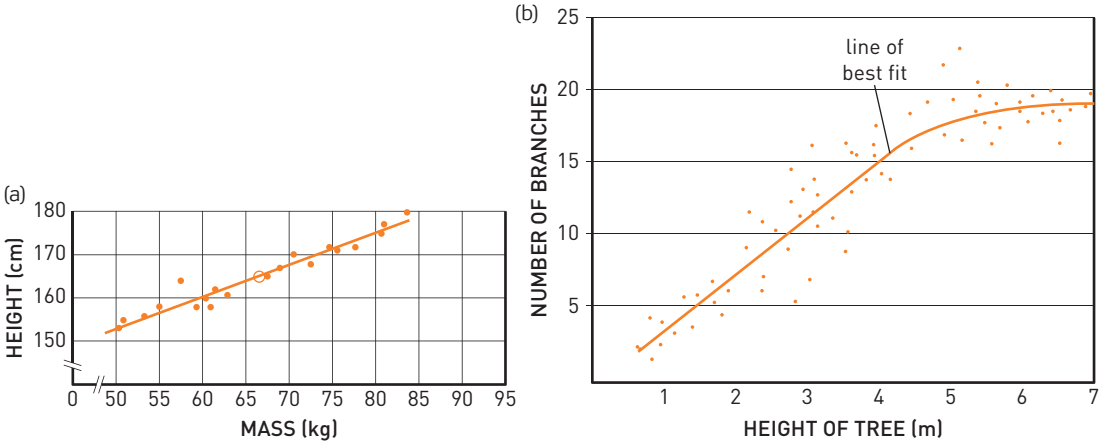


FIGURE 5 Lines of best fit on a scatterplot: (a) mass related to heights of 20 sixteen-year-old males; (b) relationship between the height of a gum tree and the number of branches over 3 cm in diameter

Scatterplots

line of best fit
a straight line drawn through the centre of a group of data points plotted on a scatter plot

trend line (line of best fit)
a line that is used to represent the behaviour of a set of data to determine if there is a certain pattern

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

Often the points plotted on a graph do not fit a straight line but are scattered, giving rise to a scatterplot. In this situation a **line of best fit** or **trend line** can be drawn so that the plotted points are evenly distributed above and below the line.

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

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

With straight line graphs both **interpolation** (determining a dependent variable value at an independent variable value that has not been measured *within* the set of data; e.g. from Figure 4a, an enzyme concentration of 5 units produces a reaction rate of 12.5 g of substrate conversion

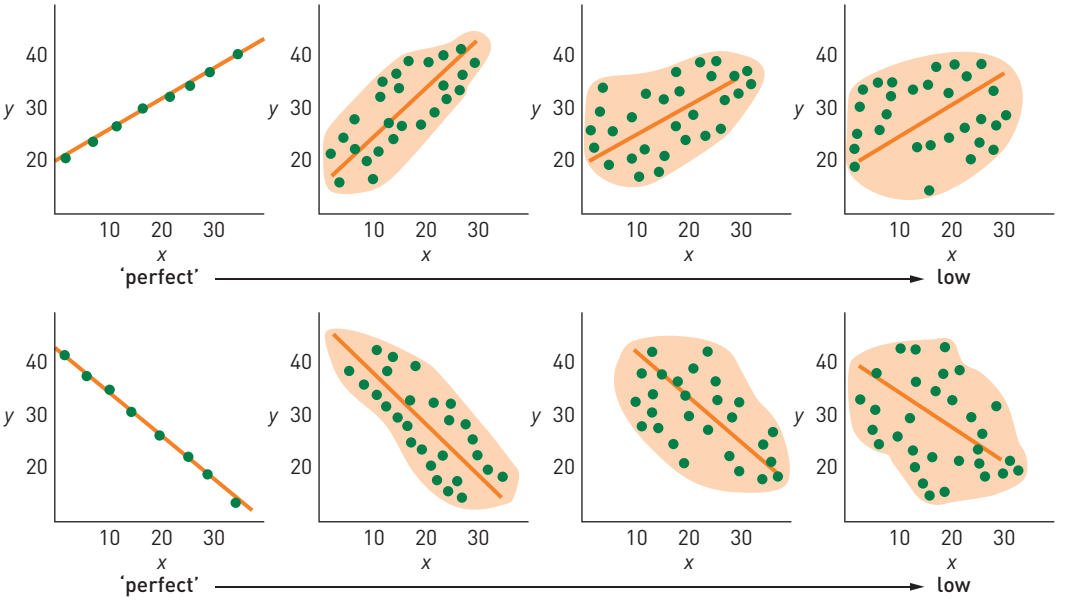


FIGURE 6 Scatterplots showing a range from 'perfect' (virtually no scatter from the line of best fit) to low (high level of scatter from line of best fit). Correlations between the two variables are shown using the line of best fit.

per minute) and **extrapolation** (*outside* the dataset; e.g. the expected reaction rate of substrate per minute at 12 units of enzyme is 30 g per minute) can be made at either end of the graph.

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

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

For example, from the graph in Figure 4a, for every 2 units of enzyme concentration increase there is an increase of 5 g substrate converted per minute.

In another example, the height of seedlings was measured over a number of days' growth. The mean growth for the seedlings was calculated at each time of measurements and the results plotted. Although these are continuous data, the graph is not a straight line, but a curve, indicating initial slow growth followed by rapid growth as shown in Figure 7. The rate of growth at any particular time can be determined from the slope of the graph at that time (the tangent to the slope). Thus, on day 7, the slope indicates a change in mean height of 33 mm (measured from the *y*-axis) over a period of 5.6 days (measured on the *x*-axis). The rate of growth on day 7 is:

$$\frac{y}{x} = \frac{33}{5.6}$$
$$= 5.9 \text{ mm per day}$$

With curved line graphs, data may be interpolated but cannot be extrapolated.

Interpreting line graphs

The ability to describe a graph in a discussion allows the relationship between the independent variable and the dependent variable to be stated. When describing a graph, the following factors should be mentioned:

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

Although there may be a correlation between the two variables, this does not mean that the independent variable caused the change in the dependent variable. **Causation** requires a higher degree of evidence than correlation.

Graphing discontinuous data

Several different types of graph can be used when the data are discontinuous. **Discontinuous data** are discrete and not related (e.g. the energy content in different food types or individual recovery rates after exercise). A **column graph** shows the distribution of a distinct characteristic within a population (e.g. human blood groups). A **histogram** represents continuous values of the independent variable that are grouped into classes of equal width (e.g. the recovery time after exercise divided in 2-minute intervals, or pulse rates of a population). A **pie graph** is useful in showing the relationship of all the parts of a whole.

Different sets of data are often drawn on the same graph using different colours or symbols in order to make comparisons.

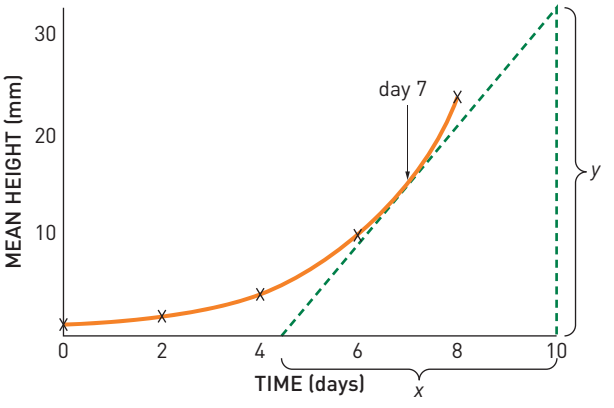


FIGURE 7 Growth of oat seedlings over time. At day 7 the slope of the graph indicates a daily growth rate of 5.9 mm.

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

causation
the capacity of one variable to influence another

discontinuous data
data that can only take particular values and may be numeric (e.g. numbers of cars) or categorical (e.g. male or female, or good or bad)

column graph
a graph consisting of vertical or horizontal bars whose lengths are proportional to amounts or quantities

histogram
a diagram consisting of rectangles whose area is proportional to the frequency of a variable and whose width is equal to the class interval

pie graph
a circular statistical graphic which is divided into slices to illustrate numerical proportions

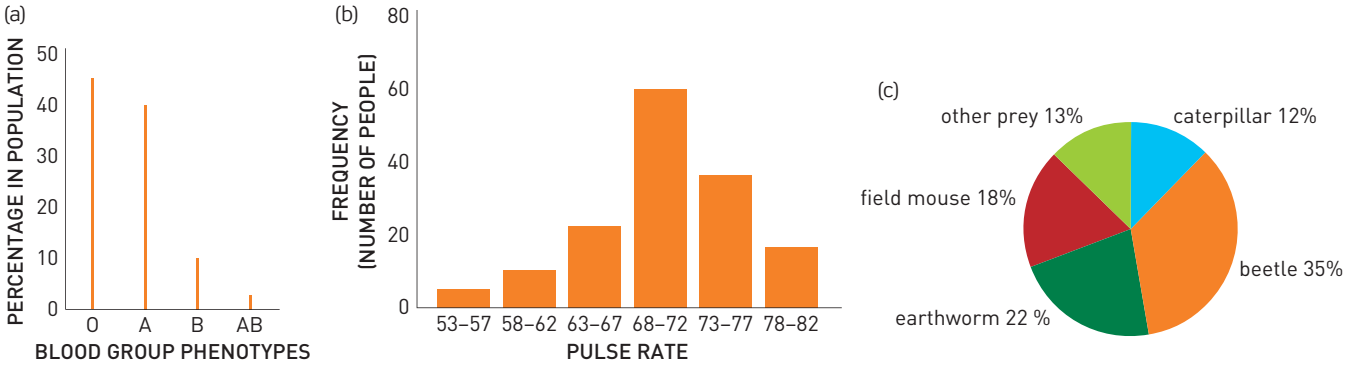


FIGURE 8 Graphing discontinuous data: (a) column graph; (b) histogram; (c) pie graph

Study tip

After describing the relationship between the independent variable and the dependent variable that is shown on a graph, take some time to think about how this applied in the experiment. Are the results relevant to the actions performed by the experimenter?

Outliers

It can be very difficult to control every element of an experiment. When errors occur, some data that are very different to the rest of the data can be produced. A data point that is outside the rest of the data set is called an **outlier**. This abnormal data point may be caused by mistakes made by the experimenter or equipment during the experiment. Outliers should always be plotted on a graph; however, they may not be included in the line of best fit. The experimenter should attempt to explain the cause of the unexpected data.

outlier
a value that 'lies outside' (is much smaller or larger than) most of the other values in a set of data

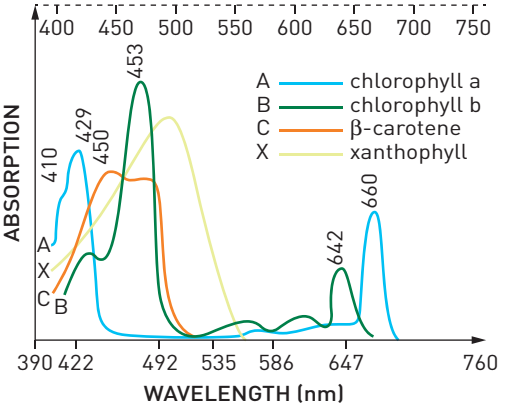


FIGURE 9 The amount of light absorbed by four leaf pigments at different wavelengths of light

The experimental report

Experimental reports need to be both concise and precise. The standard format of the report includes the following.

Title	A clear statement outlining the problem to be investigated. This is followed by the student's name and date of submission.
Abstract	A short summary of the findings
Introduction	The introduction has several sections: • a short explanation of reason for and development of the research question • findings of previous studies (library research) • reasons for the method used • a hypothesis predicting the outcomes of the investigation (dependent variable) with change of the independent variable(s), the sample used, the conditions of the experiment and the time frame.
Equipment list	A list of equipment used, including the brands and concentrations
Safety audit	A list of all possible hazards and the means taken to circumvent them

Method	An account of the activities that have been done in the investigation. It should be succinct, precise and with a logical order for apparatus set-up and activities performed in the experiment. Where appropriate, a diagram or photograph of the equipment set-up is included. The method is usually written as a concise list of instructions. It must be written in such a manner that another scientist could easily and exactly repeat the experiment.
Results	Qualitative (subjective or objective) or quantitative, and presented clearly in a form or forms best suited to the results. The forms may be a verbal description, tables of data, graphs, photographs or any other suitable form. Any mathematical analyses of data should be included.
Discussion	A brief account that may answer the question posed by the hypothesis. It should not be a verbal repetition of the results, but instead a genuine attempt to state and relate the theoretical aspects of knowledge with the experimental variables of the obtained results. It should include: • analysis of the data to support or reject the hypothesis, or show that it is inconclusive • a paragraph critiquing the methodology (the validity and reliability of the data, possible extraneous variables that could not be controlled, and other relevant observations). • possible improvements, along with suggestions for future hypotheses or experimental ideas.
Conclusion	A short statement of the findings of the investigation that is related to the hypothesis
Bibliography	An alphabetical list of all references used in the report

CHECK YOUR LEARNING 1.3

Describe and explain

1 **Explain** the terms 'validity' and 'reliability' when referring to:
   - **a** library research of published research investigations
   - **b** data collection in an investigation.

2 **Explain** how library research can assist in refining a research question and point to ways in which an investigation can be conducted.

3 **Identify** what factors need to be considered when designing an experiment.

4 **Explain** why the hypothesis needs to be written before conducting an experiment.

Investigate, evaluate and communicate

5 An investigation does not support the hypothesis or is inconclusive – decide if this means the experiment was a failure. **Explain** your answer.

6 A student has collected a large quantity of quantitative data in an experiment. **Propose** means by which these data could be interpreted in order to draw a conclusion.

7 **Comment** on which aspects of an experiment should be included in the discussion.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 1.3
- » Video
  Core experimental skills
- » Video
  Chemical safety
- » Video
  The student experiment

1.4 Research investigations

KEY IDEAS

- The use of a logbook
- Clarifying the research investigation task
- Beginning the research investigation
- Research techniques
- Interpreting data and evaluating the claim
- Writing the report for a research investigation

A research investigation requires students to evaluate a claim. This is achieved by researching, analysing and interpreting secondary evidence from scientifically credible sources to form the basis for a justified conclusion about the claim. Invariably the student will select one of several possible claims that are presented to develop and research a research question.

The use of a logbook

Study tip

Dividing a page of your logbook down the centre, with one side for supporting evidence and the other for opposing evidence, can sometimes help.

As in the student experiment, it is highly recommended that a logbook be used throughout the development of a research investigation. This is used to:

- clarify the topic
- determine the questions that need to be addressed
- write summaries of research (including bibliographies)
- interpret the information
- make note of links between different aspects that are discovered during the research.

It is advisable to date each entry. A logbook ensures that all of the information required to write the report is present in one place.

Time management

It is important to note the due dates for the task, which may include progress reports, draft report and final date. The time allowed may appear generous, but if assignments in several subjects are all due at around the same time, it is human nature to focus on the one due first. Setting aside adequate time each week for each is critical to good results in each subject. Research has shown that evenly spaced effort of short durations during the week is better than a long time spent once a week.

Clarifying the task

The research investigation contains a range of elements to consider. Determining all aspects of the task is therefore essential. Things to consider before commencing the research investigation include:

- How will the task be presented? (An argumentative essay, a poster presentation, a PowerPoint presentation.)
- How long is the response (words/minutes)?

- What course objectives are being assessed?
- The task is assessed from the marking criteria sheet. Consider the:
  - **a** relative importance of each section (criterion)
  - **b** allocation of research time to be spent on each section to complete the total task
  - **c** number of words for each section so as to comply with the total number of words for the whole task.
- How many resources are required to provide adequate information?
- What determines if a resource is relevant and reliable?

Most of these questions or points can be answered by careful reading of the assignment sheet, but the teacher will be able to assist with further information.

Beginning the task

If several claims are presented, it is important to identify the relevant scientific concept(s) associated with each. Selection of the claim to be investigated can then be based on which is the most familiar of the underlying concept(s).

1 Select the claim.

For example, the following claim has been selected for the research investigation:

'Removing a top order consumer from an environment will improve the health of other organisms in the same environment.'

The underlying concept is ecosystem dynamics.

2 Make notes on what you already know about the topic (e.g. interrelations between organisms in an environment – food webs, competition, and so on).

3 Write down any further questions you need to find out about the topic, such as:

- **a** Which ecosystem will be considered?
- **b** Where does it occur?
- **c** What organisms are involved?
- **d** What is meant by the health of the other organisms?
- **e** How will the top order consumer be removed?

These questions assist in the development of the research question, addressing aspects of the claim, and they may provide subheadings for the report.

This approach shows an informed application of understanding of the topic by developing a considered, specific and relevant research question about the claim.

Research techniques

It is very important that the research question be approached with an open mind. Too often, information that supports a preformed opinion (bias) is sought. This might mean that any data that oppose a view or hypothesis are ignored. The research should be approached so that evidence both supporting and rejecting the claim can be collected and analysed in order to reach a conclusion that can be justified.

It is also important to look for information from a range of sources. While it can be easy to use a search engine to find information online, valuable information is also available at the library in books or scientific journals. A good research investigation should refer to a range of sources from a number of different authors.

Identifying credible sources

A research investigation requires evidence to be obtained from scientifically credible sources. A topic search on a search engine such as Google will find many articles. Some of these will be simplified explanations of the topic that appear to be clear and that make strong assertions. However, anyone can submit an article and have it published on the internet; many of these are anecdotal and without scientific evidence. Questions to ask when deciding if the source is scientifically credible could include:

FIGURE 1 Seeking information for a research question can involve hard-copy texts and journals as well as online resources.

- Is the article published in a recognised scientific journal?
- Was it from a website set up by a government department (.gov) (e.g. DPI or CSIRO), a university (.edu), an independent research organisation (.org) (e.g. The Cancer Foundation) or a manufacturer of scientific and technological equipment?
- Was the information in a book written by a scientist working in the field under investigation?

Checking that the information is consistent across more than one source gives a strong indication of the validity and reliability of the source.

Study tip

Use a different colour to highlight information for each sub-question. This allows you to check that you have enough evidence to answer each section.

Analysing sources

A good way to start analysing the information obtained is to summarise the article (making sure the all key details, such as title, author, date and publication, are recorded). This should include notes on:

- how it answers the question posed
- evidence provided to support its claims
- how the evidence was collected
- further sub-questions raised by the article.

As more information is gleaned, comment on the links between ideas and evidence. This can help form the final argument.

In this way the data can be examined in order to ascertain if:

- enough information has been collected (e.g. several further sources do not provide extra information)
- the evidence is of high quality and relevant to the research question
- there are limitations in the evidence.

Interpreting the data and evaluating the claim

Using the summaries of the research articles, several questions can be posed, such as:

- Is there any inconsistency between the findings from different articles?
- How were the data collected in each source – observation, questionnaire, experiment?
- How valid is each set of data?

- Do the data show a clear cause and effect relationship?
- Are any trends obvious?
- What further analysis is required to discern a trend?

The information from the research can often be put into tables that compare (similarities and differences) and contrast (deliberate comparison of opposing arguments – for and against), or show evidence to support or refute, the claim. Both quantitative and qualitative data can be presented as graphs (see Section 1.3). Concept or mind maps could be drawn to show links between ideas and data. All of these methods assist in interpretation (clarifying a position and recognising trends). This interpretation needs to show the extrapolation of the research question to the claim.

An evaluation can then be made concerning the validity of the claim – supporting evidence is provided.

Preparing the response

The response required can be varied. Most written reports (e.g. literature review or argumentative essay) are about 2000 words long whereas a poster presentation, for example, should take 9–11 minutes. Regardless of the style of response, it should contain the following:

- the claim
- the research question posed
- the rationale for the investigation
- evidence-based, justified scientific arguments
- the conclusion to the research question based on the interpretation of the evidence
- evaluation of the claim and suggestions of improvements and extensions to the investigation
- a reference list.

Source: *QCAA Biology General Senior Syllabus 2019*

The emphasis placed on each of these areas will be indicated by the marking scheme.

CHECK YOUR LEARNING 1.4

Describe and explain

1 **Describe** factors that need to be considered when determining the scope of a research investigation.
2 **Explain** how to determine whether a source is scientifically credible.
3 **Describe** the purpose of maintaining a logbook.
4 **Describe** how you can determine if sufficient, relevant information has been collected for the task.
5 **Describe** how information from research can be presented to show trends, patterns and relationships.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 1.4

» Weblink
Google scholar

» Weblink
Credible sources

» Video
The research experiment

1.5 Exam preparation

KEY IDEAS

- Planning time and making a timetable for study
- Strategies for learning
- Exam revision
- Examination strategies

Study tip

There is too much content to cram in Units 1–4. Revision should occur throughout the year.

Some students manage to scrape through an exam by last-minute cramming of information. This may bring a level of short-term success, but the information only exists in the short-term memory and as a result is not retained. For most students this method is unsuccessful since it does not necessarily ensure understanding of the material or help to build the concepts necessary to answer questions requiring interpretation and analysis. Success in exams requires a deep understanding that is embedded in long-term memory. Since knowledge of facts and concepts learnt in Unit 1, for example, may be presumed when studying Unit 4, the development of strategies to ensure long-term memory is very important. The best way to prepare for exams is to start a study program from the first day of the academic year.

Planning the timetable

During senior studies, it is recommended that 3 hours per week be allocated for out-of-class study per subject for the average student. This should be adequate for completing set tasks and learning the work that has been covered during the week. Sometimes the set tasks may take a short time, in which case the extra time should be spent on current learning and revising and vice versa.

Each student has different extra-curricular activities (family assistance, part-time jobs, training for sport, and co-curricular classes). For those with a heavy load, prioritising time and its management is especially important. Persistence is the key.

One way to ensure that all requirements are met is to set up a weekly study timetable. In setting up this timetable the following points need to be taken into consideration:

- Eight hours sleep per night is essential.
- It is better to space the study of any particular subject over several days rather than spending the time allocation for 1 week in a single session (this could change when undertaking an assignment).
- It is more effective to review each lesson on or near the day it was covered in class.
- Determine the most effective times of the day for your learning – some people function exceptionally well early in the morning while others take some time to wake up.
- All the material for the study period should be prepared and ready prior to the allocated time.
- Study time is sacrosanct, so switch off the phone or get family members to take a message.
- Allocate a 15-minute break after every hour to stretch and refocus.
- Contrary to popular opinion, background music does not enhance learning (unless it is in a narrow genre that stimulates alpha brain waves).
- Allow for extra contingencies, such as an unexpected family visitor or outing, or illness – so that make-up time is available in the timetable.
- Allow time for social activities.
- If study classes are part of the class timetable, allocate each to a specific subject.

A weekly timetable might look something like Table 1.

TABLE 1 A weekly timetable

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6–7 a.m.	Check all set homework completed	Athletics training					
Breakfast							
Travel Classes	Study class 50 min – Physics		Study class 50 min – Biology	Study class 50 min – Maths	Study class – 50 min Chemistry	8.00 a.m. – 12.00 noon Athletics meet	9.30 – 10.30 a.m. Ancient History 11.00 a.m. – 12.00 noon Chemistry
Travel							
3.00 – 4.00 p.m.							
4–4.30 p.m.	Relax	Relax	Relax	Athletics training	Work		
4.30–5.30 p.m.	Chemistry	Biology	English				
5.30–6.30 p.m.							
7.00–8.00 p.m.	Maths	Ancient History	Physics	Physics			
8.15–9.15 p.m.	English	Maths	Ancient History	Biology			

It often a good idea to use study classes for those subjects like Physics or Mathematics as some peer assistance (such as help in interpreting a problem) is available. For many students, the actual timetable may not change from week to week during any term or semester. For others, a different timetable might need to be established each week. What will change is the actual aspect of the subject being studied.

Setting objectives for each subject for each week is of benefit since it focuses attention on what needs to be achieved in that 3-hour time frame. The objectives need to be realistic and specific. For example, for Biology week 1 they might include:

- Revise information in 2.1.
- Complete Check your learning 2.1.
- Summarise 2.2.
- Write meaning of glossary terms in own words.
- Complete Check your learning 2.2.
- Revise any points that were not clear from answering the Check your learning questions.

Summarising and learning course content as it progresses makes understanding of new subject matter easier and ensures that much of the hard work in the final examination preparation is completed. Remember that understanding is key to the ability to learn and use information effectively. The Chinese philosopher Confucius (551–479 BCE) taught that:

> Learning without thought is labor lost; thought without learning is perilous.

This is probably truer today than it was two and a half thousand years ago. Interpretation of data and informed decision-making are built on the understanding and knowledge of subject matter.

FIGURE 1 A study space can be the corner of a bedroom or another room infrequently used by the family. The most important factors are lack of distraction, a desk or table large enough for books etc., a supportive chair and lack of clutter.

Work space

Everyone's home circumstances are different and few students have an ideal area in which to study. Where possible it is best to study in quiet space with adequate light and ventilation. The desk or table should be large enough to accommodate textbook, notebook (or laptop) and any other equipment required, and the chair should be upright to support the back. Some students may need to resort to staying back at school or using the local library in order to provide a situation conducive to learning.

Learning strategies

Each person is an individual who has a specific physical appearance, bodily chemical reactions, likes, dislikes and abilities. This individuality is a result of both their genetic constitution and the environment the person has experienced in the past and experiences currently. So there are no hard and fast rules to follow to achieve the best learning outcomes. Using a variety of techniques, however, assists in consolidating knowledge and understanding.

Strategies to assist learning could include the following:

- Ask questions in class and participate in class discussions (this also assists in maintaining attention).
- Write definitions of key words and summaries of the text in your own words to gain a deeper understanding of the topic.
- Highlight written summaries and key words in different colours.
- Write and rewrite summaries until they are reduced to a simple statement or key words.
- Make lists of new points in a logical, numbered sequence.
- Classify and group ideas.
- Translate a section of text into a diagram or a concept map that shows the relationship between significant ideas.
- Organise diagrams into statements.
- Use tunes or rhymes as mnemonics.
- Watch videos or listen to podcasts on the topic.
- Learn new material while doing something active (e.g. reading, reciting notes or listening to pre-recorded summaries while on a treadmill, walking the dog or bouncing a ball).
- Explain a topic to a listener (even a pet or teddy bear).
- Break study tasks into small chunks and intersperse these with a short period of physical activity.
- Make flash cards to revise.

If working as a group, for a study session or on a group task, it is important that the task is well defined and all members of the group focus on the task at hand. Brainstorming ideas can clarify understanding and help the development of concepts.

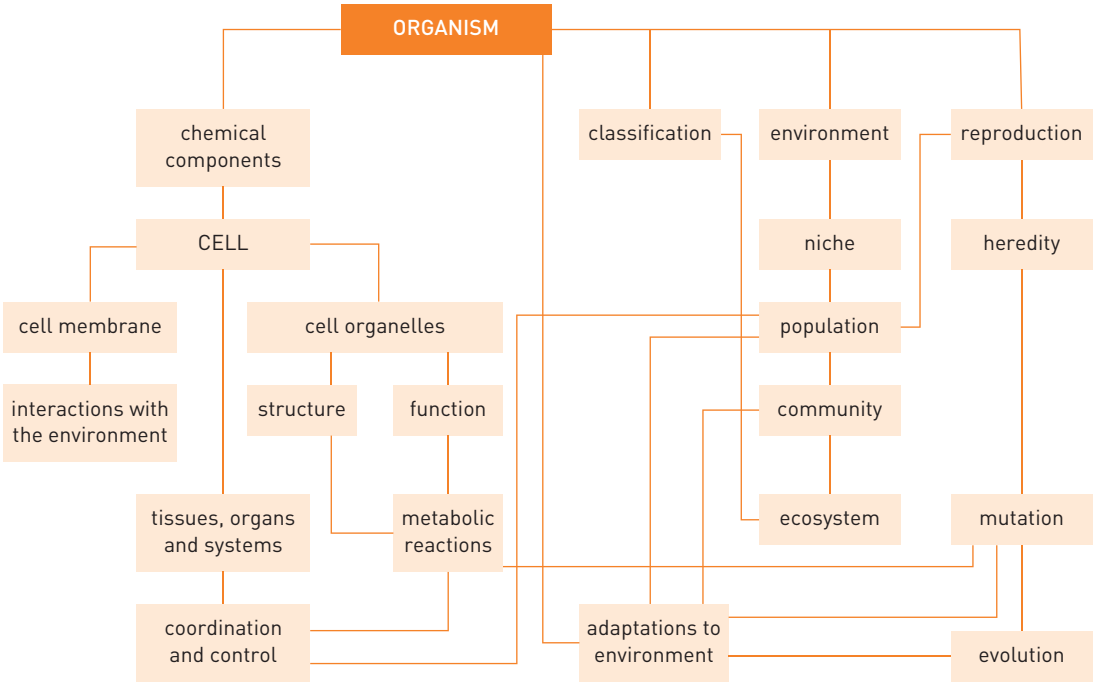


FIGURE 2 A possible concept map to show the interconnection between the organism and the study of major aspects of biology

Exam revision

The lead-up to an exam does not need to be stressful. If work has been summarised and learnt in increments throughout the course, exam preparation only requires revision of the summaries and making sure you can apply the knowledge. The first requirement then is organisation and planning – **it is important to make sure all learning is completed well before the exam**. Dividing work into manageable chunks makes learning easier.

FIGURE 3 Walking on a treadmill while reading, reciting or listening to a pre-recorded summary may help learning.

Review small sections of the material ahead of time and in different ways. For example, develop flash cards one day and check your recall the next, explain the material to a peer, or revisit the questions in the text to ensure you can do the following in relation to the topic:

- describe and explain
- apply understanding
- analyse and interpret evidence
- evaluate evidence and draw conclusions.

Clarify any difficulties in understanding of a section of the work with the teacher well before examination time.

Be honest about time spent studying; for example, be aware of time spent on Facebook rather than checking a detail of the topic on the internet.

Focus on achievements (even if it means progressing from a D grade or a C^- on the last test) and make goals realistic (a C^+ in this test).

Be persistent – some sections of the course may be tough, but extra effort makes the rewards in conquering them all the sweeter.

Remember that sharp focus and retrieval of memory depend on good eating and sleeping habits as well as a level of physical exercise.

Exam techniques

Before entering the examination room, it is important that you have all of the allowed equipment with you. Ensure that you have a highlighter and replacement pen or pencil just in case.

Some people like to talk when they are nervous, while others need a quiet space to help them think clearly. Take time to make sure you know which environment you prefer, and that you do not add to others' anxiety.

In the examination room, make yourself as comfortable as possible.

Most exams will be of 60 to 90 minutes' duration with a perusal time of 10 minutes. In Units 3 and 4, the external examinations will consist of two papers (a short-response paper and a combination paper), each of 90 minutes, with 10 minutes of perusal.

During perusal time

Use the perusal time effectively.

- First scan the paper to check the type of questions in the paper, and the approximate allocation of time you need to apply to each.
  - Multiple-choice questions are normally designed to take about a minute each, so if there are 10 of these questions no more than 10 minutes should be spent on them.
  - The mark value of short-response questions gives a good indication of the time that should be allocated, approximately a mark a minute. Ensure that the requirements of the question are understood – it is a waste of time to respond with a sentence when a single word will suffice, or a paragraph when a short statement is needed.
  - Extended answers usually take more time and should be allocated some time for planning so that the response is succinct, includes scientific evidence and answers all parts of the question. Extended-answer questions need a short introduction, the main body with justified evidence, and a short conclusion.
- Read each question carefully to ensure you understand the requirements – often a question or statement in one part of the paper jogs the memory to complete another question.
- Make a mental note of the questions with which you feel confident and those that will need further reflection.

During the exam

During the exam, highlight the important points of each question and keep track of the time spent on each section. Complete the questions you feel confident in answering first. In this way you will have time to go back to the tricky questions. Remember that, although the question may be worded in a different way, the underlying concept and facts pertaining to the concept have been covered in the course. In problem-solving questions:

- highlight the required response
- note any given information
- identify the basic concept being tested
- apply background knowledge and given information to answer the question.

This system often clarifies thoughts and leads to the successful completion of the task.

Multiple-choice questions

Most students prefer multiple-choice questions to written-response questions – perhaps because one of the options will be correct (and they hope to recognise it) or that there is a chance that they will guess the correct answer. However, the response given will be either correct or incorrect, and no part marks are given.

Many multiple-choice questions emphasise basic definitions, but others may require analysing and interpreting data. They also tend to cover a broader range of material than, for example, short-answer items. For a student to succeed in such items, they are forced to be familiar with the details of all aspects of the subject matter being examined. Thorough knowledge of the work is the best predictor of success.

Multiple-choice questions start with a question, and the student is asked to select one of several (usually four) given answers. It is recommended that the type of response is highlighted. These may be:

- complete a statement (as with true/false short-answer questions, all aspects of the answer must be correct)
- select the **best** or **most correct** answer
- select the incorrect answer (e.g. select what does **not** apply).

Only one option will be completely correct. The other options are distractors, and good distractors are designed to appear to be correct on the surface. Such an answer may in fact be correct, but is still not as good a response as one of the other options. Although no particular strategy is infallible, some tips that could help with this type of question include:

- Cover the possible alternatives when reading the stem and decide the answer.
- Look for the anticipated answer among the options and highlight this.
- Check all options so as not to miss the best response.
- If unsure of the answer, cross out the options that you know are incorrect; this improves the chances of selecting the correct response.
- Do not look for trick questions – reading too much into a question not only wastes time but also generally leads to an incorrect answer.
- Never leave a multiple-choice question unanswered (unless marks are deducted for an incorrect response) – you have one in four chances of being correct if you select an option but no chance if you leave the question blank.

Responding to cognitive verbs

In assessment tasks and examinations, students will encounter '**cognitive verbs**'. These verbs are 'task words' that will provide information on what is expected to answer a question. A list of common cognitive verbs is included on your obook assess.

It is important to understand the difference between task words. For example a question that asks a student to 'compare' is different to a command asking a student to 'contrast'. One requires a student to show similarities and differences, while the other is only asking to show the differences.

Understanding exactly what a cognitive verb is asking for means that a student can provide exactly what the examiner is looking for. Examiners want to give students marks, but can only do so if the student provides the correct information. For example, if a student **describes** data in their answer, but does not **analyse** the data, they will not receive full marks.

On the next page is a list of cognitive verbs that might come up on your assessments.

TABLE 2 List of cognitive verbs

Cognitive verb	Definition	Sample question
Analyse	dissect to ascertain and examine constituent parts and/or their relationships; break down or examine in order to identify the essential elements, features, components or structure; determine the logic and reasonableness of information; examine or consider something in order to explain and interpret it, for the purpose of finding meaning or relationships and identifying patterns, similarities and differences	**Analyse** the graph provided below to identify the relationship between people's age and number of sick days taken.
Apply	use knowledge and understanding in response to a given situation or circumstance; carry out or use a procedure in a given or particular situation	**Apply** the definition of a cell to show how multicellular life is different.
Calculate	determine or find (e.g. a number, answer) by using mathematical processes; obtain a numerical answer showing the relevant stages in the working; ascertain/determine from given facts, figures or information	**Calculate** how many molecules are in one mole of ethanol.
Compare	display recognition of similarities and differences and recognise the significance of these similarities and differences	**Compare** the different phases of mitosis.
Consider	think deliberately or carefully about something, typically before making a decision; take something into account when making a judgment; view attentively or scrutinise; reflect on	**Consider** what factors would limit photosynthetic rate.
Contrast	display recognition of differences by deliberate juxtaposition of contrary elements; show how things are different or opposite; give an account of the differences between two or more items or situations, referring to both or all of them throughout	**Contrast** percentage uncertainty and percentage error in an experimental result.
Deduce	reach a conclusion that is necessarily true, provided a given set of assumptions is true; arrive at, reach or draw a logical conclusion from reasoning and the information given	**Deduce** which part of aerobic cellular respiration would be most affected by a lack of oxygen.
Describe	give an account (written or spoken) of a situation, event, pattern or process, or of the characteristics or features of something	**Describe** photosynthesis.
Determine	establish, conclude or ascertain after consideration, observation, investigation or calculation; decide or come to a resolution	**Determine** the percent of carbon dioxide present in a sample.
Discuss	examine by argument; sift the considerations for and against; debate; talk or write about a topic, including a range of arguments, factors or hypotheses; consider, taking into account different issues and ideas, points for and/or against, and supporting opinions or conclusions with evidence	'Multicellular life evolved from unicellular life.' **Discuss** this statement.

Cognitive verb	Definition	Sample question
Evaluate	make an appraisal by weighing up or assessing strengths, implications and limitations; make judgments about ideas, solutions or methods in relation to selected criteria; examine and determine the merit, value or significance of something, based on criteria	There is an optimum amount of sunlight required for a plant to survive. **Evaluate** this claim.
Explain	make an idea or situation plain or clear by describing it in more detail or revealing relevant facts; give an account; provide additional information	**Explain** why it is impossible for the percentage yield to be 109%.
Identify	distinguish; locate, recognise and name; establish or indicate who or what someone or something is; provide an answer from a number of possibilities; recognise and state a distinguishing factor or feature	**Identify** the range of values suggested by the measurement 10.3 ± 0.8 seconds.
Interpret	use knowledge and understanding to recognise trends and draw conclusions from given information; make clear or explicit; elucidate or understand in a particular way; identify or draw meaning from, or give meaning to, information presented in various forms, such as words, symbols, pictures or graphs	**Interpret** the data to conclude which reaction was producing oxygen at the fastest rate.
Propose	put forward (e.g. a point of view, idea, argument, suggestion) for consideration or action	**Propose** a way to minimise the error caused by the vibrations of people walking past an electronic balance.
Justify	give reasons or evidence to support an answer, response or conclusion; show or prove how an argument, statement or conclusion is right or reasonable	**Justify** why gas exchange is an important process for human digestion.
Predict	give an expected result of an upcoming action or event; suggest what may happen based on available information	**Predict** what would happen if photosynthesis stopped on Earth.

Definitions from QCAA Biology General Senior Syllabus 2019

As shown in Table 2, some cognitive verbs have multiple definitions. It is therefore important to assess the whole question to determine specifically what the question requires.

CHECK YOUR LEARNING 1.5

Describe and explain

1 **Identify** three general study goals for Biology each week and two specific goals for the current topic.

Apply, analyse and interpret

2 **Organise** a weekly timetable to fit in 3 hours study per week per subject around your out-of-school activities.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 1.5
- » Study timetable
  Study timetable template
- » Video
- » How to prepare for your exam
- » Increase your knowledge
  Cognitive verbs

CHAPTER 1

Review

Chapter summary

1.1 Biology is the study of living things. It involves the study of the types of organisms that exist, how they perform their functions, and how they interact with each other and their environment. Since this involves a vast field of knowledge, researchers tend to specialise in a particular area. Organisms have complex, dynamic, ever-changing interactions with their living and non-living environment.

1.2 Biology, like all sciences, utilises the scientific method in investigations. This method involves the following cycle of activities:

- **Observation**. This may be qualitative (descriptive) or quantitative (measured) data. Repeated verified observations become facts. Observations usually need to be interpreted (logical reasoning) and this leads to the asking of questions.
- **Questioning**. Asking the right question is a key step in the scientific method. The essential requirement is that it is testable. Questions lead to hypotheses.
- **Hypothesis**. The hypothesis is a statement that attempts to answer the question(s) raised by the observation(s). This explanation is tested by experimentation. It should:
  - set limits on the problem to be solved by specifying:
    - the particular species under study
    - the area involved
    - the effects to be studied
    - the time period over which the question is to be investigated
  - point the way to a solution of the question
  - lead to the prediction of new information.

  It is harder to show a particular experimental variable has a specific effect than to reject it. So scientists tend to express the hypothesis in the negative form – the null hypothesis.
- **Controlled experiment**. The scientific method employs a duplicate set of experiments, one in which all the conditions are set (the control), and the other in which one of the conditions only (the experimental variable) is different. The experiment must be repeated with the same results to ensure that they are not due to chance and thus that the hypothesis is valid.
- **Interpretation**. A theory based on data that verifies the hypotheses.

1.3 All proposed experiments on animals must be submitted to the local bioethics committee for approval before they can be performed.

Experimental research questions usually start with an observation or need to establish further understanding of a topic.

Raw data of the dependent variable need to be presented in a way that is easy to analyse and from which conclusions can be drawn.

Qualitative data (subjective or objective) can be presented in tables, as diagrams or photographs.

Quantitative data (only objective) can be presented as tables from which mathematical applications can be applied (e.g. mean, medium, mode, variance and standard deviation) and graphs drawn.

Data are either continuous (the same parameter of an organism is measured as an aspect or a single independent variable is changed) or discontinuous (unrelated). With

continuous data, points are plotted on a graph and a line of best fit between the points is drawn. Common graphs used to represent discontinuous data are column graphs, histograms and pie graphs.

A standard format is used in writing reports of experimental investigations – title, abstract, introduction (with hypothesis), equipment list, safety audit, method, results, discussion, conclusion and bibliography.

1.4 Research assignments require a student to develop a research question related to a particular claim. Using scientifically credible sources, the question is researched, findings analysed and interpreted, and a justified conclusion about the claim is drawn. It is recommended that a logbook be kept throughout the process.

1.5 The best learning strategies employed depend on the individual. Preparation for examinations should be progressive throughout the course, with final revision taking place in the weeks leading up to the exam. In the examination, careful reading and determining time allocations on specific questions should be undertaken during the perusal time. Key words and requirements for each question should be highlighted to ensure the approach to the question is correct.

Key terms

- adaptation
- biology
- causation
- central tendency
- column graph
- continuous data
- controlled experiment
- data
- dependent variable
- discontinuous data
- ecology
- ethology
- evolution
- experimental test
- experimental variable
- extraneous variable
- extrapolation
- fact
- graph
- histogram
- hypothesis
- independent variable
- interpolation
- line graph
- line of best fit
- mean
- mean variance
- median
- mode
- morphology
- null hypothesis
- outlier
- physiology
- pie graph
- prediction
- qualitative
- quantitative
- reliable
- repeatability
- reproducibility
- ruling hypothesis
- scatterplot
- scientific law
- scientific method
- scientific theory
- standard deviation
- table
- taxonomy
- trend line
- valid
- variability
- variable factor
- variance
- zoology

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 'Koalas are adapted to their environment.' This statement means that:

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

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

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

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

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

A Results from an experiment may give support to a hypothesis.

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

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

D Hypothesis cannot be formed unless experimental evidence is available.

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

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

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

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

A Compound X stimulated the growth of some plants.

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

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

D All of the above.

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

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

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

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

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

Short answer

Describe and explain

★ **4** **Describe** the steps involved in the scientific method.

★ **5** **Explain** the importance of a logbook during a student experiment.

Apply, analyse and interpret

★★★ **6** A student noticed that there seemed to be a direct relationship (correlation) between length of leg (measured in centimetres from the hip joint to the base of the ankle) and length of a person's stride. To check the accuracy of this observation, the student measured the leg length and stride of several people. A sand area with a base board was set up. The subjects aligned the tips of their toes with this board and stepped into the sand. Length of stride was measured as the distance from the base board to the back of the heel marking in the sand. The results were plotted as shown in Figure 1.

a **Deduce** what hypothesis the student was testing.

b **Describe** the variables in the experiment.

c **Determine** if this was a controlled experiment. Explain your answer.

d **Determine** what scientists call the measurements shown on the graph.

e **Explain** why the results were presented graphically.

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

g Divide the graph into four equal boxes to give four categories: short leg, short stride; short leg, long stride; long leg, short stride; and long leg, long stride. Count the number

of people in each category. **Determine** which boxes most people fit in.

h **Reflect** on the hypothesis. Was it correct?

i **Consider** the possible extraneous variables present in this experiment.

j **Describe** how this experiment could be improved to give a more accurate interpretation.

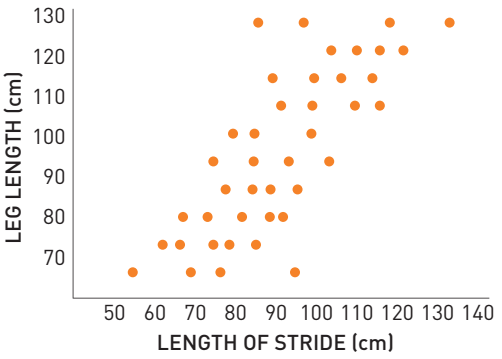


FIGURE 1 The relationship between leg length and length of stride

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

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

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

b **Construct** this data as a graph.

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

i day 3

ii day 15

iii day 22.

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

e **Judge** the reliablity of the data. **Explain** your answer.

f **Predict** the mean final height of oat plants from these data. **Explain** your answer.

Investigate evaluate and communicate

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

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

b Draw any equipment used and **explain** what and how outcomes will be measured to achieve consistent results. A qualitative measure of the amount of carbon dioxide gas formed can be achieved by bubbling any gases emitted from the solution through limewater. Limewater turns milky in the presence of carbon dioxide – the greater the amount of carbon dioxide, the milkier the solution. If the boiling point of the final solution is measured, a quantitative measure of the % volume of alcohol can be achieved. The greater percentage of alcohol present, the lower the boiling point. (Tables of boiling point versus % volume of alcohol are available on the internet.)

c **Predict** any extraneous variables in your design and devise means to eliminate them.

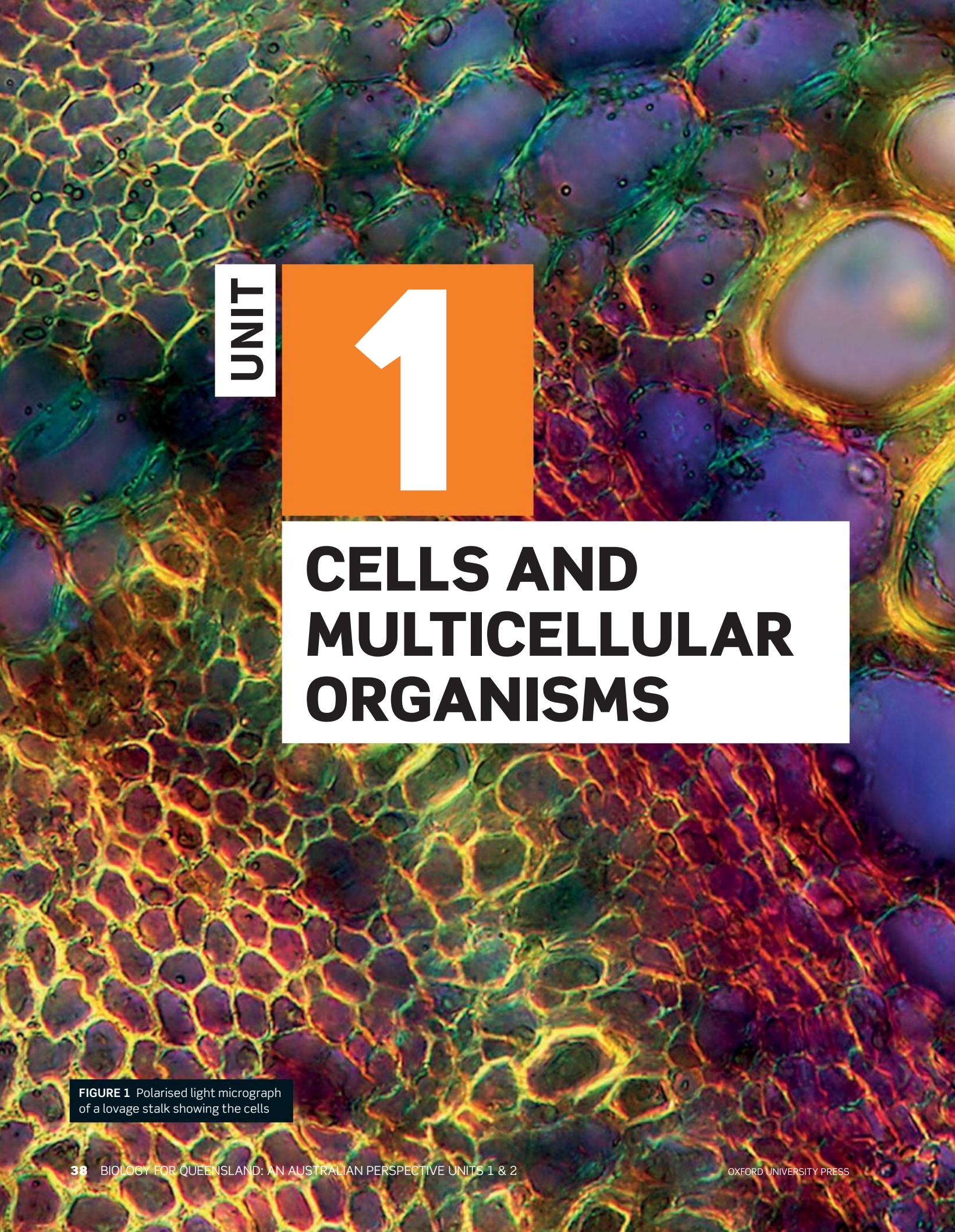
Check your obook assess for these additional resources and more:

» Student book questions
Chapter 1 review

» Revision notes
Chapter 1

» assess quiz
Chapter 1 auto-correcting multiple-choice quiz

» Flashcard glossary
Chapter 1 glossary



UNIT 1

CELLS AND MULTICELLULAR ORGANISMS

FIGURE 1 Polarised light micrograph of a lovage stalk showing the cells

The cell is the fundamental unit of all living organisms. This microscopic structure is composed of organic chemicals that have specific structures and functions. These chemicals are organised into subcellular structures or organelles. Different parts of the cell, therefore, have different structures and functions. Although most chemical reactions that sustain life occur within the cell, some occur outside the cell. Cellular activities require energy. This energy may be supplied as light energy or as chemical compounds capable of releasing energy when broken down. Each chemical reaction in the cell is mediated by a specific enzyme. The size of the cell is limited by its ability to take in and release materials efficiently. For this reason, large organisms are composed of many small cells interacting together. In complex organisms, there is division of labour, with different parts of the body carrying out different tasks. These cells are derived from stem cells. A group of similar cells that together perform a particular function is termed a tissue. Tissue development and cell replacement involve a process of cell division called mitosis. Different tissues are grouped into organs, and organs into systems. All systems are coordinated so that the body as a whole maintains homeostasis. The structure and function of plant and animal systems at cell and tissue levels determine the efficient provision or removal of materials to and from all cells of the organism.

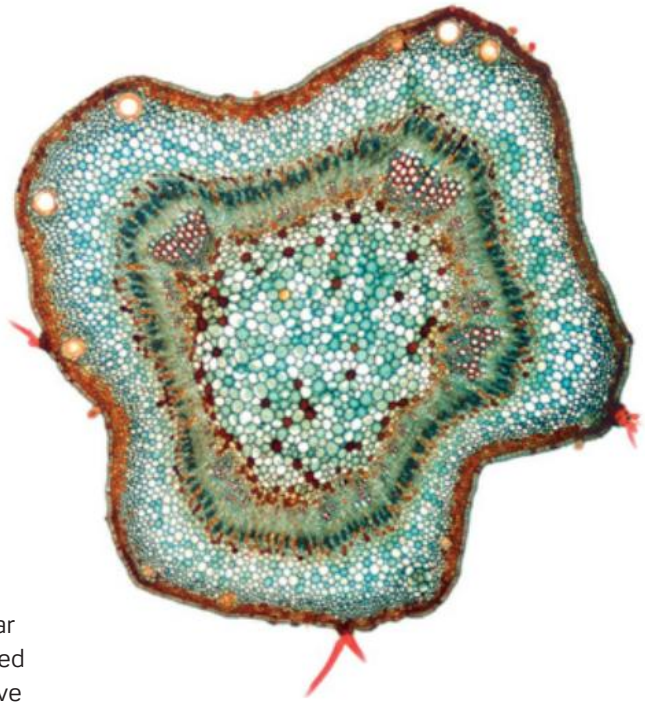


FIGURE 2 Transverse section of a stem with hairs

Unit 1 Topics

Topic 1	Cells as the basis of life	Chapters 2–4
Topic 2	Multicellular organisms	Chapters 5–8

Unit objectives

- → Describe and explain cells as the basis of life, and multicellular organisms.
- → Apply understanding of cells as the basis of life, and multicellular organisms.
- → Analyse evidence about cells as the basis of life, and multicellular organisms.
- → Interpret evidence about cells as the basis of life, and multicellular organisms.
- → Investigate phenomena associated with cells as the basis of life, and multicellular organisms.
- → Evaluate processes, claims and conclusions about cells as the basis of life, and multicellular organisms.
- → Communicate understandings, findings, arguments and conclusions about cells as the basis of life, and multicellular organisms.

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CHAPTER 2

The chemicals of life

All living organisms require an energy source and matter to survive. Living matter (organic chemicals) is composed of carbohydrates, proteins, lipids, nucleic acids and other compounds such as vitamins and ATP. The gases carbon dioxide and oxygen, water and mineral ions from the surroundings are prerequisite to the formation of these organic compounds. The energy required for cellular activities is released from organic compounds under the influence of enzymes.

OBJECTIVES

→ Recognise the requirements of all cells for survival, including:
  – matter (gases such as carbon dioxide and oxygen)
  – simple nutrients in the form of monosaccharides, disaccharides, polysaccharides
  – amino acids, fatty acids, glycerol, nucleic acids, ions and water
  – removal of waste (carbon dioxide, oxygen, urea, ammonia, uric acid, water, ions, metabolic heat)
→ Recognise that biochemical processes are controlled and regulated by a series of specific enzymes.
→ Describe the structure and role of the active site of an enzyme.
→ Explain how reaction rates of enzymes can be affected by factors including temperature, pH, the presence of inhibitors, and the concentrations of reactants and products.

Source: *Biology 2019 v1.2 General Senior Syllabus*
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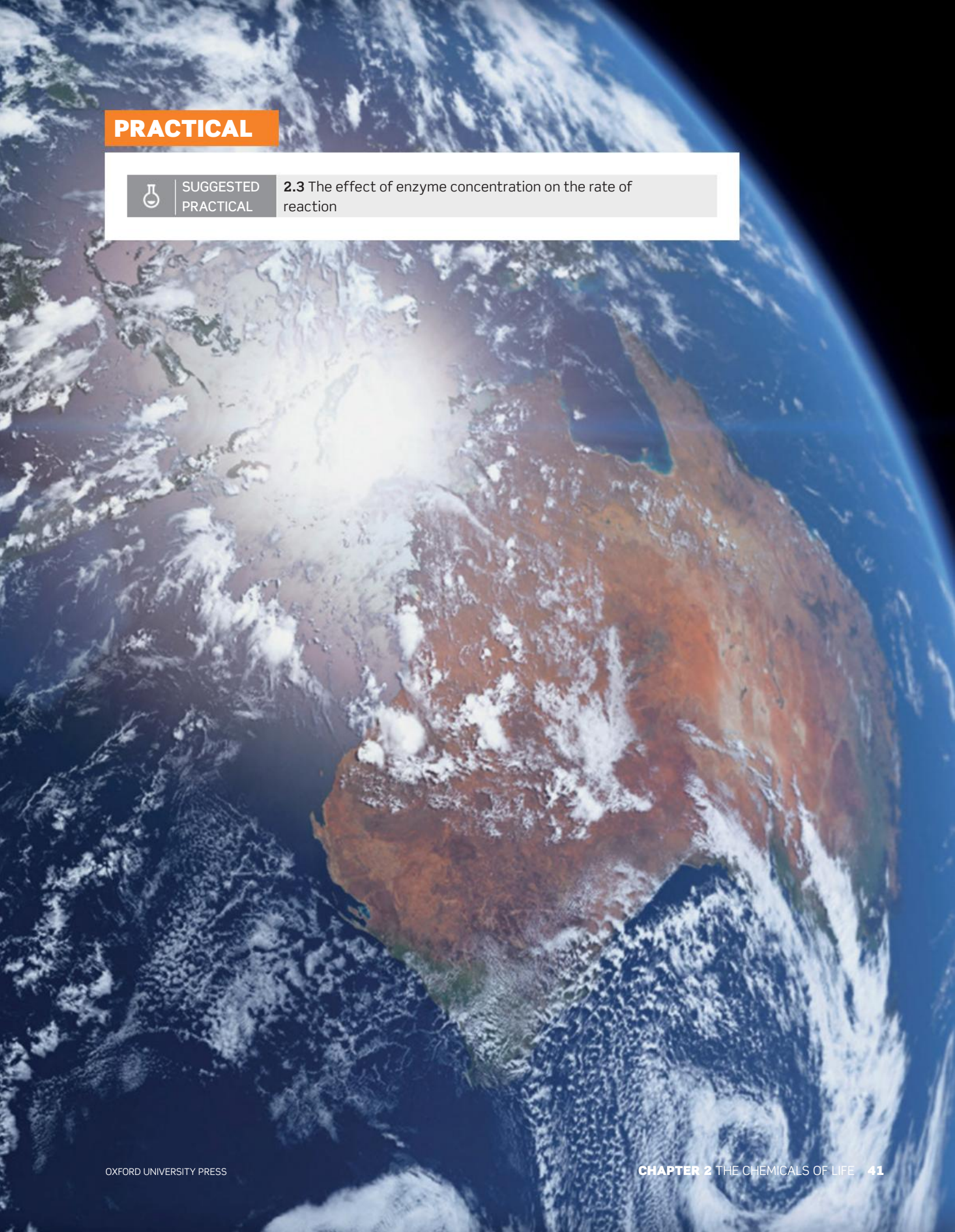
FIGURE 1 Life on Earth relies on many factors for its existence. The cells that make up all living things need energy and matter such as carbon dioxide or oxygen to function and survive.



PRACTICAL

SUGGESTED PRACTICAL

2.3 The effect of enzyme concentration on the rate of reaction

2.1 Organic compounds in living things

KEY IDEAS

- Saturated and unsaturated carbon compounds
- Monomers and polymers
- Dehydration synthesis (condensation) and hydrolysis
- Structure and function of carbohydrates, proteins, lipids, phospholipids and nucleic acids
- The function of vitamins

organic compound
a complex carbon compound formed by living things; usually a macromolecule

inorganic compound
a chemical compound that does not contain carbon (except carbonates and cyanides) or carbon–hydrogen bonds

monomer
the basic building block of an organic compound

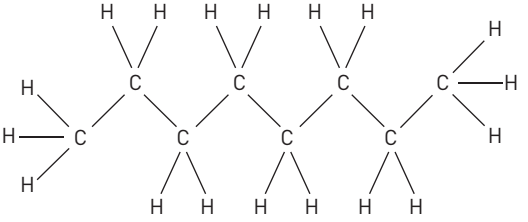
polymer
a macromolecule formed by the union of many monomers

unsaturated compound
a substance in which two or more electrons are shared between adjoining carbon atoms in a molecule

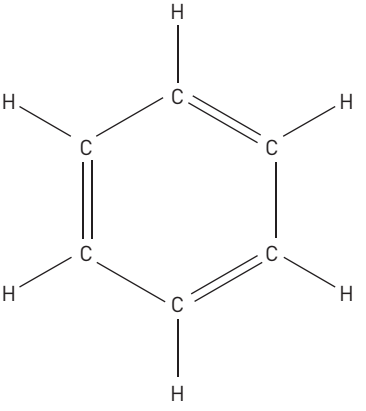
saturated compound
a compound in which only single electrons are shared between any two carbon atoms in the compound

Matter can be divided into living (**organic compounds**) and non-living (**inorganic compounds** and molecules). Inorganic substances essential for living things include water, oxygen, carbon dioxide, nitrates and phosphates. Both types of matter are made up of the same types of elements, but in organic compounds the elements are arranged into large, complex chemical compounds, which contain carbon. These large compounds consist of units of smaller molecules (**monomers**) bonded together to form large macromolecules (**polymers**).

Carbon has a valency of 4 and so can share four electrons with other atoms, each capable of forming a single covalent bond. It can form stable chains or rings with other carbon atoms. The carbon–carbon bond is often referred to as the skeleton or backbone of the organic molecule. Carbon can also share either two or three electrons with another atom (e.g. nitrogen, oxygen or another carbon atom) and therefore forms multiple strong covalent bonds. The number of lines drawn between two atoms in a structural formula indicates the number of electrons they share. If a compound contains any multiple carbon–carbon bonds it is said to be an **unsaturated compound**. Such molecules can combine with other atoms. A **saturated compound** with carbon contains only single carbon–carbon bonds and cannot combine with other atoms.



octane, C_8H_{18} = chain structure
saturated carbon compound



benzene, C_6H_6 = ring structure
unsaturated carbon compound

FIGURE 1 Carbon skeletons

Monomers and polymers

Simple organic molecules present in all living material are called monomers. They are the building blocks for the larger macromolecules or polymers. Two monomers bond together by the removal of water (a hydrogen ion is removed from one monomer and a hydroxyl ion from the other). The formation of the bond between the two monomers takes place in the presence of a biological catalyst or enzyme (a chemical which changes the rate of biological reactions)

that is specific for that particular reaction. This type of reaction is termed dehydration synthesis or **condensation** since water is removed and a larger molecule is formed.

Polymers can be broken down into smaller molecules and monomers by addition of a water molecule between each monomer. Again, a specific enzyme brings about the reaction. This type of reaction is called **hydrolysis**.

The main organic compounds in living things are:

- carbohydrates
- proteins
- lipids
- nucleic acids
- vitamins.

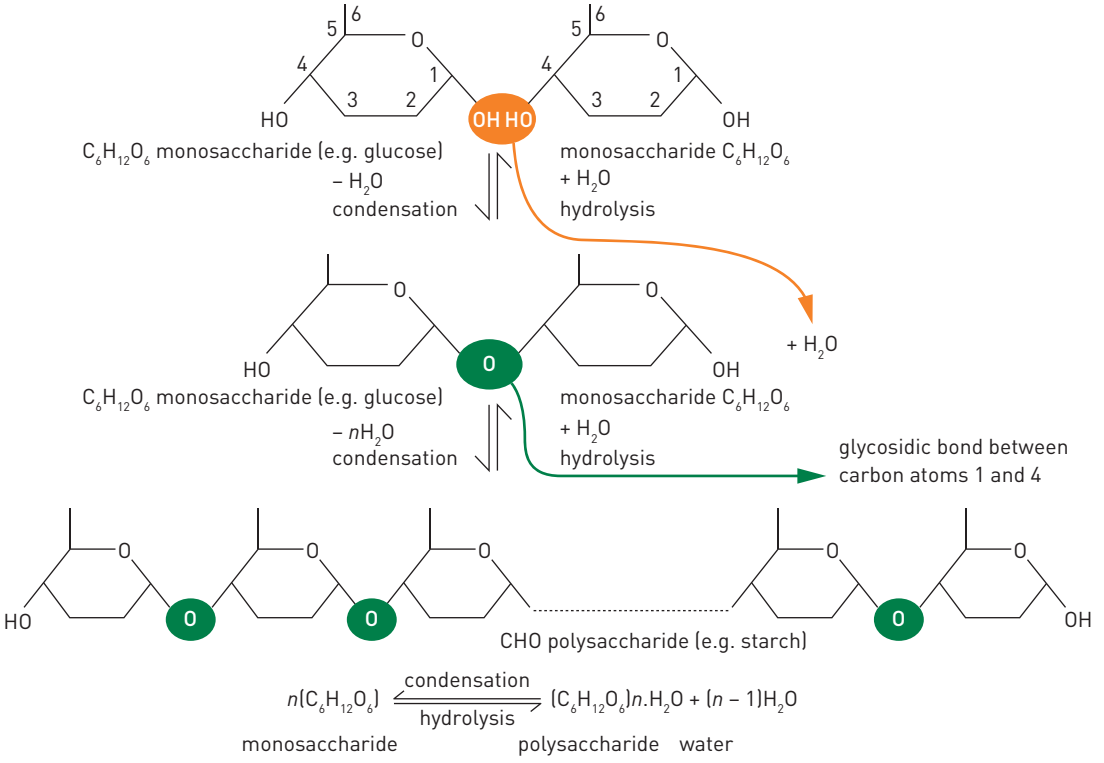


FIGURE 2 Formation of a polysaccharide where *n* = number of monomers. Monomers become linked together as a water molecule is removed between each pair of monomers (condensation). A polymer (e.g. polysaccharide) can be broken down into its component monomers by the addition of a water molecule between each pair of monomers (hydrolysis).

Carbohydrates

Carbohydrates contain the elements carbon, hydrogen and oxygen in the ratio of 1:2:1 in the monomer. They are hydrated carbons, being composed of one water molecule to every carbon atom. Carbohydrate monomers are called **monosaccharides.** Glucose is a monosaccharide with the formula $C_6H_{12}O_6$. **Disaccharides** are formed from two monosaccharides. The bond formed between the two is termed a **glycosidic bond**. Further monosaccharides can be added by condensation reactions to form **polysaccharides**.

Carbohydrates are important energy sources and can be stored in the form of polysaccharides: starch in plants and glycogen in fungi and animals. Polysaccharides may

condensation
an enzymatic build-up of monomers into a larger molecule by the removal of a water molecule between each pair of monomers

hydrolysis
the enzymatic breakdown of polymers involving the addition of a water molecule when the bond between monomers is broken

carbohydrate
a molecule of carbon hydrated with water; monomer having the general formula of $(CH_2O)n$ i.e. ratio of C:H:O = 1:2:1. Polymers have the general formula $(C_6H_{10}O_5)nH_2O$ (there is less hydrogen and oxygen due to formation of glycosidic bonds)

monosaccharide
a monomer of carbohydrates

disaccharide
a molecule composed of two chemically bound monosaccharides, e.g. sucrose

glycosidic bond
the bond formed by condensation between two monosaccharides

polysaccharide
a complex carbohydrate composed of many monosaccharides bonded together

cell wall
a rigid structure surrounding the cells of bacteria (murein), fungi (chitin) and plants (cellulose)

have a structural function (e.g. cellulose in plant **cell walls**, and chitin in fungi and the exoskeletons of arthropods). Polysaccharides are good storage molecules because:

- their large size makes them more or less insoluble in water, so they do not affect the water balance of the cell
- they are able to fold into compact shapes (e.g. starch)
- they are readily converted to sugars by hydrolysis when needed.

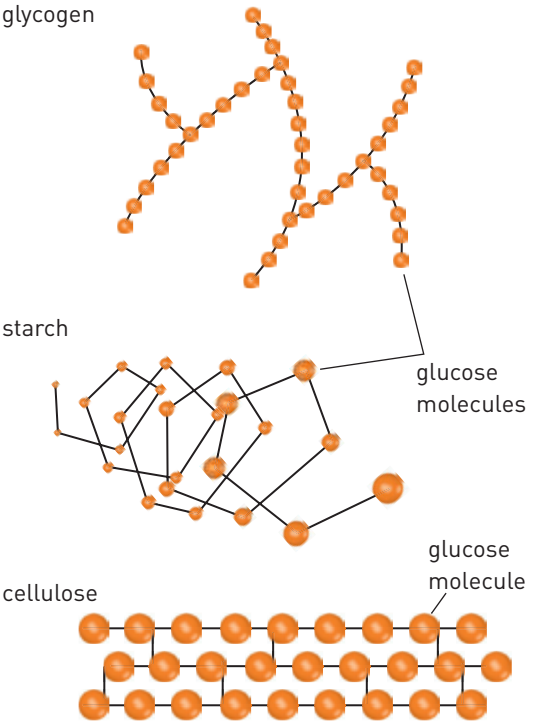


FIGURE 3 Simplified models of carbohydrates to illustrate ways in which glucose molecules can be arranged to give different structures and therefore different functions

Proteins

Proteins always contain C (carbon), H (hydrogen), O (oxygen) and N (nitrogen). Other elements, such as sulphur and phosphorus, may be present. The monomer is an **amino acid**.

amino acid
a building block of protein consisting of an amino group (NH_2), a carboxyl (acid) group (COOH), a variable (R) group and a hydrogen atom attached to a carbon atom

Each amino acid has the same basic structure except for one group of atoms, which varies and is given the general letter 'R'. There are about 20 different amino acids, each differing only in the composition of the R group, which may be a single atom or a large group of atoms.

A **dipeptide** is formed when two amino acids bond together by condensation. A **peptide bond** is formed between the two molecules. **Polypeptides** are formed by the continued condensation of more amino acids onto the molecule, and may be several hundred amino acid units long. A **protein** is a macromolecule consisting of one or more polypeptide chains that may be folded, branched and/or cross-linked at intervals.

dipeptide
a molecule formed by the bonding of two amino acids

peptide bond
a bond formed from condensation between two amino acids, where hydrogen (H) is lost from the amino group and a hydroxyl group (OH) from the carboxyl group

polypeptide
a macromolecule formed by the union of many amino acids

protein
a macromolecule, consisting of one or more polypeptide chains, which may be folded, branched and/or cross-linked at intervals

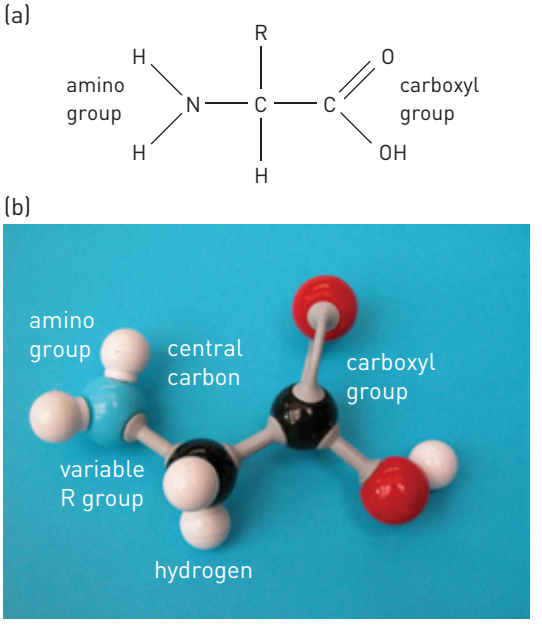


FIGURE 4 The general formula of an amino acid

Although there are only 20 amino acids, the number of possible sequences of these is infinite. A typical human cell can contain 10 million protein molecules of about 10 000 different types. Each has a function that is determined by its unique chemical nature. One small change in the amino acid sequence of a protein may alter or destroy the way in which that particular protein functions.

As a polypeptide chain is assembled, interactions between different amino acids along the chain may cause it to fold. The structure may be in the form of a pleated sheet (e.g. the silk fibres of spider webs). These proteins are known as fibrous proteins and have a structural or mechanical function.

CASE STUDY 2.1A

The amino acid sequence

Haemoglobin is the pigment carried in red blood cells. It has the special property of being able to combine loosely with oxygen, picking it up from areas where oxygen levels are high (e.g. the lungs) and depositing it in areas where it is low (e.g. active cells).

The haemoglobin molecule consists of two pairs of polypeptide chains, each of which is combined with an iron-containing group. Each type of chain contains about 150 amino acids. The entire haemoglobin molecule consists of 600 amino acids and four iron groups.

In the hereditary disease sickle-cell anaemia, one amino acid (glutamic acid) in each chain of one of the pairs is replaced by a molecule of a different amino acid, valine. The two substituted valines create two 'sticky' areas on the surface of the haemoglobin molecule. These areas are attracted to each other and distort the shape of the entire molecule into a stiffened rod.

Red blood cells containing large proportions of these altered molecules become stiff and deformed, taking on a characteristic sickle shape. These cells are much more fragile than normal red blood cells and rupture easily. Because of their shape, they tend to clog small blood vessels, creating blood clots that prevent a full supply of blood to vital organs. This results in pain, intermittent illness and often a shortened life span.

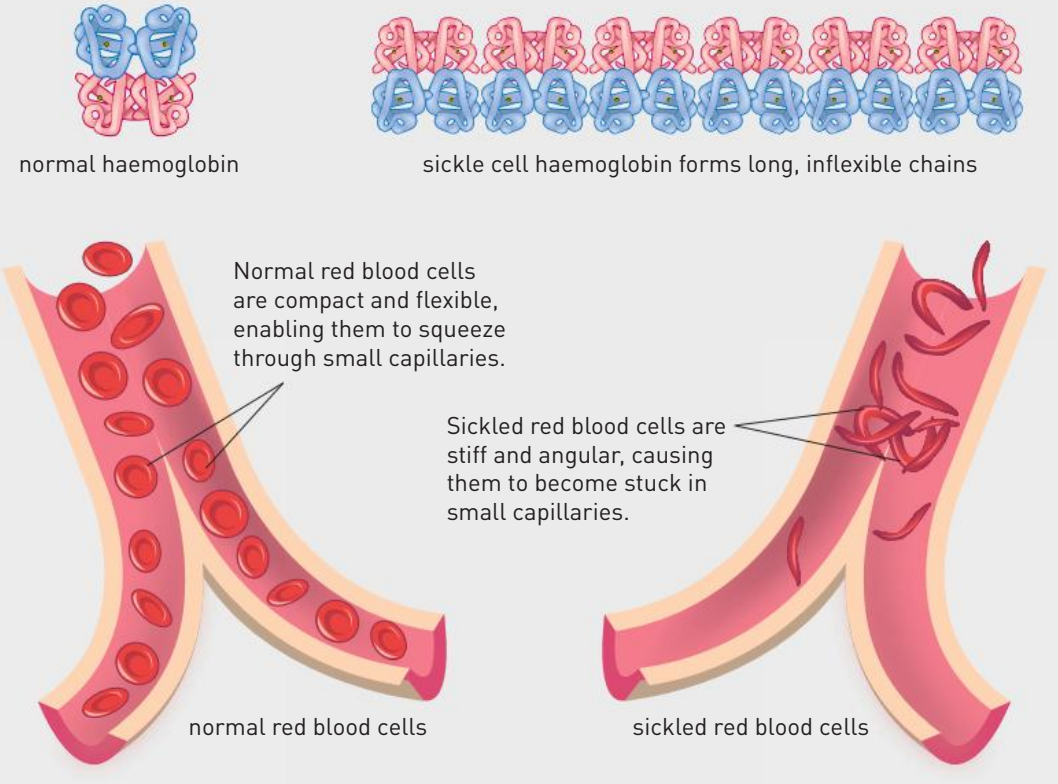


FIGURE 5 Comparison of normal haemoglobin (and red blood cells) and sickle cell haemoglobin (and abnormal sickled red blood cells)

TABLE 1 Types of proteins and their functions in living organisms

Category	Example	Type	Occurrence/function
Structural	Keratin	Fibrous	Skin, feathers, nails, hair, horn, silk
	Sclerotin	Fibrous	Exoskeleton of insects
Mechanical	Collagen	Fibrous	Tendons, cartilage, bones – resists stretching
	Elastin	Fibrous	Ligaments
Enzyme	Amylase	Globular	Catalyses hydrolysis of starch to maltose
	Trypsin	Globular	Catalyses hydrolysis of protein
Hormone	Insulin	Globular	Involved in glucose metabolism
Transport	Haemoglobin	Globular + iron group	Transports oxygen in vertebrates' blood
Protective	Antibodies	Globular	Form complexes with foreign proteins to neutralise them
Contractile	Myosin	Fibrous	Moving filaments involved in muscle contraction
	Actin	Fibrous	Stationary filaments involved in muscle contraction
Storage	Egg albumin	Globular + non-protein group	Egg white protein
	Casein	Globular + non-protein group	Milk protein
Toxins	Snake venom (enzymes)	Globular	Paralyse/kill prey

In other proteins, the amino acid chain forms a helix (e.g. keratin) and there are interactions between the R groups of the individual amino acids, forming a compact globular shape (e.g. enzymes). (See Table 1.)

Proteins may become denatured (i.e. lose their specific three-dimensional shape and therefore reactivity) by heat, strong acids and bases, organic solvents and heavy metals.

lipid
an ester of fatty acids and glycerol

fatty acid
a compound (RCOOH) formed between a carboxyl (COOH) group and a chain of hydrocarbons of variable length (R)

glycerol
a structural component of lipids

hydrophobic
describes substances that are insoluble in water

hydrophilic
describes substances that dissolve readily in water

ester bond
a bond formed by condensation between a fatty acid (removal of OH) and glycerol (removal of H)

Lipids

Lipids are fats, oils and waxes. Fats and waxes are solid, whereas oils are liquids at room temperature. Lipids contain carbon, hydrogen and oxygen but, unlike carbohydrates, there is no set ratio. They are composed of two basic units: **fatty acids** and **glycerol**.

Fatty acids have the general formula RCOOH, where R is a variable group consisting of a hydrocarbon chain. This 'tail' is non-polar (does not carry an electric charge) and **hydrophobic** (*hydro* = water; *phobos* = fear). The carboxyl (acid) group (–COOH) is polar and **hydrophilic** (= water-loving). An **ester bond** is formed by a condensation reaction which removes an –H from the glycerol and an –OH from the fatty acid.

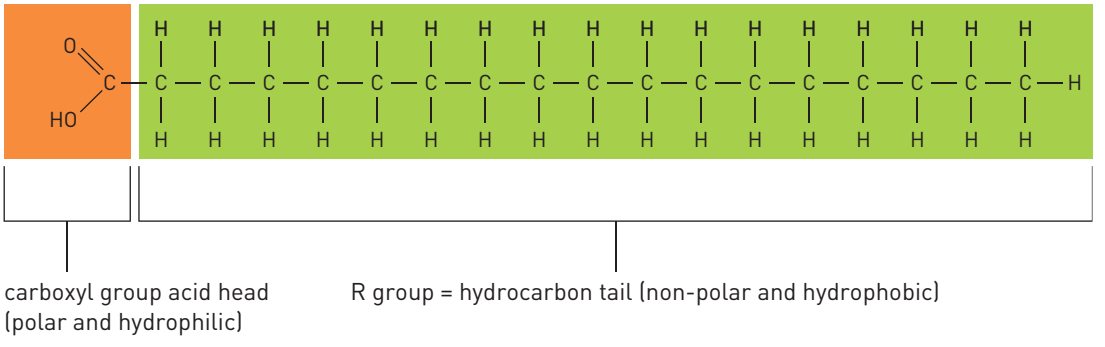


FIGURE 6 Basic structure of a fatty acid

Triglycerides

triglyceride
a lipid formed from one molecule of glycerol and three molecules of one or more different types of fatty acids

The most common lipids are **triglycerides**, formed when three fatty acids bond with a glycerol molecule (Figure 7). The fatty acids may be all the same or they may be different.

The physical nature of the lipid is determined by the length of the carbon chains in the fatty acids, and whether these chains are saturated or unsaturated. Lipids formed from saturated fatty acids are more compact, and therefore are solids (fats, e.g. butter and lard). Lipids with one or more unsaturated fatty acid chain do not pack together and so are liquid (oils, e.g. olive oil, peanut oil).

Lipids are non-polar, so they are relatively insoluble in water. They play an important role in the control of water balance in the organism. Lipids, therefore, are an important component of the membranes surrounding cells. Waxes form protective waterproof coatings on the external surface of the exoskeleton of insects, the feathers of birds and hair of mammals. Many plant surfaces, such as on the leaves and fruits, are coated with a lipid cuticle that reduces evaporative water loss.

Because they are able to store double the amount of energy as an equivalent mass of carbohydrate, lipids are important energy reserves in living organisms. In animals, fat is stored in special cells, which in vertebrates are commonly found under the skin. This fat layer is especially important to animals living in cold environments. In seals and whales this 'blubber' acts as an insulator and contributes to buoyancy. Hibernating animals build up large fat reserves during summer, to provide them with energy over the cold winter months. Fat also surrounds and protects vital organs such as the mammalian heart and kidneys. Plants store oils rather than fats and these can be used as commercial sources of edible oils. Examples include coconuts, soya beans and sunflower seeds.

Water is a product of the breakdown of fat. This metabolic water is very useful to some desert animals such as the kangaroo rat and the camel.

Animal fats and oils such as milk, eggs, butter, cod-liver oil and liver contain the fat-soluble vitamins A and D, which are both essential to the human body.

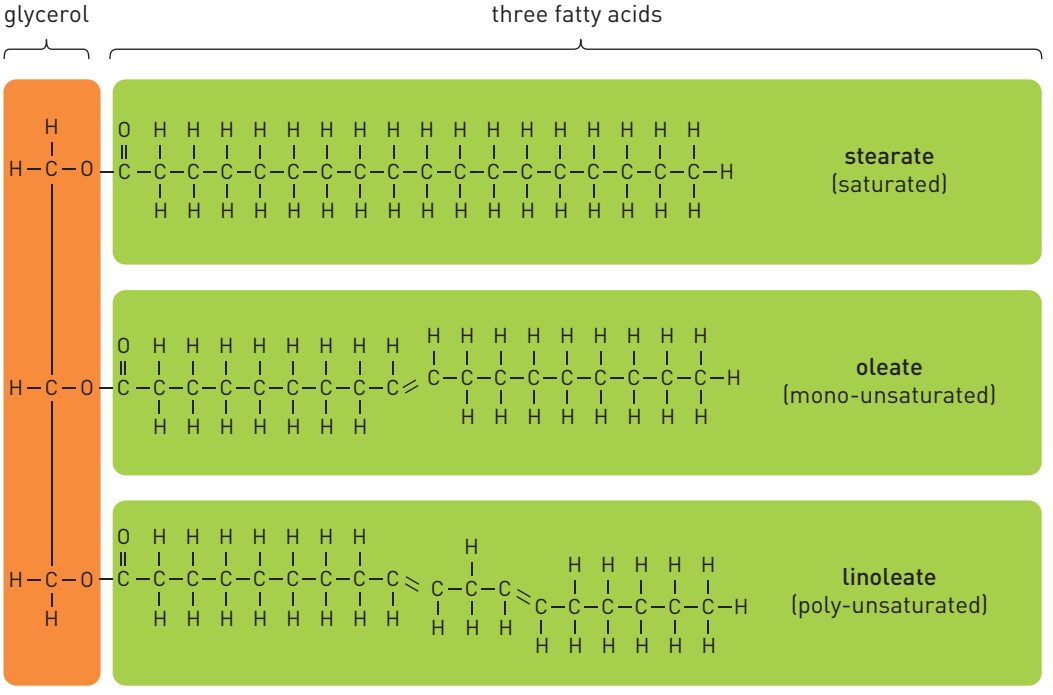


FIGURE 7 A triglyceride molecule

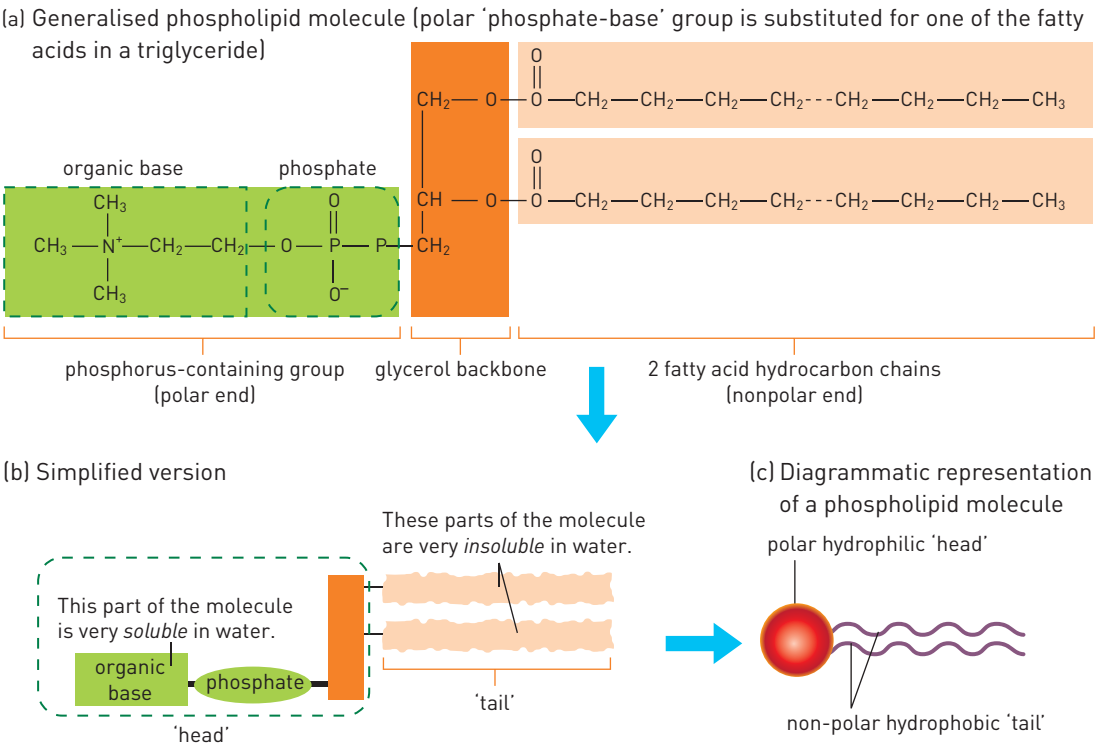


FIGURE 8 Structure of a phospholipid

phospholipid
a lipid in which a polar phosphate group replaces one fatty acid

deoxyribonucleic acid (DNA)
a double-chained, helical nucleic acid containing the sugar deoxyribose, capable of replicating and determining the inheritance of a cell's proteins

ribonucleic acid (RNA)
the single-stranded nucleic acid characterised by a ribose sugar in each nucleotide, and the bases adenine, uracil, cytosine and guanine

nucleotide
the building block of nucleic acid composed of a 5-carbon sugar, an organic nitrogen base and phosphoric acid

Phospholipids

Phospholipids are similar to triglycerides, except that a phosphate group plus an organic base substitutes for one fatty acid. They are important components of cell membranes. Similarly, a glycolipid is formed when a short carbohydrate chain replaces a fatty acid.

Steroids

Steroids have a chemical structure unlike other lipids. They are, however, classified with them since they are insoluble in water and soluble in fat solvents. Steroids include sex hormones, adrenal cortex hormones and cholesterol. They are abundant in both plants and animals where they have many important biochemical and physiological roles. Cholesterol, a steroid, is found throughout the human body as it is an important component of cell membranes and a constituent of bile, which emulsifies fats. Gallstones are cholesterol particles that have precipitated from the bile in the gall bladder.

Nucleic acids

Nucleic acids are the macromolecules that make up the genetic material of all living organisms. There are two principal types of nucleic acids – **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. The building blocks of nucleic acids are **nucleotides**, each of which consists of:

- a pentose sugar (5C) arranged in a ring
- an organic nitrogen base
- a phosphate.

CASE STUDY 2.1B

Cholesterol and heart disease

Cholesterol is an essential molecule in animal bodies and has several functions. As a component of the cell membrane, its main function is to limit uncontrolled leakage of water and soluble ions in and out of the cell. In nerve cells, it prevents the outward flow of ions that would 'short-circuit' the flow of nerve impulses. On the other hand, cholesterol can lead to heart disease and strokes.

The liver regulates cholesterol levels in the body. When cholesterol is needed, the liver synthesises it from saturated fatty acids; when there is excess in the blood, the liver breaks it down. Lipids are insoluble in water, so cholesterol molecules are 'wrapped' in a layer of water-soluble proteins for transport in the blood plasma. There are two forms of these 'packages': low-density lipoproteins (LDLs) and high-density lipoproteins (HDLs). LDLs transport cholesterol to the body cells for use. HDLs carry excess cholesterol to the liver for breakdown.

If too much cholesterol is eaten in meat, cheese and egg yolk, the liver is unable to get rid of the excess. This situation is made worse if too much fat is eaten, because the liver converts this to cholesterol. The cells lining the arteries take up this excess. The fatty deposits trigger abnormal growth and the production of fibrous materials by the cells, producing a condition known as atherosclerosis. Gradually the artery becomes more and more blocked by the growth of tissue until blood is unable to flow through the vessels. Heart attack may result from clogging of the arteries that supply the heart muscles (coronary arteries). If arteries in the brain become blocked, a stroke may occur.

Heart disease may be hereditary. Normal liver cells have special receptors on their surface that take up LDLs, but in one form of heart disease these receptors are missing. The liver cells are unable to take up LDLs and so continuously produce and export cholesterol. People with this condition usually do not live past their early twenties. Other people seem to be protected because they produce large quantities of HDLs that rapidly transport excess cholesterol to the liver for breakdown. For the majority of people, the risk of heart disease is related to level of exercise (which seems to increase HDLs), smoking cigarettes (which seems to decrease HDL levels) and diet.

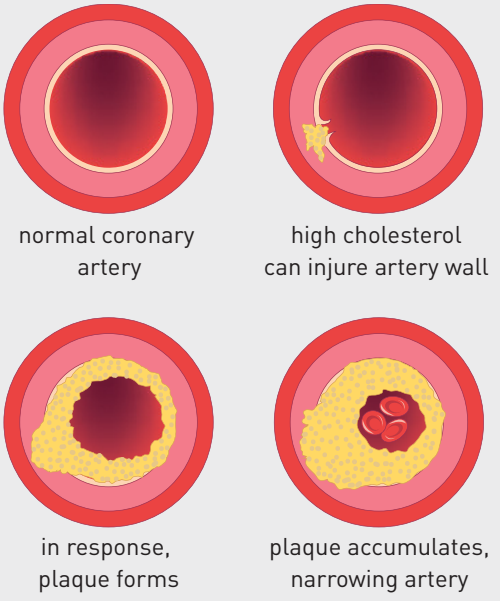


FIGURE 9 Blockage of a coronary artery due to cholesterol deposition

The formation of a nucleotide involves bonding between the sugar and the base, and between the sugar and phosphate. Two nucleotides join by condensation between the phosphate group of one and the sugar of the other nucleotide. Further condensation reactions result in chains; the sequences of the bases give each chain its structural and functional properties. The nucleotide can be broken down into its three components by the addition of two molecules of water (hydrolysis).

DNA and RNA differ in a number of ways (see Table 2):

- The sugar in DNA is deoxyribose, whereas the sugar in RNA is ribose.
- The RNA molecule is composed of a single chain of nucleotides, while DNA consists of two parallel chains held together by the pairing of bases between adjacent chains. This gives a ladder-like structure to the DNA molecule, which twists on its axis, forming a double helix.
- There are five different types of bases found in nucleic acids. In DNA these bases are adenine, guanine, thymine and cytosine. In RNA the thymine is replaced by uracil.

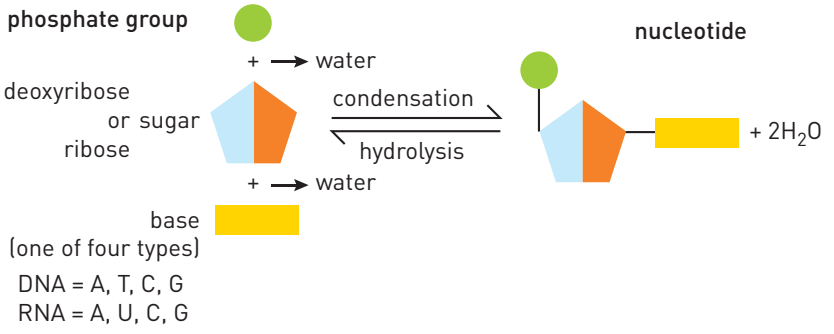


FIGURE 10 Formation of a nucleotide

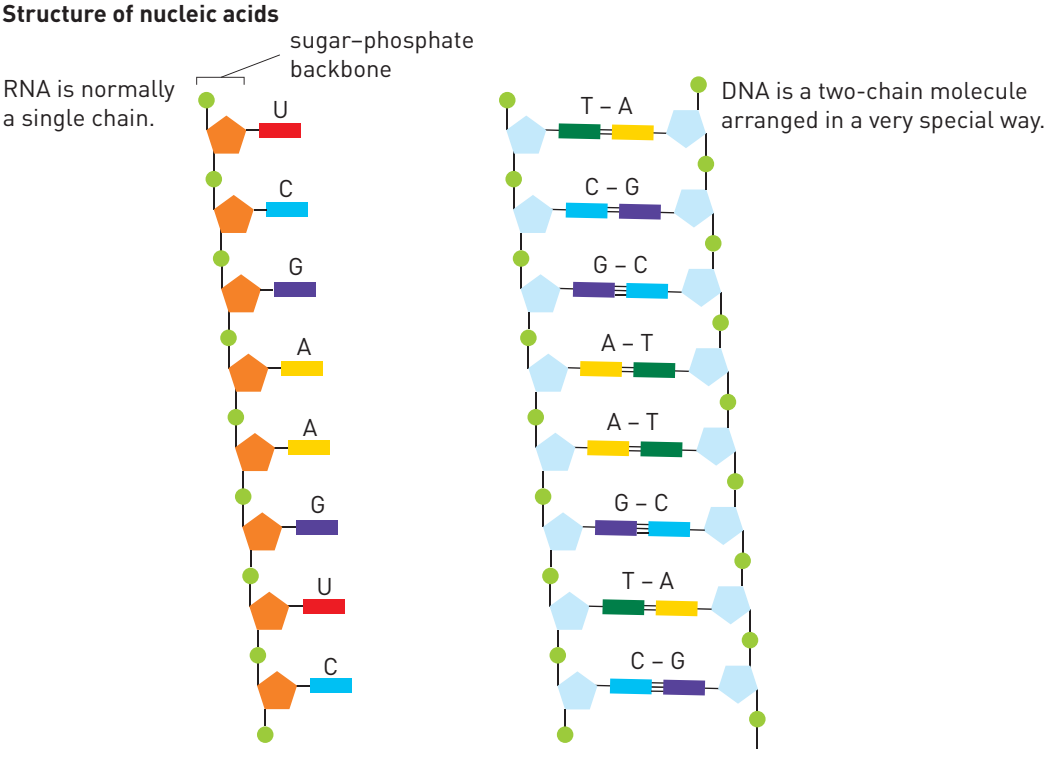


FIGURE 11 Bonding of nucleotides in the formation of nucleic acids

FIGURE 12 A model of the DNA double helix

Adenine and guanine are similar in structure, and thymine, cytosine and uracil are similar to each other. Because of their differing chemical structure, different bases form complementary pairs that are able to link together.

TABLE 2 Comparison of DNA and RNA

Feature	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	Adenine, thymine, guanine, cytosine	Adenine, uracil, guanine, cytosine
Chains	Double	Single

Therefore adenine and thymine are a complementary pair, and guanine and cytosine are a complementary pair. It is thought that hydrogen bonds between these bases hold the two chains of the DNA molecule together. Because only these combinations of bases can link, the two chains of the DNA molecule are always complementary chains.

This molecule then twists on itself to form a double helix.

A **chromosome** in eukaryotic organisms is linear and consists of DNA strands and proteins. Each DNA strand is made up of huge numbers of paired nucleotides. Segments of these paired nucleotides are **genes**, each of which is the coded instruction for the production of a particular protein. The total amount of DNA in each cell represents the organism's **genetic code**. The DNA molecule is therefore responsible for transmission of the genetic code from one generation to the next and controls the actions of the cell through protein synthesis.

There are three major types of RNA— messenger (m), transfer (t) and ribosomal (r) RNA, all of which are involved in the translation of the genetic code into protein production by the cell.

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

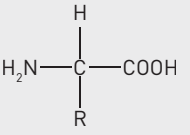
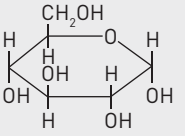
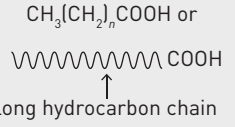
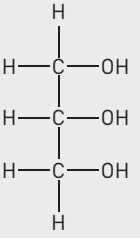
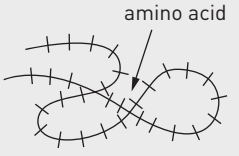
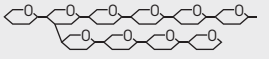
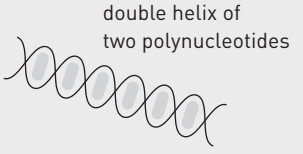
gene
a segment of DNA which controls a specific characteristic through protein production

genetic code
the sequence of nucleotides in a DNA molecule, coding for a particular protein

TABLE 3 Chemical building blocks of carbohydrates, proteins, nucleic acids and lipids

Smaller molecules (building blocks) = monomers	Macromolecules formed = polymers
Monosaccharides (e.g. glucose) = sugars (Many types, but only a few are common – usually only one type per molecule)	Polysaccharides
Amino acids (20 common types, and all may be present in one molecule)	Polypeptides proteins
Nucleotides (Sugar, phosphate and base; there are five types of bases)	Nucleic acids
Fatty acids and glycerol	Lipids (fats and oils)
Fatty acids, glycerol and phosphate	Phospholipids

TABLE 4 The structure of organic molecules

Organic substance	Elements present	Relative size	Outline of structure
Amino acid	C, H, O, N	Small	
Sugar (monosaccharide)	C, H, O	Small	
Fatty acid	C, H, O	Small	
Glycerol	C, H, O	Small	
Protein	C, H, O, N	Large (polymer of amino acids)	
Polysaccharide	C, H, O	Large (polymer of sugars or monosaccharides)	
Nucleic acid	C, H, O, N, P	Large (polymer of nucleotides; nucleotide = nitrogen base, sugar, phosphate)	

Vitamins

Vitamins are organic chemicals, most of which animals cannot make for themselves but must obtain from their diets. Mammals (except humans and guinea pigs) can make their own vitamin C, and bacteria found in the intestines (probiotic bacteria) can make some other vitamins such as vitamin K, which is essential in blood clotting.

Vitamins are essential, in small amounts, for normal cell reactions. For example, the vitamin B group is necessary for respiration, and nucleic acid and protein metabolism, while vitamin C helps in the formation of connective tissue and prevents the oxidation of cell chemicals to harmful products.

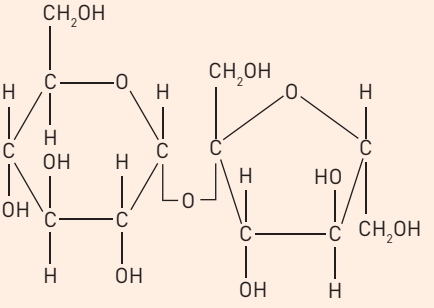
CHECK YOUR LEARNING 2.1

Describe and explain

1 Carbon has a valency of 4. **Explain** why this makes it an ideal constituent of biological molecules.
2 **Explain** how long chains or rings of carbon molecules form.
3 **Describe** the difference between a saturated and an unsaturated carbon compound.
4 **Define** a macromolecule. **Describe** the molecules of which macromolecules are composed.
5 **Explain** how bonds form between two monomers. **Identify** the name of this process.
6 **Identify** the name of the process whereby polymers are broken down into smaller molecules. **Identify** two things that are needed for this reaction to occur.
7 **Recall** the general formula for a carbohydrate.
8 **Demonstrate** the structural formula for an amino acid.
9 There are approximately 20 amino acids. How are they similar and how do they differ?
10 **Describe** how a protein differs from a polypeptide.
11 **Describe** in what ways a lipid differs from:
   a a protein
   b a carbohydrate.
12 **Identify** the three components of a nucleotide.
13 **Describe** the differences in structure between DNA and RNA.
14 **Explain** the functions of DNA and RNA.
15 **Explain** how the bases of two adjacent strands of DNA are held together.

Apply, analyse and interpret

16 The carbohydrate illustrated below is formed from two hexose sugars. Apply your knowledge to answer the following.



   a **Classify** this as a type of carbohydrate.
   b **Determine** the name of the reaction by which the two sugars joined.
17 Egg white is composed of the protein albumin. It is transparent and glue-like in consistency. When the egg is cooked, the albumin becomes rubbery and opaque. It cannot return to its original state after cooking. **Identify** what has happened to the albumin.

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2.2 Cellular energy

KEY IDEAS

- Properties of energy
- Cellular requirements for energy
- Energy transfer between cells and their environment
- Catabolic and anabolic reactions of cellular metabolism
- The concept of activation energy

A cell needs a constant supply of energy to grow, to reproduce and to stay alive. Energy is the ability to do work or to cause a change. There are different forms of energy, each given a different name:

- electrical energy
- chemical energy
- mechanical energy.

Living cells draw primarily on chemical energy. Light is an important source of this energy and will be discussed in detail in Chapter 4.

FIGURE 1 Trees gain a large portion of energy from the sun through photosynthesis.

kinetic energy energy of motion

potential energy stored energy

All of these energy forms can be divided into two main categories: **kinetic energy** (energy of motion) and **potential energy** (stored energy).

Energy conversion

Energy cannot be created or destroyed, but different forms of energy can be changed into one another. All systems have a natural tendency towards increasing disorder. A more orderly arrangement of matter needs energy to maintain that arrangement and to counteract the tendency towards disorder. Just as the structure of a house is an unnatural organisation (i.e. it is most unlikely to occur spontaneously), so too the living cell is an inherently unstable and improbable organisation. Only by constant use of energy can it maintain itself.

The molecules of many of the compounds of living cells are highly complex and are composed of many thousands of atoms bonded together. Many of these bonds, particularly C–H, are relatively rich in chemical bond energy. Therefore, a living organism is a storehouse of potential chemical energy which can be used, when necessary, to do work. But as this stored energy is converted to other forms, less and less remains in reserve. A source of usable energy outside the organism must be available to replenish its supply of chemical bond energy. For many organisms (heterotrophs), that outside energy source is other organisms; for other organisms (autotrophs), the source may be inorganic molecules (chemosynthesis) or sunlight (**photosynthesis**).

photosynthesis the process whereby light energy is converted to the chemical energy of glucose; requires chlorophyll, carbon dioxide, water and a suitable temperature; occurs in green plants, algae and some bacteria

All of these energy conversions are accomplished without reducing the total amount of energy. It might seem, therefore, that energy can be passed continuously from organism to organism and that no source of energy outside living things would be required. However, energy is constantly passed from organisms to non-living matter (e.g. heat loss from the body to the surrounding air), and is lost to the life system. The molecules of substances that leave the body retain some energy

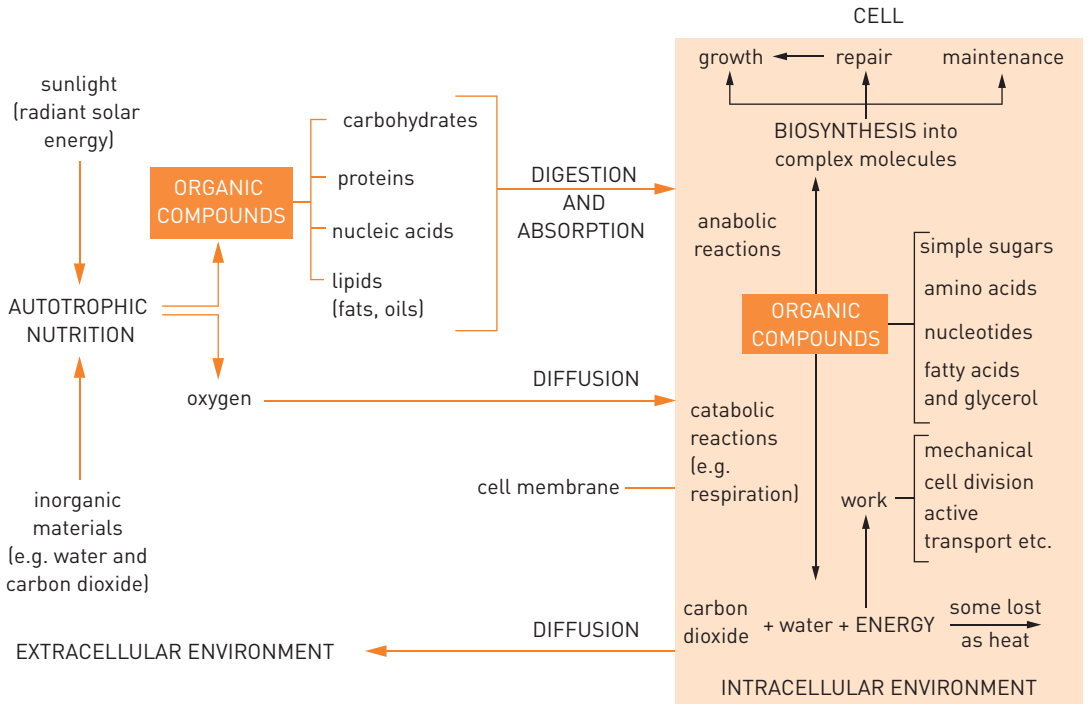

FIGURE 2 Energy transfer between the environment and a heterotrophic cell

Metabolism

Chemical reactions occurring in cells constitute **metabolism**. Metabolic processes proceed in small steps, the sum of which is called a metabolic pathway. These reactions may be synthetic (**anabolism**) or breakdown (**catabolism**). Anabolic reactions tend to absorb energy (**endergonic**), whereas catabolism tends to release energy (**exergonic**). All the catabolic and anabolic reactions occurring at any time in a cell constitute its metabolism. The energy released by catabolic reactions is required for driving anabolic reactions, for work (e.g. muscular **contractions**) and for maintenance purposes. Some energy is lost as heat energy.

catabolism + anabolism = metabolism

$$\text{simple molecules + ENERGY} \underset{\text{CATABOLISM metabolic pathway}}{\overset{\text{ANABOLISM metabolic pathway}}{\rightleftharpoons}} \text{large complex inorganic molecules}$$

One of the most important metabolic pathways yielding energy is the breakdown of sugar. This is an oxidation process. As sugar is broken down, energy is liberated as carbon dioxide and water are formed. The process can be shown in simplified form by the following formula:

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

The sugar molecule contains potential energy, which is freed only when the molecule is split and new molecules formed.

Mixing sugar and oxygen does not automatically ensure that the oxidation process will proceed. The reaction must be activated, and for this to occur **activation energy** is needed. For example, wood does not burn spontaneously. In order to release the great amount of

metabolism
chemical reactions occurring within a cell

anabolism
chemical reactions in which large molecules are built up, usually with a net input of energy

catabolism
chemical reactions in which large molecules are broken down into smaller ones, usually accompanied by the release of energy

endergonic
describes a chemical reaction requiring input of energy

exergonic
describes a chemical reaction in which energy is released

contraction
shortening (e.g. of a muscle)

activation energy
the energy needed to start a chemical reaction

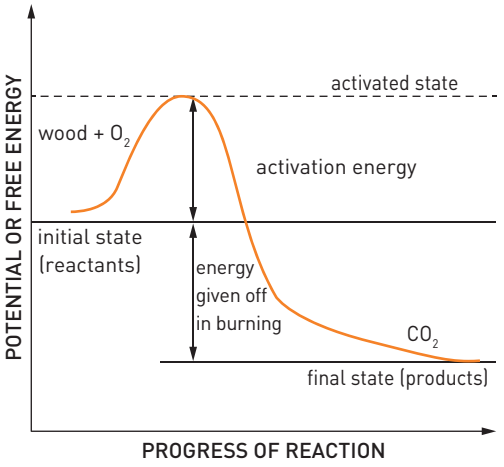

FIGURE 3 Energy relationships in a chemical reaction (e.g. burning wood)

energy stored in wood, it must first be heated. Whether any chemical reaction gives off energy or absorbs it, some energy must initially be added to start the reaction.

The molecules of the reactants in any chemical reaction are in a state of continual random motion. Only when they collide and come into contact can they react. Any factor that increases the frequency of collision will increase the speed of the reaction. In general, the two factors are:

1 concentration of the substrate molecules
2 temperature.

The more concentrated the molecules (i.e. the more densely they are packed), the more likely they are to collide and react. Raising the temperature speeds up the random motion of the molecules, thereby increasing the probability of their colliding.

Catalysts also change the rate of a reaction. The reacting molecules are absorbed onto the surface of the catalyst where, because they have been brought into close proximity, they react. The product leaves the surface of the catalyst, which is quite unchanged by the process and may be used again. Many biological reactions can be made to occur more quickly by heating. Cells, however, cannot tolerate too much heat, since many biological compounds decompose at high temperatures. Catalysts, therefore, are important in metabolism. In this case the catalysts are always organic and operate in a slightly different way from the surface catalysts described. The biological catalysts found in living systems are called **enzymes**.

enzyme
an organic catalyst, produced by living cells, that changes the rate of chemical reactions in living organisms

CHECK YOUR LEARNING 2.2

Describe and explain

1 **Explain** why cells require a constant input of energy.
2 **Summarise** the relationship between activation energy and chemical reactions.
3 **Identify** factors that determine whether or not a particular chemical reaction will take place in a cell.
4 **Identify** two factors (other than temperature) which influence the rate of enzyme activity.

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2.3 Enzymes

KEY IDEAS

- How enzymes act
- Comparison of the 'lock and key' and 'induced fit' hypotheses for enzyme action
- Properties of enzymes
- Coenzymes and cofactors
- Classification of enzymes

Enzyme action

Enzymes are globular proteins that lower the activation energy needed for a chemical reaction to take place. They speed up the actual rate of the reaction without altering, to any great extent, the temperature at which it occurs. The uncatalysed reaction is:

$$A + B \rightarrow AB$$

reactant + reactant → product

The addition of an enzyme provides an alternative set of reactions that produce the same overall change but at a lower net activation energy:

$$A + X \rightarrow AX$$
$$AX + B \rightarrow AB + X$$

where X is the enzyme, A is the substrate, AX is enzyme–substrate complex, B is the reactant and AB is the product.

substrate + enzyme → enzyme–substrate complex + reactants → products + enzyme

The enzyme does not react and therefore is not changed. It can be reused in further similar reactions.

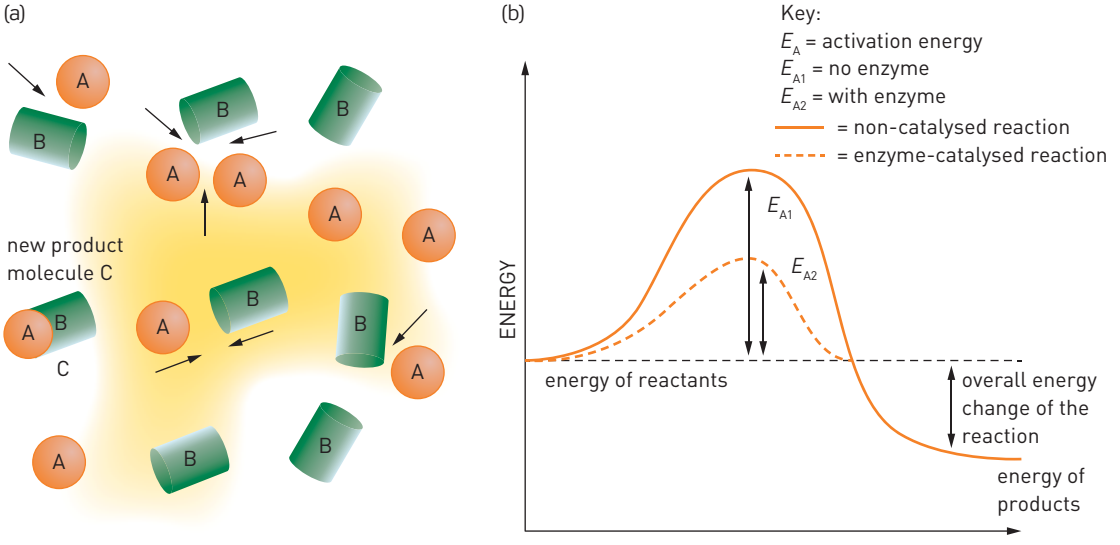
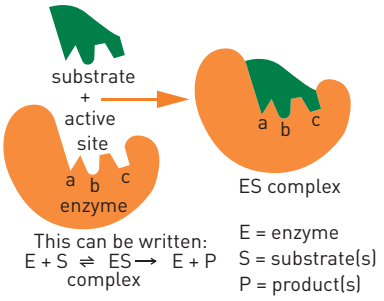


FIGURE 1 Enzymes as catalysts. (a) Molecules in constant motion, colliding with each other sometimes and occasionally reacting; only when molecules have enough energy will they collide and react; (b) energy diagram shows that having enzymes present lowers the activation energy needed for the reaction.

(a) The 'lock and key' model for enzyme action substrate



(b) The 'induced fit' model for enzyme action; the shape of the enzyme's active site is modified to accommodate the substrate.

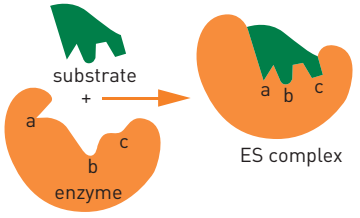


FIGURE 2 Comparison of the (a) 'lock and key' and (b) 'induced fit' hypotheses of enzyme action

Various hypotheses have been proposed to explain how enzymes lower the activation energy for a reaction. Different reactions may utilise one or more of the following methods:

- The enzyme, when bound to the substrate, may change shape. This may place stresses on some substrate bonds, making them more easily broken.
- Substrates may form weak bonds with their specific enzymes, resulting in the redistribution of electrons within the substrate molecule, making it more reactive.
- The enzyme–substrate complex may orient the substrate molecules in such a way that chemical reactions are maximised.

The 'lock and key' hypothesis and the 'induced fit' hypothesis

The overall action of enzymes can be explained by either the **'lock and key' hypothesis** or the **'induced fit' hypothesis**. The lock and key hypothesis suggests that an enzyme's function depends on its shape. Each enzyme is made up of long chains of amino acids that are folded into uniquely shaped 'globs'. An enzyme attaches to its substrate much as a lock and key fit together. The shape of the enzyme is complementary to the shape of the substrate. Because of this, the substrate molecules fit almost perfectly into the enzyme. The portion of the enzyme in contact with the substrate (**active site**) is very small in comparison with the total size of the enzyme molecule.

When an enzyme–substrate complex is formed it is 'activated' into forming the products of the reaction. Once formed, the product molecules no longer fit into the active site and escape into the surrounding medium, leaving the active site free to receive further substrate molecules.

It has been found that the substrate does not always fit precisely into the active site of the enzyme. According to the 'induced fit' hypothesis, somehow the shapes of both the enzyme and substrate are modified so that a better fit between the two is induced. This process distorts the substrate so that stresses weaken critical bonds to form a transitional substrate state. In this state, strong bonds can form between the substrate and the enzyme that lower the activation energy required for a chemical reaction.

Each enzyme controls only one (or one type of) reaction. This enzyme specificity occurs because the active site of any particular enzyme can accommodate only a certain shape of substrate molecule. Therefore, many different enzymes may be required in a multi-step reaction (e.g. respiration or photosynthesis; synthesis or hydrolysis of organic molecules).

'lock and key' hypothesis
the hypothesis explaining the interaction between an enzyme and its substrate in terms of the shapes of the molecules

'induced fit' hypothesis
idea that the active site of an enzyme, after initially attracting a specific substrate, can change in order to suit the substrate's shape and in doing so affects the shape of the substrate and thus lowers its activation energy requirements

active site
the portion of an enzyme in contact with the substrate; at this point it will have a specific shape which corresponds to the shape of at least a portion of the substrate molecule

Properties of enzymes

Enzymes have the following properties:

- All are globular proteins.
- They increase the rate of reaction without being used up.
- Their presence does not alter the nature of the end products of the reaction.
- A small amount of enzyme catalyses a large quantity of substrate.

Enzymes share the following properties:

- They are specific in action and generally catalyse one specific reaction or part of a reaction.

CASE STUDY 2.3

A metabolic pathway – phenylalanine

The catabolism or anabolism of chemical compounds in the cell usually involves several separate reactions, each mediated by a specific enzyme. For example, in a two-step pathway enzyme A would mediate the formation of an intermediate substance from a precursor chemical. This intermediate substance would then be converted to the final substance in the presence of enzyme B. If any enzyme in a metabolic pathway is absent or faulty, the correct sequence of chemical reactions cannot occur. Different products form and some of these may be dangerous to the cell's health and continued existence.

When excess proteins are taken into the body, they are not stored but are broken down in a series of catabolic steps. Each step requires an energy input, but energy is also released as an end product. In the normal course of events, the protein undergoes a series of hydrolysis reactions to release the component amino acids, one of which is phenylalanine. The liver produces the enzyme phenylalanine hydrogenase, which brings about the conversion of phenylalanine to another amino acid called tyrosine. If this enzyme is faulty, phenylpyruvic acid is formed instead of tyrosine. A disease called phenylketonuria (PKU) – with associated mental retardation, musky body odour and excessive muscular activity – results.

Tyrosine can be used in two other series of anabolic reactions – one that results in the formation of the growth hormone thyroxin and the other producing the skin pigment melanin. Each set of reactions has its own series of enzymes. Absence of any of these enzymes can again produce chemicals that can have dire effects on the body. Figure 3 illustrates the inappropriate end products that can result from enzyme failure at various points along the catabolic pathway of phenylalanine.

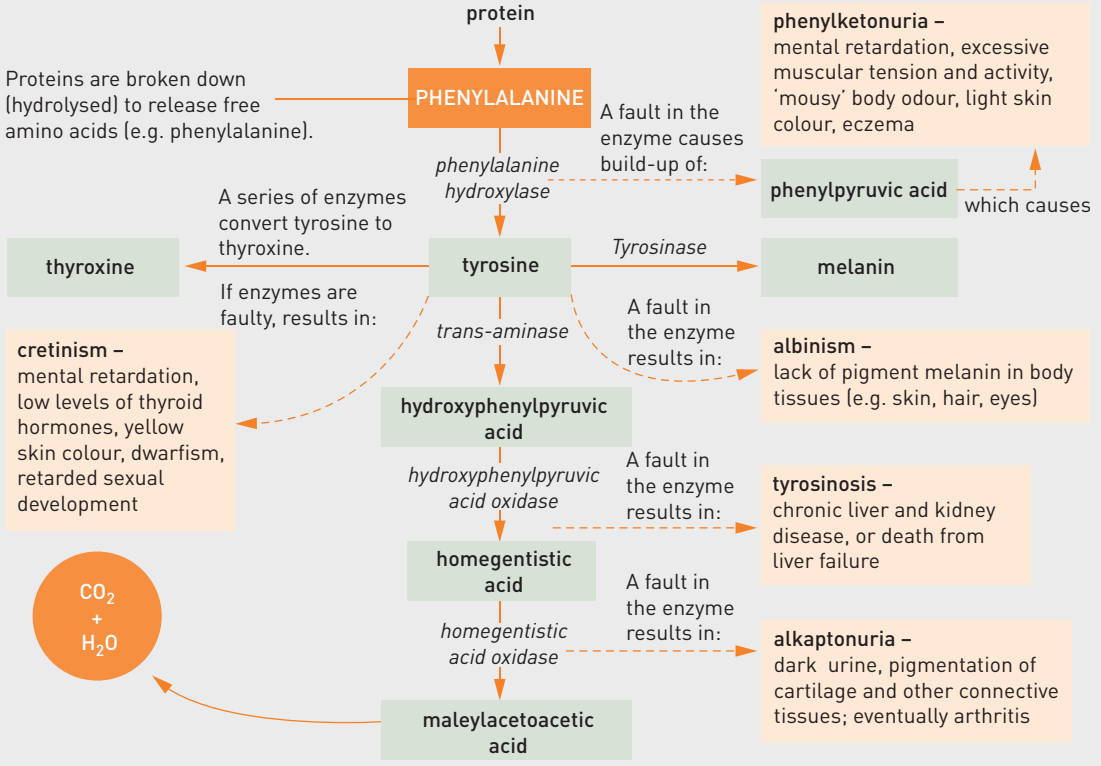


FIGURE 3 The metabolism of phenylalanine

- They catalyse a reaction in either direction according to the prevailing conditions (e.g. substrate concentration).
- They reduce the activation energy needed for a chemical reaction to take place.
- They are heat-sensitive, working best at an optimum temperature (plants 30°C; human body 37°C). At a certain temperature above the optimum (e.g. 45°C in humans), enzymes are destroyed by denaturation and coagulation, which involves a change in shape of the enzyme protein. Although the action of enzymes may be inhibited at low temperatures (e.g. freezing), their protein structure is not altered.
- They are pH sensitive; that is, they will work only within a narrow range of the optimum pH. Each enzyme has a specific optimum pH.
- As the concentration of enzyme increases, the rate of enzyme action also increases. The rate of reaction is then limited by other factors, such as the number of substrate particles, pH and temperature.
- As the concentration of substrate increases, the rate of enzyme action increases to a maximum limiting value and then plateaus.
- Enzymes are inhibited by poisons, which either compete with the normal substrate molecules for the active site (**competitive inhibition**, e.g. sulphonamide drugs), or block the active site permanently (**non-competitive inhibition**, e.g. arsenic, DDT, lead, cyanide and organophosphates). (See Figure 4.)

competitive inhibition
the process where a substance (inhibitor) occupies the active site of an enzyme and prevents the normal substrate from binding

non-competitive inhibition
the permanent blockage of the active site of an enzyme to the normal molecule by a poison

Coenzymes and cofactors

Cofactors are non-protein components needed by some enzymes for their efficient functioning. There are three types of cofactor: inorganic ions, prosthetic groups and coenzymes.

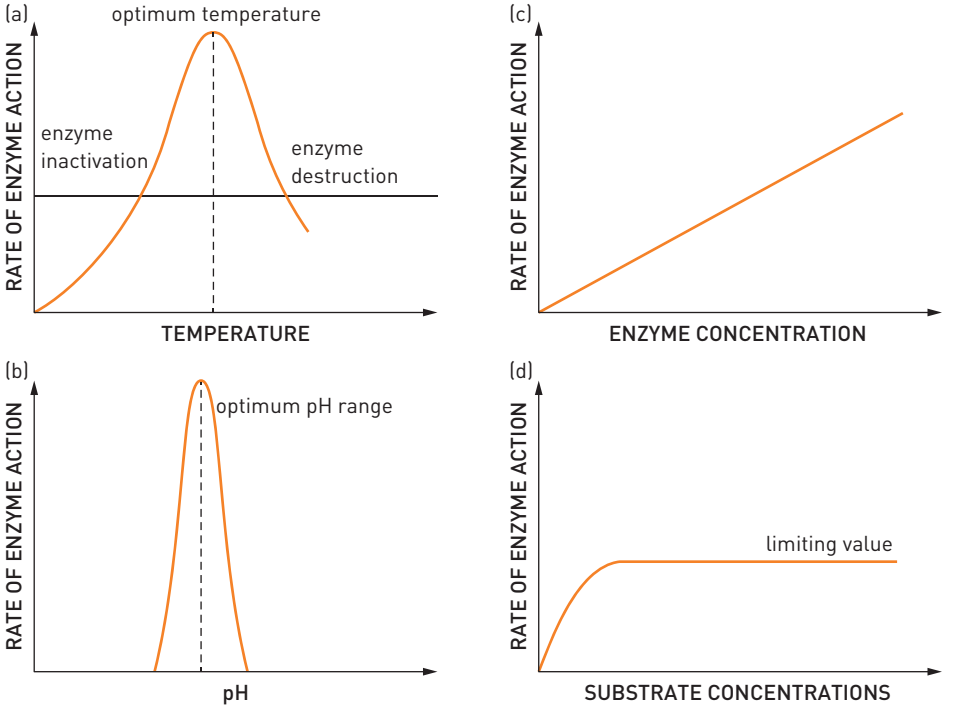


FIGURE 4 Effects on enzyme activity of (a) temperature; (b) pH; (c) enzyme concentration; (d) substrate concentrations

Inorganic ions

The activity of some enzymes is increased by the presence of inorganic ions. For example, the activity of amylase in saliva is increased if chloride ions are present. The ions may bind the enzyme and substrate together, or may serve as the catalytic site of the enzyme itself.

Prosthetic groups

These are non-protein organic molecules tightly bound to the active site. For example, the enzyme cytochrome oxidase, which is important in respiration, contains a haem (iron) prosthetic group. It takes up chemical groups from the protein part of the enzyme.

Coenzymes

Coenzymes are non-protein organic molecules loosely associated with the enzyme, which function as carriers for transferring chemical groups, atoms or electrons from one enzyme to another.

Classification of enzymes

Enzymes can be classified into two main groups: **intracellular** and **extracellular**. Intracellular enzymes occur within the cell where they control metabolism. Extracellular enzymes are catalytic proteins produced by cells, but they work outside the cell.

Normally an enzyme is named by adding the suffix *-ase* to the name of the substrate on which it acts. So, maltase acts on maltose; lipase acts on lipids.

intracellular
found within a cell

extracellular
outside the cell

CHECK YOUR LEARNING 2.3

Describe and explain

1 a **Describe** the characteristics of an enzyme.
  b **Explain** how an enzyme is believed to function.
2 **Summarise** the difference between competitive and non-competitive inhibition.
3 Refer to the following equation when answering parts a–c:

$$\text{amino acid} + \text{amino acid} \underset{\text{enzyme B}}{\overset{\text{enzyme A}}{\rightleftharpoons}} \text{dipeptide} + \text{water}$$

  a **Identify** which molecules are considered substrates during dehydration synthesis (condensation).
  b **Identify** which molecules are considered products during hydrolysis.
  c **Explain** why there are arrows pointing in opposite directions.
4 According to the lock and key hypothesis, **describe** the relationship between substrate, enzyme and product in a reaction.
5 Each of the thousands of different types of chemical reaction that occur in cells requires a different enzyme. **Explain** why this is so.
6 **Clarify** the following sentence: different enzymes have active sites which:
  A differ in composition but not shape
  B differ in composition and shape
  C differ in shape but not composition
  D differ in neither composition nor shape

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  2.3 The effect of enzyme concentration on the rate of reaction
- » Video
  Enzymes
- » Weblink
  The 'lock and key' hypothesis

2.4 Biological energy transformations

KEY IDEAS

- Molecules used in the transport and storage of energy within cells
- The structure of ATP
- High energy bonds
- Other organic molecules used in energy transfer in the cell

The energy released at one site of a cell is often required at another site. This is very important in all metabolic reactions such as photosynthesis and cellular respiration. In biological systems special molecules are used to transport the energy from place to place, or simply to store it in a readily accessible form. **Adenosine triphosphate (ATP)** is the major molecule involved in this process. It is found in all living things.

adenosine triphosphate (ATP) an organic chemical able to store and release large amounts of energy; consists of the chemical adenosine bound to three phosphate groups

The ATP molecule is composed of an adenosine unit (a complex of adenine and ribose, a 5-carbon sugar) combined with three phosphate groups arranged in sequence:

adenosine – P ~ P ~ P

The bonds by which the second and third phosphate groups are attached are not the usual type of chemical bond, and are usually represented by the symbol ~. This high-energy phosphate bond is very weak and unstable and can be readily broken. The released phosphate can react with another molecule by the formation of more stable bonds, releasing large amounts of energy. Addition of phosphate is called **phosphorylation**.

phosphorylation the addition of a phosphate group to a molecule; can be non-cyclic (e.g. formation of ATP) or cyclic (e.g. the cyclic flow of electrons along electron transport chain from chlorophyll, the energy release being used in the formation of ATP)

It is often only the terminal high-energy phosphate bond that is involved in these energy conversions. The reaction, in which this bond is broken and the terminal phosphate group removed, leaves a compound called **adenosine diphosphate** or **ADP**, consisting of adenosine plus only two phosphate groups. The overall reaction can be generalised as:

ATP → ADP + ~P

In a similar manner, a phosphate group from ADP can be removed, leaving behind **adenosine monophosphate** (**AMP**). New ATP can be synthesised from ADP and phosphate if adequate energy is available to force a third phosphate group onto the ADP.

adenosine diphosphate (ADP) the chemical adenine bound to two phosphate groups, each bond requiring an input of energy

adenosine monophosphate (AMP) the chemical adenosine bound (with an input of energy) to one phosphate group

It is the phosphate-bond energy of ATP that is used to do cellular work. Metabolism, therefore, involves enzymes and the transfer of energy. Figure 1 summarises these reactions.

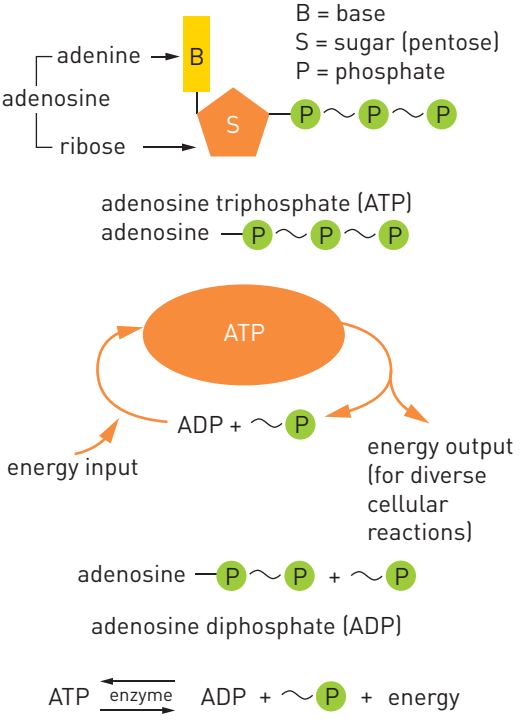
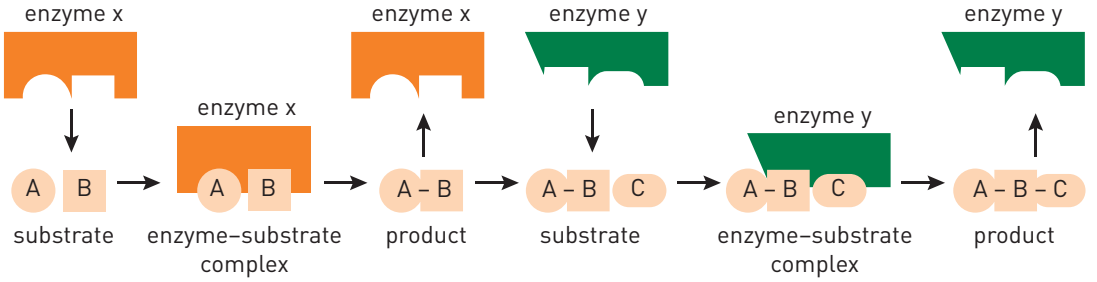
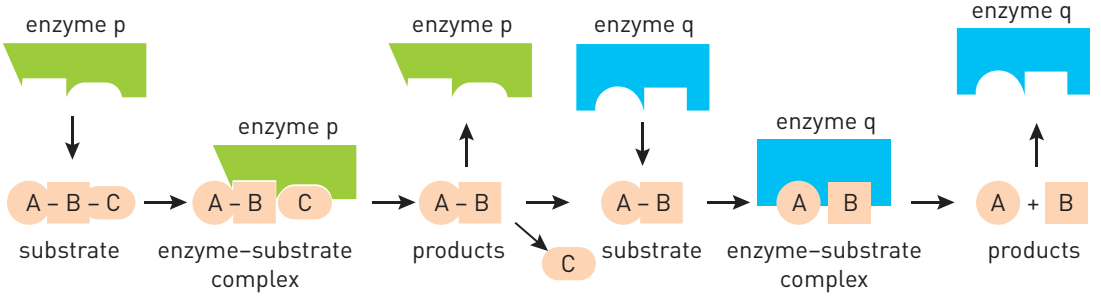


FIGURE 1 Diagrammatic representation of the action of ATP

Anabolic reactions in cells build complex molecules from simpler molecules.
These reactions usually involve specific enzymes and use energy.



Catabolic reactions in cells break down complex molecules into simpler molecules.
These reactions usually involve specific enzymes and release energy.



A substrate is a substance acted upon by enzymes.
Products are substances produced in chemical reactions.

FIGURE 2 The relationship between metabolism, enzymes and energy. These diagrams represent very simple metabolic pathways.

Other organic carrier molecules are also important in energy transfer in metabolic pathways. These include:

- NAD^+ (nicotinamide adenine dinucleotide), which reacts with hydrogen ions and electrons to form NADH, and
- FAD (flavin adenine dinucleotide), which, in a similar way, forms $FADH_2$.

It takes energy for the hydrogen ions and electrons to bond with the carrier molecules. Energy is released along with the hydrogen ions from the carrier molecule. These two molecules are important in the carriage of hydrogen in metabolic pathways.

CHECK YOUR LEARNING 2.4

Describe and explain

1 **Describe** the features of the ATP molecule which are responsible for its function as an energy carrier in biological systems.

Apply, analyse and interpret

2 **Distinguish** between metabolic reaction and metabolic pathway. Suggest a reason for the occurrence of metabolic pathways.

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CHAPTER 2

Review

Chapter summary

2.1 Carbon is the fundamental chemical of life. Small carbon molecules form the building blocks of macromolecules.

Carbohydrates contain the elements carbon, hydrogen and oxygen in their monomers in the ratio of 1:2:1. Carbohydrates are important energy sources for living organisms.

Proteins always contain carbon, hydrogen, oxygen and nitrogen, although other elements such as sulphur and phosphorus may also be present. The basic unit is the amino acid. Their main functions are structural and regulatory.

Lipids are water-insoluble carbon compounds which also contain hydrogen and oxygen, but not in a fixed ratio. They function as structural components of cell membranes, sources of energy transport and storage, insulators and chemical messengers.

Nucleic acids are chains of nucleotides, each nucleotide being composed of a pentose sugar, a phosphate and a nitrogen base. There are five nitrogenous bases: adenine, guanine, thymine, cytosine and uracil. DNA is a nucleic acid in the form of a double helix.

RNA is a single-chain nucleic acid. RNA is responsible for the translation of the nucleotide sequence of DNA into the amino acid sequence of a protein.

2.2 Energy is the ability to do work or cause a change. It may be either potential (stored) or kinetic energy (energy of motion). Energy cannot be created or destroyed, but can be converted from one form to another. In all energy transformations, some energy is converted to heat energy and lost from the system.

Living cells draw primarily upon chemical energy stored in chemical bonds. Heterotrophs gain their outside source of energy from eating other living organisms. Autotrophs utilise either sunlight (photosynthesis) or inorganic molecules (chemosynthesis) as their outside energy source.

Metabolism is the general term to describe chemical reactions in cells. Metabolic processes proceed in small steps, the sum of which is called a metabolic pathway.

2.3 Enzymes are organic catalysts that reduce the activation energy needed for chemical reactions to take place. Each enzyme has a specific active site, the chemical nature of which allows joining with a specific substrate molecule.

Enzymes are:

- globular proteins
- required in only small amounts
- specific for a particular reaction(s)
- capable of decreasing the activation energy required for the reaction
- heat sensitive
- pH sensitive
- inhibited by poisons.

Cofactors are components required by enzymes for their efficient functioning. Coenzymes are organic cofactors that function as carrier molecules, transferring chemical matter (electrons, atoms, molecules) from one enzyme to another. Enzymes may be either intracellular or extracellular.

2.4 Adenosine triphosphate (ATP) is the major molecule in living organisms involved in storing energy in a readily available form and transferring it from one site to another.

ATP consists of the nitrogen base adenine, the ribose sugar and three phosphate groups, arranged in sequence. New ATP is formed from ADP and phosphate if sufficient energy is available.

Key terms

- activation energy
- active site
- adenosine diphosphate (ADP)
- adenosine monophosphate (AMP)
- adenosine triphosphate (ATP)
- amino acid
- anabolism
- carbohydrate
- catabolism
- cell wall
- chromosome
- competitive inhibition
- condensation
- contraction
- deoxyribonucleic acid (DNA)
- dipeptide
- disaccharide
- endergonic
- enzyme
- ester bond
- exergonic
- extracellular
- fatty acid
- gene
- genetic code
- glycerol
- glycosidic bond
- hydrolysis
- hydrophilic
- hydrophobic
- 'induced fit' hypothesis
- inorganic compound
- intracellular
- kinetic energy
- lipid
- 'lock and key' hypothesis
- metabolism
- monomer
- monosaccharide
- non-competitive inhibition
- nucleotide
- organic compound
- peptide bond
- phospholipid
- phosphorylation
- photosynthesis
- polymer
- polypeptide
- polysaccharide
- potential energy
- protein
- ribonucleic acid (RNA)
- saturated compound
- triglyceride
- unsaturated compound

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Starch is changed into glucose by the chemical process of:

A hydrolysis
B condensation
C neutralisation
D oxidation

2 Simple proteins are composed of:

A fatty acids
B monosaccharides
C glycerol
D amino acids

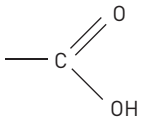
3 Both DNA and RNA:

A have the same 5-carbon sugar
B contain phosphate groups
C are single-chained molecules
D contain the same four nucleotide bases

4 Enzymes are essential for biochemical reactions because they:

A regulate the rate of reaction
B work best at temperatures over 50°C
C are not sensitive to pH changes
D are used up in chemical reactions

5 After chemical analysis a substance was found to contain a carboxyl group:
This substance could be:



A a carbohydrate or glycerol
B an amino acid or fatty acid
C a fatty acid or glycerol
D a fatty acid, glycerol or amino acid

Questions 6–8 refer to the following:

Scientists studied an enzyme called enzymase. They tested the amount of product formed at different temperatures and pH levels, and their results are shown in Figure 1. Refer to these graphs in answering questions 6–8.

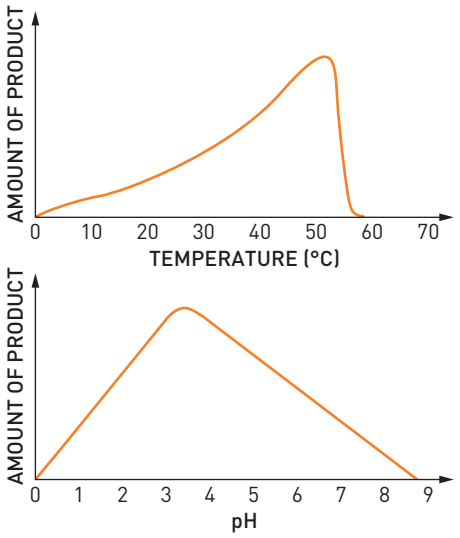


FIGURE 1

6 The enzyme functions best at which of the following temperature ranges (each given in °C)?

A 10–20
B 20–30
C 30–40
D 40–50

7 The enzyme functions best when the environment is:

A acidic
B basic
C neutral
D The pH does not affect the reaction.

8 The enzyme probably does not function at 70°C because:

A the protein in the enzyme changes shape at that temperature
B there is too little substrate at that temperature
C the amount of product increases at a higher temperature
D the pH is not favourable

Short answer

Describe and explain

★★ **9** **Identify** and describe the monomer and polymer for carbohydrates.

★ **10** **Explain** the function of an enzyme.

Apply, analyse and interpret

★ **11** **Compare** carbohydrates from a structural and functional point of view.

★ **12** **Deduce** the letter of the item in column B that most closely matches the item in column A.

Column A	Column B	
RNA	A	Carbohydrate
Monosaccharide, disaccharide	B	Lipid
	C	Protein
Composed of fatty acid and glycerol	D	Nucleic acid
	E	Both A and B
	F	Both A and C

Investigate, evaluate and communicate

★★ **13** Phosphatase is an enzyme that will release phosphate groups from certain substrates. When phenylphosphate is acted on by phosphatase, phenol is formed and its presence can be detected by a colour reaction. A student used this test to look for the presence of phosphatase in a variety of substances. Reactions included the following:

Material	Whole	Ground	Boiled
Liver	+	++	–-
Milk	++	NT	–
Bacterium A	+	++	–
Bacterium B	–	–	NT

++ strong reaction; + weak reaction;
– no reaction; NT not tested

No reaction occurred with any of the substances after the material had been boiled. **Propose** a possible reason for this.

★★★ **14** Many organisms have evolved sensitive mechanisms for detecting sugars. Human sensors are on the tongue. Those for the housefly (which are about 10 million times more sensitive than the human sensors) are in the feet. When a housefly lands on droplets of sugar solution, its tubular mouthparts are

automatically extended, and the fly begins to feed.

a **Determine** reasons why the ability to detect sugars is more sensitive than detection of other organic chemicals in many animals.

b **Develop** a hypothesis to explain the placement of sugar sensing organs in the housefly and the human. Justify your hypothesis.

★★ **15** Hair is composed of the protein keratin, which has a high percentage of the amino acid cysteine.

Bonds can form between the amino acids in keratin. If there are few bonds, the hair is straight. If there are many bonds, the hair is curly. When hair is permed, it is first treated to break the bonds. This makes the hair more flexible so that it can be set into the desired shape with rollers. The hair is then treated to form new bonds which will hold that shape.

a **Explain** why 'perms' must be renewed to maintain the desired hair characteristics.

b **Determine** how curly hair could be straightened.

★★★ **16** Fatty acids may be saturated or unsaturated. Unsaturated fatty acids (e.g. oleic acid, the chief constituent of olive oil) contain one or more double carbon bonds (C=C), allowing each carbon to react with another element or group of elements. These fatty acids melt at much lower temperatures (approximately 13°C) than saturated fatty acids (approximately 63°C). In saturated fatty acids there are only single bonds between the carbons (e.g. stearic acid found in lamb and beef fat).

Cells of ectothermic animals (animals that use behavioural means to partially control their body temperature, which varies with that of the environment) have a higher proportion of unsaturated fatty acids than endothermic animals (which control their body temperature by physiological means).

Propose a reason for this. **Justify** your answer.

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CHAPTER 3

Cell structure

The basic unit of structure and function in living organisms is the cell. The cell is a self-sustaining chemical system. All the chemical reactions necessary for it to maintain its existence occur in its protoplasm. In order to maintain its chemical integrity, the cell must be physically separated from the environment and yet capable of exchanging material with it. The cell membrane forms this boundary. The efficiency of exchange decreases with an increase in size of the cell, so there is an upper limit to how large a cell can grow. Most cells, therefore, can be seen only when viewed with a microscope.

OBJECTIVES

- → Recognise that prokaryotic and eukaryotic cells have many features in common, which is a reflection of their common evolutionary past.
- → Recall that prokaryotic cells lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes, usually have a single circular chromosome and exist as single cells.
- → Understand that eukaryotic cells have specialised organelles to facilitate biochemical processes:
  - photosynthesis (chloroplasts)
  - cellular respiration (mitochondria)
  - synthesis of complex molecules including proteins (rough endoplasmic reticulum), carbohydrates, lipids and steroids (smooth endoplasmic reticulum), pigments, tannins and polyphenols (plastids)
  - the removal of cellular products and wastes (lysosomes).
- → Explain, using an example, how the arrangement of internal membranes can control biological processes (e.g. folding of membranes in mitochondria increases the surface area for enzyme-controlled reactions).
- → Identify the following structures from an electron micrograph: chloroplast, mitochondria, rough endoplasmic reticulum and lysosome.
- → Compare the structure of prokaryotes and eukaryotes.
- → Describe the structure of the cell membrane (including protein channels, phospholipids, cholesterol and glycoproteins) based on the fluid mosaic phospholipid bilayer model.
- → Describe how the cell membrane maintains relatively stable internal conditions via the passive movement (diffusion, osmosis) of some substances along a concentration gradient.

FIGURE 1 A 3D image of a eukaryotic cell cut-away shows the many organelles inside.

→ Explain how the cell membrane maintains relatively stable internal conditions via the process of active transport of a named substance against a concentration gradient.

→ Understand that endocytosis is a form of active transport that usually moves large polar molecules that cannot pass through the hydrophobic cell membrane into the cell.

→ Recognise that phagocytosis is a form of endocytosis.

→ Predict the direction of movement of materials across cell membranes based on factors such as concentration, and the physical and chemical nature of the materials.

→ Explain how the size of a cell is limited by the relationship between surface area to volume ratio and the rate of diffusion.

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PRACTICALS

MANDATORY PRACTICAL	**3.2** The effect of surface area to volume ratio on the rate of diffusion
MANIPULATIVE SKILL	**3.3A** Use of the light microscope
MANDATORY PRACTICAL	**3.3B** Preparation and examination of wet mount specimens
SUGGESTED PRACTICAL	**3.3C** Identifying organelles from electron micrographs
SUGGESTED PRACTICAL	**3.5** Modelling the selectively permeable cell membrane

SCIENCE AS A HUMAN ENDEAVOUR

3.1 The development of the microscope

KEY IDEAS

- The development of the microscope paved the way to an understanding of cells
- Understanding of cells comes from the development of cell theory
- Cells are the smallest structural and functional unit of living organisms

Biology is the study of living things. To be considered as living, an organism needs to be able to control and regulate its internal environment, to grow, respond to stimuli and reproduce. The smallest unit of life that can perform these functions is a cell. As cells are extremely small, they could not be seen until the development of the microscope. This invention paved the way to a greater understanding of the structure and function of living matter.

The road to the development of the microscope began when the Romans first made glass in the first century BCE. At this early time, it was observed that objects viewed through a droplet of glass were magnified, even though the image was fuzzy. It was not until the late sixteenth century that the quality of glass and the technology to finely grind it was developed. These developments allowed the production of spectacles.

Work done in the 1590s by the spectacle maker Zacharias Janssen produced lenses that could magnify nine times. In 1595, he and his father built the first compound microscope. This consisted of two lenses separated in a hollow tube. The image produced, however, was not very clear and tended to split the light like a prism. This affected the microscope's resolution limits – the limit at which tiny objects that are close together stop being visibly separate.

These first microscopes were thought of as toys rather than scientific instruments. Part of the problem was that the lenses were not particularly smooth or of even thickness. Second, the smaller an object is, the less light reflects from it. Seeing anything really tiny requires a very good light source, something that was not available at the time.

Nevertheless, using such a microscope, in 1660, the Italian Marcello Malpighi was able to see blood capillaries in the tail of live fish. This showed that blood circulates in the body. Prior to this it was thought that blood was produced in the intestines and moved to other parts of the body where it was consumed.

In 1665 the Englishman Robert Hooke observed the bark of a cork tree under a microscope using reflected light. He found it was composed of minute chambers, which he called cells because they looked like the 'cells' in which monks lived. Although it is now known that there are no cells in dead cork, the modern term 'cell' comes from this label.

Hooke used a simple microscope (single lens) for examining specimens using transmitted light (light passing through the specimen) in order to get clearer images.

Dutchman Antonie van Leeuwenhoek further developed the microscope and improved the way it was used. He developed his interest in microscopes during his apprenticeship as a draper in Amsterdam in 1648 where he was able to observe the fibres that comprised different quality materials.

He learned to grind and polish small glass spheres (a biconvex lens) of such quality that they had a magnification of 270. Leeuwenhoek mounted this lens on a flat copper plate and held it very close to his eye. The object being studied was placed on the head of a movable pin attached to the plate on the other side of the lens.

Using this simple microscope, Leeuwenhoek was the first to shine a light through living single-celled animals (protozoans) in pond water. He called them animalcules.

FIGURE 1 Hooke's microscope

For about 150 years microscopic work was limited to these two 'primitive' types of microscope. By the late 1800s many of the distortions of the lenses were corrected due to the work by German engineer Carl Zeiss and his employees, Schott and Abbe. They developed optical systems that could focus on objects smaller than a wavelength (approximately 0.2 μm (micrometres)). Because they used light as an imaging system, they were called light microscopes. Although a powerful and useful tool, light microscopes still could not provide a detailed observation of the internal structure of the cell. While some recent techniques have been employed in improving light microscopes, they are still limited.

FIGURE 2 Leeuwenhoek's microscope

As an understanding of the physical nature of matter, particularly the structure of the atom, developed, new technologies arose. The application of these advances led to the development of microscopes with higher magnification and resolution.

In the 1930s, the electron microscope was developed by Ernst Ruska and Max Knoll. Like its predecessors, this changed the possibilities for science. This microscope uses a narrow beam of electrons. The beam width is adjustable, but at its smallest is below the size of a hydrogen atom. The beam is focused with magnets and the final image is converted to light in a way similar to that on a television screen. A photograph called an **electron micrograph** is taken of the image. This is necessary because the electron beam prevents the magnified image from being viewed directly. For the same reason, the electron microscope is difficult to use on living material.

electron micrograph
a photographic image of a sample magnified by an electron microscope

In summary, technological advancements in physics allowed magnification and resolution to be massively improved because the electron microscope uses a very narrow beam of electrons as opposed to the broader beam of light used previously.

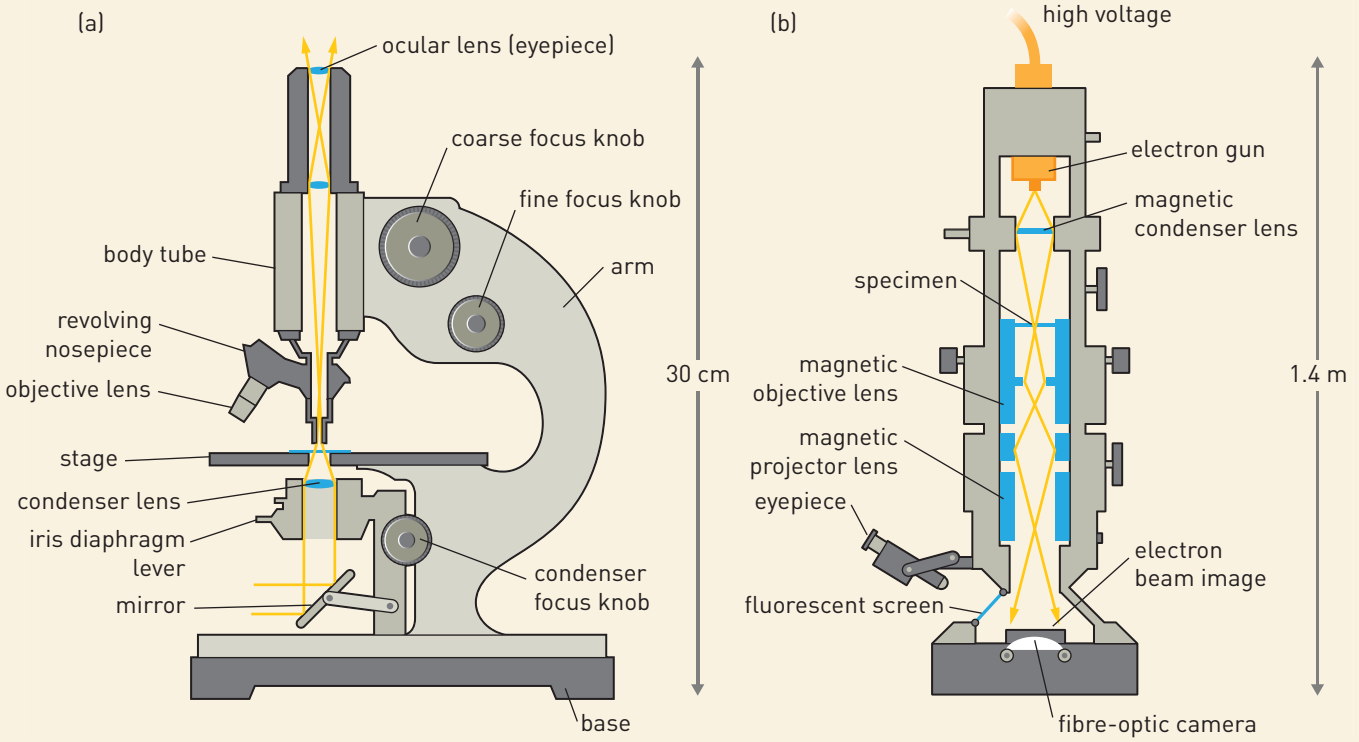

FIGURE 3 (a) A modern light microscope with inbuilt transmitted light source; (b) an electron microscope

Most microscopes can be divided into another two groups depending on how the imaging beam (light or electrons) interacts with the specimen. In scanning microscopes, the beam reflects off the surface of the specimen to produce a three-dimensional image. Transmission microscopes send the beam through the specimen and a two-dimensional image is formed.

For a specimen to be useful in the transmission microscope, the beam has to be able to pass through it and reveal its internal detail. Specimens need to be stained with special chemicals to produce clear detail. Coloured dyes are used in light microscopy while heavy metals are used for electron microscopy. The stain produces variations in absorption by different parts of the specimen.

Large or thick specimens will not allow the beam through them. They must be sectioned or sliced, then stained. The object is embedded in a material (commonly, wax in light microscopy and plastic for electron microscopy) that will hold it together while being thinly sliced. Sequences of these sections can then be used to translate the two-dimensional information into a three-dimensional model.

Cell theory

cell theory
the theory that all organisms are made up of cells and their products, and that growth and reproduction are fundamentally due to division of cells

The relationship between science and technology is clearly demonstrated in the development of the **cell theory**. Three hundred and fifty years ago there was no knowledge of cells since they were too small to be seen. It was only with the invention of the microscope that scientists like Leeuwenhoek were able to discover the previously unseen world of cells. Just as the telescope was a critical device for astronomers, the microscope was central to the progress of biology.

While the discovery of cells was first made with the advent of the microscope in the seventeenth century, further progress was slow. In the nineteenth century two scientists

(Schleiden and Schwann) were credited with the development of the cell theory, which outlined the following:

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

With the increase in knowledge since that time, this theory has been expanded and it is generally accepted that:

- The cell is the fundamental unit of structure and function in all living organisms.
- The activity of an organism depends on the total activity of independent cells.
- Energy flow (metabolism) occurs within cells.
- Hereditary information (DNA) is passed on from cell to cell.
- All cells have the same basic chemical composition.

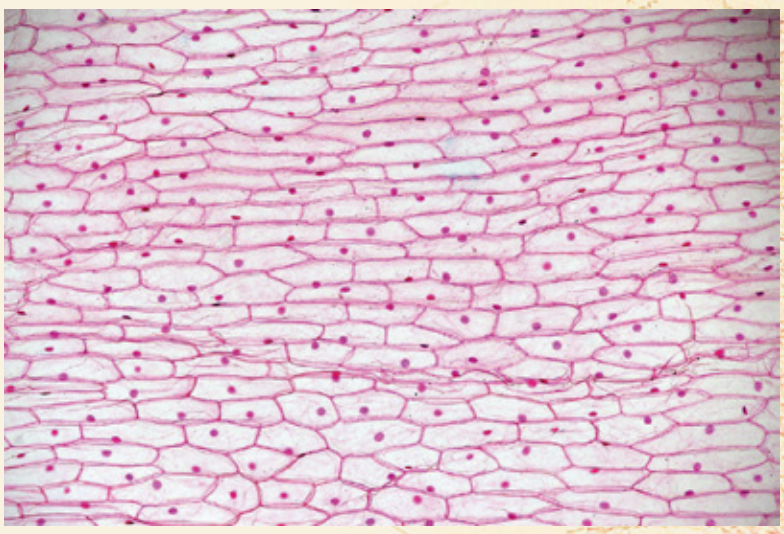

FIGURE 4 Cells are the building blocks of life. These are cells from the epidermis of an onion that have been treated with a stain.

CHECK YOUR LEARNING 3.1

Describe and explain

1 The development of the technology of the microscope represents a major advancement in science.
   - **a** **Identify** the main functions of a microscope.
   - **b** **Describe** the difference between images seen with a light microscope and those seen with an electron microscope.
   - **c** **Explain** the advantages and disadvantages of the light and electron microscopes.

2 **Explain** the cell theory. Explain why the current theory is more detailed than that proposed by Schleiden and Schwann.

Investigate, evaluate and communicate

3 **Justify** why the current cell theory is more detailed than that proposed by Schleiden and Schwann.

4 **Construct** a timeline that communicates the development of the microscope.

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3.2 The cell as the building block of life

KEY IDEAS

- The difference between prokaryotic and eukaryotic cells
- The endosymbiotic theory of the evolution of eukaryotic cells
- The size of cells including surface area to volume ratio

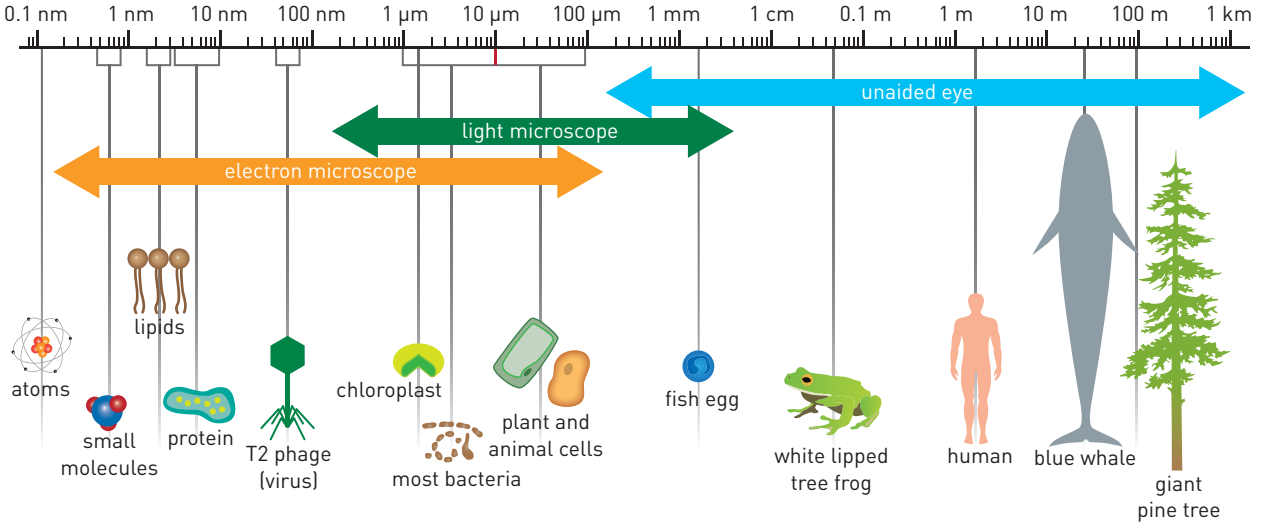
unicellular
composed of a single cell

multicellular
composed of many cells

colonial
an animal composed of the same unicellular organisms joined into a cluster where each individual can carry out all functions necessary for life

Cells tend to be very small (0.5–10 μ, or micrometres, in diameter, where 1 μ = 10^{-6} m = 1 millionth of a metre) although there are a few notable exceptions, for example an emu's egg which is 13 cm long. The smallest organisms have only one cell and are called **unicellular**. Although a size range exists in these organisms (the smaller cells are generally 'simpler'), they are all microscopic. Larger organisms are composed of several to trillions of cells working together and are **multicellular**. In these organisms, different groups of cells perform different jobs to keep the organism alive. Each cell in the group is dependent on each other to survive. Occasionally groups of cells are closely associated with each other but are not directly connected. These groups are called **colonial**. Each cell is technically able to live independently, but they band together and divide up their functions.

(a)



(b) Units of measurement

Ångstrom units (Å)	nanometres (nm)	micrometres (μm)	millimetres (mm)	centimetres (cm)	metres (m)
10 × 1000 × 1000 × 1000 Å = 1 m	1000 × 1000 × 1000 nm = 1 m	1000 × 1000 μm = 1 m	1000 mm = 1 m	100 cm = 1 m	
1 Å = 10^{-10} m	1 nm = 10^{-9} m	1 μm = 10^{-6} m	1 mm = 10^{-3} m	1 cm = 10^{-2} m	
range of sizes for atoms, molecules and viruses		range of sizes for cells	range of sizes for organs and tissues		range of sizes for organisms

FIGURE 1 The size of a range of objects

Common features

All the chemical reactions necessary for a cell to stay alive occur in its protoplasm (the colourless insides of the cell). To maintain its internal environment, the cell must be physically separated from the environment and still able to take in nutrients and remove waste. The **cell membrane** surrounds the outside of the cell and forms a boundary between the chemical reactions occurring inside the cell and the ever-changing outside of the cell. To be able to reproduce, all cells need a set of instructions that contain all the information that enable the cell to survive. These instructions are contained in genetic material called nucleic acids. The most important of the nucleic acids is deoxyribonucleic acid (DNA).

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

Prokaryotic cells

It is believed that the first life forms arose, under unique environmental conditions, about four billion years ago in a process termed **abiogenesis**. These first organisms were composed of a single cell – a cell membrane containing a watery mixture of organic chemicals, including a strand of nucleic acid. This type of cell is called a **prokaryotic cell**. All of the chemical processes required to sustain life occurred in this single cell. It is highly likely that there were many different types of nucleic acid, each coding for slightly different proteins, and so the original cells would have been slightly different to each other right from the beginning. It is thought that the early life forms arose from two different groups that are now called the Archaea and the Bacteria.

abiogenesis
the formation of a living organism from non-living matter

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

prokaryote
an organism without a membrane-bound nucleus or organelles

Over billions of years these cells have mutated and changed into diverse types with different physical and chemical characteristics. All of these prokaryotic organisms, known as **prokaryotes**, are composed of an extremely small, single cell contained within a semi-rigid cell wall. There is no compartmentalisation of the cell contents for specific functions. Some have a flagellum to help them move about in their aquatic environment (which may be the body fluids of **multicellular organisms**). Some die in the presence of oxygen while others cannot survive without it. Some are heterotrophs (feed on other organisms), some use inorganic molecules to provide for their energy needs (chemosynthesis) and others rely on photosynthesis.

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

multicellular organism
an organism composed of many integrated cells

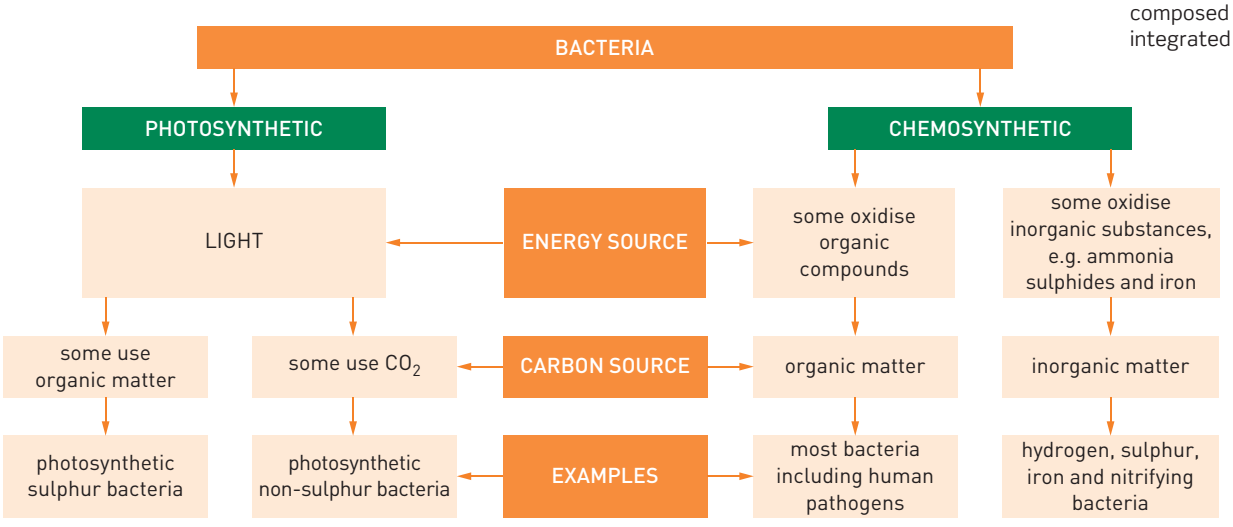


FIGURE 2 Energy and substrate requirements of bacteria

Prokaryotic cells are very small. Their DNA or genetic material is usually found in an area of the cell called the nucleoid in the form of a single circular **chromosome** (see Figure 3).

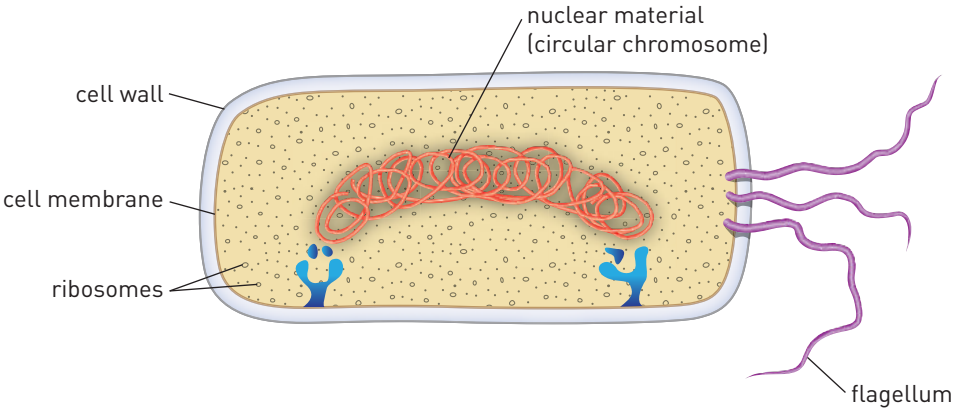


FIGURE 3 Structure of a prokaryotic cell

Eukaryotic cells

eukaryotic cell
a cell which contains membrane-bound organelles

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

cytoplasm
cell contents not including the nucleus

endosymbiotic hypothesis
the theory that eukaryotic cells evolved when a single-celled organism was engulfed and survived within the cell of another single-cell organism

As cells become larger, it becomes more difficult for nutrients to get to all parts of the cell, and for the waste to leave. **Eukaryotic cells** are larger than prokaryotes and their protoplasm contains a series of structures called organelles. Eukaryotic cells differ from prokaryotic cells in that their DNA is enclosed by a double-layered membrane to form a nucleus. This means the protoplasm is divided into **nucleoplasm** contained within the nucleus, and **cytoplasm**. The cytoplasm is compartmentalised into membrane-bound organelles, and so there is division of labour of the cytoplasmic contents, with different organelles performing different functions. The inclusion of these organelles has resulted in a cell size larger than that of the typical prokaryotic cell.

Evolution of eukaryotic cells

One view of the evolution of the eukaryotic cell is the **endosymbiotic hypothesis**. According to this hypothesis, there was such a strong symbiotic relationship between a small group of prokaryotic cells that they became permanently integrated, with smaller cells living inside a larger cell. These smaller cells became the organelles of the eukaryotic cell. (There is more information about this hypothesis on the obook.) Most scientists today accept the idea that photosynthetic and other cells were engulfed (swallowed up) by larger prokaryotes. These were not destroyed but remained within the larger cells as separate structures that performed specific functions. So chloroplasts (which convert solar energy into chemical bond energy during photosynthesis), mitochondria (which release chemical bond energy using oxygen) and other cell organelles are believed to have originated by the symbiosis (living together) of different organisms within a single structure. (More information about these processes will be covered in Chapter 4.) These organelles are described in more detail in the next section.

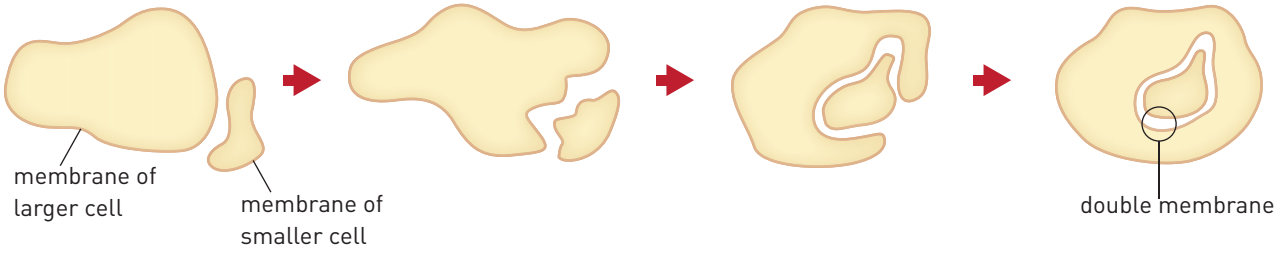


FIGURE 4 Endosymbiosis is thought to be responsible for the evolution of cells with organelles

One view of nucleus formation is that the cell membrane began to infold. Not only did the membrane enclose the DNA to form a nucleus, but it also formed other membranous structures and channels within the cell.

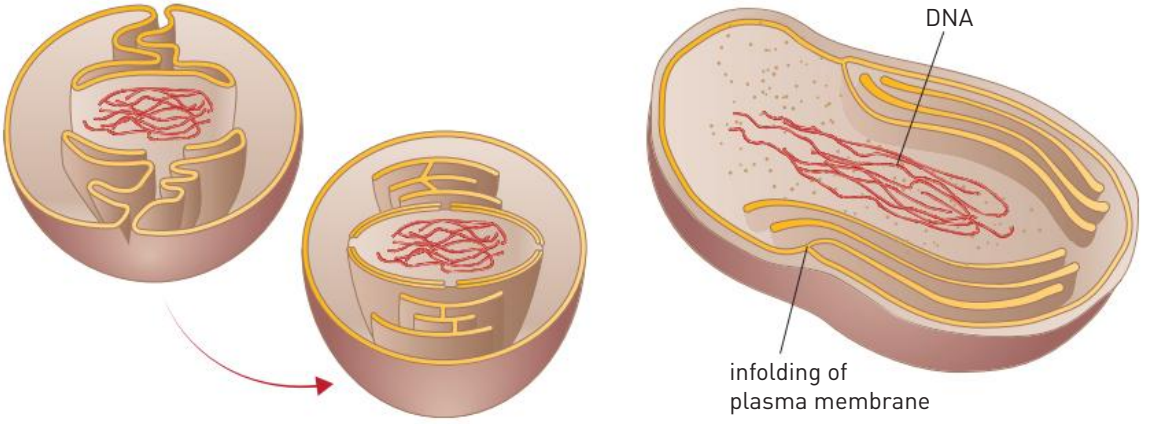


FIGURE 5 Possible formation of the nucleus and membranous structures of the eukaryotic cell

Further mutations in these cells resulted in different types of single-celled eukaryotic organisms. As different organisms evolved, they changed the environment in which they lived and this led to further evolution. The development of the eukaryotic cell paved the way for the evolution of the multicellular organism. Different cells could become specialised for specific functions as a result of the numbers and types of organelles they possessed.

Organisms made up of eukaryotic cells are known as **eukaryotes**. Examples are animals, plants, protists and fungi.

eukaryote
an organism whose cells contain membrane-bound organelles

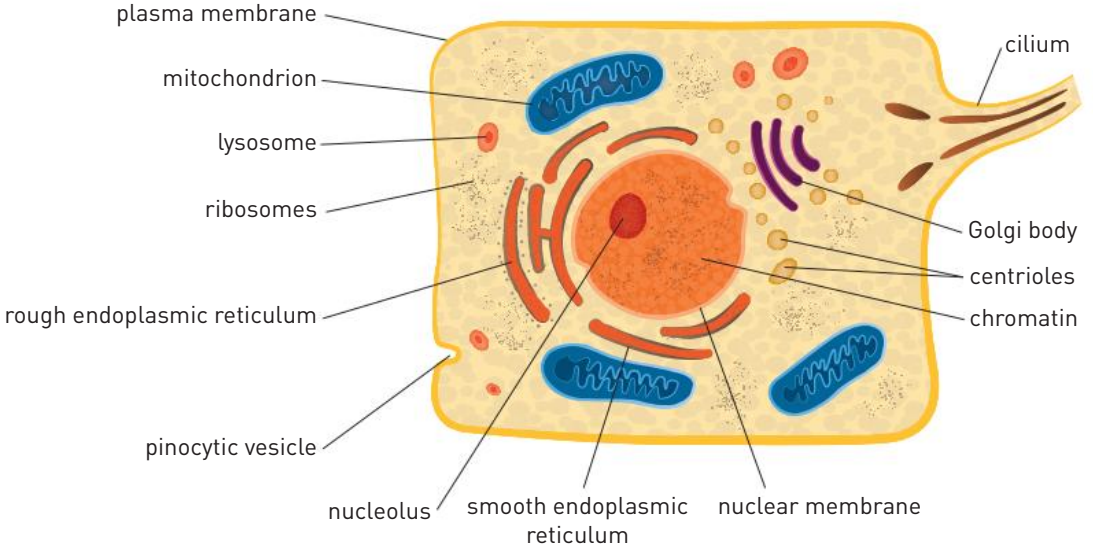


FIGURE 6 A eukaryotic animal cell

TABLE 1 Characteristics of prokaryotic and eukaryotic cells

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

Surface area to volume ratio

Cells can be different shapes, making it difficult to compare their sizes. As a cell becomes larger, both the surface area and the volume of the cell increases; however, the volume increases at a faster rate than the surface area. For this reason, biologists compare the surface area to volume ratio of cells to compare the size of cells. Large cells have small surface area : volume ratios, while small cells have large surface area : volume ratios.

All the chemical reactions (metabolism) required for cell survival occur within its volume. Cells need to be small to allow nutrients to move easily into the centre of a cell's volume and for wastes to move out. Larger cells (with a large surface area and even larger volume) have more needs and wastes than can be coped with by their limited surfaces. Therefore, when a cell becomes too large, it struggles to survive.

Ways around this dilemma involve a change in shape or the development of projections. Flattening or lengthening a cell or having numerous fine projections of the cell membrane (**microvilli**) can increase the cell's surface area : volume ratio.

microvillus (plural microvilli) minute finger-like projection from a cell's surface; can form a brush border

The largest plant cell yet discovered is found in a green alga (*Valonia*) and is about 1 cm in diameter (the average diameter of plant cells is 30–50 μm). This alga lives in the warm waters of the Great Barrier Reef and tidal movement ensures the rapid supply of nutrients and removal of wastes. The longest animal cell is the 2 m nerve cell of the giant squid. An increase in the internal membranes of the eukaryotic cell can also improve exchanges with its environment. The fact remains, however, that cells tend to be small and large organisms tend to be multicellular.

Increasing the surface area for metabolic reactions within the cell

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

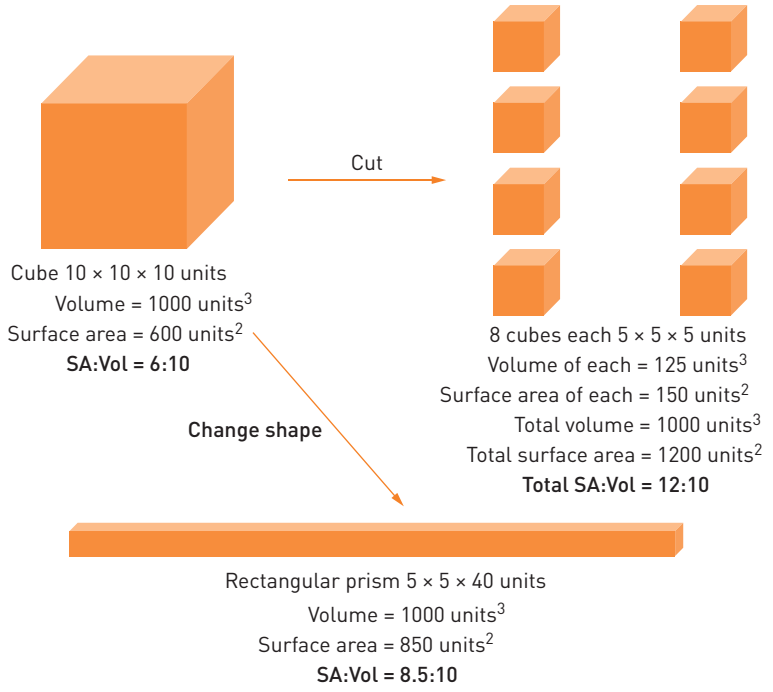


FIGURE 7 How surface area to volume ratio (SA:Vol) changes with size and shape. When the large cube is cut into eight equal-sized cubes its surface area to volume ratio is increased from 6:10 to 12:10; that is, its surface area doubles for the same volume. As the same cube is changed in shape to a rectangular prism the surface area to volume ratio increases from 6:10 to 8.5:10 – the flatter the 'cell', the greater the surface area to volume ratio for the same volume.

CHECK YOUR LEARNING 3.2

Describe and explain

1 **Explain** the difference between a prokaryote and a eukaryote.
2 **Describe** the endosymbiotic theory of the evolution of eukaryotes.
3 **Describe** how the nucleus is thought to have formed.
4 **Explain**, in terms of the cell's metabolic activities, why cells generally need to have a large surface area to volume ratio.

Apply, analyse and interpret

5 **Classify** these cells as prokaryotic or eukaryotic based on the description.
   a The cell appears to have no membrane-bound nucleus.
   b The cell has numerous organelles.
   c The sample is a specialised human skin cell.

Investigate and communicate

6 A student used Plasticine models to make 'cells' that were a sphere, a rectangular prism, a cylinder, and a flat sheet. All had the same volume.
   Predict which shape(s) would have:
   a the largest surface area to volume ratio
   b the smallest surface area to volume ratio.

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Check your learning 3.2

» Mandatory practical
3.2 The effect of surface area to volume ratio on the rate of diffusion

» Interactive
Cells

» Interactive
Plant cells

3.3 Eukaryotic cell organelles

KEY IDEAS

- Organelles and their different structures and functions
- The difference in structure between prokaryotic and eukaryotic cells

nucleus
control centre of the eukaryotic cell

chromatin
the nucleoprotein of chromosomes seen as fine, dispersed threads of genetic material and found in eukaryotic cells in the interphase stage

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

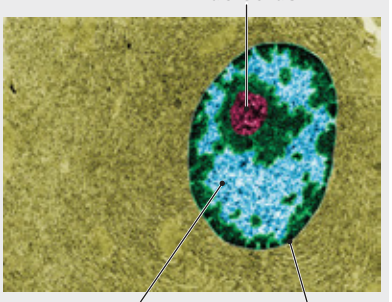
rough endoplasmic reticulum (rough ER)
a membranous structure with connections to both nuclear and cell membranes, involved in production, storage and transport of materials within the cells; proteins are synthesised on ribosomes

ribosome
the site of protein synthesis in cells; composed of RNA, produced in nucleolus and found on rough ER (eukaryotes) or in cytoplasm (eukaryotes and prokaryotes)

The cells of eukaryotic organisms (all organisms apart from archaebacteria, bacteria and cyanobacteria, which are prokaryotic) contain membrane-bound organelles. Most of these structures are not normally visible under the light microscope but can be viewed with an electron microscope.

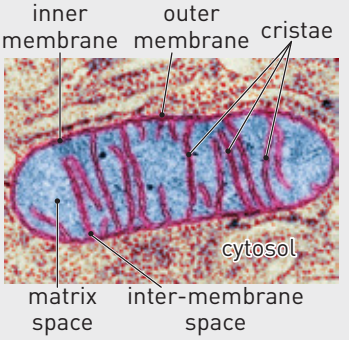
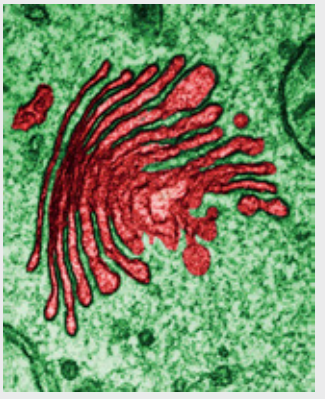
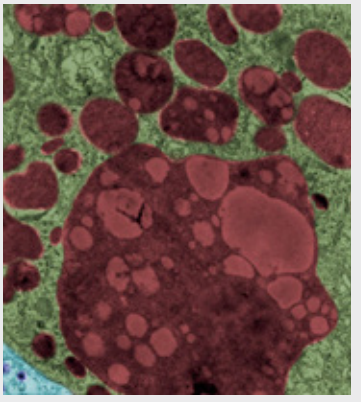
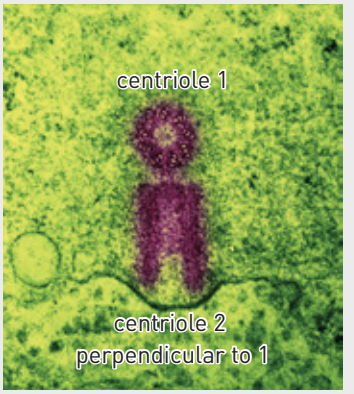
A number of organelles are found in both plant and animal cells – these are outlined in Table 1, along with an electron micrograph of each.

TABLE 1 Organelles found in plant and animal cells

Organelle	Structure and function	Electron micrograph
Nucleus	The total contents of the **nucleus** are called nucleoplasm. The nucleus controls cell activity through DNA, the genetic material that controls protein production and cell division. In the non-dividing cell, the DNA and protein form a diffuse network of threads called **chromatin**. These condense during cell division into chromosomes. The nucleus is surrounded by a double membrane, with pores that allow specific molecules into and out of the nucleus. The nucleus contains the nucleolus, which is composed of proteins, DNA and RNA, and which produces ribosomes.	
Endoplasmic reticulum	Endoplasmic reticulum is a network of flattened, membrane-bound sacs called cisternae. It is primarily involved in transporting molecules around the cell. There are two types of endoplasmic reticulum. **Smooth endoplasmic reticulum** is responsible for the synthesis and transport of lipids and steroids. **Rough endoplasmic reticulum** has **ribosomes** on the membrane surfaces that are involved in the synthesis of proteins. Transport of proteins occurs in their cisternae. The extensive network of the endoplasmic reticulum provides a large surface area for enzyme-mediated metabolic reactions to occur.	 Rough ER – ribosomes are seen as small dots on the surface

MANIPULATIVE SKILL
3.3A Use of the light microscope
Go to page 409 »

MANDATORY PRACTICAL
3.3B Preparation and examination of wet mount specimens
Go to page 404 »

Organelle	Structure and function	Electron micrograph
Mitochondria	**Mitochondria** (singular *mitochondrion*) are cigar-shaped and bound by a double membrane. The inner membrane is folded into **cristae**, which increase the surface area for attachment of enzymes and their metabolic reactions. The membranes enclose the fluid matrix. Mitochondria are the site of chemical reactions that release energy in a useable form. Mitochondria contain special mitochondrial DNA and ribosomes that control their enzyme production, and allow them to replicate themselves. Mitochondria are crucial for the process of **cellular respiration**.	
Golgi body	The **Golgi body** is composed of a stack of flattened membranous sacs or cisternae, which are continually being formed at one end and budded off as vesicles at the other. They are closely associated with the endoplasmic reticulum, receiving the enzymes, proteins, lipids, glycoproteins and polysaccharides synthesised there, enclosing them in membranes and releasing them either into the cytoplasm or outside the cell. Consequently, they serve as collecting, sorting, processing and distribution centres.	
Vesicle	A vesicle is a membranous sac that transports molecules around a cell. There are different types of vesicles including lysosomes and **vacuoles**.	
Lysosome	A **lysosome** is a simple spherical sac containing digestive enzymes. Lysosomes can fuse with vesicles or food vacuoles to digest their contents. Unwanted cellular products and wastes are broken down (autophagy) by lysosomes. They can also cause complete breakdown of damaged cells (autolysis) and so are sometimes termed 'suicide sacs'.	
Centrioles	**Centrioles** consist of a set of two cylindrical bodies next to the nucleus. They organise the DNA when a cell divides, and can form the whip-like **flagella** or hair like **cilia** that help some cells move.	

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

cristae
the folds of the inner membrane of mitochondria

cellular respiration
cellular process in which glucose is broken down to release energy in many small, enzyme-controlled reactions

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

vacuole
a cellular inclusion, or space within the cell; small in animals (food storage or digestion); large in plants (storage and osmotic control)

lysosome
an organelle containing digestive enzymes concerned with intracellular digestion

centriole
a paired tubular structure found in animals and algae; involved in formation of cilia and flagella and in cell division

flagellum (plural flagella)
a whip-like extension of the cell, used in locomotion by some Bacteria, Protozoa and spermatozoa

cilium (plural cilia)
a hair-like projection of the cell membrane

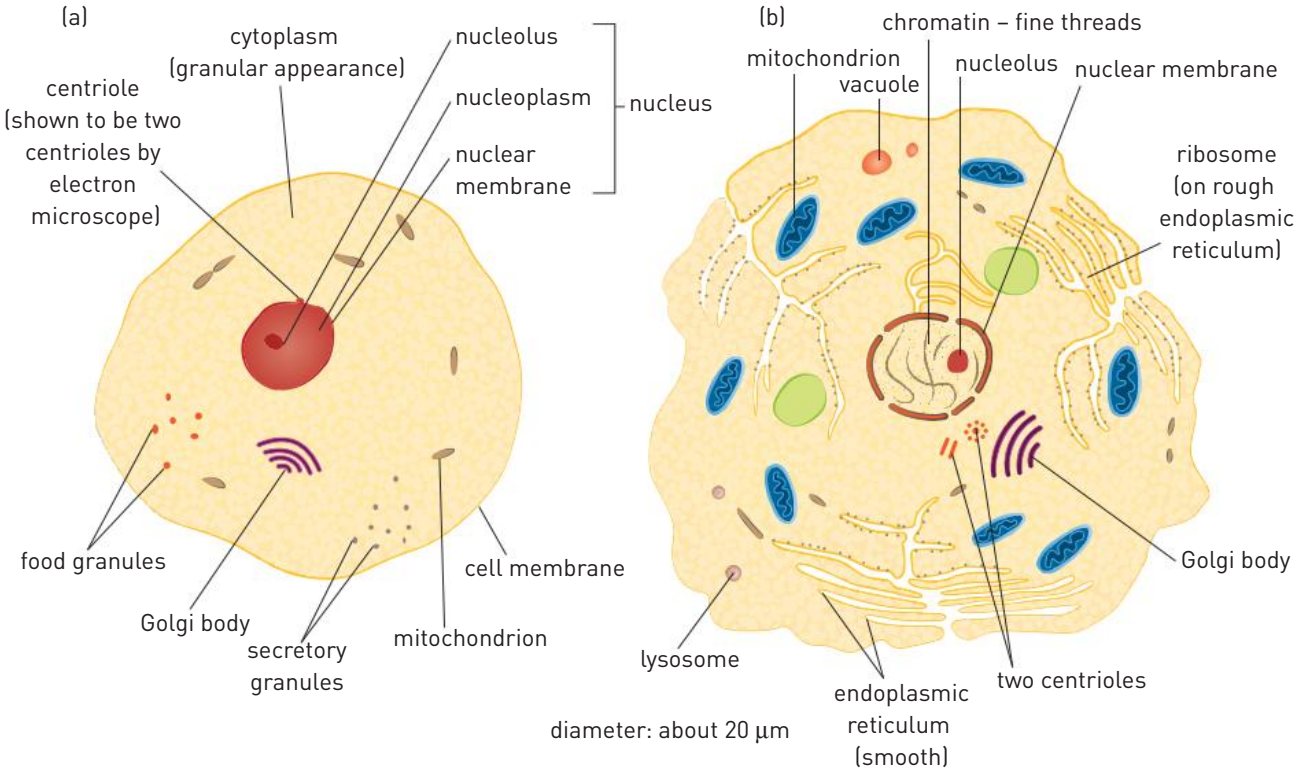


FIGURE 1 Features of an animal cell viewed with (a) a light microscope and (b) an electron microscope. The amount of detail seen in cells varies based on the equipment that is being used to view it.

Plant cells have many features in common with animal cells, but there are some distinct differences (see Table 2). They have a number of different organelles whose structure and function work to maintain a plant's survival.

Organelles are not scattered randomly throughout the cytoplasm. The nucleus generally takes a central position in the cell, with the Golgi bodies and endoplasmic reticulum clustered around it. Not all plant cells have chloroplasts. Root cells do not see sunlight and therefore do not need to use sunlight to make glucose. The chloroplasts in a leaf cell are usually oriented with their grana facing the light source.

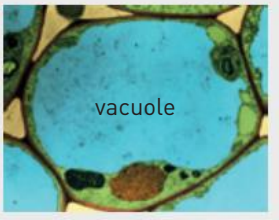
chromoplast
a plastid found in plants, containing red, yellow or orange pigments

leucoplast
a colourless plastid found in plant cells; concerned with starch or oil storage

chloroplast
a plastid found in green plants, containing chlorophyll on membranous grana, and enzymes in the liquid stroma; photosynthetic organelle

TABLE 2 Organelles found in plant cells

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

	Structure and function	Electron micrograph
Plastids (chloroplasts, chromoplasts and leucoplasts)	These are double-membraned organelles of varying shape. Three types are common. **Chromoplasts** are non-photosynthetic, containing red, yellow and orange pigments that provide colour to flowers, fruit and leaves. **Leucoplasts** are colourless and involved in starch storage. **Chloroplasts** are large, consisting of a fluid matrix or stroma and stacks of flattened membranous discs called **grana** (singular stack = *granum*). Each disc is termed a thylakoid. They contain chlorophyll and function in photosynthesis. Like mitochondria, they also contain DNA and ribosomes and can replicate themselves. Chloroplasts are an important site for photosynthesis in plant cells.	Chromoplast Chloroplast
Vacuole	A large central vacuole contains cell sap and is responsible for storage of substances and control of water levels in the cell (osmotic balance).	

grana (singular granum)
stacked portions of membranes found in chloroplasts; sites of light-dependent reactions for photosynthesis

Study tip

Students must be able to identify a chloroplast, mitochondria, rough endoplasmic reticulum and lysosomes from an electron micrograph.

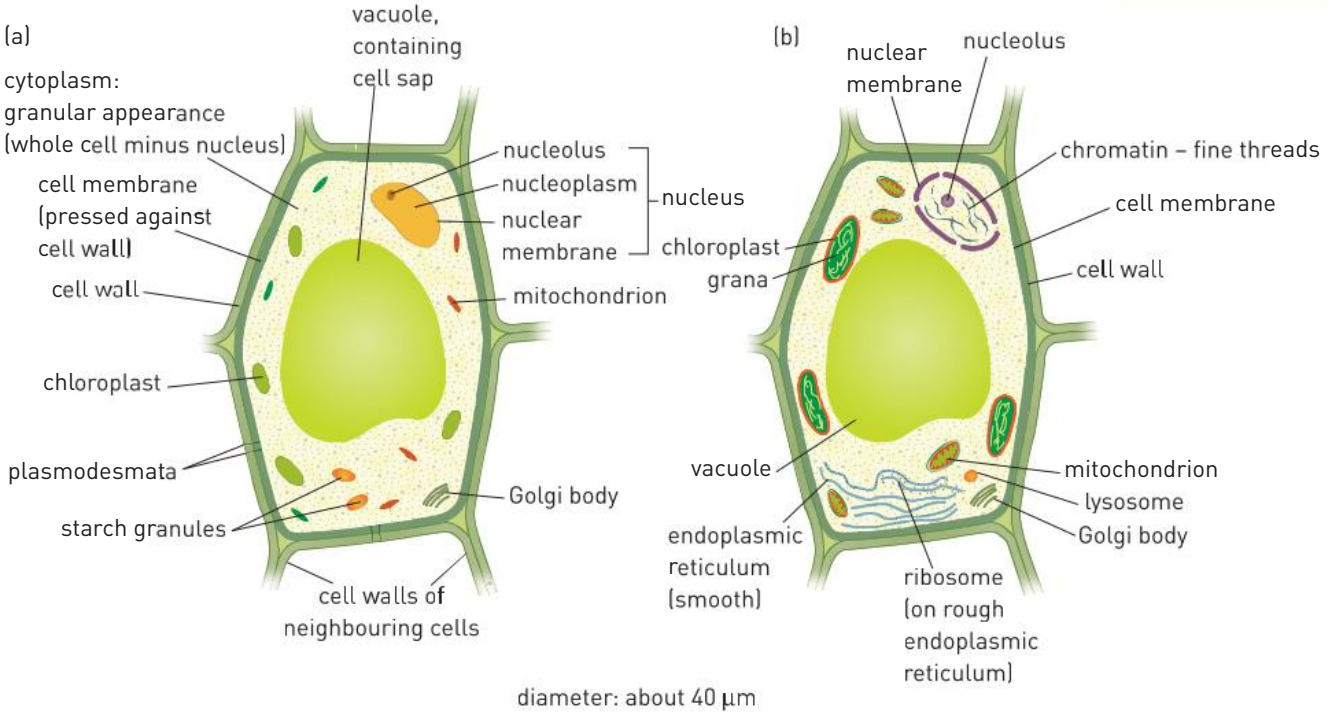


FIGURE 2 A plant cell viewed with (a) a light microscope and (b) an electron microscope. The amount of detail seen in cells varies based on the equipment that is being used to view it.

Many organelles move within the cytoplasm in an ordered fashion. They are held in place by a series of fine filaments inside the cell called the cytoskeleton. There are three main components of the cytoskeleton, outlined in Table 3.

(a)

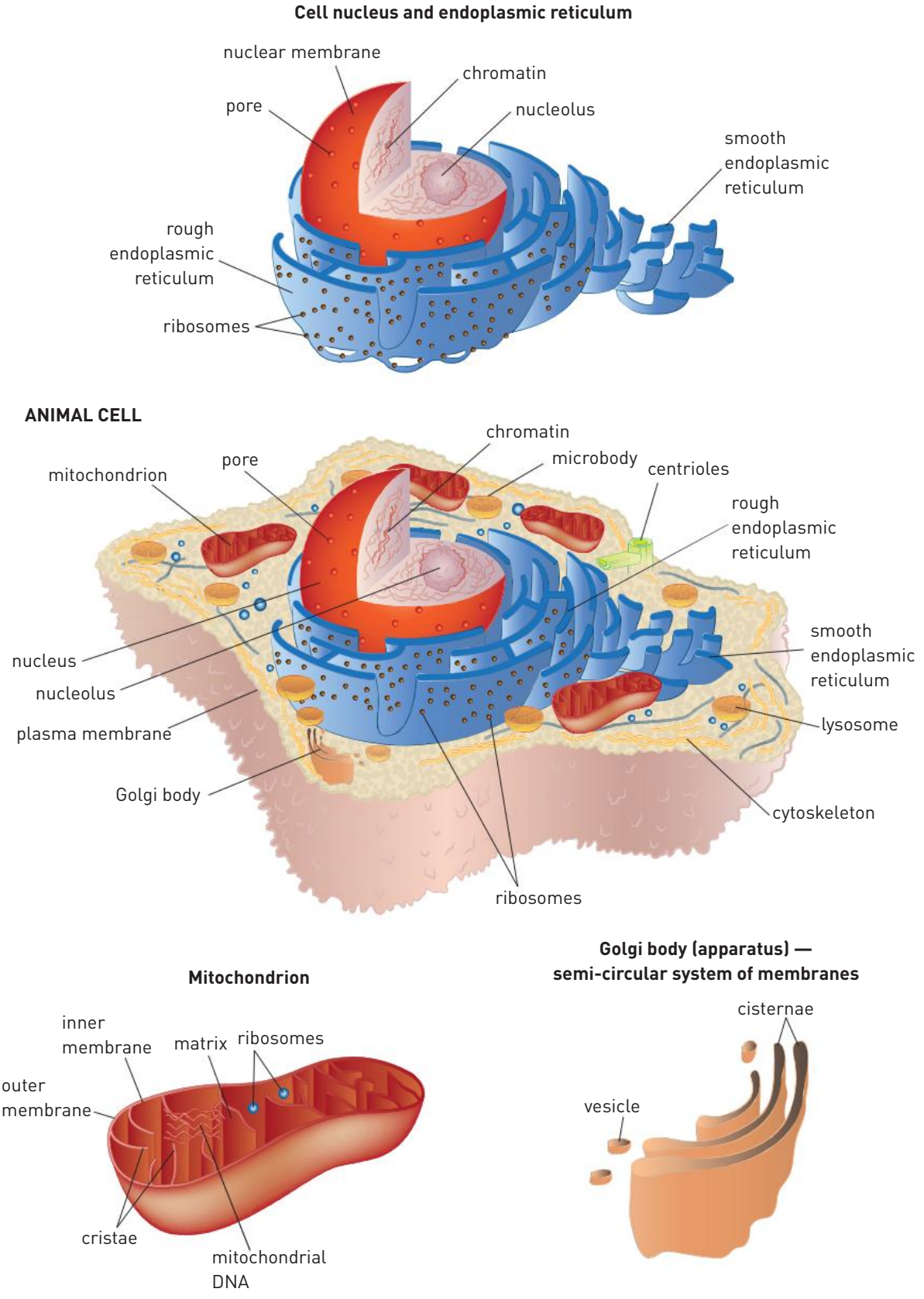
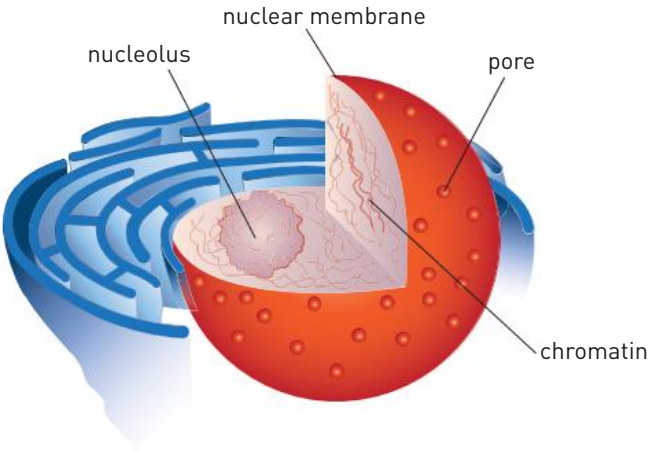


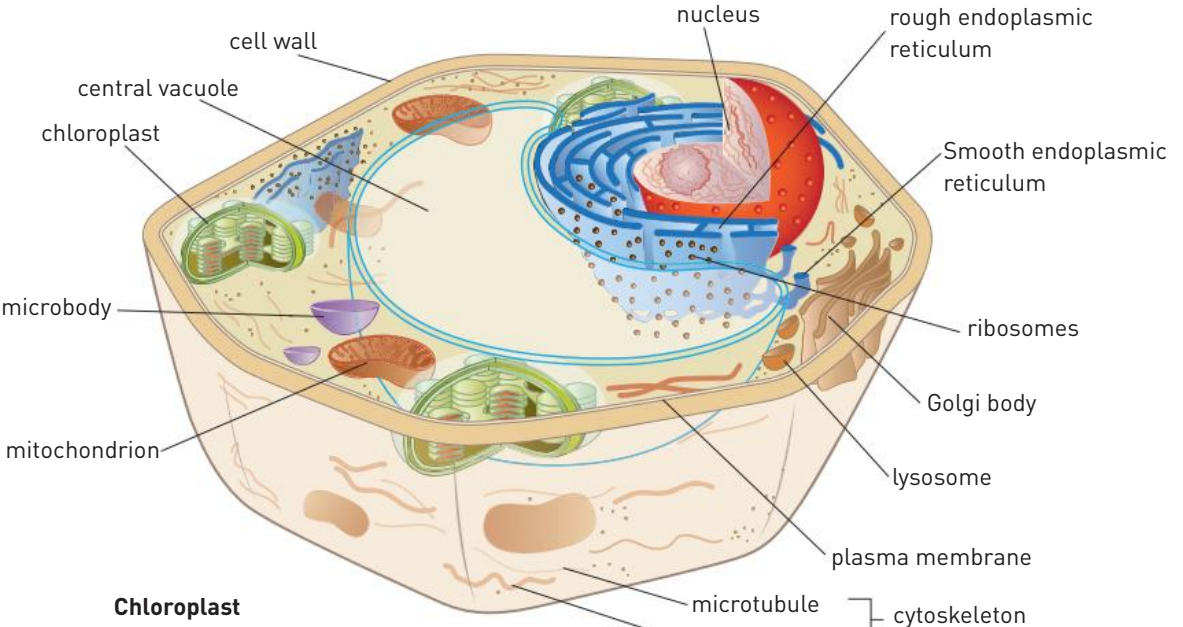
FIGURE 3 Animal cell (a) and plant cell (b)

(b)

Cell nucleus and endoplasmic reticulum



A PLANT CELL



Chloroplast

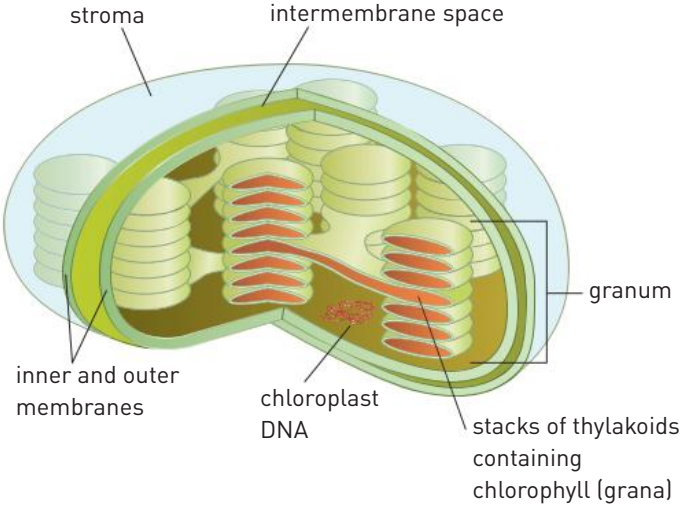


TABLE 3 Components of the cytoskeleton

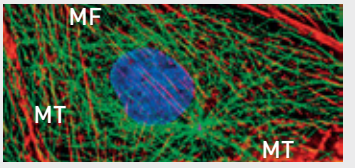
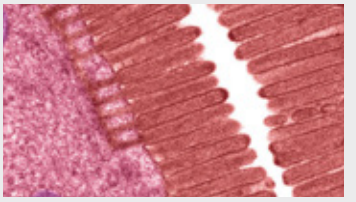
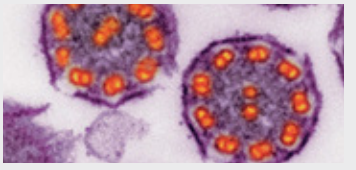
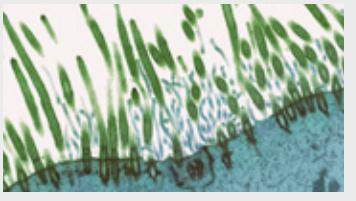
Feature	Structure and function	Electron micrograph
Microfilaments	**Microfilaments** are fine strands of the globular protein actin. They are able to bind with other proteins, and in so doing are able to hold organelles in position within the cytoplasm. Interactions of actin microfilaments with another protein, myosin, bring about general movement of the cytoplasm, organelles and the cell as a whole. Muscle cells have a high content of both of these proteins. The sliding action of actin and myosin results in contraction and relaxation and therefore movement. Some cells in animals (e.g. lining the intestine and kidney tubules) have minute finger-like projections of the membrane. These microvilli increase the cell surface area greatly without increasing volume to any great extent. Since they usually occur in large numbers and appear like the bristles of a brush, cells bearing microvilli are said to have a brush border. Actin microfilaments allow them to contract. The combined actions of increased surface area and movement facilitate uptake of materials into the cell.	MF – microfilament MT – microtubule   A cell with a brush border – each projection is a microvillus
Microtubules	**Microtubules** are hollow cylinders of the protein tubulin. Being more rigid than microfilaments, they provide greater mechanical support for the cell. In plant cell walls microtubules provide the framework along which cellulose is laid down. Microtubules also provide routes along which materials in the cytoplasm can move, assisting transport within cells. During cell division microtubules form the spindle fibres that attach to chromosomes and draw them apart. Cilia (short) and flagella (long) are cellular projections covered by the cell membrane. They are composed of an exact array of microtubules. The sliding of adjacent pairs of these tubules causes the projections to move. In this way, cilia and flagella can bring about movement of a cell or of a liquid over the cell's surface.	 Transverse section of a cilium showing the arrangement of microtubules  Cilia *Salmonella* bacteria with several flagella
Intermediate filaments	Intermediate filaments are composed of a variety of fibrous proteins, and range in size between that of the microfilaments and microtubules. These filaments are strong, stable and resistant to stretching, thereby providing mechanical support for the cell.	

TABLE 4 Comparison of eukaryotic cells: plant, animal and fungal

Feature	Plant cell	Animal cell	Fungal cell
Cell wall	Rigid, cellulose, may be lignified	None	Chitin
Vacuoles	Large: up to 80% of cell volume	Small if present	Small if present
Centrioles	Absent in most	Present	Absent in most
Chloroplasts	Present in photosynthetic cells	Absent	Absent
Granules	Starch	Glycogen	Glycogen
Cilia	Absent	Present in certain cells or cell types	Absent
Mode of nutrition	Autotrophic	Heterotrophic	Heterotrophic

microfilament
a solid rod of actin protein found in the cytoplasm, cilia and flagella of eukaryotic cells

microtubule
a hollow protein strand in cytoplasm; involved in cell transport and structure

Comparing prokaryotic and eukaryotic organelles

The prokaryotes (bacteria and cyanobacteria) are the most ancient cells. They are smaller than eukaryotic cells and have a simpler structure (see Table 5). Like plant cells, bacteria have a semi-rigid cell wall surrounding the cell membrane, but it is made of **murein** (a protein–carbohydrate complex), and also they lack distinct membrane-bound organelles and a cytoskeleton. The genetic material is bound into a single circular DNA molecule floating within the cytoplasm. Smaller segments of DNA, called plasmids, are not part of the prokaryote's chromosome, but can carry **antibiotic resistance**. Although many ribosomes are present in prokaryotes, they are not attached to any other structure and differ chemically from those of eukaryotes.

Some bacteria have flagella. The flagellum, however, is outside the cell membrane and is different in structure to that found in animals.

murein
a glycoprotein forming the cell wall in bacteria

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

TABLE 5 Comparison of eukaryotic and prokaryotic cells

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

CASE STUDY 3.3

Using cellulose

xylem
a complex tissue composed of living and dead cells; the tracheids and vessels are the non- living components through which water and dissolved mineral nutrients pass from the roots to the leaves in the transpiration stream

Cellulose and lignin are the major molecules found in plant cell walls. The lignin strengthens the cell walls, providing rigidity to the flexible cellulose. Wood comes from the central, dead part of tree trunks. The properties of these molecules in cell walls make wood ideal as a building material. The water-conducting (**xylem**) cells have died, as lignin has been embedded in their cellulose cell walls. Plant waste products can be deposited in the central cavities left behind when the cells die. Wood can support buildings for years and is more widely used in construction of buildings, bridges, furniture and tools than all other materials put together.

The stems of the papyrus reed were used by the Egyptians to construct boats, sails, mats, cloth cords and paper as early as the fifth century BCE. Cutting the stem of the reed into long strips produced papyrus scrolls. These strips were laid side by side to the required width. Another layer of shorter strips was then laid on these at right angles. This sheet was then soaked in water before being hammered and dried in the sun. Papyrus was used as a writing material in Europe until the fifth century CE. Although the reed is very light when dried, the cellulose components are very strong.

In about 105 CE, the Chinese, using the broken up bark of trees, hemp waste, old rags and fishnets, developed true papermaking. Today the fibres are pulped either mechanically or chemically to release the cellulose fibres. In high-quality papers the lignin, which can cause discolouration, is chemically removed. The pulp is washed to remove soluble impurities and filtered to remove insoluble matter, such as knots, dirt and unpulped fibres. Bleaching removes any unwanted colours in the pulp, after which the pulp is beaten. This shortens the fibres and mashes them to create hair-like fibrils that absorb water and become slimy. The whole mass of pulp can then be spread on wire frames and rolled, to press out water and enmesh the fibrils to form paper. Different types of paper are produced according to the particular plant material used.

Cellulose is used in the manufacture of a variety of textiles. Linen, produced from the flax plant (*Linum usitatissimum*), is one of the oldest textile fibres known. The fibres are obtained from the bark of the stalks. This is removed by a process called retting, in which the stalks are subjected to partial decomposition by bacteria. The fibres, after mechanical separation from the wood, can then be spun and woven. Hemp fibres from the plant *Cannabis sativa* are prepared in a similar manner. These fibres are used to produce a range of textile materials from fine fabrics to coarse ropes.

The seed hairs of the cotton plant (*Gossypium*) are almost pure cellulose and therefore do not need the same preparation as the stalks of flax and hemp. Cotton, therefore, supplanted linen and hemp as a fabric material.

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

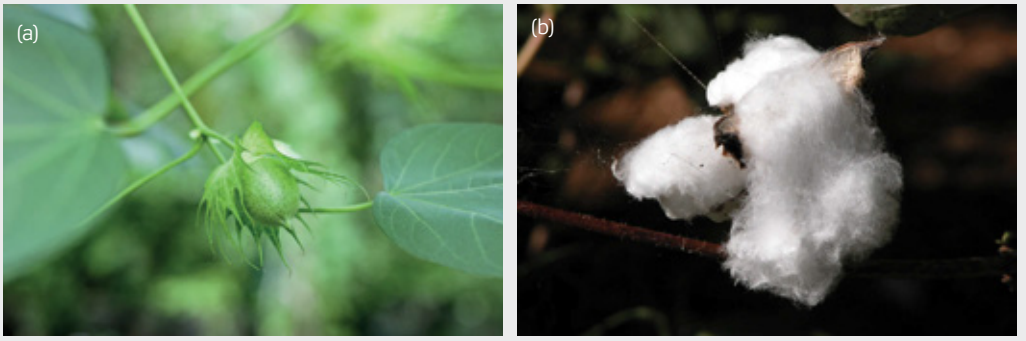


FIGURE 4 Cotton: (a) unripe and (b) ripe cotton boll

Cellulose can also be processed into a wide range of products such as thickeners for paint, stabilisers in foods and cosmetics, adhesive tapes and dialysis membranes.

CHECK YOUR LEARNING 3.3

Describe and explain

1 **Describe** the main functions of the following cell parts. Indicate the kind(s) of cells in which they are usually found.

- **a** Cell wall
- **b** Centriole
- **c** Chloroplast
- **d** Endoplasmic reticulum
- **e** Golgi body
- **f** Lysosome
- **g** Mitochondrion
- **h** Nucleolus
- **i** Nucleus
- **j** Ribosome
- **k** Vacuole

2 **Explain** why enzymes are contained within a lysosome instead of being free in the cytoplasm.

3 **Describe** the difference between rough and smooth endoplasmic reticulum.

4 **Describe** two structural features that would help to identify the difference between prokaryotic and eukaryotic cells.

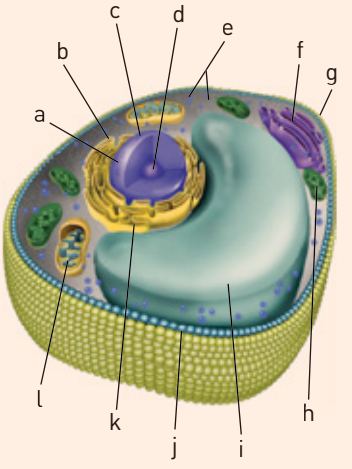
Apply, analyse and interpret

5 A protozoan is a single-celled eukaryotic organism. Many freshwater protozoans contain contractile vacuoles that can change their volume. Analysis shows that these vacuoles contain almost pure water, dissolved substances being in less concentrated solution than the same substances in the rest of the organism. **Determine** which inference is correct.

- **A** The vacuole fills by diffusion.
- **B** The vacuole fills by osmosis.
- **C** The protozoan must expend energy to fill the vacuole.
- **D** There is insufficient data to answer the question.

Provide a justified reason for your answer.

6 Using the letters given on the diagram below, correctly **differentiate** three organelles in this plant cell and give the main function for each.



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  3.3C Identifying organelles from electron micrographs

3.4 The cell membrane

KEY IDEAS

- The cell membrane as a selectively permeable barrier
- The chemical structure of the cell membrane based on the fluid mosaic phospholipid bilayer model
- The role of protein channels, cholesterol and glycoproteins in the cell membrane

The cell membrane is a selectively permeable barrier that controls the movement of substances into and out of the cell. It is described as selectively permeable because some small substances can diffuse through very easily (e.g. water), while larger molecules such as protein molecules are prevented from moving through the membrane.

A permeable membrane would allow the free movement of all molecules in both directions. A selectively permeable membrane allows particular molecules through that fit with the selective criteria.

The cell membrane and its structure has the following functions:

- To help in the active transport of materials in and out of the cell
- To provide a certain degree of mechanical support to the cell, so that it can maintain its shape
- To act as a receptor for chemical materials (e.g. hormones) and so maintaining the specificity of the particular cell type.

The chemical structure of the cell membrane

phospholipid bilayer the main structure of the cell membrane consisting of two layers of phospholipids arranged so that the hydrophilic heads face the internal and external fluid environments

The cell membrane is very thin – about 7.5 nm (nanometres) in width (1 nm = 10^{-9} m). The basic structure of the membrane is a known as a **phospholipid bilayer**. This is because it consists of two thin sheets of polar phospholipids. A phospholipid is a molecule that has a negatively charged phosphate 'head' and two fatty acid 'tails'. The phosphate end of the molecule is able to mix well with water, and is therefore described as hydrophilic (water-loving). The tails do not mix with water (fatty acids do not mix with water) and are described as hydrophobic (water-hating).

The phospholipid layer has to be arranged as a double layer because it is surrounded on either side by a water-based mixture (the extracellular fluid and the cytoplasm). This

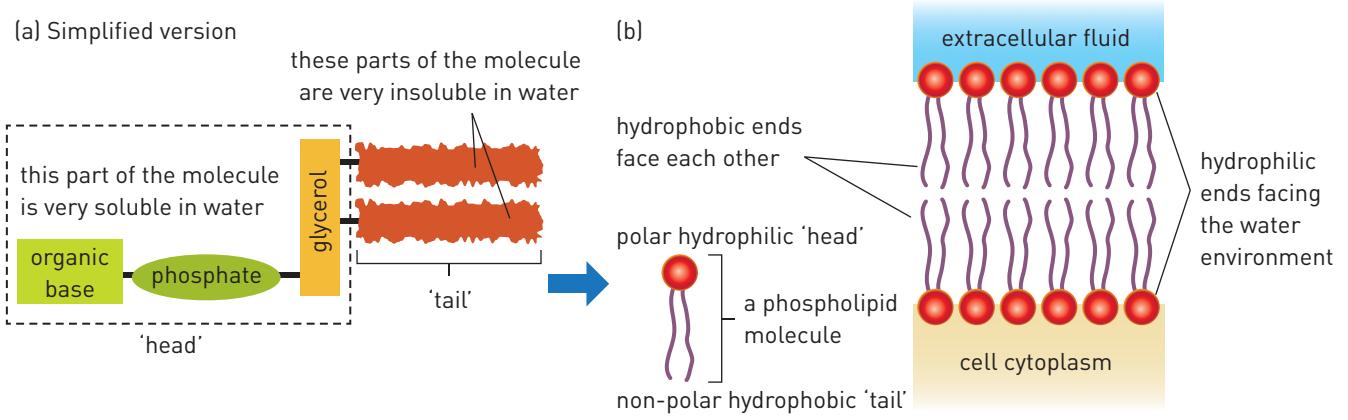

FIGURE 1 Phospholipid molecule. (a) Simplified version; (b) molecule and arrangement of the phospholipid bilayer.

also dictates the orientation of the individual phospholipid molecules. The hydrophobic tails repulse water, so the phospholipid molecules automatically arrange themselves so that the hydrophobic tails are sandwiched between the hydrophilic phosphate heads. This arrangement of these molecules is termed a bilayer.

As with all molecules, the phospholipid molecules move about. However, their polarity restricts their movement mainly to the lateral plane.

A lot of energy is required to move the phospholipid molecules from one layer to the other, since the hydrophilic head must pass through the hydrophobic tail region. The tails must come into contact with water in this action. As a result, 'flip-flop' movement is very rare.

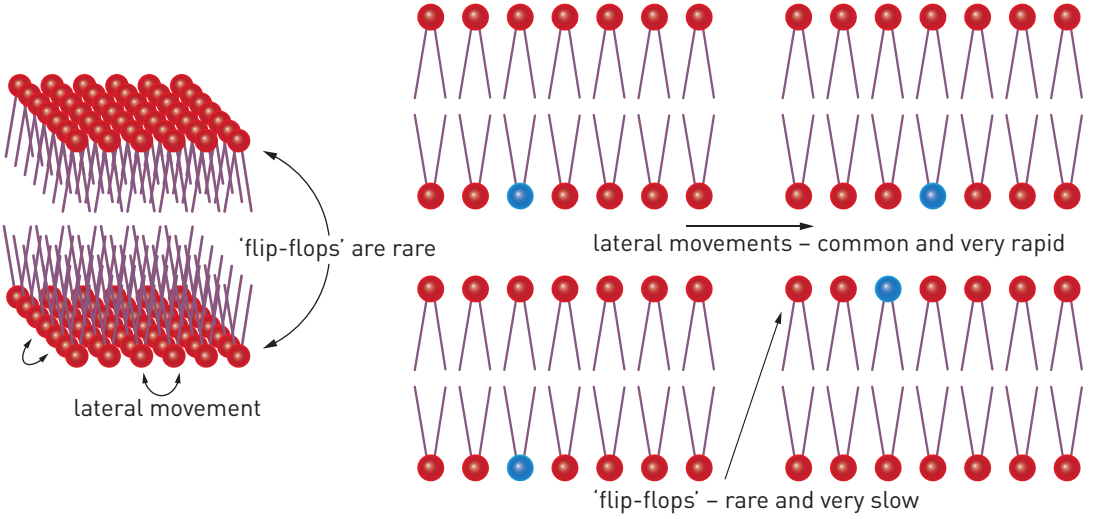

FIGURE 2 Movement of phospholipids within the membrane

The phospholipid bilayer, according to the **fluid mosaic model**, is regarded as a dynamic structure in which proteins can float – some moving about freely while others are fixed in position by microfilaments running into the cytoplasm.

Some proteins, known as **integral proteins**, penetrate either part of the way into the membrane or all the way through it. The middle parts of these proteins are hydrophobic and therefore are able to mix freely with the hydrocarbon tails of the membrane lipids. They can only be released by detergents or organic solvents. The parts of the protein in contact with extracellular or intracellular fluid are hydrophilic. Other proteins are on the outside of the membrane or attached to the outer surfaces of integral proteins and are called **peripheral proteins**. These peripheral proteins are weakly bound to the membrane or other proteins. Adding salts or changing the pH easily disrupts these bonds.

Protein channels

Usually the integral proteins have a hydrophobic portion that interacts with the phospholipids, and a hydrophilic portion facing the water-based surroundings. Some of the proteins (of which thousands may occur in membranes) may be purely structural in function. Others act as carrier molecules in transporting specific substances through the membrane. It is thought that hydrophilic channels (**protein channels**) occur within integral proteins or between adjacent protein molecules. The channels allow the passage of large or some water-soluble molecules that otherwise would be excluded by the phospholipid molecules.

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

integral protein
a protein found within the structure of the cell membrane

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

protein channel
a channel passing through the centre of a protein, the lining of which is hydrophilic

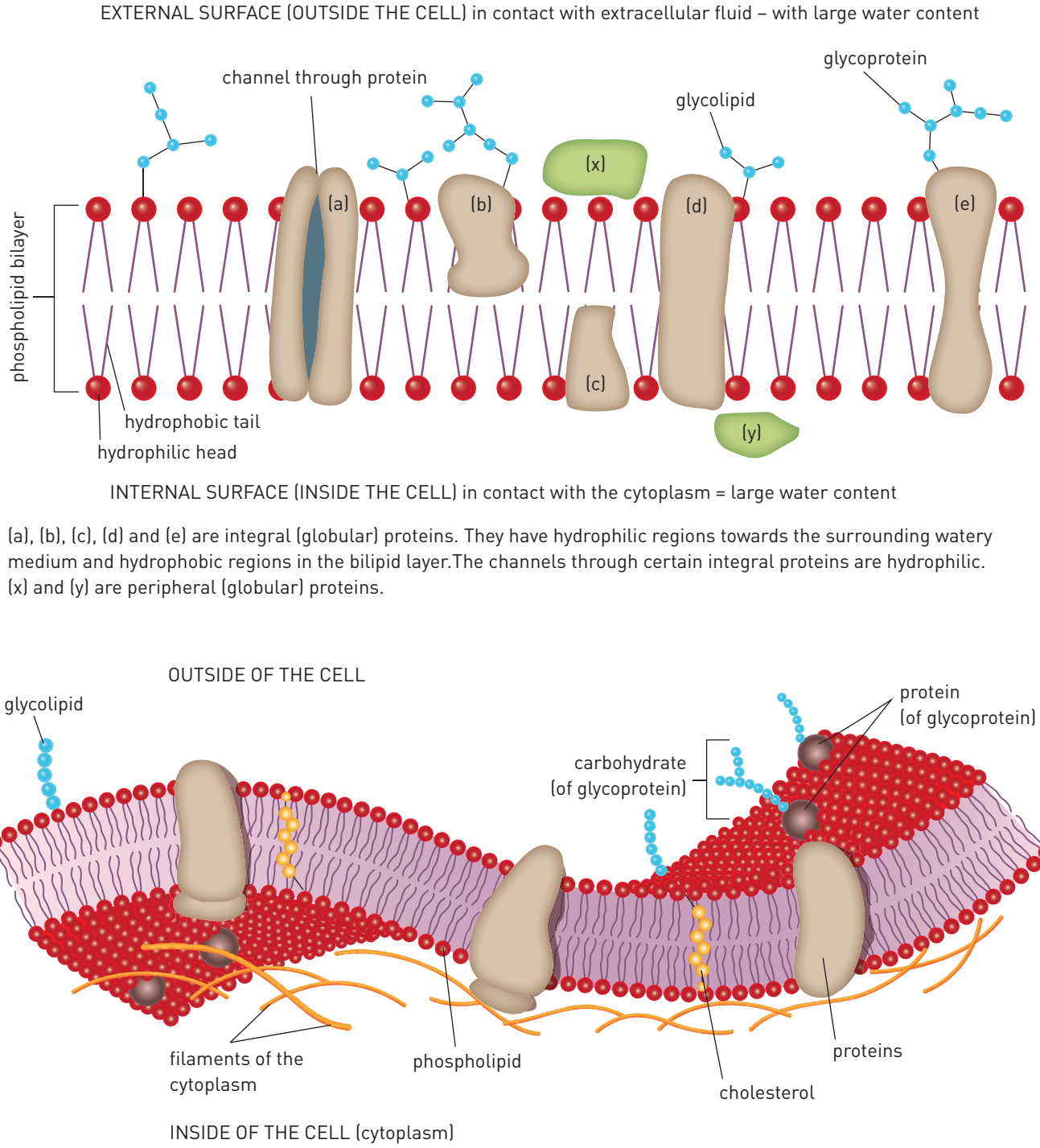

FIGURE 3 Two representations of the fluid mosaic model of the cell membrane

Other membrane proteins may act as recognition markers or receptor molecules that bind to chemical messengers that may be in the fluid outside the cell.

Glycoproteins and glycolipids are also present in the membrane. They are proteins or lipids that have branching carbohydrate portions on their free surfaces. These 'antennae' are made up of a number of sugar molecules and have a range of precisely defined patterns. They are important as recognition features:

- Sugar recognition sites of two neighbouring cells may bind to each other, causing cell-to-cell adhesion. This results in a particular orientation of the cells and the formation of tissues.
- Glycoproteins act as specific markers when the body is trying to defend itself, for example **antigens** in the immune response.
- Various control systems rely on recognition sites. For example, hormones and other chemicals have recognition sites that enable them to be taken up specifically by cells that have the complementary sites.

glycoprotein
a protein with attached polysaccharides that reacts predominantly as a protein

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

Cholesterol

Cholesterol is found between the phospholipid molecules in the bilipid layer. It also has hydrophobic and hydrophilic portions. Cholesterol regulates the fluidity of the membrane so that it is neither too rigid nor too fluid for the functioning of the cell.

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

Variations in membrane properties

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

- lipid composition and as a result fluidity
- integral proteins and as a result 'channel' sizes
- peripheral and integral proteins and as a result
  - recognition sites
  - carrier molecules
  - enzymes attached.

CHECK YOUR LEARNING 3.4

Describe and explain

1 **Explain** why the cell membrane must consist of a bilayer of phospholipids.
2 **Summarise** the functions proteins perform in the cell membrane.
3 **Identify** two factors that determine whether a particle will pass through a cell membrane.
4 **Explain** the functions of the cell membrane.

Apply, analyse and interpret

5 **Consider** the structure of the cell membrane in terms of the fact that cells vary in their ability to allow different types of molecules to pass through them.
6 **Deduce** why recognition sites on the outside of cell membranes are significant to living things.

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Fluid mosaic model

» Weblink
Glycoproteins

» Weblink
Cholesterol

3.5 Movement of chemicals in and out of cells

KEY IDEAS

- Passive transport of molecules across a membrane
- Simple diffusion, facilitated diffusion and osmosis
- Active transport of molecules across a membrane
- Protein carriers, exocytosis and endocytosis (including pinocytosis and phagocytosis) as forms of active transport

The membrane phospholipid bilayer is a major barrier that is impermeable to the usual water-soluble substances such as ions, glucose and amino acids. Lipid-soluble substances such as oxygen, nitrogen and alcohols dissolve in the phospholipids and diffuse rapidly through the cell membrane as if it were not there. Even though water is highly insoluble in the membrane phospholipids, it is readily able to penetrate the phospholipid layer as well as pass through the protein channels. The reason for this is not certain, but it is believed that water molecules are sufficiently small, and their kinetic energy sufficiently great, for them to penetrate the lipid portion before the hydrophobic 'tails' can stop them.

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

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

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

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

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

Materials move in and out of cells via **passive transport** or **active transport**. Passive transport can be further broken into categories of diffusion and osmosis, as shown in Figure 1.

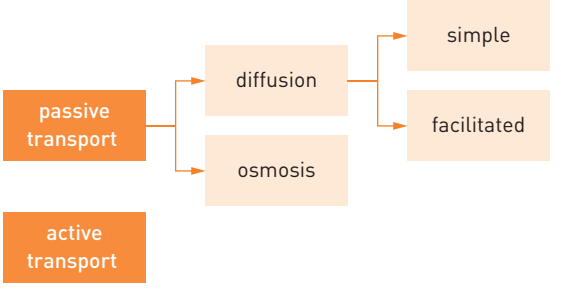


FIGURE 1 The basic mechanisms of transport across a membrane

Passive transport

Passive transport is a way of moving molecules that does not require energy. Many molecules do not need extra energy to move across a membrane.

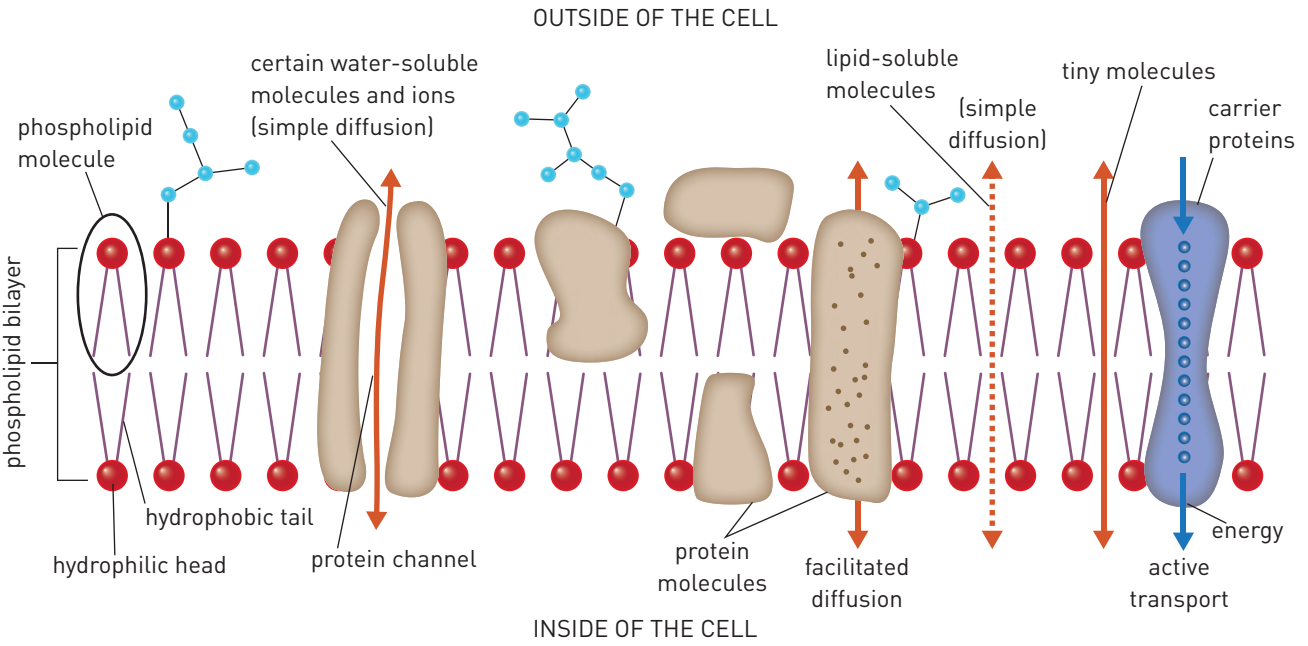


FIGURE 2 Transport pathways through the cell membrane

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

There are three main factors that affect the rate of diffusion.

1. Temperature: molecules move faster at higher temperatures. This means diffusion will occur faster at high temperatures.
2. Particle size: small molecules require less energy to move. This means smaller particles will diffuse faster than larger particles.
3. Concentration: the greater the difference in concentration between the two locations (the **concentration gradient**) the faster diffusion will occur.

Diffusion through the cell membrane may be divided into two separate processes: **simple diffusion** and **facilitated diffusion**.

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

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

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

Simple diffusion

Simple diffusion is the free and unaided movement of molecules or ions through the cell membrane from an area of high solute concentration to an area of low solute concentration. For example, oxygen molecules (solute) dissolved in water (solvent) will be in constant random motion, causing an even dispersion of them through the solvent. If the concentration of oxygen molecules outside a cell is higher than that inside the cell, a concentration gradient will exist. Oxygen molecules are soluble in both water and lipids and can therefore pass freely through the cell membrane. The oxygen molecules do not stop moving once they are inside the cell, but the number of oxygen molecules passing into the cell will initially be greater than those moving out: there will be a net flow into the cell. As the concentrations on both sides of the membrane become equal, the number of molecules passing from each direction will become the same. At this

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

point **dynamic equilibrium** has been reached. The number of molecules entering the system will equal the number of molecules leaving.

Facilitated diffusion

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

Osmosis

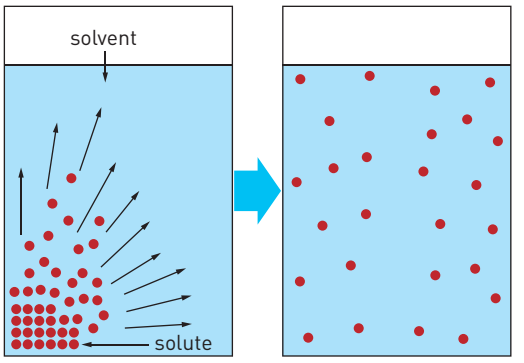
osmosis
the movement of water from a region of low solute concentration to a region of high solute concentration through a selectively permeable membrane to counteract the differences in solute concentration

Osmosis occurs when there is a concentration gradient of solute (dissolvable molecules) across a membrane which is impermeable to the solute. Osmosis is the passive movement of water molecules across a selectively permeable membrane from an area of low solute concentration to an area of high solute concentration. Because the high solute concentration traps many of the water molecules around the hydrophilic solute, the water molecules are not free to move back across the membrane.

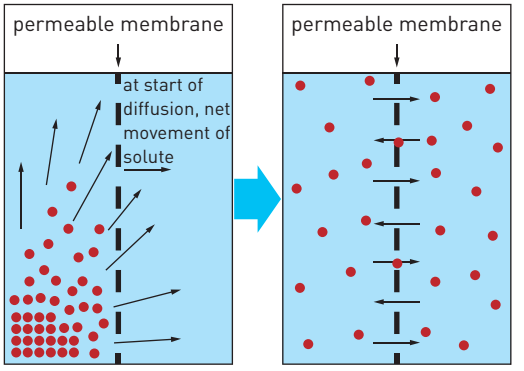
Osmotic/water potential is the capacity of a solution to lose water molecules through a selectively permeable membrane. It depends upon the concentration of the solute in the solution (e.g. the cytoplasm of a cell), compared with the concentration on the other side of the membrane (e.g. extracellular fluid). If the solute concentration in the extracellular fluid is higher than the solute concentration in the cytoplasm, the surrounding extracellular solution is said to be **hypertonic**, and its osmotic potential is low. Water will move out of the cell. If the solute concentration of the surrounding extracellular fluid is lower than the solute concentration of the cytoplasm in the

hypertonic
a solution having a higher solute concentration than that of the surroundings

(a) Simple diffusion
This results in the random but even distribution of solute molecules throughout the solvent.



(b) Diffusion through a permeable membrane, which allows the free passage of both solute and solvent molecules in both directions



(c) Diffusion through a selectively permeable membrane. This membrane excludes the solute molecule purely on size, but allows the passage of solvent molecules in both directions through the membrane.

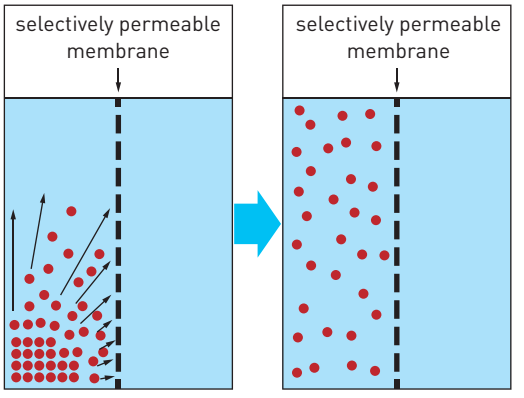


FIGURE 3 Diffusion, and the effect of different types of membranes

cell, the solution of the extracellular fluid is **hypotonic**, and its osmotic potential is high. Water will move into the cell. When the solute concentration of the extracellular fluid is the same as that of inside of the cell, the solutions are said to be **isotonic** (see Table 1).

hypotonic
a solution having a lower solute concentration than that of the surroundings

isotonic
a solution having the same solute concentration as that of the surroundings

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

Extracellular solute concentration	Cytoplasm solute concentration	Osmotic potential of extracellular fluid and direction of water movement
High (hypertonic)	Low (hypotonic)	Low – water moves out of the cell
Low (hypotonic)	High (hypertonic)	High – water moves into the cell
Same (isotonic)	Same (isotonic)	Nil – no net movement of water

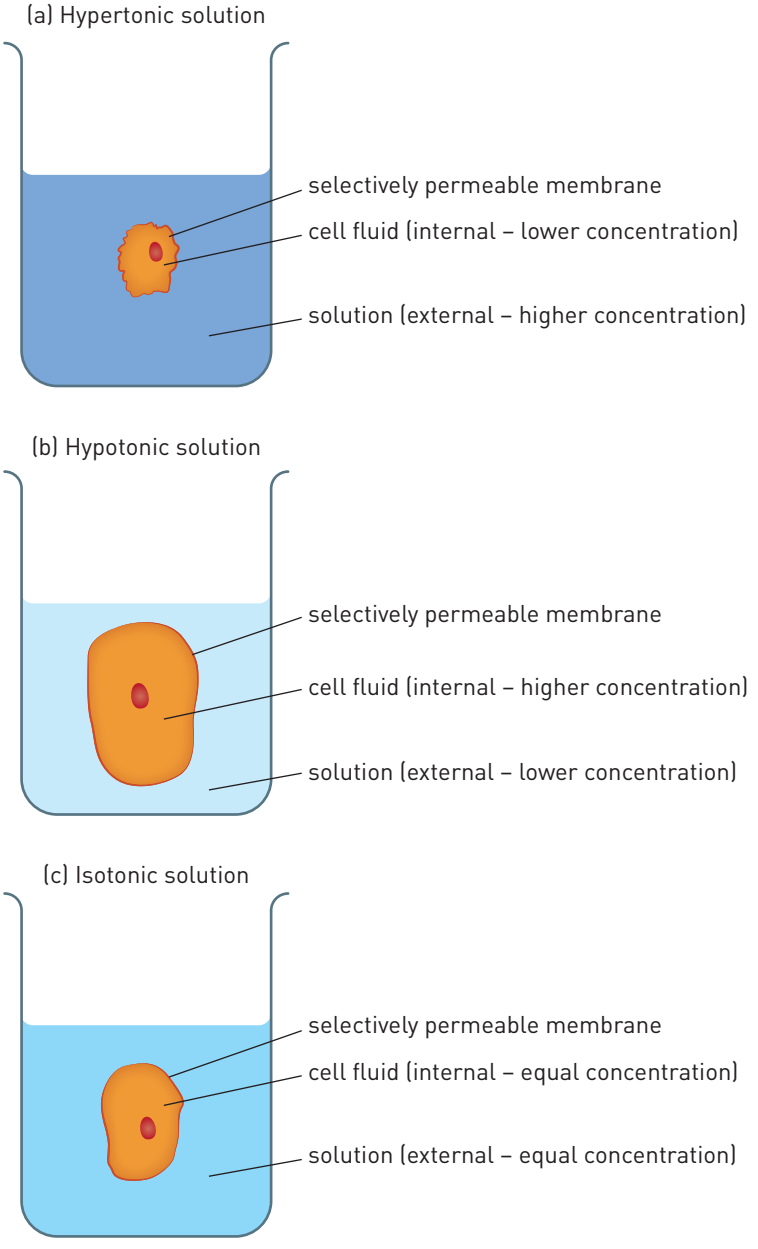


FIGURE 4 Types of extracellular solution

If the osmotic or water potential of a cell is low, there will be a net flow of water *into* the cell by osmosis. If it is high, there will be a net flow of water *out of* the cell by osmosis. In an isotonic solution the same amount of water leaves the cell as enters.

When a cell is placed in a strong sugar solution, the sugar cannot diffuse through the cell membrane. There is a net flow of water out of the cell to a region of high solute concentration, until the concentration on both sides of the cell is equal, or isotonic.

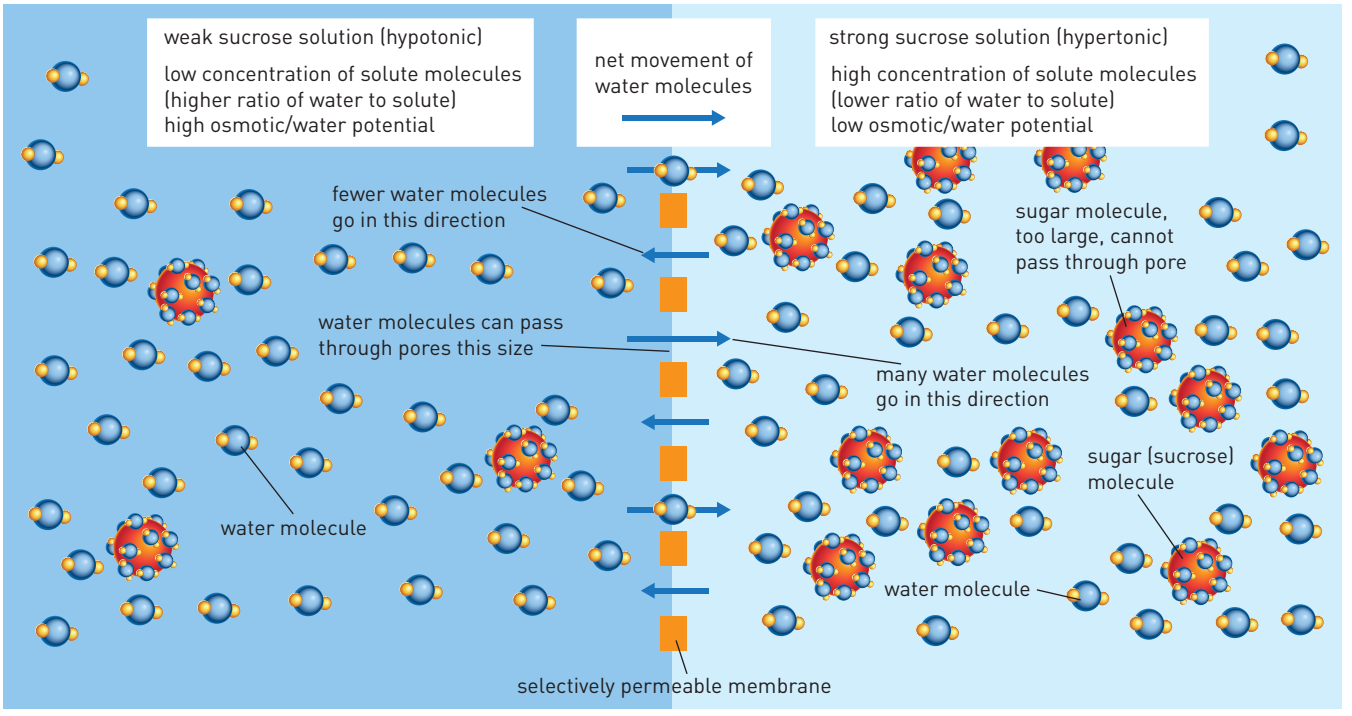


FIGURE 5 The process of osmosis

Study tip

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

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

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

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

turgor pressure
the inward pressure exerted on plant cells due to the presence of the cell wall

A similar phenomenon takes place in animal cells (e.g. red blood cells or single-celled protists such as *Amoeba*). Because it lacks a cell wall, the entire cell shrinks and shrivels in a hypertonic solution (crenation), and in a hypotonic solution it expands, stretching the cell membrane, which may burst. Red blood cells that rupture due to osmosis are said to be haemolysed since the red pigment haemoglobin is released into the surrounding liquid.

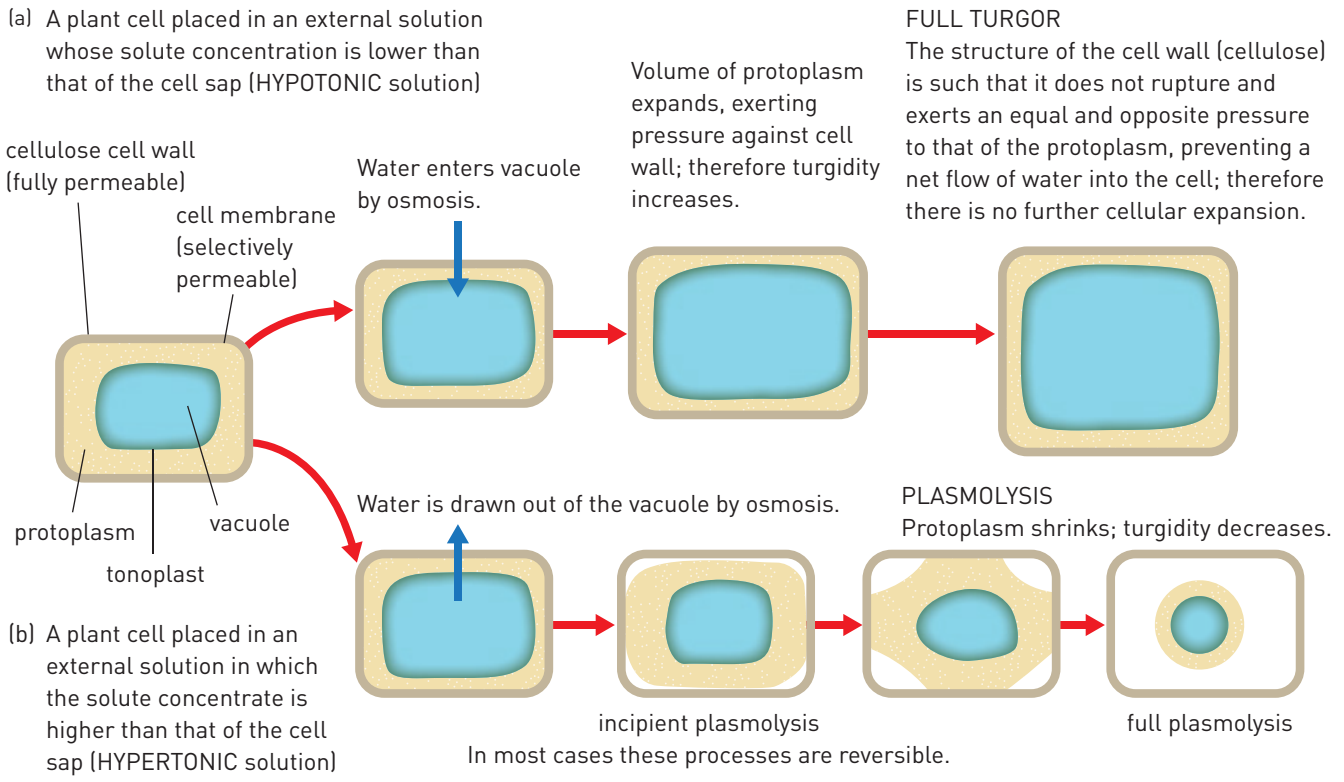


FIGURE 6 Plasmolysis and turgidity in plant cells

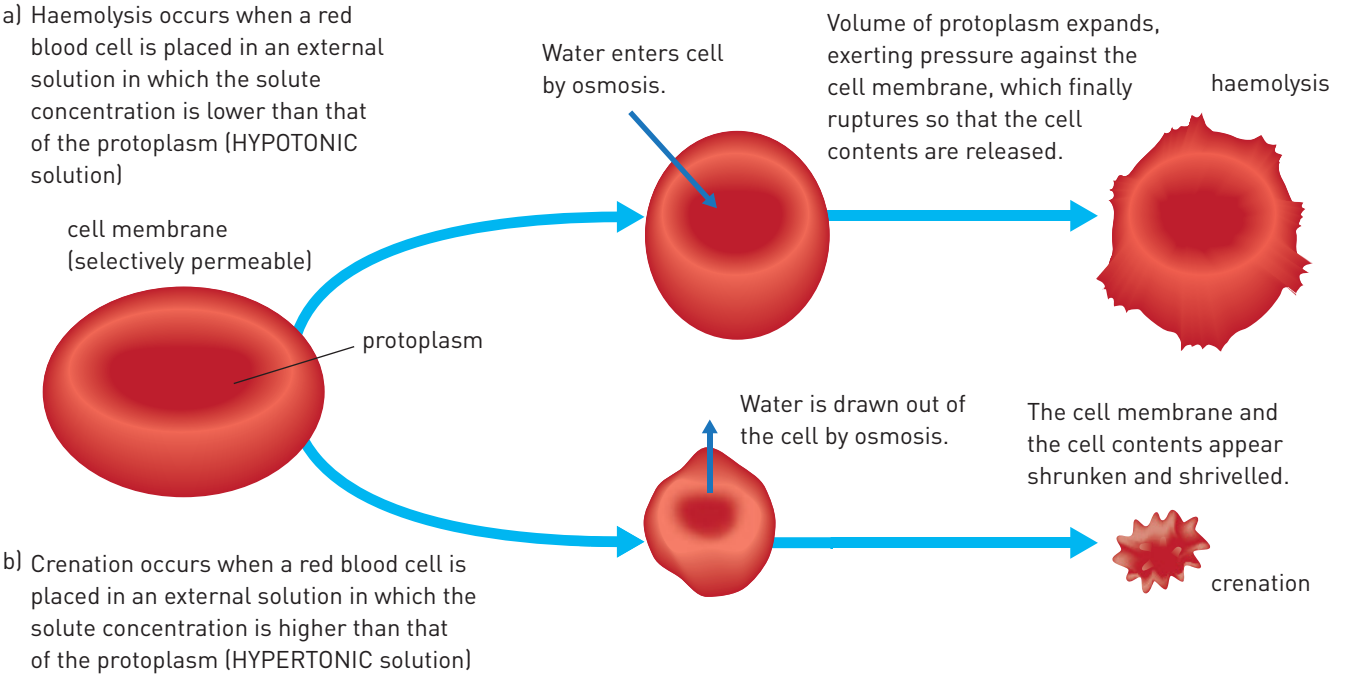


FIGURE 7 Haemolysis (a) and crenation (b) in red blood cells

Active transport

Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient. Energy is required because the substance must be moved against its natural tendency to diffuse in the opposite direction. Movement is unidirectional. In contrast, diffusion is reversible, depending on the direction of the concentration gradient. Active transport of materials out of cells is termed **exocytosis**; the active movement of materials into the cell is termed **endocytosis**. Active transport may involve:

- carrier molecules in the membrane, or
- formation or breakdown of membrane-bound 'packages' of matter. These packages are membrane-bound vacuoles formed by the processes of phagocytosis or pinocytosis.

exocytosis
the movement of materials out of the cell

endocytosis
the movement of materials into the cell

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

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

In endocytosis, the membrane may actually engulf particulate matter (**phagocytosis**) or extracellular fluid and its contents (**pinocytosis**). Phagocytosis (cell eating) involves the extension part of the cell membrane extending out and surrounding a solid particle outside the cell. The membrane fuses around the particle and, in doing so, forms a vesicle which becomes incorporated into the cytoplasm. The term vacuole is used when large particles are taken up. Lysosomes fuse with this food vacuole, releasing enzymes. The resulting digested molecules diffuse into the cytoplasm. The vacuole with its undigested matter moves to the cell membrane where it fuses, releasing the waste (exocytosis).

Pinocytosis (cell drinking) occurs by infolding the cell membrane to form a channel. The liquid material enclosed in the channel is pinched off in a vesicle as the membrane fuses at the surface.

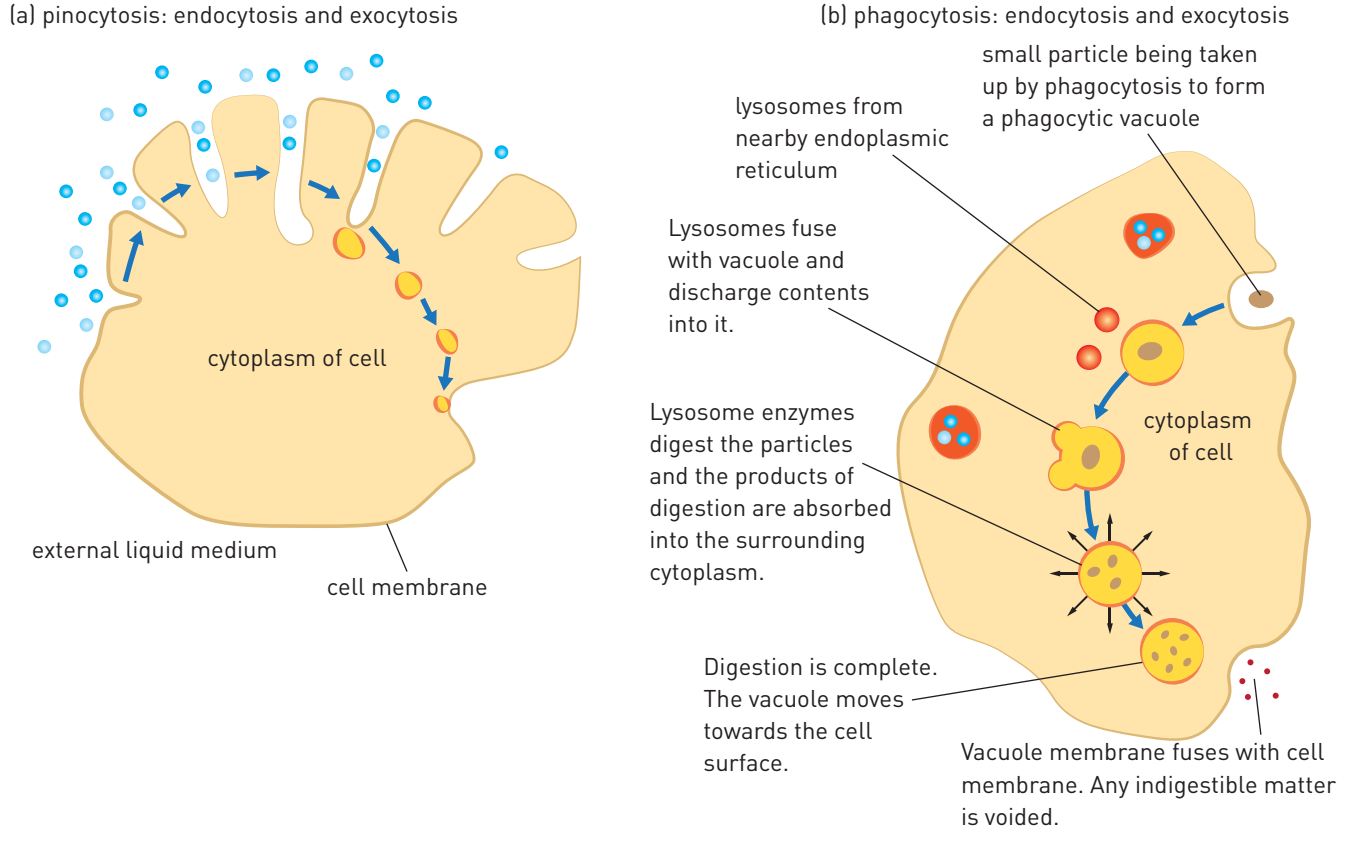


FIGURE 8 The sequence of events in pinocytosis (a) and phagocytosis (b)

Phagocytosis and pinocytosis do not occur in plant cells due to the presence of the relatively inflexible cell wall. Phagocytosis is an important feeding mechanism in many single-celled animals (Protozoa) and is one of the means that multicellular animals use to destroy invading bacteria and viruses.

Exocytosis of materials in vacuoles and vesicles involves them again fusing with the cell membrane and then opening up to the external environment to expel the contents. White blood cells use exocytosis to expel the digested remains of bacteria cells. Nerve cells (neurones) use exocytosis to pass chemical messenger molecules to other cells.

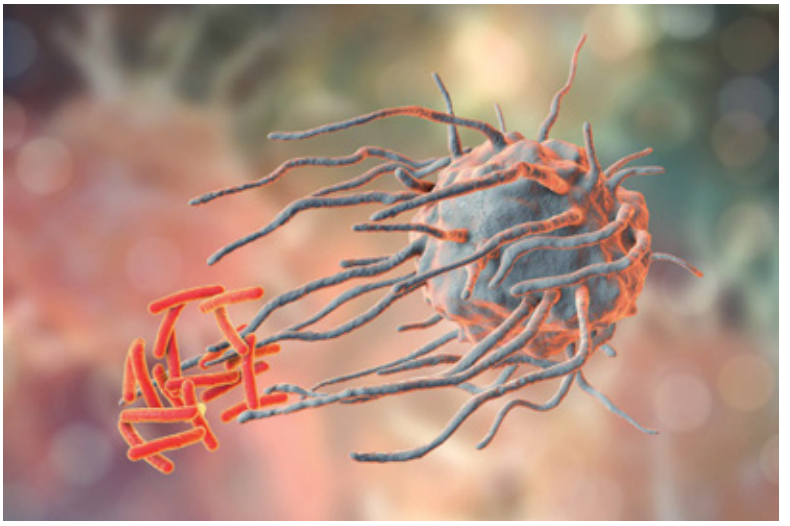


FIGURE 9 An artist's depiction of a macrophage engulfing tuberculosis bacteria

CHECK YOUR LEARNING 3.5

Describe and explain

1 **Explain** what is meant by the terms 'passive transport' and 'active transport'.
2 **Describe** the difference between a permeable and a selectively permeable membrane. Give an example of each.
3 **Explain** what is meant by dynamic equilibrium between two solutions separated by a selectively permeable membrane.
4 **Describe** simple diffusion. **Explain** how it differs from facilitated diffusion.
5 **Compare** diffusion and osmosis.
6 **Describe** the different methods of active transport used by cells.
7 **Compare** phagocytosis and pinocytosis.

Apply, analyse and interpret

8 Animal cells placed in a hypotonic solution swell and burst. Plant cells placed in a hypotonic solution swell only to a particular point and do not rupture.
   a **Classify** the process involved in the swelling.
   b **Consider** why animal cells rupture but plant cells do not.
   c **Deduce** the name given to this action in plant cells.

Study tip

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

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  Osmosis
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  Cell transport

CHAPTER 3

Review

Chapter summary

3.1 As microscope technology became more advanced, many observations were made on cellular structure, which in the mid-1800s led to the cell theory that all living things are composed of one or more cells. With further knowledge, this theory has been expanded to encompass the processes of cell division (including DNA and inheritance), chemical composition and coordination of activities between different cell types.

3.2 The first cells to develop (prokaryotic cells) were very simple, consisting of a cell membrane (some enclosed by a cell wall) and protoplasm.

Eukaryotic cells are believed to have arisen by one cell engulfing and incorporating different prokaryotic organisms into it, and the engulfed cells evolving into membrane-bound organelles (via endosymbiosis).

3.3 Eukaryotic cells are distinct from prokaryotic cells in having a 'division of labour' of the cytoplasm into membrane-bound organelles.

Plant cells, unlike animal cells, are each surrounded by a rigid cell wall of cellulose, and those cells exposed to light contain chloroplasts, which are the sites of photosynthesis, and a large, central vacuole filled with cell sap.

3.4 The cell is bound by a membrane, which consists of a phospholipid bilayer through which integral proteins are inserted and on which peripheral proteins and other chemicals, such as sugars, are bound. Different cells have membranes with different chemical compositions, and this changes their properties.

The functions of the cell membrane are to maintain each cell as an integral structure, to control movement of substances into and out of the cell (through passive and active transport), to provide some mechanical support to the cell and help maintain shape, and to provide receptors to extracellular material for different cell types.

3.5 The cell membrane is a selectively permeable structure that allows the passage of only certain molecules.

Diffusion is the passage of solutes from a hypertonic solution (one of high concentration) to a hypotonic one (one of low concentration) through a selectively permeable membrane.

Facilitated diffusion is the transport of substrate molecules through the membrane by special enzyme-like carrier molecules.

Osmosis is the passage of the solvent (water) from a hypotonic to a hypertonic solution through a selectively permeable membrane that is impermeable to the solutes in this solution.

Diffusion, facilitated diffusion and osmosis are forms of passive transport of materials.

Key terms

- abiogenesis
- active transport
- antibiotic resistance
- antigen
- cell membrane
- cell theory
- cellular respiration
- centriole
- chloroplast
- cholesterol
- chromatin
- chromoplast
- chromosome
- cilium
- colonial
- concentration gradient
- cristae
- cytoplasm
- dynamic equilibrium
- electron micrograph
- endocytosis
- endosymbiotic hypothesis
- eukaryote
- eukaryotic cell
- exocytosis
- facilitated diffusion
- flagellum
- fluid mosaic model
- glycoprotein
- Golgi body
- grana
- hypertonic
- hypotonic
- integral protein
- isotonic
- leucoplast
- lysosome

- microfilament
- microtubule
- microvillus
- mitochondrion
- multicellular organism
- murein
- nucleoplasm
- nucleus
- osmosis
- passive transport
- peripheral protein
- phagocytosis
- phospholipid bilayer
- pinocytosis
- plasmolysis
- prokaryote
- prokaryotic cell
- protein channel
- ribosome
- rough endoplasmic reticulum
- simple diffusion
- smooth endoplasmic reticulum
- turgor pressure
- unicellular
- vacuole
- xylem

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

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

A cell walls and mitochondria
B Golgi bodies and central vacuoles
C cell walls and central vacuoles
D chromosomes and mitochondria

2 In a multicellular organism the growth rate of a cell decreases as the cell gets larger. Of the following, the most probable reason for this is that:

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

3 If living cells, similar to at least some of those found on Earth, were found on another planet on which there was no free oxygen, which organelle is *not* likely to be present?

A Cell membrane
B Mitochondria
C Nucleus
D Ribosomes

4 A plant cell is in a turgid condition when:

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

Short answer

Describe and explain

★ **5** **Describe** cell theory.

★★ **6** **Contrast** a prokaryotic and a eukaryotic cell.

★ **7** **Explain** the meaning of the terms 'diffusion' and 'concentration gradient'.

★ **8** **Describe** a simple experiment to demonstrate diffusion in water.

★★ **9** **Explain** how diffusion and osmosis are necessary for cell existence.

Apply, analyse and interpret

★★★ **10** A summary of the various ways in which bacteria meet their energy needs is shown in Figure 1.

a A survey of certain hot springs that emitted strong sulphur dioxide fumes found that the only living matter in the springs was a single type of bacterium. Carbon dioxide levels in the water were measured and found to be stable over several weeks. **Classify** the bacteria sample to a major group of bacteria (photosynthetic or chemosynthetic). Give reasons for your answer.

b **Classify** bacteria that use light as an energy source.

c *Salmonella* is a bacterium that causes food poisoning in humans. **Determine** the characteristics (such as energy source, carbon source and so on) of this bacterium.

★★ **11** The surface area of a cube = $6 \times l^2$, where l is the length of one side.

The volume of a cube = l^3.

The surface area of a cylinder (both ends included) = $(2\pi r \times l) + 2r^2$, where r is the radius, $\pi = 3.14$ and l is the length.

The volume of a cylinder = $\pi r^2 \times l$.

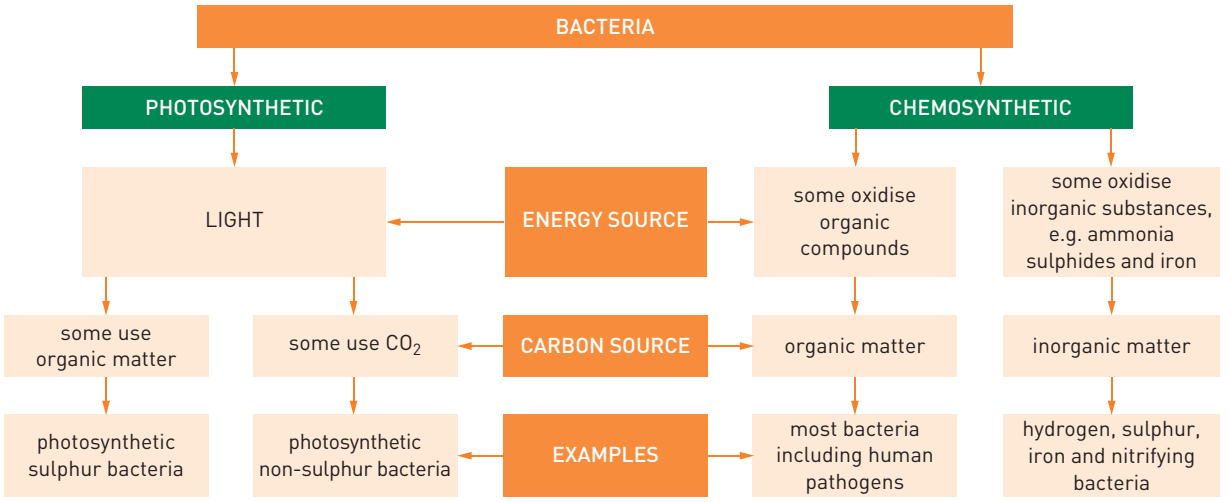


FIGURE 1 How various bacteria meet their energy needs

Showing the working for all calculations, **calculate** surface area, volume, and the ratio of surface area to volume:

a of a cube where *l* is:

i 1 µm long

ii 3 µm long

b of a cylinder where $r = 0.5$ µm and $l = 1$ µm.

Infer, referring to the calculations above, the most efficient size and shape for a cell.

★★ **12** The electron micrograph (photograph produced from an electron microscope) in Figure 2 shows a cell organelle, labelled A.

a **Identify** this organelle. Give reasons for your identification.

b **Judge** whether this organelle is found in a plant or animal cell, or both.

c **Identify** the function of this organelle.

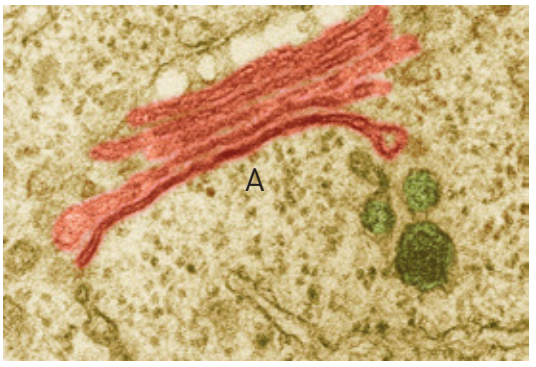


FIGURE 2 Electron micrograph of part of a cell

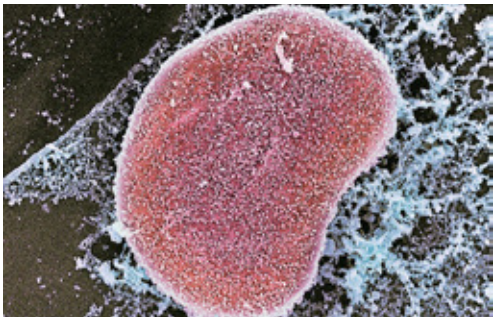
★★★ **13** Examine the three electron micrographs of cell organelles shown in i, ii and iii.

a **Identify** each organelle, giving reasons for your choice.

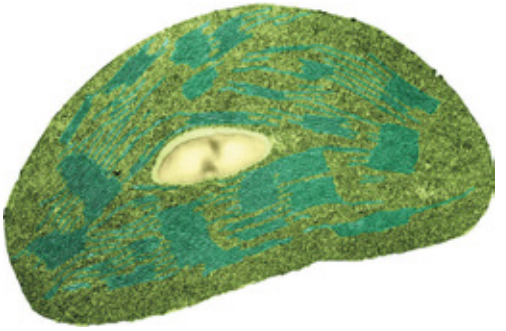
b **Judge** whether you would expect to find all three organelles in the same cell type.

c If these electron micrographs were taken from the same cell, **deduce** whether the same magnification scale is used in each. **Explain** your answer.

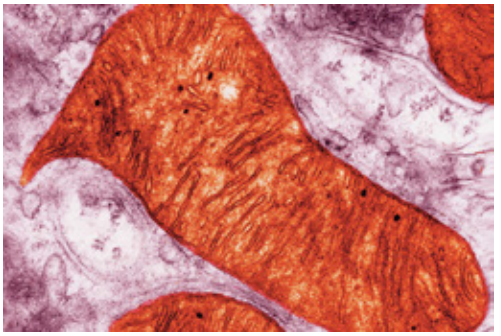
i



ii



iii



★★ **14** The electron micrograph in Figure 3 shows part of a typical cell of a certain tissue.

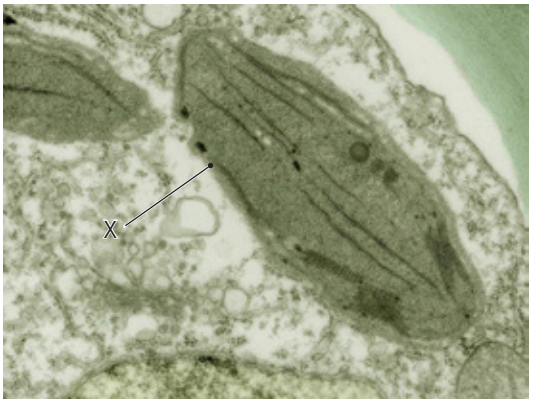


FIGURE 3 Cell tissue

a **Identify** the structure labelled X.

b **Identify** the structure as coming from a plant or animal cell. Give reasons for your answer.

c **Consider** where in the organism you would expect to find this structure.

Investigate, evaluate and communicate

★★★ **15** A group of students on an excursion to a beach collected 50 sandworms of approximately equal size. They organised the worms into five groups of 10. Each group was weighed.

Each group of worms was then placed in a separate jar. The students poured into each of the first four jars a different concentration of saline (salt) solution. The fifth jar was filled with normal sea water. The worms were left in the solutions for one hour and then reweighed. (Sandworms can tolerate extremes of salt concentration for several hours.) The weight change for each group of worms was recorded as shown in the table below.

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

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

★★★ **16** A 5% glucose solution is frequently administered intravenously to persons who have undergone surgery. **Predict** whether the 5% glucose solution will be hypertonic, hypotonic or approximately isotonic. Justify your answer.

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CHAPTER 4

Cell function and energy

All cells require energy to maintain their life functions. The ultimate source of energy for the majority of organisms is solar energy (light). Photosynthetic organisms convert solar energy into the chemical bond energy of glucose, which is then converted to other organic molecules. Organisms that cannot make their own energy must obtain their energy from the organic compounds they consume. All organisms release chemical energy from the compounds in cellular respiration. The chemical reactions in the processes of photosynthesis and cellular respiration occur in specialised cell organelles that have increased surface area for their enzyme-controlled steps.

OBJECTIVES

- → Recognise the requirements of all cells for survival, including energy sources (light or chemical).
- → Recall that the process of photosynthesis is an enzyme-controlled series of chemical reactions that occurs in the chloroplast in plant cells and uses light energy to synthesise organic compounds (glucose), and the overall process can be summarised in a balanced chemical equation:

carbon dioxide + water → glucose + oxygen + water

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

- → Summarise the process of photosynthesis in terms of the light-dependent reactions and light-independent reactions.
- → Demonstrate the relationship between the light-dependent reactions and light-independent reactions.
- → Recall that organisms obtain the energy needed to recycle adenosine triphosphate (ATP) from glucose molecules in the process of cellular respiration.
- → Recognise that cellular respiration is an enzyme-controlled series of chemical reactions and that the reaction sequence known as *aerobic respiration* (glycolysis, Krebs cycle and electron transport chain) requires oxygen.
- → Summarise the reactions of aerobic respiration by the chemical equation:

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6 + 6O_2 + 36–38\ ADP + 36–38\ {\sim}P \rightarrow 6CO_2 + 6H_2O + 36–38\ ATP$

- → Recall that, with an undersupply of oxygen, ATP is produced from glucose by the reaction sequence known as *anaerobic respiration* (glycolysis with 'fermentation').
- → Analyse multiple modes (i.e. diagrams, schematics, images) of energy transfer.

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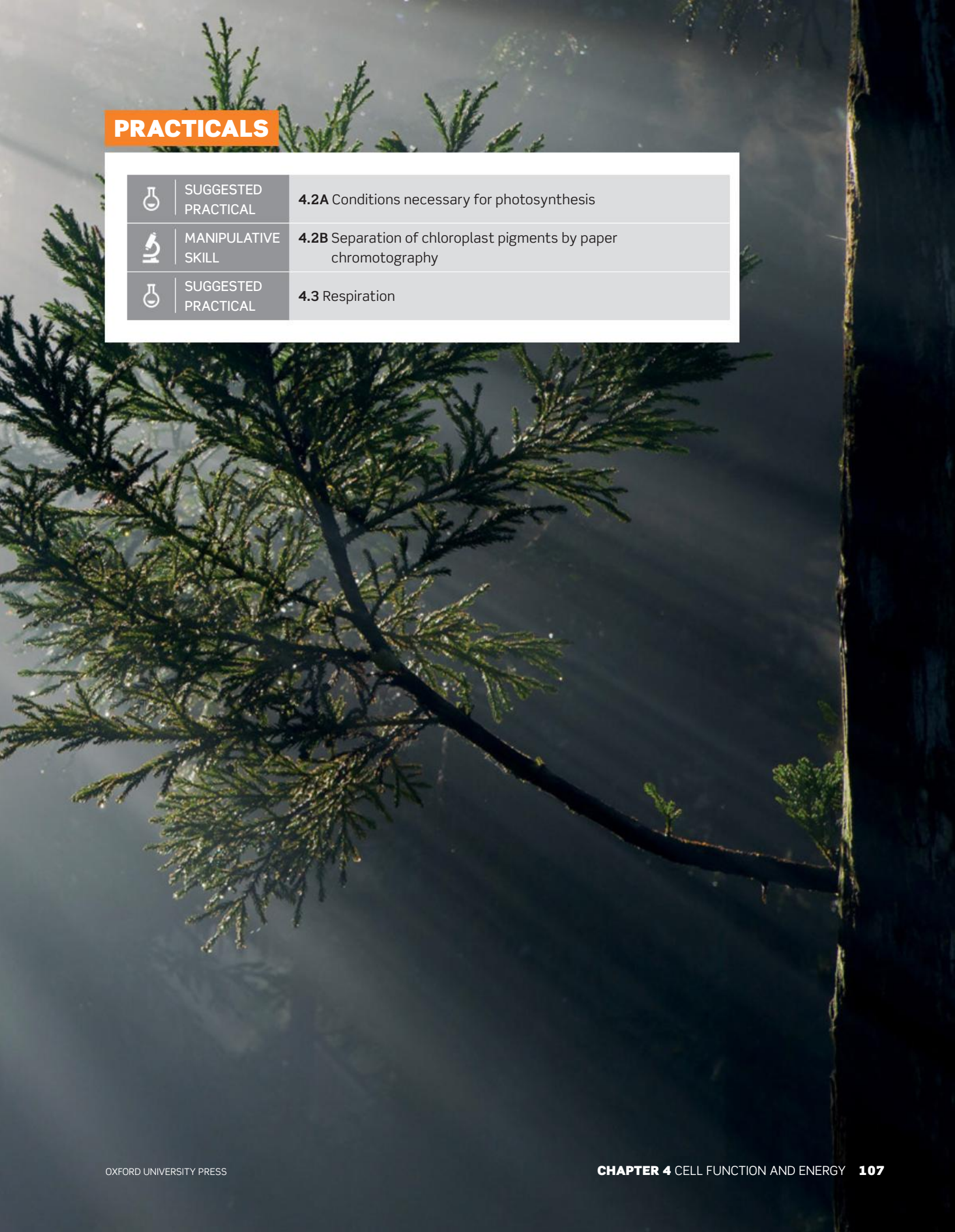
FIGURE 1 Light streams through the canopy. The living cells in this ecosystem rely on the sun's light as a source of energy.



PRACTICALS

SUGGESTED PRACTICAL	**4.2A** Conditions necessary for photosynthesis
MANIPULATIVE SKILL	**4.2B** Separation of chloroplast pigments by paper chromotography
SUGGESTED PRACTICAL	**4.3** Respiration

4.1 Sources of energy for living matter

KEY IDEAS

- Cells as energy converters
- Chemosynthesis
- Solar energy (light) as a source of chemical energy
- Levels of energy in solar radiation
- The role of pigments

In order for cells to perform life functions, they require energy. As energy cannot be created or destroyed, this means cells need to convert energy from their environment into a useable form. They take in energy, store it, release it from chemical bonds when required and use it to synthesise the chemicals needed to sustain life. This means cells are energy converters. This energy comes from two key sources: the energy released from a chemical reaction, and light energy from the sun.

Enzymes are one of the major types of chemicals produced by cells and these regulate all of the chemical reactions of the cell. A few organisms derive their energy from chemical reactions (**chemosynthesis**). For the majority of organisms, energy that is used to drive these cell functions originates from certain wavelengths of solar energy that are converted to chemical energy by cells of photosynthetic organisms.

chemosynthesis the formation of complex organic molecules from simple organic molecules, using chemical energy derived from oxidation of inorganic molecules

photosynthesis the process whereby radiant energy (in the visible spectrum) is converted to the chemical energy of glucose; requires chlorophyll, carbon dioxide, water and a suitable temperature; occurs in green plants, algae and some bacteria

Chemosynthesis

Not all organisms obtain their energy from light. Many extreme environments, including deep under the ocean, do not have access to light energy. Instead, organisms living there use the energy that is released during chemical reactions to 'power' their own processes. These chemosynthetic organisms use the methanes and sulphides that bubble up from volcanic vents deep under the ocean in a chemical reaction. The energy that is released as a result of the reaction is converted into a useable form. Currently all known chemosynthetic organisms are prokaryotes.

FIGURE 1 Light energy produced by the sun is a crucial requirement for life on Earth.

Energy, light and life

The ultimate energy source for most living systems on Earth is the sun. Much of the sun's radiant energy (29%) is reflected back into space by Earth's atmosphere. The remaining energy is absorbed by the particles in Earth's atmosphere (23%) or reaches the surface of Earth (48%). Some of this absorbed heat energy evaporates the water of the oceans, producing clouds that, in turn, produce rainfall on land. So energy, in combination with other factors, is responsible for the movement of air and water that contributes to patterns of climate. Less than 1% of this energy is converted to chemical energy in a form that can be used by living systems, as shown in Figure 2. This fraction of the sun's energy is responsible for most life forms on this planet.

FIGURE 2 The Earth's energy budget shows what happens to the energy that is generated by the sun.

Energy composition of solar radiation

Light energy (sunlight) contains the entire electromagnetic spectrum of different wavelengths. The wavelengths (the distance from the peak of one wave to the peak of the next) range from the very short gamma rays that are measured in nanometres (1 nm = 10^{-9} m) to long radio waves that are measured in kilometres.

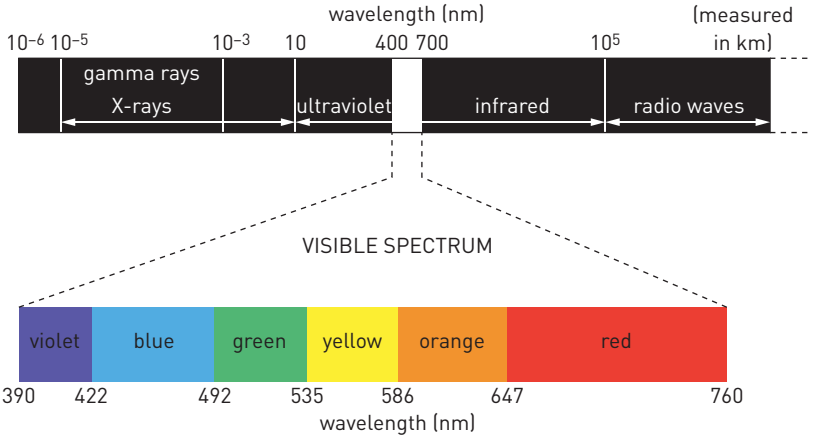


FIGURE 3 The electromagnetic spectrum

The shorter the wavelength, the greater is its energy level. Light forms a small part of this spectrum. White or visible light is composed of seven colours – red, orange, yellow, green, blue, indigo and violet. Violet light has almost twice the energy of red light. This does not mean that violet light can provide more energy to plant cells. Instead, each cell in a plant needs to find a way of trapping one or more of these wavelengths of light to convert it into a useable form. The process which uses light energy to synthesise organic nutrients (chemical energy) is called **photosynthesis**.

CASE STUDY 4.1

Detection of the electromagnetic spectrum

Organisms respond to aspects of their environment that affect their ability to survive and reproduce. Vision is a purely animal adaptation as animals have to seek out food, so the evolution of sight has been a significant factor in their evolutionary patterns.

Most animals only use the visible spectrum. Many animals cannot distinguish colours and only see many shades of grey between black and white. A few animals can detect the infrared radiation (with long wavelengths) emitted from warm bodies. Snakes can sense this radiation and use it in hunting prey.

Insects and a few birds can detect the short wavelengths of ultraviolet (UV) radiation. Some insects use this ability to guide them from areas of dark vegetation to open spaces. Detection of UV radiation (e.g. reflecting from flower petals, fungi and liquid surfaces) leads other insects to a food source.

Those species of *Eremophila* (emu bush) that are insect pollinated reflect the UV light in patterns that emphasise the central area of the flower. This attracts the insects to the reproductive and honey-producing structures of the plant. Bird-pollinated species of emu bush do not have this pattern. The interaction between the insects and flower is of mutual benefit: the insect gains food and the flower is efficiently pollinated. A large number of flower species show a UV-reflective pattern at their centre.

FIGURE 4 The flower of *Eremophila* 'Fairy Floss' (*E. racemosa* × *E. maculata* hybrid): (a) as seen by the human eye and (b) under UV light, revealing patterns that insect pollinators can detect

The role of pigments

chlorophyll
a green plant pigment

absorption spectrum
a graph of the relative absorption of different wavelengths of light by a pigment

In order for light energy to be used by living systems, it must first be absorbed. Pigments are molecules that absorb and reflect light energy. A black pigment is black because it absorbs light of all visible wavelengths. There is almost no visible light available to be reflected back to the eye. Red pigment is red because it absorbs all wavelengths except red; that is, it reflects or transmits red. This means the red can be seen by an observer. A red pigment viewed under blue light will appear black because it has no red light to reflect or transmit. **Chlorophyll**, the main photopigment involved in photosynthesis, absorbs violet, blue and red light and sends back green.

An **absorption spectrum** can be used to analyse the wavelengths of light absorbed by any particular pigment. White light is passed through a container of pigment and the transmitted colours are noted. The pigment absorbs those wavelengths not transmitted. An absorption spectrum is a graph that shows the relative absorption of the different wavelengths

of light by a pigment. In contrast, an **action spectrum** is a graph showing how effective the different wavelengths of light are in stimulating the process that is under investigation (e.g. photosynthesis).

action spectrum a graph of the effectiveness of different wavelengths of light to bring about a particular reaction

FIGURE 5 Chlorophyll is a pigment that aids photosynthesis and gives both terrestrial and aquatic plants their green colour.

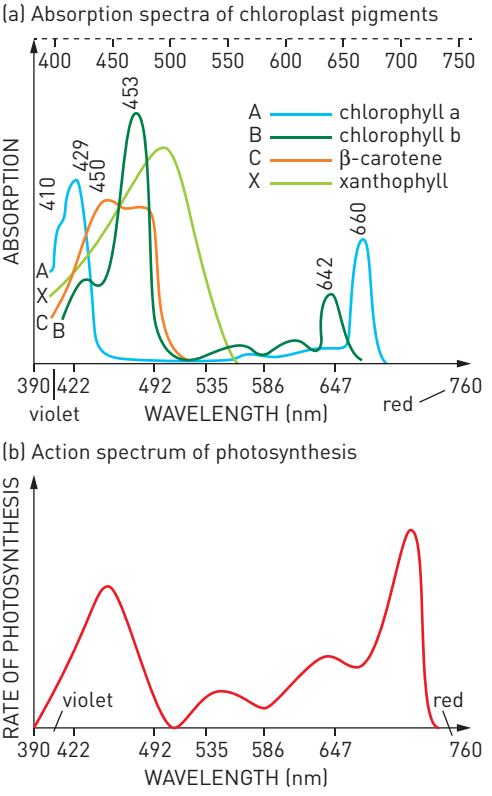


FIGURE 6 Absorption and action spectra

CHECK YOUR LEARNING 4.1

Describe and explain

1 **Desribe** the electromagnetic spectrum.

2 **Explain** the relationship between wavelength and energy content of any particular portion of the electromagnetic spectrum.

3 Some of the electromagnetic spectrum does not reach Earth. **Describe** what happens to this energy.

4 **Explain** why only a small proportion of the electromagnetic spectrum is responsible for life on Earth.

Apply, analyse and interpret

5 **Contrast** photosynthesis and chemosynthesis.

6 **Contrast** an action spectrum and an absorption spectrum.

7 **Interpret** Figure 6. **Deduce** which wavelengths of light results in the highest level of photosynthesis for chlorophyll a.

Investigate, evaluate and communicate

8 The photopigment chlorophyll is responsible for the green colour of leaves in spring. During autumn the chlorophyll is broken down, leaving red, orange and yellow coloured leaves. A student claimed that the anthocyanin pigments responsible for the red colour would absorb red light for use in photosynthesis. **Evaluate** this claim. Provide evidence to support your answer.

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- » Student book questions
  Check your learning 4.1
- » Weblink
  Chemosynthesis
- » Weblink
  Photosynthesis
- » Weblink
  Absorption spectrum

4.2 Photosynthesis

KEY IDEAS

- The structure and function of chloroplasts
- The many, small steps of the photosynthesis process, each controlled by a specific enzyme
- The light-dependent and light-independent stages of photosynthesis
- The generalised, balanced chemical equation of photosynthesis
- Factors affecting the rate of photosynthesis

During photosynthesis, light energy is converted to chemical energy (glucose molecules) by producer organisms. Other metabolic processes convert these simple carbohydrates to all other organic compounds required by living organisms. These are then passed on to consumers and decomposers through the food web. The raw materials for photosynthesis are carbon dioxide and water. The chlorophyll molecule is necessary for the energy transformations, although it is not used up in the process.

Organisms possessing chlorophyll include green plants, algae, cyanobacteria and some bacteria. Algae and green plants are eukaryotic, so chlorophyll is contained within the **chloroplast** organelle. In plants, most photosynthesis occurs in leaf cells that are exposed to light. Depending on the environment in which the plant lives, different adaptations of leaf structure and their arrangement on stems have evolved to maximise their ability to 'capture' light.

chloroplast
a plastid found in green plants, containing chlorophyll on membranous grana, and enzymes in liquid stroma; photosynthetic organelle

stroma
the fluid matrix of the chloroplast, containing enzymes for the light-independent reactions of photosynthesis

thylakoid
the membranous, flattened, disc-shaped sac (groups of which form a granum) found in chloroplasts, on which the light-dependent reactions of photosynthesis occur

granum (plural grana)
stacked portions of membranes found in chloroplasts; sites of light-dependent reactions for photosynthesis

Chloroplasts

The chloroplast is a cell organelle with two membranes. The space or **stroma** that is enclosed by these membranes is a watery mixture of different chemicals to that of the cytoplasm. Small flattened disc-shaped membrane sacs (**thylakoids**) lie one on top of another like a stack of coins. Each stack is called a **granum** (plural grana). Grana are usually connected to each other. Within the grana are the photopigment system (chlorophyll a, chlorophyll b and carotene) that capture the light energy.

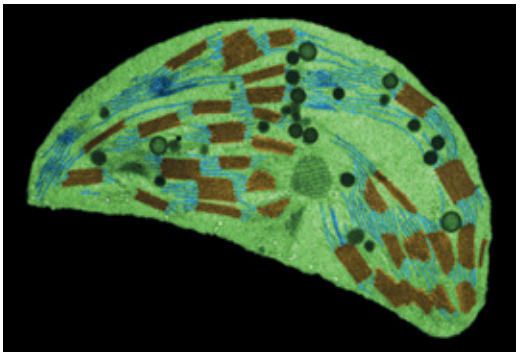

FIGURE 1 A colour-enhanced transmission electron micrograph of a chloroplast

The process of photosynthesis

Photosynthesis involves processes that take place in many small steps, each of which is controlled by a specific enzyme. Carbon from carbon dioxide is 'fixed' into organic compounds. The generalised equation for this reaction is:

carbon dioxide + water → glucose + oxygen

Or as a chemical equation:

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_5 + 6O_2 + 6H_2O$$

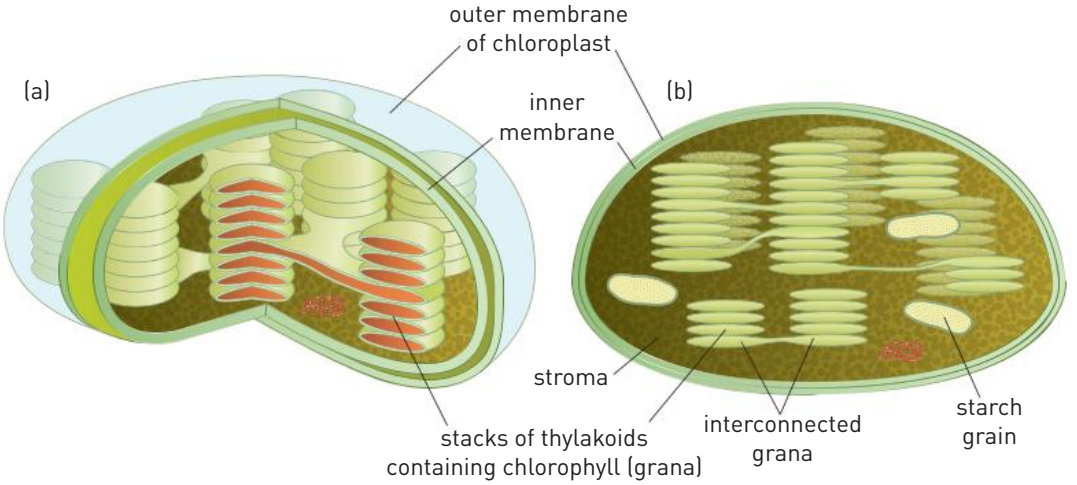

FIGURE 2 Structure of the chloroplast: (a) cutaway view; (b) transverse section

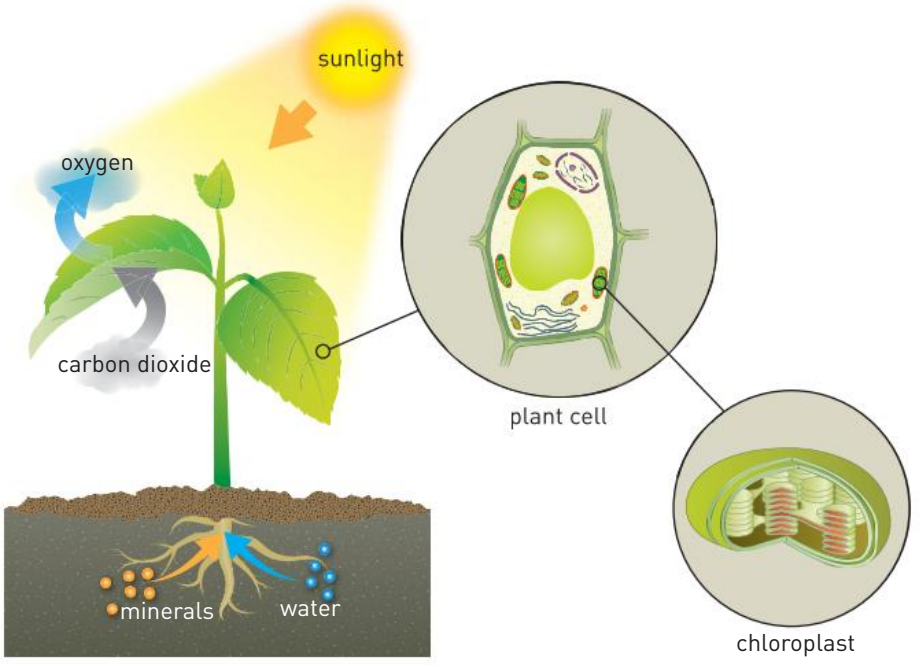

FIGURE 3 Photosynthesis

A suitable temperature is required for photosynthesis to occur, since enzymes are temperature-sensitive. Carbon dioxide is readily available in all environments. Probably the single most important factor controlling the rate of photosynthesis is the availability and intensity of light.

Photosynthesis occurs in two distinct steps.

Step 1: Light-dependent reactions

The first step of photosynthesis involves **light-dependent reactions.** These take place in the pigment systems within the thylakoid sacs of the chloroplast. In this process:

- The chlorophyll pigments absorb light energy, predominantly from the blue and red bands of the visible spectrum.
- This extra energy 'excites' electrons in the chlorophyll a molecules, resulting in their release from the molecule.

Study tip

Light energy appears above the arrow, and chlorophyll and enzymes below the arrow, in the chemical equation for photosynthesis. They are not reactants but are essential parts of the process.

light-dependent reactions chemical reactions in the chloroplast, involving excitation of chlorophyll electrons by energy transfer from specific wavelengths of light, and resulting in splitting of water to release hydrogen for the light-independent reactions and formation of ATP

MANIPULATIVE SKILL
4.2B Separation of chloroplast pigments by paper chromotography
Go to page 415 »

- The energy of the excited electrons is used:
  - in the formation of 18 ATP molecules
  - to decompose 12 water molecules into 24 hydrogen atoms and 6 oxygen molecules ($6O_2$).
- The hydrogen atoms are taken up by a hydrogen acceptor and the oxygen is released into the environment as a metabolic waste product.

The electrons, having released their extra energy, are returned to the chlorophyll molecules.

Step 2: Light-independent reactions

light-independent reactions
the second stage of photosynthesis, in which carbon dioxide is reduced by the hydrogen formed in the light-dependent reactions, with the input of energy from ATP, to form glucose; these reactions do not need the presence of light

Calvin–Benson cycle
the cyclic reactions of the light-independent phase of photosynthesis

The second step is called the **light-independent reaction** because it does not need light energy. The light-independent reactions occur in the stroma. These reactions do not need to occur in the dark, but they do not require light. They do, however, need the products of the light-dependent reactions. The hydrogen (released from the water) combines with carbon dioxide, using all the energy formed during the light-dependent reactions, and extra ATP found in the cell to form glucose. This complex series of reactions is known as the **Calvin–Benson cycle**.

Factors that affect photosynthesis

There are many factors that can affect the rate of photosynthesis. The amount or intensity of light can affect the light-dependent reactions. If less light energy is available, then the photopigments will not have enough energy to split the water into hydrogen and oxygen. If the available light contains only green wavelengths, then very little energy is available for the reaction as chlorophyll relies on blue and red wavelengths to start the reaction.

The availability of carbon dioxide or water can also limit the rate of photosynthesis. In the desert where water is scarce, plants have difficulty producing glucose through photosynthesis. This means much of the plant does not have access to the chemical energy that glucose provides. As a result, plants grow very slowly or die due to the lack of chemical energy. The elevated temperatures that occur in a desert environment can also cause the enzymes in photosynthesis to become deformed or denatured. This can cause the series of chemical reactions to slow down, even when there is a lot of water available.

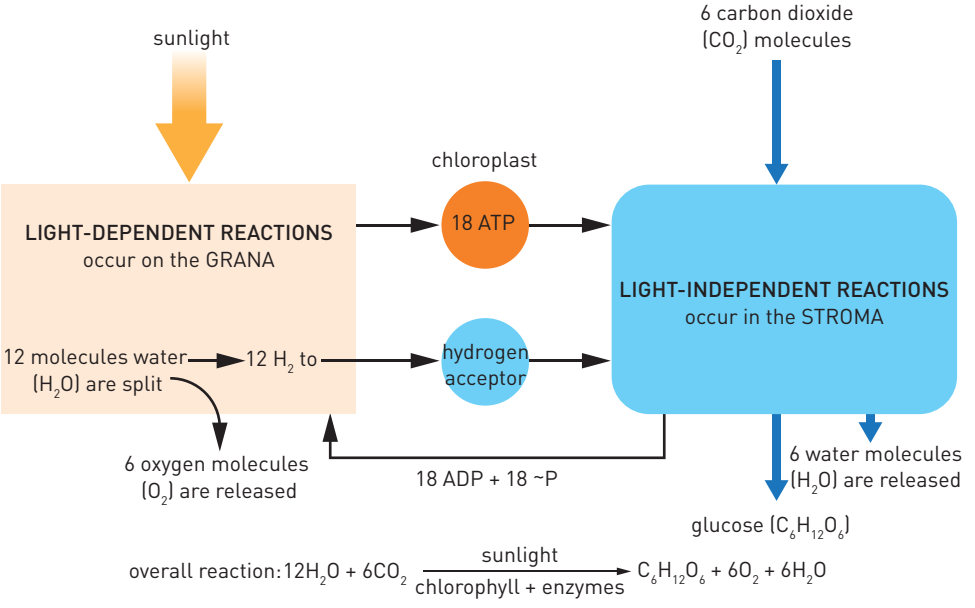

FIGURE 4 Summary of the main stages of the photosynthesis reaction

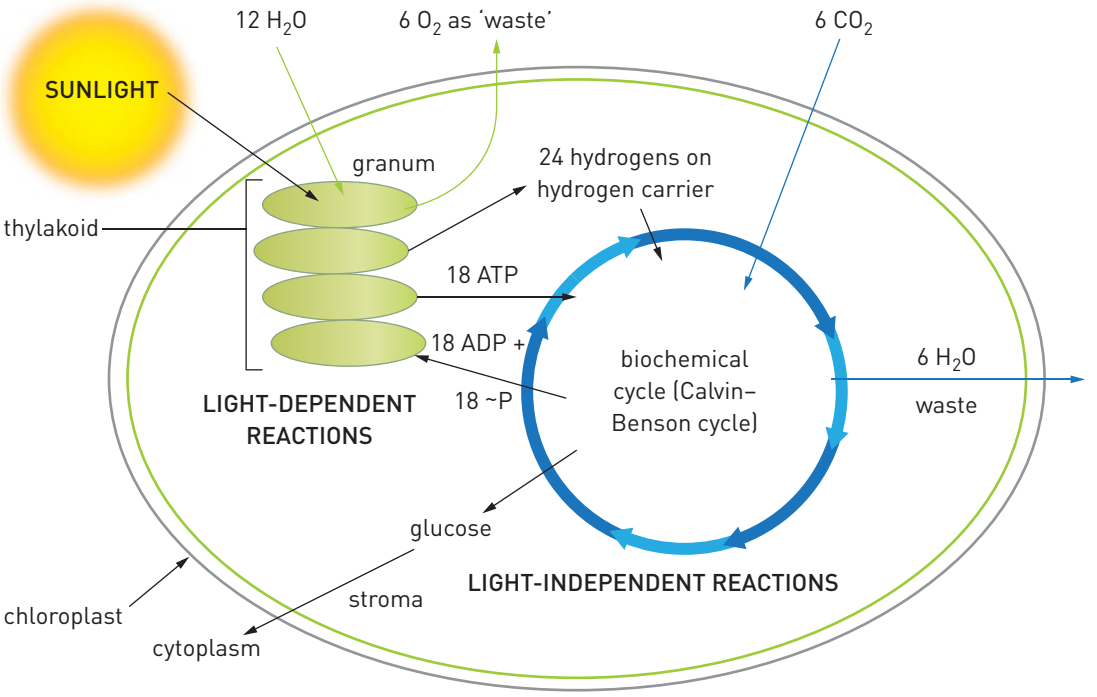

FIGURE 5 The process of photosynthesis

CHECK YOUR LEARNING 4.2

Describe and explain

1 **Explain** the purpose of photosynthesis.

2 Photosynthesis takes place in two distinct steps: light-dependent and light-independent reactions.

- **a** **Identify** where in the chloroplast each step occurs.
- **b** **Describe** the input and output that occurs in each of these steps.

3 **Describe** three factors that can slow the rate of photosynthesis.

Apply, analyse and interpret

4 Plants that live in rainforest regions usually have large, dark green leaves. Plants that live in open grassy plains have smaller, light green leaves. **Apply** your knowledge of chlorophyll and photosynthesis to **infer** the size and colour of the leaves of these plants.

Investigate, evaluate and communicate

5 **Investigate** ways in which the rate of photosynthesis can be enhanced in a plant crop. Write a report on the techniques used and the impact that this enhancement could have on agricultural sustainability, improved food productivity and fuel production. In your report undertake an analysis of why it is important to address these factors.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 4.2
- » Suggested practical
  4.2A Conditions necessary for photosynthesis
- » Manipulative skill
  4.2B Separation of chloroplast pigments by paper chromotography
- » Weblink
  Chloroplast

4.3 Cellular respiration

KEY IDEAS

- The processes of aerobic respiration and its chemical equation
- The role of the mitochondria in aerobic respiration
- The folding of the internal membrane in mitochondria to increase the surface area for enzyme-controlled reactions
- Respiration of polysaccharides, lipids and proteins
- ATP produced from glucose by anaerobic respiration (glycolysis with 'fermentation')

As discussed in section 4.2, plant cells and some bacteria convert light energy into chemical energy (glucose). Other organisms, such as humans, need to eat to have access to the chemical energy in food. However, this type of chemical energy is not useful to a cell. The type of chemical energy that is useful to a cell is stored in ATP (adenosine triphosphate).

Energy is released by **cellular respiration**. All cells must perform cellular respiration to survive. This generally involves the oxidation of sugar in a series of small steps, each controlled by an enzyme. The energy released is stored in the ATP molecule for further use by the cell or transported to other cells within the organism.

Some steps in cellular respiration are **endergonic** (energy-requiring); several are **exergonic** and release energy for the formation of ATP (described in Chapter 2). Each step in cellular respiration is controlled by a specific enzyme. Cellular respiration may occur either in the presence of oxygen (**aerobic cellular respiration**) or in the absence of oxygen (**anaerobic cellular respiration**).

All cellular respiration starts in the cytoplasm. Glucose molecules are broken down by the process of glycolysis to a compound called pyruvate. Glycolysis does not need oxygen to occur.

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

endergonic describes a chemical reaction requiring input of energy

exergonic describes a chemical reaction in which energy is released

aerobic respiration the complete conversion of glucose to carbon dioxide and water in the mitochondria of cells with oxygen present, resulting in a large release of energy (net gain of 36 ATP)

anaerobic respiration cellular respiration in the absence of oxygen, resulting in a net gain of 2 ATP and lactic acid (in animals), or ethyl alcohol and carbon dioxide (in plants and fungi)

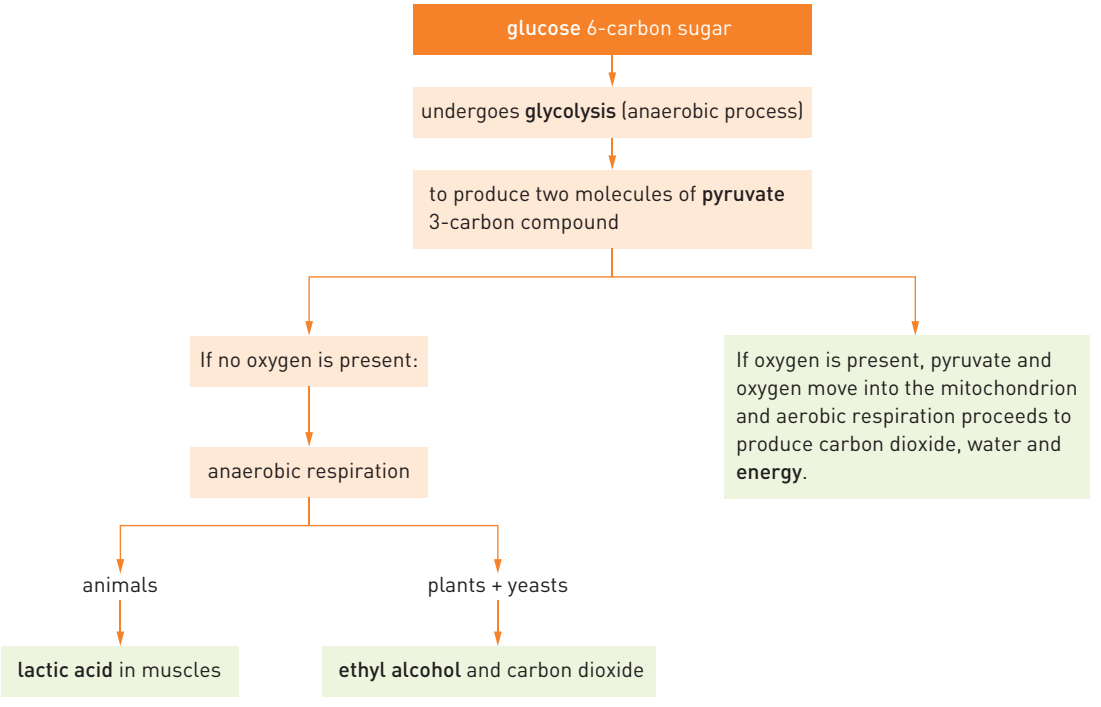

FIGURE 1 The aerobic and anaerobic respiration pathways

If no oxygen is present in the cell, this anaerobic respiration continues with pyruvate being converted to:

- lactic acid in animal cells
- ethyl alcohol and carbon dioxide in plant cells.

There is an overall gain of two ATP molecules.

If oxygen is present in the cell, aerobic respiration occurs. Pyruvate and oxygen enter the mitochondrion, where the pyruvate is completely broken down to release carbon dioxide, water and 34 further ATP molecules in the Krebs cycle and electron transport chain. The oxygen is needed to remove hydrogen released in the Krebs cycle, so that this cycle can continue.

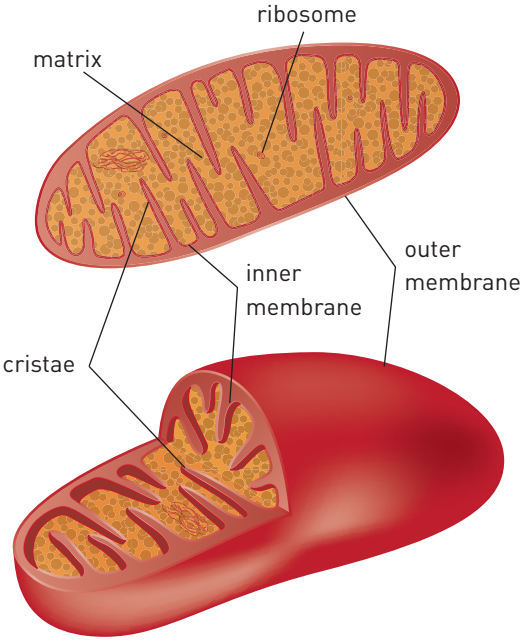

FIGURE 2 The structure of the mitochondrion: (a) longitudinal section; (b) cut-away view

The role of mitochondria in aerobic cellular respiration

The **mitochondrion** (plural, mitochondria) is a double-membraned cell organelle. Its inner membrane is deeply folded to form a series of cristae (shelves), which increase the surface area of this membrane. The whole structure is either spherical (e.g. in liver cells) or cigar-shaped, therefore providing a high surface area to volume ratio for the efficient uptake and release of materials.

The outer membrane controls the passage of materials into and out of the mitochondrion. The inner membrane contains the enzymes responsible for ATP production.

The matrix within the mitochondrion contains ribosomes, circular DNA molecules and the enzymes required for many of the steps in aerobic cellular respiration.

Stages in aerobic cellular respiration

Aerobic respiration occurs in three stages in eukaryotic cells:

1 **glycolysis**
2 **Krebs cycle**
3 the **electron transport chain**.

The overall chemical reaction for aerobic cellular respiration is:

$$\text{glucose} + \text{oxygen} + \text{ADP} + \sim\text{P} \rightarrow \text{carbon dioxide} + \text{water} + \text{ATP}$$

Step 1 Glycolysis

All living organisms carry out glycolysis. These chemical reactions occur in the cytoplasm of the cell. It is an anaerobic process, as it does not require oxygen.

- This initial step requires an input of two ATP molecules to activate glycolysis where each 6-carbon glucose molecule is converted to two 3-carbon pyruvate molecules.

mitochondrion (plural mitochondria) a membrane-bound cellular organelle; has inner membrane forming folds (cristae) on which are found enzymes for aerobic respiration, and a fluid matrix

glycolysis the first stage in cellular respiration; occurs in the cytoplasm and results in the gain of 2 ATP and 2 pyruvate molecules; does not require oxygen

Krebs cycle the cyclic series of chemical reactions in mitochondria of cells in which 2 molecules of acetyl-CoA are converted to citric acid which, with the addition of 6 water molecules, releases 4 carbon dioxide molecules as waste and 24 hydrogen atoms, which are transferred to carrier molecules; 2 ATP are formed

electron transport chain a series of coenzymes along which high-energy electrons pass, releasing energy to form ATP at each step in the chain; the final stage in aerobic cellular respiration in which most ATP molecules are formed

activation energy the energy needed to start a chemical reaction

- Four ATP molecules are formed (there is a **net gain of two ATP**, as four ATP molecules are produced but two ATPs were needed as **activation energy**).

$$\text{glucose} + 2\text{ATP} + 2\text{ADP} + 2{\sim}\text{P} \rightarrow 2 \text{ pyruvate} + 4\text{ATP}$$

Step 2 Forming coenzyme A

If oxygen is present, the two pyruvate molecules leave the cytoplasm and enter the mitochondrion by passing through both the outer and inner membranes. The enzyme-activated steps of aerobic respiration occur in the mitochondrial matrix:

- A molecule of **carbon dioxide** is removed from each pyruvate.
- Two carbon dioxide molecules are released as a **waste product**.
- Two **coenzyme A** molecules are formed and hydrogen ions and electrons from this reaction are passed to hydrogen carriers.

Each 3-carbon pyruvate molecule undergoes a series of reactions that forms a coenzyme A molecule and releases a carbon dioxide waste product. Since **a single glucose forms two pyruvate molecules**, then two coenzyme A and two carbon dioxide molecules will be formed from that single glucose molecule.

Step 3 The Krebs cycle

The Krebs cycle is a series of chemical reactions that start and finish with the same four-carbon molecules. The two coenzyme A molecules enter the cycle separately by combining with these four-carbon compounds to form two molecules of citric acid. Each step in the cycle is enzyme driven. For the cycle to proceed, it requires an input of six water molecules for each citric acid molecule, which releases:

- 24 hydrogen ions and electrons that are passed to hydrogen carriers
- another two ATP molecules
- four carbon dioxide molecules as a **waste product**
- a molecule that reacts with water to reform the original 4-carbon molecule.

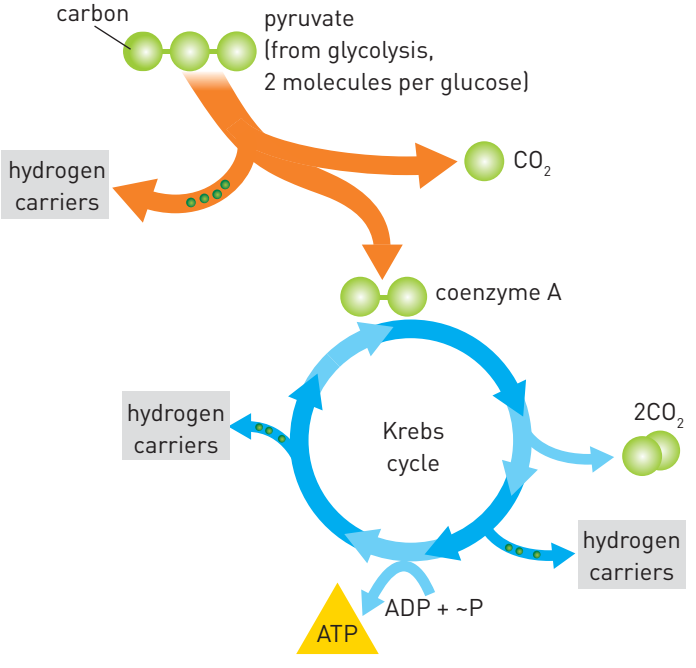

FIGURE 3 Glycolysis produces two 3-carbon pyruvate molecules. If oxygen is present, the pyruvate moves into the mitochondria. Each pyruvate loses carbon dioxide to become coenzyme A. This coenzyme A then enters the Krebs cycle, resulting in the formation of carbon dioxide, ATP, and hydrogen ions and electrons on their hydrogen carriers.

Step 4 The electron transport chain

The inner membrane of the mitochondrion is very folded to increase its surface area for the chemical reactions. A series of specialised enzymes associated with these reactions are embedded in the inner mitochondrion membrane. Hydrogen ions formed in the previous steps are released from their carriers along with high energy electrons to the electron transport chain. At each step in the chain, energy is released from the electrons and is used in the formation of ATP. At the end of the chain, the low energy electrons combine with the hydrogen ions and, with an input of six oxygen molecules, form water. Overall this step produces:

- 32–34 ATP molecules
- 12 water molecules, so there is a net of six molecules as a waste produce.

Therefore the overall equation for aerobic cellular respiration is often written as:

glucose + 6 oxygen + 6 water + ADP + ~P → 6 carbon dioxide + 12 water + energy (ATP)

$$C_6H_{12}O_6 + 6O_2 + 6H_2O + 36–38ADP + 36–38{\sim}P \rightarrow 6CO_2 + 12H_2O + 36–38\ ATP$$

Respiration can be summarised as:

$$C_6H_{12}O_6 + 2ATP + 6H_2O + 36–38\ ADP + 36–38{\sim}P + 6O_2 \rightarrow 2ADP + 2{\sim}P + 6CO_2 + 12H_2O + 36–38ATP$$

Depending on certain conditions, either 32 or 34 ATP molecules can be produced during electron transport chain reactions. There is a net gain of either 36 or 38 ATP molecules for every glucose molecule aerobically respired.

For each glucose molecule, there is the release of $6CO_2$ and $6H_2O$ (as wastes), and 36 ATP molecules (as a chemical energy transfer molecule).

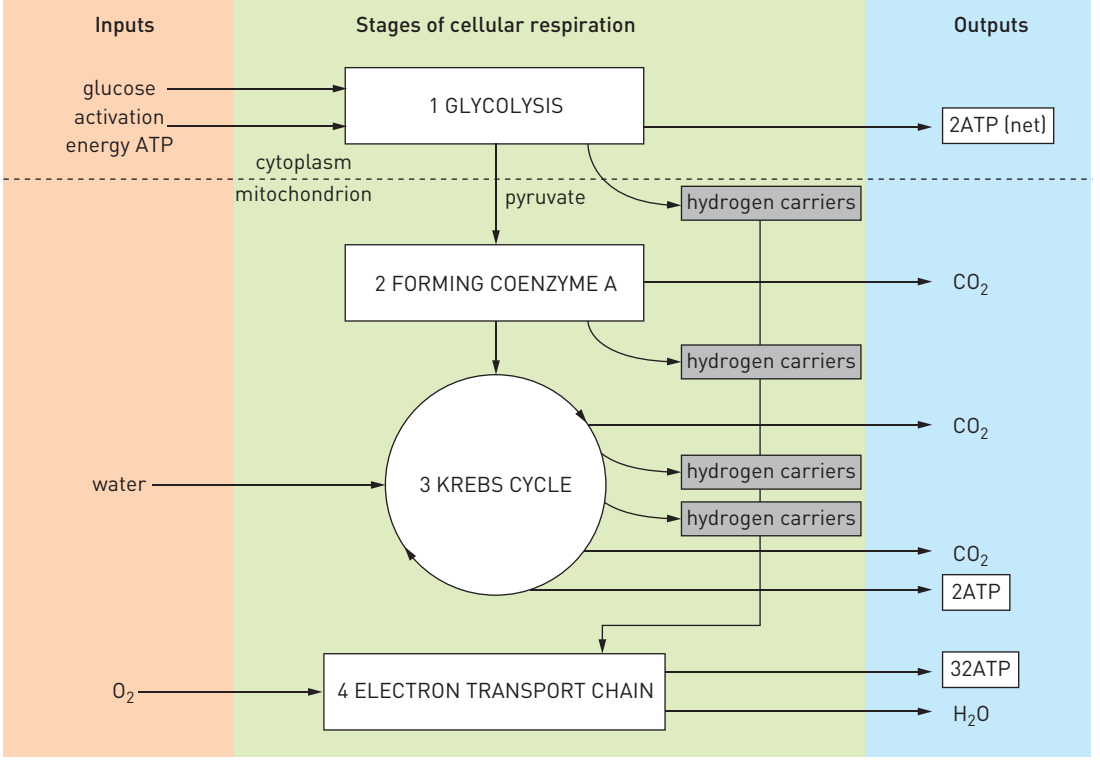

FIGURE 4 Simplified flow chart of aerobic cellular respiration

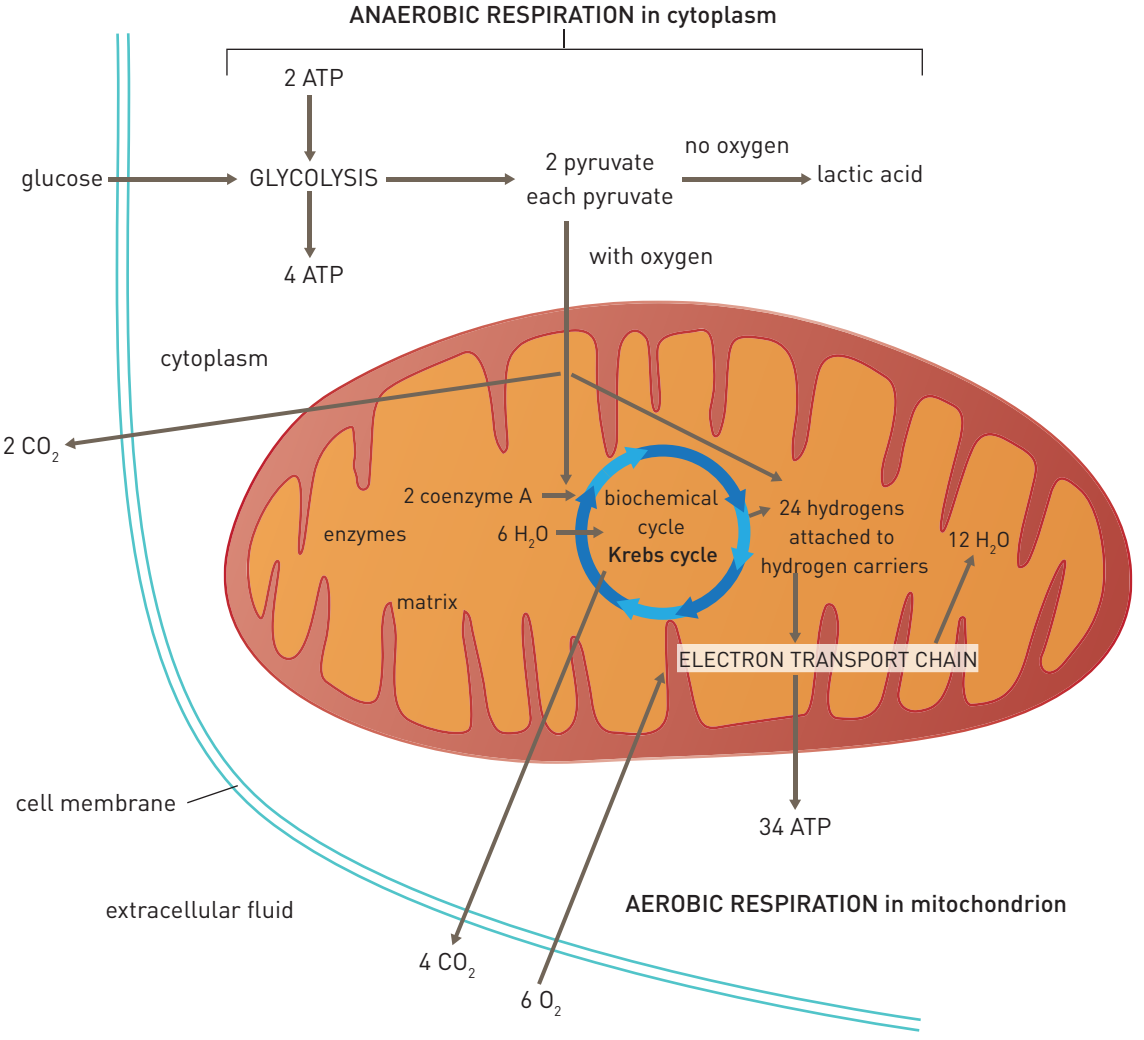

FIGURE 5 Aerobic and anaerobic cellular respiration in an animal cell

Cellular respiration of polysaccharides, lipids and proteins

Fats and amino acids can also be used as energy sources, after first being converted to coenzyme A, which can enter the Krebs cycle. The breakdown of fats for cellular respiration occurs when there is no more free glucose or glycogen (in animals) or starch (in plants) available to convert to glucose. When all fat reserves have been depleted, the organism will then convert proteins for cellular respiration.

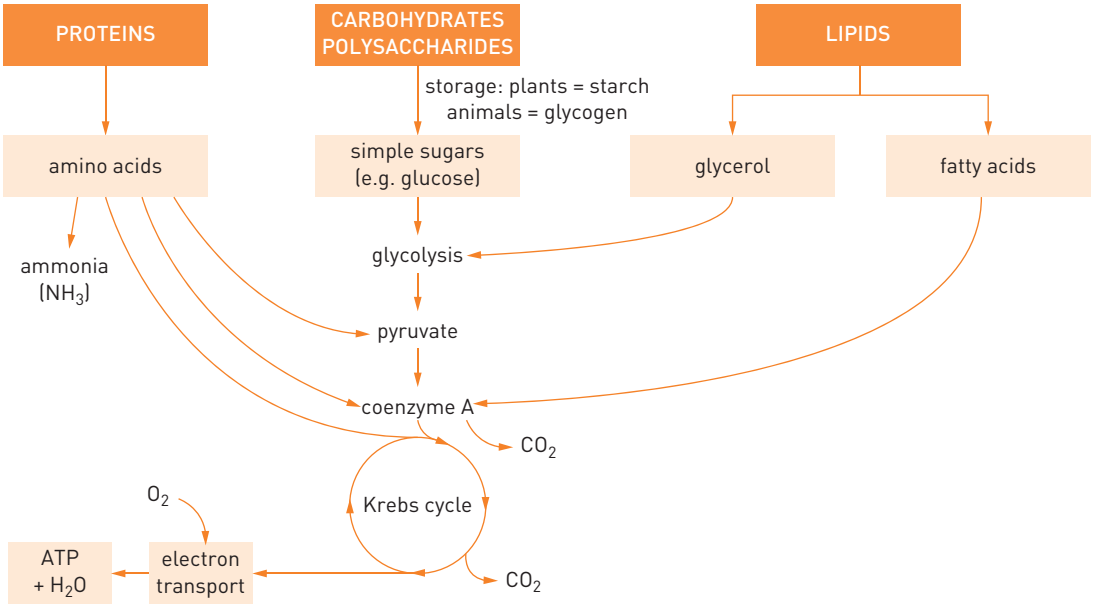

FIGURE 6 Respiration of carbohydrates, lipids and proteins

CHECK YOUR LEARNING 4.3

Describe and explain

1 **Construct** a word and a balanced chemical equation to describe aerobic cellular respiration.
2 **Describe** three ways cells use ATP.
3 **Summarise** aerobic cellular respiration using the table below.

	Glycolysis	Coenzyme A and Krebs cycle	Electron transport chain
Location			
Input			
Output			
Number of ATP formed			

4 **Explain** why the folded inner membrane cristae of a mitochondrion is important for aerobic cellular respiration.
5 **Describe** the circumstances in which the following substances are substrates for cellular respiration:
- **a** carbohydrate
- **b** fat
- **c** protein

Apply, analyse and interpret

5 Use the information in question 3 to **deduce** which part of aerobic cellular respiration would be most affected by a lack of oxygen.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 4.3

» Suggested practical
4.3A Respiration

» Weblink
Glycolysis

» Weblink
Krebs cycle

4.4 Factors that affect cellular respiration

KEY IDEAS

- Effects of substrate concentrations
- Anaerobic cellular respiration in animals
- Fermentation in plants and yeast
- Effect of temperature

Like all chemical pathways driven by enzymes, there are many factors that can affect the rate of cellular respiration. One of these is the availability of glucose. People with diabetes are often unable to control their blood sugar levels – the glucose levels become too low and this can result in inadequate ATP for cellular processes. This will be examined in more detail in Chapter 7. Another key substrate in cellular respiration is oxygen.

Anaerobic cellular respiration

Oxygen is essential for the electron transport chain to produce ATP; however, oxygen is not always freely available. Some organisms get enough energy from anaerobic respiration alone. They are able to undergo glycolysis and produce a net of 2ATP. In general, two types of anaerobes are recognised. **Complete anaerobes** live permanently in oxygen-deficient conditions. Some (including certain bacteria and some parasites) may be poisoned by even small concentrations of oxygen.

complete anaerobe
an organism that is independent of oxygen for cellular respiration

Partial anaerobes thrive in the presence of oxygen, but resort to anaerobic respiration if oxygen is absent or in short supply. Examples include worms living in the mud at the bottom of stagnant pools or oceans, and diving mammals such as whales that can stay under water for long periods. The length of time an organism can survive without oxygen varies – a matter of minutes for humans, while some lower organisms and plants can respire anaerobically for much longer periods.

partial anaerobe
an organism that can undergo a period of anaerobic cellular respiration when oxygen supplies are depleted or oxygen is in short supply

Fermentation

Fermentation is an anaerobic process that does not require oxygen to break down glucose. The pyruvate that is formed from glycolysis enters one of two fermentation pathways depending on the organism. Animals undergo **lactic acid** fermentation, while yeasts undergo ethanol fermentation.

fermentation
the anaerobic breakdown of sugar by bacteria and yeasts to form ethyl alcohol, carbon dioxide and 2 ATP

Fermentation in animals

If a person undergoes vigorous exercise, more energy is required than can be supplied aerobically. This is because the breathing and circulatory systems cannot operate fast enough to sustain an adequate supply of oxygen. When oxygen levels in the blood start to run low, oxygen is released from myoglobin, an oxygen-storage molecule in the muscle. The levels of oxygen attached to the myoglobin are very limited and eventually they become too low to sustain aerobic cellular respiration. Muscle fibres then provide energy anaerobically and produce lactate (which can become lactic acid). Like all acids, lactic acid is a metabolic poison and it can cause damage if it accumulates.

lactic acid
an organic acid formed by the breakdown of glucose during anaerobic cellular respiration in animals

When exercise is completed the lactate can re-enter the aerobic cellular respiration pathway and be broken down into carbon dioxide and water. Alternatively, it is converted to a complex

carbohydrate. Oxygen is needed for both processes. The amount of oxygen that is needed to get rid of the lactic acid is called the **oxygen debt**. 'Stiffness' of muscles occurs because lactic acid accumulates in sufficient amounts to cause muscle fibre damage before it is broken down.

oxygen debt
the amount of oxygen required to convert lactic acid, produced during a period of anaerobic respiration, to pyruvate

$$1 \text{ glucose} \rightarrow 2 \text{ lactate} + 2\text{ATP}$$

Fermentation in plants

In an anaerobic environment, plants used a different pathway. Although glycolysis still occurs, different enzymes result in the production of ethyl alcohol and carbon dioxide in plants. The ethyl alcohol cannot be broken down by the plant and as a result it can accumulate to toxic levels. While many plants can resort to anaerobiosis for a short period of time (e.g. germinating seeds or roots in waterlogged soil), they must revert to aerobic respiration before the ethyl alcohol levels reach toxic levels and cause death.

Fermentation in yeasts

The natural fermentation of yeasts (single-celled fungi) and bacteria has been used for thousands of years in making products for human use.

Fermentation in plants and yeasts can be summarised as:

$$1 \text{ glucose} \rightarrow 2 \text{ ethyl alcohol} + 2CO_2 + 2\text{ATP}$$

Temperature affects cellular respiration

One of the ways the human body fights an infection is to develop a fever. While this is good for killing the infective agent (bacteria or viruses), it can also cause damage to the cells in the body. High temperature can affect the shape of the enzymes involved in cellular respiration. This can result in the enzymes becoming ineffective and slowing the rate of cellular respiration and ATP production. At low temperatures, all molecules move more slowly. This makes it difficult for glucose and oxygen to bind with the enzymes responsible for cellular respiration. As a result, the overall rate of cellular respiration will slow, causing ATP production to slow. This explains why plants and animals grow very slowly in cold environments.

CHECK YOUR LEARNING 4.4

Describe and explain

1 **Explain** why a low blood glucose level is dangerous for someone with diabetes.
2 **Identify** where anaerobic cellular respiration occurs.
3 **Explain** how temperature affects cellular respiration.
4 **Identify** the circumstances in which the following substances are the end products of cellular respiration:
   - **a** carbon dioxide
   - **b** ethyl alcohol
   - **c** lactate (lactic acid)

Apply, analyse and interpret

5 **Compare** aerobic and anaerobic cellular respiration.
6 **Distinguish** between a complete and a partial anaerobe.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 4.4
- » Weblink
  Anaerobes
- » Weblink
  Fermentation
- » Weblink
  Temperature and cellular respiration

4.5 Connecting photosynthesis and cellular aerobic respiration

KEY IDEAS

- The relationship between products and reactants of photosynthesis and cellular respiration
- The significance of these two processes in maintaining the balance of carbon dioxide and oxygen in Earth's atmosphere

product
the chemical(s) formed as a result of a chemical reaction

reactant
a chemical taking part in a chemical reaction

Most life on Earth is dependent on the **products** of photosynthesis – glucose and oxygen. The glucose produced in photosynthesis is broken down by cellular respiration using oxygen to make ATP. The carbon dioxide and water waste products are recycled in photosynthesis using the energy of sunlight and the chemical chlorophyll. Both cellular respiration and photosynthesis are processes involving products and **reactants**.

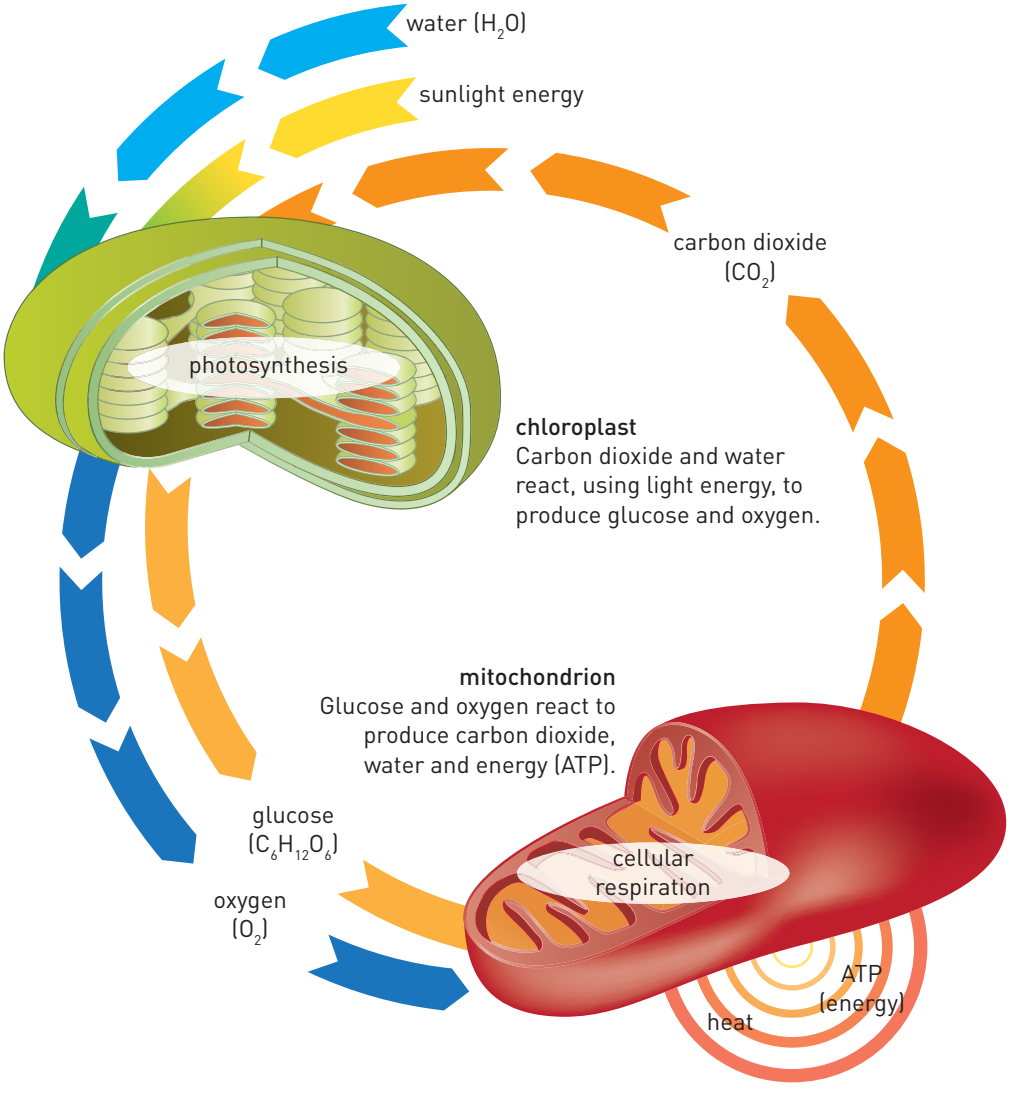

FIGURE 1 The connection between photosynthesis and aerobic cellular respiration

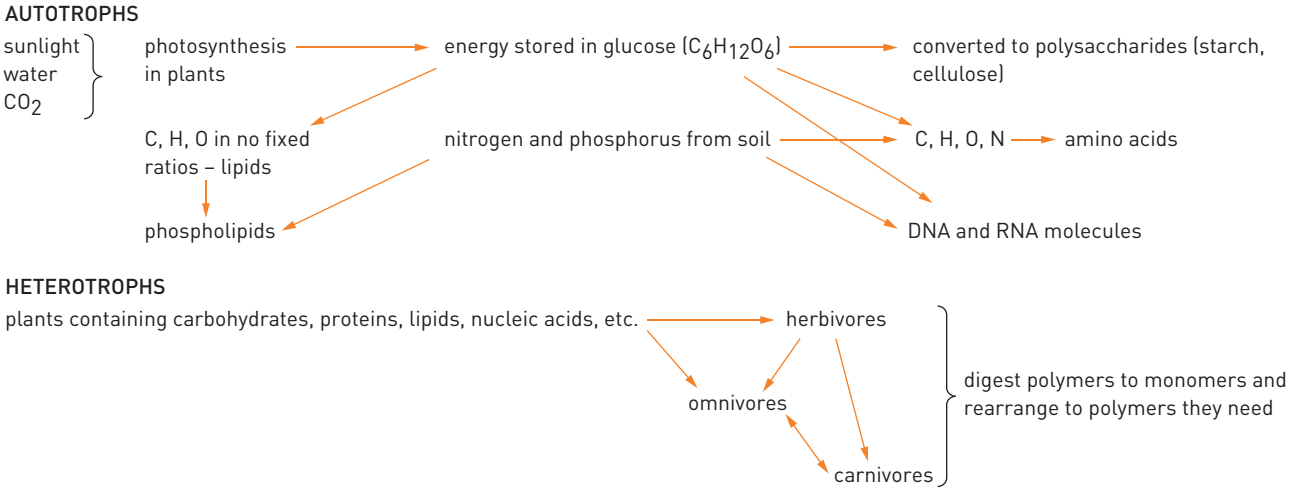

FIGURE 2 Relationship between autotrophs and heterotrophs

Although different chemical reactions are involved, photosynthesis and cellular aerobic respiration are directly opposite net reactions.

- Energy from the sun enters a plant and is converted during photosynthesis into glucose, which stores energy in its bonds.
- In the presence of oxygen, the bond energy of glucose is released and used to make ATP in the mitochondria during aerobic cellular respiration. Some energy is lost to the environment as heat.

These two reactions help to maintain the balance of carbon dioxide and oxygen in Earth's atmosphere. While forests produce 70% of terrestrially formed oxygen, cyanobacteria, algae and phytoplankton (microscopic floating algae) are responsible for 75% of Earth's total oxygen formation. During respiration, all aerobic organisms use oxygen and release carbon dioxide. Human activities that disrupt this balance (e.g. clearing of forests or destruction via chemical run-off of oceanic algae) could have drastic effects on all life on Earth.

CHECK YOUR LEARNING 4.5

Describe and explain

1 **Summarise** the inputs and outputs of:
   - **a** light-dependent reactions of photosynthesis
   - **b** light-independent reactions of photosynthesis
   - **c** anaerobic respiration (glycolysis)
   - **d** aerobic respiration (glycolysis, Krebs cycle and electron transport chain)
   - **e** fermentation in animals, plants and yeasts.

Apply, analyse and interpret

2 Most photosynthetic activity on Earth is carried out by microscopic algae found at the ocean's surface. **Consider** the impact a drastic decrease in their numbers would have on terrestrial animals.

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  Products of photosynthesis
- » Weblink
  Reactants of photosynthesis
- » Weblink
  Autotrophs and heterotrophs

CHAPTER 4

Review

Chapter summary

4.1 Different wavelengths (and colours) of light provide different energy levels.

Photosynthesis is the process that uses light energy to synthesise chemical energy in the form of organic nutrients. Photopigments (including chlorophyll) trap light energy for use by the cell.

Chemosynthesis is the process that uses the energy released from chemical reactions to synthesis organic nutrients.

4.2 Photosynthesis in plants and algae takes place in the chloroplasts of the cell. Chloroplasts are organelles with a double membrane. Thylakoid stacks of pigment-containing membranes (grana) are found within the watery matrix (stroma) of the chloroplast.

Photosynthesis is a two-stage process, the first stage requiring light (and taking place on the grana) and the second capable of occurring without light (and taking place in the stroma). There are many steps in the photosynthesis process, each of which is controlled by a specific enzyme.

The function of the light-dependent stage is to produce ATP, and to split water into hydrogen and oxygen. The oxygen is released as a waste product and the hydrogen is taken up by a hydrogen carrier.

In the light-independent stage, carbon dioxide is used to produce the carbohydrate glucose, using the hydrogen atoms and ATP that were formed in the light-dependent reactions.

The intensity and colour of light, temperature and availability of water and carbon dioxide can affect the rate of photosynthesis.

4.3 Cells require energy to perform their life functions. Since there is a constant loss of energy from cells in the form of heat, energy must be replaced. Energy is needed in endergonic reactions, stored as chemical energy and released as required. Cells are energy converters.

Cellular respiration releases energy from organic molecules to ATP. Carbon dioxide and water are waste products. There are three phases in the complete metabolic pathway. Glycolysis is an anaerobic process that occurs in the cell cytoplasm. A glucose molecule is converted to two molecules of pyruvate, releasing a net of two ATP molecules and hydrogen, which becomes attached to hydrogen carrier molecules.

If oxygen is present, pyruvate can enter the mitochondrial matrix, along with the oxygen. Pyruvate produces coenzyme A and a carbon dioxide molecule.

The Krebs cycle is a series of chemical reactions that produces two carbon dioxide molecules and an ATP from each coenzyme A and loads hydrogen ions and their electrons onto hydrogen carrier molecules.

The folding of the internal membrane in mitochondria increases the surface area for the electron transport chain reactions. The electron transport chain uses six oxygen molecules, the hydrogen ions and their electrons to produce net six water molecules and 32–34 ATP.

Polysaccharides, lipids and proteins can enter the cellular respiration pathway after glycolysis has occurred.

4.4 If oxygen is not present, only two ATP are produced from glucose by anaerobic cellular respiration (glycolysis with fermentation). In animals this fermentation process produces lactate (lactic acid) and two ATP, while in plants and yeast it produces ethyl alcohol, carbon dioxide and two ATP.

Temperatures and low substrate concentrations can slow the rate of cellular respiration.

4.5 The general equation for photosynthesis is the direct opposite of that for cellular respiration although the chemical processes are very different.

The exchange of carbon dioxide and oxygen through photosynthesis or cellular respiration helps to maintain Earth's levels of atmospheric oxygen and carbon dioxide at stable levels.

Key terms

- absorption spectrum
- action spectrum
- activation energy
- aerobic respiration
- anaerobic respiration
- Calvin–Benson cycle
- cellular respiration
- chemosynthesis
- chlorophyll
- chloroplast
- complete anaerobe
- electron transport chain
- endergonic
- enzyme
- exergonic
- fermentation
- glycolysis
- granum
- Krebs cycle
- lactic acid
- light-dependent reaction
- light-independent reaction
- mitochondrion
- oxygen debt
- partial anaerobe
- photosynthesis
- product
- reactant
- stroma
- thylakoids

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 In the process of photosynthesis:

A Complex organic molecules are broken down into simple inorganic molecules.

B Light is used to produce heat and kinetic energy.

C Carbon dioxide is a waste product and oxygen is a reactant.

D Light energy is converted to chemical energy.

2 Anaerobic cellular respiration is a chemical reaction that:

A occurs in the mitochondria of cells

B forms lactate (lactic acid) and a large amount of ATP in plants and yeasts

C occurs in the cytoplasm and releases small amounts of ATP

D forms ethyl alcohol and a small amount of ATP in animals

3 Which of the following factors does NOT affect photosynthesis?

A the amount of chlorophyll

B the temperature of the environment

C the intensity of light available

D the fatty acids in the cell

4 Which of the following will increase the rate of cellular respiration?

A Increasing the temperature from 5°C to 35°C

B decreasing the temperature from 35°C to 5°C

C increasing the amount of carbon dioxide

D increasing the intensity of the light

5 Fermentation is used by plant cells in a low oxygen environment. The products of fermentation are:

A lactate and 2 ATP

B lactate, CO_2 and 2 ATP

C ethyl alcohol and 2 ATP

D ethyl alcohol, CO_2 and 2 ATP

Short answer

Describe and explain

★ **6** **Explain** the advantages to the cell of having a cyclical metabolic system such as the Calvin–Benson cycle or Krebs cycle.

Apply, analyse and interpret

★★ **7** Several jars of strawberry jam were made and stored in a cupboard. When opened several months later, they were found to be frothy and smelled of alcohol.

a **Deduce** what has happened.

b **Explain** how this could have been prevented.

★★★ **8** In graph A in Figure 1, the purple line shows the absorption spectrum of a solution of pigments extracted from bean leaves. The red line shows the action spectrum of a bean plant, determined by measurement of the rate of photosynthesis when the plant was illuminated by different wavelengths of light. Graph B shows the absorption spectra of three pigments that have been extracted from bean leaves and examined individually.

a With reference to graph A:

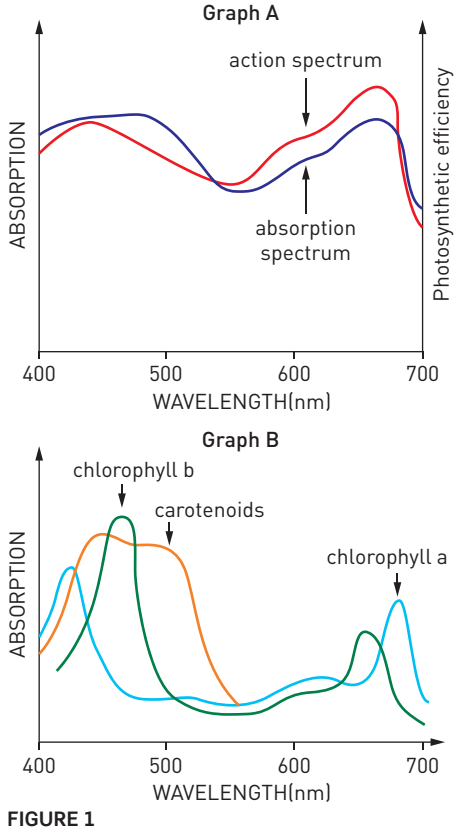

FIGURE 1

i **Interpret** the graph to comment on the biological significance of the relationship between the action spectrum and the absorption spectrum.

ii **Determine** the approximate wavelengths at which photosynthesis is most efficient.

b With reference to graphs A and B, **interpret** the differences between the photosynthetic rate and light absorption rate at a wavelength of 490 nm.

★★★ **9** The graphs below (Figure 2) show the effects of temperature, light intensity and carbon dioxide on the rate of photosynthesis.

a **Consider** why the rate of photosynthesis reaches a maximum level despite increases in either light intensity or carbon dioxide concentration.

b **Determine** what feature(s) of biological systems would explain the decrease in photosynthetic rate at temperatures higher than about 37°C.

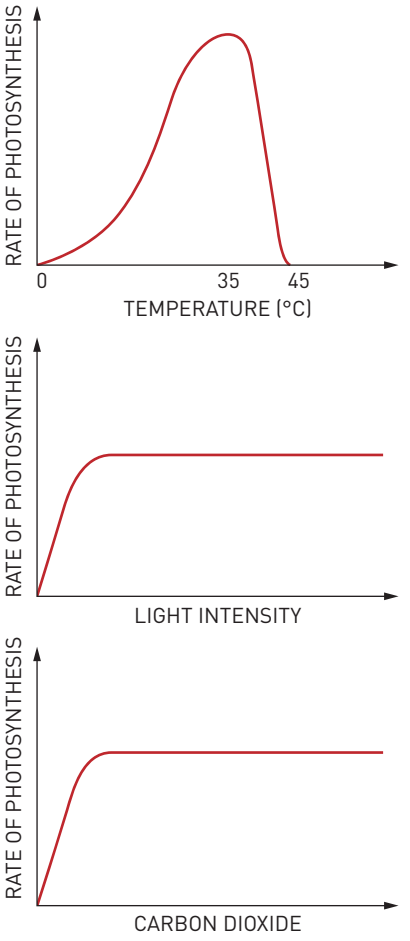

FIGURE 2

c **Consider** what factors would limit photosynthetic rate. (Not all factors are necessarily shown on the graphs.)

★★ **10** A camel stores fat in the hump primarily as a water source rather than an energy source. By what metabolic process would water be made available from fat? **Justify** your reasoning.

★★ **11** ADP and ATP are often referred to as a chemical energy shuttle. Using the last phase of aerobic respiration as an example, **explain** how this shuttle analogy is appropriate.

Investigate, evaluate and communicate

★★ **12** A large glass-stoppered flask containing nasturtium leaves and air was exposed to bright sunlight for 3 hours. Figure 3 shows the apparatus used.

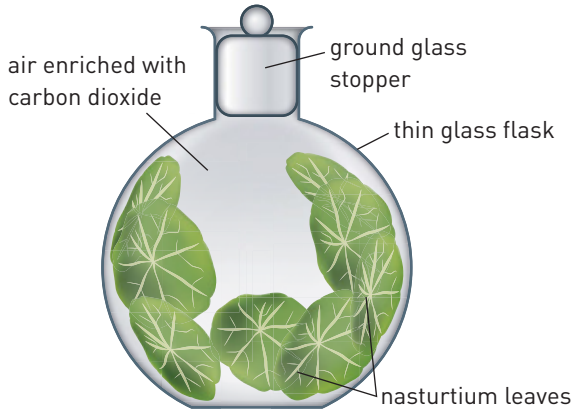

FIGURE 3 Glass containing nasturtium leaves and air

Two samples of gas were withdrawn from the apparatus. The first (sample A) was withdrawn at the beginning of the experiment and the second (sample B) was withdrawn at the end of the 3 hours. The volume of each sample was measured after exposure, first, to potassium hydroxide and, second, to alkaline pyrogallol solutions. (Potassium hydroxide absorbs carbon dioxide and alkaline pyrogallol solution absorbs oxygen.) The results are tabulated below.

	Sample A	Sample B
Original volume	100 cm^3	100 cm^3
Volume after exposure to potassium hydroxide solution	94 cm^3	98 cm^3
Volume after exposure to alkaline pyrogallol solution	73 cm^3	73 cm^3

a **Determine** the percentage of carbon dioxide present in each of the samples A and B.

b **Discuss** the difference in carbon dioxide volume between the two samples.

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CHAPTER

5 From cell to multicellular organism

A multicellular organism originates from a single cell. The processes involved in their development include cell proliferation (mitosis), cell specialisation (from stem cells), cellular interactions and movements in the formation of tissues, organs and systems.

OBJECTIVES

→ Understand that stem cells differ from other cells by being unspecialised and have properties of self-renewal and potency.
→ Recognise that stem cells differentiate into specialised cells to form tissues and organs in multicellular organisms.
→ Recognise that multicellular organisms have a hierarchical structural organisation of cells, tissues, organs and systems.

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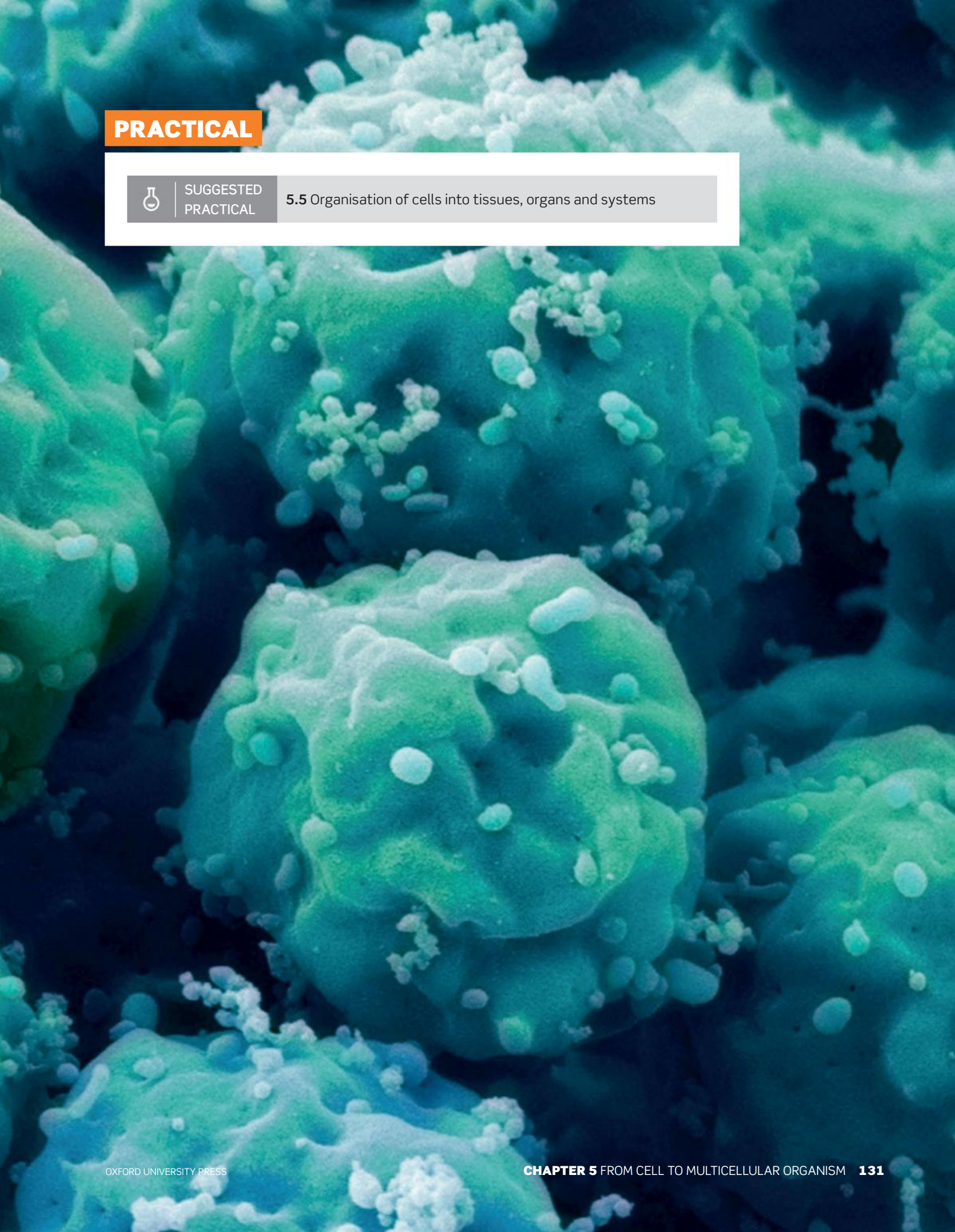
FIGURE 1 Coloured scanning electron micrograph (SEM) of embryonic stem cells



PRACTICAL

SUGGESTED PRACTICAL

5.5 Organisation of cells into tissues, organs and systems

5.1 Formation of the multicellular organism

KEY IDEAS

- Cell size limitation and cell proliferation (multicellular organisms)
- Cell specialisation for a particular function
- Coordination between cells

All organisms undertake the same life functions: they require nutrients and gases from their environment to perform metabolic reactions, they remove waste products of cellular reactions and they reproduce. The cell of the unicellular organism must perform all of these functions and there must be some form of chemical communication between the different parts of the cell to coordinate its activities. Because exchange of materials across the cell membrane needs materials to be in solution, unicellular organisms are restricted to environments rich in moisture or are fully aquatic.

In order to operate efficiently, cells cannot grow too large. The ratio of surface area to volume decreases with increased size, limiting the rate of diffusion of nutrients into a cell and the removal of wastes out of the cell. It is not possible for a single cell to grow into a large organism. Instead an organism needs to increase the number of cells and these cells need to be able to hold together and communicate in some way.

multicellular organism
an organism composed of many integrated cells

Multicellular organisms are all eukaryotes and start life as a single cell. In sexually reproducing organisms this cell has a combination of the genetic material of both parents, with each parent contributing half of their genetic material to their offspring. In asexually reproducing organisms, the daughter cell is a genetically identical copy of the parent's cells. In both of these examples, the single cell contains all the genetic instructions that are needed to produce every cell in the multicellular organism.

The first cell of any multicellular organism must undergo a long series of stages to produce the final organism.

1. The cell must first produce many more cells with the same genetic code.
2. The cells must specialise their structure and function. A multicellular organism, such as an elephant, cannot absorb water and nutrients though its skin. Instead the elephant must take them in through its mouth and find a way to transfer them around its body to the cells that need them. Therefore, the elephant needs specialised blood cells and fluid to transport the water and nutrients around the body, and to transfer waste out.
3. The cells must be able to communicate with each other in a coordinated manner. For example, a muscle cell that needs extra nutrients such as glucose or oxygen must be able to communicate with the rest of the multicellular organism that more glucose or oxygen must be supplied.
4. The cells forming the multicellular organism must be located near the cells that support them. This means as the cells start forming the multicellular organism, they must be able to move to the correct position so that each cell is surrounded by the cells that will provide its requirements. In this way, special **tissues** and organs are formed.

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

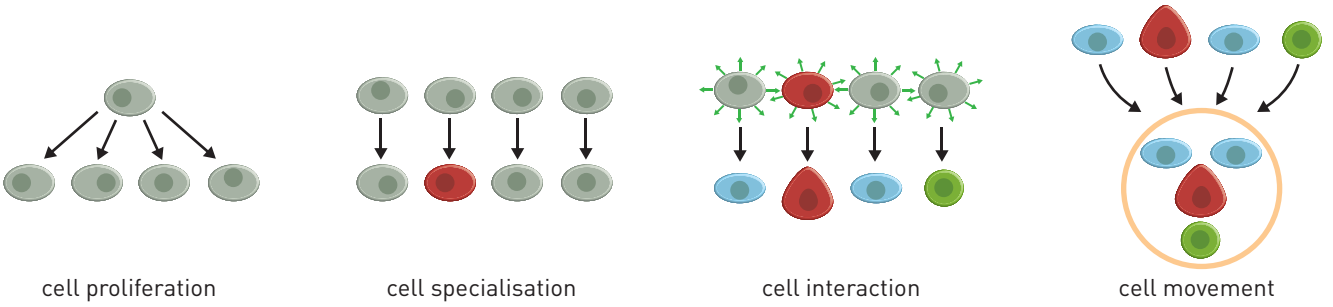


FIGURE 1 Stages in the development of the multicellular organism

The hierarchy of structures can be shown in a flow chart:

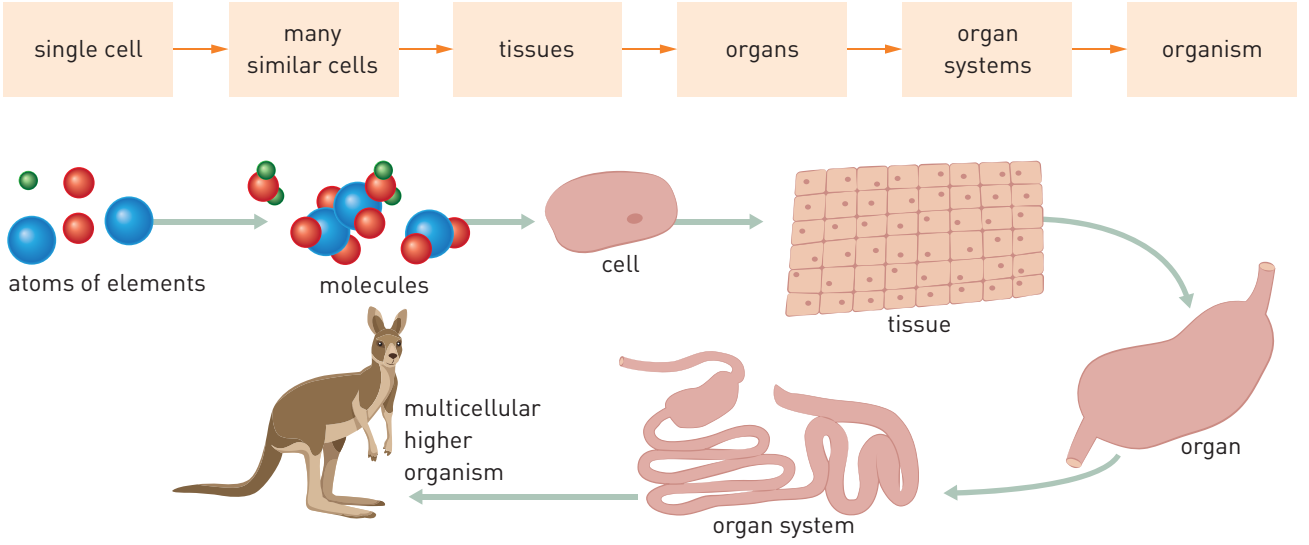


FIGURE 2 Multicellular organisms all share the same basic structural hierarchy.

CHECK YOUR LEARNING 5.1

Describe and explain

1 In terms of cell function, **summarise** the cells of unicellular and multicellular organisms.

2 **Identify** four processes involved in the formation of a multicellular organism from a single cell.

3 **Explain** why unicellular organisms are found only in moisture-rich environments.

4 **Explain** why multicellular organisms have an advantage when competing against unicellular organisms.

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  Formation of multicellular organisms
- » Weblink
  Eukaryotes

5.2 Cell proliferation

KEY IDEAS

- Stages in cell division
- Significant features of the cell cycle
- The difference in cytokinesis between plant and animal cells

The cell cycle

cell cycle
the continuous cycle of growth and division in cells

interphase
stage in the cell cycle in which the cell grows, stores energy and replicates chromosomes

The **cell cycle** is an organised series of events that involves the growth of a cell (**interphase**), and its division into two genetically identical cells. During interphase, the cell is actively undergoing the many chemical reactions that it requires to stay alive. Most cells in multicellular organisms spend the majority of their time undergoing the everyday metabolic activities of this first stage of interphase, known as the G1 (G = gap) phase.

Preparation of the cell for division: interphase

Once a cell reaches the maximum size for efficient nutrient and waste exchange across the membrane, it has two choices; maintain its function level (e.g. adult brain cells), or prepare to undergo cellular division (mitosis).

Before undergoing mitosis, a cell must first check that all the genetic material (DNA) is intact and that all the organelles and enzymes are functioning correctly. If the chemical messengers inside the cell suggest that something is wrong, the cell will undergo a process of organised cell death called **apoptosis**.

apoptosis
cell death

chromatid
a replicated chromosome, still attached to the original at the centromere

centromere
the point of attachment of two chromatids

mitosis
nuclear division resulting in daughter cells with the same number and types of chromosomes as in the parent cell

cytokinesis
division of cells after mitosis

If the chemical messengers inside the cell suggest that cellular functioning is occurring correctly, the cell will pass into the second part of interphase, S phase. This phase involves the replication of deoxyribonucleic acid (DNA). During interphase, the genetic material is strung out in long chromatin threads. As the cell grows and matures, the genetic material (DNA) of each chromatin thread is copied using the existing DNA molecules as the patterns for the new strands. The two strands of identical DNA (now called **chromatids**) remain connected at a central point called the **centromere**.

The third stage of interphase, G2, involves an energy- and nutrient-intensive phase of the cell synthesising the organelles and proteins in preparation for cell division. In animal cells the centrioles replicate. Strands of protein that will form the spindle fibres start to develop.

The cell has now accumulated the chemical resources and energy necessary to make a whole new copy of the nucleus (**mitosis**). This involves the separation of chromatids and the accumulation of a complete set of chromosomes at opposite sides of the cell. At the completion of mitosis, the entire cell divides (**cytokinesis**) so that each new daughter cell has a complete set of chromosomes as well as cytoplasm and organelles. Each of these cells then enters interphase and the cycle repeats itself.

As seen in Figure 1, the actual phase of mitosis and cell division is relatively rapid compared with the length of time needed for the cell to synthesise new chemicals and ATP.

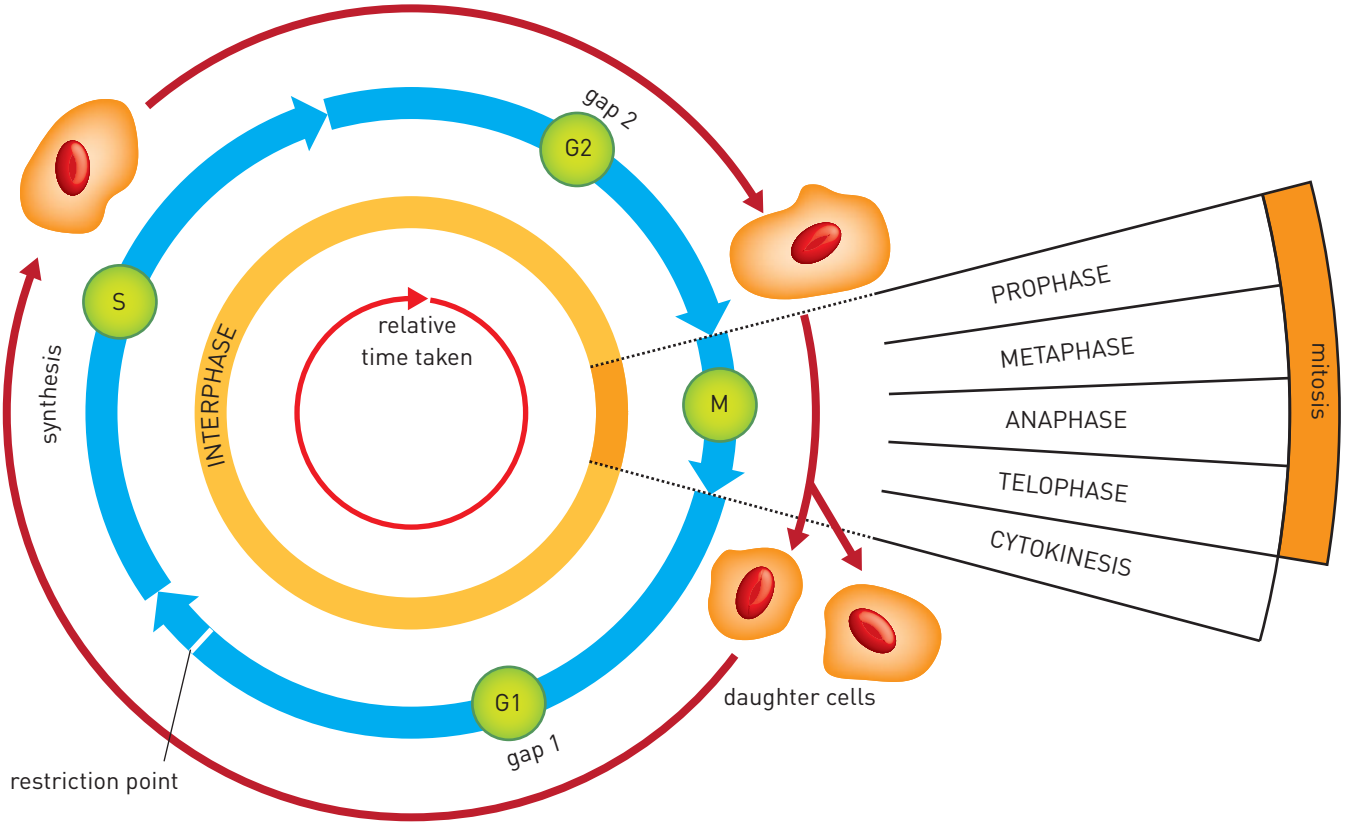


FIGURE 1 The cell cycle. Interphase is the period between two mitosis phases.

Mitosis and cytokinesis

There are four stages in nuclear division or mitosis: prophase, metaphase, anaphase and telophase. These phases are followed by division of the cytoplasm to form two cells (cytokinesis).

Prophase

The DNA threads or chromatin condense to form distinct, thickened chromosomes. Each of these chromosomes consists of two strands (chromatids), which lie parallel to each other along their length and are joined at the centromere. Each chromatid contains one side of the original DNA and a new complementary, replicated side. While the chromosomes are condensing, a series of protein threads create a spindle that reaches the length of the cytoplasm of the cell. The two ends of the spindle are called the poles and the middle region is the equator. In animal cells the spindle-producing centrioles separate and migrate to opposite poles of the spindle. The nucleolus of the nucleus breaks down, as does the nuclear membrane.

Metaphase

With the disappearance of the nuclear membrane, the chromosomes migrate to the centre (equator) of the cell and each attach their centromere to an individual spindle fibre. The arrangement of the chromosomes on the spindle fibres is apparently random and may change from division to division.

Anaphase

During anaphase the chromatids of each chromosome separate so that they are no longer attached by their centromeres. Once they have separated, the chromatids are called sister chromosomes. Each of the identical sister chromosomes is pulled by the spindle to opposite poles of the cell. The exact mechanism is not known, but congregation of mitochondria around the spindle suggests that large amounts of energy are required. It is thought that the spindle fibres, with the input of energy, contract and separate at the equator and as they pull towards opposite poles the centromeres separate to release the sister chromosomes.

Telophase

On reaching the polar ends of the spindle, the chromosomes congregate tightly together. The spindle breaks down and a new nuclear membrane is formed around each bundle of chromosomes. The nucleolus starts producing nucleotides and the chromosomes uncoil to revert to chromatin threads.

Cytokinesis

Study tip

Metaphase has chromosomes lined down the **M**iddle of a cell.
Anaphase has chromosomes moving **A**way from each other.

While the events of telophase are occurring, division of the cytoplasm between the new groups of chromosomes commences. In animal cells the cell membrane constricts across the centre (equator) of the cell to form two new cells. In plants a cell plate, formed from vesicles of the Golgi apparatus, grows across the middle of the cell. The new membrane joins with the existing cell membrane to form two cells. New cell walls are produced between the membranes of the plate prior to separation.

Significant features in the cell cycle are:

- Just prior to division there is replication of DNA. Each chromosome now consists of two identical chromatids.
- Each chromosome attaches to a separate spindle fibre.
- Separation of the chromatids of each chromosome to opposite poles of the spindle ensures that each pole contains the same number and types of new chromosomes.
- The daughter cells will therefore have exactly the same number and type of chromosomes as the original cell.
- At each division two daughter cells are produced.
- An amount of time between divisions (interphase) is needed for the cell to grow, store energy, and replicate DNA and organelles.

Although cytokinesis normally follows the formation of the new nuclei (mitosis), there are exceptions. The formation of skeletal muscle fibres in vertebrate animals, for example, results from mitosis without cytokinesis. These cells often have multiple nuclei in a single cell. Some cell types go through the cell cycle – growth, mitosis and cytokinesis – continuously throughout the life of the organism. Since red blood cells of vertebrates do not have a nucleus and live only for about 120 days, cells in the bone marrow constantly divide to maintain enough red blood cells in the body. Other cell types (e.g. some brain cells) do not undergo further division once the organism is mature. A third category of cells divide only at a sufficient rate to produce the number of cells that are required for growth and replacement. Human liver cells, for example, do not normally divide after the liver has reached a certain size. If some of the liver is surgically removed, the existing cells are triggered into division mode until the liver has regained its original size. Cell division then stops.

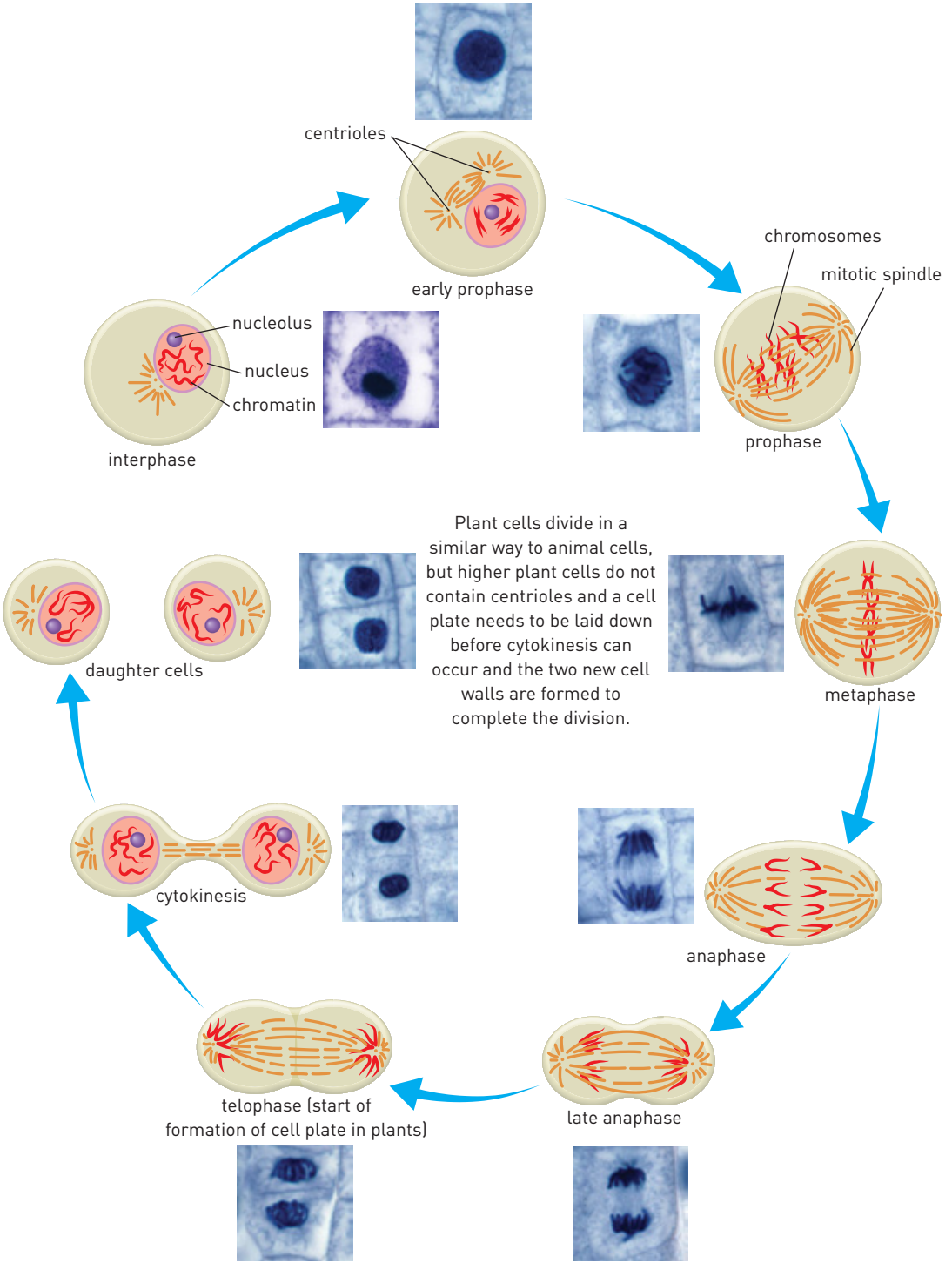


FIGURE 2 Stages in mitosis and cytokinesis in a diploid (having two of each type of chromosome) animal cell (drawings) and a plant cell (photographs)

The nature of the control system or systems that regulate the cell cycle is still unclear. Certain hormones (e.g. growth hormones) and other chemicals have been shown to stimulate cell division. Other chemicals or cell overcrowding can inhibit it. The control of cell division is of particular interest to researchers since cancers result from uncontrolled cell division in multicellular organisms.

CASE STUDY 5.2

Cancer – uncontrolled cell division

Within each cell of multicellular organisms is a series of genes which programs for cell death, or apoptosis (*apo* = away; *ptosis* = fall) and causes the cell to shrink and fragment. The fragments are then destroyed. Other genes suppress these death genes. It appears that the balance of activity between these two sets of genes determines whether a cell lives or dies. In many cases studied, any damage to the cell's DNA triggers the activity of the death genes and suppresses that of the survival genes. These sets of genes help prevent a cell from growing uncontrollably.

A cell needs up to six changes to its DNA in order to mutate and become a cancer-causing cell.

1. A cell needs to become self-sufficient: Most cells need signals from other cells before they can undergo mitosis. Cancerous cells can signal themselves to divide.
2. A cell needs to block the signal that stops mitosis. All cells have genes that supress mitosis and prevent the cell from growing uncontrollably. A mutation in these genes allows a cell to divide anytime.
3. A cell needs to avoid apoptosis. For this to occur, the cell needs a mutation in the genes that cause the cell to apoptose.
4. A cell needs to be able to undergo limitless cell cycles. Cancerous cells can divide an unlimited number of times.
5. A cell needs to have access to nutrients through a good blood supply. Most cancerous cells can encourage blood vessels to grow around them.
6. A cell needs to be able to migrate (metastasise) around the body. This enables it to spread to new sources of nutrition.

Cancer cells kill the surrounding cells, either by strangling them or by being more competitive in using the limited resources available. Vital functions of the body are therefore disrupted and this can affect the survival of the multicellular organism.

The causes of cancer are numerous. All cancer cells result from changes in the DNA of body cells. Some cancers result from constant injury or aggravation of tissue (so that benign moles can become cancerous), mutagens (radiation and chemicals that cause DNA changes or mutations) or viruses.

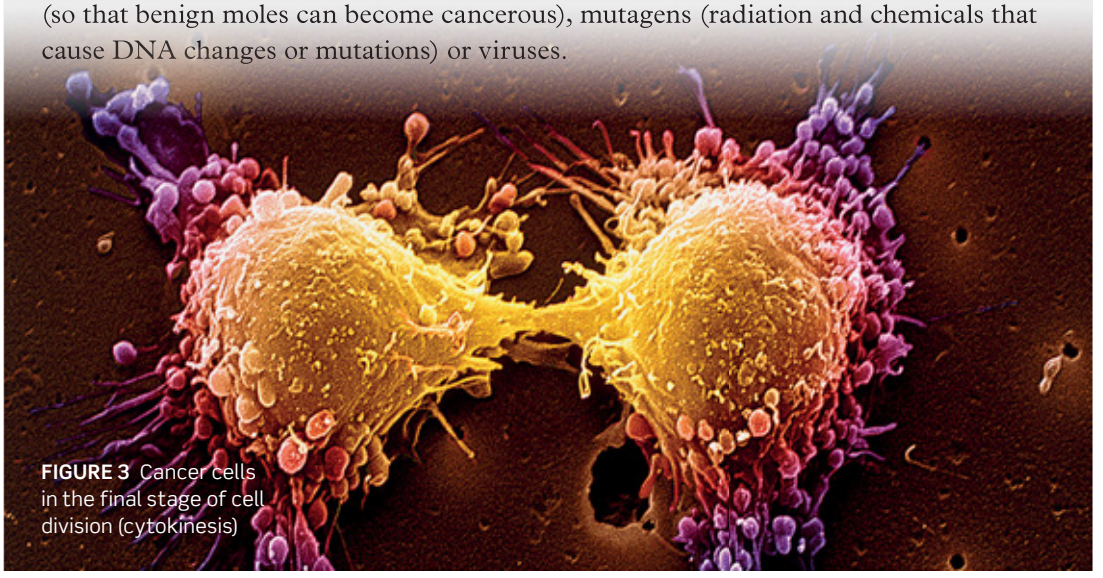


FIGURE 3 Cancer cells in the final stage of cell division (cytokinesis)

CHECK YOUR LEARNING 5.2

Describe and explain

1 **Select** the correct order for the following events of the cell cycle:
- DNA replicates.
- Chromosomes line up at the equator of the spindle.
- Spindle forms.
- Nuclear membranes form.
- Chromatids separate.
- The nuclear membrane disintegrates.
- Chromosomes move to the ends of the spindle.

2 **Identify** and **describe** the structures that take part in the cell cycle of animal cells but not that of plant cells.

3 **Describe** the structure that is unique to plant cell division.

4 **Explain** why it is necessary for DNA to replicate before mitosis takes place.

Apply, analyse and interpret

5 An old biology textbook described interphase as a 'resting phase'. **Apply** your knowledge to **explain** why this term is inappropriate.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 5.2

» Interactive
Mitosis

» Weblink
Interphase

» Weblink
Cell division

5.3 Stem cells and the multicellular organism

KEY IDEAS

- The definition of a stem cell
- Differentiation of cells
- Types of animal stem cells
- Stem cells in plants

Multicellular organisms will often receive damage in their normal movement or interaction with their environment. This damage may require the cell to be repaired or replaced. If a cell is specialised, for example a skin cell or a retinal cell in the back of the eye, then it needs to be replaced with an equally specialised cell. It is not practical for a multicellular organism to keep a set of specialised cells in case of damage. Instead, multicelled organisms have sets of unspecialised stem cells that can be used.

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

Stem cells are unspecialised cells that have the capacity to develop into many different cell types under special conditions. Some of these cells can activate any part of their genetic

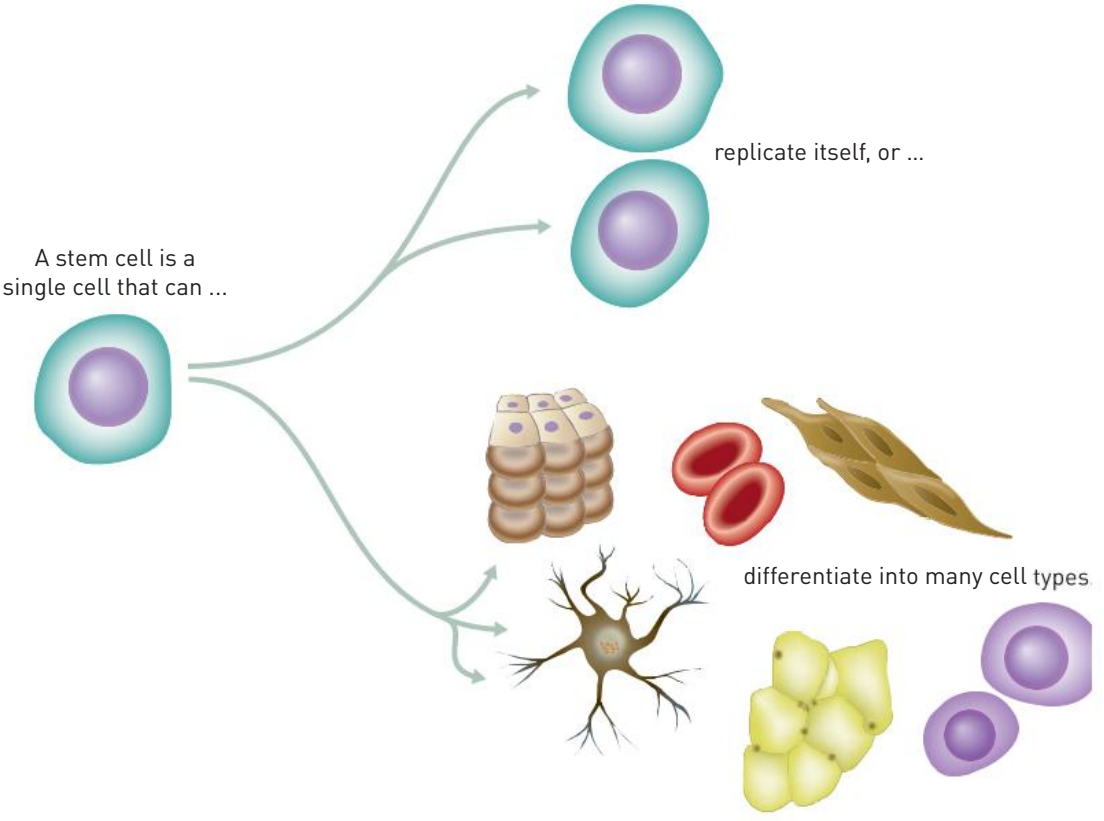


FIGURE 1 General definition of a stem cell

material if it is needed. This is different to specialised cells that may have some parts of their DNA permanently switched off. For example, a skin cell does not need many of the molecules that are used by kidney cells. Therefore, the skin cell switches off the parts of the DNA (the genes) that contain the instructions for these kidney cell molecules. The skin cell is now described as specialised or **differentiated**.

All stem cells have two main properties:

1 **self-renewal**: the ability to go through several cell cycles without further differentiation, and
2 **potency**: the ability to differentiate (change) into specialised cell types.

The first cells that form during cell proliferation in a multicellular organism are **totipotent stem cells** – all of their genetic material is expressed in the daughter cells formed.

Stem cells in animals

In animals, the first mass of cells formed develop as a hollow ball with a single layer of outer cells called the **blastula**. As further division occurs, in all animals except sponges, one end of the mass begins to push into the cavity of the embryo to form a double layer called the **gastrula**. This triggers the first stage of **cell differentiation**. Depending on where the cell is in the gastrula, it will receive a chemical message to switch on or off the DNA of specific genes. This will provide a specific set of instructions of what shape to take and what functions to perform, e.g. the cell may become skin, muscle or gut cells. These cells will only express specific parts of the DNA that are associated with that cell group. These cells are called **pluripotent stem cells** because they can proliferate into any of the cell types in that group. Totipotent or pluripotent stem cells are found in the embryo of animals and are therefore called **embryonic stem cells**.

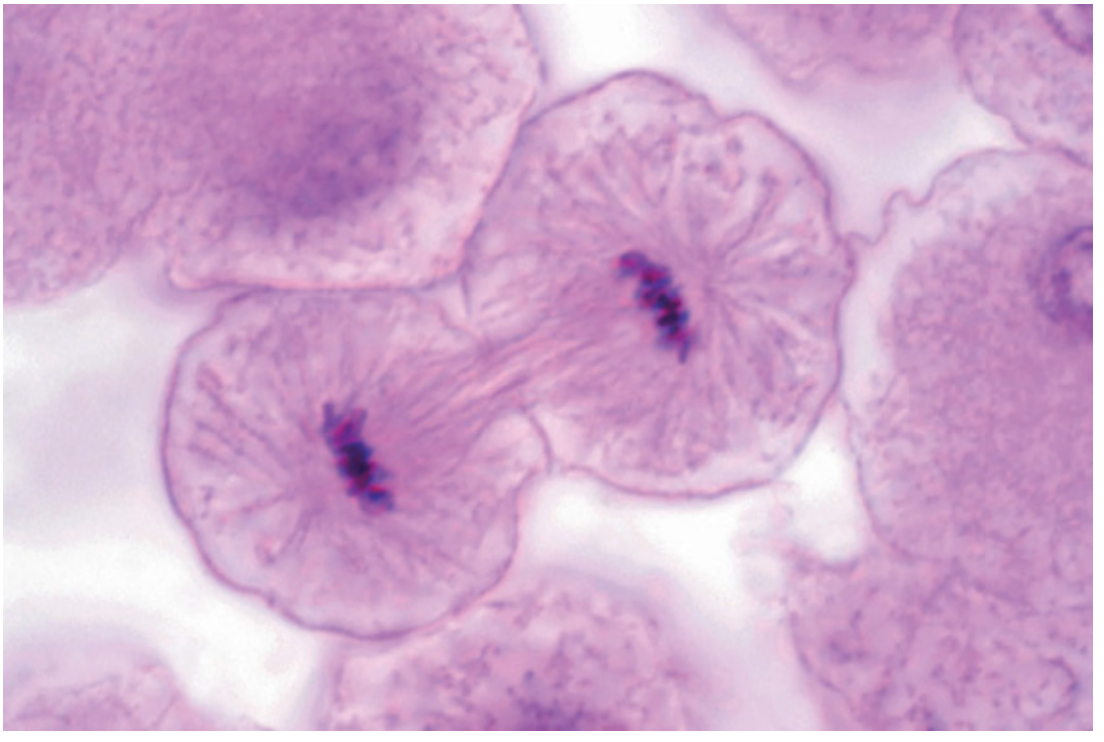


FIGURE 2 Blastula in the process of cell division

differentiation
the process of change in cells, tissues and organs during development, resulting in division of labour within cells or organisms

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

blastula
a hollow ball of cells resulting from division in the animal zygote

gastrula
the early embryonic stage in the animal formed from the ingrowth of cells at one end of the blastula to produce a double layer of cells from which future tissues and organs develop

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

embryonic stem cell
an undifferentiated, totipotent or pluripotent cell found in the early embryo

cell differentiation
the process by which a cell becomes specialised in order to perform a specific function

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

oligopotent stem cell
a stem cell that can only differentiate into a few cell types

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

With further development, these pluripotent cells become more and more specialised. Once the infant is born, the cells have become so specialised that they can only differentiate into a limited number of cell types. These **multipotent stem cells** can only specialise into a single, closely related 'family' of cells. Cells in the bone marrow are multipotent as they can become any of the cells found in the blood (red blood cells, white blood cells or platelets).

Each of the multipotent cells then further specialises to become **oligopotent stem cells**, forming only a few cell types, or **unipotent stem cells**, which can produce only their own cell type.

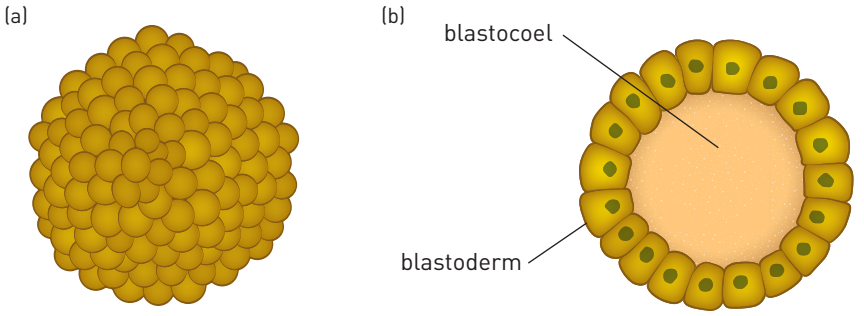


FIGURE 3 Blastula (totipotent stem cells) of the animal embryo: (a) Outer view; (b) transverse section through the blastula

adult stem cell
a partially differentiated animal cell, responsible for repair and maintenance of the adult body

Stem cells that are found in multicellular organisms after birth (including multipotent, oligopotent or unit potent cells) are called **adult stem cells**. They are responsible for repair and maintenance of the adult body.

Stem cells in plants

Both plants and animals shared a common unicellular eukaryotic ancestor. This means plants and animals have many genes in common that determine growth and development. Plants get their energy from sunlight, not by ingesting other organisms. They therefore have a different body plan to animals.

Animal cells are largely protected from environmental change and so the embryo develops the same genetically determined body structure regardless of most external conditions. Development of most plants, however, is dramatically influenced by the environment. If there is little water, or the sunlight is too harsh, the developing plant embryo in a seed cannot move to a more suitable environment. Therefore, a plant must alter the course of its development so that it can grow and survive. As a result, the overall structure of plants of the same species may appear different. Although the large-scale structure – pattern of roots or branches, and so on – is dictated largely by the environment, other factors such as the structure of the stem or leaf are highly determined by their genes.

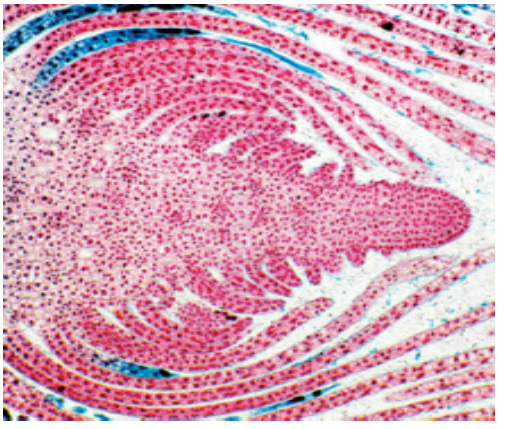


FIGURE 4 Magnified section of a huckleberry. The pale pink cells are stem cells that are undergoing elongation and vacuolisation. The smaller and darker pink cells towards the top are undergoing mitosis. Surrounding the apical meristem and stem cells are young leaves.

The plant embryo, and later the adult plant, grows outwards by forming an extra layer at its outer edges. These groups of cells are called **apical meristems**, which contain stem cells. As each pluripotent cell divides it leaves behind a daughter cell that enlarges and differentiates to build roots, shoots and leaves. The other cell from this division becomes the new mother stem cell.

apical meristem
the growing point of the tip of the root and stem in vascular plants

Some cells outside the apical meristems are also multipotent stem cells. In this way the trunk and roots of trees and other perennial plants can increase in girth over time or sprout new shoots from dormant cells if the plant is damaged. The cells responsible for this are found in the **cambium**, a zone of tissues between the water-conducting (xylem) and food-conducting (phloem) vessels.

cambium
the layer of actively dividing plant cells

CHECK YOUR LEARNING 5.3

Describe and explain

1 **Describe** a stem cell.
2 **Explain** the meanings of 'self-renewal' and 'potency' with respect to stem cells.
3 **Explain** how a cancerous growth occurs.

Apply, analyse and interpret

4 **Compare** totipotent, pluripotent and multipotent stem cells.
5 Skin cancer is often described as an accumulation of sun damage. **Apply** your knowledge to **demonstrate** how increasing the number of times you are sunburnt can increase your chances of developing skin cancer.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 5.3
- » Weblink
  Embryonic stem cells
- » Weblink
  Adult stem cells
- » Weblink
  Multipotent stem cells

SCIENCE AS A HUMAN ENDEAVOUR

5.4 Stem cells and medical therapies

KEY IDEAS

+ The use of adult and embryonic stem cells in medical technology

induced pluripotent cells a differentiated cell that is treated (genetically reprogrammed) back to a pluripotent state

trans-differentiation the change of a differentiated cell into another type of cell, bypassing stem cells

Since the discovery of stem cells by Canadian scientists in the 1960s, much research has been undertaken by growing them in laboratory cultures. Most of the work on embryonic stem cells has used the inner cell mass of the blastula of mouse and human embryos. Each species needs specific conditions to prevent the cells from becoming pluripotent, but stimulants that trigger the formation of particular cell types, such as nerve cells or heart cells, have been found. Scientists have been able to experimentally study these cells in terms of complications of diseases or reactions to various drugs.

Although a human trial, using embryonic stem cells for spinal injury research, was approved and conducted in the United States in 2010, it was discontinued in 2011. Several problems led to its halting:

- Embryonic stem cells need specific chemical signals before they differentiate into the required cell type. If they are injected directly into another body, they form many different types of cells that may result in a tumour.
- Each individual has the ability to detect any molecules that do not belong in their body. Embryonic stem cells from one individual will be detected by another as 'foreign' and so may be rejected.

For ethical reasons, many nations either prevent or limit human embryonic stem cell research because it requires the destruction of the embryo.

FIGURE 1 The use of human embryonic cells in medical research is a controversial practice.

Another line of research has been focused on multipotent adult stem cells. Professor Fiona Wood, a Western Australian surgeon, developed a technique that isolated the multipotent stem cells in skin and separated them so that they could be sprayed across the damaged area and so allow the new skin to start growing across all areas at once. Bone marrow is a rich source of adult stem cells and has been used in the treatment of several conditions such as cirrhosis of the liver and some forms of heart failure. Using bone marrow transplants from a compatible donor, treatment of leukaemia and related bone/blood cancers has been successful for many years.

More recently scientists have developed a technique that genetically reprograms (switches back on the 'switched off' genes using viruses). This process converts differentiated multipotent cells back to their pluripotent capabilities (**induced pluripotent cells**). Although these cells have a tendency to differentiate back to their multipotent type, they have been a useful tool for drug development and modelling diseases.

Another line of research has been focused on **trans-differentiation.** This is a process where already differentiated cells can be transformed into other types of cells and so bypass stem

cells altogether. If this process is successful, healthy cells from one type of tissue may be transformed and transplanted into diseased tissue of the same person and thus avoid an immune system rejection.

Research into stem cells helps to determine how tissues and organs are formed. This can then lead to a better understanding of how some cancers and birth defects occur and how they can be treated. Another line of research is in the generation of specific cells and tissues that could be used in cell-based therapies since the demand for transplantable tissues and organs is greater than the supply. Hurdles still remain in actual clinical transplant use. Further research needs to be conducted in order to ensure that the stem cells:

- divide extensively and make enough to make the correct tissue
- differentiate into the desired cell types
- survive in the recipient after transplant
- integrate into the surrounding tissue after transplant
- function appropriately for the life of the recipient
- avoid harming the recipient in any way, and
- are not rejected by the recipient.

FIGURE 2 Maintaining a stem cell line in the laboratory

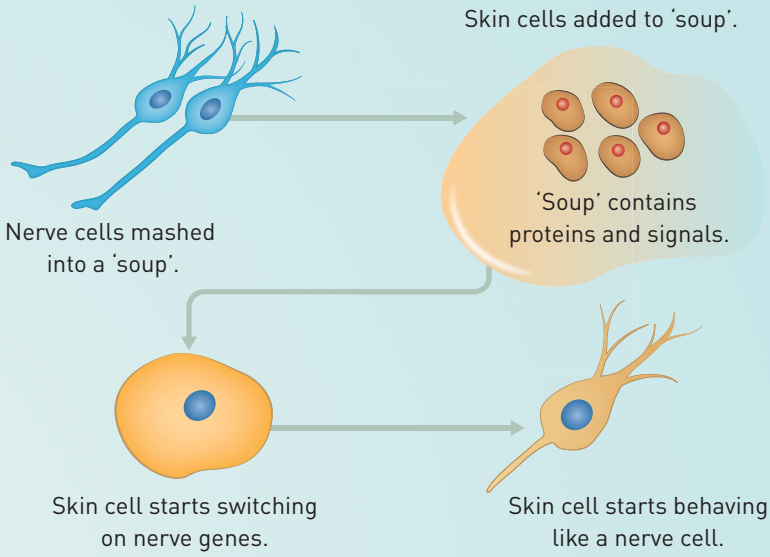


FIGURE 3 Trans-differentiation of a skin fibroblast cell into a nerve cell. DNA from nerve cells affects which genes in the skin cells are switched off and on, so that the skin cells change into nerve cells.

CHECK YOUR LEARNING 5.4

Describe and explain

1 **Explain** why embryonic stem cells are potentially more useful than adult stem cells in research investigations.
2 **Explain** the process of trans-differentiation.

Investigate, evaluate and communicate

3 **Construct** a table that identifies the advantages and disadvantages of using embryonic stem cells.
4 **Construct** a table to evaluate the advantages and disadvantages of using adult stem cells.
5 **Investigate** the current laws that govern the use of embryonic stem cells in Australia. Taking into account ethical considerations and possible advantages, write a short report that justifies or refutes, with evidence, embryonic stem cell research.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 5.4
- » Video weblink
  Stem cell research
- » Video weblink
  Stem cell therapy
- » Weblink
  Stem cell transplant

5.5 Cell specialisation

KEY IDEAS

- Differentiation of embryonic cells into germ layers and totipotent cells in animals
- Specialisation in plant cells
- Connections between cells in multicellular organisms

cell specialisation the changes in a cell that allow it to perform a specific function

Since relatively few cells are in a position to directly exchange materials with the environment, the cells of multicellular organisms are specialised for particular functions. This **specialisation** comes from differentiation and leads to the inclusion of some structures in particular cell types and the loss or decrease of others. Although the exact process that starts cell differentiation is not clear, it appears that two classes of molecules are involved:

1. *transmembrane molecules*, which are used for binding cells together and cell signalling, and
2. *gene regulatory proteins*, which determine which genes are switched on or off in the cell and therefore determine the cell's structure and function.

Differentiation in animal cells

ectoderm the outer primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

In animals, the number of cells present and their position in the central cell mass of the early embryo (the gastrula) can determine their eventual specialisation. The cells that remain on the outside of the ball of cells stick together to create a sheet of cells facing the external fluid medium. Most of these cells remain external and form the **ectoderm** layer. The cells that become tucked into the cavity of the blastula form the **endoderm**. More cells move from the endoderm as its cells divide to form a middle layer, the **mesoderm**. Ectoderm, mesoderm and endoderm form the three primary germ layers from which all other cells in the body of most animal groups are derived.

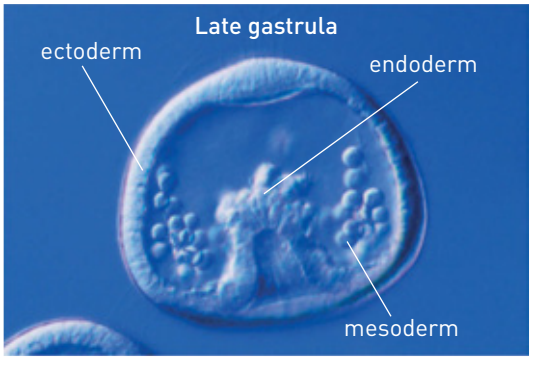


FIGURE 1 Formation of the gastrula and predetermined tissue types

These three layers contain cells with a fate that is now determined to a large extent by their position in the embryo. Specific genes in the cells of each layer are switched on or off causing the cells to become more specialised and ultimately multipotent, resulting in specific tissues and organs. Table 1 summarises the end products of this process.

endoderm the inner primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

mesoderm the middle primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

TABLE 1 Origins of tissues and organs

The primary germ layers		
Ectoderm	Mesoderm	Endoderm
Skin Nervous system Hair, nails	Skeleton Muscles Kidneys, uterus Blood and blood vessels Dermis Reproductive organs	Lining of alimentary canal, trachea, bronchus, lungs Lining of urethra and bladder Glands (including liver and pancreas)

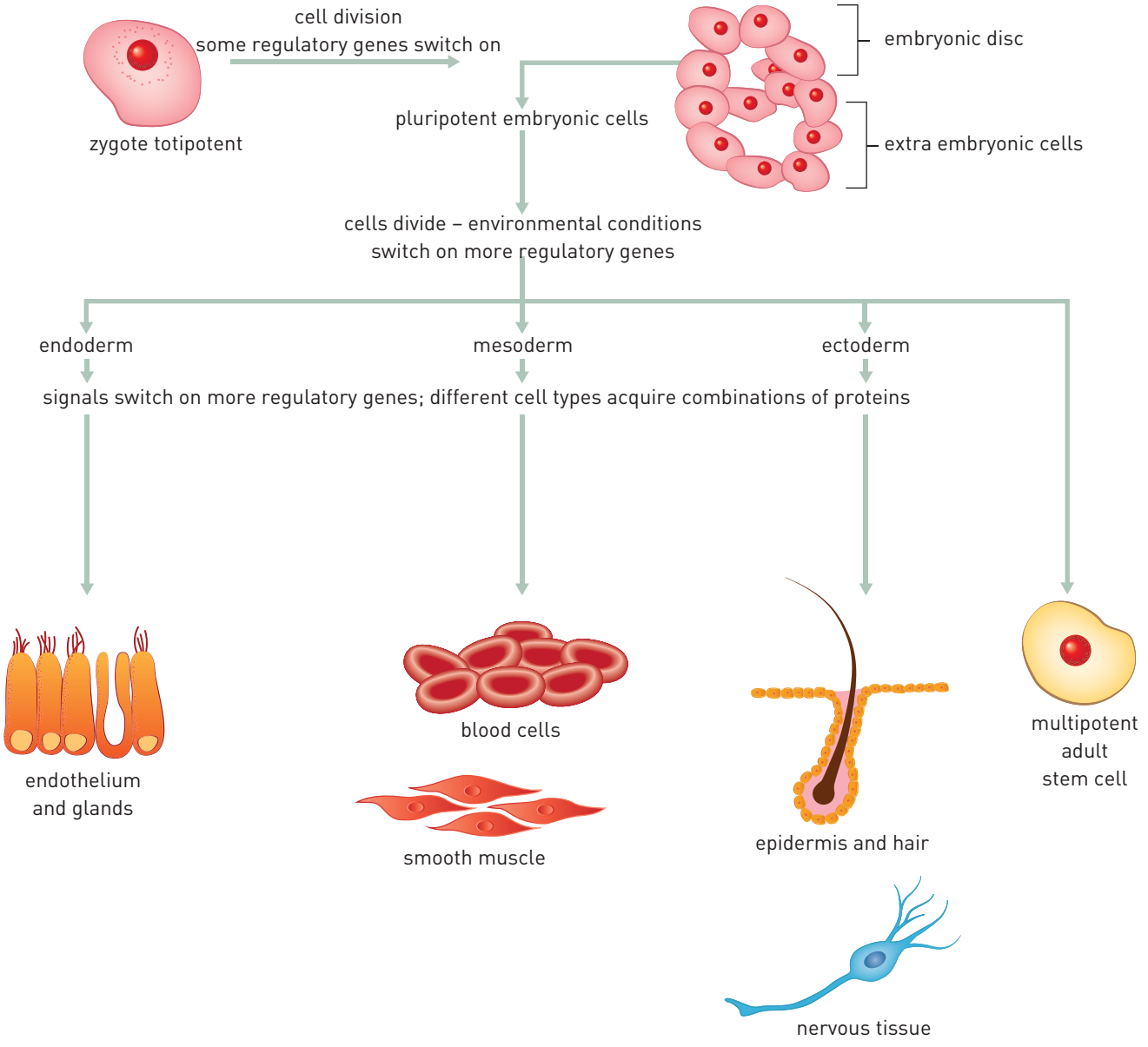


FIGURE 2 Changes in embryonic cells from totipotent to some of the fully differentiated cells of the body and multipotent cells

Differentiation in plant cells

In plants, the process of gene regulation (switching genes on or off) follows a similar pattern to that in animals, although the end results in structure and function are very different. Being encased in a cell wall and therefore glued to their immediate neighbours, plant cells cannot actively move away from their original location. However, non-adjacent cells can be moved apart passively by mitotic cell divisions that occur between them. In this way, cell division at successive times and positions brings about shape changes in the developing plant embryo that are similar to the cell movements in gastrulating animal embryos.

The totipotent cells of the very early plant embryo initially form a root–shoot axis with the cells specialising as root cells at one end and the specialised shoot cells at the opposite end. Further division establishes the future epidermal cells, ground tissue cells (taking up most of

Study tip

Ectoderm forms the **c**overing of the organism (skin, hair, nails etc.).
Mesoderm forms the **m**iddle organs of an organism (skeleton, **m**uscles, kidneys etc.).
E**n**doderm forms the **in**side li**n**ings of the organism (lining of digestive system, lungs, bladder etc.).

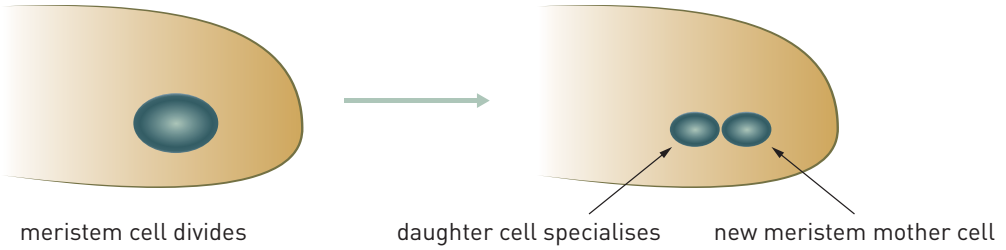


FIGURE 3 Maintaining the meristem mother cell while producing a daughter cell

TABLE 2 Functions of plant tissues derived from the meristems

The primary germ layers		
Epidermis	**Ground tissues**	**Vascular system**
Protection from the environment Gas exchange	Photosynthesis Storage Reproduction Mechanical support	Xylem – water and mineral ion transport Phloem – transport of organic nutrients

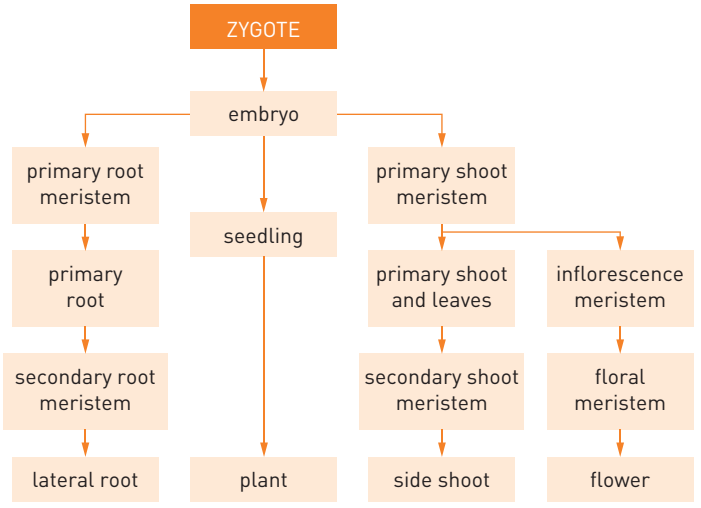


FIGURE 4 Development of a plant

the interior) and future vascular tissue cells. These layers are like the three germ layers of the animal embryo.

Further development then occurs as a result of division of the pluripotent cells of the root and shoot tips (apical meristems). As each of these cells divides, the daughter cell inside the tip differentiates into a specialised cell. The outermost cell from the division becomes the new mother (meristem) cell. The daughter cells are exposed to different internal and external cues. This results in different cell fates, where cells close to ground tissue become further ground tissue, causing the shoot or root to elongate. A similar situation occurs in a group of cells found between the water- and food-conducting cells – the **vascular cambium**, which cause an increase in the diameter of the plant.

vascular cambium the layer of actively dividing cells between the xylem and phloem of vascular plants

Seed producing plants are organised into three germ layers that are established by the meristems. These layers (epidermis, ground tissue and vascular system) largely remain as separate tissues throughout the development and life of these plants.

Further growth and development are continued through the apical meristems and cambium throughout most of the plant's life. The specialisation of the cells and tissues is determined by their position in the plant.

Junctions between cells

intercellular fluid composed of water, electrolytes and proteins that reside inside a cell

Cells of multicellular organisms must remain linked together in some way. Animal cells are often bound together by a non-cellular matrix. This is composed of fibres spread through the **intercellular** fluid. There are also physical connections between cells. There are two main groups of junctions in animals:

1 **Tight junctions** involve the fusing of cell membranes of adjacent cells by proteins on each membrane surface. This fusion is so tight that even small molecules cannot pass through the intercellular space.

2 **Anchoring junctions** can be of several types. They may form localised thickenings where filaments penetrate through the membranes of both cells. Contractile bundles of the protein actin may pass from the cytoplasm of one cell to another, forming an elastic connection between the cells. An example of this type of junction is the **desmosome**. Other cells have on their surfaces a very sticky, complex sugar that glues the cells together.

Plant cell walls have a thin layer of polysaccharides (pectin) that cement adjoining cells.

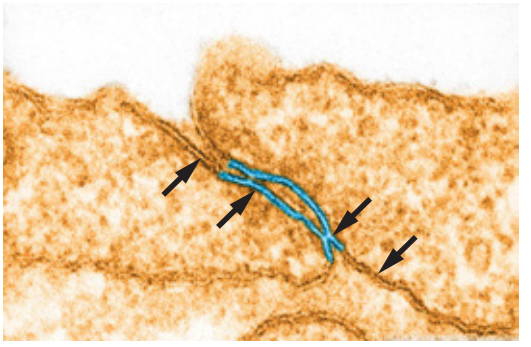
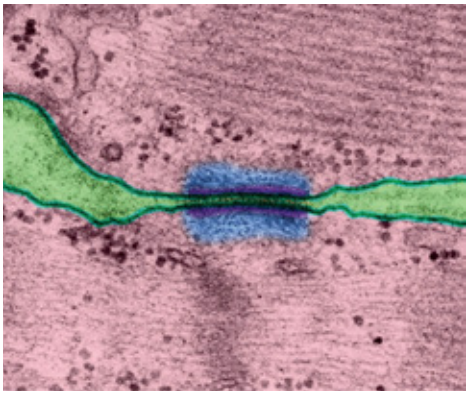


FIGURE 5 A tight junction (indicated by the arrows) between two cell membranes

(a)



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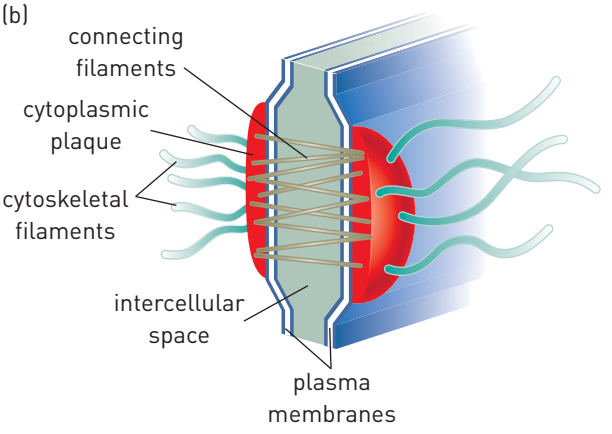

FIGURE 6 A desmosome: (a) electron micrograph; (b) diagram

tight junction
the fusion of the cell membranes of adjacent cells by proteins

anchoring junction
a cell junction formed from parts of the extracellular matrix that hold adjacent cells together

desmosome
an anchoring junction formed by localised thickenings where filaments penetrate the membranes of both cells

CHECK YOUR LEARNING 5.5

Describe and explain

1 **Identify** the two types of molecules involved in cell specialisation.
2 **Describe** what is meant by the primary germ layers in an animal embryo.
3 **Explain** why plant cells are unable to migrate to specific locations in the developing plant.
4 **Explain** how the cell wall influences the structure and functions of the plant.
5 **Explain** how the apical meristems in plants maintain their pluripotent action.

Apply, analyse and interpret

6 **Compare** the three primary germ layers of a plant and an animal.
7 **Compare** stem cell potency of a blastula and gastrula of an animal.
8 **Apply** your knowledge to **deduce** why plant cells need to remain connected after they have differentiated.
9 **Apply** your knowledge to suggest why animal skin cells need tight junctions connecting each other.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 5.5
- » Suggested practical
  5.5 Organisation of cells into tissues, organs and systems
- » Weblink
  Mesoderm
- » Weblink
  Endoderm

5.6 Organisation of cells in multicellular organisms

KEY IDEAS

- The difference between tissues, organs and systems in animals
- The organisation of specialised cells in plants
- How cells communicate with each other
- Systems and their functions in multicellular organisms

Tissues

In most multicellular organisms, cells are arranged in tissues. A tissue is a group of the same type of cells specialised to perform a specific function. The cells in a tissue are bathed in extracellular fluid. Exchanges of chemicals occur between the cell and its surrounding fluid in a similar way to those between unicellular organisms and their aquatic environment. Tissue formation involves structural changes to the individual cells of each tissue type. For example, muscle cells engaged in the energy-requiring activities of movement will have many more mitochondria than adipose (fat storing) cells which do not need much energy.

Cells specialised for production of enzymes will have a large number of mitochondria, rough and smooth endoplasmic reticulum and ribosomes. These enzymes are passed to the Golgi bodies and packaged either for export from the cell or for use within the cell (e.g. as lysosomes).

Sometimes the specialisation for function results in a change to cell shapes. Tissues that line parts of an animal are called epithelium. Cells on the outside of the organism tend to be flat; this type of tissue is called squamous epithelium. Stability and binding are provided by this shape and so underlying tissues are protected. The cells of other epithelial tissues may be column-shaped or cuboidal. They may have cilia or microvilli on their border to increase their surface area for absorption.

Because different genes are activated during cell differentiation, each cell type produces different proteins. This difference in protein production dictates the cell's structure and function.

Organs and systems

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

system
different organs working together to perform a specific function

An **organ** is composed of more than one tissue, forming a structural and functional unit such as the heart, stomach or liver of an animal. A **system** is composed of different organs working together for one main function (e.g. the excretory system). Systems are coordinated so that they facilitate the supply of nutrients to and production/removal of materials from all cells of the organism.

Plants are also made up of systems and organs. There are only two systems described in plants. The shoot system is composed of all the tissues found above the ground, and the root system controls the function of the tissues found below the ground. The shoot system is composed of a series of organs, including the leaf, shoots and reproductive flowers (in flowering plants). The root system is composed of the roots, tubers (storage organs) and rhizomes (a modified underground stem).

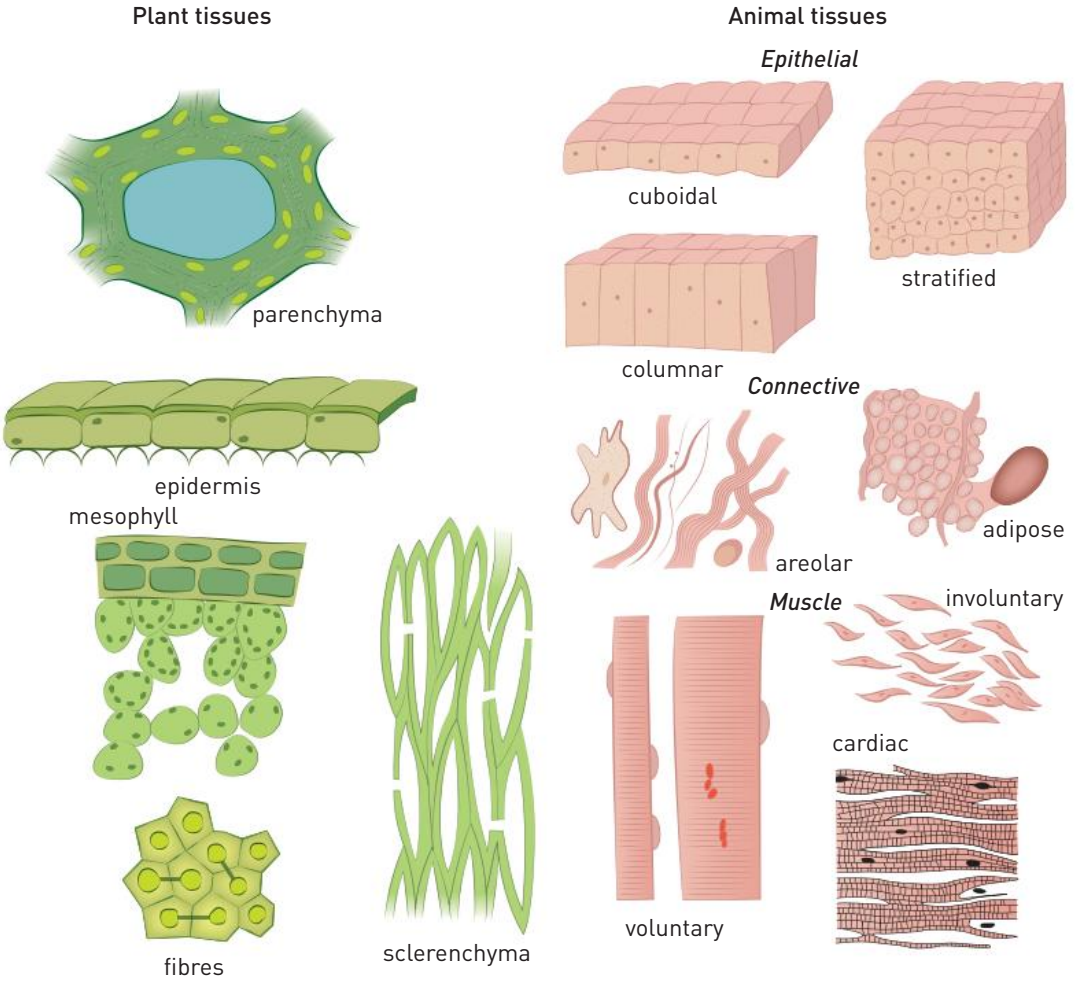

FIGURE 1 Some typical plant and animal tissues

TABLE 1 Comparison between plant and animal tissues in relation to their function

Function	Flowering plant	Vertebrate animal
Digestion of food	No comparable tissue	Glandular tissue
Connecting parts and packing spaces	Parenchyma	Connective tissues
Food storage	Parenchyma	Fatty connective tissue
Protective surfacing	Epidermis, bark	Epithelium
Support	Xylem, sclerenchyma and collenchyma fibres	Cartilage and bone
Food production	Chlorenchyma	No comparable tissue
Production of new cells for growth and repair	Cambium and meristem	No localised tissues
Production of sex cells	Germinal tissues in anthers and ovaries	Germinal tissues in testes and ovaries
Transport	Dead xylem tissue – tracheids and vessels (water) Living phloem tissue – sieve tubes (organic molecules)	Blood, combination of epithelium muscle and connective tissue forming a system of tubes
Coordination	Meristematic tissues	Nerve tissue and glandular tissue
Locomotion	No comparable tissue	Muscle tissue attached to skeletal system

Like animals, plant organs are composed of more than one type of plant tissue. Some of these tissues include the vascular tissue that controls the flow of water and nutrients around a plant, epidermal tissue that covers the external parts of the plant and parenchyma tissue (the location of photosynthesis).

gap junction
a junction between animal cells that allows direct passage of ions and small molecules in solution between them

Communication between cells

An organism cannot survive if the cells, tissues, organs and systems are not coordinated with each other. Communication among the cells of tissues, between organs and so between systems is achieved by means of chemical signals. Substances transported out of one cell travel to another cell, causing some change in the recipient (target) cell. Sometimes the chemical signal is very specific to a particular tissue. In these cases, the cells have special recognition sites on their membranes. Only cells with the specific recognition receptor will respond to that chemical.

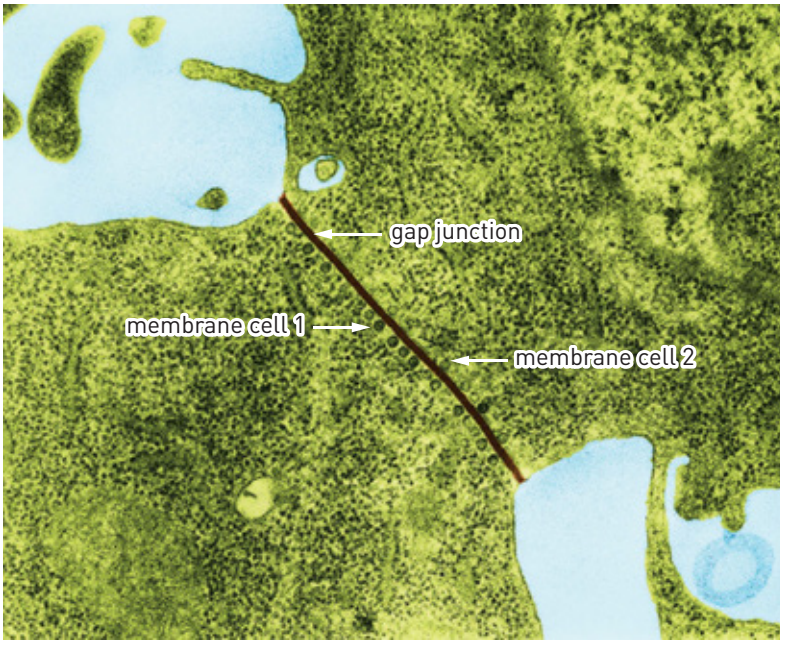

FIGURE 2 Electron micrograph of a gap junction between two cells

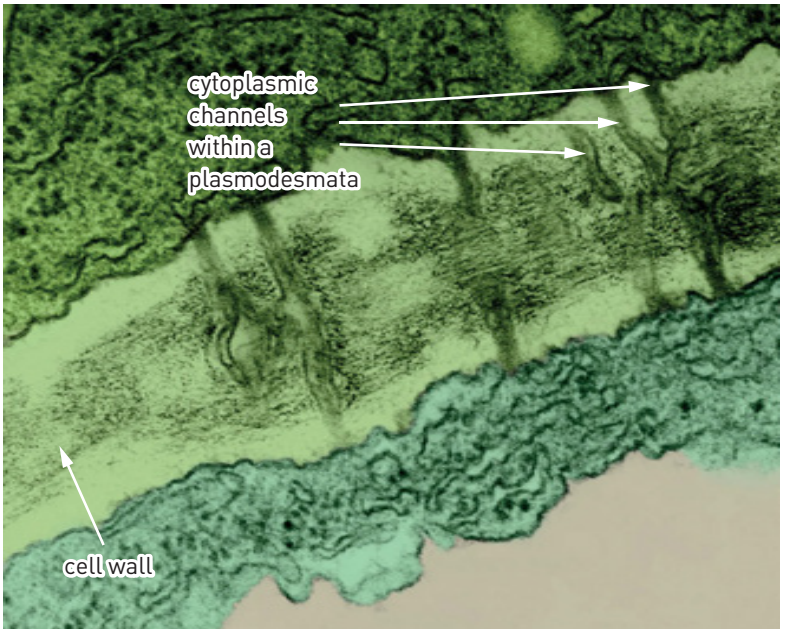

FIGURE 3 Electron micrograph of plasmodesmata

Special **gap junctions** between animal cells can aid communication between cells by permitting the direct passage of ions and small molecules in solution between them.

Direct communication between plant cells occurs through **plasmodesmata** – strands of cytoplasm linking one cell with the next and allowing every cell in the plant to communicate with each other. The cell wall around plant cells limits movement of the cell and restricts direct cell-to-cell communication to the plasmodesmata. As a consequence, locomotion in plants is not possible. This determines the strategies that are employed by the plant in carrying out its life functions.

Animal cells are more flexible, can communicate effectively and can achieve some degree of movement within their matrix. As a result, locomotion of the whole body can occur as muscle cells can lengthen or shorten. Since they lack cell walls (and therefore turgidity), however, animals must have some form of support structure as they increase in size.

Coordination of the activities of the whole animal is achieved through two special systems – the nervous system and the endocrine system. The nervous system

supplies a rapid, generally short-acting response to an internal or external change (stimulus). The endocrine system produces chemicals (hormones) in specific organs in response to a stimulus. These hormones pass into the bloodstream and eventually reach the target cells. Each type of hormone will only be recognised by the cells that have a complementary recognition receptor. Hormone coordination, therefore, is slower to achieve, but much longer lasting than that of the nervous system.

Plants do not have a nervous system. They can, however, coordinate activities through production of hormones at specific sites in their body. For example, the direction of light can be detected at shoot tips. If the light is only coming from one direction over a period of time, some cells in the tip secrete a hormone that causes cells below the tip to lengthen on the side away from the light source. This causes the plant stem to bend towards the light source. Roots, on the other hand, grow away from light and in the direction of gravity under chemical influence. Unlike animals, plants do not have organs that produce hormones.

plasmodesma (plural plasmodesmata) a junction between plant cells allowing direct communication between the cytoplasm of each cell

Mammalian body systems

Most vertebrates have similar body systems although their precise structure and function can vary according to the environment in which they live. In mammals these systems are more uniform. Although some systems are regarded as more important than others, in reality almost every system is needed for normal survival. Damage or malfunction of one organ within a system can cause large scale consequences for other systems that may result in the death of the organism.

A summary of the vital systems of the human body, their functions and component organs can be found in the obook (Table 2).

CHECK YOUR LEARNING 5.6

Describe and explain

1 **Describe** the following:
   - **a** tissue
   - **b** organ
   - **c** system

2 **Explain** how cells in animal tissues:
   - **a** remain together
   - **b** communicate.

3 **Explain** how cells in plant tissues:
   - **a** remain together
   - **b** communicate.

4 **Identify** ways in which the cell wall influences the structure and functions of a plant.

5 **Explain** how coordination between tissues, organs and systems occurs in animals.

Apply, analyse and interpret

6 **Deduce** why some systems in humans are considered more important than others.

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  Plant tissues
- » Weblink
  Animal tissues
- » Weblink
  Communication between cells

CHAPTER 5

Review

Chapter summary

5.1 The size of a cell is limited by its ability to exchange materials with its environment. Large organisms are composed of many cells organised into tissues, organs and systems, each of which has its own function. These cells communicate with each other for the overall functioning of the organism.

5.2 The development of the multicellular organism from either a fertilised gamete or spores is a complex process starting with an increase in cell numbers.

Multiplication of cells is part of the cell cycle. At interphase, cells grow, store energy and replicate chromosomes (DNA) and cytoplasmic inclusions. During mitosis, the nuclear membrane breaks down, spindle fibres attach to chromosomes and the replicated chromosomes are drawn to opposite poles (ends) of the cell along spindle fibres in a precise manner so that each pole (end) has the same number and types of chromosomes as the original. New nuclear membranes form around each set of chromosomes. The cell cycle is completed at cytokinesis or division of the cytoplasm. In this way, the two 'daughter' cells are genetically identical to the 'mother' cell. Cytokinesis is different between plant and animal cells.

5.3 The early cells of the embryo all have the capacity to form any type of cell. They are termed totipotent or embryonic stem cells. As the number of cells reaches a particular level, some structural genes of some cells are switched off while in other cells other genes are switched on and so become pluripotent and eventually multipotent. From then on, when that group of cells divide they produce daughter cells with particular characteristics. In this way, during the development of the organism different types of stem cells arises, with different levels of self-renewal and potency.

5.4 Embryonic stem cells are studied by scientists to treat disease or reaction to drugs.

5.5 Specialisation of cells into different cell types leads to groups of cells that have different structures and functions.

Animal cell specialisation occurs in the early embryo when three layers of cells – the ectoderm, mesoderm and endoderm – are developed in most animal groups. All future tissues and organs arise from one or other of these layers.

Due to the immobility of the plant cells, the early plant embryo established a root–shoot axis and future epidermal, ground tissue and vascular cells. Further growth and development occur due to division of meristem cells in the root and shoot apices.

Cells of multicellular organisms must stay together.

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

Communication between cells in a multicellular organism is essential for survival. Cell to cell communication occurs through gap junctions, hormones and nerves (animals) and plasmodesmata (plants).

All vertebrate animals have similar body systems, although they show variations due to the environment in which they live. Although all systems are instrumental in the survival of an organism, in humans some are considered more important than others in keeping the body alive.

Key terms

- adult stem cell
- anchoring junction
- apical meristem
- apoptosis
- blastula
- cambium
- cell cycle
- cell differentiation
- centromere
- chromatid
- cytokinesis
- desmosome
- differentiation
- ectoderm
- embryonic stem cell
- endoderm
- gap junction
- gastrula
- induced pluripotent cells
- intercellular
- interphase
- mesoderm
- mitosis
- multicellular organism
- multipotent stem cell
- oligopotent stem cell
- organ
- plasmodesmata
- pluripotent stem cell
- stem cell
- system
- tight junction
- tissue
- totipotent stem cell
- trans-differentiation
- unipotent stem cell
- vascular cambium

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 The table below shows the results recorded from cells of a tissue during a cell cycle. Which of the following statements would be correct?

Stage in cell cycle	Prophase	Metphase	Anaphase	Telophase	Interphase
Time taken (min)	6	7	4	9	14

A The spindle would be visible for no more than 26 minutes.
B Separation of the chromatids would take approximately 11 minutes.
C One cell cycle would be completed every 26 minutes.
D The cytoplasm would start dividing after the chromosomes became visible.

2 If you were observing a cell undergoing mitosis, which of the following would be evidence that it was a plant cell rather than an animal cell?
A Absence of a spindle
B Absence of centrioles
C Replication of chromosomes
D Disappearance of the nuclear membrane

3 The table below shows the major tissues in an animal body and their main functions.

Tissue	Function
Epithelial	Covers exposed surfaces Lines internal passageways and chambers
Connective	Fills internal spaces Provides structural support Stores energy
Muscle	Contracts to produce movement
Nerve	Conducts electrical impulses Carries information

Fat is an important way that the body stores energy reserves.
What type of tissue is fat?
A Epithelial
B Connective
C Muscle
D Nerve

4 Two cells which are the product of mitosis each have:
A double the number of chromosomes of the 'parent' cell
B half the number of chromosomes as the 'parent' cell
C the same number of chromosomes as the 'parent' cell
D a mixture of chromosomes from each 'parent' cell

5 In order, the stages of the cell cycle are:
A prophase, anaphase, interphase, metaphase, telophase, cytokinesis
B interphase, prophase, metaphase, anaphase, telophase, cytokinesis
C interphase, cytokinesis, prophase, telophase, metaphase, anaphase
D prophase, interphase, cytokinesis, anaphase, metaphase, telophase

6 Totipotent stem cells:
A have many genes pernamently switched off
B can only differentiate into a single cell type
C can differentiate into a limited number of cell types
D can turn on any gene in their genetic material

7 The potency of a stem cell refers to its ability to:
A go through several cell cycles in a short period of time
B maintain its integrity even with long delays between cell divisions
C remain unspecialised
D differentiate into specialised cell types

8 In plants, pluripotent stem cells are found in the:
A apical meristems
B leaf stalks
C leaf blades
D main stem

9 An embryonic animal system develops in the folowing sequence:

A organs → cells → tissues
B tissue → cells → organs
C cells → organs → tissues
D cells → tissues → organs

Short answer

Describe and explain

★ **10** **Describe** the ethical issues involved in embryonic stem cell research for medical therapies.

★ **11** Cells are invariably very small in size and can usually only be seen under a microscope. As organisms become larger their cell numbers remain the same size, but increase in number. **Explain** this phenomenon.

Apply, analyse and interpret

★ **12** **Compare** a stem cell, a fully differentiated body cell and a cancer cell.

Investigate, evaluate and communicate

★★ **13** **Define** a bioartificial organ. **Discuss** how the organ is generated.

★★ **14** In the United States there are 'banks' of stem cell samples. In one such stem cell bank in North Carolina there are over 100 000 different samples of stem cells that have been collected from the amniotic fluid surrounding embryos within wombs. This form of collection does not harm the embryo. **Evaluate** the advantages of such a bank of stem cells to producing a compatible bioartificial organ for a recipient.

★★ **15** **Evaluate** the current use of stem cell therapies, discussing the effectiveness of each.

★★★ **16** With modern medical technology, organs and tissues can be transplanted from a donor to a recipient (refer to Section 5.4, page 144). In Western countries, the need for donor organs for exceeds the number of legal donors. This has led to trafficking in organs, and even people, to supply the demand. **Investigate** this practice and write a report with emphasis on the ethics involved.

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CHAPTER 6

Transport and gas exchange in animals

The cells of all multicellular organisms need to extract nutrients from their environment, exchange respiratory gases and eliminate wastes. As multicellular organisms increase in size, their internal cells are further and further away from the surface where these exchanges take place. Specialised systems are needed to perform these functions, as well as some form of transport system to link them.

OBJECTIVES

- → Explain the relationship between the structural features (large surface area, moist surface, one or two cells thick and surrounded by an extensive capillary system) and function of gaseous exchange surfaces (alveoli and gills) in terms of exchange of gases (oxygen, carbon dioxide).
- → Explain how the structure and function of capillaries facilitates the exchange of materials (water, oxygen, carbon dioxide, ions and nutrients) between the internal environment and cells.
- → Use data presented as diagrams, schematics and tables to predict the direction in which materials will be exchanged between:
  - alveoli and capillaries
  - capillaries and muscle tissue.

Source: *Biology 2019 v1.2 General Senior Syllabus*
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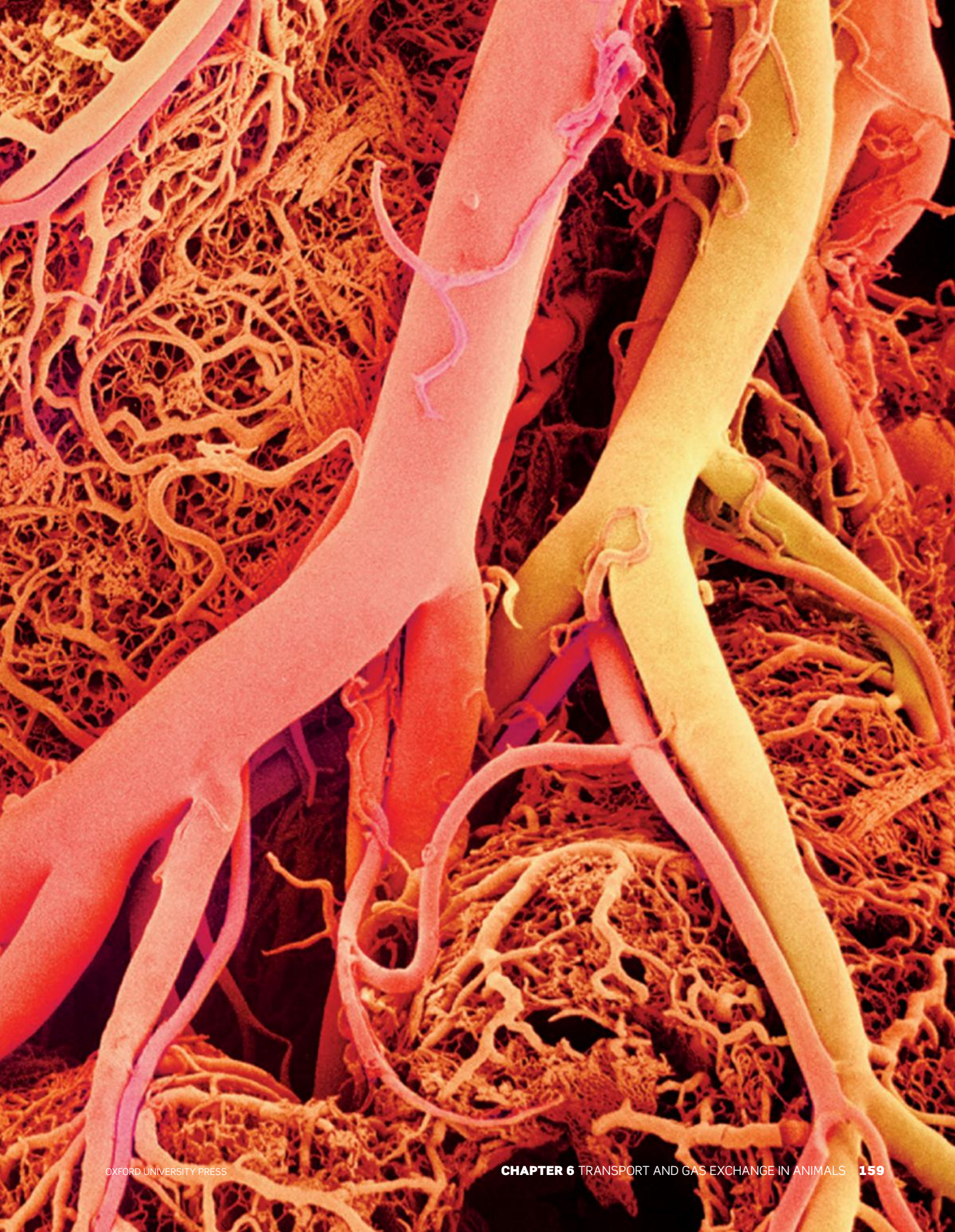
FIGURE 1 Coloured scanning election micrograph of a resin cast of blood vessels supplying the small intestine



6.1 Transport in animals

KEY IDEAS

- The need for a transport system in 'large' animals
- Types of transport systems in mammals
- The structure and functions of blood

transport system
a system of vessels responsible for the movement of materials through an organism

tissue fluid (extracellular fluid)
fluid formed from plasma pushed out through the walls of capillaries under arterial pressure; surrounds the cells, providing a medium for exchange between the blood and the cells

blood
the transporting medium of the animal body; in mammals, it is composed of plasma, platelets, and red and white blood cells

lymph
tissue fluid, containing a high volume of white blood cells, which has been taken up by the lymphatic vessels to be returned to the blood vascular system

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

artery
a thick-walled blood vessel that leaves the heart or aorta and ends in an arteriole

Plants and animals have the same basic requirements, although there are some differences due to their mode of nutrition and level of mobility. The structure of the systems and how they operate reflect this.

Digested food material and respiratory gases must be transported from the external environment to animal cells. In the majority of animals, special systems have evolved for the transport of materials and for regulating the chemical contents of the body.

In small animals, transport often involves diffusion only. Larger animals need a transport system to move materials around the body.

During the course of evolution, the role of the transporting fluid has passed from the water that surrounds an animal to special complex tissues such as blood. This fluid both increases the transporting capacity and serves a protective function.

Transport systems

The **transport system** in humans is typical of all mammals. Materials are transported throughout the body in a liquid medium. Three different fluids are involved:

1 **tissue fluid** (or intercellular fluid)
2 **blood**
3 **lymph**.

The tissue fluid surrounds individual cells. It is the primary source of nutrients and gases from the blood and takes up wastes from the cell to the blood or lymph. The plasma membrane surrounding the cell controls the passage of molecules in and out of the cell through diffusion, facilitated diffusion or **active transport**.

Blood moves through a series of tubular vessels. These vessels, the **arteries**, **veins** and **capillaries**, vary in size, in the structure of their walls and in function. The pumping action of the muscular heart moves the blood through the vessels. Other movements of the body aid this.

Lymph is carried in **lymphatic vessels**. It picks up tissue fluid and particles and returns these to the blood system. The lymph is very important in the body's immune response.

TABLE 1 Composition and function of transporting fluids in mammals

Fluid	Composition	Functions
Plasma (55% of blood)	92% water 7% proteins Serum and fibrinogen	Transport of nutrients, waste products, hormones and heat
Tissue fluid (bathes living cells)	Similar to plasma but has less protein	Cell homeostasis Transport
Lymph (inside lymph vessels)	No protein Rich in lipids Contains lymphocytes	Transport to veins Phagocytosis of bacteria

The structure and function of blood

Human blood is composed of red cells (**erythrocytes**), white cells (**leucocytes**) plasma proteins and platelets suspended in a straw-coloured fluid called plasma. Figure 2 (page 162) shows the composition of blood found in mammals and the significance of each component in the body.

Plasma also carries a number of substances, including:

- proteins (e.g. enzymes, hormones and enzyme-coated lipids)
- specific plasma proteins involved in water balance, immunity and blood clotting
- carbon dioxide and nitrogenous wastes
- ions (salts)
- vitamins
- nutrients from digestion.

The main function of the red blood cells (erythrocytes) is to transport oxygen from the respiratory surfaces to the tissues. Mature red blood cells have no nucleus and must therefore be constantly produced in the bone marrow. This occurs at a rate of about 1.5 million per second. Their biconcave shape (concave on both sides) ensures a maximum ratio of surface area to volume for the uptake and release of respiratory gases (oxygen). The shape also ensures smooth flow through the smallest blood vessels, their diameter being about the same as that of the finest capillaries.

The inside of a red blood cell is packed with the red pigment **haemoglobin**. The haemoglobin molecule consists of two pairs of polypeptide chains, each of which is combined with an iron-containing (haem) group – a total of four iron haem groups. Each haem group can carry one oxygen molecule. Without a nucleus, more haemoglobin (and thus more carriage of oxygen) can be included within the cell. A single red blood cell can carry 1000 million oxygen molecules.

One of the most common plasma proteins is albumin, which is involved with regulating the water content of cells and tissues through osmosis.

Globulin proteins are also found in the plasma. Two important groups of globulins are the gammaglobulins and fibrinogen. The gammaglobulins are rich in antibodies and are produced by white blood cells. They play a significant function in the immune response (covered in Chapter 10). Fibrinogens (glycoproteins) are an essential component in blood clotting. These, and all other plasma proteins, are formed in the liver.

vein
a blood vessel that begins in a capillary bed and enters the heart in animals

capillary
a fine blood vessel with walls one cell thick, permeating tissues; pressure in these vessels causes plasma to pass out into the tissue fluid

lymphatic vessels
the tubular structure that carries lymph from tissue to the blood circulatory system

erythrocyte
a red blood cell

leucocyte
white blood cell

haemoglobin
the pigment molecule found in red blood cells; contains four iron-containing (haem) groups, each of which can combine with one oxygen molecule; has a high affinity for oxygen

Blood clotting

Elaborate mechanisms have evolved to prevent the accidental loss of blood when a vessel is damaged. One of these mechanisms is to form a solid clot to plug the broken vessel.

Clotting involves the conversion of soluble fibrinogen to insoluble fibrin. This involves a series of complex chemical reactions, each needing a specific protein factor. These reactions are set in action when the damaged tissue releases a lipoprotein called thromboplastin. The insoluble fibrin forms a complex web that binds platelets together and covers the damaged blood vessel. The reactions are illustrated in Figure 5.

Normal blood usually contains a small amount of thromboplastin. It also contains a strong anticoagulant (sometimes called a blood thinner), **heparin**. Heparin is produced in the liver and lung cells and inhibits the conversion of prothrombin to thrombin in the general circulation. The synthesis of prothrombin in the liver needs an adequate supply of vitamin K. Too much heparin causes the blood to become more fluid and can causes a person to bleed more easily. Too little heparin can result in blood clots forming, blocking blood flow to the brain, heart or lungs.

heparin
a chemical secreted by basophils that prevents blood clotting

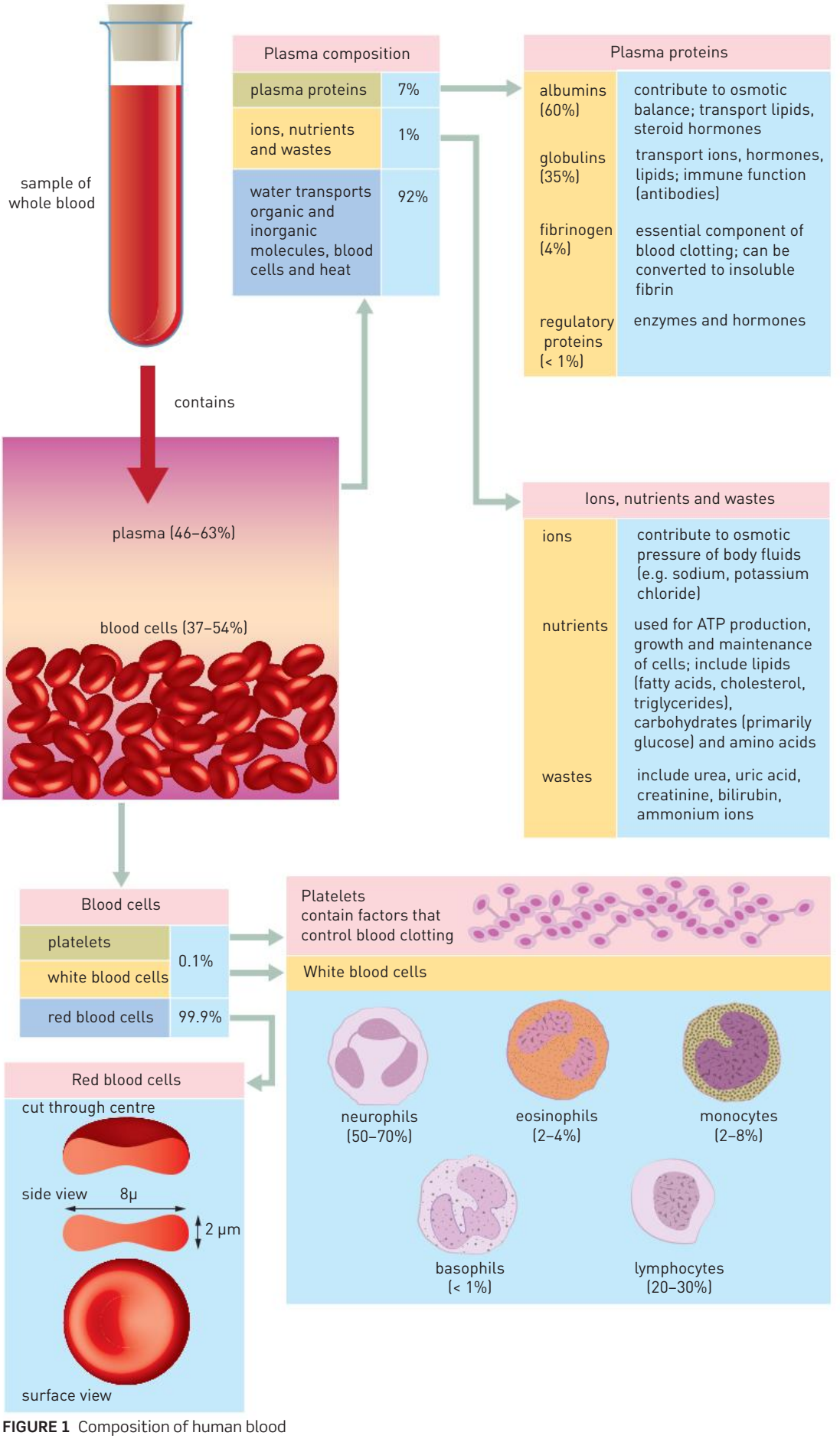
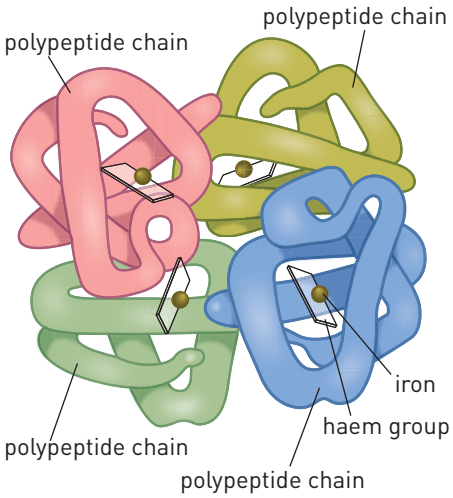


FIGURE 1 Composition of human blood



Each folded polypeptide chain is a protein molecule, globin.

FIGURE 2 Structure of haemoglobin

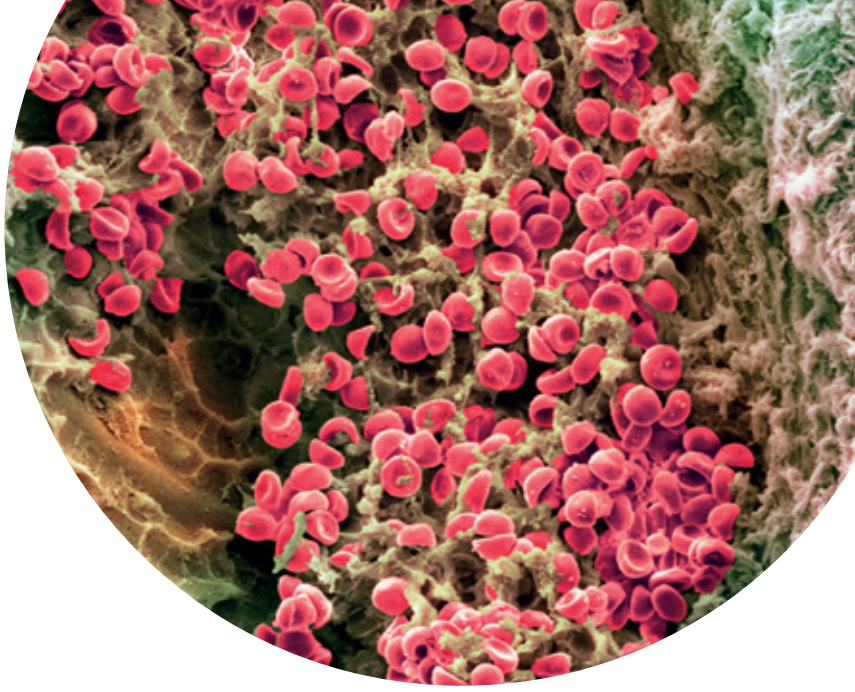


FIGURE 3 Colourised electron micrograph image of a blood clot

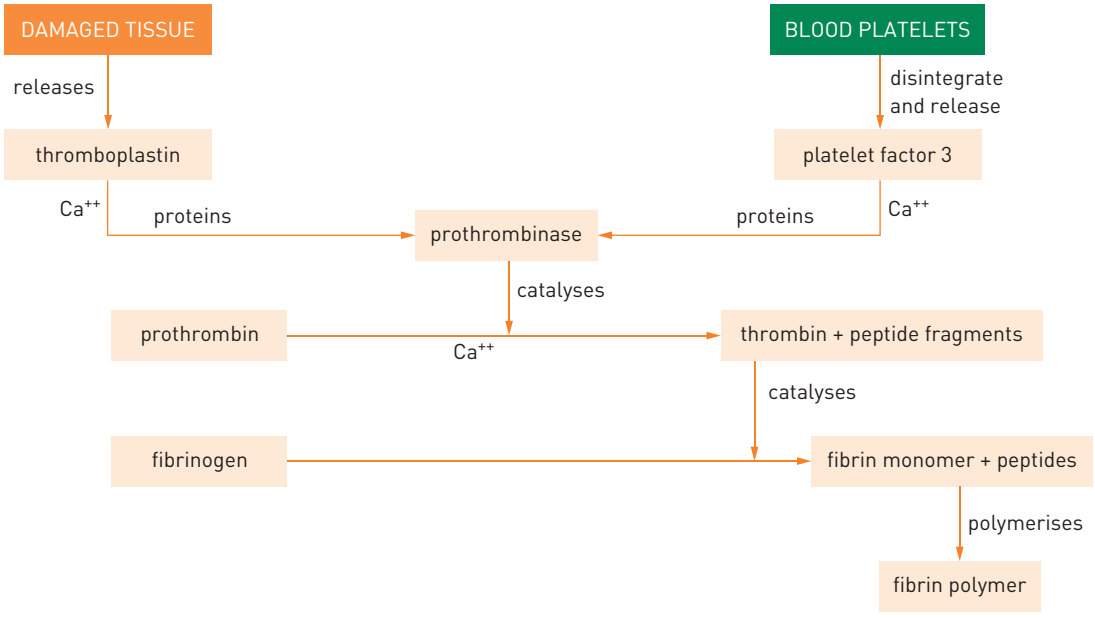


FIGURE 4 Formation of fibrin in blood clotting

CHECK YOUR LEARNING 6.1

Describe and explain

1 **Explain** why it is important for large animals to have transport systems.

2 **Describe** how tissue fluid, blood and lymph play a role in the transportation of materials around the human body.

3 **Identify** the constituents of blood and, for each, describe their function.

4 **Explain** how the structure of a red blood cell (erythrocyte) aids its function.

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6.2 The mammalian circulatory system

KEY IDEAS

- The flow of blood in a double circulatory system
- The structure and function of arteries, veins and capillaries
- The formation of tissue fluid in the capillary bed
- The exchange of materials between the blood, tissue fluids and cells

The double circulatory system

double circulatory system
a system of blood vessels where the blood passes through the heart twice in a single circuit around the body

alveolus
the thin-walled ending of alveolar ducts (end divisions of the bronchioles) in the lung through which gas exchange occurs

pulmonary circulation
the circulation of deoxygenated blood from the right side of the heart to the lungs and the return of oxygenated blood from the lungs to the left side of the heart

systemic circulation
the circulation of blood from the left side of the heart to all body cells and back to the right side of the heart

The mammalian circulatory system is made up of a series of vessels through which blood is pumped. Blood is moved around the body as a result of the rhythmic contractions of the heart. In mammals, the system is termed a **double circulatory system**, because the blood passes through the heart twice in its circuit around the body.

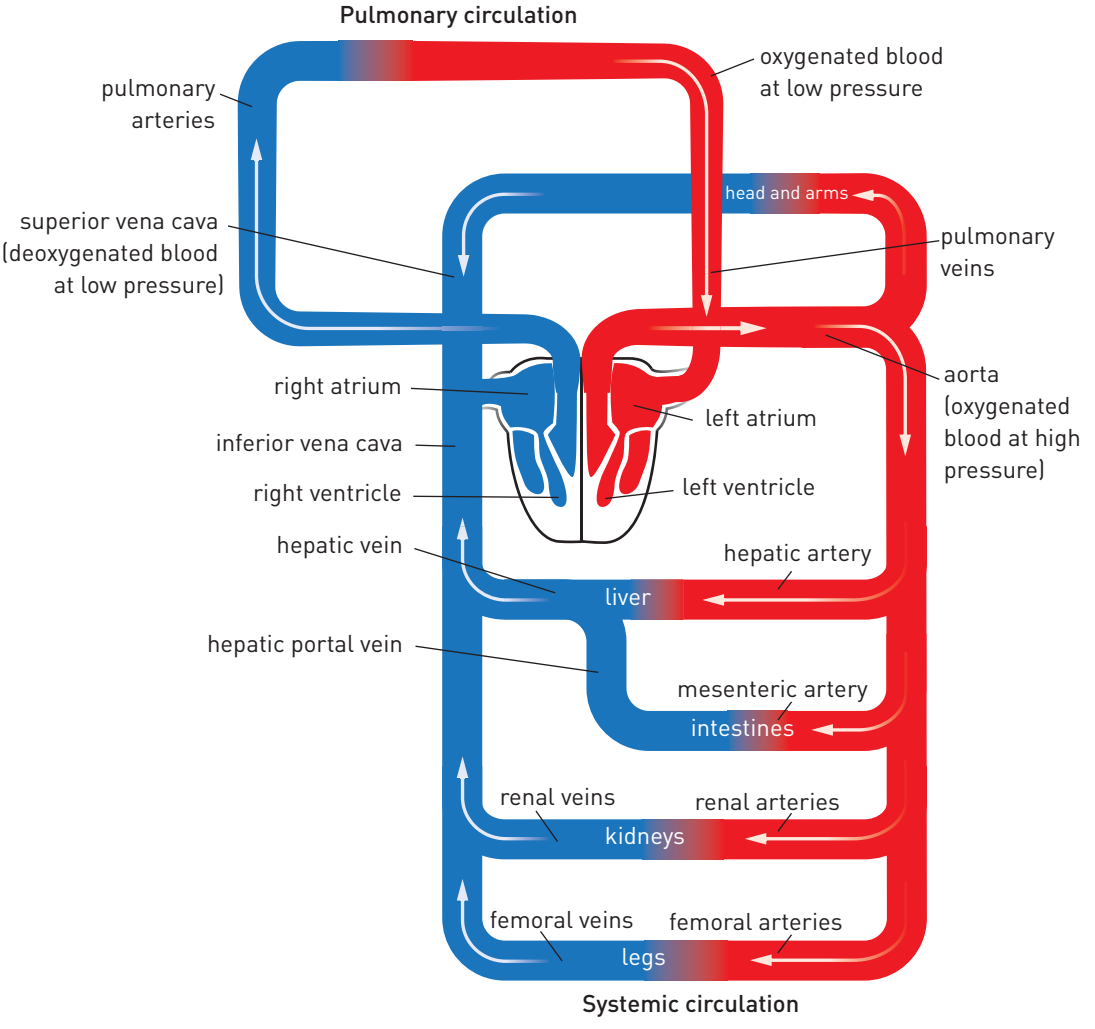

FIGURE 1 Schematic diagram showing the principal arteries and veins of a human

In the first passage through the heart, deoxygenated blood returning from the body is pumped to the surfaces of the **alveoli** in the lungs for gas exchange; and oxygenated blood is pumped back to the heart. This is the **pulmonary circulation**. The **systemic circulation** is the second passage of blood through the heart. Oxygenated blood flows from the heart to the body tissues, and deoxygenated blood flows back to the heart. The body cells use the oxygen for aerobic cellular respiration.

Vessels of the circulatory system

The blood circulatory system is called a closed system because the blood vessels are continuously connected to each other. The vessels involved in the blood circulatory system are the arteries, veins and capillaries. Table 1 summarises some differences in structure and function of the blood vessels.

Arteries are the blood vessels that carry the blood away from the pumping heart. The large arteries leaving the heart are subjected to high pressure and so must be thick to prevent bursting. Exchange of material cannot occur between the arteries (or veins) and tissues due to the thickness of their walls, which consist of several tissue layers.

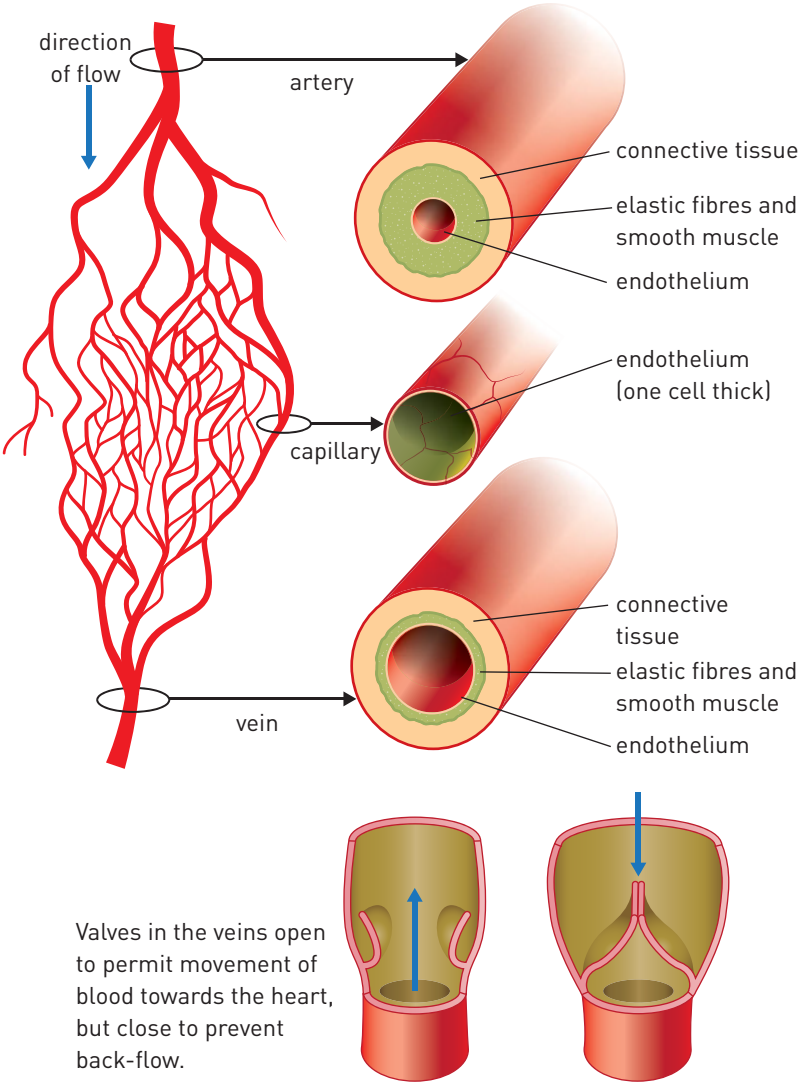

FIGURE 2 The structure of arteries, veins and capillaries

TABLE 1 Comparison of the structure and function of arteries, veins and capillaries

Arteries	Capillaries	Veins
Transport blood away from the heart	Link arteries to veins	Transport blood towards the heart
Thick muscular walls	Walls one cell thick, no muscle	Thinner, less muscular walls
Elastic tissue	No elastic tissue	Less elastic tissue than arteries
Can contract	Cannot contract	Cannot contract
No valves	No valves	Valves present
Circular cross-section	Circular cross-section	Oval cross-section
Not permeable	Permeable to tissue fluid and white blood cells	Not permeable
High blood pressure	Intermediate blood pressure	Low blood pressure
Rapid flow	Slow flow	Slow flow
Pulse	No pulse	No pulse

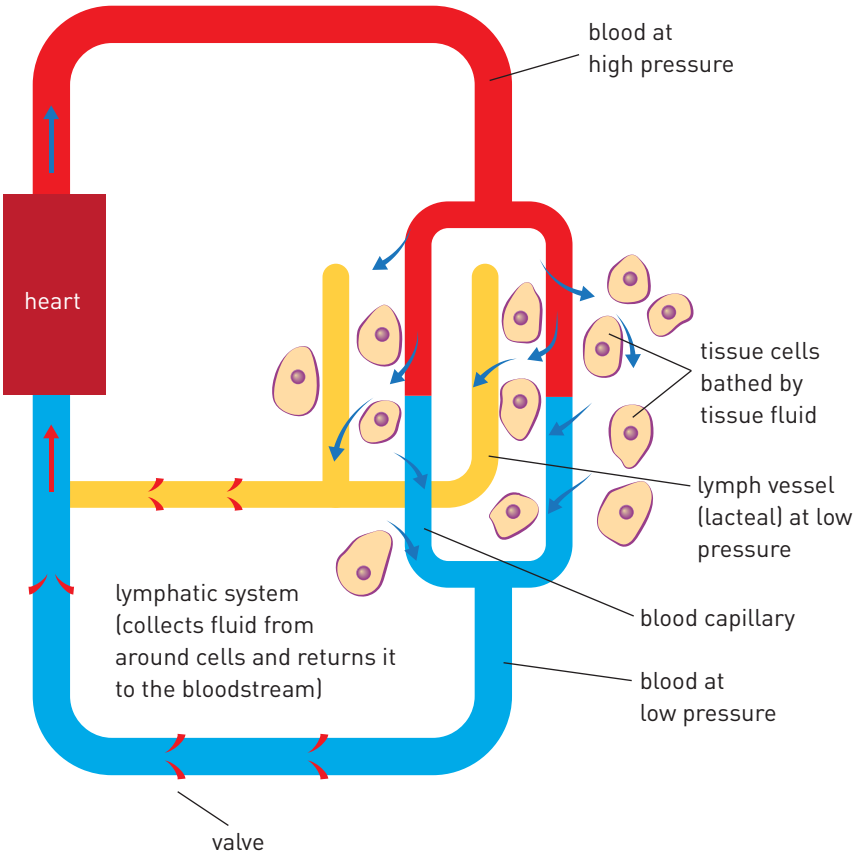

FIGURE 3 A circulatory system capillary bed

arteriole
the branch of an artery that breaks up into capillaries

venule
a thin-walled vessel that directly connects capillaries to veins

The middle layers of the arteries are composed mainly of elastic fibres that enable them to expand (dilate) during ventricular contraction. When the ventricles relax, the muscles in the artery walls contract. This produces an even flow of blood along the length of the arteries.

Friction between the plasma and the artery walls reduces pressure. Further away from the heart, where blood pressure is lower, the artery walls contain more smooth muscle fibres that are serviced by nerves. Nervous stimulation controls the diameter (or size) of these vessels and therefore blood flow. As the diameter decreases, blood pressure will increase.

Blood passes from the arteries into smaller branches called **arterioles**. Arterioles become finer and finer. They eventually lead into capillaries that form a vast network of capillary beds pervading all parts of the body. These capillaries unite to form fine **venules** that increase in size to form veins.

No cell is more than 0.5 mm away from a capillary. The diameter of the capillary is approximately that of a red blood cell. Capillary walls are composed of a single layer of thin flat cells (with a large surface area to volume ratio) that are permeable to all blood components except red blood cells and plasma proteins.

Study tip

Arteries carry blood **a**way from the heart. **V**eins have **v**alves and carry blood back to the heart. **C**apillaries **c**onnect the arteries and the veins.

Blood under pressure enters the capillaries. The blood pressure forces the fluid, ions, gases and nutrients (other than red blood cells and plasma proteins) through the minute spaces between the cells of the capillary wall. These form the extracellular or tissue fluid that surrounds the cells. **Exchange of materials between the cells and blood is made in this tissue fluid**. Eventually the concentration of large proteins left behind in the capillaries at the venous end becomes large enough to form an osmotic gradient, encouraging the movement of water back into the capillary. This fluid has negligible pressure. Excess tissue

fluid not returned to the capillary vessels is taken up by the lymphatic vessels.

These capillaries unite to form fine venules that increase in size to form veins. The veins have thinner walls than arteries and are surrounded by skeletal muscle.

Blood is returned to the heart primarily due to muscular contractions of the skeletal muscles surrounding the veins. Valves along the length of the veins prevent backflow of blood when these muscles relax. If a person is sitting still on an aeroplane or in front of a computer for a long time, their leg muscles are not contracting, and the blood is not being pushed through the veins. This causes the fluid to accumulate in the tissue, increasing the number of blood cells bumping against each other in the veins. As a result, blood clots can form in a process called deep vein thrombosis. If parts of this blood clot travel to the heart, lungs or brain, it can result in death.

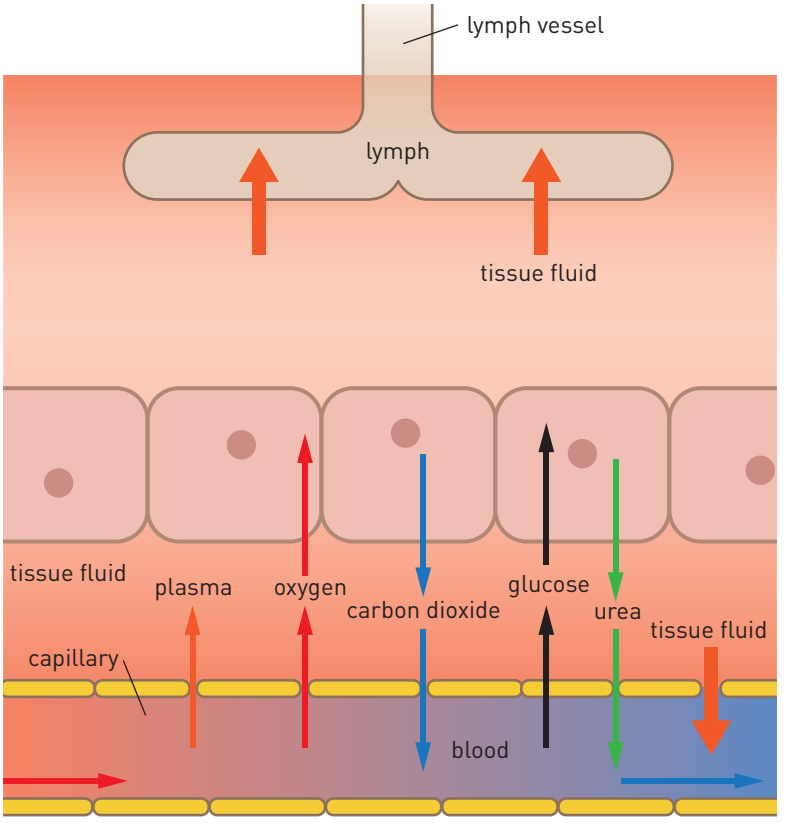

FIGURE 4 The formation of tissue fluid. Exchange of materials occurs between the capillaries, the extracellular tissue fluids and the cells.

CHECK YOUR LEARNING 6.2

Describe and explain

1 **Explain** the movement of nutrients from the blood system into the cells and waste material from cells back into the blood.

2 **Explain** why some activity trackers will vibrate if a person has been sitting for more than an hour.

3 A fish has a single circulatory system, but a dog has a double circulatory system. **Describe** the difference between these two systems.

Apply, analyse and interpret

4 **Contrast** and **explain** the difference between plasma, tissue fluid and lymph.

5 Veins have valves, but arteries do not. **Contrast** their structure and relate it to their position relative to the capillary bed.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 6.2

» Video
Blood cells in veins

» Weblink
Clogged arteries

» Weblink
Double circulatory system

6.3 Carriage of respiratory gases in the blood

KEY IDEAS

- The movement of oxygen from gas exchange surfaces into the blood
- The formation of oxyhaemoglobin and dissociation of oxyhaemoglobin in the tissues
- The formation of carboxyhaemoglobin
- The significance of foetal haemoglobin and myoglobin
- The ways in which carbon dioxide is carried in the blood

Carriage of oxygen in the blood

Oxygen is needed for the production of ATP in aerobic cellular respiration. Without a continuous supply of oxygen, the cells will undergo anaerobic cellular respiration and produce fewer ATP molecules.

oxyhaemoglobin haemoglobin that is combined with oxygen

Oxygen diffuses into the red blood cell across its thin elastic membrane and combines with the haemoglobin to form **oxyhaemoglobin**. This is a weak bond that allows rapid

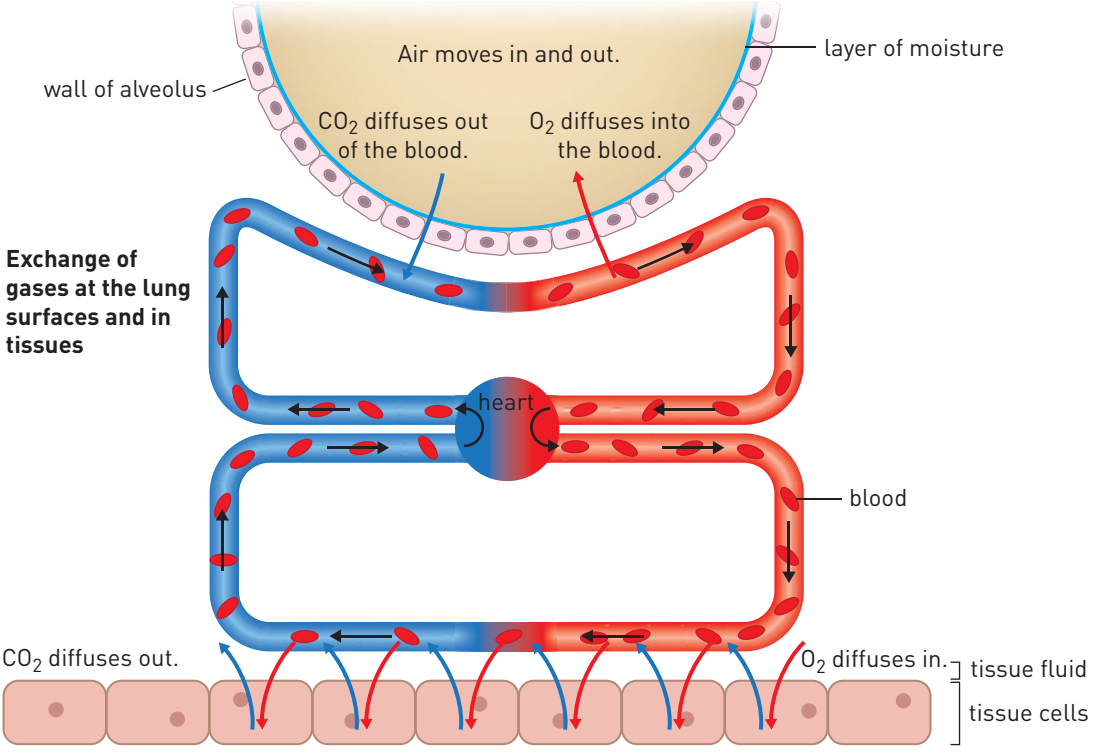

FIGURE 1 Exchange of gases at the lung surfaces and in tissues. (Figure 2 on page 179 shows the gas exchange surfaces in more detail). The gases are in solution as they pass between one structure (e.g. tissue cells) and another (e.g. a blood vessel).

attachment and detachment. The colour of the blood changes from red-blue to red-orange.

$$Hb + 4O_2 \underset{\text{tissues}}{\overset{\text{lungs}}{\rightleftharpoons}} HbO_8$$

haemoglobin + oxygen ⇌ oxyhaemoglobin

Haemoglobin has a strong affinity for oxygen. In areas of the body where the oxygen concentration is high – for example, at the alveoli of the lungs – the haemoglobin rapidly takes up oxygen. When blood carrying oxyhaemoglobin encounters an area of low oxygen concentration at actively respiring tissues, the oxygen is unloaded from the haemoglobin and moves into the tissue fluid. This allows the blood to transport oxygen at a rate sufficient to supply all the cells with their needs.

Oxygen dissociation curves

An **oxygen dissociation curve** shows the percentage saturation of blood with oxygen at different oxygen levels (Figure 2). This is experimentally derived. The pressure exerted by the oxygen molecules in air is known as its partial pressure or tension. Partial pressure of a substance is a measure of the pressure its molecules contribute to the total pressure exerted by a mixture.

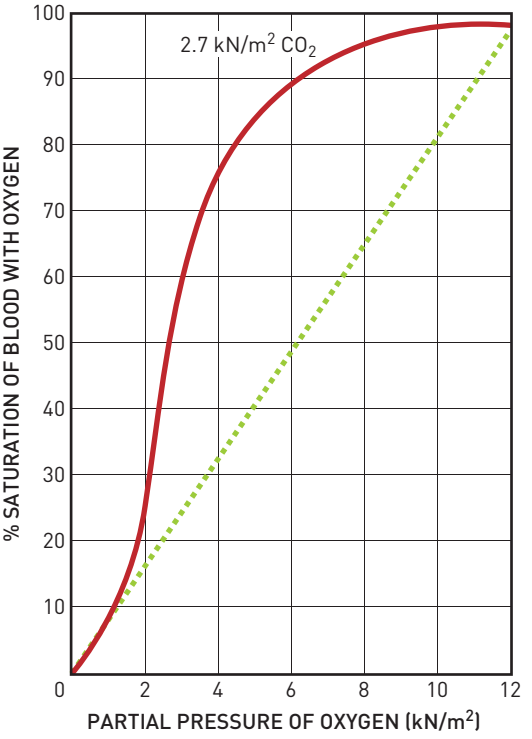

FIGURE 2 Oxygen dissociation curve for human blood

The curve indicates that blood can become fully saturated (with all haemoglobin molecules containing oxygen) at a relatively low oxygen tension. If the relationship were linear (the broken line), the percentage oxygen saturation at any particular oxygen tension would be lower. For example, at 6.0 kN/m², the actual saturation is 90%, whereas a linear relationship would give about 48% saturation of blood.

As well as taking up oxygen at the gas exchange surfaces, haemoglobin rapidly releases it at low oxygen tensions (e.g. in the tissues which are constantly using oxygen in cellular respiration). The steep part of the curve represents the range of oxygen tensions encountered in the tissues. A small drop in oxygen tension produces a large drop in percentage saturation of the blood. A large amount of oxygen is released from the haemoglobin to the tissues needing it.

An increase in carbon dioxide levels, as occurs in the tissues, has a profound effect on the oxygen dissociation curve. It reduces the amount of oxygen that can be carried by oxyhaemoglobin. The oxygen dissociation curve is shifted downwards and to the right. This shift is named the **Bohr effect** (see Figure 3).

An increase in the amount of carbon dioxide present causes haemoglobin to release oxygen at higher than normal oxygen tensions. The release of oxygen in actively respiring tissues (with high levels of carbon dioxide) is therefore accelerated to accommodate the needs of the cells. At the gas exchange surfaces, where carbon dioxide is constantly being released, the haemoglobin

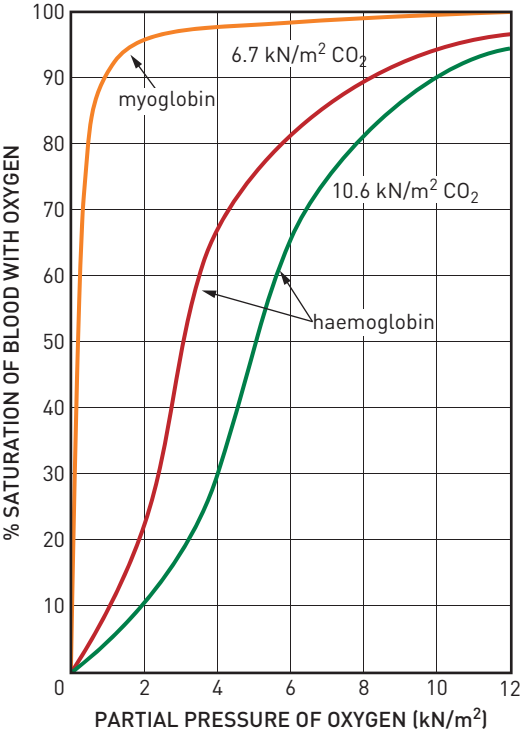

FIGURE 3 The Bohr effect (green line)

oxygen dissociation curve
a graphical representation of the percentage saturation of blood with oxygen at different levels of 'environmental' oxygen

Bohr effect
the shifting of the oxygen dissociation curve downwards and to the right in the presence of carbon dioxide or hydrogen ions

carboxyhaemoglobin
the product of the union of carbon monoxide with haemoglobin in red blood cells

foetal haemoglobin
a form of haemoglobin with higher affinity for oxygen than adult haemoglobin

myoglobin
a variety of haemoglobin, found in vertebrate muscles, with a high affinity for oxygen

carbaminohaemoglobin
a compound formed by the attachment of carbon dioxide to amino acids of the haemoglobin molecule

can take up oxygen at lower tensions. The Bohr effect favours uptake of oxygen at the gas exchange surfaces and its release in the tissues.

A higher release of oxygen from oxyhaemoglobin also occurs if the pH of the blood decreases (i.e. the blood becomes more acidic) or if the temperature increases (e.g. during a severe fever).

Although haemoglobin has a strong affinity for oxygen, its affinity for carbon monoxide is even greater. Carbon monoxide is a molecule formed when fuels are burnt without enough oxygen present. Carbon monoxide is highly toxic and has no distinctive smell. Haemoglobin replaces oxygen with the carbon monoxide, forming **carboxyhaemoglobin**. The colour of the haemoglobin is changed to a bright cherry red and the red blood cells can no longer carry oxygen to the tissue fluid. Carbon monoxide, therefore, is a powerful respiratory poison. Since this is present in motor vehicle exhaust fumes, it has serious environmental effects.

There are two other respiratory pigments found in humans – **foetal haemoglobin** and **myoglobin**. Both of these pigments have oxygen dissociation curves to the left of that for adult haemoglobin. They take up oxygen more readily than adult haemoglobin.

Foetal haemoglobin must obtain oxygen through the placenta from the maternal system. This is why it must have a greater affinity for oxygen than the haemoglobin of the mother.

Myoglobin is a special pigment found in muscles. It takes up oxygen from haemoglobin for storage. Myoglobin releases oxygen only when the oxygen tension is extremely low (e.g. in severe muscular exertion). Athletes who are under an anaerobic training regimen gradually build up the amount of myoglobin in their muscle tissues.

Carriage of carbon dioxide in the blood

Carbon dioxide is a waste product of aerobic and anaerobic respiration in the cells. It must be transported away from the cells to a gas exchange area (e.g. the lungs) to be released into the external environment. It is carried in the blood in several ways:

- About 5% is carried directly in the plasma.
- 93% is transported to the red blood cells. Some of the carbon dioxide binds with the haemoglobin to form **carbaminohaemoglobin**.

The rest of the carbon dioxide in the red blood cells and in the plasma combines with water to form carbonic acid. This slow process is accelerated by the presence of the enzyme carbonic anhydrase.

$$CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} \underset{\text{carbonic acid}}{H_2CO_3}$$

This acid dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). The increase in hydrogen ions lowers the pH (acidic environment) in the blood, resulting in rapid release of oxygen from the haemoglobin. The bicarbonate ions in the red blood cells diffuse into the plasma where they rapidly dissolve. Chloride ions, Cl^-, pass from the plasma to the red blood cells to balance this.

When the blood with high carbon dioxide levels reaches the capillary beds in the lungs (where oxygen tension is high and carbon dioxide tension low), the reactions are reversed. Carbon dioxide is rapidly released from the blood and haemoglobin molecules are again available for oxygen uptake.

If the carbon dioxide levels (and hence acid levels) remain high in the blood, such as when a person holds their breath, a signal is initiated in the brain for the person to take a breath.

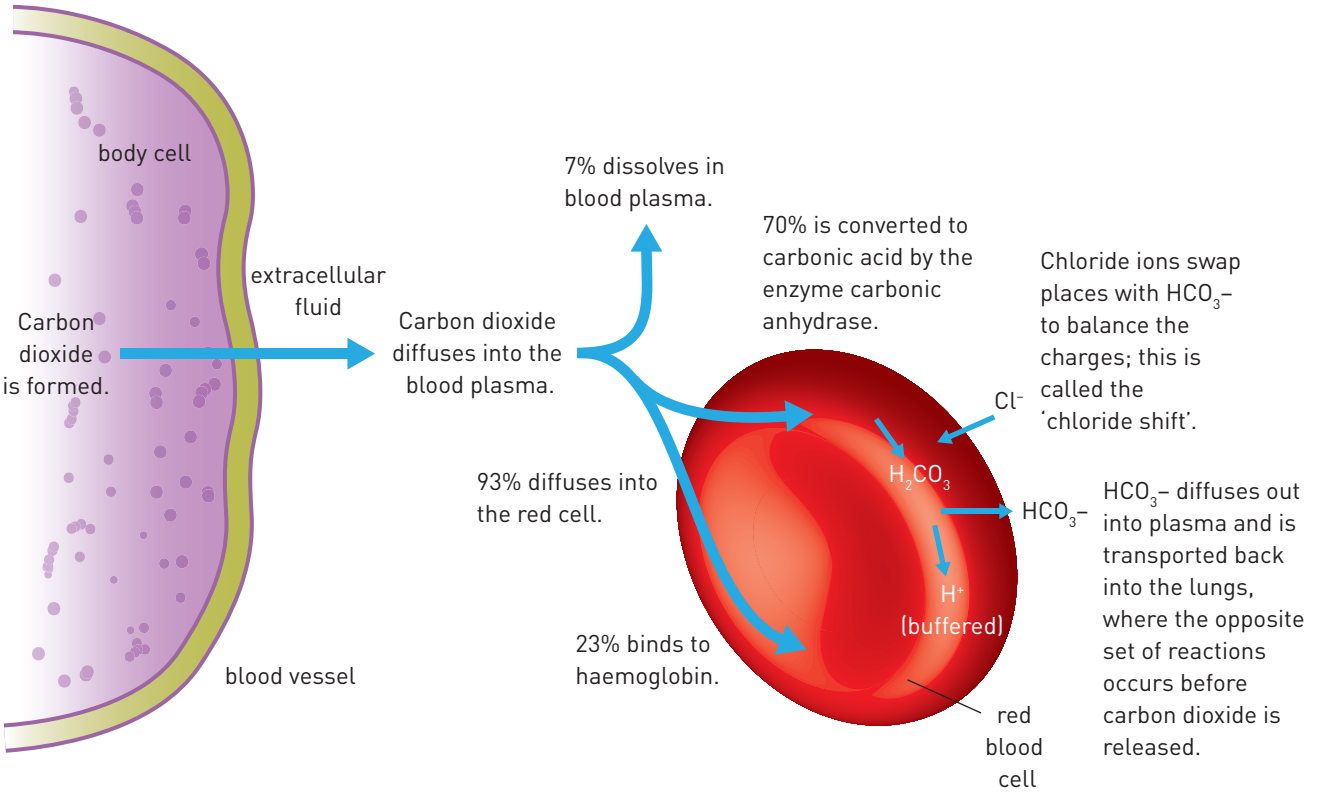

FIGURE 4 The carriage of carbon dioxide in the blood

CHECK YOUR LEARNING 6.3

Describe and explain

1 **Explain** how each of the following is carried in the red blood cell:
   - **a** oxygen
   - **b** carbon dioxide.

2 **Identify** the factors contributing to the following:
   - **a** Loss of carbon dioxide and uptake of oxygen at the capillary beds of the lungs
   - **b** Release of oxygen from haemoglobin at the tissues

3 Sketch the oxygen dissociation curve. **Explain** how this curve illustrates loading and unloading of oxygen in red blood cells.

4 **Describe** the Bohr shift.

5 **Explain** why it is important for oxygen to be transported around the body.

6 **Explain** why the average person cannot hold their breath underwater for more than 2 minutes.

Apply, analyse and interpret

7 A diseased person was found at an autopsy to have bright red blood. **Determine** what a pathologist may conclude about the cause of death.

8 **Consider** why it is essential that foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 6.3
- » Weblink
  Oxygen in the blood
- » Weblink
  Bohr effect
- » Weblink
  Carbon dioxide in the blood

6.4 The lymphatic system

KEY IDEAS

- The return of the tissue fluid to the blood
- The role of lymph
- The structure of the lymphatic system

lacteal
a blind-ending lymph vessel that collects tissue fluid

Unlike the circulatory system, the lymphatic system is an open circulatory system. The lymphatic vessels are like veins in general structure but have small, blind-ending tubules called **lacteals** in the tissues. Not all of the tissue fluid returns to the capillaries as some is taken up by these lacteals that drain into lymphatic vessels. The fluid in these vessels is called lymph. Like veins, every time the skeletal muscle contracts, the lymph moves along the vessels. Small lymphatic vessels join up with each other to become larger, and the lymph fluid is prevented from moving backwards by one-way valves. Eventually the lymph fluid is returned to the heart via two major veins in the neck region of the mammal.

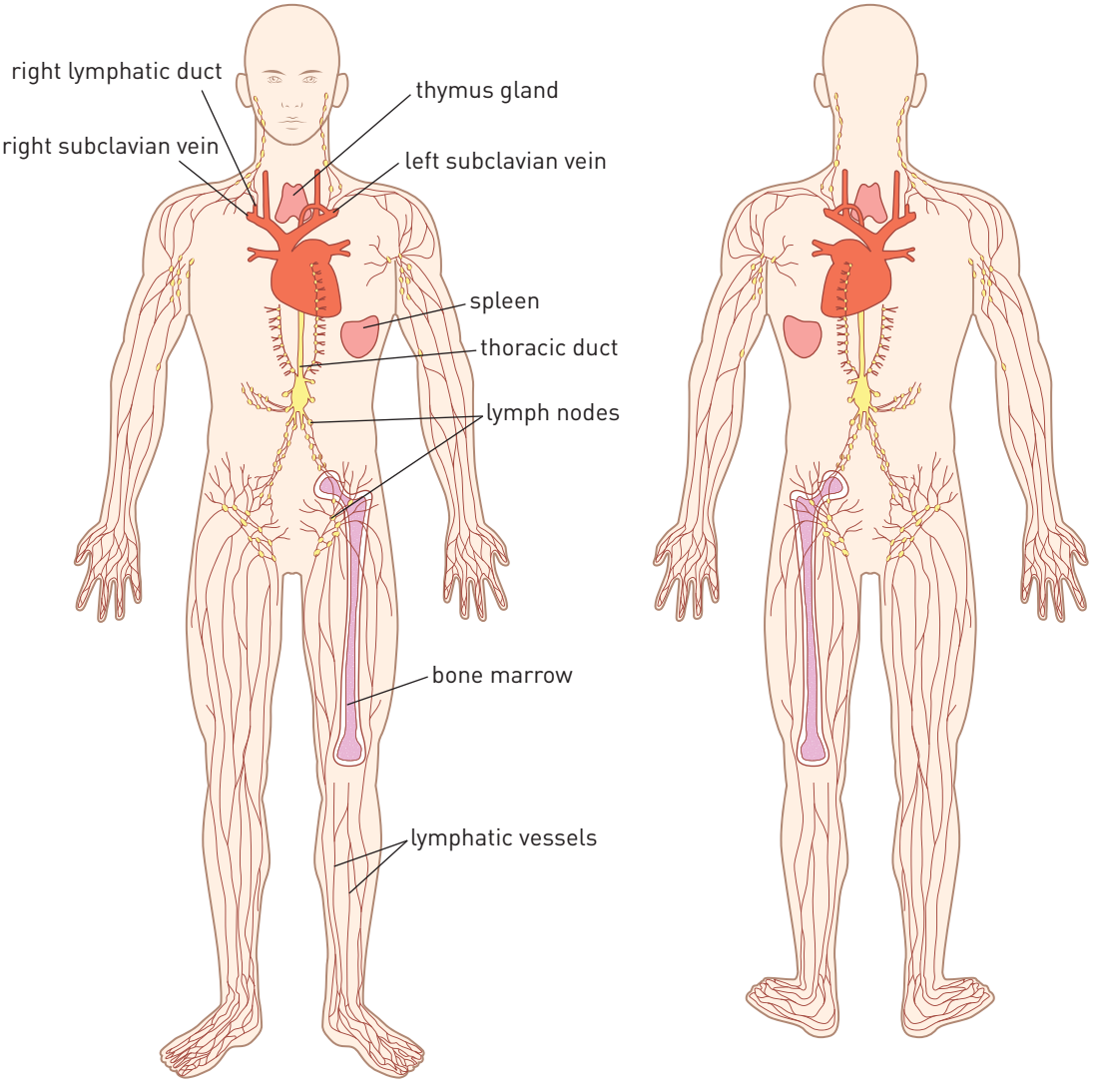

FIGURE 1 The lymphatic system of the human body

A major role of lymph is the carriage of lipids from the digestive system to the cells, particularly those of the liver. At points along the major lymph vessels are **lymph nodes**. These are nodules of tissues where **macrophages** (matured **monocytes** – phagocytic white blood cells) accumulate. The lymph sometimes carries bacteria and other foreign matter. When the lymph enters the spaces in the nodes, the bacteria and other foreign matter are filtered out, and the macrophages ultimately destroy them by phagocytosis. The lymph vessels that exit the node are narrow, preventing the loss of macrophages from the node. The nodes produce lymphocytes that are involved in antibody formation. Both lymphocytes and macrophages are white blood cells involved in the immune response.

lymph node
an organ on the course of major lymph vessels containing cells involved with the immune system

macrophage
a matured monocyte (a type of white blood cell) that destroys foreign matter and bacteria by phagocytosis

monocyte
a large white blood cell that is formed in the bone marrow, circulates in the blood, and destroys pathogenic bacteria by phagocytosis; monocytes develop into macrophages in various body tissues

CASE STUDY 6.4

The treatment of snake bite

Our understanding of snake venom has changed greatly in recent times. Most snake venom is a mix of three different types of chemicals; cytotoxic enzymes that start digesting the tissue and muscle at the bite site, neurotoxin that blocks the electrical signals in the nerves and haemotoxins that rupture red blood cells, cause clotting or the blood vessels to leak. The last two groups of molecules need to travel away from the site of the bite to have an effect on the organism. The first treatment for snake bites involved applying a tourniquet above the site of the bite, blocking the flow of blood to the heart and lungs. This had very limited effectiveness as the lack of blood (and therefore oxygen and nutrients) often caused major damage to the rest of the affected limb, and the venom was still able to travel to the major organs. The modern technique for treating snake bite arose as a result of understanding how most snake venom travelled in the lymphatic system rather than the blood circulatory system. When a snake bites an organism, it usually injects its venom into the tissue fluid that drains into the lymphatic vessels. As the lymph fluid is pushed along the vessels when the skeletal muscle contracts, immobilising the muscles will slow the toxins reaching the internal organs.

CHECK YOUR LEARNING 6.4

Describe and explain

1 With reference to structure, **explain** the function of the lymph nodes.
2 **Describe** lymphocytes.

Apply, analyse and interpret

3 **Compare** the blood circulatory system and the lymphatic system.
4 Some toxicologists suggest that pressure immobilisation in some snake bites can result in an increase in damaged to the localised bite area. **Apply** your knowledge of the types of molecules in venom to **explain** this concern.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 6.4
- » Weblink
  Lymph nodes
- » Weblink
  Snake bites
- » Weblink
  Phagocytosis

6.5 General features of gas exchange in animals

KEY IDEAS

- The distinction between gas exchange and cellular respiration
- Factors affecting the efficiency of diffusion
- The effect of size and the surrounding medium on gas exchange

Cellular respiration occurs in all cells of all organisms to release energy from complex organic molecules such as glucose. It may be either anaerobic (no oxygen) or aerobic (requiring oxygen). Anaerobic respiration yields little energy, and organisms that rely entirely on this process are very sluggish and limited in size. Aerobic respiration completely metabolises glucose to carbon dioxide and water, and in so doing releases a great deal of energy that was locked in the chemical bonds of the glucose molecules.

Aerobic respiration demands a continuous flow of oxygen into cells, accompanied by the rapid removal of the carbon dioxide they produce. These two processes involve gas exchange where molecules pass into and out of cells by diffusion along a concentration gradient in an aqueous solution.

FIGURE 1 The sea anemone, flatworm and jellyfish use diffusion as their sole means of gas exchange.

Factors affecting diffusion

Diffusion in water is relatively slow. The rate at which respiratory gases pass into and out of cells by diffusion can vary. The efficiency of diffusion is determined by:

- the surface area over which diffusion takes place
- the distance over which molecules in a concentration gradient must travel (i.e. the length of the diffusion pathway)
- the concentration gradient. In the case of oxygen, this depends on the external oxygen concentration and the rate at which oxygen is used up.

The type of gas exchange system employed by an organism, therefore, depends on two factors: the size of the organism, and the environmental medium.

Effect of size

The surface area of the organism and the distance from the surface to the innermost respiring cells determine whether diffusion through the body surface can supply its gas exchange needs. If both conditions are appropriate, then diffusion for gas exchange occurs.

Among animals, diffusion as the sole means of gas exchange is used only by cnidarians (jellyfish, sea anemones and similar animals), flatworms and certain other small animals whose ratio of surface area to volume is large. As animals increase in size this ratio decreases, and diffusion alone becomes inadequate to supply all the cells. Therefore, roundworms and earthworms, although they exchange gases across the body wall, also need a transport system to ensure that all their cells have adequate gas exchange.

Proportionately, the body surface of larger, more active animals, or of those living in an oxygen-depleted environment, is usually too small to supply respiratory needs, even with the presence of a transport system. In such circumstances, large, specialised gas exchange surfaces, such as lungs and gills, either supplement or replace gas exchange through the skin.

These specialised surfaces increase the surface area available for the exchange of gases through diffusion. They have thin, flat, moist cells lining them, and a neighbouring supply of blood vessels. This decreases the distance the oxygen needs to diffuse to reach the red blood cells.

The constant flow of the circulatory system allows the removal of oxygenated red blood cells from the gas exchange surfaces. This keeps a high concentration gradient of oxygen across the surface. For example, the concentration gradient of oxygen molecule causes it to move from the exchange surface to the blood, where it can bind to the haemoglobin in the red blood cell. The movement of the blood in the capillaries carries the oxygen-laden red blood cells away from the gas exchange surface. These are replaced by red blood cells low in oxygen, which maintains the concentration gradient. There is a net movement of oxygen towards the internal cells of the organism. The larger the concentration gradient, the faster the net movement of oxygen. The surface is often associated with some kind of ventilating mechanism. Ventilation ensures a constant renewal of either air or water at the gas exchange surface to maintain the concentration gradient.

Effect of the surrounding medium

The medium in which an animal lives has a significant bearing on its gas exchange system. Gases must first dissolve in a liquid before they can pass across the cell membranes. Land-based animals must have a fine film of liquid coating their gas exchange surface. Aquatic animals have no need for a mechanism to keep exchange surfaces moist.

In terms of gas exchange, there are two major disadvantages to living in water:

1. Oxygen is not very soluble in water – there is only about 1% in water compared with 21% in air.
2. Water is very viscous (it does not flow as easily as air) and this limits the flow of water across gas exchange surfaces to one direction. It would require too much energy to move water in and out the same opening when compared to air.

The greatly increased amount of oxygen in air allows a higher metabolic rate in terrestrial and air-breathing aquatic animals. The disadvantage for these animals is the drying effects of air and its lack of support (low buoyancy). Therefore, large terrestrial animals keep their moist respiratory surfaces internal and link them to an active ventilation system that ensures movement of gases across them while reducing water loss.

Gills

In fish, gaseous exchange takes place between the water and highly vascularised (having many blood vessels) **gills**. These consist of several paired gill arches lying on either side of the buccal cavity (mouth), protected from the external environment by the **operculum**. From each gill arch extend two rows of **gill filaments** that spread out.

gill
the gas exchange surface of aquatic animals

operculum
the bony covering of the gills of bony fish

gill filament
a thin-walled, highly vascular structure arising from the gill arches of the gill of bony fish; a gas exchange surface

The filaments are further subdivided to increase the surface area even more. Each section contains a capillary network where gas exchange takes place. The total surface area over which gas exchange occurs is extremely large. It may be as much as 10 times the surface area of the body. The more active the species of fish, the larger is the gill filament area.

A constant stream of water must be passed over the gills to maintain an oxygen supply to the body and so maintain a concentration gradient. When the fish is actively swimming, this can be achieved by keeping the mouth open; water will then be forced through the mouth into the buccal cavity and across the gills. When the fish is inactive, however, water does not automatically keep moving through the buccal and opercular cavities. Most fish, therefore, use muscular movements of the operculum and buccal cavity to ventilate the gills.

Oxygen diffuses from the water into the filament capillaries along a concentration gradient, and carbon dioxide diffuses in the opposite direction.

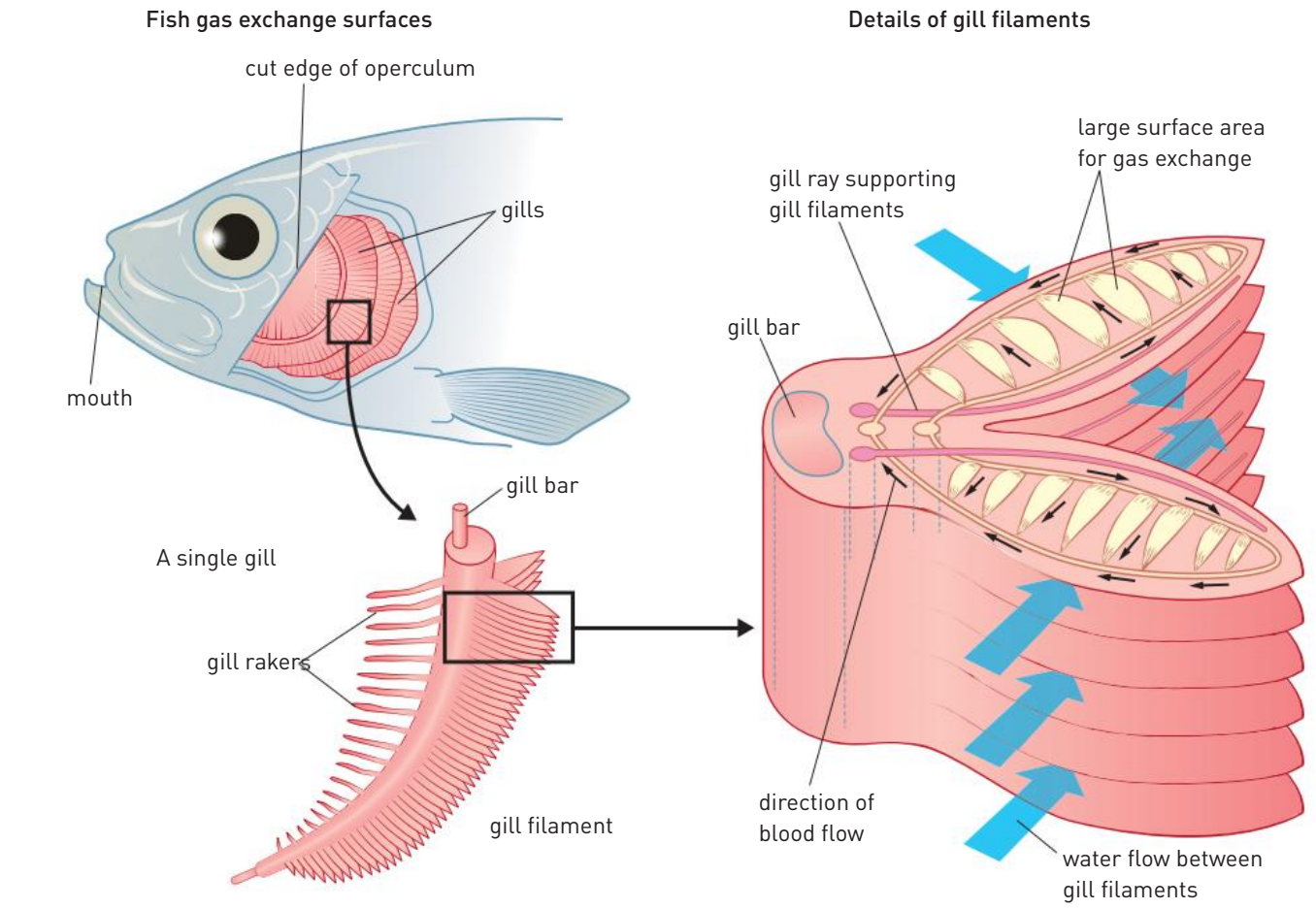

FIGURE 2 Gas exchange surfaces of the bony fish

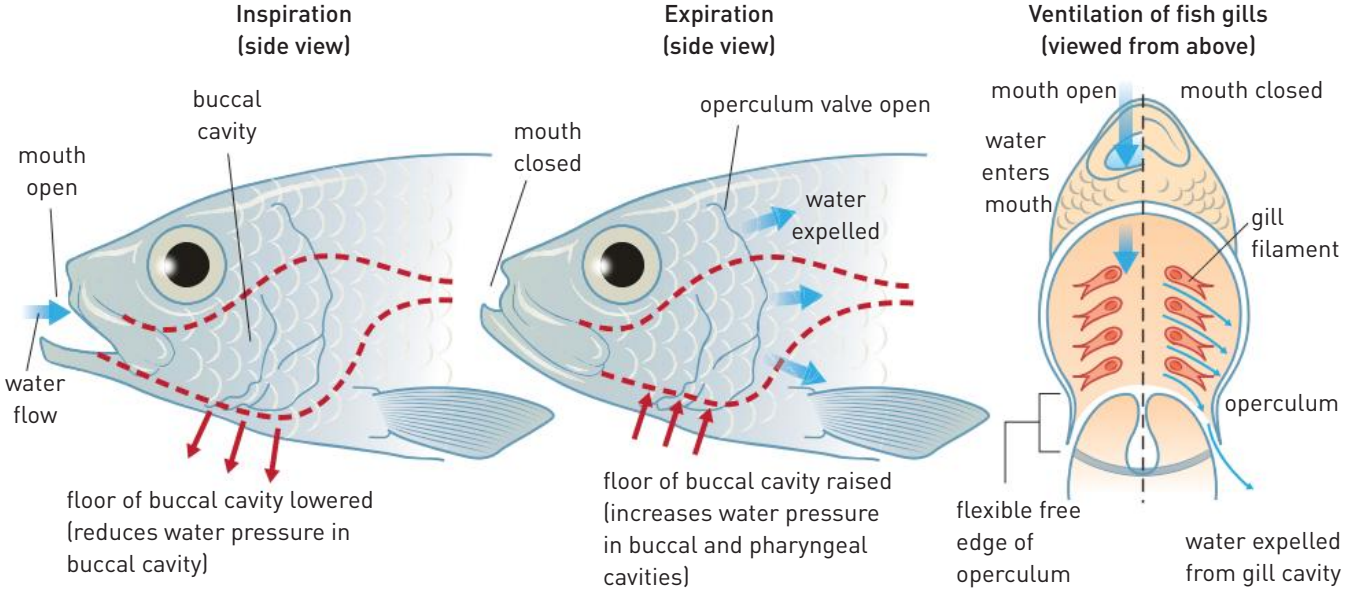

FIGURE 3 Gas exchange inside the bony fish

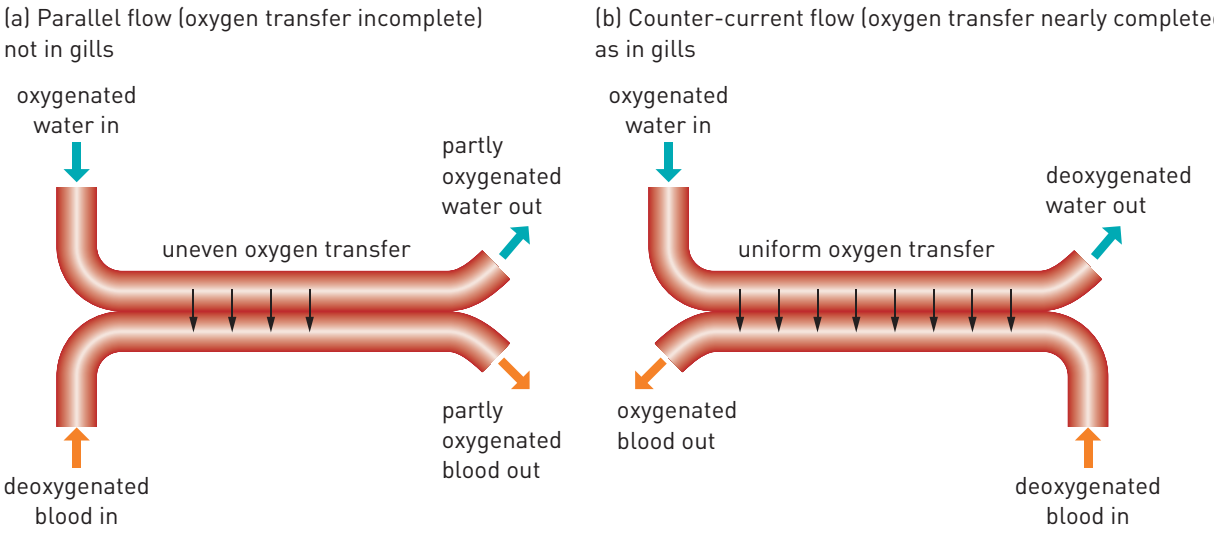

FIGURE 4 A comparison of gas exchange in (a) parallel flow and (b) counter-current flow systems

The concentration gradient is maintained at the surface of the gills by:

- the continuous removal of oxygen from solution by haemoglobin in the red blood cells
- blood flow, which removes oxygenated blood from the gills
- continuous ventilation of the gill surface.

The flow of water through the gills is in the opposite direction to the flow of blood through the capillaries, forming a **counter-current** system. The counter-current flow significantly increases the efficiency of gas exchange because it helps to maintain a large concentration gradient over the large surface area. The oxygen concentration in the water is always higher than that of the blood along the entire length of the filament. So, as blood flows across the respiratory surface, it meets water that has less and less oxygen extracted from it, and a steep concentration gradient is maintained along the entire surface, enabling blood to remove as much as 96% of the oxygen (low solubility) from the water passing through the gills.

counter-current the movement of two media (usually fluids) parallel to each other but in opposite directions

CHECK YOUR LEARNING 6.5

Describe and explain

1 **Describe** how the following factors determine the efficiency of diffusion:
   - **a** the size of the surface of the gas exchange area
   - **b** the thickness of the gas exchange area
   - **c** the concentration gradient across the gas exchange area.

2 **Explain** why most aquatic animals have a one-way flow of water across their gas exchange area.

3 **Explain** how the medium in which an animal lives determines the type of gas exchange system used.

4 **Describe** how fish use gills for gas exchange.

Apply, analyse and interpret

5 Many people with cystic fibrosis develop a thick, viscous layer of fluid on their gas exchange surfaces. **Apply** your knowledge to show why this may make it difficult for oxygen to enter their bloodstream.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 6.5
- » Weblink
  Fish gills
- » Weblink
  Diffusion in water
- » Weblink
  Counter current systems

6.6 Gas exchange in humans

KEY IDEAS

- The general structure of the mammalian gas exchange system using the human as an example
- The structure and function of the lungs
- Muscular actions of the thorax and diaphragm in achieving ventilation through altering the pressure in the thoracic cavity

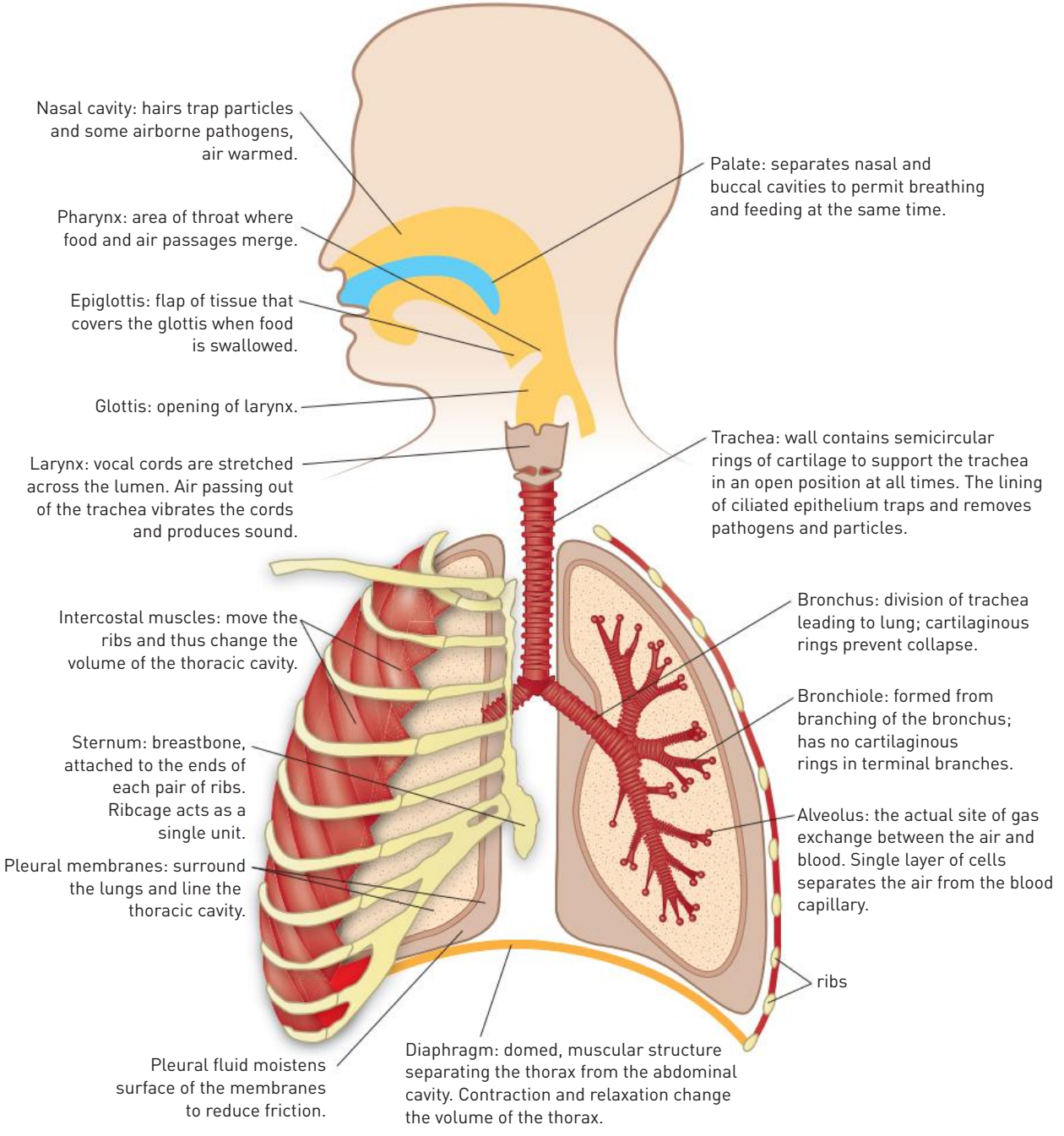

FIGURE 1 Structure of the human gas exchange system

All mammals have a similar gas exchange system. The human gas exchange surface consists of a pair of lungs situated in the thoracic cavity and connected to the exterior by a series of air passages. The only attachment of the lungs in the thoracic cavity is at the point of entry of the major air tubes and blood vessels. Between the two lungs are the heart, with its major blood vessels, and the oesophagus. The thoracic cavity is separated from the abdominal cavity by a muscular sheet called the **diaphragm**.

diaphragm
the muscular sheet of muscle separating the thorax and abdominal cavity of mammals

Air moves in through the mouth and nose, down the pharynx and trachea, until the pathway splits into two bronchi (singular, bronchus). Each bronchus branches into a network of tubes (bronchioles) that become progressively smaller. They finally open into tiny bubble-like sacs, the alveoli (singular, alveolus). The total surface area of the gas exchange alveoli is equivalent to that of a tennis court (about 70 square metres). The interior of each alveolus has a moist lining to allow the oxygen to dissolve. The alveoli are enclosed by a single layer of flattened cells that are in close proximity to a capillary, ensuring a narrow diffusion pathway and therefore rapid exchange of gases between the alveolus and blood in the capillary.

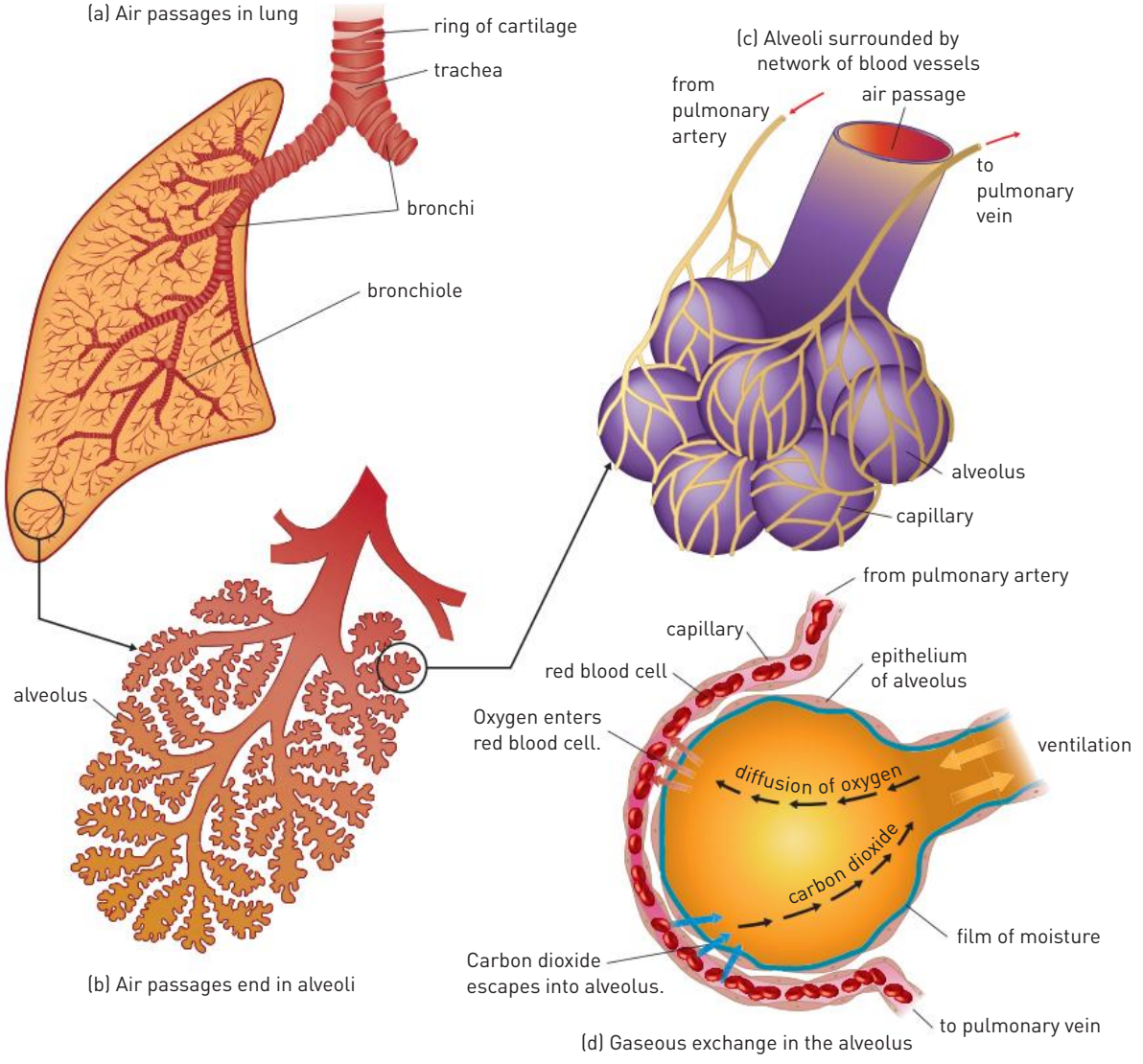

FIGURE 2 (a) Air passages in the lung; (b) air passages end in alveoli; (c) alveoli are surrounded by a network of blood vessels; (d) gaseous exchange in the alveolus

Ventilation

ventilation
active movement of the passage of air (or water) over gas exchange surfaces

inspiration
the movement of air into the lungs in tetrapods (four-'legged' animals)

expiration
the movement of air out of the lungs in tetrapods (four-'legged' animals)

The thoracic cavity, in which the lungs are located, is a closed box supported externally by the ribs. It is separated from the abdominal cavity by the dome-shaped diaphragm. Changes in the volume of the thorax immediately cause changes in the pressure of the air in the lungs. This results in the flow of air into and out of them. Active movement of air into and out of the lungs is termed **ventilation**. Movement of air into the lungs is called **inspiration**; its movement out of the lungs is **expiration**.

On inspiration (breathing in), one set of muscles between the ribs contracts while the other set relaxes. This causes the ribs to move up and out. Because the ribs are attached to the sternum, this increases the diameter of the thoracic cavity. Simultaneously, the muscles of the dome-shaped diaphragm contract, flattening and lowering it and effectively increasing the length of the thorax. The combined effect of both muscular actions increases the volume of the thoracic cavity. This results in the air pressure in the thorax being lower than the external atmospheric air pressure. Atmospheric air moves into the air passages and lungs along the pressure gradient – that is, from higher external atmospheric pressure to lower internal thoracic pressure.

On expiration (breathing out), the two sets of rib muscles reverse their actions, causing the ribs to move down and in, and decreasing the diameter of the thoracic cavity. The muscles of the diaphragm relax, allowing it to become more dome-shaped and decreasing the length of the thoracic cavity. This results in a decreased thoracic volume and an increase in air pressure in the lungs that is higher than atmospheric pressure. Air is expelled from the lungs under pressure. The lungs are passive and take no active part in the ventilation process.

During active exercise, other muscles also come into play during the breathing cycle. Abdominal muscles increase pressure within the abdomen, pushing the diaphragm further up during expiration. The sizes of the nostrils and glottis are increased by muscles during inspiration and in this way reduce resistance to air flow.

Only about 10% of the air in the lungs is expelled during normal expiration. Even with forced breathing about 20% of the air remains in the lungs, keeping the alveoli from collapsing. Similarly, not all of the oxygen in the alveoli diffuses into the blood and some will be expelled when breathing out. The oxygen content being breathed in is 21%, while expired air is 18% oxygen. For this reason, the CPR performed during first aid can provide oxygen to the non-breathing person.

TABLE 1 Ventilation in humans

Part of respiratory tract	Inspiration	Expiration
Diaphragm	Contracts and flattens downwards	Relaxes and moves upwards to dome shape
Intercostal muscles between the ribs	External intercostal muscles contract	Internal intercostal muscles contract
Rib cage and sternum	Move upwards and outwards	Move downwards and inwards
Thorax volume	Increases	Decreases
Air pressure	Pressure decreases inside thorax and lungs	Pressure increases inside thorax and lungs
Air movements	Higher external air pressure drives air into lungs at low pressure	Air forced out of lungs by thorax compression and elastic recoil of lungs

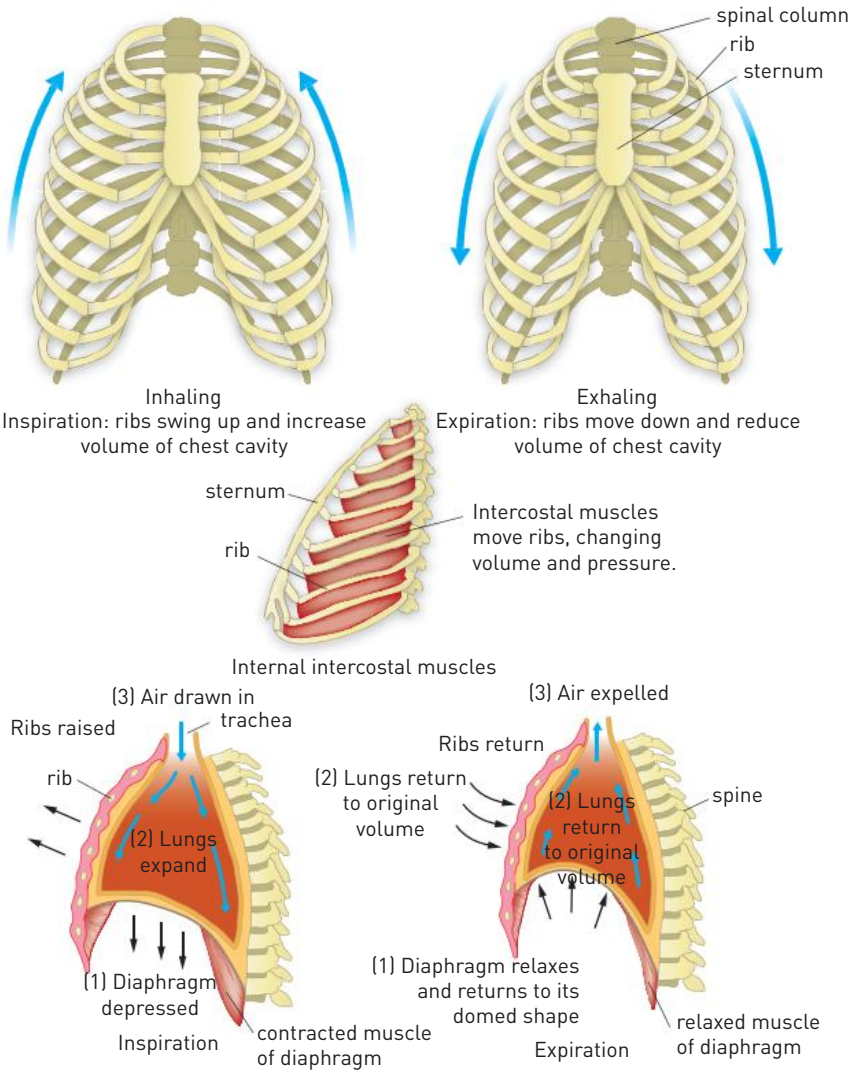

FIGURE 3 Action of the ribs and diaphragm in human ventilation

CHECK YOUR LEARNING 6.6

Describe and explain

1 Actual gas exchange occurs between the alveolus and the capillaries. **Describe** the features of these structures that are adaptations for gas exchange.

2 During ventilation the lungs are passive and take no active part in inspiration and expiration. **Explain** how air is moved into and out of the lungs.

Apply, analyse and interpret

3 During mouth-to-mouth resuscitation, the resuscitator's expelled air is forced into the patient. **Consider** how this can provide oxygen to the patient.

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CHAPTER 6

Review

Chapter summary

6.1 Multicellular organisms need to transport nutrients, oxygen and waste around their bodies.

Human blood transports dissolved substances in the plasma and respiratory gases within red blood cells.

White blood cells are involved in defence against disease.

The structure of the red blood cell allows it to be packed with haemoglobin molecules. Each haemoglobin molecule is composed of four interlocking polypeptide chains, each of which contains an iron haem group. Each haem group can carry an oxygen molecule.

Platelets and the plasma protein fibrinogen are important agents in blood clotting. Other plasma proteins are involved in immunity and controlling the water balance of the body.

6.2 The circulatory system consists of heart, arteries, capillaries and veins.

Mammals have a double closed circulatory system: blood flows through the heart twice for every complete circuit of the body.

Arteries are blood vessels that carry blood away from the heart. Arteries lead into capillaries that come into close contact with the tissue cells.

Capillaries lead into veins, which are less muscular and elastic than arteries, and which return the deoxygenated blood from the body and oxygenated blood from the lungs to the heart.

The blood in veins is moved by the contraction of surrounding muscles.

6.3 Oxygen passes from the gas exchange surfaces of the lungs into the capillaries along a concentration gradient. In the blood, it combines with haemoglobin in the red blood cells to form oxyhaemoglobin.

In the tissues, where the oxygen concentration is low, the oxyhaemoglobin dissociates and oxygen passes from the blood into tissue fluid and on to the cells.

The oxygen dissociation curve describes the loading and unloading of oxygen in the blood at different partial pressures of oxygen. Foetal haemoglobin and myoglobin have a higher affinity for oxygen than haemoglobin.

The dissociation of oxygen from oxyhaemoglobin increases as the levels of carbon dioxide in the blood increase – the curve shifts to the right and downwards. This is known as the Bohr effect.

6.4 The open lymphatic system moves fluid in one direction – from tissue fluids to major veins returning blood to the heart. Lymphatic vessels begin as lacteals (blind ended tubules) that collect tissue fluid that is not returned by the capillaries to the veins. This fluid is termed lymph and contains a high proportion of lipids. The vessels enter nodes which contain white blood cells that are involved in the immune response.

6.5 For gas exchange to occur across cell membranes, oxygen and carbon dioxide must be dissolved in water.

The efficiency of this diffusion depends upon:

- the concentration gradient
- the area over which diffusion takes place
- the length of the diffusion pathway.

The size of the organism and the environment in which it lives determine whether special gas exchange surfaces and/or a transport system are required to supply all cells of the body with adequate gas exchange.

6.6 The mammalian lungs consist of bronchioles, alveolar ducts, alveoli and blood vessels, held together by connective tissue. The alveolar walls are only one cell thick and are coated in moisture. Each alveolus is surrounded by a capillary. Exchange of gases occurs between the alveolus and the capillary.

Key terms

- active transport
- alveolus
- arteriole
- artery
- blood
- Bohr effect
- capillary
- carbaminohaemoglobin
- carboxyhaemoglobin
- counter-current
- diaphragm
- double circulatory system
- erythrocyte
- expiration
- foetal haemoglobin
- gill
- gill filament
- haemoglobin
- herapin
- inspiration
- intercellular
- lacteal
- leucocyte
- lymph
- lymph nodes
- lymphatic vessel
- macrophage
- monocyte
- myoglobin
- operculum
- oxygen dissociation curve
- oxyhaemoglobin
- pulmonary circulation
- systemic circulation
- tissue fluid
- transport system
- vein
- ventilation
- venule

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Haemoglobin has the highest affinity (combining power) for:
- **A** oxygen
- **B** nitrogen
- **C** carbon dioxide
- **D** carbon monoxide

2 The human red blood cell is structurally suited to its function because it:
- **A** contains haemoglobin which can reversibly form a complex with oxygen
- **B** is disc-shaped to increase surface area
- **C** contains enzymes to digest foreign bodies that enter the blood
- **D** contains a nucleus to ensure a long and active life

3 Capillaries of the body are:
- **A** thin-walled blood vessels
- **B** tiny veins leading towards the heart
- **C** vessels which carry deoxygenated blood
- **D** tiny structures in the heart which help to operate the valves directing blood flow

4 Lymph nodes:
- **A** are places where red blood cells are made
- **B** are places where iron is stored
- **C** are the places where iodine is manufactured
- **D** contain white blood cells that combat infection

5 When a person expires, air passes through the gas exchange tract in the order:
- **A** nasal cavities → larynx → trachea → bronchi → alveoli
- **B** nasal cavities → trachea → larynx → bronchi → alveoli
- **C** bronchi → trachea → alveoli → larynx → nasal cavities
- **D** alveoli → bronchi → trachea → larynx → nasal cavities

The next three questions refer to the following diagram.

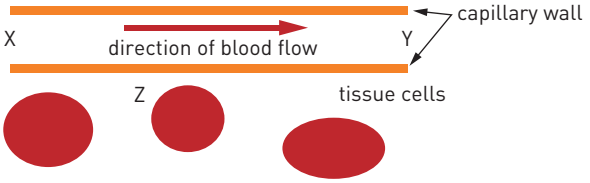

FIGURE 1

6 X is connected to:
- **A** an artery
- **B** a venule
- **C** an arteriole
- **D** a vein

7 The fluid filling the space labelled Z is the:
- **A** plasma
- **B** tissue (extracellular) fluid
- **C** blood
- **D** intracellular fluid

8 The process responsible for the exchange of materials taking place through Z is:
- **A** diffusion
- **B** osmosis
- **C** hydrolysis
- **D** haemolysis

Short answer

Describe and explain

★★9 **Explain**:
- **a** the feature of a capillary that allows it to exchange materials with the extra-cellular fluid
- **b** the movement of materials between the capillaries and extracellular fluid
- **c** why exchange of matter cannot occur between the other blood vessels and the extracellular fluid.

Apply, analyse and interpret

★10 **Consider** why it would be detrimental for all the carbon dioxide produced during respiration to dissolve in the bloodstream.

★★★11 People suddenly exposed to the air in an underground car park often feel faint. **Apply** your knowledge of carbon monoxide, oxygen and haemoglobin to suggest a reason for this.

TABLE 1 Percentage saturation with oxygen of blood of a bony fish at different partial pressures of oxygen and carbon dioxide

Partial pressure of oxygen (Pa)*	Partial pressure of carbon dioxide at 500 Pa	Partial pressure of carbon dioxide at 600 Pa
500	30	5
1000	70	13
2000	90	24
3000	96	33
4000	98	41
5000	99	48
7000	100	60
9000	100	69
11000	100	76
13000	100	81

*A pascal (Pa) is a unit of pressure. A pressure of 100 000 Pa is approximately equal to atmospheric pressure (760 mmHg).

- **a** **Determine** the difference in percentage saturation of blood at the two different partial pressures of carbon dioxide, and at an oxygen partial pressure of 5500 Pa. Show your working.
- **b** **Judge** how changes in the oxygen content of the blood at different partial pressures of carbon dioxide are important in the release of oxygen to the tissues of the fish.
- **c** **Consider** what information experiments of this type give about the environmental conditions in which fish would maintain a high level of growth as required in commercial fish farming.

12 During hibernation, many animals allow their body to cool down, decreasing the amount of aerobic cellular respiration that is needed. The oxygen dissociation curve of wombats in

the Victorian high country shifts to the left as shown in Figure 2.

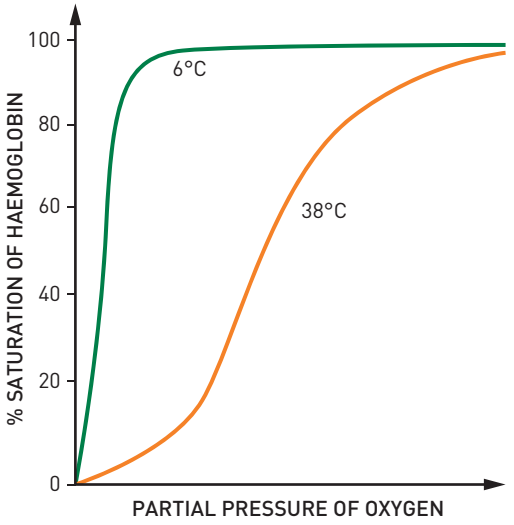

FIGURE 2

Interpret the dissociation curve and suggest how this might be an advantage to a hibernating animal.

Investigate, evaluate and communicate

★★★ **13** Observations of the Tamar wallaby on cold mornings revealed that, during its bounding locomotion, small 'puffs' of condensed air were ejected from the nostrils as the wallaby brought the hind limbs forward, but not when they were extended. Similar observations were made on racehorses. The 'puffs' were seen when a horse's back was flexed, with the hind limbs in the forward position. (See Figure 3.)

a **Discuss** what causes the 'puffs' of condensed air.

b **Generate** a hypothesis to explain these observations.

c **Discuss** how this mechanism may help quadrupeds to travel large distances at speed.

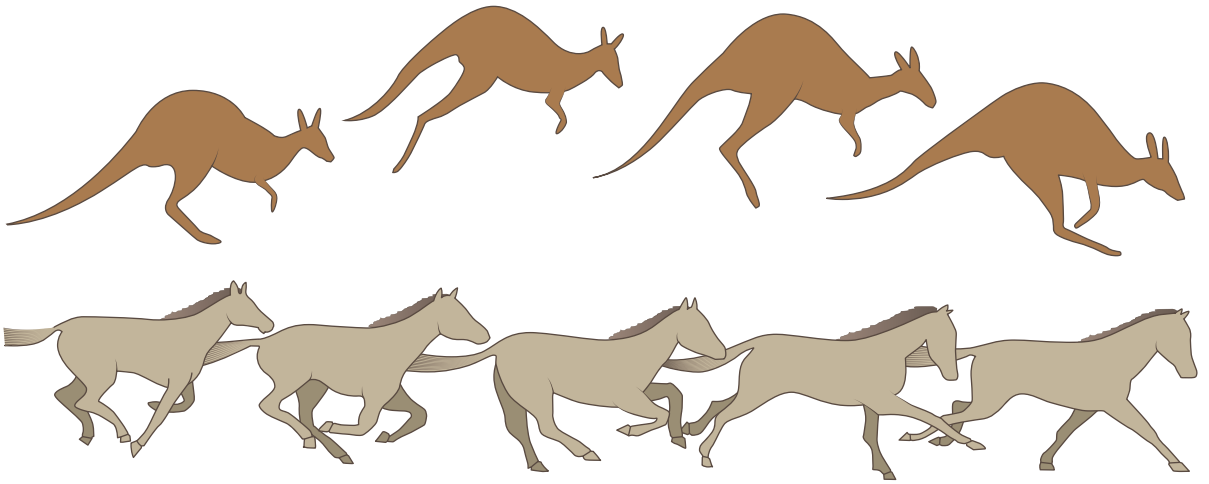

FIGURE 3 The locomotion of the Tamar wallaby and the horse

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CHAPTER 7

Exchange of nutrients and waste in animals

Animals are heterotrophs and so cannot synthesise their own food. They take in nutrients in organic form. Large macromolecules are broken down, through physical and chemical digestion, into monomers that can pass into the cells. Reconfiguration of these monomers in the cell provides it with its energy and nutrient requirements. Waste materials result from cellular activities. Since animals undertake locomotion to seek food, they require a high-protein diet. Amino acids from protein digestion that are in excess of immediate needs cannot be stored. Most are converted in the liver to a nitrogenous waste material that is eliminated by the kidney.

OBJECTIVES

- → Identify the characteristics of absorptive surfaces within the digestive system and relate to the structure and function of the villi.
- → Describe the role of digestive enzymes (amylase, protease, lipase) in chemical digestion.
- → Recognise the different types of nitrogenous wastes produced by the breakdown of proteins.
- → Explain the function of each of the sections of the nephron and its function in the production of urine (glomerulus, Bowman's capsule, proximal and distal tubules, loop of Henle and collecting tubule).
- → Explain how glomerular filtration, selective reabsorption and secretion across nephron membranes contribute to removal of waste.

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FIGURE 1 Coloured scanning electron micrograph of a biopsy from the small intestines. The interior (lumen) is lined with a highly folded surface. The folds, known as villi (purple), project into the lumen, increasing the surface area for absorption.

PRACTICALS

MANDATORY PRACTICAL	**7.2A** The effect of temperature on the rate of reactions of an enzyme
SUGGESTED PRACTICAL	**7.2B** The effect of pH on the rate of enzyme reactions

7.1 Supplying nutrients: the digestive system

KEY IDEAS

- The distinction between a non-essential and an essential nutrient
- Heterotrophic nutrition
- The distinction between physical and chemical digestion
- The processes of extracellular and intracellular digestion

nutrient
any substance used as food by an organism

non-essential nutrient
a nutrient that can be synthesised by an organism

essential nutrient
a nutrient that must be ingested and absorbed since it cannot be synthesised by the organism

heterotroph
literally, other-feeder; an organism which derives its external source of energy from other living organisms

mouth
the opening of the anterior region of the alimentary canal through which food is ingested

anus
the end of the alimentary canal through which faeces (undigested food) are egested

egestion
the removal of undigested food (faeces) from alimentary canal

chunk feeder
an animal that ingests large pieces of food

All living organisms need to take into their cells many different substances that will be used for maintenance, growth, repair and reproduction. A **nutrient** is any substance used by an organism. **Non-essential nutrients** are those that can be synthesised by the organism from basic materials. Some nutrients cannot be synthesised, and must be taken in from an outside source; these are termed **essential nutrients**.

Heterotrophs cannot synthesise organic compounds from inorganic matter and must therefore obtain their carbohydrates, proteins, lipids, nucleic acids and vitamins by eating other organisms.

Cellular respiration releases chemical bond energy from organic molecules to be used in metabolic processes.

Heterotrophic nutrition in animals

In most animals, the alimentary canal is a muscular tube that runs through the centre of the animal and has two openings to the outside. Food enters by one opening, the **mouth**, and is processed as it passes through the tube. Nutrients released by these actions are transferred from the alimentary canal to the body cells via the circulatory system. Any material that is not processed is released through the other opening, the **anus**. The matter in the alimentary canal flows in one direction – from the mouth to the anus, followed by **egestion**.

Ingestion

Chunk feeders must have a means of obtaining food and then breaking it down into molecules small enough to pass across the cell membranes. A variety of structures which aid in obtaining food have evolved. These include teeth, tentacles, claws and other appendages. These structures are involved in the process of ingestion or placing food into the digestive system.

Alimentary canal

Once the food is ingested, muscular contractions move this food mass through the system as well as physically breaking and churning it. In animals, such as cnidarians and flatworms, which do not have a body cavity, food in the alimentary canal can move only if the whole animal is moving. In these animals, therefore, the entire length of the alimentary canal functions in digestion and absorption, and the amount of food actually digested before elimination occurs is related to the rate of movement of the animal.

The body cavity, which is found in most animals, separates the alimentary canal from the body wall. The body can be thought of as consisting of two tubes, one inside the other. The outer tube, which is in contact with the external environment, protects the inner organs and provides a framework for support and movement. The outer tube is connected to the inner

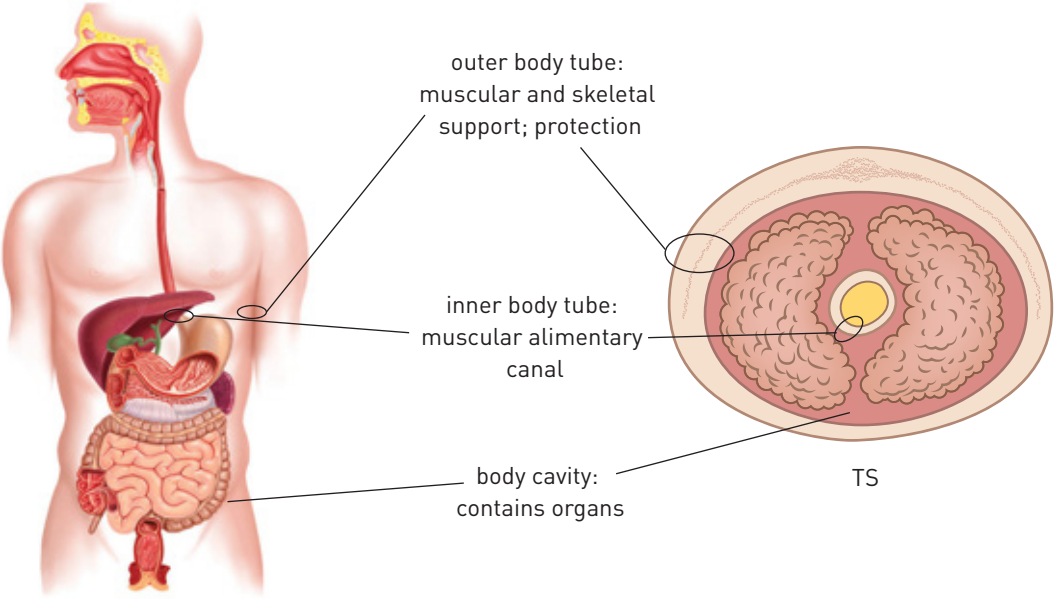

FIGURE 1 In animals with a true body cavity, the body can be thought of as comprising two tubes, one inside the other.

tube only at the two openings to the external environment: the mouth and the anus. For the rest of its length the outer tube is separated from the inner tube by a space in which are found many organs, such as the heart, liver, lungs and kidneys. The inner tube, the alimentary canal, can act independently of the outer tube because it has its own muscular system. This arrangement is shown in Figure 1.

Two muscle layers are found throughout the length of the alimentary canal. One layer, the circular muscle, travels in rings around the circumference. When these muscles contract, the internal diameter of the tube becomes smaller. The second layer, the longitudinal muscle, is oriented along the entire length of the tube. When this muscle layer contracts, the tube becomes shorter. Waves of contraction and relaxation of these muscle layers move the food through the canal in a process called **peristalsis**. The muscles just in front of the food relax, providing an enlarged area into which the food can pass. The muscles just behind the food contract and push the food forward. As the food moves, the muscles behind it then contract so that a region of contraction follows the food and constantly pushes it forward.

peristalsis the waves of contraction and relaxation in muscular walls of the alimentary canal, aiding in mechanical digestion and moving food forward through its length

The separation of the muscular alimentary canal from the body wall has allowed the development of specialisation of parts of this canal for different functions. Some parts of the gut have developed into storage areas, others for digestion, absorption or elimination.

Within the alimentary canal, the solid food is subjected to a variety of actions that convert it into soluble compounds that can then be absorbed.

Physical digestion

The large pieces of food are broken down into smaller pieces during **physical digestion**. Special structures such as the rasp-like tongue of the snail and teeth of vertebrates help in this process. The movement of the muscles of the alimentary canal plays a major role in breaking the food into very small particles.

physical (mechanical) digestion the breakdown of food into small units by crushing or cutting actions of mouthparts (in invertebrates), teeth, muscles, etc.

Bile, made in the liver and released from the gall bladder, is an emulsifier (a mixture of chemical substances that act like a detergent). It physically breaks down large fat particles in the small intestine into small droplets. These small droplets are then digested chemically by enzymes.

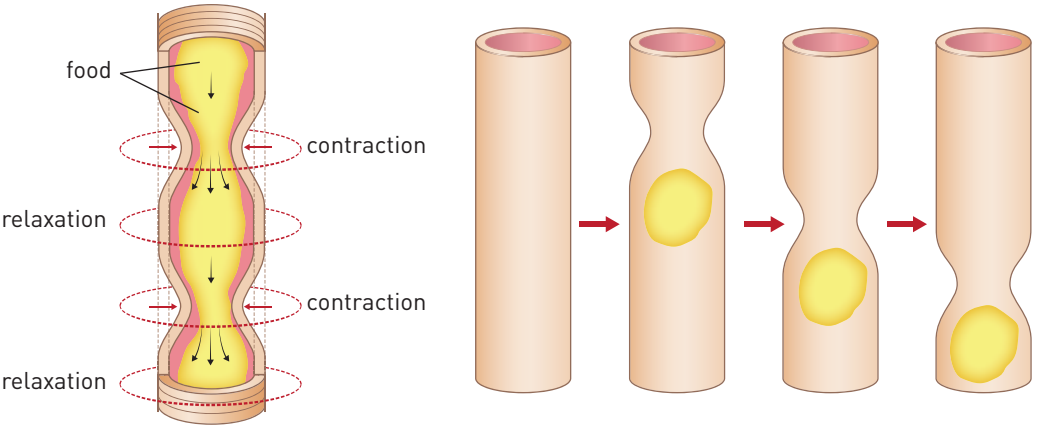

FIGURE 2 Peristalsis moves the food in the alimentary canal.

chemical digestion
the hydrolysis of complex organic molecules to smaller units that are small enough to pass through cell membranes; mediated by enzymes specific to each chemical

carbohydrase
the general term for an enzyme that breaks down carbohydrate

amylase
an enzyme that stimulates the conversion of polysaccharides to disaccharides

protease
the general term for an enzyme involved in the hydrolysis of proteins

lipase
the general term for an enzyme that is involved in the hydrolysis of lipids

nuclease
the general term for an enzyme involved in the hydrolysis of nucleic acids

As the pieces of food become smaller, their ratio of surface area to volume increases (see Figure 7 on page 79). This gives a greater surface area for the enzymes to attach and chemically digest the food. Physically breaking up the food makes digestion more efficient.

Chemical digestion

The decomposition of the large organic molecules involves hydrolysis that breaks down the chemical bonds between their basic units (monomers). This is known as **chemical digestion**. Complex carbohydrates are broken down into monosaccharides (such as glucose). Proteins are broken into amino acids, lipids into the subunits fatty acids and glycerol, and nucleic acids into nucleotides.

A different enzyme mediates the chemical digestion of each type of carbohydrate, protein, lipid or nucleic acid. The enzymes that chemically digest carbohydrates are called **carbohydrases** (e.g. **amylases,** lactase, maltase and sucrase). Each of these enzymes is

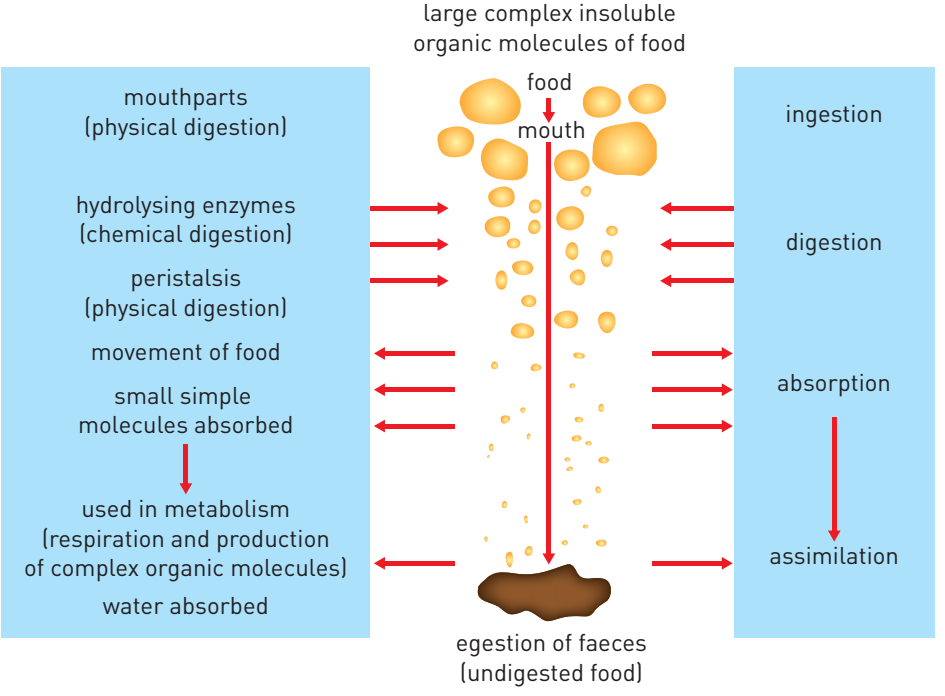

FIGURE 3 Stages in the acquisition of nutrients

specialised to digest only one type of carbohydrate. **Proteases** are the group of enzymes that digest proteins into their amino acid monomers, **lipases** chemically digest lipids and **nucleases** digest nucleic acids.

Some of these enzymes are produced in the cells lining the wall of the alimentary canal; others are formed in specialised glands (e.g. salivary glands) and pass through ducts (small tubes) into the cavity of the alimentary canal.

Digestion that occurs outside the cells is termed **extracellular** digestion. Chemical digestion may also occur within the cells of the body, and this is termed **intracellular** digestion.

extracellular
outside the cell

intracellular
inside cells

Absorption

Most nutrient molecules produced by digestion are small enough to pass through cell membranes by simple diffusion. Other molecules such as glucose require facilitated diffusion. Active transport will be used if a substance is absorbed against a concentration gradient. In larger animals, these molecules generally pass from the alimentary canal to a circulatory system which transports them to the appropriate cells.

Study tip

If the name of a molecule has -ase on the end, then it is usually an enzyme. The rest of the name is often a hint of its function. **Carbohydr**ases digest **carbohydr**ates, **prot**eases digest **prot**ein, **nucle**ases digest **nucle**ic acids and **lip**ases digest **lip**ids.

Assimilation

Once in the cells, digested nutrients are assimilated. The monomers are built up into complex compounds required by the body, converted into other forms as storage products for later use or broken down for energy release during cellular respiration.

Elimination

Any undigested food is eliminated from the gut as **faeces** in the process of egestion. Egestion is the process of removing food that was never part of the organism. This is different to excretion, which is the removal of the waste products of the chemical reactions in a cell.

faeces
a compacted, undigested food mass that is voided from an animal

CHECK YOUR LEARNING 7.1

Describe and explain

1 **Explain** the difference between the following pairs of terms:
   - **a** 'nutrition' and 'nutrient'
   - **b** 'autotroph' and 'heterotroph'
   - **c** 'intracellular digestion' and 'extracellular digestion'
   - **d** 'chemical digestion' and 'physical digestion'
   - **e** 'absorption' and 'assimilation'
   - **f** 'egestion' and 'excretion'.

2 **Explain** why digestion of food is necessary.

3 **Explain** how the development of a true body cavity has allowed specialisation of the alimentary canal.

4 **Explain** how the food is moved along the alimentary canal.

Apply, analyse and interpret

5 **Classify** digestion in the alimentary canal as 'intracellular' or 'extracellular'. **Explain** your answer.

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  Alimentary canal
- » Weblink
  Physical digestion
- » Weblink
  Chemical digestion

7.2 Digestion in humans

KEY IDEAS

- Humans as chunk feeders
- The general structure of the digestive system
- How the structure of the alimentary canal aids peristalsis
- The successive stages of chemical digestion of food
- The structure of the small intestinal lining to maximise nutrient absorption
- The assimilation of absorbed nutrients

Humans feed on large chunks of solid organic material derived from plant and animal organisms. Like other chunk feeders, they must be able to:

- obtain and ingest food
- physically and chemically digest the food
- absorb the digested molecules and transport them to the cells for assimilation
- egest undigested food.

Structure of the human digestive system

The digestive system of humans consists of an alimentary canal and associated organs. Throughout the length of the alimentary canal, each part is modified for a specific function. Other organs, such as the liver and pancreas, are linked with it and support its function. The overall structure of the digestive system, and the functions performed at each specialised part, are summarised in Figure 1. In the abdominal region, there are thin membranes (mesentery), through which blood and lymph vessels run, connecting the alimentary canal to the body wall. The mesentery membranes also hold the loops of the alimentary canal in the correct position.

The inner layer of the human alimentary tract differs along its length, reflecting its function at any particular point. However, the general structure is the same and consists of four basic layers:

1. The outer layer is connective tissue and is continuous with the thin supporting membrane (mesentery).
2. Inside the connective tissue is an external muscle layer, usually consisting of an outer layer of longitudinally oriented cells and an inner circular layer. These are smooth (involuntary) muscle cells. The muscles are not consciously controlled and are responsible for peristalsis.
3. The third layer contains the major blood and lymphatic vessels, nerves and stretch receptors connected by strong fibres of connective tissue.
4. The innermost layer consists of more smooth muscle fibres and loose connective tissue that supports the lining or epithelium. All glands of the alimentary tract are derived from this epithelium.

1. Salivary glands
2. Palate
3. Tongue
4. Teeth
5. Oesophagus
6. Diaphragm
7. Liver
8. Bile duct
9. Stomach
10. Gall bladder
11. Duodenum
12. Ileum
13. Appendix
14. Pancreas

In the **mouth**, food is digested both mechanically (physically) and chemically. Biting, chewing and grinding by the teeth increase the food surface area for the action of the digestive enzymes.

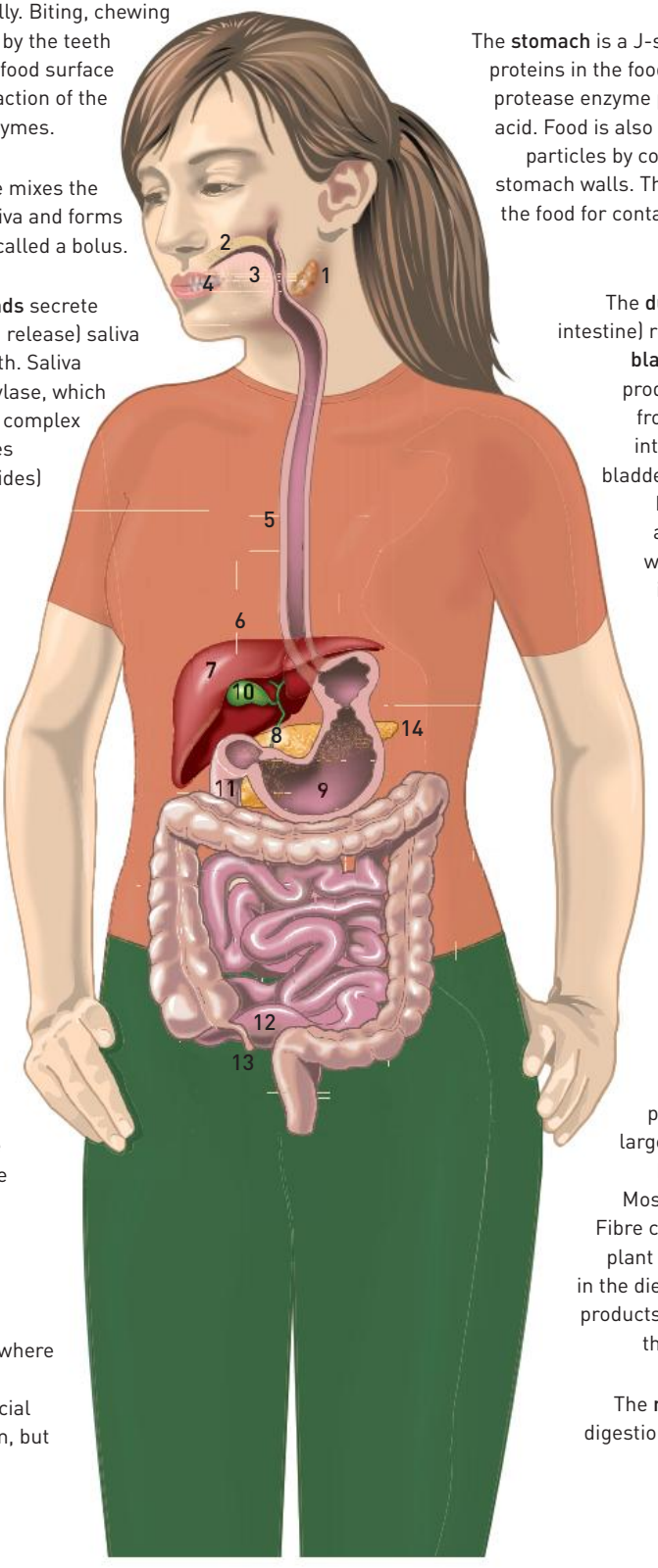
The B tongue mixes the food with saliva and forms it into a ball called a bolus.

Salivary glands secrete (produce and release) saliva into the mouth. Saliva contains amylase, which breaks down complex carbohydrates (polysaccharides) into the disaccharide maltose.

Digested food travels to the liver. Lipids, fatty acids and glycerol travel to the **lacteals** (lymph vessels), which join with veins and so enter the blood and move to the liver. The liver is the processing centre for the body's nutrients and wastes. It is the largest organ in the mammalian body other than the skin.

The **ileum** is the coiled, long section of the small intestine and follows from the duodenum. Digested food molecules are absorbed across the walls into blood capillaries. The walls of the ileum are arranged into projections called villi, which contain more projections called microvilli. The **villi** and **microvilli** increase the surface area for the absorption of food. The total surface area for absorption of nutrients has been estimated at over 4000 square metres.

The **caecum** is a blind pocket close to where the large and small intestine join. The caecum and the appendix have no special function in the human digestive system, but they are important in herbivores.



The **oesophagus** is a muscular tube down which food passes to the stomach.

The **stomach** is a J-shaped sac in which some of the proteins in the food are chemically digested by the protease enzyme pepsin activated by hydrochloric acid. Food is also physically broken down into fine particles by contractions of the muscles of the stomach walls. This increases the surface area of the food for contact with pepsin and the enzymes in the intestine.

The **duodenum** (first part of the small intestine) receives secretions from the **gall bladder** and the **pancreas** and also produces its own digestive enzymes from the glands in the walls of the intestine (intestinal juice). The gall bladder stores bile, which is produced by the liver. Bile has a detergent action, enabling the lipids to mix with the aqueous (water) solution in the intestine. Pancreatic juice contains proteases, amylases and nucleases, which break down proteins, complex carbohydrates, nucleic acids and some lipids into amino acids, sugars, phosphates, nitrogen bases, fatty acids and glycerol. The food is now present as small molecules, which can pass through the intestinal walls into the blood.

The **large intestine** (colon) absorbs water from the undigested food that passes from the small intestine. It also absorbs vitamins that are produced by bacteria living in the large intestine; for example, vitamin K is made by intestinal bacteria. Most of the undigested food is fibre. Fibre consists mainly of cellulose from plant cell walls. The presence of fibre in the diet is necessary, as it helps waste products to retain some water and move through the large intestine faster.

The **rectum** stores waste products of digestion (faeces), which are passed out through the **anus**.

FIGURE 1 The human digestive system

MANDATORY PRACTICAL
7.2A The effect of temperature on the rate of reactions of an enzyme
Go to page 407 »

SUGGESTED PRACTICAL
7.2B The effect of pH on the rate of enzyme reactions
Go to your obook »

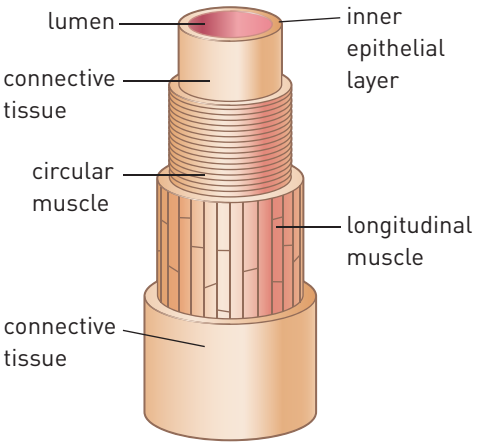


FIGURE 2 Section of the alimentary canal showing the general structure of the wall

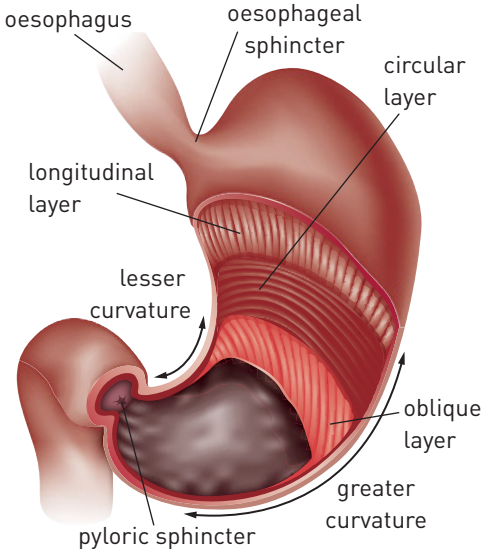


FIGURE 3 The structure of the stomach

Chemical digestion

The chemical digestion of each food type is controlled by specific enzymes, each of which works at an optimal pH. If the acid levels surrounding the enzyme are too high or too low, the enzyme becomes deformed and therefore will be unable to catalyse the digestion reaction. Different parts of the alimentary canal, therefore, carefully control the pH levels of their environment.

Chemical digestion of complex carbohydrates begins in the mouth where the pH is about 7.5 (slightly basic – alkaline). The salivary glands secrete a juice containing mucus and the enzyme salivary amylase. The mucus moistens the food and the salivary amylase starts the digestion of starch to a disaccharide (maltose).

Once the food reaches the stomach, gastric juice is secreted by glands in the stomach wall. This very acidic solution (pH 2) immediately stops the action of salivary amylase. Gastric juice contains the protein-digesting enzyme (a protease) called pepsin, which breaks complex proteins into smaller polypeptide chains and dipeptides. Pepsin is produced by the stomach gland cells in an inactive form and only becomes active when mixed with the stomach contents. Other proteases are also released. Some glands in the lining secrete mucus that protects the stomach wall from being digested. If this protective mucus is not produced in sufficient amounts, the stomach walls may become damaged by the acid and ulcers may form.

In the first part of the small intestine (the duodenum), secretions from both the liver (via the gall bladder) and the pancreas are introduced through the bile and pancreatic ducts to the acidic food mass that leaves the stomach. Bile (pH 7–8) contains waste materials from metabolism and the breakdown of old red blood cells by the liver. One of these products (bile salts) physically breaks up (**emulsifies**) lipids into small droplets. This increases the surface area available for lipases to act during chemical digestion. Pancreatic juice (pH 7–8.8) contains amylase, proteases, lipases and nucleases that chemically digest complex carbohydrates, proteins, lipids and nucleic acids respectively. The pH of both secretions neutralises the stomach acid to provide optimal pH for the pancreatic enzymes to act.

emulsify
break up large lipid particles into small droplets

TABLE 1 Key enzymes involved in digestion and their function

Enzyme	Function
Amylase	Digests amylose in complex carbohydrates to the disaccharide maltose (a simple sugar)
Carbohydrases	Digest disaccharides to monosaccharides
Proteases	Digest proteins to polypeptide chains and amino acids
Lipases	Digest lipids to fatty acids and glycerol
Nucleases	Digest nucleic acids to nucleotides to pentose sugars, phosphate groups and organic bases

Other secretions from glands in the walls of the small intestine (intestinal juice, pH 7.5–8.5) provide further carbohydrases, proteases, lipases and nucleases to complete chemical digestion of polymers to the monomers that can be absorbed. Mucus is also secreted to protect the cells lining the small intestine.

Absorption of nutrients

Absorption of nutrients involves osmosis, diffusion and active transport. Diffusion of the nutrients depends on a concentration gradient and the length of the diffusion pathway. For this reason, there is a large capillary network immediately below the lining cells of the intestinal cavity to remove the diffused nutrients. This maintains the large concentration gradient that contributes to effect diffusion.

Some absorption of water and glucose occurs across the lining of the stomach wall into the underlying capillaries. Most absorption of the small molecules resulting from chemical digestion occurs in the very long, coiled, second part of the small intestine, the ileum. The inner surface of the ileum has folds from which small finger-like **villi** (singular, villus) project. The folds help to slow down the passage of food and the villi increase the surface area for digestion and absorption. By contraction and swaying, the villi also circulate the contents.

The surface area is further increased in this area by hair-like extensions of the epithelia cells of the villi, called **microvilli**. As absorption proceeds, there is a rapid build-up of nutrients in epithelial cells. Monosaccharides, nucleotides and amino acids are removed from these cells into the bloodstream by the capillaries of the villi. Transport away from the cells is not always rapid enough and a concentration barrier may build up. It is only by active transport across the cell membranes that this can be overcome.

Glucose and galactose are absorbed more rapidly than the other monosaccharides. This is possibly because they undergo a chemical conversion when they first enter the epithelial cells, ensuring the maintenance of a very steep concentration gradient. These sugars then pass by diffusion into the capillaries that drain into the **hepatic portal vein**. This blood vessel acts as a short circuit, carrying the absorbed food molecules directly to the liver.

Small droplets of lipids, and their subunits, glycerol and fatty acids, are absorbed into the epithelial cells of the villi. There they are assembled into fat storage molecules (triglycerides), phospholipids and cholesterol (part of cell membranes) and packaged in a protein coat by the cells' Golgi bodies into structures called **chylomicrons**. They are released into the tissue fluid and taken up by lacteals (of the lymphatic system) in the villi. The lacteals lead to lymphatic vessels, which enter the blood supply just before its return to the heart. Small amounts of fatty acids and glycerol may also enter the capillaries of the villi.

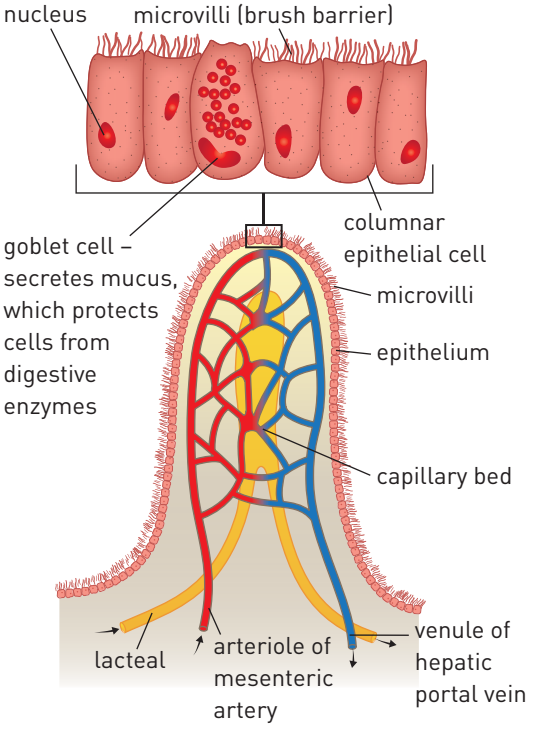


FIGURE 4 The structure of a villus

villus (plural villi)
a finger-like projection of the lining of the small intestine; increases the surface area available for absorption

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

hepatic portal vein
the vein which transports absorbed food molecules directly from the small intestine to the liver

chylomicron
small droplets of lipids, glycerol and fatty acids enclosed in a protein coat; involved in the absorption of products of fat digestion in the alimentary canal directly into the lymphatic system

Study tip

The term 'lipids' includes all fats and oils. Fats are solid at room temperature, while oils are liquids at room temperature.

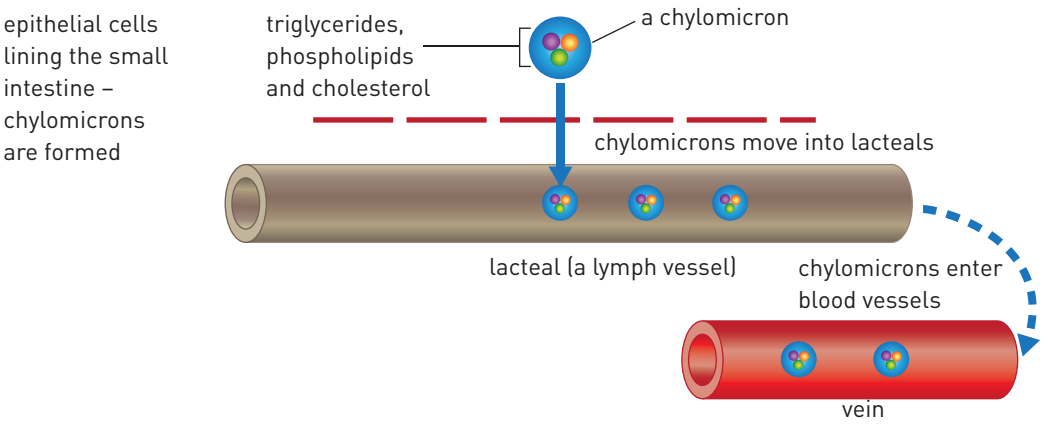


FIGURE 5 The transport of lipids as chylomicrons

Absorption of vitamins, inorganic salts and water also occurs in the small intestine. Water absorption takes place by osmosis as the gut contents develop a lower solute concentration (i.e. become hypotonic) compared to the blood.

The main function of the large intestine is the absorption of water. About 7 L of water enters the alimentary canal each day as a solvent for the digestive juices. Although most of this is reclaimed by absorption in the small intestine, the remainder must be removed in the colon, the largest part of the large intestine. This results in the compaction of solid, insoluble undigested material that is referred to as faeces. If the lining of the colon is irritated – for example, by some sort of infection – the undigested material moves too quickly, less water than normal is reabsorbed, and diarrhoea results. If the material passes through the colon too slowly, an excess of water is removed. The result is a faecal blockage called constipation.

In addition to the waste materials secreted in the bile from the liver, excess mineral salts may be secreted into the colon of the large intestine from blood vessels in its walls.

Normally there is quite a large bacterial community present in the large intestine. They obtain their nourishment from undigested food. In return for this continual supply of nutrients, they release by-products of their metabolism, vitamin K and several of the B group vitamins. These vitamins are absorbed through the large intestinal epithelium. This is virtually the only source of vitamin K, which is essential in the blood-clotting reactions in humans. Therefore, there is a mutualistic relationship (where both organisms benefit) between these bacteria and the human organism harbouring them.

Assimilation

assimilation the incorporation of simple organic molecules, or products of digestion, into complex constituents of the organism

Assimilation is the incorporation of nutrients into the body. These chemicals are carried from the intestine to the liver by the hepatic portal vein. In the liver they are stored, changed or redirected to other organs.

Amino acids are needed for growth, maintenance, repair and secretion, but they cannot be stored within cells. Amino acids taken into the body in excess of immediate needs must be changed in one of three ways:

- conversion to urea for removal by the kidneys
- transfer of amino groups to carbohydrates to produce glycoproteins which are needed by the body
- conversion to glucose and other carbohydrates.

CASE STUDY 7.2

Alcoholic beverages

Ethyl alcohol, the active component of alcoholic beverages, is a small molecule that is readily absorbed by the stomach and small intestine. This process is increased if there is no food present, particularly fats and proteins that slow down alcohol absorption. Absorption is also increased if the alcohol is mixed with carbonated fluid. Carbon dioxide stimulates movement of alcohol through the stomach, passing it rapidly to the intestine where the absorption rate is higher. In this way alcohol is rapidly absorbed into the bloodstream. The blood distributes the alcohol to the body tissues where it is slowly absorbed. Alcohol may therefore be present in the blood 18 hours after it was ingested.

Ten per cent of alcohol is removed from the body in the urine, breath and sweat. The remaining 90% must undergo three chemical reactions before it is eliminated. The first stage, conversion of alcohol to acetaldehyde, occurs only in the liver. The second and third stages – acetaldehyde to acetic acid, which is then converted to carbon dioxide, water and energy – may also occur in other organs.

Alcohol exerts its effects by depressing brain activity. As its concentration in the blood rises to between 0.05 and 0.1%, higher centres of the brain that control judgment, self-criticism and learnt inhibitions cease to operate effectively. Anxiety is therefore reduced and the individual has a sense of well-being and excitement. Between 0.1 and 0.5%, depression of brain activity causes the person to be less alert, have a hazy awareness of the surroundings, lose muscular coordination and become sleepy. At blood alcohol levels greater than 0.5%, they become impaired. This may lead to respiratory failure and/or shock associated with low blood pressure. Coma and death usually result at blood alcohol levels of approximately 0.55%.

Alcoholics are people who have an addiction to alcohol. Research has shown that alcoholism can result from a range of factors, including a genetic predisposition, environmental stress, social pressure or psychological disorders. For example, a person with an anxiety disorder is more vulnerable to alcohol use as a coping mechanism.

For alcoholics, alcohol assumes the characteristics of food. The body cells become so adapted to alcohol that they operate poorly in its absence. Continued excessive drinking causes inflammation of the stomach lining and poor digestion of food. Nausea makes food unpalatable. These factors result in loss of essential nutrients. Nerves, particularly in the legs, begin to degenerate and the excessive drinker experiences pain and weakness. Liver degeneration, caused by a number of changes to the cells collectively termed cirrhosis, usually results in death.

FIGURE 6 Alcohol can have a wide range of effects on the body

CHECK YOUR LEARNING 7.2

Describe and explain

1 **Explain** why protein-digesting enzymes are produced and secreted in an inactive form in the stomach.

2 **Describe** features of the small intestine that make it an efficient organ for the absorption of digested food.

3 **Describe** the digestion and absorption of fats in humans.

Apply, analyse and interpret

4 Read the following passage carefully and **apply** your knowledge to answer the questions.

Peristaltic contractions of the stomach keep the partly digested food moving towards the duodenum, the first loop of the small intestine. The duodenum is the main site of digestion in the gut. The agents of digestion come from three sources: the liver, pancreas and wall of the intestine. The liver produces bile, a mixture of substances not all of which are concerned in digestion. The digestive components are the bile salts that emulsify fats. It must be stressed that bile salts are not enzymes. Bile is also rich in sodium bicarbonate, which neutralises acid from the stomach. The pH of the small intestine is therefore distinctly basic (alkaline), which favours the action of the various enzymes. Some of these enzymes are constituents of the pancreatic juice that flows into the duodenum from the pancreas via the pancreatic duct. The main enzymes flowing into the small intestine are carbohydrases, proteases, lipases and nucleases.

- **a** **Describe** peristaltic contractions and what causes them.
- **b** **Explain** the term 'emulsify'.
- **c** **Consider** why bile salts are not classed as enzymes.
- **d** **Deduce** why the stomach contents are acidic.
- **e** **Determine** the function of each of the enzymes in the small intestine.

5 **Apply** your knowledge of digestion in humans to show how, after removal of the stomach, a person may continue to eat and digest a fairly normal diet. **Consider** what difficulties would arise in such a situation.

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7.3 Excretion

KEY IDEAS

- Osmoregulation and excretion
- The need for animals to excrete the products of the breakdown of excess amino acids
- Types of nitrogenous excretory products related to the medium in which the animal lives
- The structure and function of the human kidney
- The loop of Henle as a counter-current multiplier in water conservation

osmoregulation the physiological regulation of water and salt concentrations within the body

excretion the removal of metabolic wastes from the body

Animals are mobile heterotrophs. They expend energy in locating a food source and processing the food into molecules needed by the body and for general life functions. The concentrations of these different molecules dissolved and suspended in the cytoplasm, intercellular fluid and circulating fluid must be maintained within a particular range. This is achieved by **osmoregulation** (the control of water balance) and the **excretion** of metabolic wastes produced by the cell. In the majority of animals, an excretory system is involved in both processes.

Much metabolic waste material is removed from the animal through surfaces in contact with the environment. Carbon dioxide diffuses from the blood to the gas exchange and skin surfaces. Salts may be removed through the skin (e.g. by sweat in mammals). Salts are also secreted into the large intestine.

Not all molecules can be disposed of through the gas exchange surfaces or the skin. Protein molecules are much larger than carbon dioxide or metal salts. Proteins provide structural elements such as the muscles that bring about locomotion. As a result of their high metabolic demands, a large number of enzymes are needed, and these too are proteins. Proteins, therefore, are significant nutrients for animals. Many omnivores, including humans, and carnivores cannot synthesise all of the amino acids they need for the production of specific proteins, and these essential amino acids must be obtained from another animal source.

Amino acids derived from cell replacements and those taken in that are surplus to the body's requirements cannot be stored, and are broken down by the liver in vertebrates. In this process the nitrogen-containing amino group is removed from the amino acid. The nitrogen-based products either enter the respiratory pathway or are converted to a storage material and the nitrogenous compound **ammonia**.

ammonia an inorganic nitrogen compound; in animals, a toxic product of the breakdown of excess amino acids

Ammonia

Ammonia (NH_3) is highly toxic to animal cells. It dissolves readily in water and forms a caustic base that will damage cells. For this reason, ammonia must be either rapidly removed from the body or converted to a less toxic compound such as urea or uric acid.

Marine and freshwater invertebrates, bony fish and larval or permanently aquatic amphibians can excrete ammonia directly to their environment by rapid diffusion through permeable surfaces (e.g. the gills) in contact with water. The surrounding water quickly removes the ammonia from the area.

Urea and uric acid

urea a water-soluble nitrogenous excretory product of protein breakdown

Urea is less toxic than ammonia and can be retained in the body for limited periods before removal. Being more soluble than ammonia, it requires less water for elimination, but energy is needed to convert ammonia to urea. Mammals and most adult amphibians excrete urea in their urine.

uric acid
a complex non-toxic nitrogenous excretory product that is only slightly soluble; present in waste in reptiles and birds

urine
the excretory fluid produced in the kidney, containing metabolic wastes (urea, salts) in a watery solution

ureter
the duct which leads from the kidney to the bladder

bladder
the storage organ for urine in vertebrate animals

urethra
the tube running from the bladder to the body's exterior; in human females, it functions to eliminate urine; in human males, the vas deferens joins the urethra, which therefore functions in the elimination of semen as well as urine

cortex
the outer part of a structure, e.g. the outer part of the vertebrate kidney in which are found the Bowman's capsule, glomerulus and convoluted tubules of the nephron

medulla
the inner layer of a structure, e.g. the medulla of the vertebrate kidney contains loops of Henle and collecting tubules

Study tip

The kidney medulla is in the middle of the kidney. The **c**ortex is just under the **c**apsule of the kidney.

FIGURE 1 Human kidneys

Terrestrial insects, snails, birds and most reptiles excrete **uric acid**. Conversion of the toxic ammonia to the less toxic uric acid is a complex energy-requiring process that is an adaptation to water conservation (it helps animals avoid having to dilute the urea or ammonia in water). Uric acid is virtually insoluble in water and is non-toxic. It is excreted as a thick white paste of uric acid crystals in birds and as a solid pellet in insects.

In mammals, the separation of excretory substances from blood and the conservation of water are performed in a pair of kidneys. Waste materials dissolved in water (**urine**) pass from the kidneys through the **ureters** to be stored in the **bladder**. The urine eventually passes to the external environment through the **urethra**.

Structure and function of the human kidney

The excretory system includes a pair of kidneys that remove excretory products from the blood plasma. The urine formed passes through the ureters to the bladder for storage and is eventually eliminated from the body via the urethra.

The kidney is a bean-shaped organ. It is enclosed by a capsule of connective tissue and composed of two layers of tissue: an outer, darker-coloured **cortex** and an inner, lighter-coloured **medulla**, surrounding a central cavity.

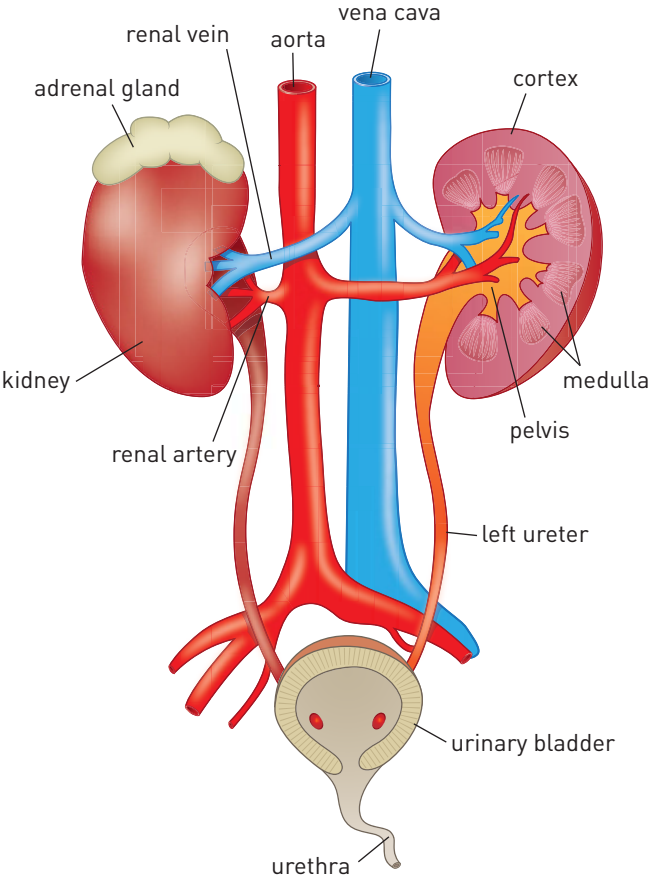

FIGURE 2 The human excretory system

The two kidneys are found at either side of the vertebral column in the abdominal cavity between the lowest rib and the top of the hip bone. They are connected to the circulatory system via the **renal arteries** (which carry the blood to the kidneys) and the **renal veins** (which return the 'cleaned blood' to the heart) and to the bladder via the ureters. Within the central cavity of the kidney, the top of the ureter expands to form the **renal pelvis**. The inner medulla of the kidney is divided into lobes of approximately conical shape that are called the **pyramids**. The renal artery forms branches between the pyramids that deliver blood to the outer cortical region containing the **nephrons.** These are drained by branches of the renal vein.

The nephron is the functional unit of the kidney. Each kidney contains between one and two million nephrons embedded in loose connective tissue and richly supplied with blood. Each nephron consists of an elongated tubule closely associated at one end with a group of blood capillaries (the **glomerulus**) via a cup-shaped **Bowman's capsule** and opening at the other end into a **collecting duct**. Many nephrons open into each collecting duct, which drains into the pelvis as urine and so out through the ureter.

The nephron tubule has distinct portions. The Bowman's capsule, wrapping around the glomerulus, opens into the **proximal convoluted tubule**, which is highly coiled. This leads to the U-shaped **loop of Henle** and on to the coiled **distal convoluted tubule**, which opens into the collecting duct. Only the loop of Henle and the collecting duct are in the medulla. The rest of the nephron is contained within the cortex of the kidney.

Blood enters the capillaries of the glomerulus from the **afferent arteriole**, a branch of the renal artery. It leaves in the **efferent arteriole**, which leads into a capillary bed surrounding the nephron tubules. In this way, blood passing through the renal tissues passes successively through two sets of capillaries before entering the venous drainage leaving the kidney.

Each nephron has three main functions:

1 The blood is filtered.
2 Required molecules and water are reabsorbed.
3 Unwanted waste molecules are secreted.

Filtering

Blood enters the glomerulus under high pressure. Water, ions and small molecules such as glucose, amino acids and urea are forced through the capillary wall and lining of the Bowman's capsule into the capsular space by **ultrafiltration**. The filtrate has a composition similar to that of plasma, but without the larger protein molecules. Blood cells normally do not leave the blood vessels.

Reabsorption

As the filtrate leaves Bowman's capsule it passes into the proximal convoluted tubule where many of the useful constituents are reabsorbed into the surrounding capillary network. The cells lining the proximal convoluted tubule actively absorb glucose and amino acids. The tubule cells have a brush border of microvilli to increase surface area for absorption and are heavily loaded with mitochondria for energy production. Sodium ions are also actively absorbed in the proximal tubule, creating an ionic imbalance that results in the passive diffusion of the negative chloride ions. Water leaves the tubule under the influence of the osmotic gradient established by the high plasma protein levels in the capillaries. The function of the loop of Henle is the reabsorption of water. The distal convoluted tubule appears to be responsible for the uptake of certain ions.

The loop of Henle as a counter-current multiplier

The loop of Henle enables mammals to reabsorb very large quantities of water from the filtrate, resulting in urine that is hypertonic to the blood.

The walls of the descending loop are permeable to water but impermeable to sodium chloride and urea. In solution, sodium chloride dissociates into positive sodium ions and negative chloride ions. The walls of the ascending loop are impermeable to water and urea but actively pump sodium ions into the surrounding tissue fluid. The negative chloride ions

renal artery
the blood vessel entering the kidney

renal vein
the blood vessel leaving the kidney

renal pelvis
the funnel-shaped expansion of the ureter before it leaves the kidney

pyramid
the bundle of collecting ducts in the mammalian kidney

nephron
the functional unit of the vertebrate kidney

glomerulus
the capillary knot found in Bowman's capsule through which ultrafiltration of blood (plasma minus protein) into the nephron of the mammalian kidney occurs

Bowman's capsule
the area of the mammalian kidney nephron in which ultrafiltration of the blood occurs

collecting duct
a duct into which waste materials from each nephron in the kidney drain

proximal convoluted tubule
the tubule of the kidney nephron arising from Bowman's capsule and leading to the loop of Henle; responsible for the reabsorption of glucose, sodium chloride and water

loop of Henle
area between proximal and distal convoluted tubules of the nephron in the mammalian kidney; is a counter-current multiplier whereby high salt concentration in the tissue fluid is maintained, resulting in diffusion of water from the filtrate to the surrounding blood capillaries

distal convoluted tubule
part of the nephron which joins the loop of Henle to the collecting duct; responsible for the reabsorption of sodium, potassium, phosphate and calcium ions under the control of hormones

afferent arteriole
the arteriole leading into a structure, e.g. the glomerulus of the kidney

efferent arteriole
the arteriole leaving a structure, e.g. the glomerulus of the kidney

ultrafiltration
the removal of most of the plasma and its contents from a capillary under high pressure, e.g. in the kidney

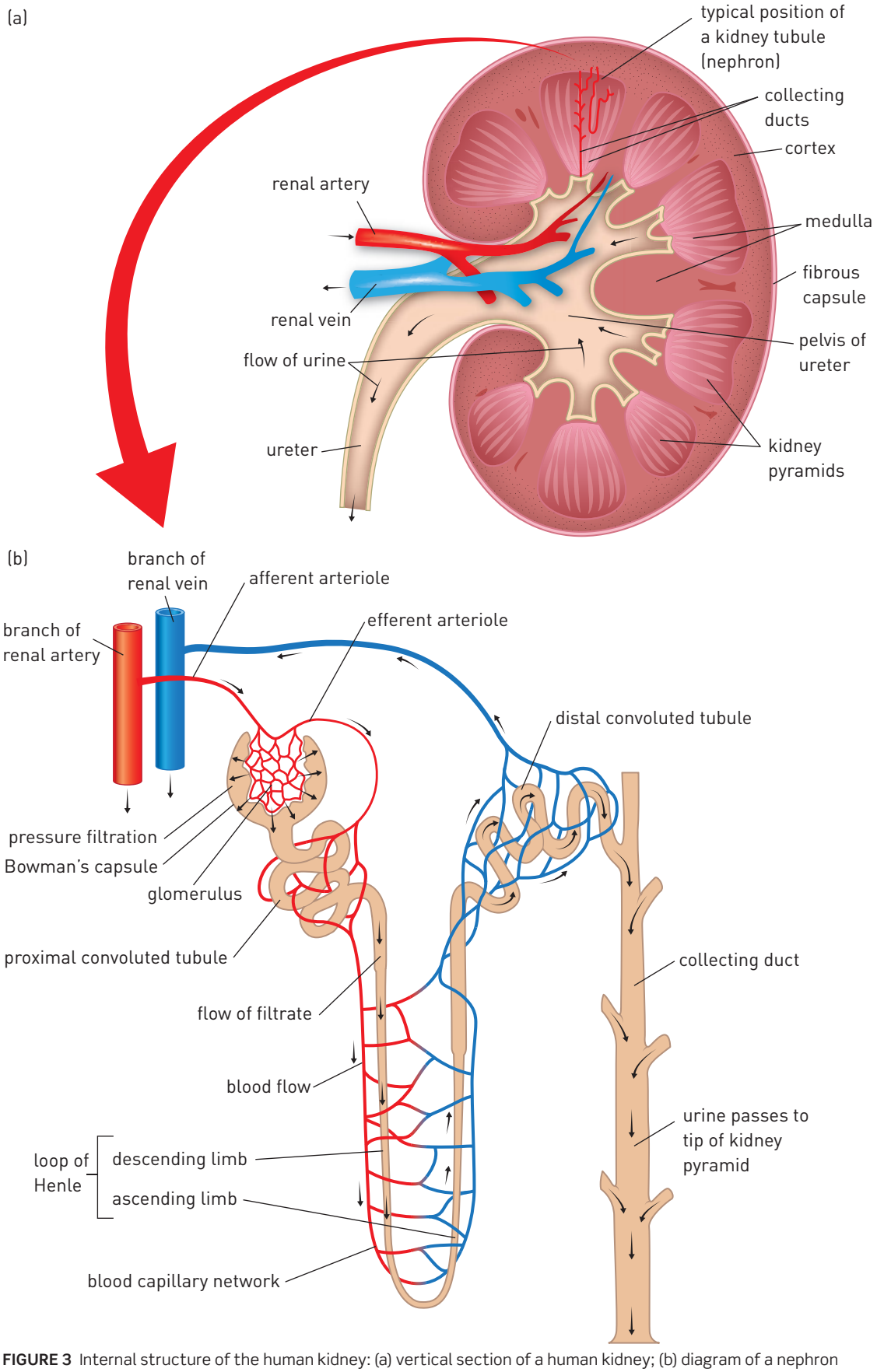

FIGURE 3 Internal structure of the human kidney: (a) vertical section of a human kidney; (b) diagram of a nephron

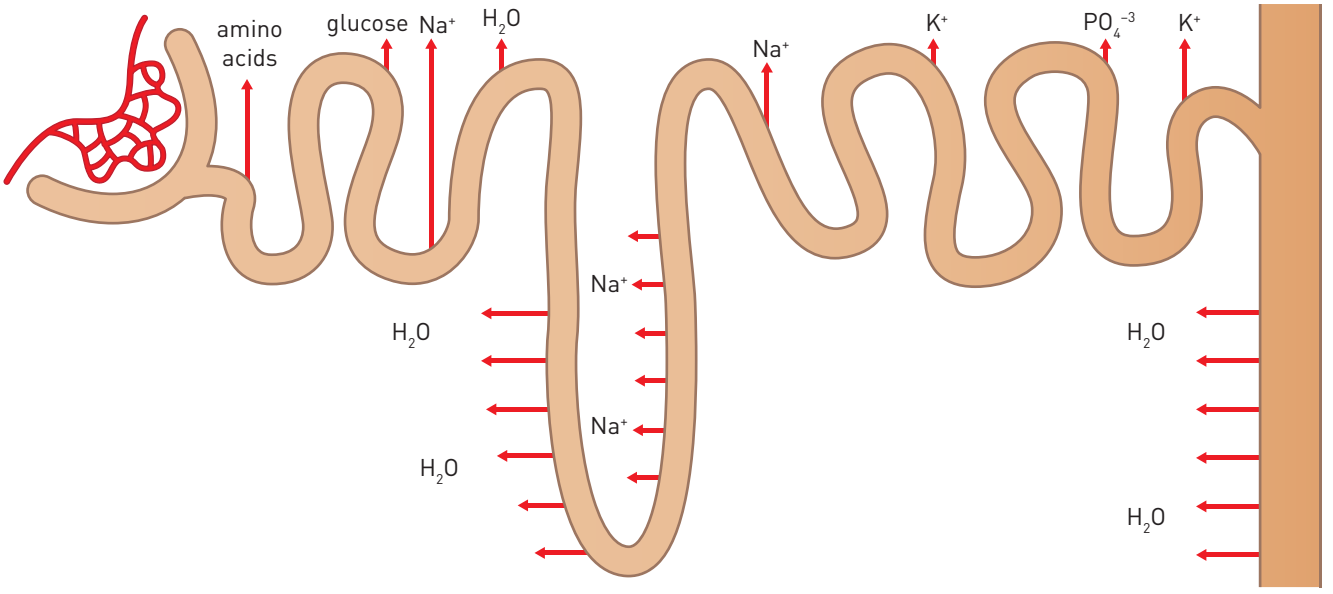

FIGURE 4 Summary of absorption in the nephron

follow along an ionic gradient. This means the filtrate that travels down the descending limb loop of Henle is surrounded by a highly concentrated tissue fluid. The concentration of filtrate increases towards the base of the loop. This then maintains a large concentration gradient along the whole depth of the loop. Water therefore diffuses out of the descending limb. Some of the sodium chloride diffuses into the blood capillaries, followed by water. The flow of blood constantly removes these substances from the kidney into the general body circulation.

As the water is removed from the descending loop, the salt concentration of the filtrate increases and is hypertonic (more concentrated) to the blood at the bottom of the loop.

When the salt is reabsorbed from the ascending loop, the filtrate becomes hypotonic (less concentrated than blood) once more.

At any given level of the loop, therefore, the sodium concentration in the descending loop is raised slightly above that in the ascending loop. The sodium concentration in the descending loop is always just below that of the fluid surrounding it, ensuring removal of water. This concentrating effect is multiplied along the length of the loop from top to bottom, so that the longer the loop, the greater is the concentration that can be reached. This system is therefore termed a counter-current multiplier.

The high concentration of sodium chloride in the tissue fluids also brings about diffusion of water from the collecting duct. Hormones regulate how much water can be reabsorbed by the collecting duct. The build-up of sodium ions around the base of the loop of Henle creates an osmotic gradient between this region and the urine in the collecting duct. If the walls of the collecting duct are permeable to water, water moves from the duct to the surrounding tissues by osmosis. The water passes to the capillaries. The higher the sodium concentration in these conditions, the greater is the amount of water that can be withdrawn from the urine. The amount of urine produced will be small and highly concentrated. If, however, the walls of the collecting duct are impermeable to water, then no further changes to the concentration occur and the animal excretes large amounts of dilute urine.

The amounts of sodium, potassium, phosphate and calcium reabsorbed by the distal tubule cells are regulated by hormones from the adrenal and parathyroid glands, depending on their levels in the plasma.

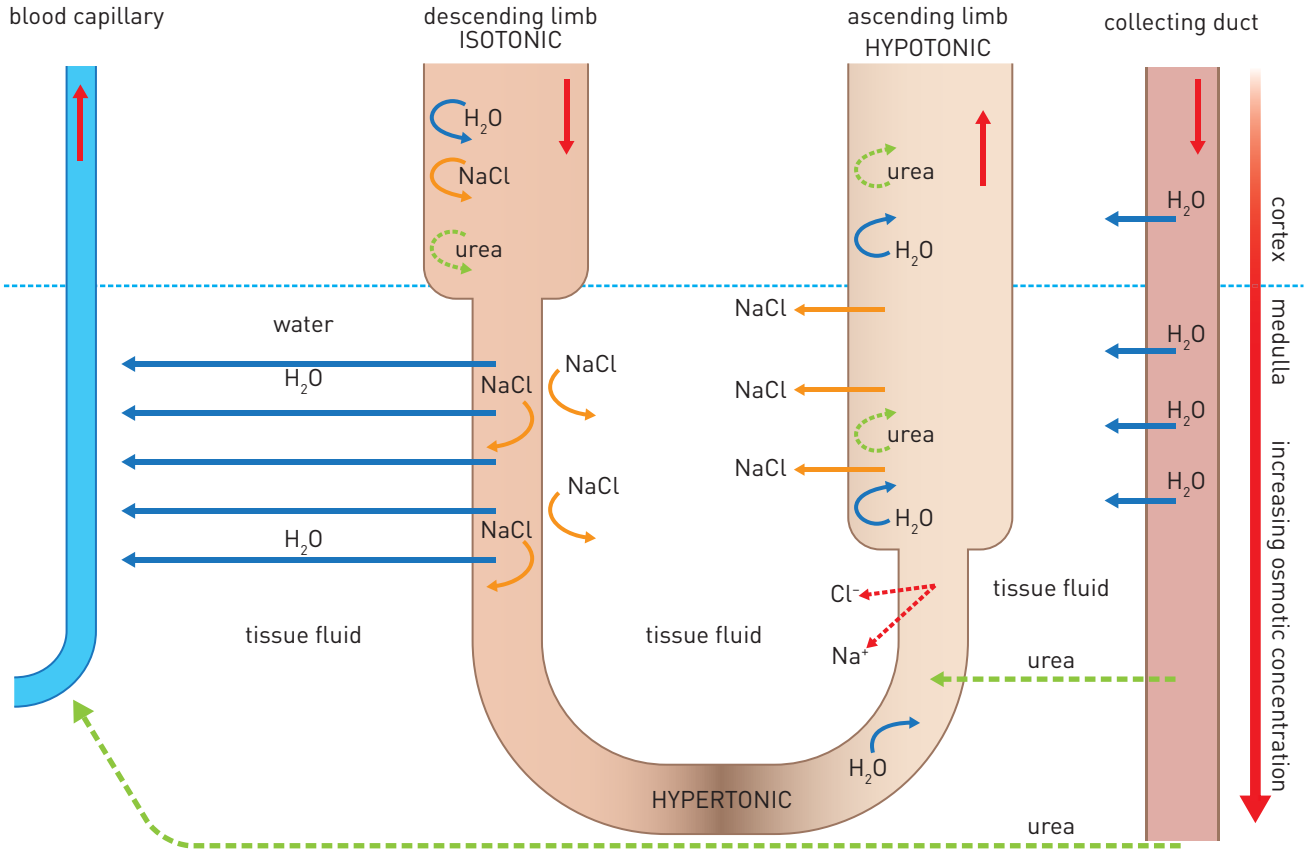

FIGURE 5 The role of the loop of Henle in water reabsorption

Effect of diabetes on kidney function

Diabetes is a medical condition that can occur in two forms. Diabetes mellitus results from an inability to control blood sugar levels. Normally the pancreas secretes the hormone insulin, which converts excess blood glucose to glycogen for storage. A person may not be able to produce enough insulin (diabetes type 1) or may develop an insulin resistance (diabetes type 2). In both cases, there is an excess of glucose in the blood. The proximal convoluted tubule of the nephron can remove only a limited amount of glucose from the glomerular filtrate. When this threshold is reached, the glucose is excreted in the urine. This affects the ability of the nephron to reabsorb water.

Diabetes insipidus is another form of diabetes. It results from either a failure in the production of the hormone that controls water reabsorption by the distal convoluted tubule and collecting duct, or the failure of the kidneys to respond to this hormone. Copious, dilute urine is therefore released.

In both forms of diabetes, there is excessive urination, dehydration of the body and extreme thirst.

CHECK YOUR LEARNING 7.3

Describe and explain

1 **Explain** the difference between osmoregulation and excretion.

2 **Explain** why animals produce a high level of nitrogenous wastes.

3 Read through the following account of kidney function and then fill in the most appropriate word or words to complete the account.

Blood entering the kidney from the . . . (a) . . . passes into an afferent arteriole which divides to form the . . . (b) . . . inside the cup of a . . . (c) . . . Much of the blood is forced into the tubule by the process of ultrafiltration. Only blood cells and large molecules such as . . . (d) . . . and some fluid remain in the blood vessel. The filtrate is a watery fluid rich in food substances such as glucose and . . . (e) . . . . Normally all the glucose is reabsorbed by the blood vessels surrounding the proximal convoluted tubule. Most of the . . . (f) . . . are also reabsorbed, causing a passive movement of water out of the tubule due to the osmotic gradient now exerted by the blood. Further reduction of the water content of the filtrate takes place when . . . (g) . . . occurs in the loop of Henle as a result of . . . (h) . . . being actively pumped out of the . . . (i) . . . limb of the loop. This forms a very high osmotic gradient between the loop of Henle and the . . . (j) . . . resulting in water being withdrawn and production of a . . . (k) . . . urine. Any increase in the osmotic pressure of the blood stimulates . . . (l) . . . in the . . . (m) . . . to bring about increased release of . . . (n) . . . by the posterior pituitary gland. This hormone . . . (o) . . . the permeability of the collecting duct wall so that . . . (p) . . . leaves it.

4 **Explain** the effect that each of the following will have on the quantity and composition of urine.

- **a** Drinking a large amount of water
- **b** Eating a very salty meal
- **c** A hot dry day
- **d** Low arterial pressure

5 **Explain** the function of the kidney in:

- **a** excretion
- **b** osmoregulation.

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CHAPTER 7

Review

Chapter summary

7.1 Heterotrophs get their food, and therefore energy requirements, from other organisms. Different sources of organic matter are available to heterotrophs from living and dead organisms. Since the food eaten contains particles too large to pass through the cell membrane, it must be broken down into small molecules. All heterotrophs must take in, digest, absorb and assimilate organic matter. Undigested material is egested.

7.2 Human digestion occurs in the alimentary canal. Different parts of the alimentary tract are specialised for different functions.

In the buccal cavity, the teeth and tongue are responsible for physical digestion of food, and chemical digestion of starch by salivary amylase occurs. The stomach can enlarge to store food. Muscular contractions of the stomach continue physical digestion of food and mix the contents. The folded inner lining contains glands that produce gastric juice, containing acid and enzyme precursors that are activated only within the cavity of the stomach. The enzyme pepsin digests proteins to polypeptides. Absorption of water and glucose occurs.

The duodenum is primarily involved in digestion. The lining is folded, slowing down movement of food. It has numerous small projections, or villi, which increase surface area; it also has glandular areas.

Acidic 'food' in the duodenum stimulates secretions from the gall bladder, intestinal glands and pancreas. Bile from the gall bladder brings about emulsification of fats. Pancreatic juices contain enzymes and their precursors in an alkaline fluid. Intestinal juice secreted from glands in the duodenal wall also contains enzymes in an alkaline medium. Other glands secrete mucus that protects the intestinal wall. Enzymes (carbohydrases, proteases, lipases and nucleases) in the intestine, which operate in alkaline conditions, complete digestion of the food.

Small molecules pass by diffusion and active transport into the cells of the villi that line the ileum and on to the capillaries. Most of the fat molecules are absorbed by lacteals and transferred to lymphatic vessels. Undigested food is passed into the large intestine.

Bacterial decay of remaining food occurs in the colon. This produces vitamin K, which is important in human blood-clotting, and also produces vitamins in the B group. These vitamins and water are absorbed in the colon. Excess salts are secreted from blood vessels into the large intestine for elimination. Compacted undigested material is passed to the rectum and finally egested through the anus as faeces.

Absorbed food is stored, changed or redirected in the liver.

7.3 Metabolic wastes are excreted through the skin, the respiratory and the urinary systems.

The human urinary system also acts as an organ of osmoregulation.

Blood, carrying wastes, passes into the kidney. The wastes are removed and the water balance normalised. The urine so formed leaves the kidneys in the ureters to the bladder, where it is stored until removal through the urethra.

The functional unit of the kidney is the nephron. Blood serum containing small molecules enters the nephron under pressure. Constituents such as glucose, salts and water are reabsorbed by the nephron tubules. The amount of water that is lost in the urine is controlled at both the loop of Henle and the collecting ducts.

Key terms

- afferent arteriole
- ammonia
- amylase
- anus
- assimilation
- bladder
- Bowman's capsule
- carbohydrase
- carbohydrate
- chemical digestion
- chunk feeder
- chylomicron
- collecting duct
- cortex
- distal convoluted tubule
- efferent arteriole
- egestion
- emulsify
- essential nutrient
- excretion
- extracellular
- faeces
- glomerulus
- hepatic portal vein
- heterotroph
- intracellular
- lipase
- loop of Henle
- medulla
- microvillus
- mouth
- nephron
- non-essential nutrient
- nuclease
- nutrient
- osmoregulation
- peristalsis
- physical digestion
- protease
- proximal convoluted tubule
- pyramid
- renal artery
- renal pelvis
- renal veins
- ultrafiltration
- urea
- ureter
- urethra
- uric acid
- urine
- villus

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 In mammals, the structure that takes urine from the bladder to the exterior is called the:

- **A** urethra
- **B** ureter
- **C** uriniferous tubule
- **D** anus

2 The Bowman's capsule is found in the region of the kidney called the:

- **A** pelvis
- **B** pyramid
- **C** cortex
- **D** medulla

3 The best description of digestion is the:

- **A** action of enzymes on food in the digestive tract
- **B** breakdown of complex organic molecules into small molecules that can be used by the body
- **C** dissolving of food and its absorption into the blood
- **D** breaking up of food into soluble molecules that can diffuse through cell membranes

4 Three of the following aid the transfer of certain substances from the bloodstream to the tubules of the mammalian kidney. Which one does **not**?

- **A** The considerable surface area of the capillaries comprising the glomerulus
- **B** The relatively small sizes of the molecules (or ions) of these substances
- **C** The larger diameter of the arteriole leaving Bowman's capsule compared with the diameter of the arteriole entering the capsule
- **D** The relatively great length of each of the tubules

Short answer

Describe and explain

★**5** **Explain** what happens to the blood as it passes through the kidney and lungs.

★**6** The presence of fat in the small intestine has been shown to inhibit the secretion of gastric juice and therefore slow down the activity of the stomach. **Explain** why, in normal circumstances, this would be an advantage.

Apply, analyse and interpret

★★**7** The table below shows the percentage of nitrogen excreted in various forms by four different animals.

Animal	Percentage of nitrogen excreted			
	Ammonia	Urea	Uric acid	Other
I	68.0	3.0	0.7	28.3
II	3.5	85.0	2.2	9.3
III	3.0	0.2	80.8	16.0
IV	73.3	9.9	0.0	16.8

Analyse the information to **determine** which animal would be best adapted to a dry terrestrial environment in terms of water conservation. Explain your answer.

★**8** **Determine** which factors contribute to the movement of substances out of the blood at the glomerulus and into Bowman's capsule.

★★**9** The table below gives information about substances filtered from blood in normal human kidneys, and excreted as urine.

Substance	Approximate daily quantities	
	Filtered through glomerulus (g)	Excreted in urine (g)
Water	180×10^3	1.5×10^3
Sodium as (Na^+ ions)	550.0	2.5
Glucose	187.0	0.0
Amino acids	8.5	0.1
Urea	51.0	30.0

Of the filtered water, 80% is reabsorbed in the proximal convoluted tubule and in the descending loop of Henle. Using this information and your own knowledge, **infer** a reason for the differences in quantities for each of these substances.

Investigate, evaluate and communicate

★ **10** Digestion of chunks of food is either within a food vacuole or extracellular. **Propose** possible reasons for this phenomenon.

★★ **11** Diets that are low in nutrients, such as those consisting of mainly corn and beans, can lead to a prolonged loss of genuine appetite. To help restore proper diets in regions where this is common, considerable scientific research has been applied in recent years to finding alternative, inexpensive foods for people affected by this.

You have been asked to evaluate the following Australian breads for production (and consumption) in regions affected by nutrient-deficient diets.

Type	Protein (%)	Fats (%)	Carbohydrates (%)
White bread I	20.0	2.4	38.4
White bread II	7.4	3.2	62.5
Brown bread III	10.7	1.3	47.8
Cornmeal bread IV	5.8	2.4	50.7

Having regard to the dietary needs of people, **determine** which bread should be recommended? Fully **justify** your response.

★★★ **12** In *The Beverly Hills Diet*, author Judy Mazel claims that we get fat not because we eat too many calories, but because we do not digest our food properly. Anything that is not digested is turned into fat. She also claims that we must not combine fats, carbohydrates and proteins in one meal since they cannot be digested together.

Evaluate these claims and write a scientifically justified response to them.

Check your obook assess for these additional resources and more:

- **» Student book questions**
  Chapter 7 review
- **» Revision notes**
  Chapter 7
- **» assess quiz**
  Chapter 7 auto-correcting multiple-choice quiz
- **» Flashcard glossary**
  Chapter 7 glossary

CHAPTER 8

Plant systems – gas exchange and transport

The cellular structure of plants determines their overall structure and the way they perform their life functions. Due to the cell wall around each cell, plant cells (and so the organism as a whole) lack mobility. Plants therefore either drift on the surface of water or are attached to the substratum. As a result, they must be able to utilise resources effectively from very limited surroundings. Since they are non-motile, however, the energy demands of plants are relatively low. If conditions become adverse, plants without the necessary adaptations will die.

Although the cell wall limits movement, it also brings about turgor pressure within the cells, which provides a 'skeletal' structure to individual cells and therefore to the whole plant. This support is further enhanced in some plants by the deposition of lignin in the cell walls of particular tissues. Rings and spirals of lignin within the cell wall produce strong mechanical properties.

As the major producers of chemical bond energy and oxygen, plants play a vital role in all ecosystems.

The gas exchange and transport systems, as in animals, are integrally linked. Photosynthesis requires water that is supplied by the transport from the roots and a gas exchange system that occurs in the leaves, stems and root hairs.

FIGURE 1 The cross-section of a dicotyledon root shows the conducting tissues (xylem and phloem) that are vital to the plant's survival.

OBJECTIVES

→ Explain how the leaf facilitates gas exchange (oxygen, carbon dioxide and water vapour) in plants.
→ Explain the relationship between photosynthesis and the main tissues of leaves (spongy and palisade mesophyll, epidermis, cuticle and vascular bundles).
→ Describe the role of stomata and guard cells in controlling the movement of gases (oxygen, carbon dioxide and water vapour) in leaves.
→ Describe and contrast the structure and function of xylem and phloem tissue (sieve tubes, sieve plates, companion cells).
→ Explain how water and dissolved minerals move through xylem and the roles of root pressure, transpiration stream and cohesion of water molecules.
→ Discuss the factors (light, temperature, wind, humidity) that influence the rate of transpiration.
→ Explain the transport of products of photosynthesis and some mineral nutrients via translocation in the phloem.

Source: *Biology 2019 v1.2 General Senior Syllabus*
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PRACTICALS

SUGGESTED PRACTICAL	**8.5A** Investigation of plant leaves, stems and roots
MANIPULATIVE SKILL	**8.5B** The passage of water through flowering plants
MANIPULATIVE SKILL	**8.5C** Stomatal function
SUGGESTED PRACTICAL	**8.6** Factors affecting the rate of transpiration

8.1 Gas exchange: photosynthesis

KEY IDEAS

- The structure of the plant leaf
- Adaptations of the leaf for photosynthesis by maximising uptake of light and providing the raw materials required

lamina
the leaf blade

petiole
leaf stalk

xylem
a complex tissue composed of living and dead cells; the tracheids and vessels are the non-living components through which water and dissolved mineral nutrients pass from the roots to the leaves in the transpiration stream

phloem
a complex tissue composed of living and dead cells; its functional unit consists of a sieve element and a companion cell. Sieve tubes (composed of sieve elements end-to-end) provide the route for the movement of organic solutes in vascular plants

epidermis
the outermost layer of cells in plants and animals

cuticle
the superficial, non-cellular layer covering a plant or animal

stoma (plural stomata)
pore in leaf epidermis, bound by guard cells; allows gas exchange and transpiration

Photosynthesis is the process that converts radiant energy from the sun into the chemical bond energy of glucose. As described in Chapter 4, it occurs in chloroplasts within specialised cells. Oxygen is released as a waste product of the process. The overall reaction can be given as:

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose + oxygen}$$

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

In this way, inorganic compounds, such as water and carbon dioxide, with low chemical bond energy are converted to an organic compound with high chemical bond energy. Plants exhibit a wide variety of adaptations to obtain access to sufficient light for photosynthesis.

Plant adaptations for photosynthesis

In complex plants, most photosynthesis occurs in one specialised organ, the leaf. The typical leaf consists of a broad, flat part called the **lamina**, which is joined to the rest of the plant by a stalk or **petiole**. Running through the petiole are vascular bundles containing the **xylem** (transporting water and mineral ions from the roots) and **phloem** (transporting sugars and other small organic molecules between different parts of the plant).

The leaf consists of several layers of tissues. A layer of closely fitting, flat cells covers the top and bottom surfaces of the leaf (the **epidermis**) and protects the inner layers of cells. The epidermal cells often secrete a waxy **cuticle** reduces evaporation of water from the cells. Small holes called **stomata** (singular, stoma) are usually found in the lower epidermis on the underside of the leaf, although they can also be found on the upper epidermis. A pair of sausage-shaped guard cells that can open or close the space between them surrounds each stoma. If the plant has lost a lot of water through evaporation, the guard cells also lose water and become less turgid. This causes the cells to move close to each other and make the space (stoma) between them become smaller. When the plant (and guard cells) have a lot of water, the cells become turgid and the ends push against each other. This pushing apart causes the stoma to become larger. Unlike epidermal cells, the guard cells contain chloroplasts.

In most leaves the majority of photosynthesis is carried out in the upper cell layers. The upper leaf surface therefore receives most of the light energy. As a consequence, it is also subjected to higher temperatures and greater air movement. Both of these factors increase the rate of evaporation. Water loss from the leaf is reduced when most stomata are on the under surface of the leaf.

Much of the carbon dioxide needed for photosynthesis passes through the stomata along a diffusion gradient from the air to the cells. Carbon dioxide is continually being used in the

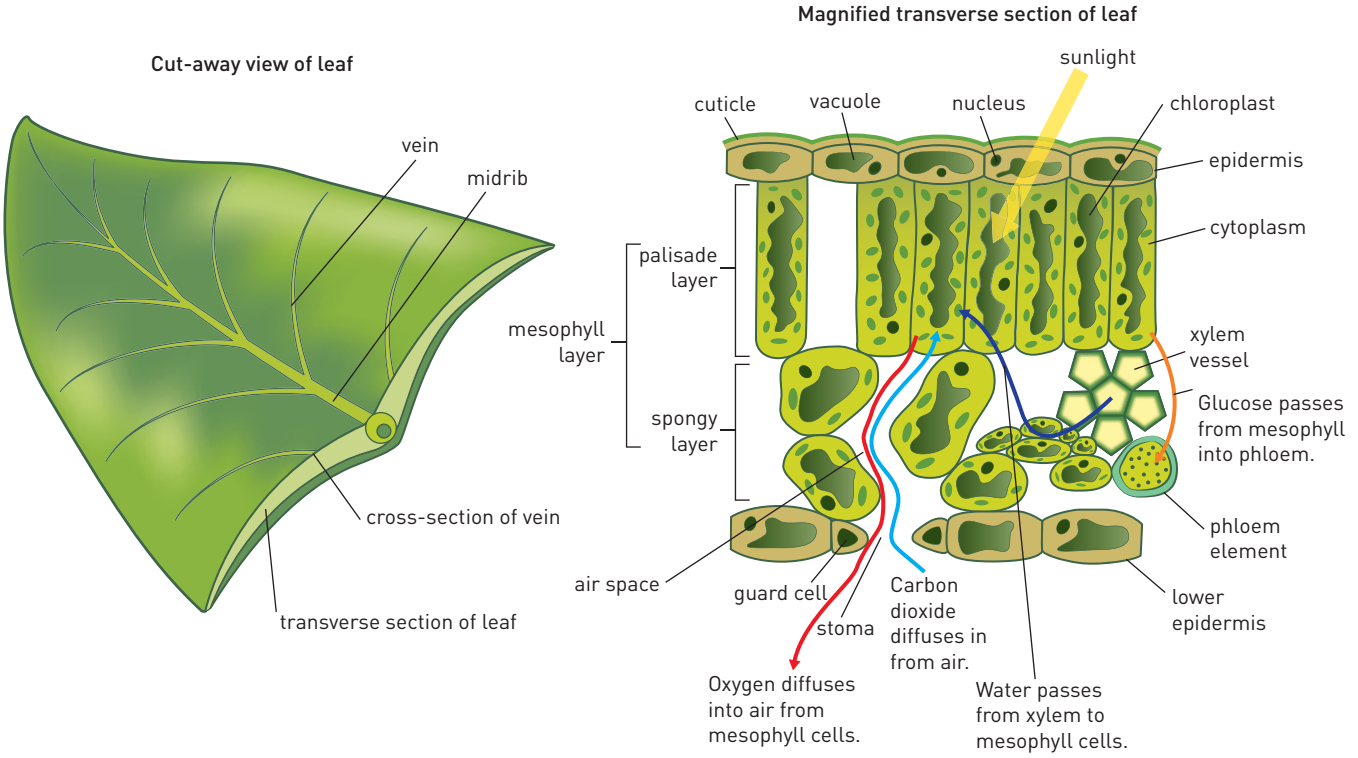


FIGURE 1 Structure of the leaf, showing movement of raw materials for photosynthesis into the palisade cells, movement of glucose into the phloem and elimination of oxygen

leaf. The concentration of carbon dioxide within the inner **mesophyll** cells will therefore be lower than that in the atmosphere. Similarly, the oxygen released in photosynthesis passes out of the stomata along a diffusion gradient (Table 1).

Mesophyll cells (*meso* = middle; *phyll* = leaf) all contain chloroplasts. The cells near the top of the leaf are columnar in shape and closely joined, forming the **palisade cell** layer. The photosynthesising cells in this layer continually move their chloroplasts around the cell in a process called **cytoplasmic streaming**. This allows the chloroplasts to maximise their access to sunlight. The cells beneath the palisade layer are rounder and arranged quite loosely, with large air spaces between them. They form the **spongy mesophyll** layer. Running through the mesophyll are **veins** carrying the vascular tissue.

FIGURE 2 Photosynthesis plays a vital role in the productivity of rainforests such as Wooroonooran National Park in Innisfail, Queensland

mesophyll
plant tissue of two types (palisade and spongy) specialised for photosynthesis

palisade cells
photosynthetic mesophyll cells, usually found below the surface of plant leaves

cytoplasmic streaming
the flow of cytoplasm around the cell

spongy mesophyll
parenchyma tissue that has many spaces between cells to facilitate the circulation of air and the exchange of gases

vein
blood vessel which begins in a capillary bed and enters the heart; vascular bundle of a leaf

TABLE 1 Adaptations of leaves for photosynthesis

Adaptation	Function
Supported by stem and petiole	Exposes as much of leaf as possible to sunlight and air
Arrangement of the leaves on stem	Maximises light absorption
Large surface area	Exposes as much of leaf as possible to sunlight and air
Thin	Allows sunlight to penetrate to all cells; allows CO_2 to diffuse in and O_2 to diffuse out as quickly as possible
Stomata on lower epidermis	Allows CO_2 and O_2 to diffuse in and out; reduces evaporative water loss
Air spaces in spongy mesophyll	Allows H_2O, CO_2 and O_2 to diffuse into and out of all cells
No chloroplasts in epidermis	Allows sunlight to penetrate to mesophyll layers
Mesophyll layers packed with chloroplasts	Allows sunlight, providing energy, to combine CO_2 and H_2O
Palisade cells arranged end on	Keeps as few cell walls as possible between sunlight and chloroplast
Chloroplasts in palisade cells oriented horizontally to the light rays	Exposes as much chlorophyll as possible to sunlight
Xylem vessels within a short distance of every mesophyll cell	Supplies water to chloroplasts for photosynthesis
Phloem tubes within short distance of every mesophyll cell	Takes away organic products of photosynthesis
Cytoplasmic streaming	Maintains chloroplasts in position to receive maximum light

CHECK YOUR LEARNING 8.1

Describe and explain

1 **Describe** photosynthesis.
2 **Describe** features of the plant leaf that are adaptations for photosynthesis.
3 **Identify** where in the plant photosynthesis occurs. **Describe** the specific cells and locations of these cells in which this process takes place.

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 8.1

» **Video**
Leaf close-up

» **Weblink**
Leaf structure

» **Weblink**
Mesophyll cells

8.2 Gas exchange: respiration

KEY IDEAS

- Oxygen requirements for respiration
- Relationship between amount of sunlight and oxygen uptake by the plant
- The concept of compensation point and compensation period

Aerobic cellular respiration was fully described in Chapter 4 (pages 116–21). In this process, the release of chemical bond energy generally involves the breakdown of sugar in a series of small steps, each controlled by an enzyme. This energy is stored in the ATP molecule for further use by the cell, or transported to other cells within the plant.

The energy produced during cellular respiration is used by the plant to convert the carbohydrates formed during photosynthesis into other organic compounds such as proteins and lipids, and for the chemical reactions required for just living.

All living cells need a continuous supply of energy for life functions. Therefore, all living plant cells, like animal cells, are always respiring. Some plant cells also photosynthesise. In the leaf cells the chloroplasts take in carbon dioxide and release oxygen during the daytime. At the same time cellular respiration is occurring in the mitochondria, using some of the oxygen and glucose provided by photosynthesis.

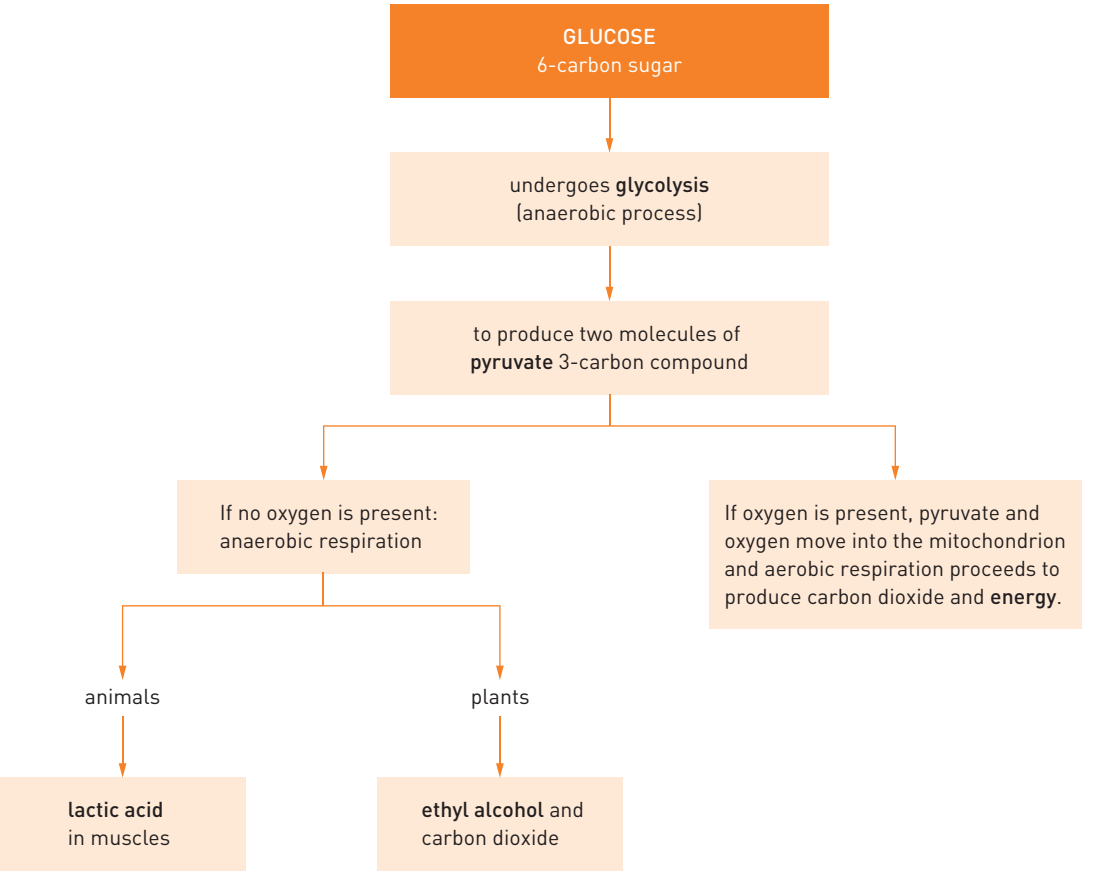


FIGURE 1 Cellular respiration

In the daytime photosynthesis proceeds at a faster rate than cellular respiration and all of the carbon dioxide released in cellular respiration is used up in the chloroplasts, in addition to extra carbon dioxide taken in through the stomata.

At night photosynthesis ceases, but cellular respiration must continue. Oxygen diffuses into the leaf from the atmosphere through the stomata and is used up. Carbon dioxide is released through the stomata.

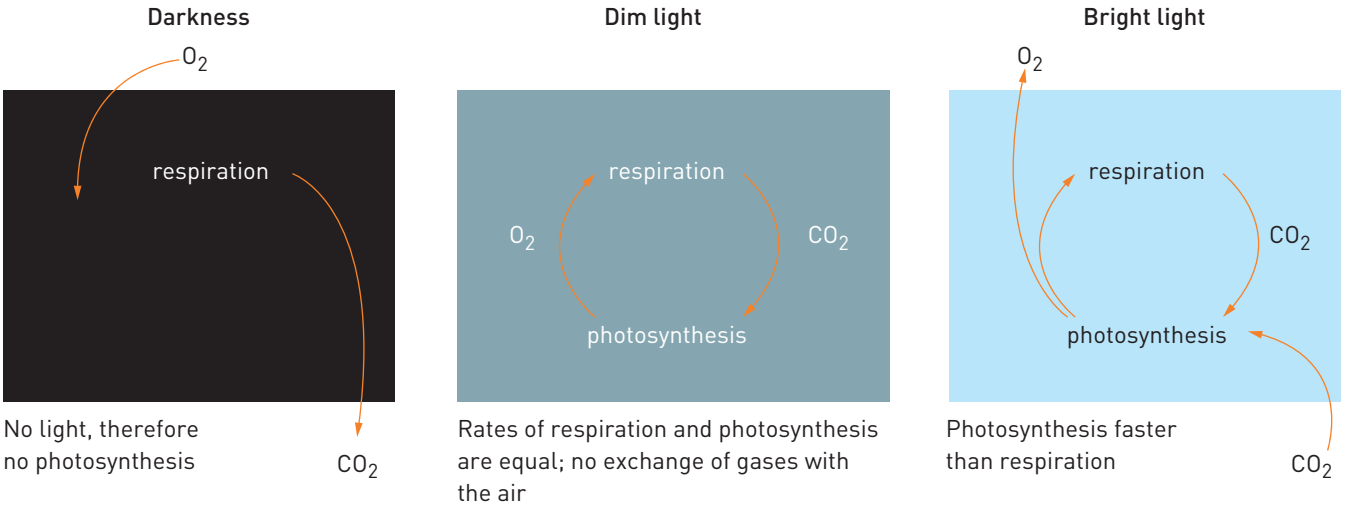


FIGURE 2 The balance between photosynthesis and respiration in a green plant

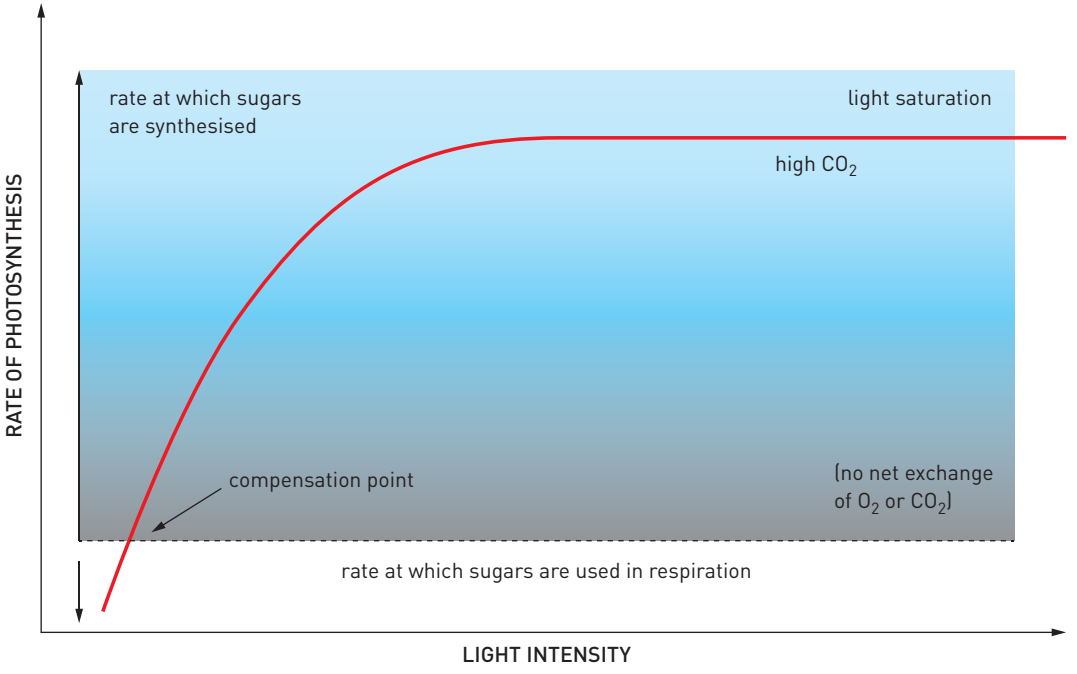


FIGURE 3 Compensation point

Oxygen is not transported around the plant, but all plant cells, even if they do not photosynthesise, require it. Oxygen diffuses to non-photosynthetic cells in the stems through special pores (lenticels). Roots get their oxygen from the air spaces in the soil by diffusion through the root hair cells.

The glucose that is produced during the day is stored as a complex carbohydrate (starch). Those carbohydrates that are used during respiration at night are normally replaced when photosynthesis resumes at dawn. The rate of photosynthesis increases with increasing light intensity. Sooner or later the rate of photosynthesis equals the rate of respiration and there is no net gain or loss of carbohydrates (Figure 2).

The light intensity at which photosynthesis and respiration proceed at the same rate is known as the **compensation point** (Figure 3). The time taken for a plant to reach its compensation point is known as the **compensation period**. With further increase in light intensity, the rate of photosynthesis is greater than respiration and there is a net gain in carbohydrate.

compensation point
the point at which the rate of photosynthesis equals the rate of respiration

compensation period
the time taken, after the onset of daylight, for the rate of photosynthesis to equal that of respiration in plants

CHECK YOUR LEARNING 8.2

Describe and explain

1 **Explain** why plants need to undergo cellular respiration at all times.
2 **Construct** a general equation describing aerobic cellular respiration.
3 **Define** the compensation point of photosynthesis and cellular respiration.

Apply, analyse and interpret

4 **Apply** your knowledge to plot a graph that shows how the rates of photosynthesis and respiration in a green plant vary during one day.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 8.2
- » Weblink
  Chloroplasts
- » Video weblink
  Plants growing at night
- » Weblink
  Compensation point

8.3 Gas exchange surfaces

KEY IDEAS

- The reason why plants do not have special organs for gas exchange
- Adaptations of the leaf for gas exchange
- How gas exchange occurs in stems and roots

Both photosynthesis and respiration require exchange of gases between the cells and the external environment. Since plants are relatively inactive and produce oxygen as a by-product of photosynthesis, they generally require much less oxygen than animals. Even the largest plants do not require special organs for gas exchange. They rely on diffusion alone to supply their gas exchange needs.

Primitive plants such as mosses and liverworts are imperfectly adapted to life on land. These plants have no transport system for water or nutrients. They must therefore use the entire body surface for gas exchange and so are small in size and limited to moist environments.

Other plants have evolved adaptations in response to these problems. Gas exchange in these plants occurs in leaves, stems and roots.

Adaptations for gas exchange in leaves

The leaf is well adapted for gas exchange if:

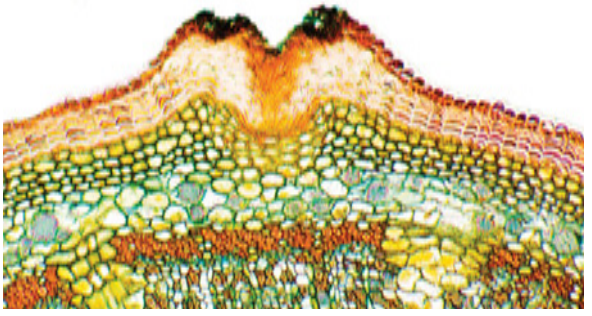
- The surface area for gas exchange is very large.
- A waterproof cuticle reduces water loss from the surface except through the stomata.
- Gas exchange between the environment and the leaf tissues is only through the stomata.
- There are many intercellular air spaces within a leaf (spongy mesophyll) so the gases can reach each cell directly.
- The leaf epidermis protects the internal exchange surfaces.
- Gas exchange surfaces and all cells within the leaf are always moist, because they are exposed only to the air in the intercellular spaces. This air remains humid because the spongy mesophyll cells maintain a transpiration stream, and the stomata close if moisture loss becomes excessive.

FIGURE 1 The common liverwort (*Marchantia polymorpha*) and moss, shown growing on stone, uses the entire body surface for gas exchange.

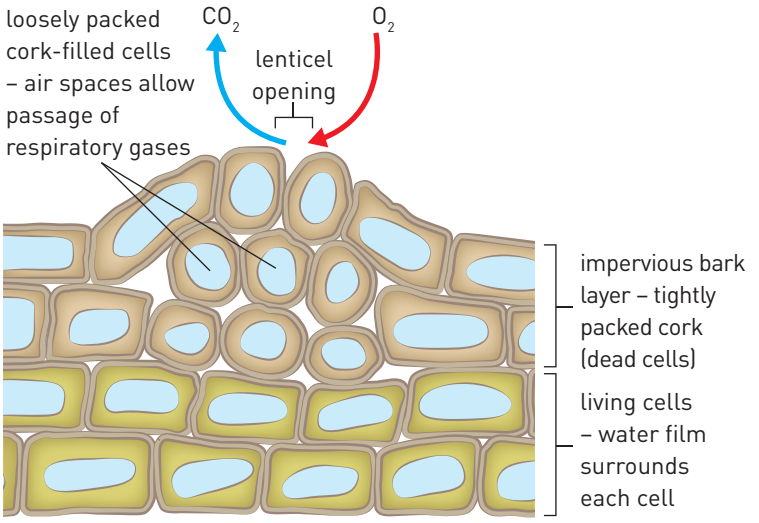
Gas exchange in the stem

Herbaceous stems and young growing shoots of woody plants have stomata. Thicker woody stems can become covered with a layer of impervious cork. These layers contain small areas of loosely arranged cells, each with many intercellular spaces, through which air may diffuse. These areas are called **lenticels**.

lenticel
the specialised area of tissue in the corky bark of woody plant stems which allows gas exchange



(a) Micrograph: transverse section through a lenticel



(b) Diagram showing structure and function

FIGURE 2 Structure of a lenticel

Gas exchange in roots

In the roots gas exchange occurs by diffusion across root hairs and other epidermal cells. Root hairs are finger-like projections of root epidermal cells. They increase the surface area for gas exchange by diffusion. This exchange requires good aeration of the soil and so will vary in differing soil types.

FIGURE 3 Pneumatophores, surrounding the main stem of the mangrove tree, are upright extensions of the subterranean roots that collect oxygen at low tide.

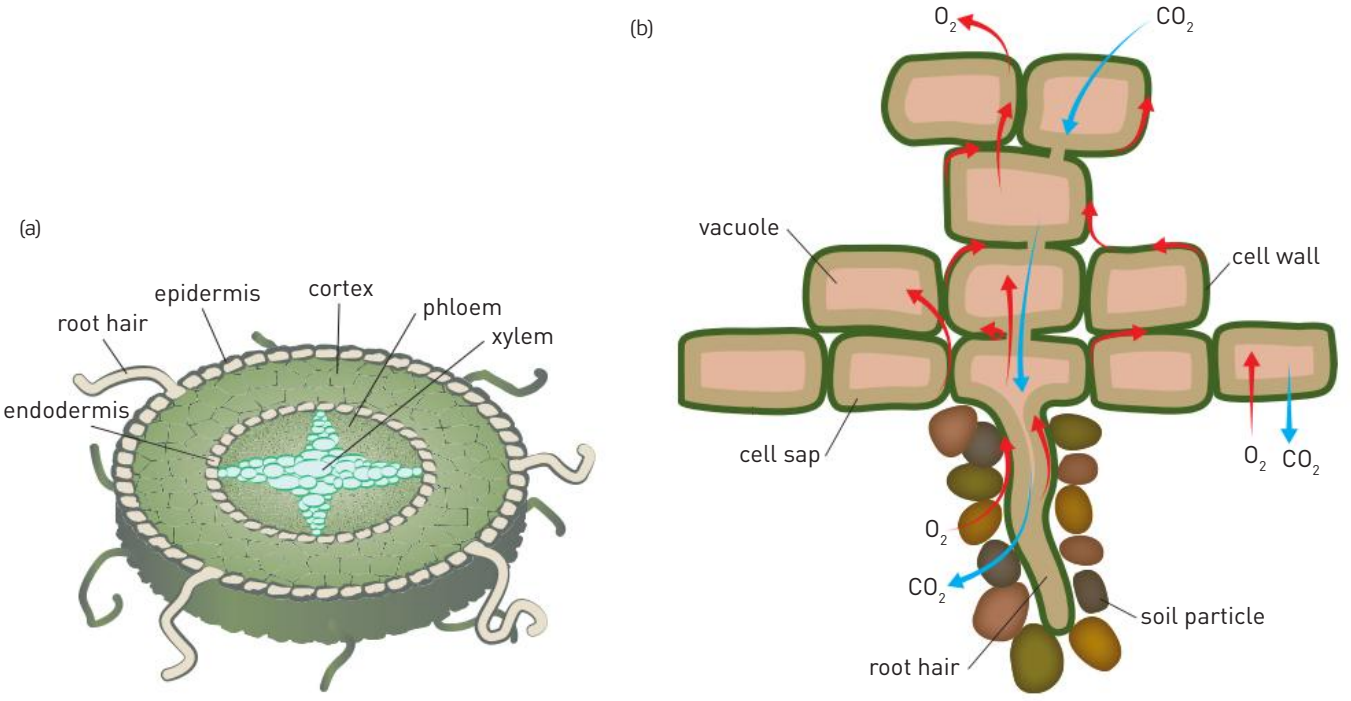


FIGURE 4 Structure of roots: (a) cross section and (b) transverse section.

If soils become waterlogged, plants cannot get access to oxygen in the soil. This is particularly evident in intertidal areas where roots are covered twice daily by tides. Mangrove trees have a number of specialised root forms; the best known are the peg roots (pneumatophores), which are aerial roots that protrude above the ground. The pneumatophores are studded with lenticels, and are able to collect and store oxygen at low tide.

The stems and roots, like the leaf, need to have adequate internal air spaces to allow effective diffusion of gases to individual cells, and no special internal gas transport system is required.

CHECK YOUR LEARNING 8.3

Describe and explain

1 **Explain** why diffusion is adequate to supply the gas exchange need of plants.
2 With the aid of a labelled diagram, **describe** features of the leaf which show adaptations for gas exchange.
3 **Describe** a lenticel and its structure for gas exchange.

Apply, analyse and interpret

4 Some of the roots of certain mangrove plants have lenticels. From your knowledge of the mangrove environment, **determine** the significance of this adaptation.
5 Many trees in city regions are surrounded by trodden down soil or concrete pathways covering their roots. **Apply** your knowledge to suggest how this may affect the growth rate of the plant.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 8.3
- » Video
  Aerial roots in mangroves
- » Video
  Aerial roots in the rainforest
- » Weblink
  Gas exchange in stems

8.4 Transport

KEY IDEAS

- The need to transport matter within an organism
- The transport systems in plants
- The difference between intracellular and intercellular transport

FIGURE 1 This waratah relies on the transport of substances such as ions, oxygen and carbon dioxide for survival.

Gases, water and nutrients from the external environment and metabolic wastes must be moved around the organism, even if it is only within the cytoplasm of a single-celled organism.

Simple organisms rely upon the physical process of diffusion (including osmosis) and active processes that expend cellular energy for movement of materials between the environment and cells. These same processes operate in the individual cells of multicellular organisms.

As organisms become larger, and specific parts of the body become differentiated for particular functions, these processes become very inefficient except at the cellular level. With increase in size and specialisation, organisms have evolved a separate system, the **transport system**, to perform this function.

transport system a system of vessels responsible for the movement of materials through an organism

Materials in flowering plants are transported in two separate sets of 'tubes'. Water and dissolved ions are taken up from the soil and pass into the xylem to travel to the leaves in a one-way flow. Organic molecules produced by photosynthetic cells may move from the leaves to other parts of the plant, such as roots, or from areas of storage back to the growing apices (tips). These molecules are transported in the phloem. Movement of material in the phloem can be in any direction.

Study tip

Glucose and other molecules **flow** around a plant through the **phloem**.

CHECK YOUR LEARNING 8.4

Describe and explain

1 **Describe** ways in which intracellular transport is achieved.

2 Simple organisms do not have special transport systems.
Explain:
- **a** how they operate without such a system
- **b** limitations that lack of a transport system places on them.

Apply, analyse and interpret

3 **Distinguish** between intracellular and intercellular transport.

4 The transport of water and dissolved ions occurs in different structures to that of organic molecules in the flowering plant. **Classify** these two systems and **contrast** any differences in the flow of material in them.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 8.4
- » Video weblink
  The transport system
- » Weblink
  Osmosis
- » Weblink
  Phloem

8.5 Movement of water and ions into the root

KEY IDEAS

- Passage of water in the transpiration stream
- Pathways of water through the root hairs and root cells to reach the xylem
- The structure of the root in monocotyledonous and dicotyledonous plants
- How plants regulate the movement of water into the xylem
- The concept of root pressure

transpiration stream
the water column from the roots of the plant to the intercellular spaces of a leaf

transpiration
evaporation of water from the stomata of leaves

Water (containing dissolved mineral ions) enters through the root hairs of land plants. The water movement is in one direction only, from roots to leaves, and is referred to as the **transpiration stream**. Water loss from the plant by evaporation from its surfaces is called **transpiration**.

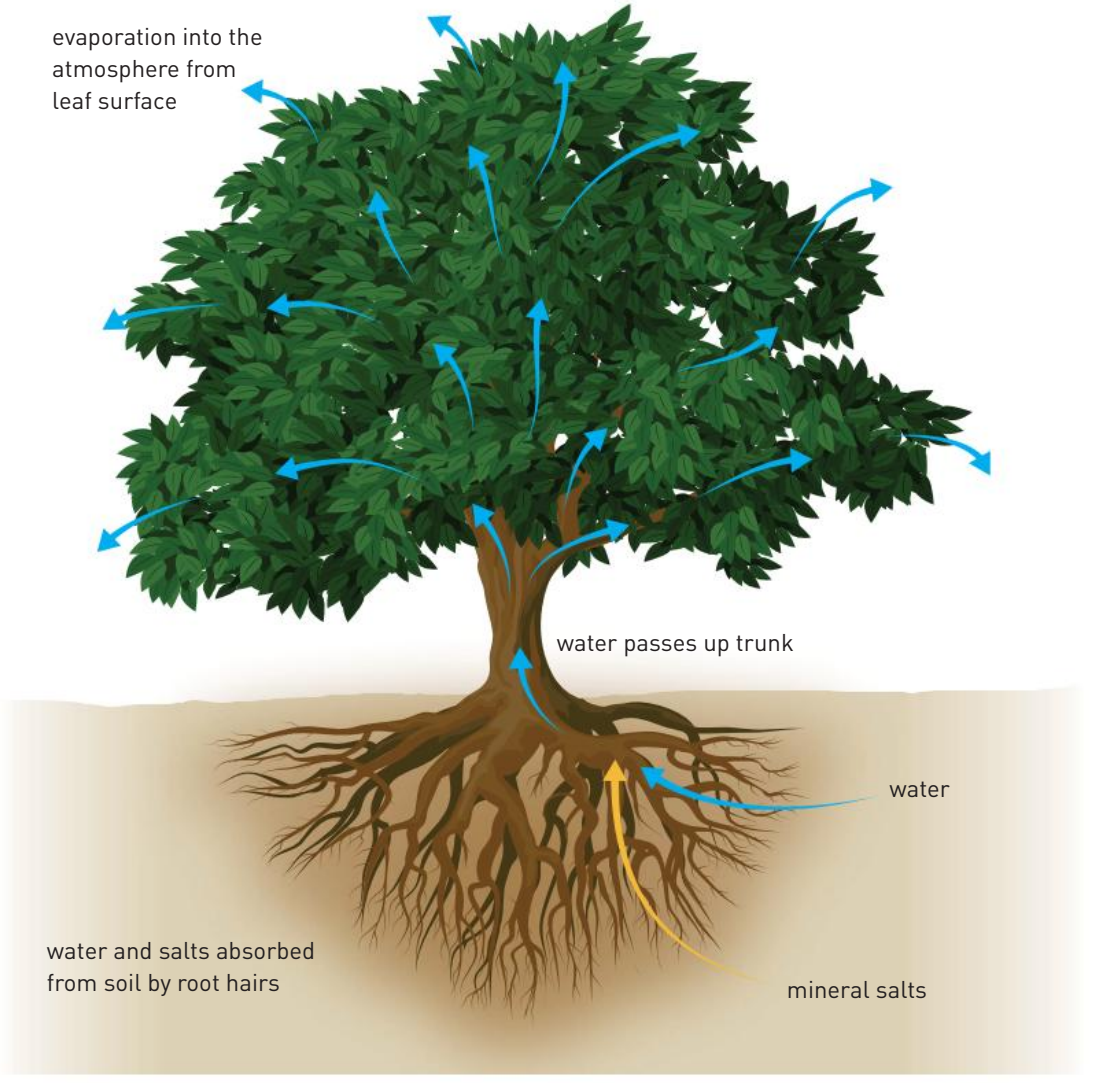


FIGURE 1 The transpiration stream

SUGGESTED PRACTICAL
8.5A Investigating plant leaves, stems and roots
Go to your obook »

MANIPULATIVE SKILL
8.5B The passage of water through flowering plants
Go to page 418 »

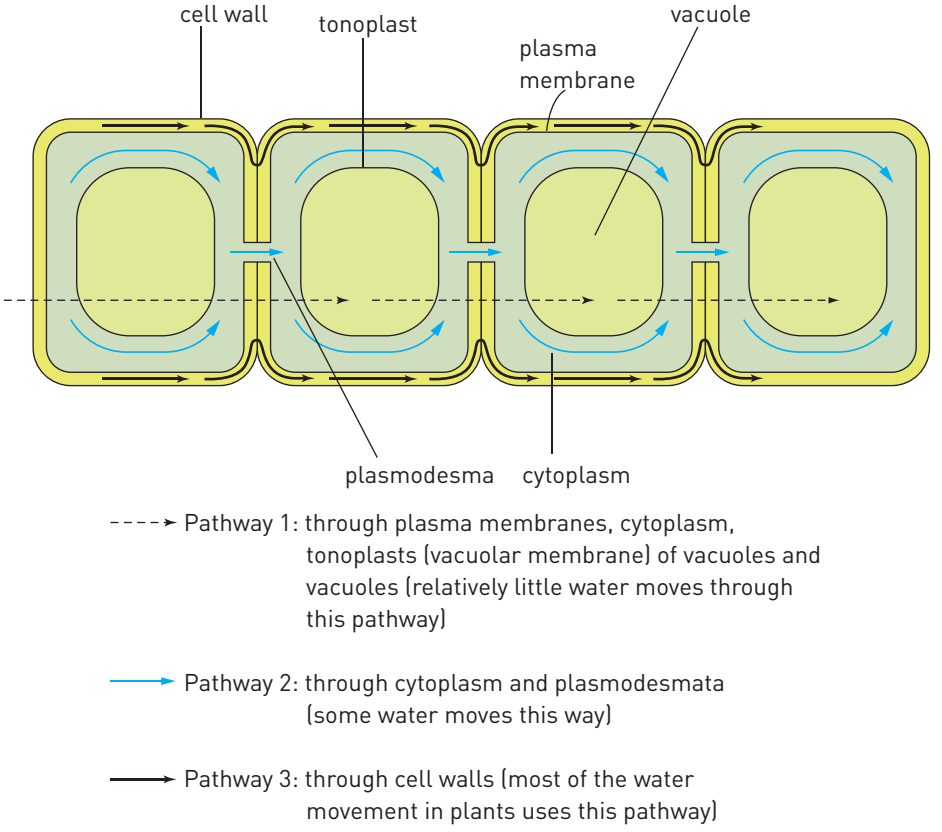


FIGURE 2 The possible pathways for movement of water through plant cells

Most water absorption occurs in the root hairs. These are fine outgrowths from the outer cells of the growing tip of the root. Collectively they provide a very large surface area in close contact with the soil particles. Water passes from the soil into the root hairs by osmosis as a result of the higher concentration of solutes in their cell sap. This process continues so long as the cell sap is more concentrated than the surrounding soil water.

Water passes from the root hair, across the cortex to the xylem by one of the three different pathways (see Figure 2):

Pathway 1: passing from one cell vacuole to the next by osmosis, through cell walls and all cell contents

Pathway 2: moving through the plasmodesmata (fine protoplasmic connections between neighbouring cells) from one cell to the next by osmosis

Pathway 3: moving between the cells along and through the intercellular spaces and cellulose cell walls from one cell to the next (i.e. bypassing cell membrane and contents).

These pathways also occur between cells in the leaf (Figure 2).

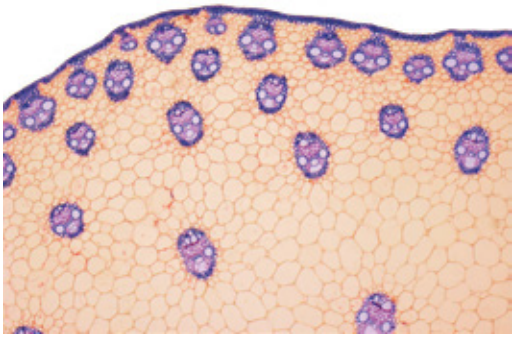
The general structure of roots and stems, and the tissue arrangements in the two types of flowering plants, monocotyledons and dicotyledons, is shown in Figure 3 (page 224) and Figure 4 (page 225).

Any pathway taken by water that involves the cell walls is interrupted in the root by a ring of specialised cells surrounding the vascular tissue. These cells are termed the **endodermal cells**, and are illustrated in Figure 5 (page 226). In most species, these cells have a thickening of a waxy, waterproof substance called suberin, the **Casparian strip**, which forms a tight seal around one diameter of the wall.

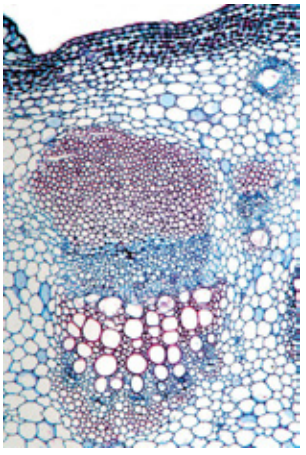
endodermal cell
a cell of the central, innermost layer of living cells of the cortex in some land plants

Casparian strip
a thickening of waxy, waterproof suberin found in the endodermal cells of the root of angiosperms and which directs the flow of water and dissolved ions into the root xylem

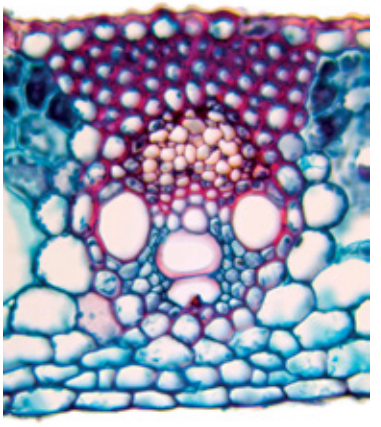
(a) TS typical dicotyledon stem



(b) TS typical monocotyledon stem

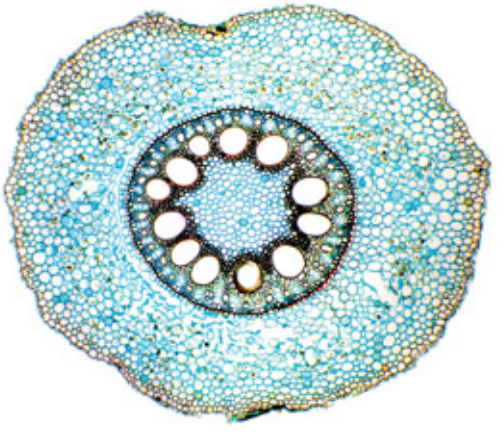


(c) TS dicotyledon vascular bundle



(d) TS monocotyledon vascular bundle

(e) Typical dicotyledon root



(f) Typical monocotyledon root

FIGURE 3 Microscope photographs of stem and root of dicots and monocots (TS = transverse section)

By forcing water through the cytoplasm it is thought the movement of water into the xylem is regulated along with that of salt in the root. It may also prevent the entry of toxic substances, and fungal and other pathogens.

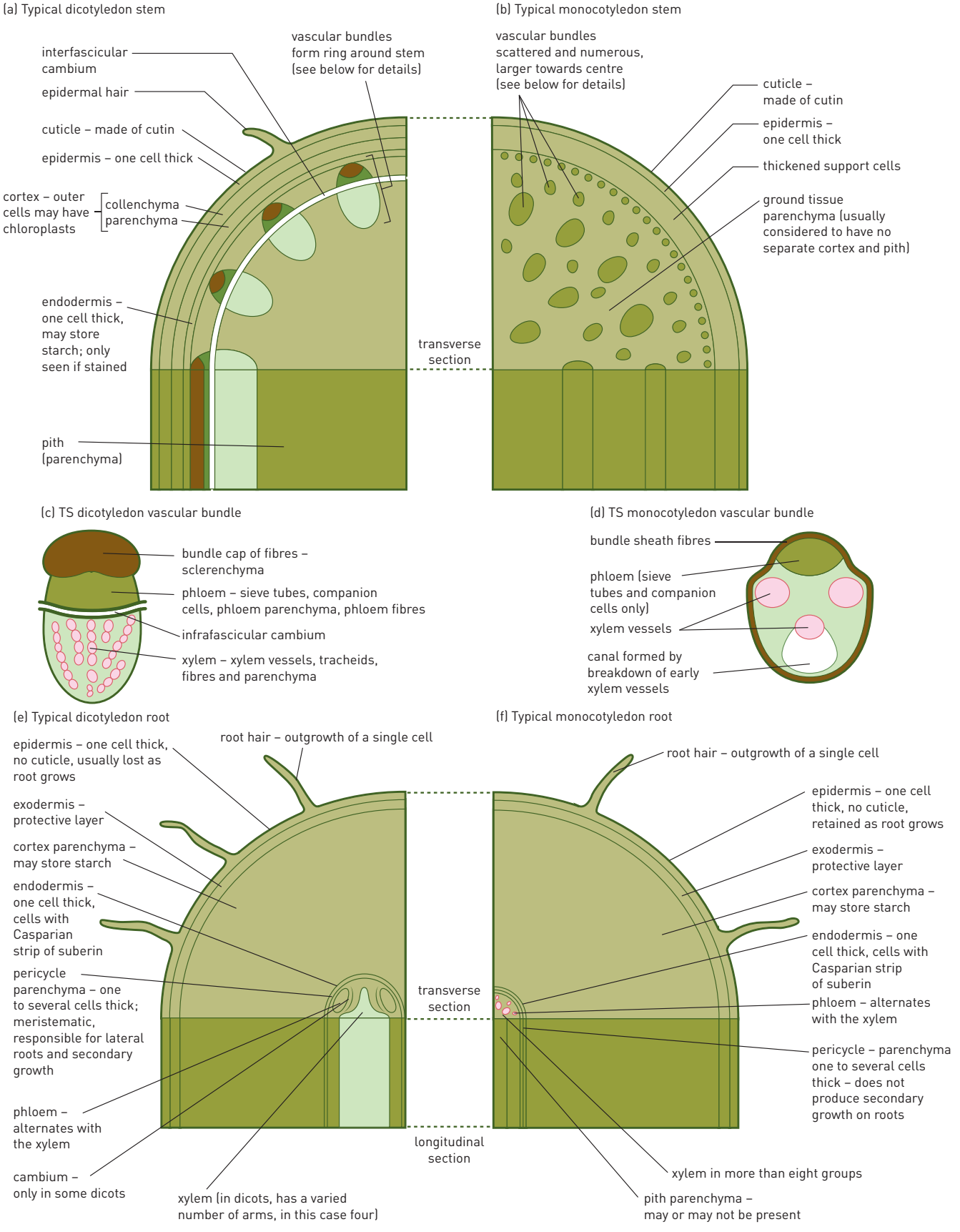


FIGURE 4 Zone diagrams of stem and root of dicots and monocots (TS = transverse section)

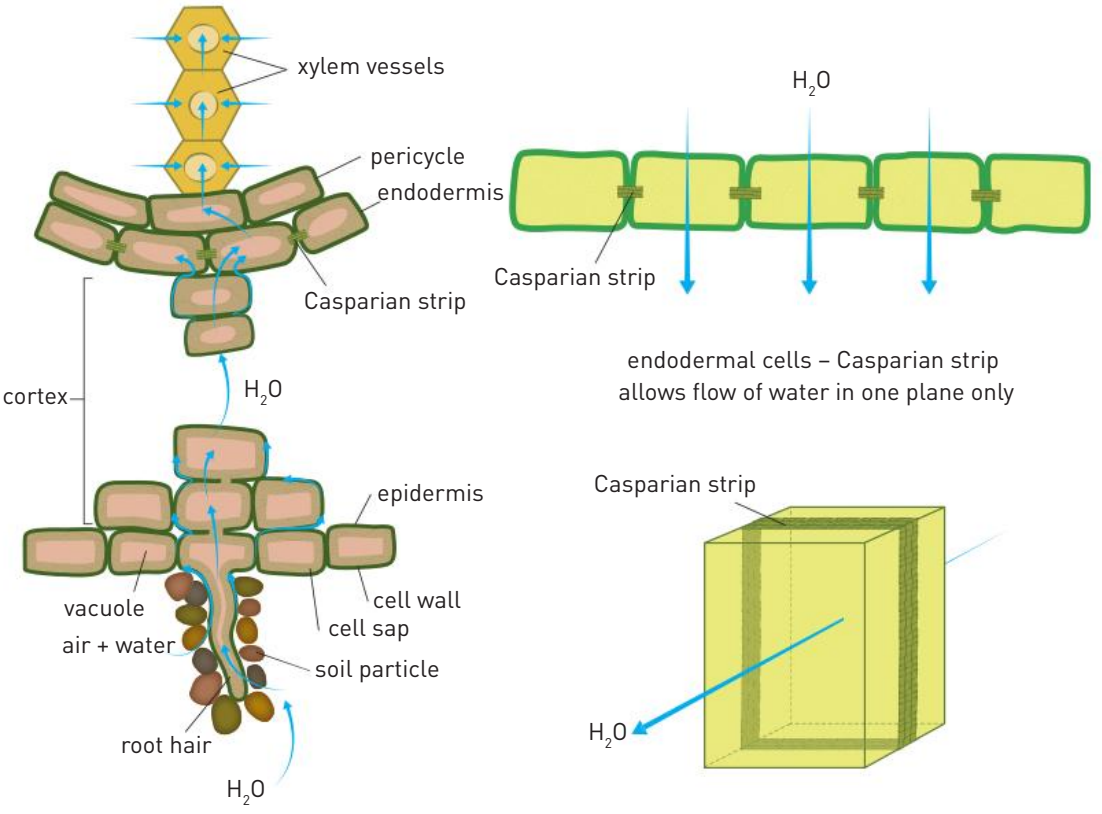


FIGURE 5 Movement of water into the root

root pressure the pressure exerted on water in the roots of plants due to the continued uptake of water from the soil by osmosis; it forces water a certain way up the stem of the plant until counteracted by the force of gravity

Water can also enter the xylem by active secretion from the surrounding living cells, creating a **root pressure** that forces the water a short distance up the stem. The extent to which water can move up the stem as a result of root pressure is limited, and it is counteracted by a downward gravitational pull, which increases with the height of the stem.

Nutrient ions enter the plant dissolved in water and pass with the water to the xylem. It is thought that positive ions are actively transported into the root hairs. This is an energy-consuming process. Negative ions passively diffuse into the cell to counteract the electrical imbalance created in the cell sap.

CHECK YOUR LEARNING 8.5

Describe and explain

1 **Explain** how the plant obtains:
   - **a** water
   - **b** minerals ions.

2 **Describe** how water passes from the root hairs to the central xylem of the root by the three different pathways.

3 **Explain** the significance of the Casparian strip.

4 **Explain** why root pressure will not push water very far up the stem of a tall plant.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 8.5
- » Manipulative skill
  8.5B The passage of water through flowering plants
- » Manipulative skill
  8.5C Stomatal function
- » Suggested practical
  8.5A Investigating plant leaves, stems and roots

8.6 Movement of water in the xylem

KEY IDEAS

- The structure of xylem
- How movement of water in the plant involves osmosis, root pressure, adhesion, cohesion and transpiration
- Methods used by plants to control water loss
- The function and operation of the guard cells
- Factors affecting transpiration rate

Xylem is a mixture of living and dead cells:

- dead cells – tracheids, vessels and supporting fibres
- living cells – parenchyma (packing/support tissue and starch storage).

The vessels and tracheids are very narrow tubes that offer little resistance to water movement. When the vessels and tracheids mature, lignin (a supporting and waterproofing molecule) is embedded in the cellulose cell walls and so the cell contents are destroyed.

Vessels are composed of a series of cells called vessel elements arranged end to end. The end walls of these elements break down during maturation, leaving a continuous hollow tube. At numerous points in their lateral walls are thinner, unlignified regions called pits. They are composed only of the cellulose wall. Water can easily pass sideways from cell to cell through these pits. Pits may have a border or projecting rim of lignin surrounding them. Some of these pits have a central plug of lignin, a torus, which may regulate lateral water movement.

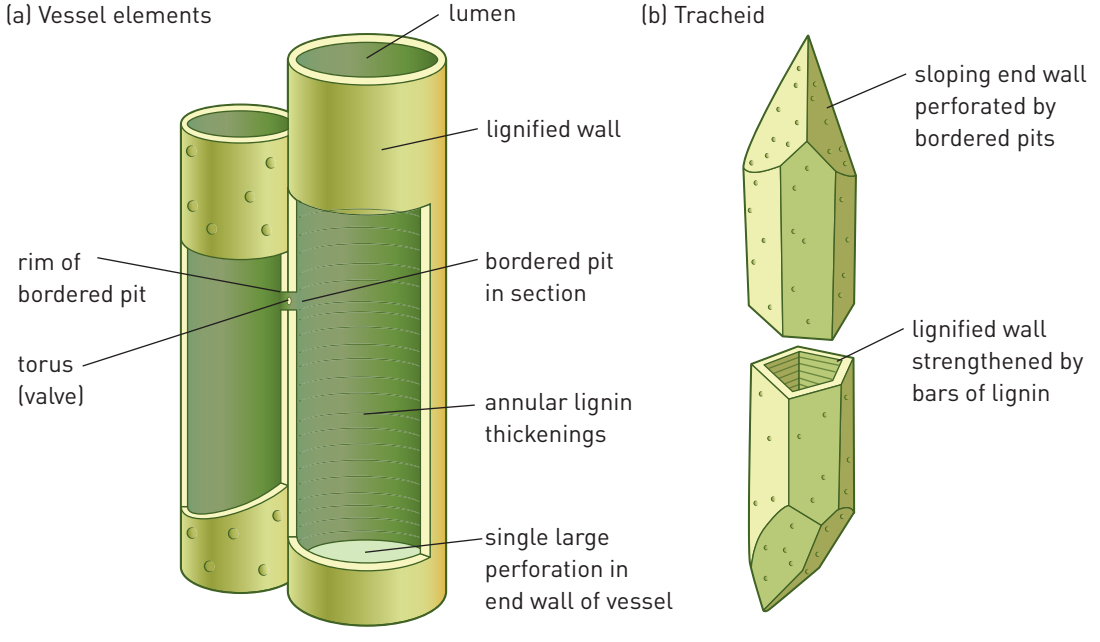


FIGURE 1 Water-carrying components of xylem

FIGURE 2 Lower epidermis of leaf showing stoma and guard cells

Tracheids offer much more resistance to water flow because they still have their end walls which taper and overlap each other. They (like the lateral vessel element walls) are pitted. Angiosperms (flowering plants) contain both vessels and tracheids, but gymnosperms (cone-bearing plants) have only tracheids.

Two strong forces act on water molecules in the xylem: cohesion and adhesion. Cohesion acts between the water molecules, holding them together. Adhesion acts between the water molecules and the cellulose of the cell walls. Since the vessels and tracheids are very narrow in relation to their length, there is a large surface area in contact with the water that enhances the force of adhesion. The water column in the xylem also has a very narrow diameter and so the forces of cohesion between the water molecules are great.

As water transpires (evaporates) through the stomata (see Figure 2), the spongy mesophyll cells of the leaf draw water from the xylem in the veins (like water being soaked up by blotting paper). This exerts a pull on the water column in the leaf xylem. Due to the strong force of cohesion between the water molecules, the water is drawn up from the roots, up the stem to the leaves.

During rapid transpiration, the pull exerted on the network of water columns in the xylem can be so strong that a negative pressure is generated. Since adhesion is strong, the xylem walls can be pulled inwards, causing the whole diameter of the stem to shrink.

Damage to individual xylem cells or groups of them does not interrupt water flow. Airlocks associated with damage may stop at the perforated end walls of vessels, and water can pass to adjacent cells via the lateral wall pits. This overcomes any potential loss of cohesion due to air bubbles in the stream.

To summarise, water transport through the plant involves:

- **osmosis** along a diffusion gradient from the leaves down to the roots and the soil
- **root pressure** causing water to move a limited distance up the stem until counteracted by the force of gravity
- **adhesion** of water molecules to the walls of the vessels and tracheids and the spongy mesophyll cells
- **cohesion** between the water molecules forming the thin water columns in the xylem
- **transpiration**, causing loss of water from the stomata of the leaves.

At no stage does the plant expend any energy in water transport. A large amount of energy is, however, required for its operation, but the sun provides this energy. Heat is absorbed by the water, bringing about its evaporation at the leaf's surface.

Controlling water loss

Terrestrial plants can be subject to conditions that may cause severe water loss. Water loss from the plant occurs primarily from the leaves. Although the internal cells of the leaf are kept moist to facilitate photosynthesis, several features of the leaf prevent excessive water loss.

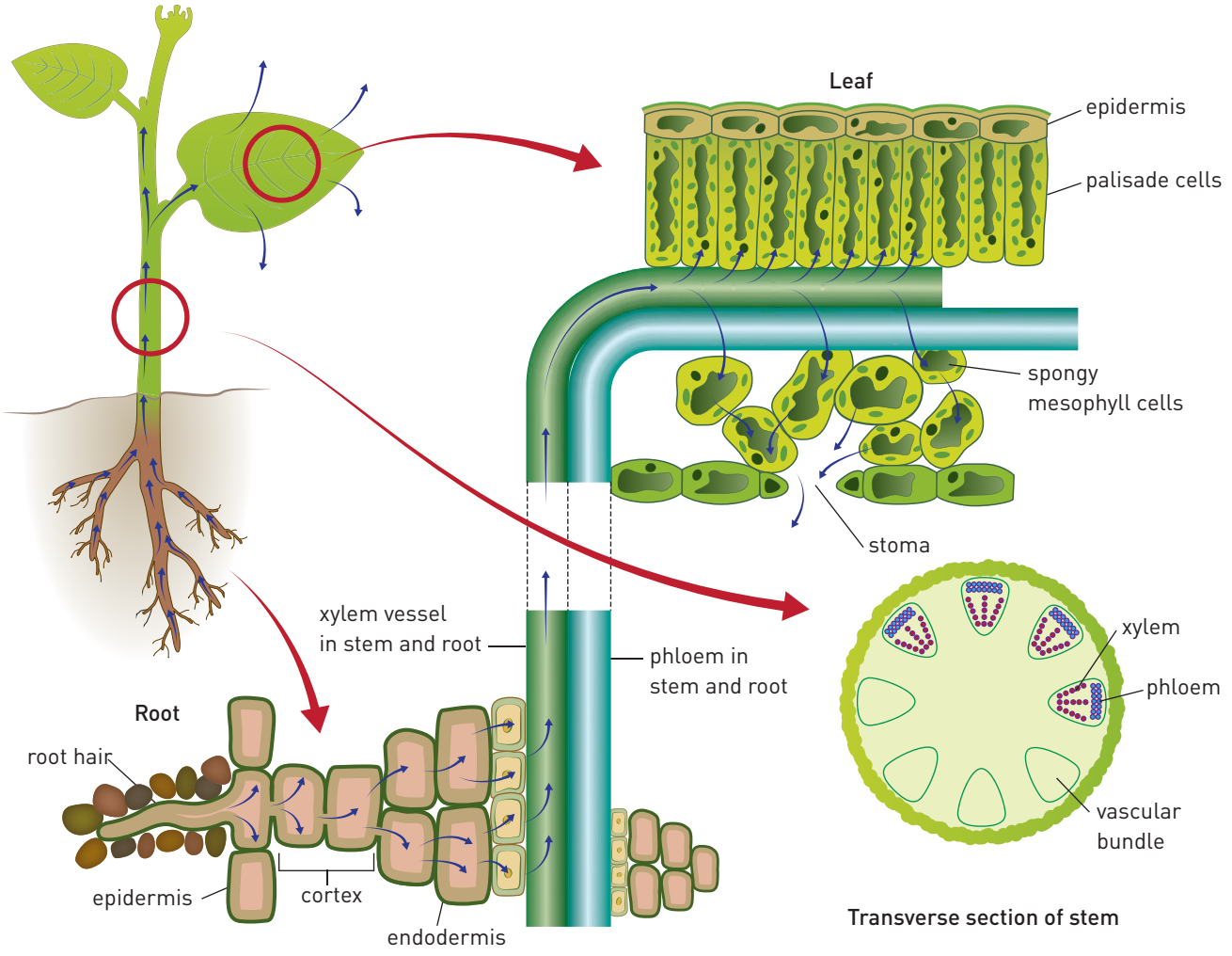


FIGURE 3 A summary of the passage of water through the plant

The epidermis is nearly waterproof and airproof because of its waxy outer surface of cutin, which covers both surfaces of the leaf. Transpiration can only occur through the stomata.

The carbon dioxide needed for photosynthesis enters the leaf through the stomata along a diffusion gradient, and diffuses into the cells from the air spaces in the mesophyll layer. Because the stomata are open during the process, moisture is lost by evaporation from the wet cell walls surrounding the intercellular spaces.

Unless this water is continually replaced, the stomatal guard cells will collapse, and the stomata will close, preventing further diffusion of carbon dioxide into the leaf. If this happens, the supply of carbon dioxide for photosynthesis is restricted to what is produced by the respiration of the leaf cells. In this case, there will be no increase in organic matter produced by the plant. For a net increase in photosynthetic products, plants must continually take in water through their root systems to compensate for water lost through transpiration.

The function of guard cells

Two modified epidermal cells called guard cells, which are supported by the surrounding epidermal cells, surround each stoma. They occupy a very small proportion of the leaf's surface, but diffusion through the stomata is extremely efficient.

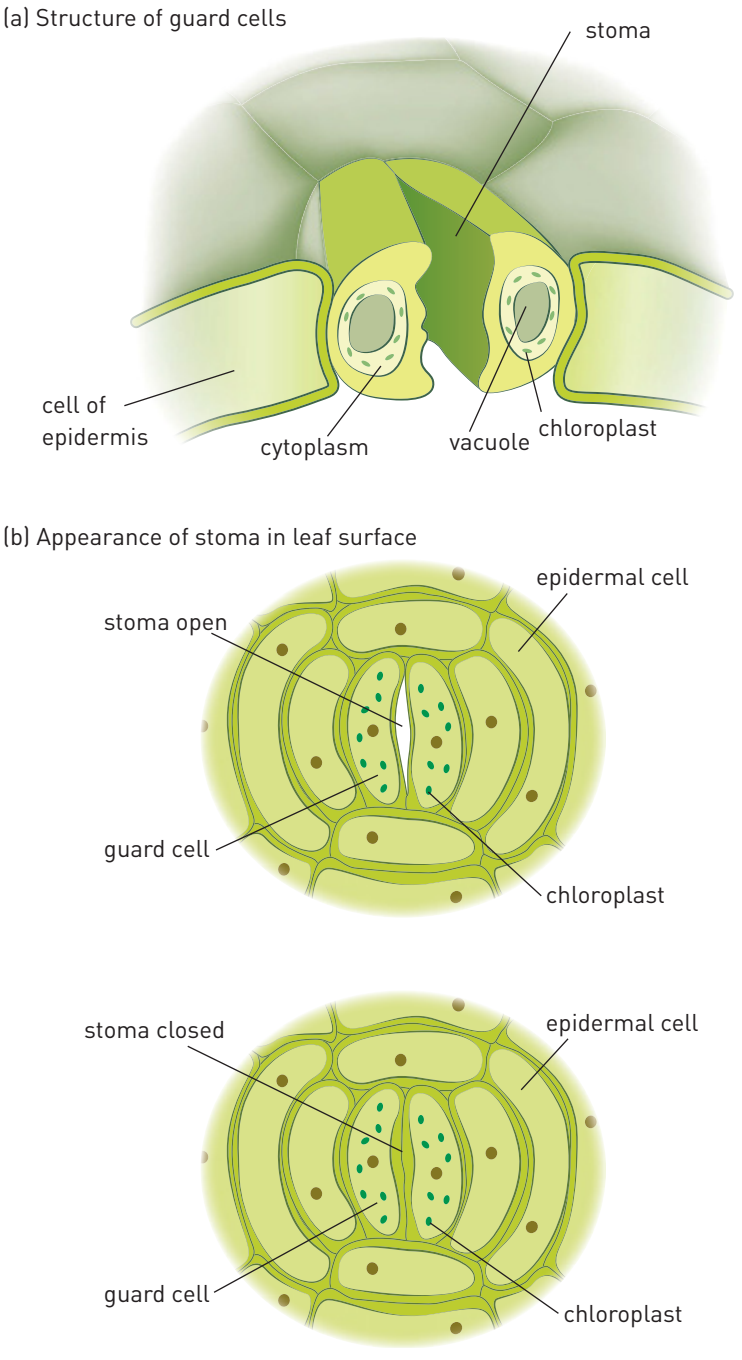


FIGURE 4 The structure of a stoma

The opening and closing of stomata involves variations in the water content of the guard cells. Their cell walls are thicker next to the pore than next to the surrounding epidermal cells. When they are full of water (turgid), their thin walls stretch more than the thick ones, causing the two cells to curve away from each other and the pore to open. As the guard cells lose water and their turgor pressure decreases, the guard cells become straighter and the pore closes.

Hypotheses on the operation of guard cells

The way in which guard cells work has not, as yet, been fully explained. There are various hypotheses, however.

Unlike other epidermal cells, guard cells contain chloroplasts and photosynthesise. Glucose therefore accumulates in them during the day. It has been proposed that carbon dioxide from cell respiration accumulates in the saturated intercellular spaces of the leaf during darkness. Carbon dioxide dissolves in water to form carbonic acid, and this lowers the pH inside the leaf. Acidic conditions trigger the conversion of glucose in the guard cells to starch, which is osmotically inactive. This causes the guard cells to lose water by osmosis, collapse and close the stomata.

In the light, the carbon dioxide is rapidly used in photosynthesis. This raises the pH and favours the conversion of starch to glucose, an osmotically active substance. Water is therefore drawn into the guard cells, creating turgor pressure and opening the pore.

Since the movement of the guard cells can be quite rapid, it is proposed that a second mechanism also may act in altering the turgidity. Experimental evidence suggests that an ATP-driven potassium ion pump operates in the guard cell membrane. Potassium ions are pumped into the cell in response to a decrease in the levels of a hormone. This increases the osmotic pressure in the cell, causing an osmotic influx of water and making the guard cell turgid.

These are only possible ideas to explain the opening and closing of guard cells; as yet there is no definitive explanation of this process.

SUGGESTED PRACTICAL

8.6 Factors affecting the rate of transpiration
Go to your obook »

Factors affecting transpiration rate

Transpiration rate has been shown to be affected by a range of external factors.

Light

Stomata usually open in the light and close in the dark.

Temperature

An increase in temperature increases the rate of transpiration.

Humidity

An increase in humidity causes a decrease in transpiration. This is due to a decreased diffusion gradient between the intercellular spaces and the atmosphere, which reduces evaporation.

Wind

Wind increases transpiration by the removal of water vapour around the stomatal pore. This maintains a concentration gradient for all gases and water vapour.

Soil water

If the supply of soil water is reduced, the solute concentration of the soil will increase. This results in a decrease in the amount of water absorbed by the roots and a decrease in the transpiration rate.

CHECK YOUR LEARNING 8.6

Describe and explain

1 Photosynthetic rate and transpiration are closely linked. **Explain** the factors that connect these two processes.
2 With the aid of diagrams, **describe** the structure of a stoma of a flowering plant. **Explain** the series of events that are believed to lead to the opening of the stoma.
3 **Explain** the high loss of water from stomata in relation to the pore size.
4 **Describe** two factors affecting transpiration rate.
5 **Explain** how each of the following contribute to the maintenance of the transpiration stream:
   a osmosis
   b root pressure
   c cohesion
   d adhesion
   e transpiration

Investigate, evaluate and communicate

7 **Devise** a way to demonstrate that movement of water occurs in the xylem.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 8.6

» Suggested practical
8.6 Factors affecting the rate of transpiration

» Video
Stomata

» Weblink
Xylem

8.7 Movement of organic molecules

KEY IDEAS

- The meaning of translocation
- The structure of phloem
- Direction of movement of translocation

translocation
the movement of organic solutes in the phloem in any direction; also a chromosome aberration in which a segment of DNA has been moved to another chromosome

sieve tube
the element of phloem functioning to transport organic molecules within the plant; consists of thin-walled, elongated living cells arranged in a longitudinal row and forming a connected series by means of perforations in their end walls through which pass strands of cytoplasm

Translocation is the movement of organic molecules throughout the plant. It occurs in the **sieve tubes** of the phloem. This movement can occur in all directions, from leaves to roots, leaves to apex and vice versa. Molecules (sugars, amino acids, etc.) produced in the photosynthetic cells of the leaf must be transported to the non-photosynthetic cells of the plant, particularly to actively growing points such as the apex, branches and root tips. Excess food materials can be stored in specific parts of the plant (in modified roots, stems and leaves) for future needs. The stored material can be transported to active cells at a later time.

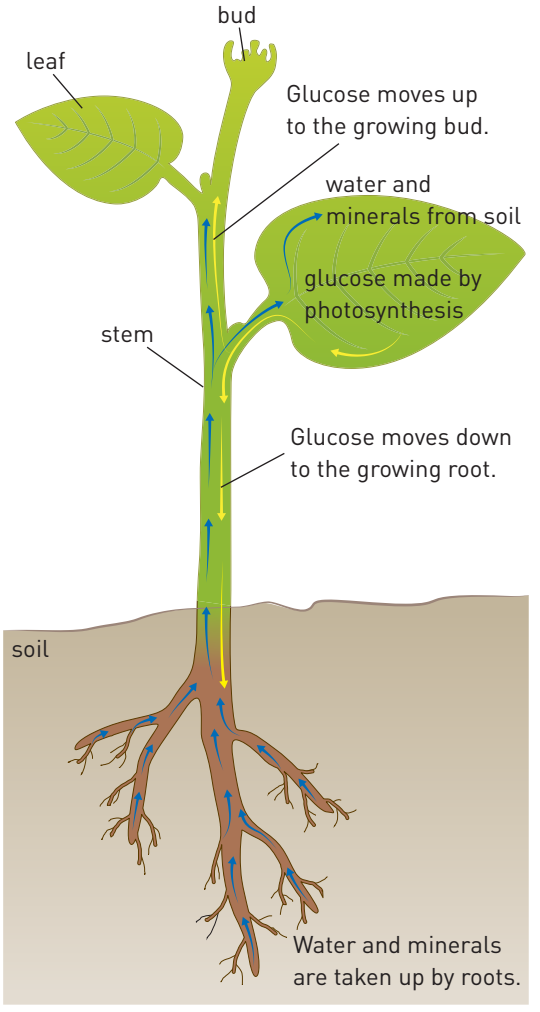


FIGURE 1 Water moves in one direction in the xylem from the root to the plant leaves while organic molecules (e.g. glucose) can move in any direction in the phloem.

Phloem is a complex tissue composed of supporting fibres and sclereids (both dead) and the living sieve tubes, companion cells and parenchyma. The sieve tubes run parallel to the long axis of the plant, from the top leaves of the plant to the roots. They are made up of elongated sieve tube elements placed end on end. Each sieve tube cell has a specialised end wall (sieve plate) that is perforated by numerous pores. Although the cell nucleus and most organelles disintegrate once the element is mature, some organelles remain close to the cellulose wall and structurally simple cytoplasm filaments exist. These filaments are continuous with those of adjacent elements through the pores of the sieve plate. They link adjacent sieve tube cells and so create a cytoplasmic stream throughout the length of the tube.

Specialised long companion cells are found next to each sieve tube element in most flowering plants. The walls of these two cell types are thin where they are in contact and connected by plasmodesmata. It has been hypothesised that the nucleus of the companion cell controls the cytoplasm of both cells.

Gymnosperms do not have companion cells but do have closely associated parenchyma cells that may also serve this function. The functional unit of the phloem in flowering plants, therefore, consists of a sieve tube element and its companion cell.

The way in which phloem functions is not fully understood. The following observations have been made on the movement of solutes in the phloem:

- The movement is often more rapid than can be accounted for by simple diffusion.
- The speed of movement differs in different phloem cells.
- The direction of movement within a given sieve tube may be reversed.
- The direction of movement in adjacent sieve tubes may be opposite.
- The direction of movement of solutes carried on separate cytoplasmic filaments within one sieve tube may be opposite.
- Metabolic poisons such as hydrogen cyanide inhibit carbohydrate translocation.
- Up to 35°C, a rise in temperature increases the rate of translocation.

Although it is generally agreed that solutes enter and leave the sieve tubes by active transport, it is not certain how they travel through the tubes.

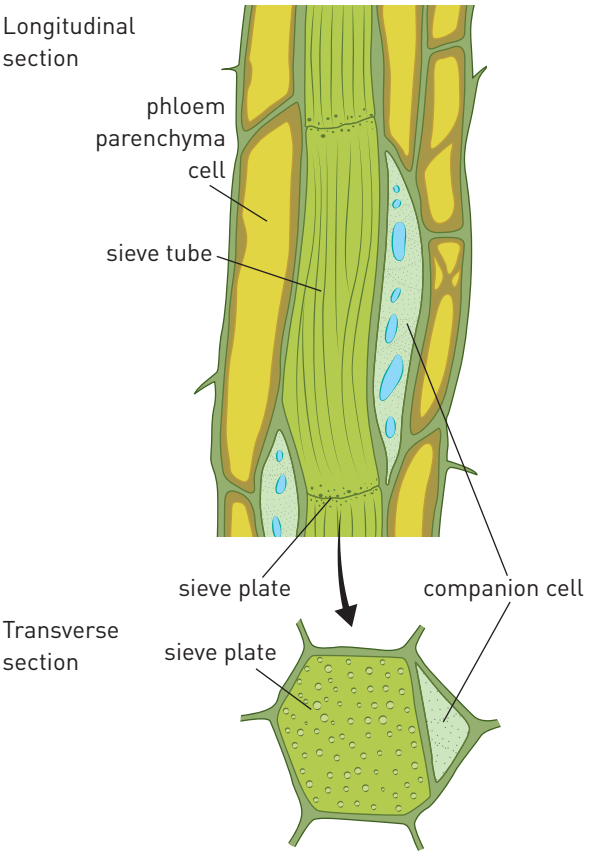


FIGURE 2 Components of phloem

CHECK YOUR LEARNING 8.7

Describe and explain

1 **Identify** two molecules that are transported through the phloem.

2 **Construct** a labelled diagram of the cells that form the phloem.

3 A student suggested that glucose and other sugars flowed down from the leaves to the roots. **Identify** errors in this statement.

Apply, analyse and interpret

4 **Consider** one way translocation in a plant could be increased.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 8.7
- » Weblink
  Translocation
- » Weblink
  Sieve tubes
- » Weblink
  Movement of water in plants

CHAPTER 8

Review

Chapter summary

8.1 Photosynthesis in plants takes place in the chloroplasts of the cell. In complex plants, photosynthesis mainly takes place in the leaf.

A stoma is a leaf pore surrounded by guard cells, often located on the underside of the leaf. It is the location of gas exchange.

Water travels from the roots to the leaves through the xylem. Glucose and other molecules travel around the plant through the phloem.

8.2 Plants require energy from cellular respiration to perform their life functions. During daylight photosynthesis occurs at a greater rate than respiration, whereas at night only respiration occurs.

8.3 Exchange of gases between the external environment and the cells of the plant is achieved by diffusion. Diffusion occurs in leaves and green stems through stomata, in woody stems through lenticels, and in roots through root hairs and other epidermal cells.

8.4 Transport is the movement of materials within the organism. It may be intracellular or intercellular. Intercellular transport may involve a system of vessels.

8.5 To replace the water lost by transpiration, water taken up by the roots flows through the plant in the transpiration stream. There is a one-way flow from roots to leaf surface in the xylem.

Movement of water from the soil to the vascular tissues (and between all plant cells) occurs in three ways:

1. from one cell to the next by osmosis through cell wall and all cell contents
2. by osmosis through plasmodesmata
3. along and through the intercellular spaces and cellulose walls from one cell to the next.

Dissolved mineral ions are taken up by root hairs using active transport, and move with the water into the xylem.

8.6 The transpirational stream is achieved by:

- osmosis along a diffusion gradient between the leaves and the roots and soil
- root pressure, causing water to move up the stem a limited distance until counteracted by the force of gravity
- adhesion of water molecules to the walls of the xylem elements and the spongy mesophyll cells
- cohesion between the water molecules, forming thin water columns in the xylem
- transpiration, causing a water loss from the stomata of the leaves.

Due to lack of water in terrestrial environments, plants have evolved adaptations to prevent water loss or to maximise water uptake. The transpiration rate is affected by light, temperature, humidity, wind and the availability of soil water.

8.7 Organic compounds are translocated throughout the plant in sieve tubes in the phloem of the vascular bundles.

Simple chemical solutes only are translocated. Several observations have been made on the movement of solutes in the phloem, but no single translocation hypothesis fully accounts for all observations.

Key terms

- Casparian strip
- compensation period
- compensation point
- cuticle
- cytoplasmic streaming
- endodermal cell
- epidermis
- lamina
- lenticels
- mesophyll
- palisade cells
- petiole
- phloem
- root pressure
- sieve tube
- spongy mesophyll
- stomata
- translocation
- transpiration
- transpiration stream
- transport system
- vein
- xylem

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Which of the following features of the leaf of a flowering plant suit it for gas exchange?

A Epidermis covered with cuticle
B Large, humid intercellular air spaces
C Stomata found in pits surrounded by numerous fine hairs
D A large diffusion pathway

2 In plants, which cells are involved in transporting sugars?

A Root cells
B Xylem cells
C Companion cells
D Guard cells

3 In plants, the compensation point refers to the light intensity at which the rate of photosynthesis is:

A greater than the rate of respiration
B the same as the rate of respiration
C less than the rate of respiration
D at its maximum level

4 Which of the following is a plant adaptation for photosynthesis?

A Guard cells that keep the stomata closed during daylight hours
B Xylem tissue to transport sugars from the leaf to other parts of the plant
C Column-shaped, chlorophyll-containing cells directly below the upper epidermis
D A waxy cuticle covering the epidermis

5 In plants, respiration occurs:

A in all living cells at all times
B in all living cells at night when photosynthesis ceases
C only in leaf cells when there is inadequate light for photosynthesis
D when the compensation point is reached

6 Guard cells are specialised epidermal cells in plants. They are best characterised by the fact that they:

A occur only in the leaves of plants
B do not contain chlorophyll
C have cell walls of uneven thickness
D are always associated with epidermal hairs

7 What is the name given to the conducting tissue in plants that transports mainly water and inorganic nutrients?

A Phloem
B Vascular tissue
C Xylem
D Sclerenchyma

8 Which of the following contribute to translocation?

A Root pressure
B Transpirational pressure
C Adhesion
D None of these

Describe and explain

★ **9** Stomatal guard cells have been described as 'turgor-regulated valves'. **Explain** why they are so described.

Apply, analyse and interpret

★ **10** **Compare** the structure and function of the xylem and phloem.

★★ **11** After severe or prolonged saturation of the soil by water during floods, many plants die. **Apply** your knowledge to suggest reasons for this.

★★★ **12** An experiment was conducted on gas exchange in plants. The rates of oxygen uptake and release by a shoot of a water plant were measured over a 10-hour period. For 5 hours of the experiment the shoots were in darkness and for 5 hours they were placed in daylight. All other factors were kept constant. The results are plotted in Figure 1.

a **Infer** why the shoot used was from a water plant and not a land plant.

b **Explain** how the plant obtained the oxygen needed for cellular respiration.

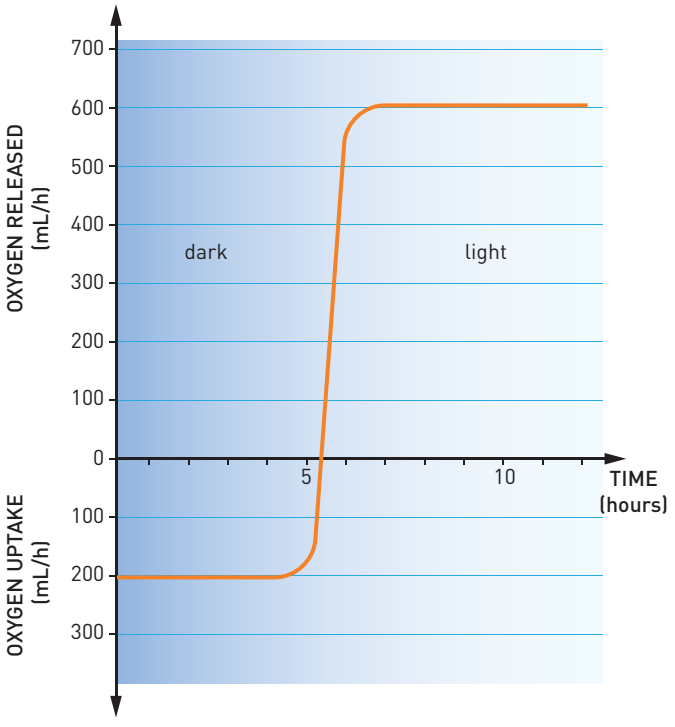


FIGURE 1

c If it is assumed that the changes in light intensity have no effect on the rate of cellular respiration, **determine** the total volume of oxygen taken up by the shoot for respiration during the 10 hours of the experiment. **Explain** your answer.

d **Interpret** the information provided to determine what time after the experiment began the compensation point was reached, and **explain** your answer.

★★ **13** Both maintenance of the transpiration stream and translocation require a large amount of energy. **Classify** the process during which the plant expends more energy. **Explain** your answer.

★ **14** **Deduce** why many leaf cells have large air-filled gaps between the parenchyma cells called spongy mesophyll.

★★★ **15** Figure 2 represents a microscopic view of part of a plant.

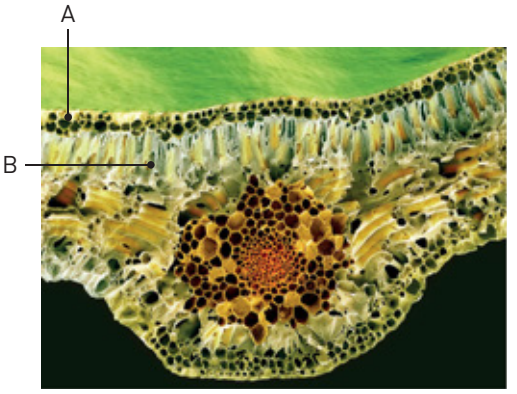


FIGURE 2

a **Identify** the part of the plant shown. **Justify** your response.

b **Determine** the function of cells labelled A.

c **Determine** the function of the cells labelled B.

d **Identify** the role of this structure in the plant.

e Copy the main features of this structure. Using different coloured arrows, sequence the movement of materials within the structure and then **summarise** the processes involved in the structure.

Investigate, evaluate and communicate

★★★**16** **Propose** a reason for each of the following statements:

a In summer, it is better to water plants in the evening than in the morning.

b After transplanting plants, it is a good idea to remove some leaves.

c Water moves up a stem more quickly on a hot dry day than on a cool wet day.

★★★ **17** Water loss from the leaves of two different species of plants, species A and species B, was compared. One leafy shoot was taken from each plant. The leaves were weighed, hung in air and reweighed at 15-minute intervals. The results are shown in the table (a dash indicates that a result was not available).

Time after start of experiment (minutes)	Mass of leafy shoot (g)	
	Species A	Species B
0	210.0	240.0
15	195.3	–
30	184.4	–
45	176.4	–
60	170.1	–
75	166.3	231.1

a **Sketch** a graph of mass against time for species A. Account for the shape of this curve.

b **Calculate** the percentage change in mass for each species after 75 minutes.

c **Evaluate** these two species and **discuss** which you would expect to be more successful in an arid region.

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UNIT 2

MAINTAINING THE INTERNAL ENVIRONMENT

FIGURE 1 Neurons convey information around the body in the form of nerve impulses.

Homeostasis is the maintenance of a constant internal composition or steady state within an organism despite changes to its internal or external environment. In order to maintain homeostasis, the organism must be able to detect changes in both the internal and external environment and respond to them. Both of these processes involve changes in the chemicals within an individual cell or in the specialised cells of a sense organ and are regulated by a feedback system.

All organisms use chemical feedback systems to achieve homeostasis. In vertebrates, specific chemicals, hormones, are produced in endocrine glands and released into the bloodstream to bring about a response in a target group of cells. Only cells that have the specific recognition sites (receptors) on their membranes will respond to the matching hormone.

Animals have an additional coordinating and control system – the nervous system. This allows a much more rapid response than the endocrine system although its action is shorter. Although passage of a nerve impulse along a neuron is an electrochemical transmission, the communication between neurons or receptor/effector and neuron is purely chemical.

Animals need to regulate their temperature and water balance. This is achieved, to varying extents depending on the environment of the animal, through structural, behavioural and physiological means. Osmoregulation (water balance) is also significant in flowering plants. This is mainly brought about by structural features that are modified in particular environments and hormonal intervention.

Organisms can suffer diseases that may result from environmental or genetic conditions, or as a result of infectious agents. Pathogens (non-living organic particles such as prions and viruses, or living organisms such as bacteria, fungi, protozoa and macro-parasites) cause infectious disease. Infectious diseases are contagious when they pass directly from one individual to another of the same species. A large number of infectious pathogens are transmitted via a vector organism or secondary host.

A variety of barriers are present in plants and animals to inhibit entry of pathogens into the body. If these are breached, a series of innate and/or induced responses can occur via the organism's immune system. These responses occur as a result of the organism's ability to detect antigens – non-self proteins on the surface of the invading pathogen. As a result of induced immune responses, animals may become passively immune to further infections from any specific pathogen. Immunity may be achieved for varying periods from injections of antibodies (passive) or vaccinations of altered pathogens (active).

Epidemiology is the study of the cause of non-infectious disease and effectiveness of control measures of all kinds of disease. Once isolation of the possible pathogenic cause of infectious disease is achieved, Koch's postulates (derived from his research in 1876) are followed to verify the observations.

Control measures to prevent the spread of disease include personal hygiene, avoidance and/or elimination of vectors and quarantine.

Unit 2 Topics

Topic 1	Homeostasis	Chapters 9–10
Topic 2	Infectious diseases	Chapters 11–12

Unit objectives

1 Describe and explain homeostasis and infectious disease.
2 Apply understanding of homeostasis and infectious disease.
3 Analyse evidence about homeostasis and infectious disease.
4 Interpret evidence about homeostasis and infectious disease.
5 Investigate phenomena associated with homeostasis and infectious disease.
6 Evaluate processes, claims and conclusions about homeostasis and infectious disease.
7 Communicate understandings, findings, arguments and conclusions about homeostasis and infectious disease.

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CHAPTER 9

Coordination and control

For organisms to survive, they need to maintain a constant internal environment within a narrow tolerance range (homeostasis). Since both internal and external environments are constantly changing, they need to detect, monitor and respond so that these changes may be regulated. The basis of these processes is chemical. In animals, both the endocrine (hormonal) and nervous systems are involved in maintaining homeostasis.

OBJECTIVES

- → Understand that metabolism describes all of the chemical reactions involved in sustaining life and is either catabolic or anabolic.
- → Explain why changes in metabolic activity alter the optimum conditions for catalytic activity of enzymes (with reference to tolerance limits).
- → Recall that homeostasis involves a stimulus–response model in which change in the condition of the external or internal environment is detected and appropriate responses occur via negative feedback
- → Interpret feedback control diagrams for either nervous or hormonal systems (i.e. recognise stimulus, receptors, control centre, effector and communication pathways).
- → Recall that hormones are chemical messengers (produced mostly in endocrine glands) that relay messages to cells displaying specific receptors for each hormone via the circulatory or lymphatic system.
- → Recognise how a cell's sensitivity to a specific hormone is directly related to the number of receptors it displays for that hormone (an increase in receptors = upregulation; a decrease = downregulation).
- → Describe how receptor binding activates a signal transduction mechanism and alters cellular activity (results in an increase or decrease in normal processes).
- → Identify cells that transport nerve impulses from sensory receptors to neurons to effectors.
- → Discriminate between a sensory neurone and a motor neurone (consider dendrites, soma, body, axon, myelin sheath, nodes of Ranvier, axon terminal and synapse).
- → Explain the process of the passage of a nerve impulse in terms of transmission of an action potential (conduction within neuron) and synaptic transmission (communication between neurones). Refer to neurotransmitters, receptors, synaptic cleft, vesicles, postsynaptic and presynaptic neurones, and signal transduction.
- → Recall that effectors are either muscles (which contract in response to neural stimuli) or glands (which produce secretions).
- → Recognise that sensory receptors (chemo, thermo, mechano, photo, noci) detect stimuli and can be classified by the type of stimulus.

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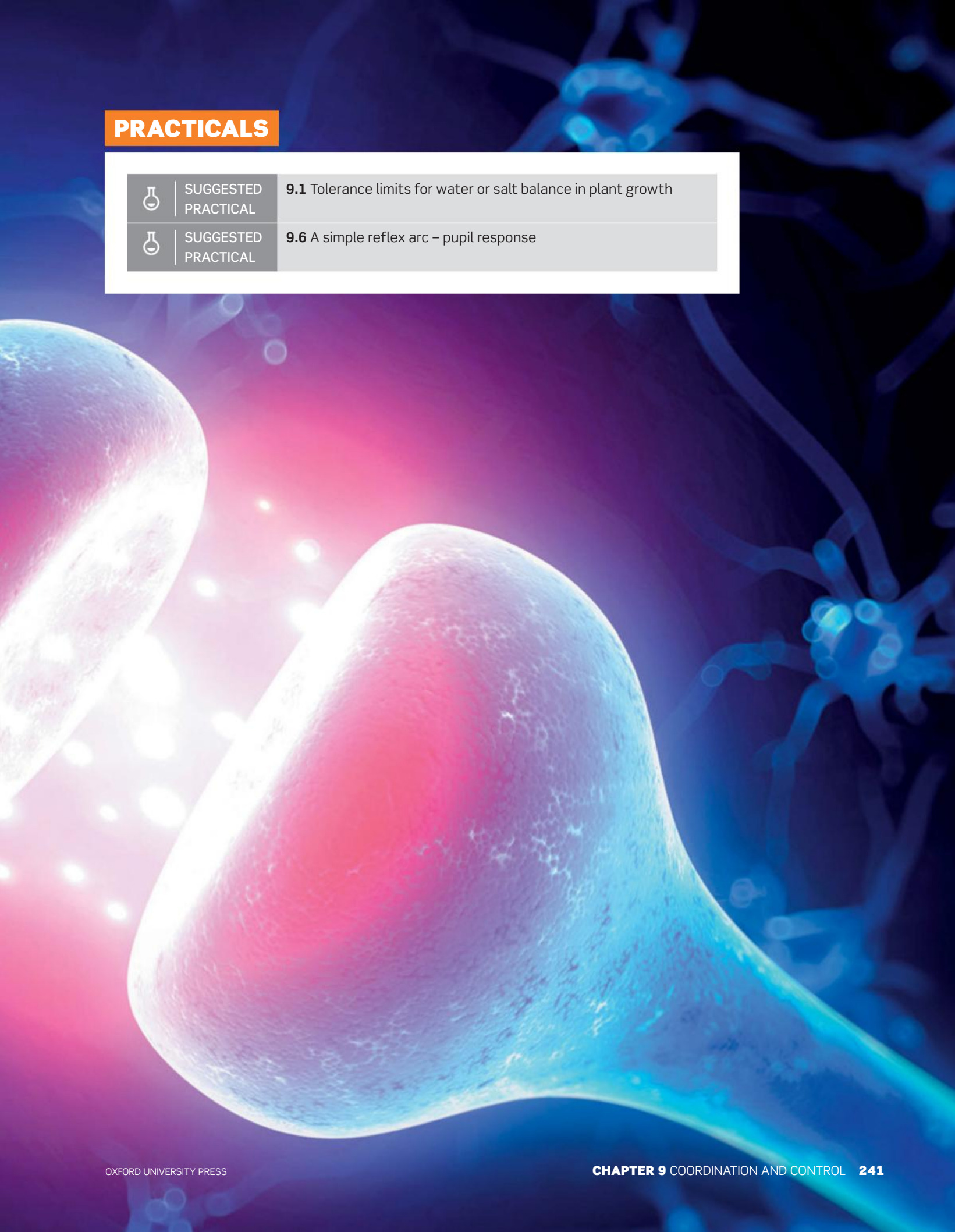
FIGURE 1 Synapses allow information to be passed from one neuron to another.

PRACTICALS

SUGGESTED PRACTICAL	**9.1** Tolerance limits for water or salt balance in plant growth
SUGGESTED PRACTICAL	**9.6** A simple reflex arc – pupil response



SUGGESTED PRACTICAL
9.1 Tolerance limits for water or salt balance in plant growth
Go to your obook »

9.1 Homeostasis: responding to change

KEY IDEAS

- The importance of organisms monitoring both their internal and external environment
- The term 'homeostasis'
- Tolerance ranges of both internal and external environmental conditions for survival
- The difference between irritability and coordination
- The stimulus–response model, and positive and negative feedback

homeostasis maintenance of a constant internal environment, mediated by feedback systems

catabolic reaction a chemical reaction in which large molecules are broken down into smaller ones, usually accompanied by the release of energy

anabolic reaction a chemical reaction in which large molecules are built up, usually with a net input of energy

optimal level the state of something that is the most advantageous for an outcome

tolerance range a certain range of a particular factor in which an organism can survive

tolerance limit the upper and lower limits to the range of particular environmental (e.g. light, temperature, availability of water) or physiological (particular chemical concentrations) factor within which an organism can survive

Organisms must be able to monitor their environment. This may involve detecting changes in the chemicals within the body, such as the levels of glucose or carbon dioxide. Other important environmental aspects that must be monitored are outside the body. The direction of water currents, the relative position of light, temperature or detection of food sources are all important clues for an organism's ability to survive.

Both the internal and external environment are constantly changing. The abiotic and biotic conditions surrounding an individual can vary from moment to moment. As cells undergo metabolic reactions, the internal and external concentrations of cellular chemicals change. These changes have an impact on the individual and may be detrimental to its survival. But organisms can survive many internal and external changes. This is achieved by a variety of anatomical, physiological and behavioural adaptations. **Homeostasis** is the term used to describe a constant internal environment within a living organism despite internal or external changes.

As seen in Chapter 2, the cells (and therefore the entire body) of an organism are composed of chemicals that are constantly reacting in order to maintain survival. These metabolic reactions are either catabolic or anabolic:

- **Catabolic reactions** are breakdown reactions. For example, the breakdown of glucose into carbon dioxide and water in cellular respiration to release energy (in the form of ATP) is a catabolic reaction.
- **Anabolic reactions** require energy as they build complex (higher energy) molecules from their base parts (e.g. the production of glucose during photosynthesis).

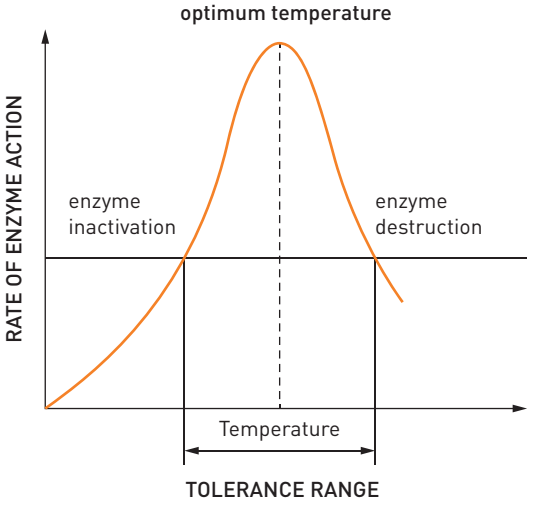


FIGURE 1 Temperature tolerance range of an enzyme

Each step of these metabolic pathways requires a specific enzyme (see Section 2.3) for the reaction to occur. Enzymes require very specific internal environmental conditions. Each enzyme has an **optimal level** of temperature and pH at which it acts. The enzyme can still work within a narrow band of the environmental condition, however it will not be as effective. This is termed the **tolerance range** or **limit** for that enzyme. Outside of that range, the enzyme is deactivated.

One set of metabolic reactions brings about changes in the cells; these reactions are then counteracted by other reactions to bring the cell back to its optimal condition.

In a similar way, the external environment of the organism dictates the availability of resources for the organism's survival. These external conditions may determine the internal conditions of the organism. For example, the temperature of the environment can affect the temperature of the organism's cells, and therefore the effectiveness of the enzymes in that cell. The organism as a whole, therefore, has a tolerance range for the conditions in which it can live. The role of homeostasis is to ensure that all metabolic reactions in the body can occur at a rate that ensures the survival of the organism.

Irritability – the ability to detect and respond to changes in the environment – is a characteristic of all living matter. **Coordination** occurs when different body parts work together to maintain homeostasis.

Mechanisms that maintain homeostasis provide the organism with some degree of independence from its environment. Mammals are among the most successful of all animals since their homeostatic mechanisms are such that they are able to maintain relatively constant levels of activity despite fluctuations in environmental conditions – control of the internal environment can be achieved. In plants, homeostatic control is usually limited to patterns of growth. Most plants, therefore, are more restricted with respect to the environment in which they can successfully grow.

irritability
the basic property of protoplasm: detection and response to changes in the environment

coordination
working together

stimulus
change in the environment of an organism that brings about a response

sense organ (receptor)
a cell or group of cells that receives stimuli

regulator
a substance or process that regulates or controls another

response
the reaction of an organism to a particular stimulus

effector
an organ or cell by which an animal acts, e.g. muscles, glands

The stimulus–response model

A **stimulus** is a detectable change (input) in either the internal or external environment that acts as a signal for cells. It may be physical (e.g. heat, pressure or light) or chemical (e.g. food or other substances). The cells must be able to detect the change and this is achieved by molecules in the cell that undergo some kind of change as a result of the incoming signal. In multicellular organisms, certain cells are highly specialised to receive particular external stimuli. Other cells are specialised to send or receive signals to coordinate the functions between different parts of the body. Further groups of cells are able to determine if some sort of change to cellular activities needs to occur in order to maintain homeostasis.

Detection of the stimulus (input) involves changes in chemical molecules within the individual cell or in animals. In multicellular animals the specialised cells are found in a **sense organ** (**receptor**). A chemical message is then transmitted to a coordinating centre (the **regulator**) that determines if a change is required. If so, another chemical message brings about a **response** (output). The response is again a change in chemicals within a single cell or within an **effector** organ. Effectors can be either a muscle (with a movement response) or a gland (which will secrete molecules).The basic components of any control system are illustrated in Figure 3. In plants, a chemical transmitter (hormone) is released by the cell when an appropriate stimulus acts on it. The transmitter brings about a response.

FIGURE 2 A lizard that is feeling the cold may move into the sun to warm itself. This is an example of stimulus and response.

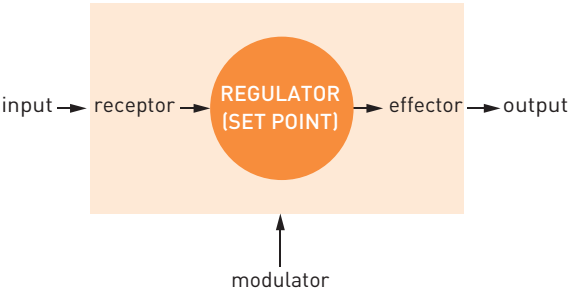


FIGURE 3 Basic components of a control system

feedback
modification or control of a process or system by its results or effects, e.g. in a biochemical pathway or behavioural response

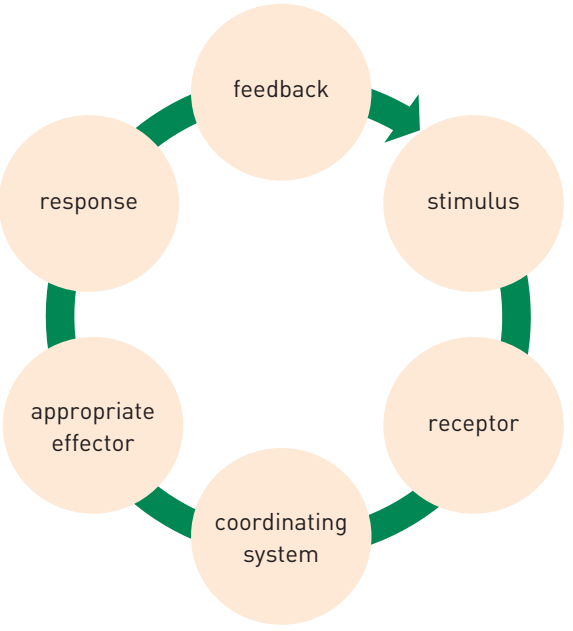


FIGURE 4 Stimulus–response model showing feedback

positive feedback
a physiological control mechanism in which a change in some variable triggers mechanisms that amplify the change

negative feedback
a change which reverses a particular trend

The efficiency of the animal control system is measured in terms of:

- the displacement from the optimal level or set point
- the speed at which the optimal level is restored.

Fluctuations from the set point (the optimal level) activate the control system, which returns the particular factor towards its optimal level. The reaction may then act as another stimulus to either stop or maintain the behaviour. In this case, **feedback** occurs. Linking all components of the control system allows the output to be regulated in terms of the input.

Positive and negative feedback

There are two types of feedback: **positive feedback**, in which the same response will continue, and **negative feedback**, in which the response is reversed or negated.

In most stimulus–response systems, the response by the effector results in removing the original stimulus. For example, a person that is too cold may start shivering to warm up. The cold on their skin or blood was the stimulus; the effector muscles respond by moving. This response causes the person to warm up, removing the original cold stimulus. This is an example of a negative feedback system where the response has a negative impact on the stimulus.

The majority of vertebrate homeostatic control mechanisms display negative feedback. They are self-adjusting because any change in optimal levels in the feature being regulated trigger the appropriate corrective mechanism. If the stimulus indicates that the level is too high, the response will be to lower the level. If the stimulus indicates that the level is too low, the effector organ will respond so that the level increases again. Fluctuations around the optimal level occur within any response because the level of response cannot be controlled and this causes an 'overshooting' of the set point. Therefore, these responses fluctuate above and below the optimal level until stability is achieved. This control system is activated by hormones or the nervous system or a combination of both in mammals.

There are two coordinating systems in the bodies of multicellular animals – the nervous system and the hormonal or endocrine system. These two systems mediate between a stimulus and a response; that is, between detecting a change in the internal or external environment and an appropriate reaction. In plants all coordination of cellular activities is achieved through either a direct response to the chemical composition of the cells or through hormonal control.

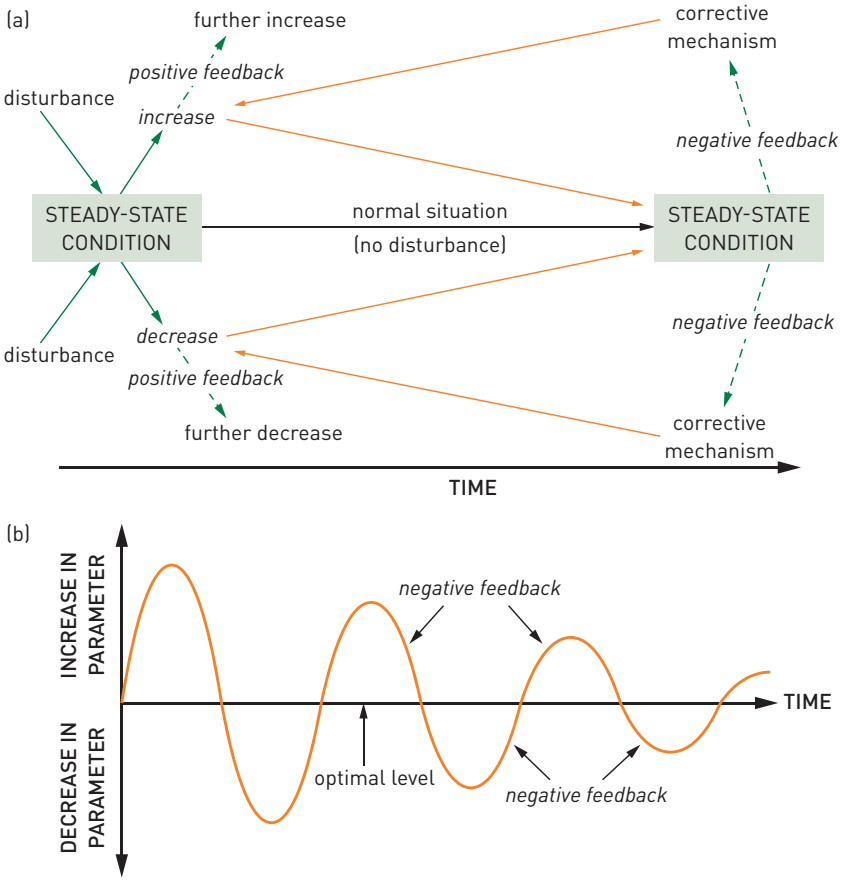


FIGURE 5 Homeostatic control mechanisms shown (a) diagrammatically and (b) graphically

CHECK YOUR LEARNING 9.1

Describe and explain

1 **Explain** what is meant by 'coordination' within the body.

2 **Describe** what is meant by a feedback system.

3 All communication systems in living organisms involve a stimulus, a transmitter and a response. **Define** these three terms.

Apply, analyse and interpret

4 **Distinguish** between positive and negative feedback.

5 A simple stimulus–response model can be written as:
stimulus → receptor → coordinating system → effector → response
Consider why this would be ineffective as the only means of control of a metabolic activity.

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  Homeostasis
- » Weblink
  The stimulus-response model

9.2 Chemical control

KEY IDEAS

- The underlying chemical nature of all control systems in organisms
- Signal transduction in the response of a cell to a stimulus
- General types of hormones and their action on cells
- Other chemical signals in animals
- Cell membrane receptors – up-regulation and down-regulation

Within any living cell, vast numbers of chemical reactions are occurring at any given moment. The chemical environment in every part of the cell is constantly undergoing slight changes, as some substances are synthesised and others are used, destroyed or removed. Any change in the chemical environment will affect subsequent chemical reactions and thereby exert some control over them. This simple relationship, which regulates most of the cell's reactions, forms the basis of more complex chemical regulatory mechanisms.

Cells have special receptor molecules embedded in their membranes and in their cytoplasm. Different types of cells have different types of receptors and so will only respond to specific chemical messages in their environment. For a cell to respond to a stimulus, **signal transduction** must occur. Changes occur in the receptor molecule that allows transmission of molecular signals from the cell's exterior to its interior. An appropriate response can then be made by the cell.

signal transduction
a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane

It is from this basis that hormone systems are thought to have evolved. In this type of system certain cells have become specialised to produce and secrete specific regulatory chemicals.

Hormones as chemical signals

Hormones are chemical messengers that are produced by an organism to regulate the activity of cells and organs. They are produced by cells in very small quantities and transported to cells in other parts of the body. Each hormone regulates and controls the activity of a specific target structure. This may be an individual cell, a muscle or another gland.

hormone
a regulatory chemical of the control and coordination system; capable of bringing about a specific response to a particular stimulus

There are three ways a hormone may effect a change.

- **Autocrine** hormones will bind to receptors in the same cell that produced them. An example of this is a white blood cell (T lymphocyte) activating itself with an autocrine hormone (IL-2) during an infection.
- **Paracrine** hormones will bind to receptors on neighbouring cells. Infected plant cells use paracrine hormones to warn neighbouring cells to protect themselves.
- **Endocrine** hormones travel long distances through the blood supply of animals to reach the target cells that have receptors that are complementary to the shape of the hormone.

Other hormones that act at a distance are **pheromones**. They are released from the body and act as a species-specific signal to other members of the species. Female dogs and insects release sex pheromones into the air when they are ready to mate. The chemical molecules released can be detected at very small concentrations over large distances by the males of their species. Other pheromones are released in urine or specialised glands to mark out territories.

pheromone
a hormone released as an external signal to other members of the species

FIGURE 1 Terminal shoot of the red cedar (*Toona ciliata*) infected with tip moth larvae

Some plants also produce pheromones. For example, the growing tip of the primary shoot of the red cedar (*Toona ciliata*) releases a pheromone that attracts the tip moth. The moth lays its eggs into the tissues and the emerging larvae feed on them. This prevents further growth from the apex, but stimulates growth of lateral branches.

The action of hormones tends to be slow because they travel long distances to find their complementary receptors. Similarly, since there will be some of the released hormone still available even after its production has been 'switched off', the action is long-lasting.

A stimulus causes production and secretion of a hormone appropriate to that stimulus:

- Information about the external environment is relayed to hormone excreting cells via the nervous system in most animal groups, and in plants the cells are directly stimulated by an external cue (e.g. the direction of light).
- Hormone secreting cells respond directly to changes in their immediate internal environment, often via a circulating fluid (in animals) or diffusion (in plants).

The hormone is then carried throughout the body. It does not initiate any unique cellular activities, but instead modifies the rates of existing activities. There are two main types of hormones – water-soluble and fat-soluble.

When a water-soluble hormone (proteins or amino acid derivatives) reaches the target organ receptors, glycoprotein molecules on the cell membranes 'capture' the hormones. This binding between the receptor molecule and hormone can:

- couple directly with an ion channel to influence the passage of specific ions into or out of the cell (i.e. they influence the permeability of the cells to particular solutes)
- allow the hormone-receptor molecule to pass across the membrane where it can be linked to a specific protein or become associated with a particular enzyme to induce or repress their action and therefore specific chemical reactions.

Fat-soluble hormones (such as steroids) are able to pass directly through the cell membrane. In the cytoplasm, they bind with their complementary receptors, allowing them to pass through the pores of the nuclear membrane. The linkage of the hormone and receptor has a particular shape that has an affinity with a specific nucleotide sequence in the DNA. This interaction changes the gene expression of the cell so that specific enzymes are either produced or their synthesis is inhibited; that is, they affect the function of specific genes.

Hormones are often referred to as 'chemical signals', since they cause a change in activity of the target cells. Hormones differ in their molecular structure. Some are proteins and others are steroids. Therefore, different hormones will be recognised by different target sites and bring about different chemical reactions.

Other chemical signals in animals

There are many different types of signals received by cells. These include neurotransmitters (chemical messengers released from the nervous system), messages from the immune system, growth factors and toxins. As with hormones, only cells with a complementary receptor for that chemical messenger will be influenced by it. The more receptors present for that chemical, the more actively the cell responds to the message.

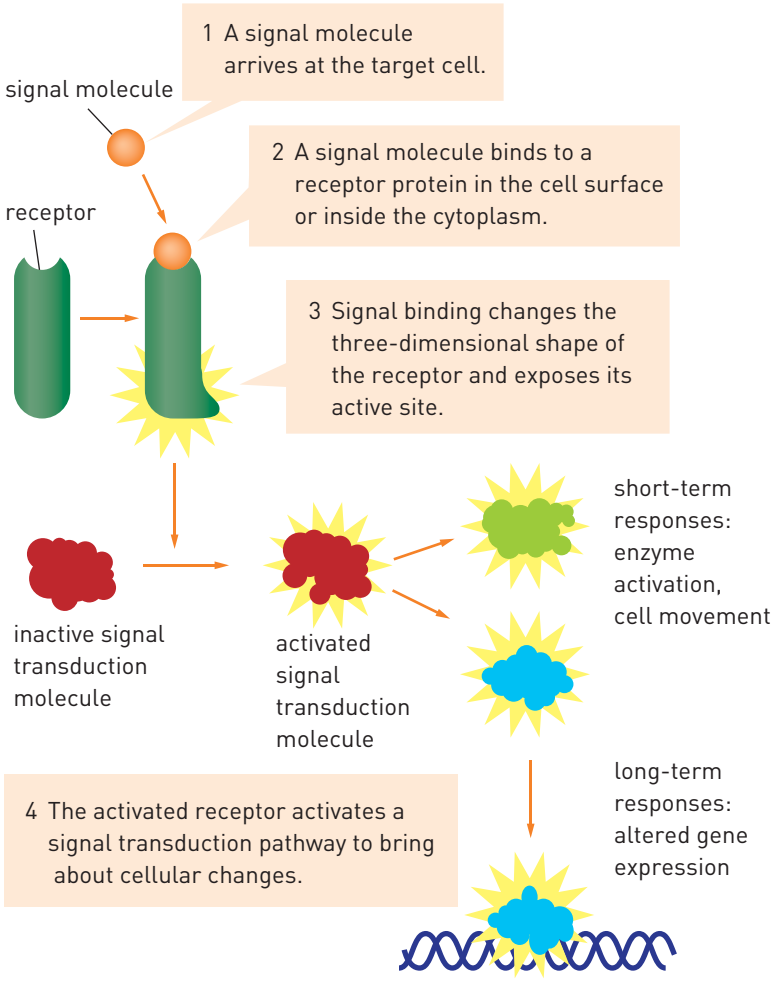

FIGURE 2 The process of signal transduction

Signal transduction

For a cell to respond to a stimulus, a **signal transduction pathway** must be activated. When a hormone binds to its specific receptor, the receptor rearranges its shape. This change in conformation can signal to other molecules (called secondary messengers) in the cell to change their function. Like a game of Chinese whispers, the secondary messenger molecules cause changes in the chemical pathways throughout the cell until these result in a final response to the hormone message. These responses include:

- activating or inactivating enzymes
- exocytosis of molecules
- the switching on or off genes
- opening or closing protein channels.

signal transduction pathway
a cascade of biochemical reactions inside a cell that eventually reach the target molecule or reaction; it is initiated when a molecule (e.g. a hormone) attaches to a receptor on the cell membrane

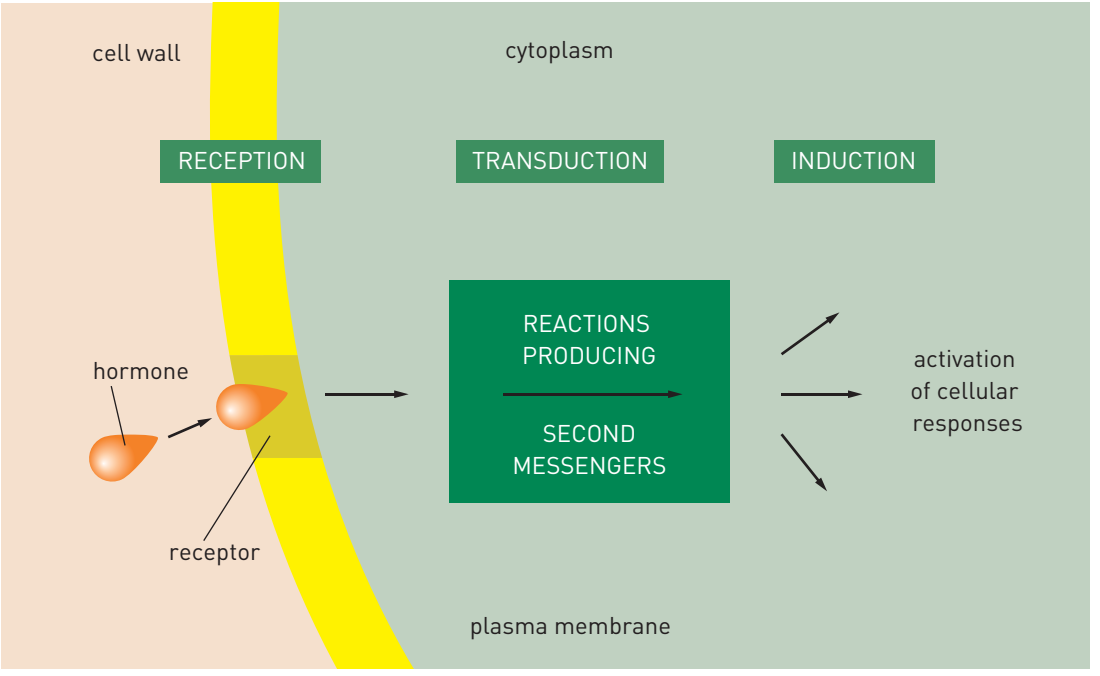

FIGURE 3 The signal transduction of a hormone acting on its target plant cell

The life cycle of receptors

The types of receptors found on the cell's surface or in its cytoplasm are determined by the DNA of the cell. The DNA molecules contain genes that code for the specific receptor (each receptor molecule is a protein), which becomes embedded in the cell membrane or remains in the cytoplasm. There are a great many different types of cell receptors present at any one time, each type responding to a different signal.

The cell constantly monitors what signals are coming in to its receptors and adjusts the quantities of each type of receptor accordingly.

Membrane receptors can be removed or recycled. When this occurs, there are fewer of that particular type of receptor present to detect signals and so there is a reduction of the cell's sensitivity to that message. This process is termed **down-regulation**. This is what happens when the body is exposed to high insulin levels in the blood. The number of insulin receptors is down-regulated, reducing the body's sensitivity to the insulin hormone.

If the cell receives a weak signal, more receptors can be synthesised to increase the cell's sensitivity to the message. The increase in the number of those receptors is termed **up-regulation**. For example, during pregnancy, the uterus up-regulates oxytocin receptors. When childbirth starts, the uterus is more sensitive to the oxytocin that is released from the brain.

down-regulation
the process of reducing or suppressing a response to a stimulus by reduction in the number of receptors on the cell surface

up-regulation
the process of increasing the response to a stimulus due to an increase in the number of receptors on the cell surface

CHECK YOUR LEARNING 9.2

Describe and explain

1 **Describe** what happens during a signal transduction pathway.
2 **Define** a hormone.
3 **Explain** why only certain target cells are affected by each type of hormone.
4 **Explain** how a cell can change in response to a hormone.
5 Hormones are not the only chemical signals in a multicellular organism. **Identify** one other type of chemical signal.
6 **Describe** a pheromone. Give an example of an animal and a plant pheromone.

Apply, analyse and interpret

7 **Distinguish** between up-regulation and down-regulation of cell membrane receptors. How is each process achieved?

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  Signal transduction
- » Weblink
  Receptor life cycle

9.3 The human endocrine system

KEY IDEAS

- The human endocrine glands and their role in intercellular coordination and homeostasis
- Control of the release of a particular hormone
- The role of the brain (hypothalamus and pituitary gland) in control of the release of hormones.

endocrine glands ductless glands in animals which secrete hormones into the bloodstream

In mammals, the group to which humans belong, hormones, or chemical messengers, are produced in ductless **endocrine glands**. These glands pass their secretions directly into the blood vessels. The endocrine and nervous systems function in a coordinated fashion to maintain homeostasis. It is thought that these two systems originated and developed side by side as the increasing size and complexity of organisms made intercellular communication more important.

Figure 1 shows the location of the main human endocrine glands. In spite of their physical separation from one another, endocrine organs do not work in isolation. Many hormones interact with each other to bring about a particular response.

The stimuli controlling the release of any particular hormone include:

- the presence of a specific metabolite in the blood
- the presence of another hormone in the blood
- stimulation by the autonomic nervous system.

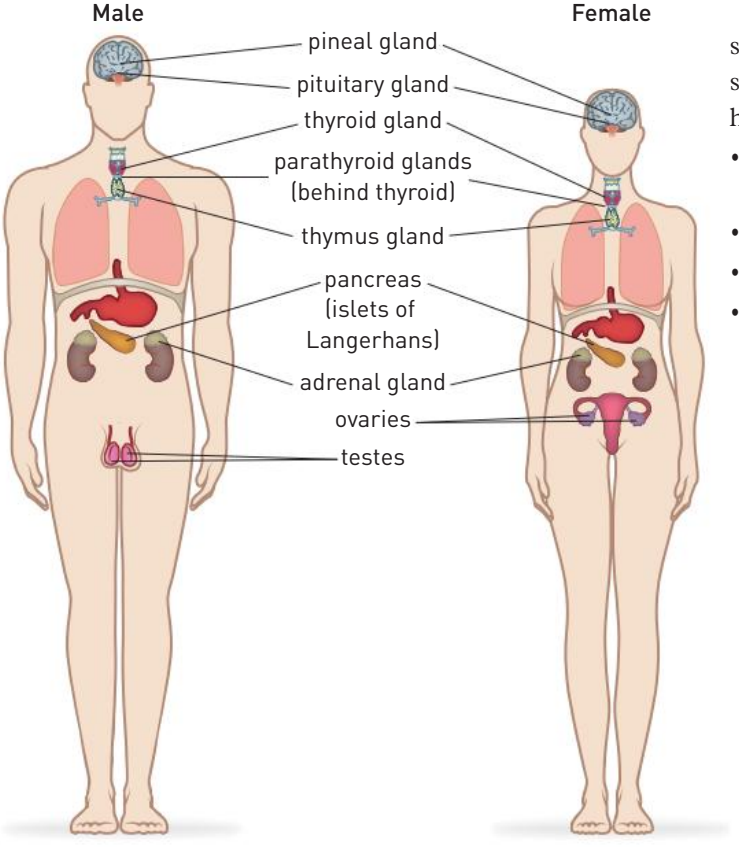

FIGURE 1 Position of the main human endocrine organs

Each hormone will bring about an effect only on specific body cells. The target cells have recognition sites for specific hormones. There are several ways a hormone can influence a target cell. It may:

- change the permeability of the membrane to particular chemicals
- influence enzymes located in the membrane
- influence cell organelles
- activate genes to bring about specific protein production.

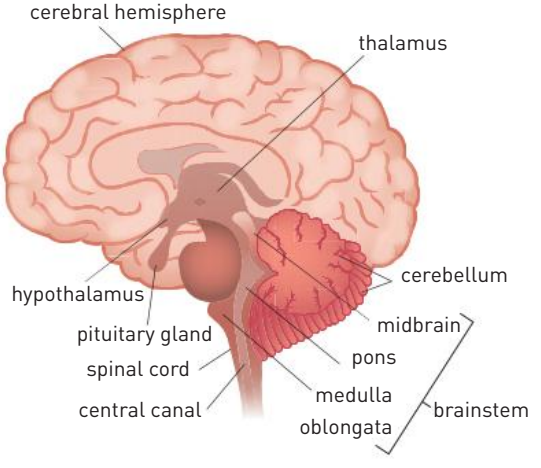

FIGURE 2 The human brain, showing the structure and relationship of the hypothalamus and pituitary gland

TABLE 1 The major human endocrine glands, the hormones they produce and their functions

Endocrine gland	Hormones	Major function
Hypothalamus	Releasing and release-inhibiting hormones	Control release of hormones from adenohypophysis (anterior pituitary)
Hypothalamus via neurohypophysis (posterior pituitary)	Oxytocin	Stimulates release of milk and uterine contractions
	Anti-diuretic hormone	Stimulates reabsorption of water in kidney
Adenohypophysis (anterior pituitary)	Adrenocorticotropic hormone (ACTH)	Stimulates adrenal cortex
	Follicle-stimulating hormone (FSH)	Stimulates development of ovarian follicles and seminiferous tubules
	Luteinising hormone (LH)	Stimulates ovulation and also stimulates progesterone and testosterone production
	Melanocyte-stimulating hormone (MSH)	Stimulates dispersion of pigment (melanin) in the skin of amphibians; stimulates melanin production in humans
	Prolactin	Maintains lactation after pregnancy; maintains secretion of progesterone during pregnancy
	Thyroid-stimulating hormone (TSH)	Stimulates thyroid gland
	Growth hormone	Promotes growth
Thyroid	Thyroxine and tri-iodothyronine	Increase metabolic rate by stimulating cellular respiration; play an important role in growth, tissue development and differentiation
	Calcitonin	
Parathyroid	Parathormone	Acts in opposition to calcitonin – brings about removal of calcium from bone; and increases reabsorption of calcium in the kidney, so raising the blood calcium level
Adrenal cortex	Glucocorticoids, e.g. cortisone	Regulate carbohydrate metabolism
	Mineralosteroids, e.g. aldosterone	Regulate salt and water metabolism
Adrenal medulla	Adrenalin and noradrenalin	Prepare animal to meet emergency conditions, e.g. fight, flight or shock, by increasing heart rate and the blood supply to skeletal muscles, lungs and liver, and raising the blood sugar level
Pancreas	Glucagon	Increases blood sugar level by converting glycogen to glucose
	Insulin	Decreases blood sugar level by stimulating the formation of glycogen
Glands in stomach lining	Gastrin	Maintains flow of gastric juice
Glands in duodenum lining	Secretin	Stimulates secretion of intestinal juices
	Pancreozymin	Stimulates secretion of pancreatic juice
	Cholecystokinin	Stimulates release of bile from gall bladder
Ovary	Oestrogens	Initiate and maintain female secondary sexual characteristics; initiate thickening of uterus lining; and control FSH and LH secretions
	Progesterone	Maintains thickening of uterus lining; inhibits FSH and LH
Testis	Testosterone	Initiates and maintains male secondary sexual characteristics

It takes time for a stimulus to result in the release of a specific hormone, for the hormone to reach the target cells and for these to respond. Similarly, once further release of a hormone is inhibited, it will be some time before all the circulating hormone is attached to target cells. Therefore, hormonal control is slow-acting but long-lasting.

The hypothalamus, a section of the forebrain of vertebrates, plays a dominant role in hormone release. It collects information from other parts of the brain, as well as monitoring levels of hormones and other chemicals in the blood vessels passing through it. Any changes that are detected are passed to the pituitary gland, which is directly below and adjoining it, by nervous conduction or the release of neurohormones. The pituitary gland may then respond and generate a negative feedback response.

The pituitary: the master gland

The pituitary gland is formed from two tissues: a glandular portion (the anterior lobe or adenohypophysis) that produces and releases hormones, and a neural portion (the posterior lobe or neurohypophysis) that releases the neurohormones that were produced in the hypothalamus.

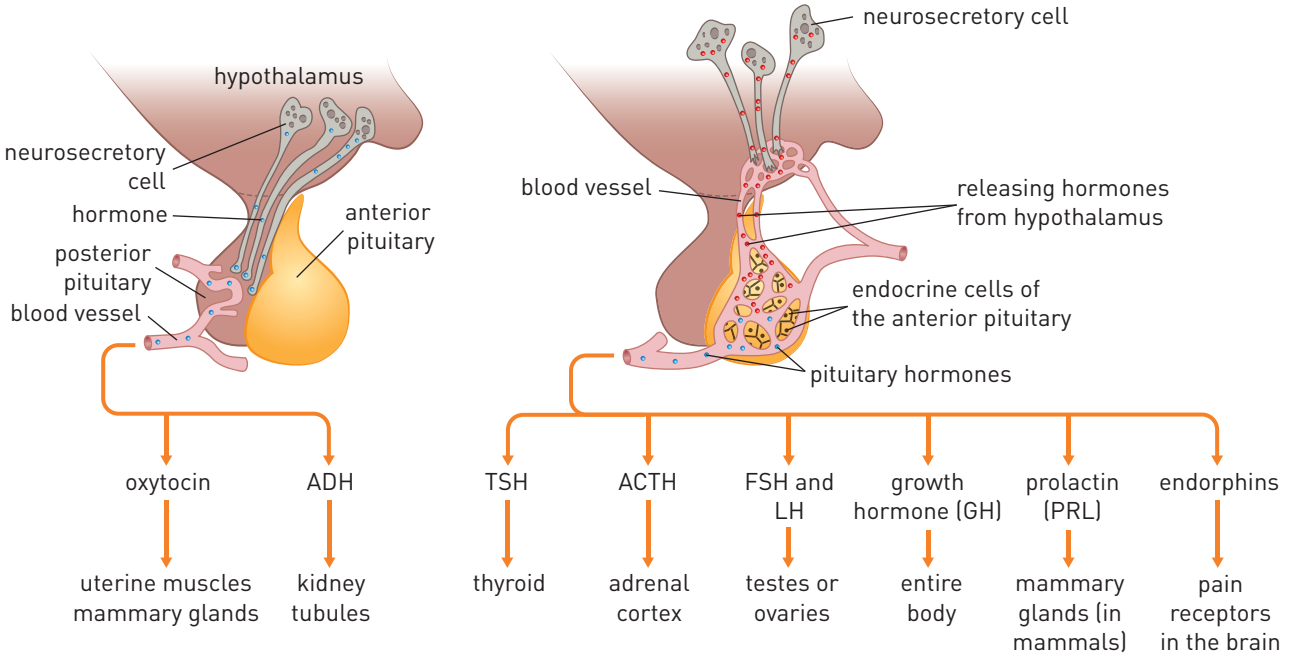

FIGURE 3 The hormones released from the anterior and posterior lobes of the pituitary glands

tropic hormone
a hormone which brings about changes in growth patterns

pituitary gland
the 'master gland' of the human body, the pituitary gland is responsible for the production of a number of hormones in the body and the coordination of hormone production in other glands

The adenohypophysis produces seven hormones. One promotes growth, one influences pigmentation and the others, the **tropic hormones**, stimulate other endocrine glands. The pituitary gland exerts its influence over other parts of the endocrine system through these tropic hormones. The production of the hormones by the adenohypophysis is controlled by the hypothalamus.

Hormones produced by the nerve cells in the hypothalamus act as either releasing hormones or release-inhibiting hormones to the adenohypophysis. Some of the adenohypophysis hormones – for example, growth hormone and prolactin – respond to the relative proportions of releasing and release-inhibiting hormones. Others respond only to releasing hormone.

The hypothalamus also produces the hormones antidiuretic hormone (ADH) and oxytocin, which are transported in blood vessels and stored in the neurohypophysis. The release of these hormones from the posterior lobe of the pituitary is triggered by nervous stimulation from the hypothalamus.

Due to the multiplicity of hormones released either directly or indirectly by the **pituitary gland**, it has been termed the master gland of the body; and the hypothalamus has been termed the **control centre**.

Not all endocrine glands are under the sole control of the hypothalamus and pituitary gland. Some are self-regulating, as they respond directly to changes of metabolites in the blood. The secretion of insulin and glucagon from the pancreas, for example, are responses to blood sugar levels. Other organs, such as the adrenal cortex, are under direct nervous control.

control centre (hypothalamus) the group of ganglia in the brain that release hormones that bring about the release or inhibition of hormones by the anterior lobe of the pituitary gland

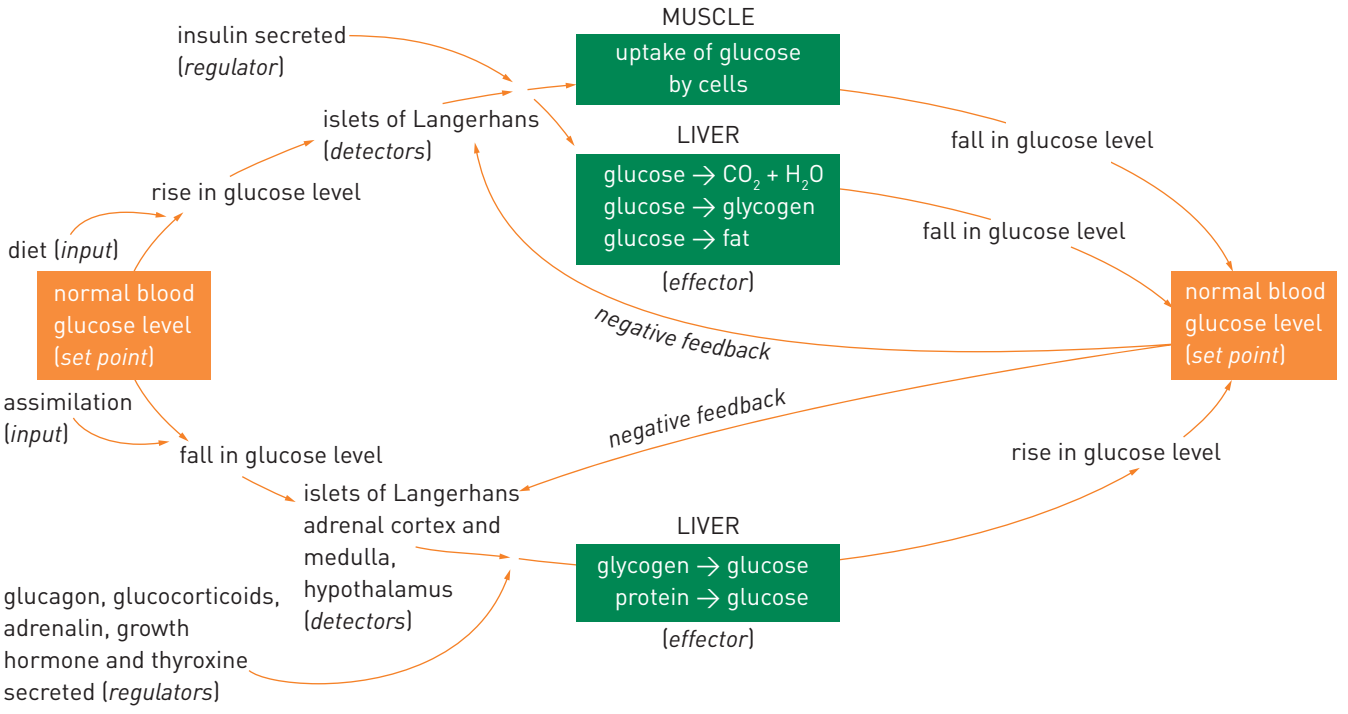

FIGURE 4 Summary of the control of the pancreatic hormones

CHECK YOUR LEARNING 9.3

Describe and explain

1 **Describe** an endocrine gland.
2 **Describe** how the anterior and posterior lobes of the pituitary gland differ.
3 **Explain** why the hypothalamus is referred to as the control centre and the pituitary as the master gland.
4 **Identify** which hormones are secreted by the thyroid gland and **describe** how they act.
5 Endocrine glands are very small and yet they can be responsible for large changes in the body. **Explain** how this can be accomplished.
6 Using one example, **demonstrate** how the pituitary gland can act to control the production and/or secretion of another hormone.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 9.3

» Video
The endocrine system

» Video worksheet
The endocrine system

» Weblink
The pituitary gland

9.4 Evolution of the nervous system

KEY IDEAS

- The need for and evolution of the nervous system in animals
- The structure and function of the nerve cell (neuron)

nerve
a fibre (dendrite or axon) or group of fibres which carry impulses between the central nervous system and body parts

neuron
a nerve cell consisting of dendrite(s), cell body and axon(s)

cell body (soma)
the mass of cytoplasm with a nucleus, from which arises the branches of a nerve cell

fibre
the thread-like extension of the nerve cell body – the axon

dendrite
the branching cytoplasmic projection of a nerve cell; it receives and transmits impulses

axon
the extension of the nerve cell body through which impulses are passed

action potential
chemical impulse that passes along the nerve fibre

The second coordinating system, found in most animals, is the nervous system. It links receptors, which detect stimuli, with effectors – muscles or glands that bring about a response. **Nerves** (bundles of nerve cells) carry information from the receptors to regulator areas (e.g. the brain) to effectors (e.g. muscles).

A typical nerve cell, or **neuron**, consists of a **cell body (soma)** which contains the nucleus and from which extend **fibres** (**dendrites** or **axons**). Information is carried from cell to cell by electrical impulses (called **action potentials**) that are generated by changes in ions across the neuron membrane.

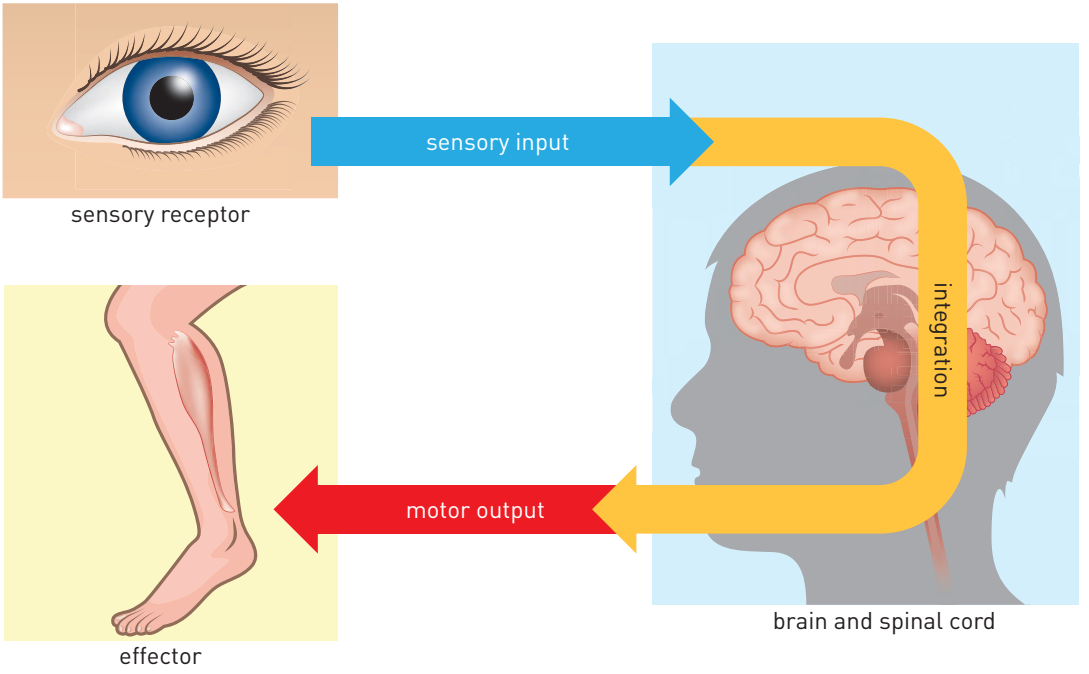

FIGURE 1 Detection and response to a stimulus

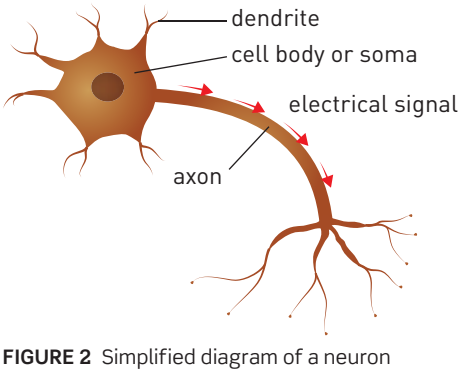

FIGURE 2 Simplified diagram of a neuron

The organisms with the most primitive nervous system are found in the phylum Cnidaria (e.g. jellyfish and *Hydra*). The neurons are linked together and form a nerve net, which makes contact between sensory receptor cells and muscle or gland cells. A nerve net allows impulses (action potentials) to spread out in all directions from the point of stimulus. Although relatively slow, this mechanism is adequate for a small, fairly inactive animal.

Two trends can be seen in more developed animals. Neurons have become assembled into tracts (usually longitudinally) and nerve cell bodies are grouped into masses called **ganglia**

(singular, ganglion). Tracts are generally produced by longer axons. This speeds up the transmission of impulses because there are fewer **synapses** (gaps between neurons) to cross. Synapses in cnidarians allow nerve impulses to pass in either direction along the axon, but with the development of tracts, nerve impulses can pass across synapses in one direction only (from the axon branches or terminal of one neuron to dendrites of the next neuron). Each individual ganglion is like a primitive brain as it gathers information from different receptors and then coordinates the responses by different effectors.

ganglion (plural 'ganglia')
an area of concentration of nerve cell bodies

synapse
the position where two adjoining neurons meet

In association with bilateral symmetry, the annelids (segmented worms), many arthropods (e.g. prawn) and vertebrates have evolved a double or single longitudinal tract or nerve cord, which ensures rapid communication between the two ends of the body. Since the front end of the body in these animals is the first to encounter the 'new' environment, receptors became concentrated in this area. In turn this led to an increased number and size of ganglia in the anterior end (head) to deal with the sensory input and transmit the required information to the effectors. The overall result was an increase in cephalisation – development of a head and brain.

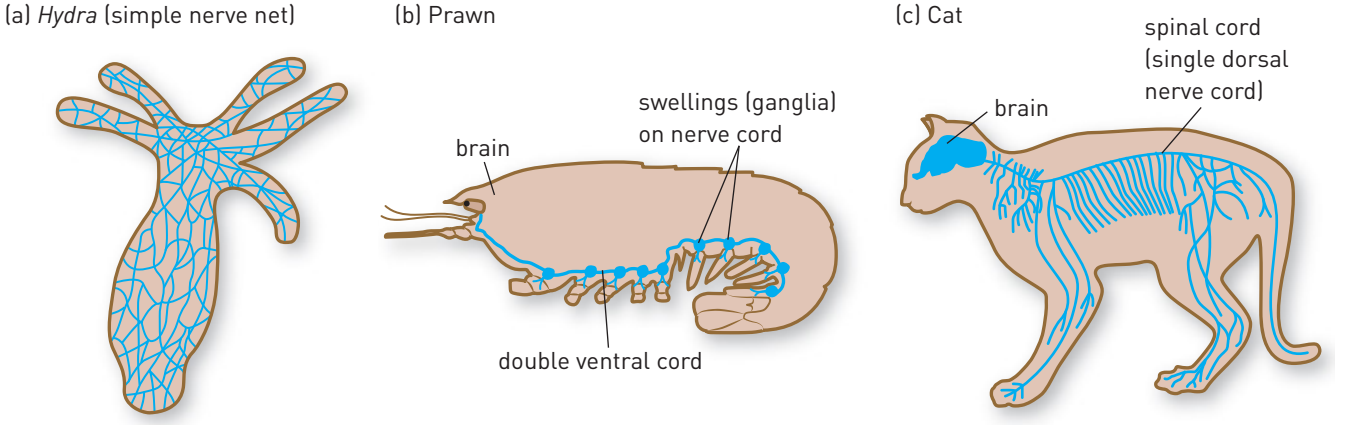

FIGURE 3 Nervous systems of (a) a *Hydra*; (b) a prawn; and (c) a cat

CHECK YOUR LEARNING 9.4

Describe and explain

1 **Explain** why the nervous system provides a faster communication pathway than that of the hormonal system.
2 **Define** the following terms:
   a action potential
   b synapse
   c stimuli
3 **Construct** a labelled diagram of three connecting neurons. Draw an arrow that shows the direction of the action potential in a well-developed animal.

Apply, analyse and interpret

4 The coordination achieved by the nervous system, like the hormonal system, is basically chemical. **Reflect** on why this is the case.
5 From the diagrams in Figure 3, **compare** the nervous systems of a *Hydra*, a prawn and a cat. List the similarities and differences between the three systems.

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» Student book questions
Check your learning 9.4

» Interactive
The neuron

» Weblink
The human neuron

» Weblink
Nervous system of a dog

9.5 The mammalian nervous system

KEY IDEAS

- The structure of the vertebrate neuron
- The generation and propagation of a nerve impulse
- Transmission of the impulse from one neuron to the next and from neuron to muscle

Schwann cell
a cell, rich in fats, which ensheaths peripheral nerve fibres

myelin sheath
a fatty sheath surrounding some nerve fibres formed by Schwann cells

node of Ranvier
the regularly repeated constriction of the myelin sheath of neurons between adjacent Schwann cells

The nervous system is composed of excitable cells called neurons (singular neuron), which are specialised to convey information in the form of nerve impulses. Although there are different types of neurons, each adapted for a particular function, they all share certain features.

Structure of the vertebrate neuron

The nucleus is contained in an expanded portion of the cytoplasm called the cell body or soma, from which a number of thin cytoplasmic fibres extend. Two main types of fibres can be distinguished, the axons and dendrites. Axons are usually long and rarely branched, except at their termination. Dendrites are usually shorter and have many branches. Neurons of primitive invertebrates usually have several axons. Those of higher invertebrates and vertebrates have one axon.

The cell body is concerned with controlling and maintaining the cell and its activities. With the dendrites, it serves as the main receiving area for the input of impulses from other neurons. The main pathway for the conduction of impulses is the axon. In most animals, the axons are covered with special non-nervous cells, called **Schwann cells**. These are wrapped so tightly around the axon that there is no cytoplasm between the layers of membrane. The sheath that is formed is rich in lipids and is termed the **myelin sheath**. Between adjacent Schwann cells there is a gap where the axon is exposed, and this is termed the **node of Ranvier**.

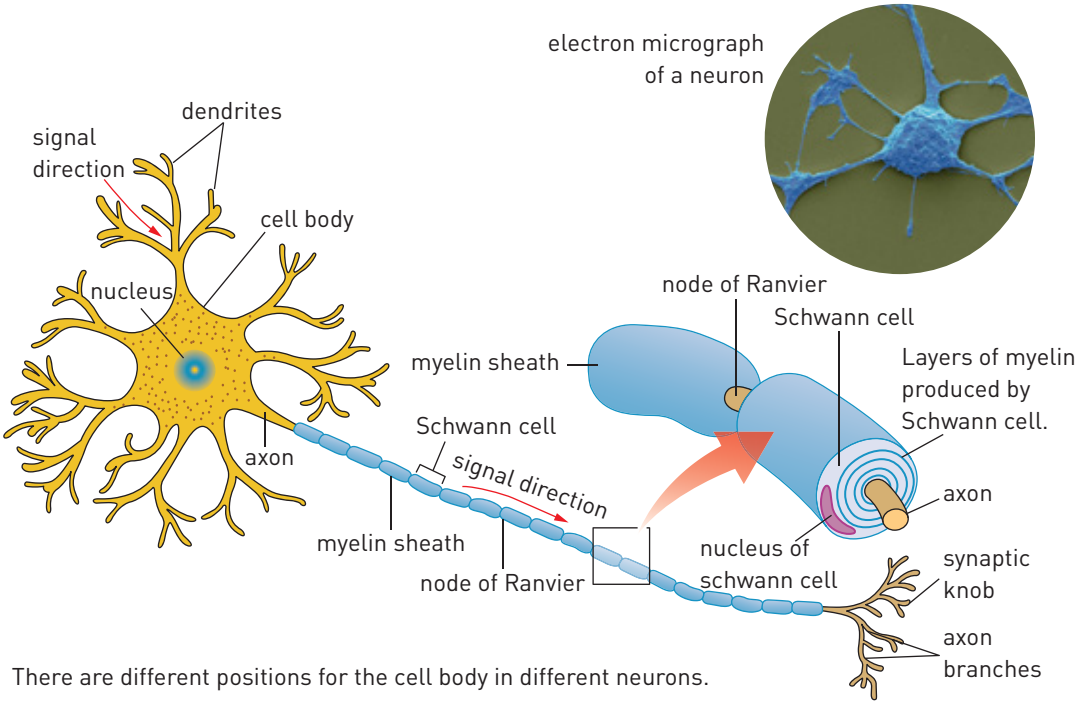


FIGURE 1
Structure of the generalised vertebrate neuron

There are different positions for the cell body in different neurons.

Those neurons associated with stimuli are termed **sensory (afferent) neurons**, whereas **motor (efferent) neurons** bring about a response. **Association neurons (interneurons)** link sensory and motor neurons. (See Section 9.6.)

sensory (afferent) neuron
a nerve cell which carries information from a receptor to the central nervous system

motor (efferent) neuron
a nerve cell which transmits information from the central nervous system to an effector organ

association neuron (interneuron)
the nerve cell within the central nervous system which relays information between sensory input and motor output

Conduction of nerve impulse

The conduction of a nerve impulse along a neuron is accompanied by both chemical and electrical changes along the neuron membrane.

All cells are **polarised**, meaning there is a difference in positive and negative charge between the two sides of the cell membrane. The inside of the cell membrane is more negatively charged than the outside due to an uneven distribution of positively charged sodium (Na^+) and potassium (K^+) ions across the cell membrane. This is maintained by sodium ions being 'pushed' out through special membrane channels against a concentration gradient. This action requires an outlay of energy and is called a **sodium pump.**

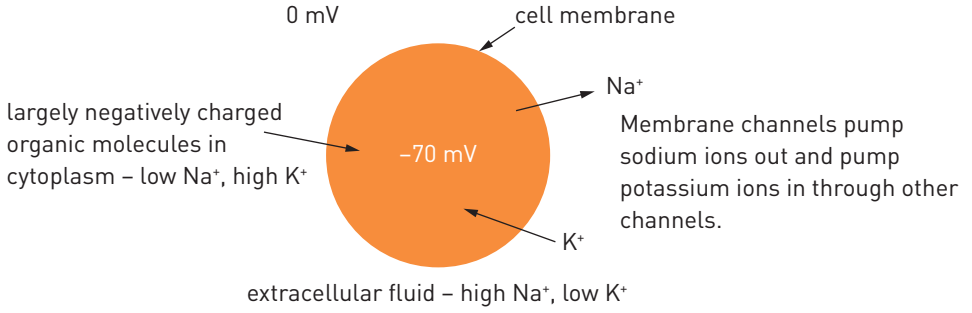


FIGURE 2 The polarised neuron – a difference in electric charge between the inside and outside of the cell is due to uneven distribution of positive and negative ions.

Sodium ions cannot diffuse back into the cell because the membrane channels are closed. Potassium ions, however, are pumped through other channels in the cell membrane. There is therefore a flow of potassium ions from the extracellular fluid into the cell, balancing the outward movement of the positive sodium ions. Two potassium ions move into the cytoplasm for every three sodium ions pumped out. Large, negatively charged organic molecules in the cytoplasm, however, maintain an overall negative charge on the inside of the membrane. This polarisation (positive on the outside and negative on the inside) creates an electrical potential difference between the two sides of the membrane of about 70 millivolts (mV).

polarised
a condition in which there is an unequal distribution of charges between two points (e.g. inside and outside the cell membrane)

sodium pump
a special transport protein in the membrane of animal cells that transports sodium out of the cell, and potassium into it, against their concentration gradients

Excitable cells, such as neurons, can temporarily change the potential difference across their cell membranes as a result of a stimulus. At its normal polarised (inactive) state the neuron is at **resting potential**.

resting potential
polarised state of neuron membrane due to a sodium pump, resulting in the inside of the membrane being negative relative to the outside

Receptor cells (or another neuron) generate a nerve impulse in the neuron. The impulse, however, does not occur in the entire neuron simultaneously. It starts at the dendrite endings as a chemical signal that passes through the cytoplasm to the start of the axon. If the stimulus is strong enough, it brings about a change in the potential of the axon membrane that passes along the membrane to the synapse. At the synapse chemicals are released to stimulate the dendrites of the next neuron. These stages, from initiation at the dendrites to release of chemicals at the synapse, are examples of signal transduction.

Action potential

Generation and conduction of the nerve impulse results from changes in the electrical potential difference in sections of the axon membrane. The potential changes in one section

of the membrane cause the adjacent section to change potential and so on along the axon. Immediately after the change, the section of membrane is restored to resting potential. The conduction of a nerve impulse can, therefore, be likened to a wave of electrochemical changes. The changes in each part of the membrane are summarised below.

1 At rest, there is a net negative charge (–70mV) inside the neuron, maintained by the sodium-potassium pumps (two K^+ ions are actively pumped into the neuron for every three Na^+ pumped out). The resting state is polarised.
2 A stimulus depolarises a section of the membrane. The sodium channels open and sodium ions move into the cytoplasm. Therefore, the inside of the neuron becomes more positive relative to the outside. As Na^+ enter, more sodium channels open, causing a greater influx of ions (+40 mV). This process of depolarisation causes a burst of electrical energy to pass along the axon. This is an action potential.
3 The charge reversal moves to the next region of the axon (in one direction only towards the axon terminal). This process is called propagation.
4 After the action potential (a charge of +40 mV) has been reached, the sodium channels close and the potassium channels open. The potassium ions move out of the cytoplasm and restore the positive charge on the outside of the membrane. This section of membrane is now undergoing **repolarisation**.
5 The movement of potassium ions causes a temporary overshoot of the resting electrical gradient – the inside is more negative than usual. This is called the **relative refractory period** and represents the time taken for the membrane to restore its resting potential. During depolarisation and repolarisation (**absolute refractory period**) and the relative refractory period, no further action potentials can be generated in the section of membrane.
6 The sodium pump is restored. Sodium ions are actively pumped out of the cytoplasm and potassium ions re-enter until the resting potential is achieved.

This entire process takes about 6 milliseconds.

For an action potential to occur the stimulus must be large enough to open enough channels to cause a potential change from –70 mV to –55 mV. If this **threshold potential** is not achieved, no action potential occurs. An increase in stimulus over this threshold level will not increase the size of the action potential, although it can increase the frequency at which action potentials are generated. Because the magnitude of the action potential is the same regardless of the strength of the stimulus above threshold, this is called an **all-or-nothing response**.

Once generated, the action potential moves along the neuron membrane. During the action potential some of the sodium ions diffuse laterally along the axon cytoplasm. The presence of the sodium ions stimulates the next section of membrane to generate an action potential. So depolarisation of one segment of the neuron membrane initiates depolarisation of the next part of the membrane.

The conduction of the impulse can be likened to a row of spring-loaded dominoes. A stimulus causes the first domino to drop (= depolarisation) and it hits the top of the second domino, causing it to drop (transduction causing depolarisation). The first domino then springs upright (repolarisation). This process continues to the end domino. Once a domino is upright again (refractory period resulting in the resting potential being restored), it can receive another stimulus to once again fall (another action potential).

repolarisation
the change in membrane potential that returns it to a negative value just after the depolarisation phase of an action potential has changed the membrane potential to a positive value

relative refractory period
the period shortly after the firing of a nerve fibre when partial repolarisation has occurred and a greater than normal stimulus can stimulate a second response

absolute refractory period
the period immediately following an action potential when the nerve fibre cannot be stimulated no matter how great a stimulus is applied

threshold potential
the minimum stimulation required to initiate a nerve impulse

all-or-nothing response
a type of response in which neuron membranes will respond completely to a stimulus, regardless of its strength, if it is above a threshold intensity, but will not respond if it is below the threshold intensity

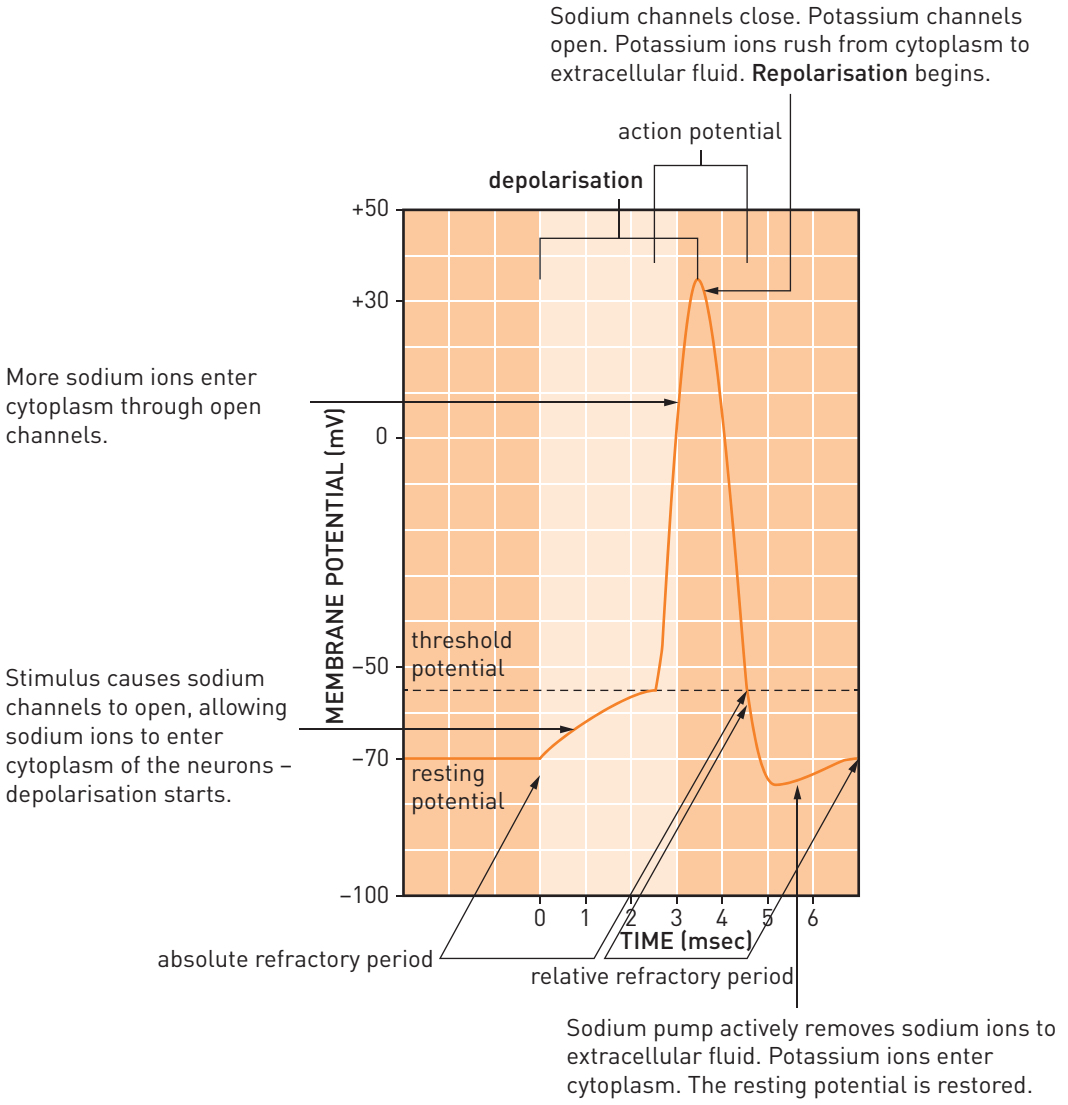


FIGURE 3 Simplified diagram of depolarisation and repolarisation of a section of the neuron membrane

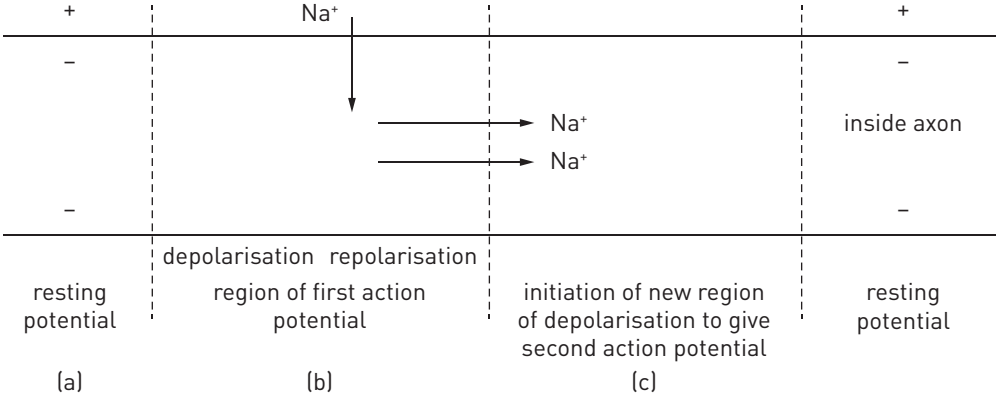
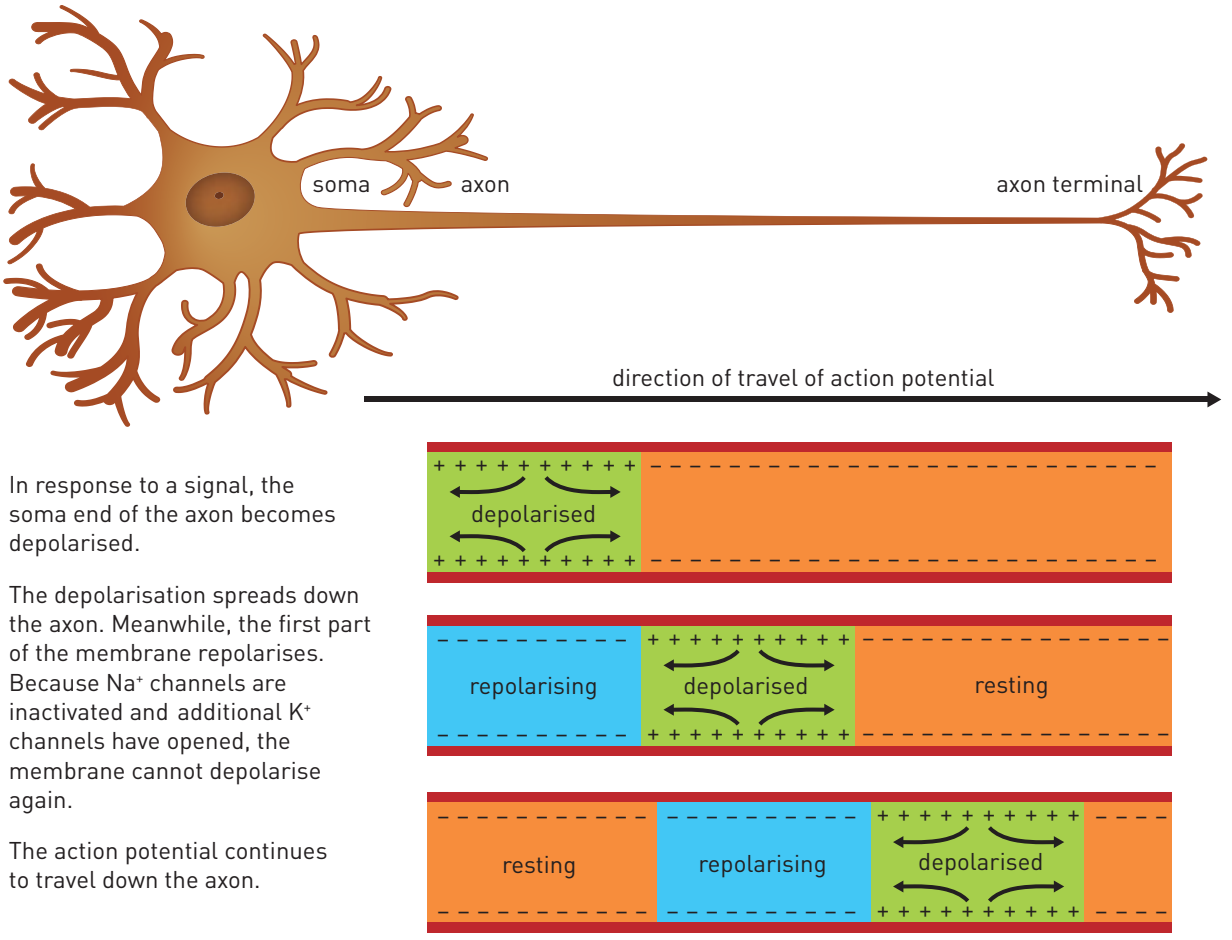


FIGURE 4 Conduction of an action potential along an axon. Some of the sodium ions (Na^+) from an area of depolarisation diffuse along the axon cytoplasm to generate an action potential in the adjacent section of the membrane.



(a) In response to a signal, the soma end of the axon becomes depolarised.

(b) The depolarisation spreads down the axon. Meanwhile, the first part of the membrane repolarises. Because Na^+ channels are inactivated and additional K^+ channels have opened, the membrane cannot depolarise again.

(c) The action potential continues to travel down the axon.

FIGURE 5 Sequence of events as the impulse travels along the axon

Conduction velocity

Conduction velocity varies according to the type of neuron and the diameter of the axon. The larger the diameter of the axon, the faster will be the rate of conduction. The myelin sheath also increases the rate of conduction, since action potentials are generated only at the nodes of Ranvier and not along the entire length of the axon.

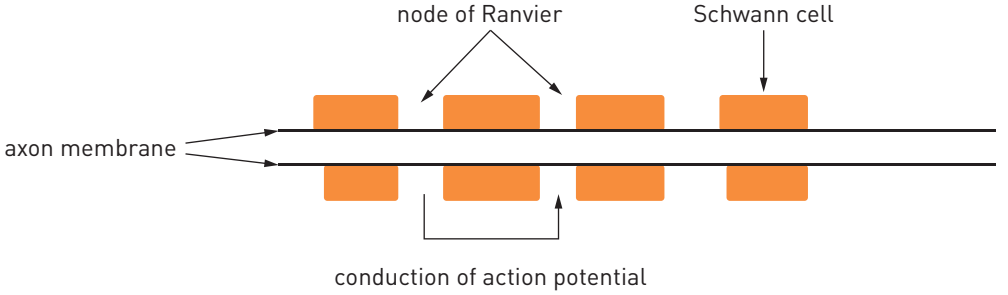


FIGURE 6 The myelinated sheath (Schwann cell) inhibits changes in ion channels in the axon membranes with which they are in contact. Action potentials therefore only occur at the nodes of Ranvier. This increases the speed of conduction of the nerve impulse.

The rate at which a nerve impulse can travel ensures that the response to a stimulus is much more rapid than that elicited by hormones. The nerve impulse can also be rapidly inhibited. Nervous control is rapid but of short duration.

TABLE 1 Events within the axon membrane with the passage of the impulse

State of membrane	Type of potential	Polarisation	Ionic movement	Internal potential	External potential
Resting	Resting	Polarised	Stable, differential ion concentration maintained	Negative	Positive
Active	Action	Depolarised	Increased permeability to sodium and potassium ions	Positive	Negative
Recovering	Resting	Repolarising	Almost stable, differential ion concentration being restored	Negative	Positive

Junctions between neurons

Some means of transmitting information from one neuron to another is essential. The zone of interaction between two neurons is called a synapse. The narrow gap separating the neurons is the **synaptic cleft**.

Synapses occur between axons and dendrites, between axons and cell bodies, or between axons and effectors such as muscles. The output area of the neuron – the axon end that passes on information to other neurons – is called the **pre-synaptic element**. The part that receives information – the dendrite, cell body or effector – is the **post-synaptic element**. Usually the pre-synaptic area forms a swelling, which is termed the **synaptic terminal or knob**. Since some neurons, such as those in the brain, have many branched dendrites, they may make contact with a large number of other neurons.

Some synapses have a very narrow cleft. This is seen in some neurons in the brain. The action potential at the pre-synaptic area can directly stimulate an action potential in the post-synaptic area. There is electrical transmission across the synapse.

Most synapses, however, have a wider cleft across which the direct passage of the action potential is not possible. In this case the synaptic knob contains numerous synaptic vesicles which contain a **chemical transmitter substance (neurotransmitter)**. When the action potential arrives at the synaptic knob, it causes the vesicles to move to the pre-synaptic membrane and release the neurotransmitter into the gap (cleft). The transmitter then diffuses across the cleft to the postsynaptic membrane where it combines with special receptor sites. This combination is thought to alter the permeability of the membrane, and bring about its depolarisation (signal transduction). Because the receptor sites occur on only one side of the synaptic cleft, chemically transmitting synapses impose a one-way direction on the passage of nerve impulses through the nervous system.

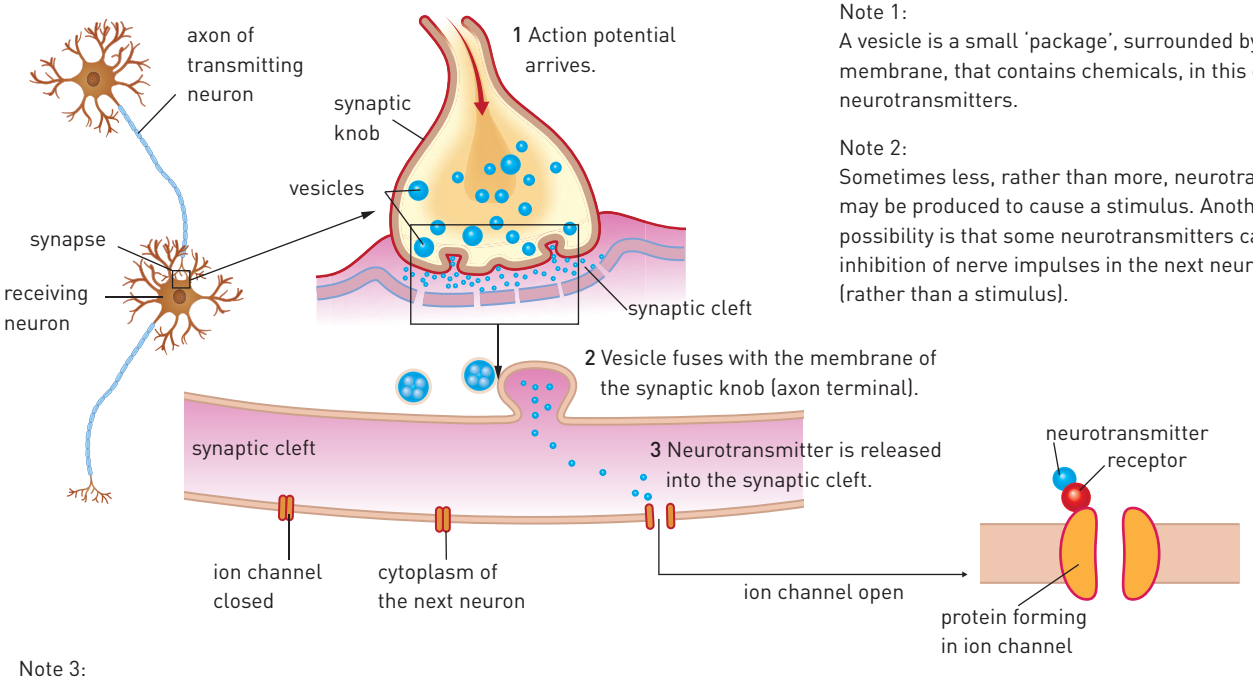
synaptic cleft
the space between the elements in a synapse

pre-synaptic element
the axon knob and its membrane, from which an impulse will pass across a synapse

post-synaptic element
the membrane of the structure (e.g. a dendrite) to which an impulse is transferred across a synapse

synaptic terminal or knob
the swollen axonic end of a synapse

chemical transmitter substance (neuro-transmitter)
a chemical that passes from one area to another (e.g. from the axonic end of one neuron to the dendritic end of the adjoining neuron) to bring about a change



Note 1:
A vesicle is a small 'package', surrounded by a membrane, that contains chemicals, in this case neurotransmitters.

Note 2:
Sometimes less, rather than more, neurotransmitter may be produced to cause a stimulus. Another possibility is that some neurotransmitters cause inhibition of nerve impulses in the next neuron (rather than a stimulus).

Note 3:
When the neurotransmitter is broken down (by an enzyme), it is removed from the receptor so that the ion channel closes again – after the action potential has passed.

4 Neurotransmitter binds to a receptor on the ion channel. The ion channel opens so that Na^+ diffuse in, setting up an action potential in the next neuron.

FIGURE 7 General features of a chemically transmitted synapse

acetylcholine (ACh)
a chemical released from nerve endings when nerve impulses arrive there, stimulating the adjacent neuron or effector organ

noradrenalin
the chemical secreted by nerve endings of sympathetic nerves; closely related to the hormone adrenalin secreted by the adrenal gland in the 'flight or fight' response

synaptic fatigue
the condition that occurs when no more transmitter substance is available to transmit an impulse across a synapse

Many different substances function as neurotransmitters. The best-known neurotransmitters are **acetylcholine (ACh)** and **noradrenalin**. Once depolarisation (action potential) of the post-synaptic membrane has been achieved, enzymes in the cleft (gap between the two neurons) break down the neurotransmitter. This frees the receptor sites to receive further emission of neurotransmitters when another action potential arrives at the synaptic knob. Repeated impulses arriving at the synapse can lead to the depletion of neurotransmitters in the vesicles. This condition is known as **synaptic fatigue**. No more impulses can cross the synapse until the supply has been replenished.

A **neuromuscular junction** is a synapse between a neuron and a special thickened and folded part of the muscle fibre membrane, called an **end plate**. The neurotransmitter in this case is always acetylcholine. It is released from the axon terminal of the neuron, causing depolarisation (or action potential) of the end plate and bringing about muscle contraction.

Synapses can be excitatory and bring about a depolarisation action potential of the joining element. They can also be inhibitory, in which case the receptor–transmitter combination causes an increase in negativity of the inside of the post-synaptic membrane. This hyperpolarisation makes it more difficult for subsequent depolarisation. Inhibitory synapses therefore act as 'brakes' on the post-synaptic cell.

Many drugs and poisons exert their effects by interfering with the synaptic mechanism. They may:

- prevent the release of the neurotransmitter (e.g. botulism)
- prevent the neurotransmitter from combining with the receptor (e.g. curare, which competes with ACh for the receptor sites at neuromuscular junctions and so results in muscular paralysis)

- inactivate the enzyme that breaks down the neurotransmitter (e.g. organophosphate poisons). Prolonged end-plate stimulation and subsequent uncontrollable muscular spasms result.

Synapses do not merely transmit nerve impulses from one cell to another. They can filter out weak stimuli, by not generating an action potential in the post-synaptic membrane unless a particular frequency is reached. Most synapses enable information from different sources to interact. Sorting out of nerve impulses can be achieved by information from one source acting as an inhibitor to information from other sources.

neuromuscular junction
the junction between nerve and muscle cells

end plate
a thickened and folded part of a muscle fibre membrane which receives nerve impulses

FIGURE 8 St Ignatius' bean (*Strychnos ignatii*) can be used in the preparation of the poison curare, which causes muscular paralysis and possible death

CHECK YOUR LEARNING 9.5

Describe and explain

1 **Construct** and label a diagram of a neuron.
2 **Explain** how a nerve impulse is transmitted along an axon. In your answer, use the following terms: polarised, depolarised, action potential, sodium pump, resting potential, recovery period.

Apply, analyse and interpret

3 'Nerve conduction is an all-or-nothing response.' **Interpret** the meaning of this statement.
4 **Determine** how a chemical synapse brings about one-way nerve conduction.

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» Student book questions
Check your learning 9.5

» Weblink
Action potential

» Weblink
Junctions between neurons

» Weblink
Motor neuron disease

9.6 Organisation of the nervous system

KEY IDEAS

- Organisation of the nervous system into peripheral and central systems
- The functions of the brain
- Nerve pathways

central nervous system (CNS)
a mass of nervous tissue, comprising the brain and spinal cord in vertebrates, which coordinates the activities of animals

peripheral nervous system (PNS)
the system of nerves between effectors/receptors and the central nervous system; subdivided into somatic (outer body tube) and visceral (inner body tube)

cerebrospinal fluid
the fluid that fills the cavity inside the vertebrate brain and spinal cord

spinal cord
the part of the vertebrate central nervous system within the backbone

white matter
the myelinated neurons within the central nervous system

grey matter
the part of the central nervous system, associated with coordinating activities, where the fibres are not myelinated

The two parts of the nervous system are:

- the **central nervous system (CNS)** – brain and spinal cord
- the **peripheral nervous system (PNS)** – cranial and spinal nerves.

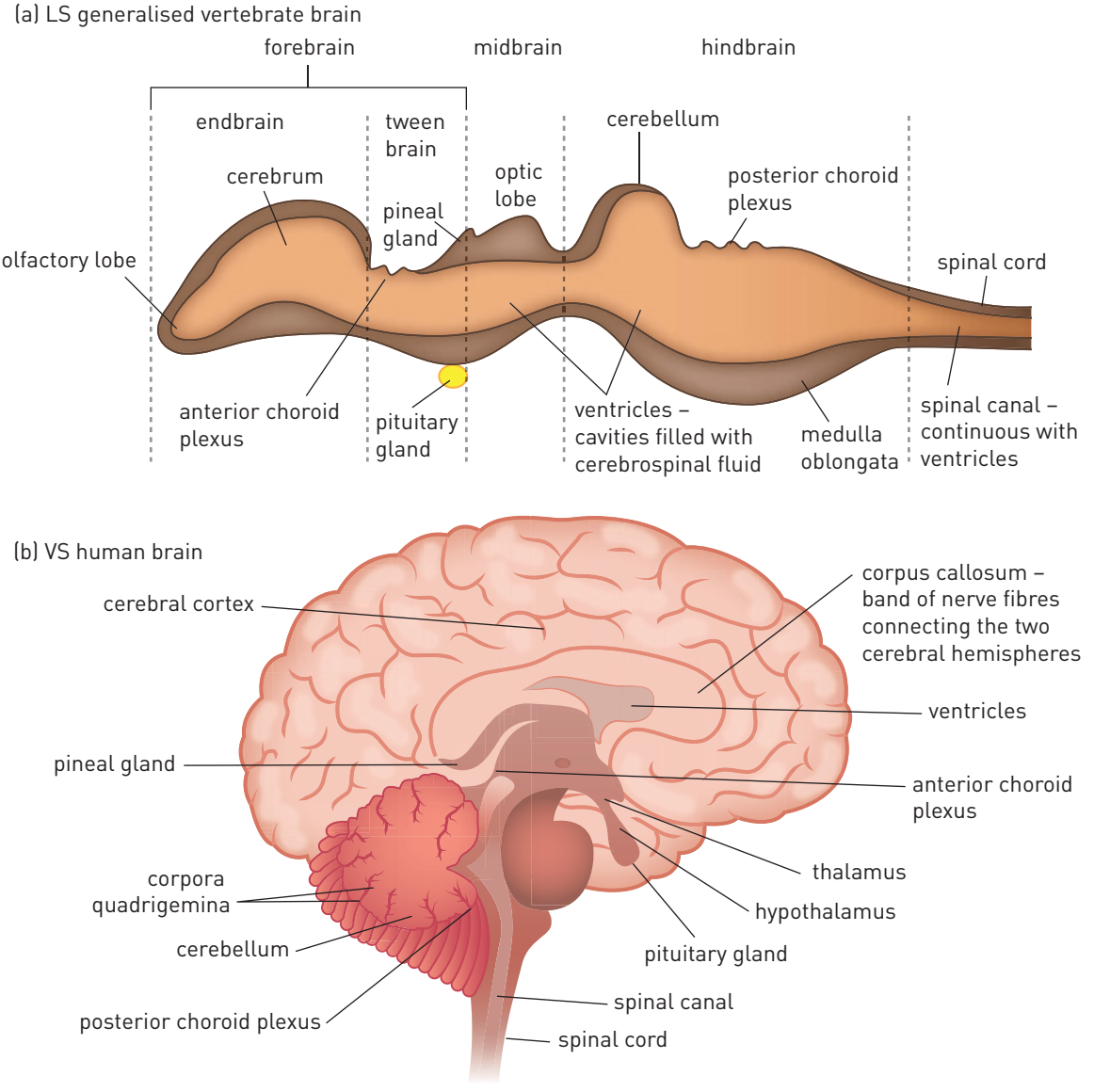

FIGURE 1 Sections through vertebrate brains

The CNS develops in chordates from a hollow, dorsal neural tube that extends the length of the body. The anterior end of the tube swells to form the brain and the rest develops into the spinal cord. The hollow centre persists in the adult as spaces or ventricles in the brain and the central canal of the spinal cord. These spaces are filled with **cerebrospinal fluid**, which distributes nutrients and oxygen to the nervous tissue and removes wastes.

The **spinal cord** is surrounded and protected by the vertebral column. It is composed of outer **white matter** and inner **grey matter**. The grey matter contains cell bodies and non-myelinated fibres, whereas the white matter consists of myelinated fibres. The two main functions of the spinal cord are to connect the spinal nerves to the brain and to act as a coordination centre for reflex actions.

The **brain** of all vertebrates, enclosed within a protective cranium, consists of a forebrain, midbrain and hindbrain. The extent of the development of each of these areas varies in the different classes of vertebrates, having maximum development in the higher mammals.

Like the spinal cord, the brain is composed of white matter and grey matter. Areas of grey matter form centres for cell bodies concerned with specific sensory and motor impulses, such as the respiratory centre in the hindbrain. The white matter consists of tracts of fibres which link various parts of the brain together and with the receptors and effectors.

All sensory impulses entering the brain pass through the brainstem (medulla, midbrain and thalamus) before being relayed to the cortex. Branches in the brainstem direct stimuli to appropriate parts of the brain. The major functions of the mammalian brain are summarised in Table 1.

brain
the enlarged, anterior part of the central nervous system which coordinates sensory input and responses

dorsal root of spinal cord
the area emerging from the dorsal region of the spinal cord forming the afferent, sensory part of a spinal nerve

TABLE 1 Major functions of the mammalian brain

Section	Area	Functions
Hindbrain	Medulla oblongata	Controls heart rate, blood pressure, respiration rate, swallowing, salivation, vomiting, sneezing and coughing
	Cerebellum	Controls posture, equilibrium and fine adjustments of movement
Midbrain	Corpora quadrigemina	Controls eye movements and auditory reflexes
	Red nucleus	Controls movement and posture; inhibits excessive contraction of postural muscles
Forebrain:	Thalamus	Contains tracts which form the link between forebrain and spinal cord
(a) Tweenbrain	Hypothalamus	Controls sleep, feeding, drinking, speech, body temperature, certain emotions and osmoregulation
	Pineal body	Believed to be involved in light sensitivity
	Pituitary gland	Regulates endocrine glands; controls osmoregulation, growth, metabolism and sexual development
(b) Endbrain	Cerebrum	The outer cortex is deeply folded, therefore increasing the surface area. It is the centre of integration and coordination of all but hindbrain activities via a network of neurons called the reticular formation; correlates incoming information with past experience and memory; and has some direct sensory (e.g. olfactory) and motor functions.

A nerve is a bundle of neuron fibres (axons or dendrites), each surrounded by connective tissue, wrapped in a sheath. Within the nerve, some of the sensory fibres transmit information towards the CNS while motor fibres carry impulses from the CNS to effector organs. Due to the myelin sheath surrounding each fibre, they are insulated from each other and so impulses are retained within the individual fibre.

In humans, there are 31 pairs of spinal nerves, one per body segment. Each nerve carries fibres to and from all parts of the body except the head region. It has two separate connections with the spinal cord: a **dorsal** and **ventral root**. Sensory fibres enter the spinal

ventral root of the spinal cord
the area emerging from the ventral region of the spinal cord forming the efferent, motor part of a spinal nerve

somatic nervous system
the system of nerves that are associated with the tissues of the outer body tube (outside the body cavity)

visceral nervous system
the system of nerves associated with the organs of the body cavity and the inner body tube (alimentary canal)

autonomic nervous system
the system controlling the actions of the inner (visceral) body tube, not under conscious control. Two types of motor nerves are present: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action

sympathetic nervous system
the division of the autonomic nervous system involved in the unconscious control of organs

parasympathetic nervous system
the section of the autonomic nervous system involved in the unconscious control of body organs

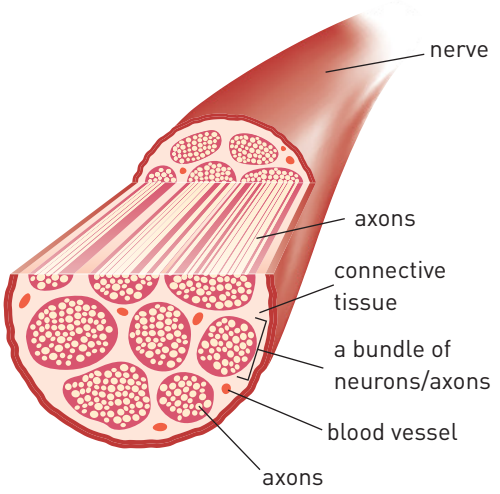

FIGURE 2 Structure of the nerve

cord at the dorsal root, whereas motor fibres leave at the ventral root. Each of these nerves divides into a number of branches. For example, a dorsal branch innervates the skin and muscles of the back, and a ventral branch innervates the skin and muscles of the ventral part of the body. The cell bodies of sensory neurons are found just outside the spinal cord in a swelling (ganglion) of the dorsal root that connects the sensory nerve to the spinal cord. The cell bodies of motor neurons are inside the spinal cord.

There are 12 pairs of cranial nerves in the human body, arising from the ventral surface of the brain. All, except the vagus nerve, are involved in behaviours associated with the head only. Some of these nerves, such as the optic nerve from the eye, are sensory nerves. Others – for example, the hypoglossal nerve to the tongue and neck muscles – are motor nerves only. Some nerves contain both sensory and motor fibres.

There are two major divisions of the peripheral nervous system: the **somatic** and the **visceral nervous systems**. The somatic nervous system is concerned with the outer body tube (skin, skeletal muscle and associated organs). The visceral nervous system is concerned with the inner body tube and organs. Both of these divisions contain sensory and motor neurons. The motor area of the visceral nervous system is also called the **autonomic nervous system** since it is generally not under conscious control of the higher centres of the brain. These motor neurons are part of either the **sympathetic** or **parasympathetic nervous system**.

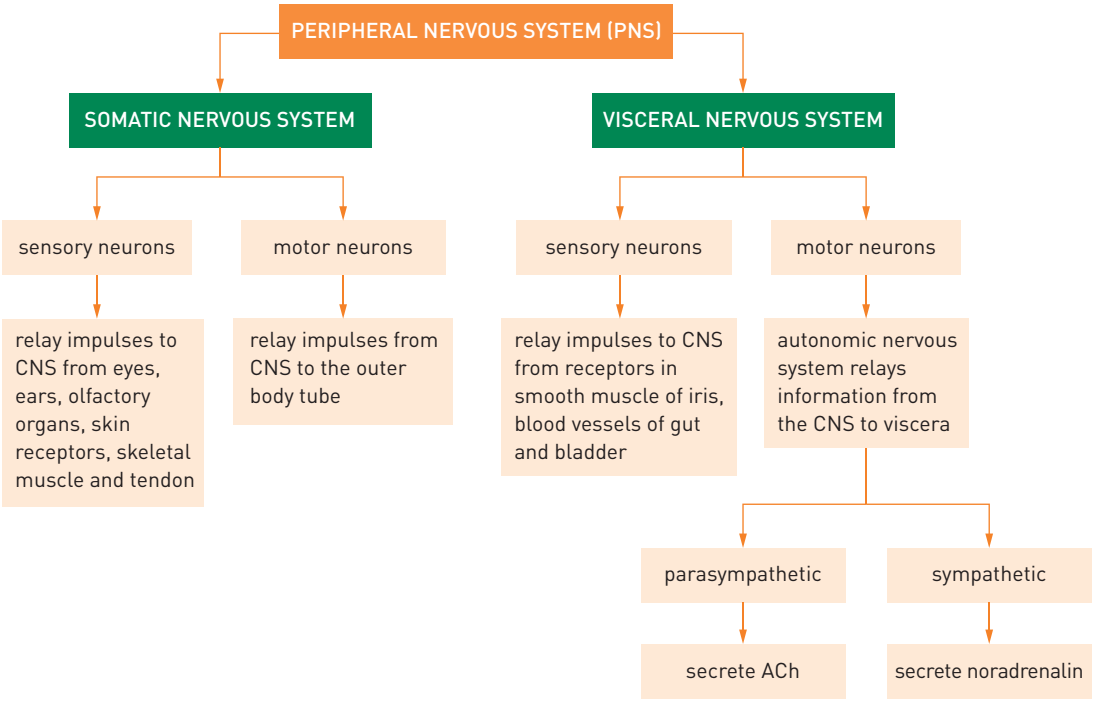

FIGURE 3 Divisions of the peripheral nervous system

TABLE 2 Summary of the responses evoked by the autonomic nervous system

Sympathetic	Parasympathetic
Dilates pupil	Constricts pupil Stimulates tear gland
Suppresses secretion from salivary gland	Stimulates secretion from salivary gland
Contracts hair erector muscles	
Dilates bronchioles	Constricts bronchioles
Slows peristalsis	Accelerates peristalsis
Accelerates heart	Slows heart
Constricts arteries	Dilates arteries
Contracts anal and bladder sphincters	Relaxes anal and bladder sphincters
Controls vasodilation	Controls vasoconstriction
Increases sweat secretion	
Causes secretion of adrenalin	

Nerve pathways

Most behaviour is brought about by the passage of impulses from a receptor to the CNS and then on to an effector. Three main types of neurons are involved in this process: sensory, association (interneuron) and motor neurons.

Sensory or afferent neurons

Those neurons associated with receiving stimuli from the external environment and sending the information to the central nervous system (CNS) are called sensory or afferent neurons. Many sensory neurons, especially those with receptors far from the CNS, have a different structure to that shown in Figure 1 in section 9.5 (page 256). The short dendrites (receptive endings) unite to form a myelinated axon that has two sections. The peripheral section of this axon travels to the dorsal root of the spinal cord that houses the cell body. The central section of this axon travels from the cell body into the grey matter of spinal cord where it links with an association neuron. The cell body branches off at the junction between the peripheral and central sections of the axon.

Association neurons (interneurons)

Association neurons are found only within the CNS. They function in linking sensory and motor neurons or different parts of the CNS. These neurons may form longitudinal tracts running the length of the spinal cord and into the brain.

Motor or efferent neurons

In contrast, motor or efferent neurons send the message from the CNS to the effector (muscles or glands). The dendrites of motor neurons are short and non-myelinated. The cell body is within the CNS and the myelinated axon exits the CNS via the ventral root to run to the effector organ.

The simplest nerve pathways are **reflex arcs**, which are responsible for bringing about reflex actions such as the knee jerk. Such actions are unlearned, automatic responses to a stimulus. The reflex arc may involve only a sensory neuron and a motor neuron, which make a synaptic contact within the CNS, although usually an association neuron (interneuron) is also involved.

reflex arc
the nervous pathway along which impulses pass from sensory to motor nerves, with little or no coordination by the central nervous system, leading to a reflex behaviour to a specific stimulus

Study tip

Use the acronym SAME to remember sensory = afferent, motor = efferent.

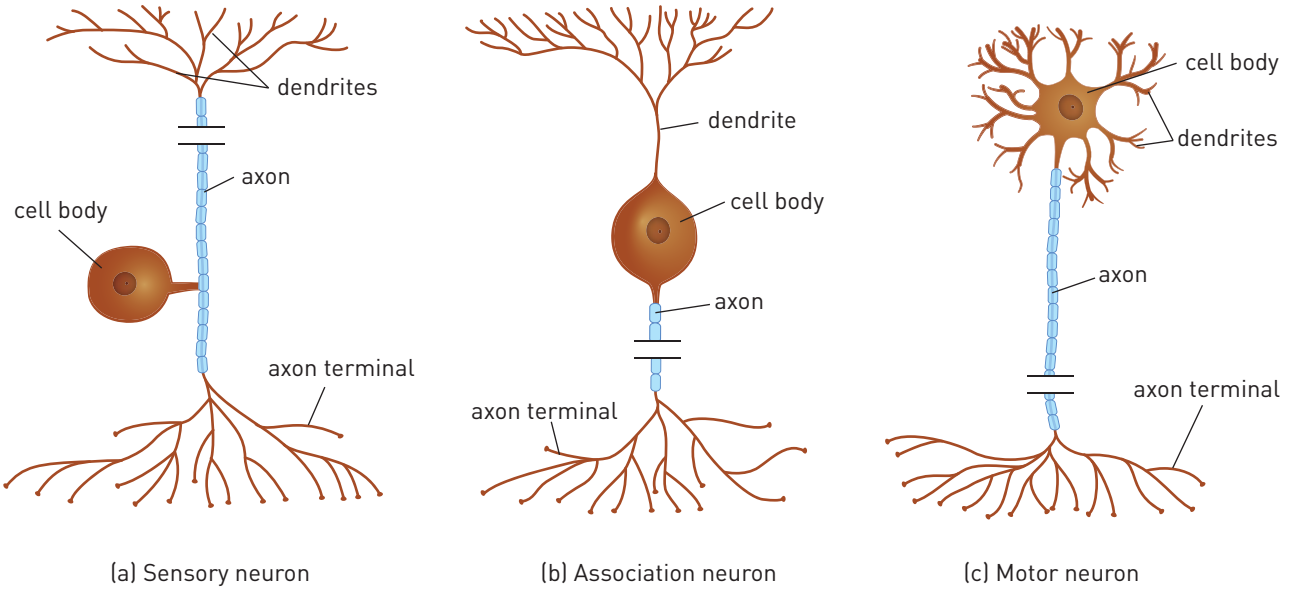

FIGURE 4 Types of neurons

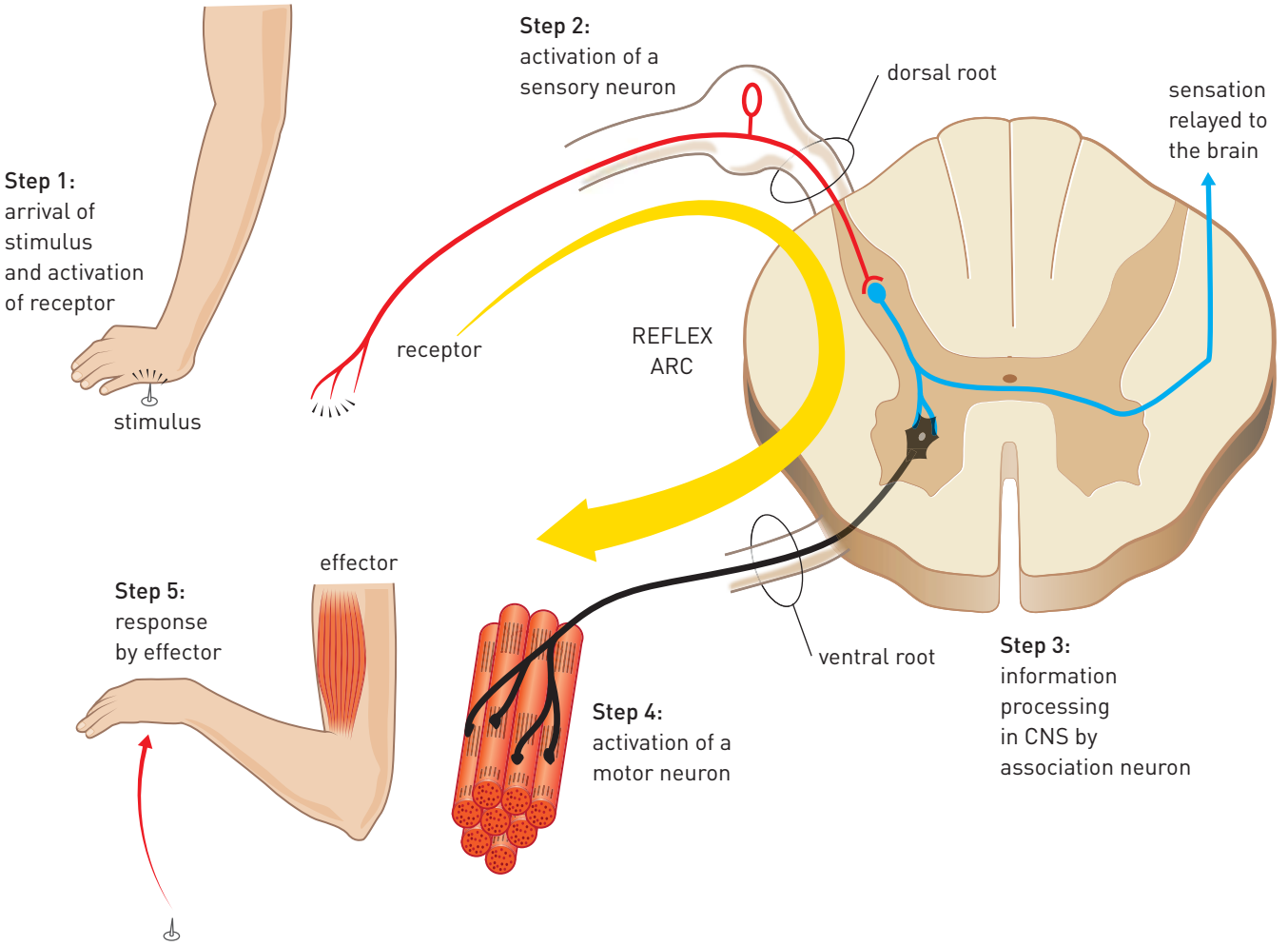

FIGURE 5 A reflex arc. The immediate response is to pull away from the stimulus. Since information is also sent to the brain, shortly after the reflex action has been achieved, the person may also respond to the pain by exclaiming 'Ouch!'

Most behaviours, however, are more complex than this and often involve many individual responses. These responses are coordinated in the brain via impulses conducted by association neurons running in ascending and descending tracts in the white (myelinated) matter of the spinal cord.

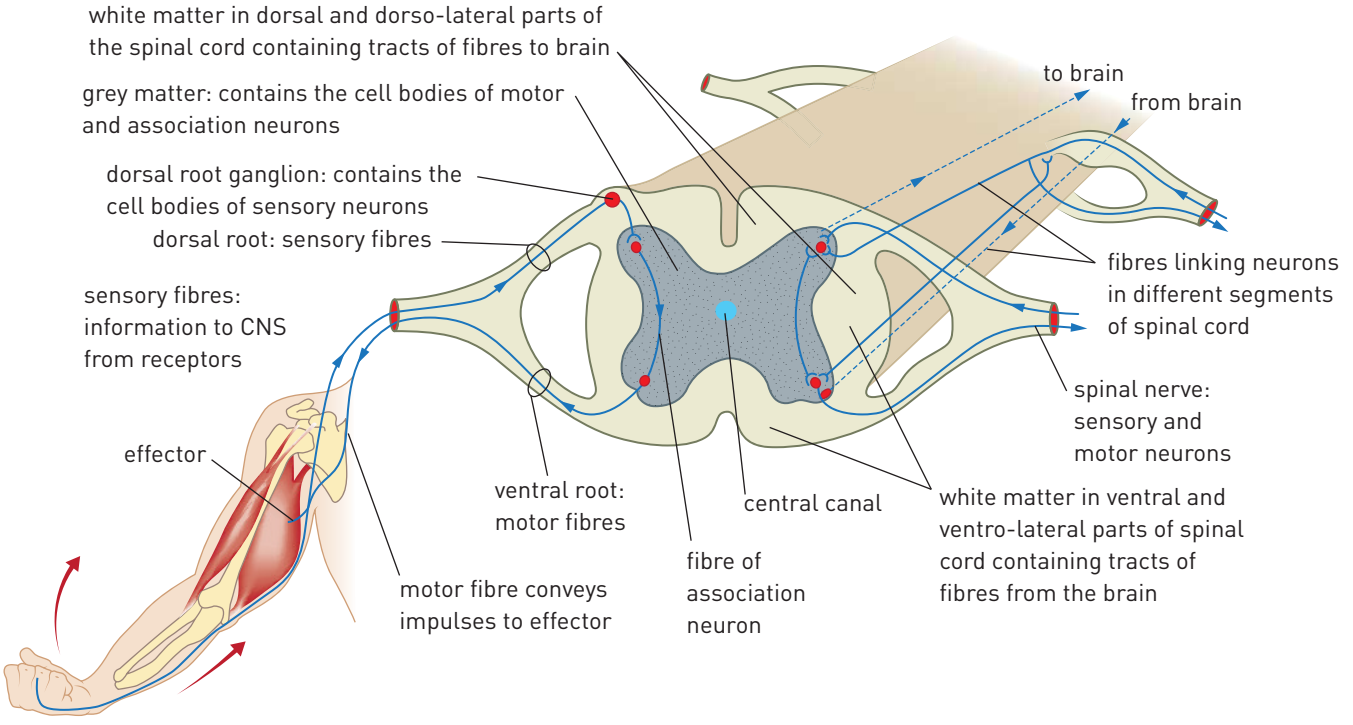

FIGURE 6 A portion of the human spinal cord, showing possible nerve pathways

CHECK YOUR LEARNING 9.6

Describe and explain

1 **Describe** the divisions of the vertebrate nervous system.

2 For each of the underlined words in the sentence below, **select** one of the following terms to replace them with: stimulus, receptor, central nervous system, effector, impulse.

The student's salivary glands produced saliva when the sound of the bell entered her ear and the message reached her brain.

3 **Explain** a reflex arc. **Construct** and label the structures involved.

4 **Identify** the part of the CNS that controls:
- **a** thinking
- **b** body reflexes
- **c** balance and coordination
- **d** heart rate and breathing.

Apply, analyse and interpret

5 **Distinguish** between sensory, motor and association neurons.

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  The core of the nervous system

9.7 Sensory receptors

KEY IDEAS

- Some of the sensory receptors found in the animal body
- The relationship between the types of receptors and environmental clues significant for survival of an animal
- The structure of a variety of sense organs
- Aspects of the stimulus recognised by sensory systems

Information about the environment is carried to the CNS by sensory neurons. These neurons are triggered by a stimulus. The energy of the stimulus is converted to the energy of an action potential in the sense organ. Temperature, pressure, humidity, light, vibrations and chemical stimuli each possess a different type of energy, which must be translated to the nerve impulse. Sense organs are therefore specialised to respond to a particular stimulus. In all cases, the more intense the stimulus, the greater is the frequency of action potentials.

The types of environmental cues to which an animal responds are ultimately related to the significance of its survival. Different animals have different roles in the environment in which they live. For example, some are herbivores while others are hunters. Therefore, they will respond to different types of stimuli. Many bats and dolphins, for example, emit and can hear reflected ultrasound that cannot be detected by other animals. Dogs use smell in both intraspecific communication and hunting. Their olfactory organs are therefore particularly sensitive. Many insects can detect ultraviolet light and pit vipers can detect infrared light. Sense organs must therefore be specialised to respond to a particular stimulus.

proprioceptor a sensory receptor which receives stimuli from within the body, especially one that responds to position and movement

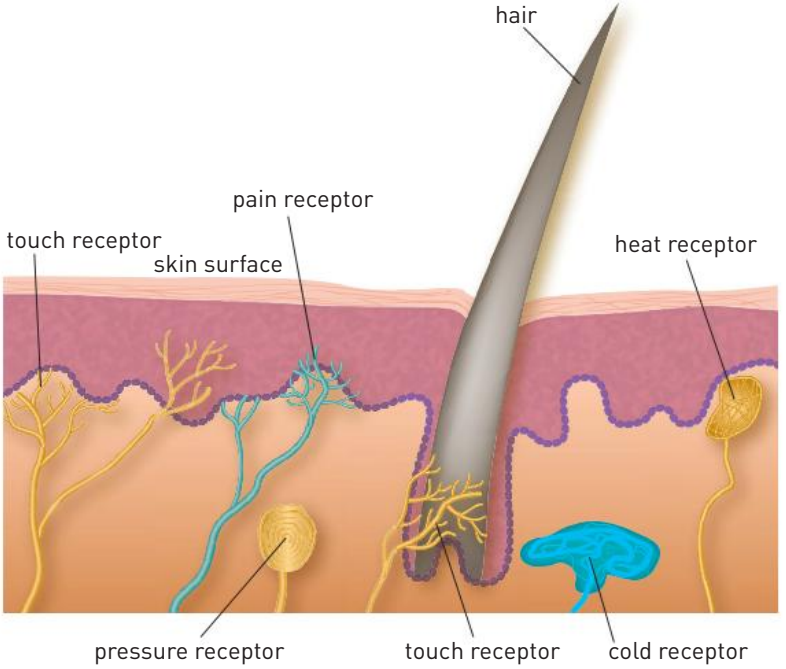

FIGURE 1 Sensory receptors of the skin

Different sensory neurons transmit information to different parts of the brain. In many cases, several different types of sense organs are stimulated simultaneously. The interpretation of the information involves communication between the different centres in the brain. Past experiences (memory) may also be a significant factor in the animal's response to a particular situation.

Sensory receptors are found throughout the body. Those involved in detecting the external environment are found in the skin (noci or pain, touch, temperature receptors), the mouth (taste and smell) and the head (light, sound). Internal sense receptors in muscles, joint capsules and surrouding tissues that signal information to the CNS about the position and movement of body parts are termed **proprioceptors**. Stretch receptors are found in tissues in the lungs and muscles, chemical receptors located in the carotid

and aortic bodies detect blood pH, and receptors that measure distension and pH are in various parts of the intestine.

Sensory cells tend to be grouped together in such a way as to maximise the reception of a stimulus as a sense organ. All of these organs share basic features:

- They contain receptor cells that are particularly sensitive to one class of stimulus energies. They usually only respond to a restricted range of intensity within that energy class so that each receptor has its own normal stimulus. The receptors in the eye, for example, normally only respond to set light wavelengths.
- The sensitive mechanism for each type of receptor is often localised at a receiving membrane or surface (e.g. the retina of the eye) where sensory neurons are found. Many have accessory tissues to magnify, select or filter particular stimuli. In the human eye the transparent cornea and lens focus light on the retinal sensory neurons. Even within the retina there is differentiation between receptor cells. There are two types of photoreceptors in the human eye. The rods are extremely sensitive to low light intensities and are responsible for black and white vision as well as the detection of movement. The less numerous cones are concentrated into a central area of the retina. There are three types of cone cells, each with different pigment systems (red, blue and green), which are stimulated by different frequencies of light. Colour vision is detected in this way.

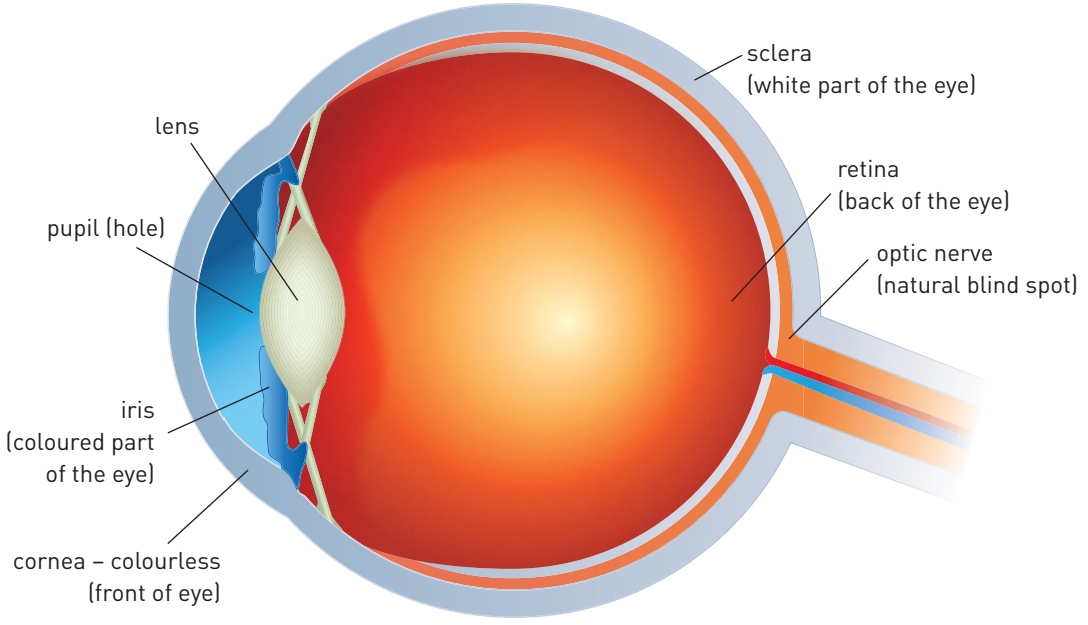

FIGURE 2 Structure of the human eye in cross-section

- The sensory neurons in the receptor structure normally synapse with an afferent nerve cell that carries the nerve impulse. In some receptors, for example those found in the skin, the peripheral axons of the sensory neurons may be over a metre long. They wind from just below the skin surface (e.g. of the foot), through a variety of tissues until they reach the spinal cord. Here they terminate and synapse with an association neuron.

Each sensory system codes for four aspects of a stimulus:

1 Type (modality) – only specific receptors respond to a particular class of stimulus (e.g. touch or temperature change).
2 Intensity – the receptors send impulses in different patterns to inform the brain of the intensity of the stimulus.

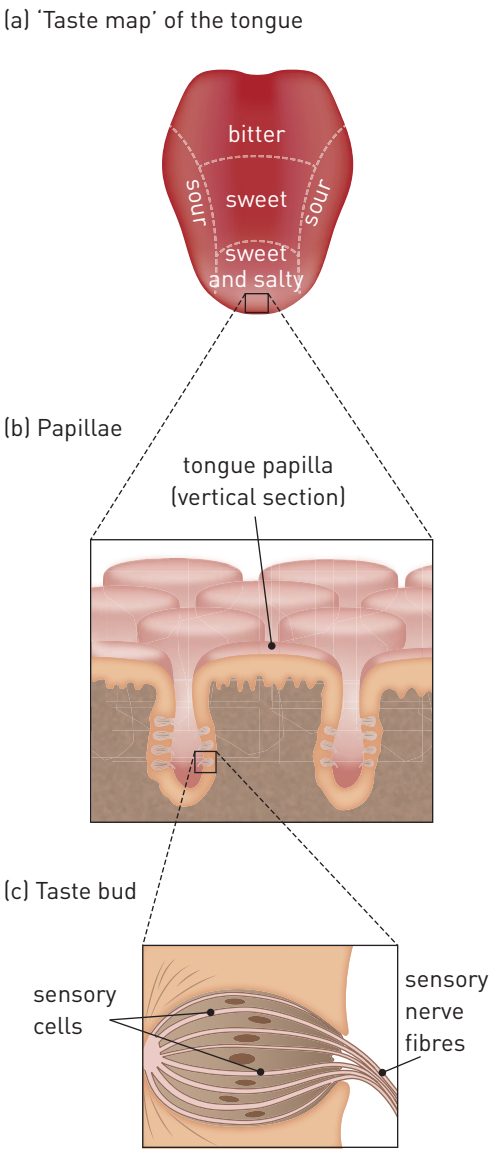

FIGURE 3 Distribution of taste receptors on the tongue. The number of receptors and combination of different receptors that are activated can determine the 'taste' the person perceives.

3 Location – this is often determined by the location of the receptor on the body. In other cases, such as in locating a sound source, different factors, such as the arrival of a sound pulse and phase differences of continuous sound, come into play.

4 Duration – is determined by the firing sequence of the receptors.

Chemoreceptors

Chemoreceptors are usually molecules that change their shape when they bond to a particular 'flavour' molecule. They are located in the back of the nose, or on the tongue. There are two primary types of chemoreceptors. **Distance chemoreceptors** are found at the back of the nasal cavity and respond to chemical molecules carried in the air (i.e. they provide a sense of smell).

Direct chemoreceptors, on the other hand, are in contact with the origin of the stimulus. Taste receptors on the tongue, palate and throat are clustered into groups, called taste buds, in tiny swellings called papillae. Each group can detect the presence of a particular quality of the food or beverage:

- Sour – due primarily to the hydrogen ions of acids, although it seems that the rest of the acid molecule affects the efficiency of hydrogen ion stimulation rather than pH alone.
- Salt – particularly those with a low molecular weight, such as potassium, calcium and sodium salts. Other salts with a high molecular weight tend to affect the bitter receptors.
- Sweet – is associated with alcohols and sugars. It is thought that a common feature for all of the sweet stimuli is the presence of a hydrogen ion acceptor, such as the hydroxyl (–OH) group of carbohydrates.
- Bitter – is associated with a group of chemicals known as alkaloids, such as quinine and caffeine. These substances have an extremely low taste threshold and are detected in very weak concentrations. This is significant since many alkaloids are toxic.
- Umami – is associated with the savoury flavour of glutamate found in meat broths and fermented products. It is often added to some food stuffs as monosodium glutamate (MSG).

Other direct chemoreceptors are important in regulating body systems. For example, the levels of respiratory gases in the blood are detected by specific receptors. Respiratory needs vary with different levels of body activity. To maintain homeostasis, therefore, both the depth and rate of respiration must be capable of adjustment. When doing exercise, the metabolic rate increases, and so the oxygen requirement and carbon dioxide production will also increase. If too little oxygen is supplied, then the very inefficient anaerobic cellular respiration occurs. Conversely, too much oxygen can destroy cells by unwanted oxidation reactions. Associated with low oxygen supply is a high carbon dioxide accumulation. This results in a lowered pH in the tissue fluids, which can cause enzyme inhibition. Carbon dioxide forms carbonic acid in solution, so a low pH in blood and tissue fluids indicates a high carbon dioxide content.

The most important factor in the control of ventilation is the concentration of respiratory gases in the blood. Several chemoreceptors for detecting gas levels exist:

distance chemoreceptor
a sensory receptor able to detect chemical stimuli from a source that is not in direct contact

direct chemoreceptor
a sensory receptor able to detect chemical stimuli with which it is in direct contact

- pH and oxygen sensors of the blood in the carotid bodies – nodules of tissue in the carotid arteries leading to the brain
- pH and oxygen sensors of the blood in the aortic body – nodules of tissue in the aorta
- pH sensors of tissue fluids in centres of the medulla oblongata (hindbrain) adjacent to the inspiration and expiration centres.

The respiratory centres of the medulla are directly affected by changes in gas concentrations in the blood and therefore in tissue fluids. Nerves must transmit the information to these respiratory centres from the carotid and aortic bodies.

For humans, detection and removal of carbon dioxide are critical. The concentration of oxygen in the air is relatively high. A control system that detects only blood oxygen levels could result in an accumulation of carbon dioxide in the tissues. This would cause the internal pH to change and so disrupt metabolic activities. Therefore, inspiration and expiration centres are responsible for the rate of ventilation.

A third centre, the pneumotaxic centre, controls the depth of breathing. Increased levels of carbon dioxide stimulate the autonomic nerves arising from the respiratory centres to bring about appropriate increased changes in the depth and rate of ventilation. These changes are accompanied by changes in heart rate and dilation of the arteries. As the body's immediate needs are exceeded by this increase, a negative feedback operates to slow down these processes again.

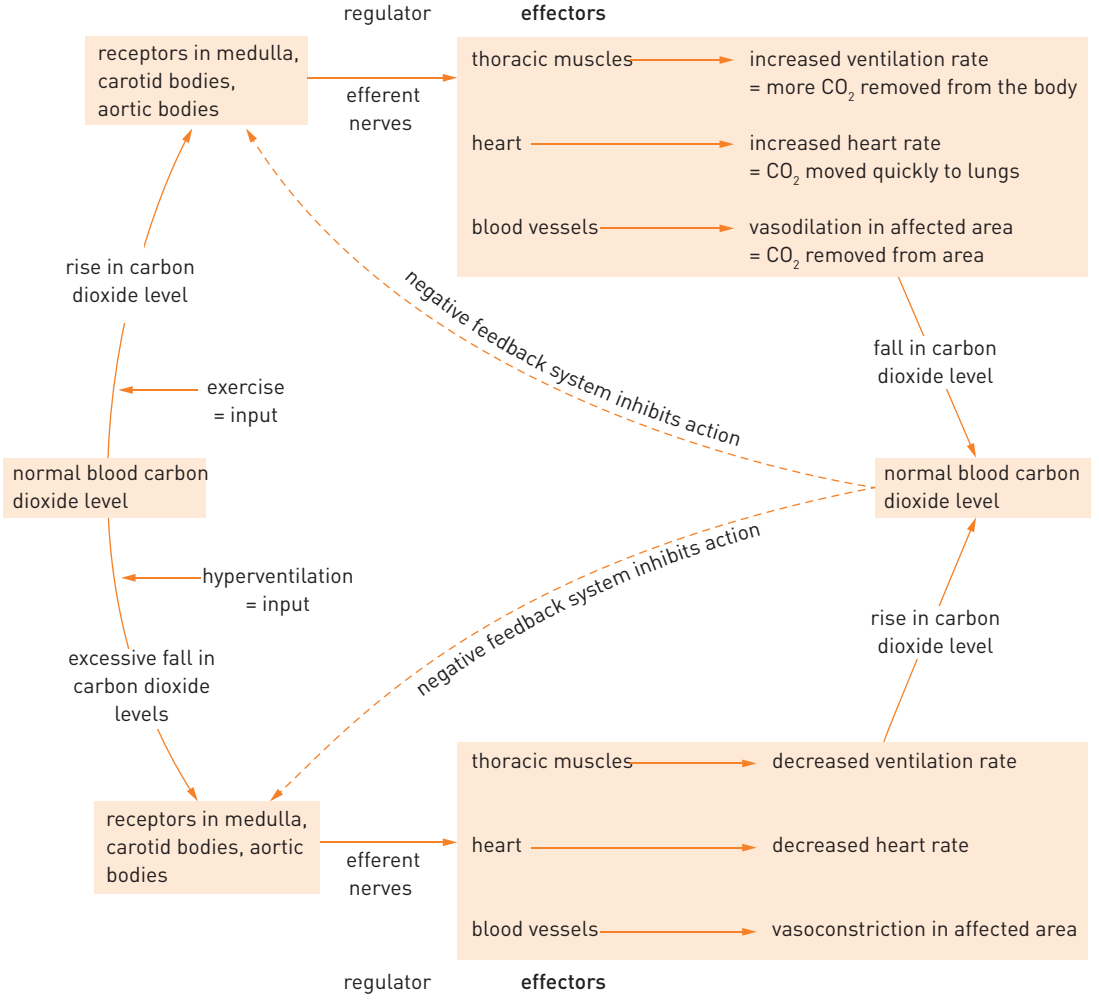

FIGURE 4 Control of carbon dioxide levels in the blood

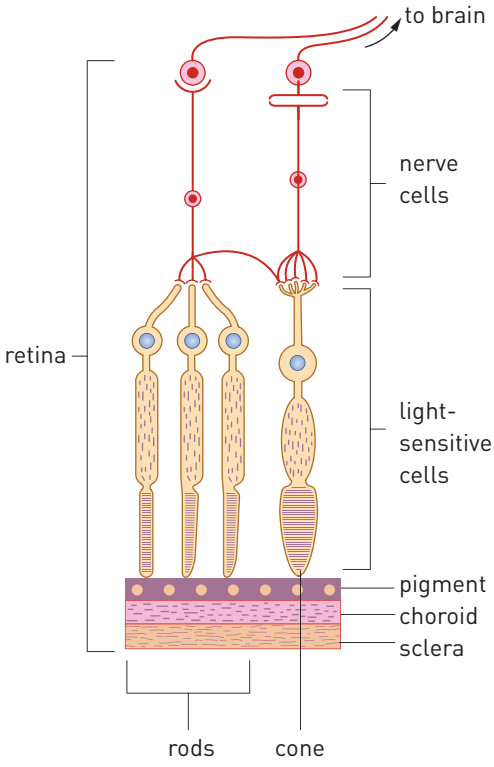

FIGURE 5 Rods and cones in the retina of the eye

Photoreceptors

Photoreceptors transform light energy into action potentials that are then interpreted in the brain as visual images. Depending on the types and numbers of photoreceptors present, an animal may be adapted to nocturnal (night) activity or diurnal (day) activity, or will see only black and white images or a specific colour range. Cones are photoreceptors that respond to colour. There are three types of cones – those that respond to the relatively short wavelengths of visible light (blue), to medium wavelength (green) and to long wavelength (red). Rods are sensitive to the intensity of light and not colour. In a nocturnal animal the ratio of rods to cones is about 1000:1, whereas in the diurnal human it is 20:1. Another type of photoreceptor is the ganglion cell. It also responds to the intensity of light. Instead of producing an optic image, however, it is connected to the autonomic nervous system and regulates the amount of light entering the eye through pupil diameter.

Mechanoreceptors

These receptors respond to mechanical forces such as pressure or distortion. While many of these are present in hair cells (e.g. in the ear where they respond to sound vibrations in the air, or balance), the majority of mechanoreceptors are found in the skin. There are three main types:

1. Slowly adapting types may have either a small or large receptive field.
   - **a** Those with a small receptive field respond to static stimulation and are primarily used to detect form and roughness of an object.
   - **b** The receptors with a large receptive field produce a sustained response to continued stretching.
2. Rapidly adapting mechanoreceptors have a small receptive field and are responsible for the perception of slipping.
3. Pacinian receptors are able to detect high frequency vibrations.

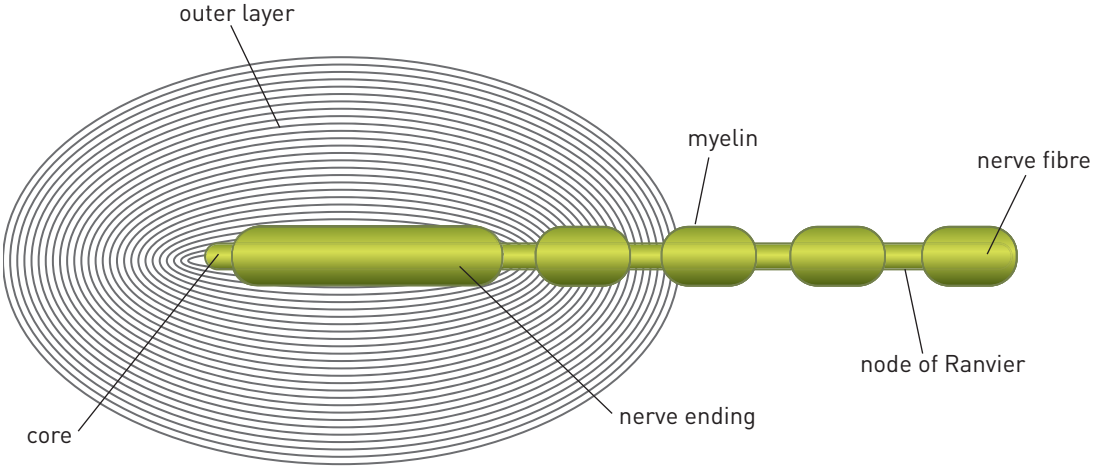

FIGURE 6 A Pacinian corpuscle, which is a pressure receptor

Thermoreceptors

Thermoreceptors are able to detect changes in body temperature. There are two distinct types of thermoreceptors in mammals – one that detects an increase in temperature and one that detects a decrease in temperature. In endothermic animals (birds and mammals) detection of these temperature variations stimulates a variety of physiological changes to ensure a constant internal temperature. These changes are further explored in Chapter 10.

Nociceptors

Nociceptors respond to damaging stimuli by sending signals to the spinal cord and brain that result in the perception of pain. These receptors are installed in the body as it grows from birth. Since the damage may occur on the external surfaces or internally, these receptors are found in the organs and in the skin. They will only respond to a potentially damaging situation or to actual damage and their threshold for activation is high. 'Silent' nociceptors respond to actual tissue damage.

The types of stimuli to which they respond are varied, for example extremes of temperature, excessive pressure or mechanical deformation, or a wide variety of chemicals some of which are signs of tissue damage (e.g. large amounts of lactic acid in muscles).

CHECK YOUR LEARNING 9.7

Describe and explain

1 **Describe** how sensory receptors function.
2 **Explain** where sensory receptors are found.
3 **Describe** features common to all sensory organs.
4 **Identify** the features of a stimulus to which a sensory receptor responds.
5 **Describe** the following forms of sensory receptors:
   - **a** chemoreceptors
   - **b** photoreceptors
   - **c** mechanoreceptors
   - **d** thermoreceptors
   - **e** nociceptors
6 **Describe** functions the rods and cones perform in the retina of the eye.
7 Many sensory receptors in higher animals are found in the head region. **Explain** the significance of this.

Apply, analyse and interpret

8 Chemoreceptors can be either distance or direct receptors. **Distinguish** between these two types.
9 Nociceptors often detect potential damage in a tissue, giving the perception of pain. **Apply** your knowledge to demonstrate the significance of this to an animal.
10 **Deduce** why the ear is considered to be a mechanoreceptor.

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CHAPTER 9

Review

Chapter summary

9.1 Irritability, a property of living organisms, is the ability to detect changes in the environment and respond to them. The environment may be internal or external. The response may be an overt movement or a change in some metabolic reaction.

Irritability involves communication between different parts of the organism, the basis of which is ultimately chemical. Metabolic activities are constantly occurring. Therefore, the chemical environment in every part of the cell (and therefore the whole body) is constantly changing. This affects other chemical reactions.

In multicellular organisms, control of the internal environment is achieved through some form of coordination of the various body systems. In plants, the control system is through plant hormones. Animals coordinate their activities using both nervous and hormonal control.

The stimulus–response model shows the flow of messages from the inception and detection of the stimulus, through the coordinating centre to response by an effector (an individual cell or organ)

Fluctuations from the optimal levels for cell activities are detected and a coordinating centre brings about responses to maintain homeostasis. These feedback mechanisms either reverse a trend (negative feedback) or reinforce it (positive feedback).

9.2 Any change in the chemical environment of a cell will exert a control over the cell by influencing the chemical reactions it can undertake. All cells have receptor molecules in their membranes and cytoplasm that determine their response to chemicals in their environment. Signal transduction occurs when a chemical stimulus causes changes in the membrane receptor molecules that allow passage of the stimulus into the cytoplasm and the cell's response to it.

Hormones are chemicals produced in specialised cells in minute amounts in response to a stimulus. They are released and move to other cells by diffusion or in a circulating fluid. Each hormone can only bring about a change in cells with specific cell-membrane receptors. Because of their method of transport, hormones are slow to bring about change, but act for long periods. Hormones may provide control in their individual cells, their immediate surroundings or at a distance from where they are produced. Some distance hormones (pheromones) are released into the external environment and are species-specific signals. Fat-soluble and water-soluble hormones act on the cell in different ways.

In animals, other chemicals released from nerve cells or the immune system, such as toxins, also act as chemical signals.

The cell continually monitors the types of signals it receives. Since the receptors are proteins, coded by DNA, the numbers and types of cell receptors can be controlled. If a particular receptor is not stimulated regularly, it can be removed from the membrane – this is down-regulation. If more chemical stimuli are present than the receptors can transduce, more receptor molecules are synthesised – this is up-regulation.

9.3 Animal hormones are secreted by special ductless glands (endocrine glands) into the bloodstream. Different hormones may interact with each other in a coordinated manner by feedback mechanisms. The whole endocrine system is under the control of the hypothalamus.

When a hormone reaches a target cell, it may exert its effect at the level of the cell membrane, enzymes located in the cell membrane, cellular organelles or genes. Factors that control the release of hormones are:

- the presence of a specific substance in the blood (e.g. glucose stimulates the release of insulin)
- the presence of another hormone in the blood (e.g. thyroid stimulating hormone – TSH – stimulates the release of thyroxine)
- stimulation by the autonomic nervous system.

9.4 The nervous system provides the fastest means of communication within the body. In most animals, the nervous system consists of cells called neurons connected in longitudinal tracts. The cell bodies of these neurons tend to be concentrated together as ganglia in the head end of the animal. The more highly developed the animal, the larger the ganglia and so eventually this led to evolution of the brain.

9.5 Neurons possess a cell body from which arise a variable number of dendrites with one or more axons. The axon generally has a myelin sheath. Nerve cells are classified as sensory (carrying information from a receptor to the CNS), association (carrying information only within the CNS) or motor (carrying information from the CNS to an effector).

Neurons are excitable cells whose functions are to generate a nerve impulse (action potential), conduct the impulse along the neuron and chemically transmit a signal to another cell.

At rest, the inside of the neuron membrane is negatively charged with respect to the outside. During the passage of a nerve impulse, this situation is briefly reversed. To achieve an action potential, the stimulus must be strong enough to exceed the threshold level.

For a short period during the passage of an impulse, no further impulse can pass (refractory period). Once the membrane is repolarised, a new impulse can be generated. The size of an action potential is independent of the strength of the stimulus (all-or-nothing response).

Adjacent nerve cells are connected by synapses. The impulse passes from one neuron to the next via a transmitter substance that depolarises the membrane of the next neuron. The transmitter substance is subsequently broken down to prevent continuous stimulation. The nerve–muscle junction acts in a similar manner.

9.6 Nerve pathways are frequently organised into reflex arcs, which involve receptor, sensory neurons, association neurons of the spinal cord only, motor neurons and an effector.

The vertebrate CNS consists of the brain and spinal cord. The brain is subdivided into forebrain, midbrain and hindbrain. The brain is involved in the higher coordination of responses.

The peripheral nerves are divided into spinal and cranial nerves. They may be associated with the outer body tube (somatic) or inner body tube (visceral). Visceral motor neurons constitute the autonomic nervous system and form the sympathetic or parasympathetic system.

9.7 Sensory receptors are cells or groups of cells that convert the energy of environmental stimuli to action potentials in sensory neurons. This information is transmitted to specific centres in the brain which register the incoming information and coordinate appropriate responses.

Key terms

- absolute refractory period
- acetylcholine
- action potential
- all-or-nothing response
- anabolic reactions
- association neuron (interneuron)
- autonomic nervous system
- axons
- brain
- catabolic reactions
- cell body
- central nervous system
- cerebrospinal fluid
- chemical transmitter substance
- control centre
- coordination
- dendrite
- direct chemoreceptor
- distance chemoreceptor
- dorsal root of spinal cord
- down-regulation
- effector organ
- end plate
- endocrine gland
- feedback
- fibres
- ganglion
- grey matter
- homeostasis
- hormone
- irritability
- motor (efferent) neuron
- myelin sheath
- negative feedback
- nerve
- neuromuscular junction
- neuron
- node of Ranvier
- noradrenalin
- optimal level
- parasympathetic nervous system
- peripheral nervous system
- pheromone
- pituitary gland
- polarised
- positive feedback
- pre-synaptic element
- proprioceptor
- reflex arc
- regulator
- relative refractory period
- repolarisation
- response
- resting potential
- Schwann cell
- sense organ (receptor)
- sensory (afferent) neuron
- signal transduction
- signal transduction pathway
- sodium pump
- somatic nervous system
- spinal cord
- stimulus
- sympathetic nervous system
- synapse
- synaptic cleft
- synaptic fatigue
- synaptic terminal or knob
- threshold potential
- tolerance limit
- tolerance range
- tropic hormone
- up-regulation
- ventral root of spinal cord
- visceral nervous system
- white matter

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Homeostasis is best described as:

A maintenance of a stable cellular environment

B control of the concentration of substances in the blood

C control of the supply of nutrients to cells and the removal of wastes

D maintenance of a steady temperature and chemical composition in the animal body

2 Which of the following statements about hormonal control is correct?

A It gives rapid response to stimuli.

B It only responds to external stimuli.

C It is usually responsible for long-term adjustments of the body.

D Its action is completely independent and does not involve the brain.

3 The tolerance range of an organism refers to:

A the limit of a particular environmental (internal or external) feature (e.g. temperature) at which the organism can survive

B the range of enzymes any specific organism can utilise

C the range of light intensities required for animal sight

D the range of a particular environmental (internal or external) feature (e.g. temperature) at which the organism can survive

4 Signal transduction refers to:

A changes in specific receptor molecules of cell membranes allowing transmission of secondary messengers from the cell's exterior to interior environment

B changes in specific receptor molecules of cell membranes allowing transmission of secondary messengers from the cell's interior to exterior environment

C changes to all parts of the cell membrane allowing transmission of secondary messengers from the cell's exterior to interior environment

D the movement of potassium ions out of the axon at the instigation of an action potential

5 Which of the following statements concerning feedback mechanisms is correct?

A Positive feedback results in the reversal of an existing condition.

B Positive and negative feedback result in further change in the direction of an existing condition.

C Negative feedback results in the reversal of an existing condition.

D Positive feedback reinforces negative feedback.

6 The functions of the pituitary gland are to:

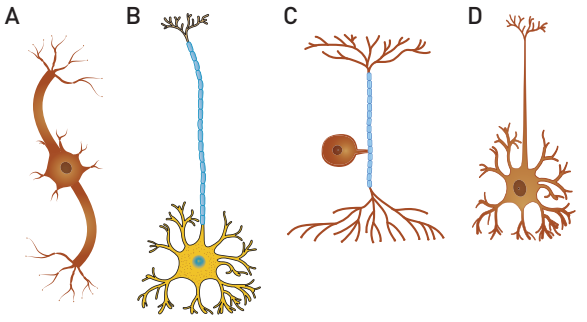
A regulate the uptake and use of carbohydrates

B stimulate the body into a state of readiness for physical exertion

C regulate growth and influence the activities of the other endocrine glands

D control the rate of mental and physical development

7 Opposite are diagrams of four types of nerve cells. The sensory neuron is:



8 A nociceptor responds to:

A mechanical forces such as pressure or distortion

B extremes in temperature

C relatively short wavelengths of light

D pH of the blood

Short answer

Describe and explain

★**9** **Describe** the mechanism of a nerve impulse moving along a neuron from the arrival of the neurotransmitter at the receptor to the release of the cell's own neurotransmitter. Include the following words in your description: signal transduction, ion channels, action potential, dendrites, axon, synapse, vesicle.

Apply, analyse and interpret

★**10** **Identify** two advantages in the body of controlling physiological processes by the action of hormones compared with nervous control.

★★★**11** Thyroxine is a hormone involved in the control of metabolic activity.

a **i** **Apply** your knowledge to explain how thyroxine affects metabolic activity.

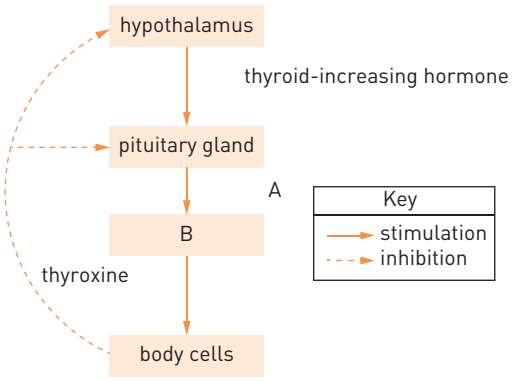
ii **Identify** how thyroxine is transported around the body.

b The figure on the next page shows some of the factors regulating secretion of thyroxine. **Interpret** the information provided to answer the following questions.

i **Identify** A and B.

ii **Deduce** the region of the pituitary gland from which substance A is released.

iii **Classify** the regulation of thyroxine as an example of a positive or negative feedback system. Give reasons for your response.



c A daily dose of 1 mg of thyroxine increases the adult metabolic requirement from 10 500 kJ per day to 14 700 kJ per day. If the equivalent of 10 500 kJ is consumed in the diet, then body energy reserves will be used.

Infer why a daily dose of 1 mg of thyroxine would not result in continued weight loss.

★★**12** The table below shows the speed of conduction of a nerve impulse along axons from three different species of animals.

Species	Diameter of axon (μm)	Speed of conduction (m/s)
A	7	1.2
B	500	33.0
C	15	90.0

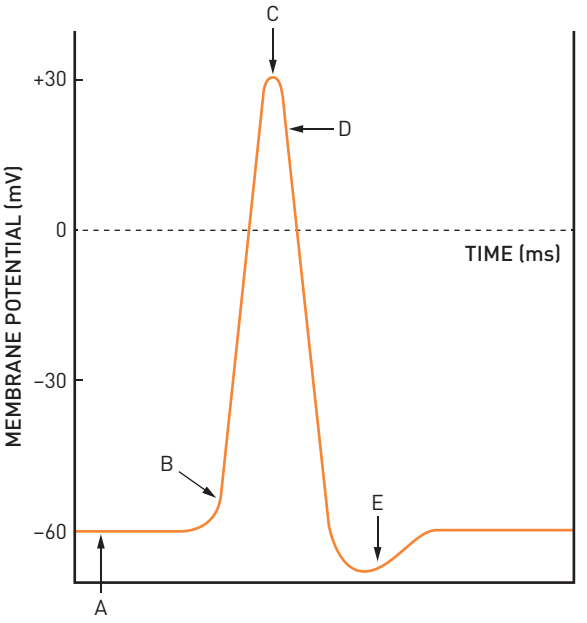
Analyse which one of these three species is most likely to possess myelinated nerve fibres. Give a reason for your answer.

★★**13** **Discuss** how living organisms detect changes in their environment.

★**14** The diagram opposite shows the trace obtained on a cathode ray oscilloscope, a device to show changes in electrical potential, when an isolated axon of a neuron is stimulated. The following statements refer to events at specific points – A, B, C, D and E – on the trace. **Classify** the statements 1 to 5 with points A to E. Each letter should only be used once.

Statement		Letter
1	Region corresponding to relative refractory period.	
2	Rapid decrease in the permeability of the axon membrane to sodium ions.	
3	No net movement of ions and the axon membrane is negatively charged.	
4	Rapid increase in the number of sodium ions inside the axon.	
5	Sodium permeability of the axon membrane insufficient to trigger an action potential.	

(University of London External Assessment Centre, January 1993, Paper III, No. 3)



Investigate, evaluate and communicate

★★★**15** The poison arrow frog of South America, *Dendrobates lehmanni*, has bright red and black colouration. The frog produces a potent poison in its skin. This chemical, curare, causes skeletal muscle relaxation. Indians of the area use the poison to coat their hunting arrows.

a **Consider** what function the poison would serve for the frog.

b **Hypothesise** why the frog is brightly coloured.

c **Determine** the mechanism that brings about muscle relaxation in prey shot with poisoned arrows.

d **Propose** two reasons why capture of prey is more effective using poisoned arrows.

★★**16** A small patch of tissue in a mammal is known to be secretory in function. **Devise** an investigation to discover whether the secretion acts as a hormone.

★★**17** The drug atropine acts predominantly by depressing the activity of the parasympathetic nervous system.

a **Predict** the effects of this drug on:

i heart rate

ii rate of salivation

iii pupil diameter.

b **Discuss** why atropine could have useful applications in dental surgery and eye examinations.

★★★**18** Many drugs have the action of mimicking or blocking the action of the neurotransmitter acetylcholine. The table below shows a range of drugs and some of their more common effects on the mammalian nervous system.

Substance	Site of action	Most common effect
Botulism toxin	Presynaptic membrane	Prevents release of acetylcholine
Nicotine	Postsynaptic membrane	Mimics action of acetylcholine
Strychnine	Postsynaptic membrane	Inhibits the breakdown of acetylcholine
Curare	Postsynaptic membrane of neuromuscular junction	Blocks action of acetylcholine

a **Describe** the events occurring between the arrival of an action potential at the presynaptic membrane of a cholinergic synapse (one in which the transmitter substance is acetylcholine) and the generation of an action potential in the postsynaptic cell.

b **Construct** a clearly labelled diagram of a synapse, indicating the precise site of action of the following substances (using the appropriate numbers).

1 Botulism toxin

2 Nicotine

3 Strychnine

4 Curare

c Using notes below your diagram, **predict** the effect you would expect each substance to have on the postsynaptic generation of an action potential.

Check your obook assess for these additional resources and more:

» **Student book questions**
Chapter 9 review

» **Revision notes**
Chapter 9

» **assess quiz**
Chapter 9 auto-correcting multiple-choice quiz

» **Flashcard glossary**
Chapter 9 glossary

CHAPTER 10

Control of temperature and water balance

There is a large variety of environments available for organisms to live in, each of which may have different temperature ranges and water availability. Organisms have specific adaptations to cope with the limitations imposed by their environment. Animals employ structural features and behavioural responses to adjust their body temperatures. Endotherms also use physiological mechanisms and homeostatic controls that allow them to be active in a wide range of environmental temperatures. Similarly, different animals employ a variety of mechanisms to maintain the water balance in their cells.

The water balance in plants is mainly controlled by structural features. Terrestrial plants may lose their leaves during prolonged periods of low water availability.

OBJECTIVES

→ Identify and explain the varying thermoregulatory mechanisms of endotherms and how they control heat exchange and metabolic activity in terms of:
- structural features (brown adipose tissue, increased number of mitochondria per cell, insulation)
- behavioural responses (kleptothermy, hibernation, aestivation and torpor)
- physiological mechanisms (vasomotor control, evaporative heat loss, counter-current heat exchange, thermogenesis/metabolic activity from organs and tissues)
- homeostatic mechanisms (thyroid hormones, insulin).

→ Identify and explain the various homeostatic mechanisms that maintain water balance in animals (osmoregulators and osmoconformers) in terms of:
- structural features (excretory system)
- behavioural responses
- physiological mechanisms
- homeostatic mechanisms (antidiuretic hormone (ADH) and the kidney).

→ Identify and explain the various mechanisms that maintain water balance in plants in terms of structural features (stomata, vacuoles, cuticle) and homeostatic mechanisms (abscisic acid); consider xerophytes, hydrophytes, halophytes and mesophytes in responses.

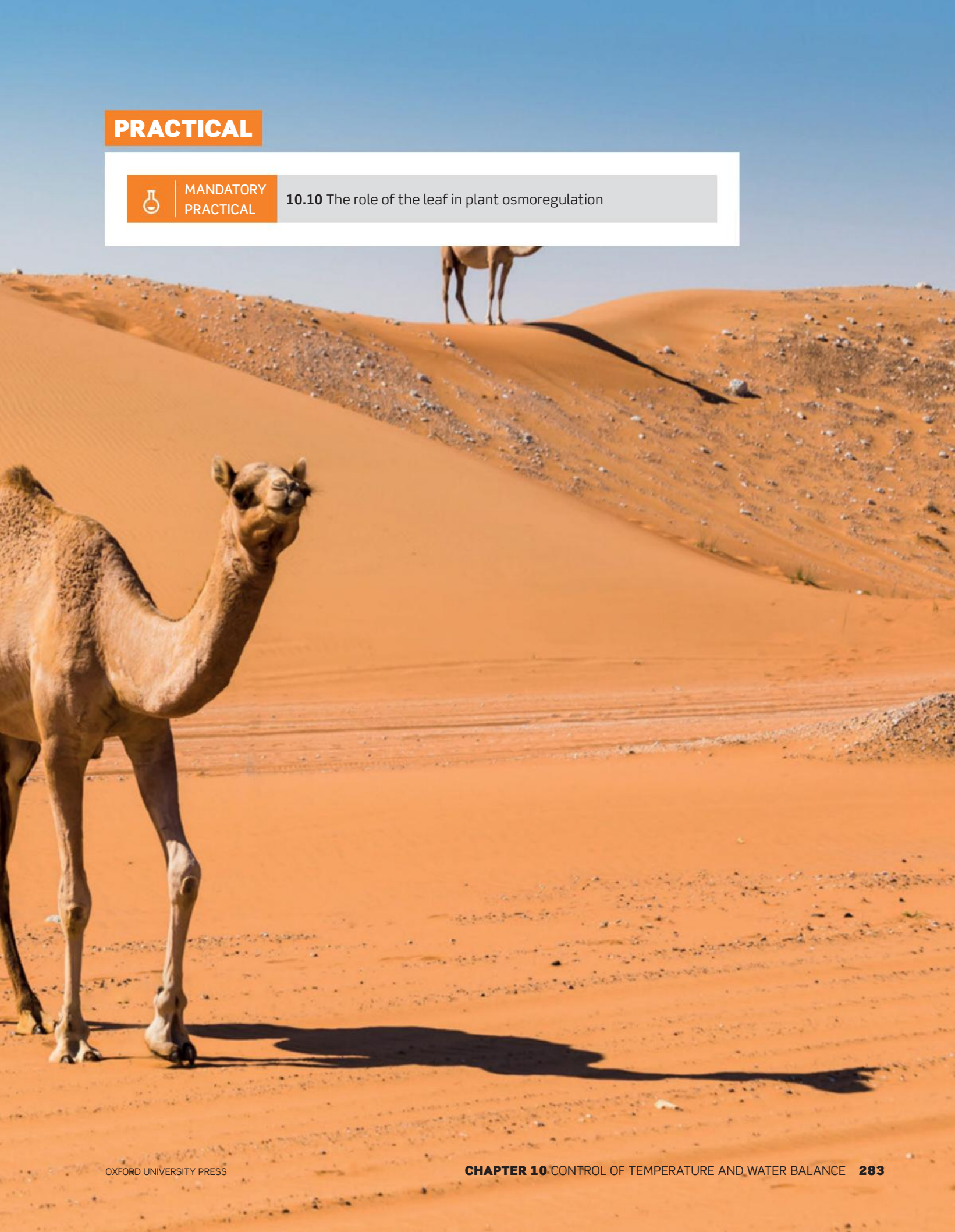
Source: *Biology 2019 v1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority*

FIGURE 1 Camels have many adaptations that allow them to maintain temperature and water balance in the extreme conditions of the desert.

PRACTICAL

MANDATORY PRACTICAL

10.10 The role of the leaf in plant osmoregulation



10.1 Tolerance ranges for environmental temperature and water

KEY IDEAS

- The range of environmental temperature and water availability of different habitats on Earth
- The difference between the optimal and tolerance range of abiotic factors for each species and how organisms suffer physiological stress outside the optimum range for any factor
- The concept of adaptation
- Types of adaptations to a particular habitat

niche
the 'role' of an organism in a habitat

habitat
a specific locality, with a particular set of abiotic conditions, inhabited by an appropriately adapted community of organisms

abiotic
non-living

optimal range
the most favourable condition of, for example, temperature, light and moisture, for the growth or reproduction of an organism

physiological stress
an organism's response to a stressor such as an environmental condition

tolerance range
the range of environmental conditions at which an organism can survive

adaptation
a feature of an organism which enhances its ability to survive and reproduce in a particular environment

The physical conditions that exist on Earth vary enormously. The temperature of environments, for example, can vary from –40°C in Arctic regions to 90°C in hot springs. In some terrestrial environments, rainfall is exceptionally high and availability of fresh water does not present a problem. In other areas (e.g. deserts), rainfall is scarce and water availability for organisms almost non-existent. Despite this, some organisms can survive in these extreme conditions. Although chemotrophs can survive without other organisms, photosynthetic algae and plants require at least decomposers to recycle nutrients back into the environment for their continued existence. All animals depend ultimately upon the plants in the area in which they live to survive. The physical conditions of the area determine the types of plants that will grow and therefore the types of animals that will be present. Organisms exist in communities made up of their own and other kinds of organisms.

Each type of organism has a particular **niche** or role in its community. The niche includes the species' requirements, the physical conditions and resources in its environment, and its adaptations to meet those requirements and use the resources.

Different organisms live in different living places, or **habitats** in the environment. The physical conditions (e.g. temperature range, humidity, wind and air currents, water currents, pH, availability of light, water, nutrients) of habitats vary dramatically. These conditions are known as **abiotic** conditions (from the Greek *a* = without and *bios* = life). To carry out its life functions successfully, each organism in a particular habitat is adapted to the physical and chemical conditions imposed upon it.

Each species has an **optimal range** for each abiotic factor in the environment. This is the level at which it can best survive. For example, a certain plant will grow very well in a pH range of 6.5 to 8.0. This is its optimal range for that particular factor. Although it can grow in soils of pH 6 or pH 8.5, it does not function as efficiently – in other words, it suffers **physiological stress**. Habitats with these pH values provide only a marginal niche. This plant cannot survive in soils with a pH outside this range and so these habitats become an unavailable niche. For this species, the **tolerance range** for soil pH is 6 to 8.5. An organism will be found only in an area where it encounters the tolerance range for all of its abiotic requirements.

Those organisms with particular genetic variations that allow them to best exploit a set of environmental conditions will survive in that habitat. Those that do not have the features that enable them to live within the tolerance range either move away to a new habitat or die out. Eventually only those species that have the features suited to that habitat will be found there. They are adapted to survive in that habitat. **Adaptations** are any structural, functional

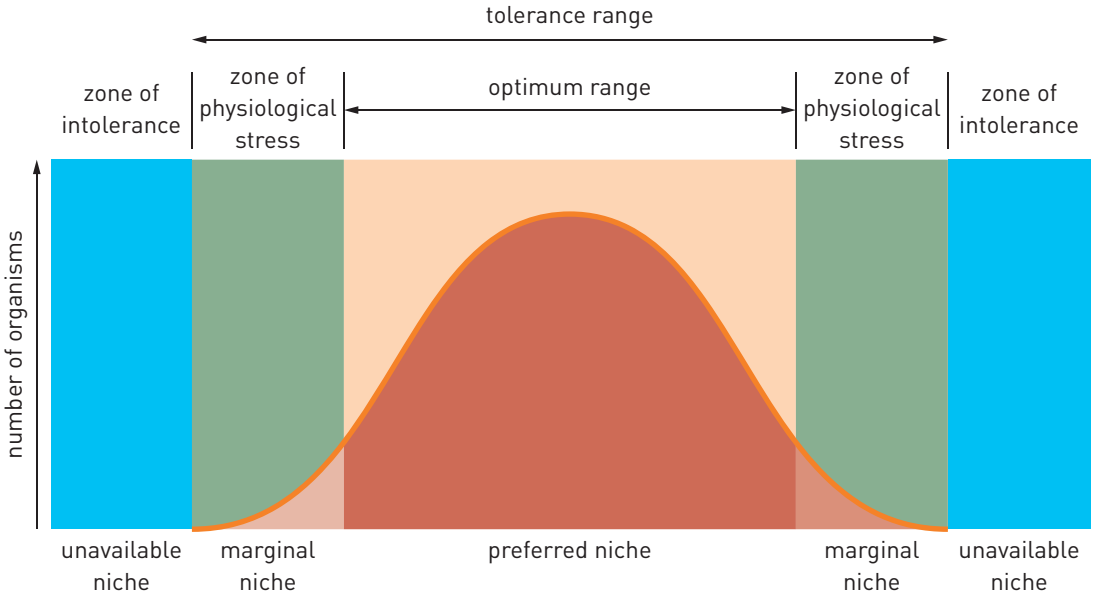


FIGURE 1 The relationship between tolerance range and optimum range for any particular requirement of an organism

or behavioural feature of a species that ensures that individual organisms are suited to their environment. The adaptations of a species that increase its chance of survival may be:

- structural – physical features such as glands that can secrete excess water in rainforest trees, or very short ears and other extremities in animals living in very cold habitats
- behavioural – changes in the way an organism behaves; for example, animals congregating close together to share body heat in very cold weather
- physiological – the ability to regulate the cells or tissues within a systems, such as blood flow in the outer body areas, to maintain a constant internal environment.

Two environmental factors of particular significance are temperature and water availability. In plants, these two factors are intricately interwoven. For example, a plant's response to cold weather may in fact also be a response to lack of water. Even though there may be a large amount of water present, it may be locked in the form of snow or the ground water may be frozen or too deep to be available. In all of these cases, water is not available for use by the plant.

CHECK YOUR LEARNING 10.1

Describe and explain

1 **Explain** why different species are found in different environments throughout the world.

2 **Define** the term 'adaptation'.

Apply, analyse and interpret

3 **Compare** the optimum range and the tolerance range.

4 **Describe** one example of each of a structural, behavioural and physiological adaptation.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 10.1

» Video
Galapagos niches

» Video worksheet
Galapagos niches

» Weblink
Temperature and rainfall

10.2 Thermoregulation

KEY IDEAS

- The interplay between environmental temperature and enzyme (and so metabolic) activity
- The difference between thermoregulators and thermoconformers
- The main means by which organisms gain and lose heat from the body
- The difference between ectotherms and endotherms, poikilothermic and homoeothermic organisms

Although some bacteria can live in very hot, acidic conditions (such as hot springs where the temperature can reach as high as 90°C), most organisms live in environments that have a narrow range of 10–30°C. Metabolic activity is affected by changes in temperature as a result of enzymes only being able to function effectively between 10 and 45°C. As the temperature approaches 10°C enzyme activity slows and it ceases below this temperature. Above 45°C enzymes start to denature, stopping metabolic activity. The cells of organisms contain a high proportion of water (about 75%). As the temperature drops towards 0°C, the water starts to form ice crystals that will not only prevent metabolic activity but also cause irreparable cell damage. To survive, some control over body temperature is needed. This regulation of body temperature is called **thermoregulation**.

thermoregulation maintenance of a constant internal temperature of an organism independent of the temperature of the environment

Some organisms, however, are **thermoconformers**. They simply adopt the surrounding temperature as their own body temperature. While this saves energy, it does limit the temperature range of the habitat in which they can survive. Since the temperature of deep bodies of water, such as the oceans, is very stable, most thermoconformers live in marine environments. Because the temperature of these habitats rarely exceeds 5°C, the metabolic rates of thermoconformers are very low and they are invariably slow-moving animals or algae.

thermoconformer any organism whose body temperature changes according to the external temperature

Organisms can gain heat in two main ways:

1. metabolism of food
2. absorption of solar energy either directly or indirectly from:
   - heat radiated from objects
   - heat convected from the warming of the ground
   - heat conducted from the ground.

Organisms can lose heat from the body through:

- evaporation of water (e.g. through the stomata of plant leaves or sweating)
- conduction from the body to the environment
- convection from the body to the air or water
- radiation from the body to the environment.

Conduction involves direct transfer of heat from one particle to another, such as between the particles of the outer body surface and air particles. Convection occurs when a current of air or water flows over the surface of the body. Heat from the hot surface is transferred to the moving fluid, which is then replaced by cooler air or water. Radiation is the transfer of heat by electromagnetic infra-red rays that are generated from a hot surface. In all cases heat moves from the hot 'object' to the cold 'object'. During evaporation water absorbs enough heat from the body for it to become a gas. As the water vapour moves away from the body, the heat moves with it. The body is cooled during this process.

Many organisms maintain a temperature difference between their central core and the surfaces exposed to the environment. This is invariably associated with structural features at the surface that can better withstand the environmental temperature. In this way, the main metabolic activities can be maintained at a regular rate.

Ectotherms and endotherms

Organisms use two different strategies for surviving extremes or even moderate variations of temperature. One group, the **ectotherms**, get their body heat mainly from their environment and can tolerate a reasonably wide range of body temperatures. These organisms were once called cold-blooded; however, a lizard lying in the sun does not have cold blood. Instead, these animals change their behaviour so that they minimise the impact of the surrounding environment. A lizard may lie on a dark-coloured rock in the sun to warm its body. When it gets too hot, it may find a place in the shade. All ectotherms control their body temperature by either gaining heat from their environment or reducing any heat loss from their bodies.

The second group of organisms are called **endotherms**. Most of their heat is generated internally through metabolic activity and they are not so reliant on environmental conditions. They are able to maintain internal core temperature within a narrow range using a variety of physiological strategies in addition to structural and behavioural mechanisms. Most endotherms are also **homoeothermic** and have a constant internal temperature. In the animal world, birds and mammals are homoeothermic endotherms. A few plant species (e.g. the sacred lotus) are also endothermic. Although energy-consuming, this strategy enables these organisms to have a wider tolerance range of environmental temperatures at which they can maintain activity.

ectotherm
any animal whose regulation of body temperature depends on external sources

endotherm
an animal that can maintain a constant body temperature independent of the environment

homoeothermic
the ability to maintain a relatively constant body temperature that is independent of the temperature of the surrounding environment

CHECK YOUR LEARNING 10.2

Describe and explain

1 **Describe** thermoregulation.
2 **Explain** the ways organisms gain heat from, and lose heat to, the environment.
3 **Describe** the features of a thermoconformer.
4 **Explain** why thermoconformers are usually found only in cold, marine environments and not in hot or terrestrial environments.

Apply, analyse and interpret

5 **Contrast** an ectotherm and an endotherm.
6 'Most endotherms are also homoeothermic.' **Analyse** what is meant by this statement.

Investigate, evaluate and communicate

7 **Discuss** why biologists no longer use the term 'cold-blooded'.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 10.2

» Weblink
Thermoregulation of polar bears

» Weblink
Body heat loss

» Weblink
Thermoregulation of lizards

10.3 Conservation of heat in endothermic animals

KEY IDEAS

- Physiological features that reduce heat loss to the environment
- Metabolic features that enhance heat production (thermogenesis)
- The significance of brown adipose tissue
- Behavioural adaptations such as kleptothermy and means of conserving energy
- The difference between hibernation and torpor
- Structural features that reduce heat loss

homoeotherm
an animal that maintains a relatively constant body temperature that is independent of the temperature of the surrounding environment

arteriole
the branch of an artery that breaks up into capillaries

shunt vessel
a blood vessel that links an artery directly to a vein, allowing the blood to bypass the capillaries in certain areas

erector muscle
a muscle composed of bundles of smooth muscle fibres, attached to the deep part of hair follicles, contraction of which erects hairs

insulation
material used to reduce the rate of heat transfer (e.g. subcutaneous fat, hair and feathers)

Most **homoeotherms** maintain their internal core temperature within a narrow range of 32–45°C. This allows the enzymes that drive the chemical reactions to function effectively. Because the movement of muscles requires production of ATP through aerobic cellular respiration, the more active the animal (e.g. the hummingbird), the higher its core temperature. This means the core temperatures of active animals are higher than the air temperature of the habitat in which they live. If the animals are able to keep the warmth in their body, then they are able to survive in a greater range of cold environments. Over time, these animals have evolved responses that reduce heat transfer to the environment.

FIGURE 1 A hummingbird has a high core temperature because it is so active.

Physiological features that reduce heat loss

How quickly heat is lost is dependent on the difference in temperature between the animal's body and its environment (temperature gradient). The bigger the temperature gradient, the faster heat is lost. Animals with a large surface area to volume ratio will also lose heat faster. This means a tall, slender animal (emu) will lose heat faster than a small, compact animal (finch). Animals can reduce the loss of heat from their bodies by lowering the temperature in their limbs (arms and legs). This decreases the temperature gradient between the large surface area limbs and the environment. Temperature of limbs can be lowered in the following ways:

- **Arterioles** supplying the skin capillaries can be constricted. This reduces the blood flow to the skin. Since the blood carries heat, less blood flowing to the outer surface results in a decreased heat loss to the environment.
- Special **shunt vessels** between arterioles and venules in the inner part of the skin occur in some animals living in very cold habitats. The blood bypasses the skin capillaries. This is why very cold people can appear pale as they have very little blood flowing through their skin.

- The arrangement of blood vessels passing to the extremities of cold-habitat animals (e.g. the flukes of whales and legs of the Artic fox) forms a counter-current system. The arteries entering the extremity are in close contact with the veins leaving it – in dolphins and whales, the vein is branched and coiled around the artery to increase the area of contact between them. The warmth in the arterial blood is passed to the colder blood returning from the limbs. This cools down the blood going to the limbs and warms up the blood returning to the heart. At all points along their lengths, the temperature of blood leaving the core in the artery is higher than that of the vein returning to the core. Heat flows from the artery to the vein so that by the time the capillary bed is reached, the temperature of the blood is very low. This allows exchange of skin metabolites (nutrients, gases and wastes) while minimising heat loss.

Other features to reduce heat loss include the following:

- Hair or feathers can be raised by contraction of their **erector muscles**. This increases the thickness of the insulating layer of air trapped between hair or feathers and the skin. Heat leaving the skin of the animal must move through the extra layer of air before being lost to the environment. Air is a poor conductor of heat and so less heat is lost from the skin. As the hair or feather is raised, it pulls up some of the skin and small bumps occur that are commonly called 'goose bumps'.
- Many animals have a layer of **insulation**, via subcutaneous fat layers or thick hair or feathers, to help reduce heat lost in a cold environment. As the air temperature drops during the onset of winter, the amount of subcutaneous fat increases, as does the density of the outer body covering. In many sub-Arctic mammals, thick fur may prove a disadvantage when hunting prey as the heat generated by muscle activity during strenuous activity may not be lost rapidly enough, causing them to overheat. These animals often have thinner fur on their bellies to compensate for this.

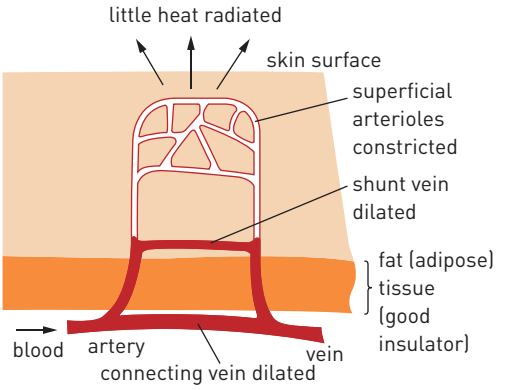


FIGURE 2 Vasoconstriction of cutaneous arterioles

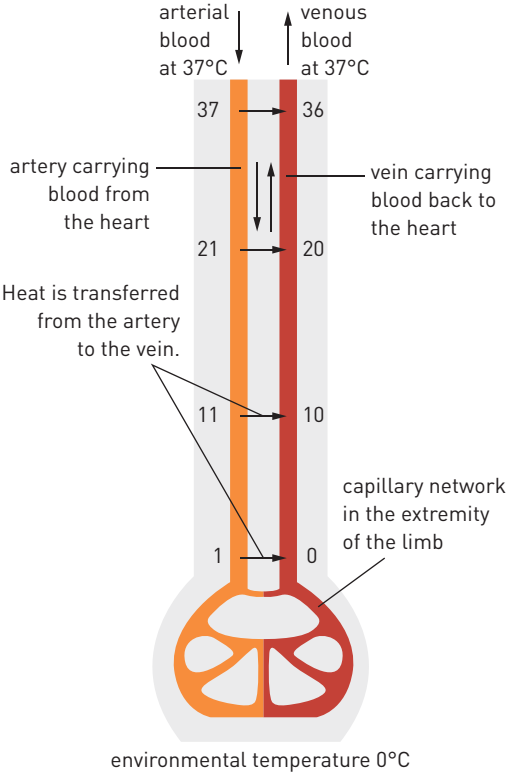


FIGURE 3 Counter-current heat exchange

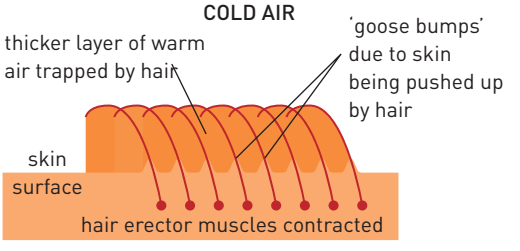


FIGURE 4 Raising hair or feathers to reduce heat loss

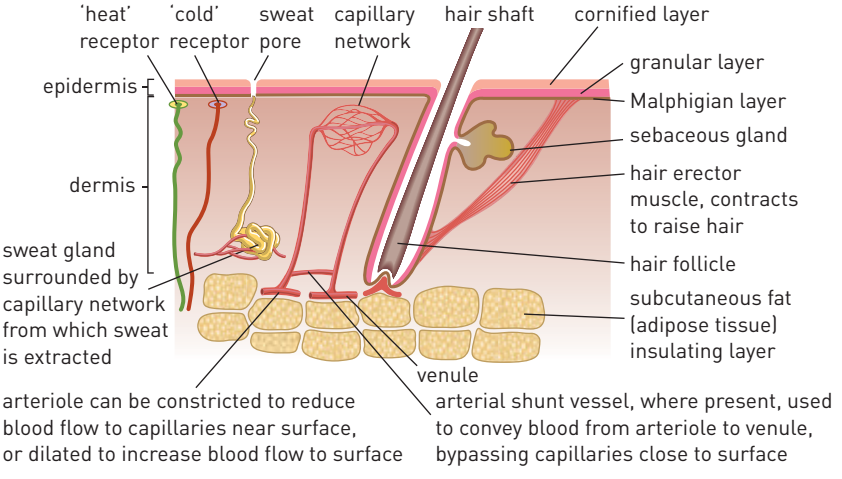


FIGURE 5 Features of the skin that assist in thermoregulation

FIGURE 6
Humpback whale

Marine mammals need a streamlined body shape and a smooth surface that does not become waterlogged. They build up an especially thick layer of subcutaneous fat known as blubber. As well as providing insulation, the blubber also acts as a high-energy food source in times of scarcity or during long migrations. Humpback whales, for example, feed on krill normally only found in cold waters. In their annual breeding migration from Antarctica to the Central Queensland coast, the adult whales rely on this fat for all of their nutritional requirements (including provision of milk for their newborn young). They do not feed again until they reach Antarctic waters many months later.

Physiological processes in heat production

Sometimes, preventing heat loss is not enough and animals need to also generate extra heat – this is called **thermogenesis**. Metabolism generates heat that can warm the body and the rate of heat production can be increased by either:

- increasing contraction of muscles by moving around or shivering, or
- by the action of certain hormones (e.g. adrenalin and thyroxine) that increase the metabolic rate.

The hormonal triggering of heat takes place throughout the body. Some mammals have **brown adipose tissue**, especially in the neck and between the shoulders, that is specialised for rapid heat production. Brown fat cells store lipids and contain large numbers of mitochondria. These specialised mitochondria make little ATP and release most of the chemical energy as heat. Being endothermic means that the animal can remain more active in a cold environment than its ectothermic counterpart. But it also means that a lot of energy is expended to maintain that activity and therefore food intake is higher. For example, at rest at 20°C, a human male uses 7532 kJof energy per day but a young ectotherm of similar weight (e.g. a crocodile) uses only 251 kJ per day.

thermogenesis
the process of heat production in organisms

brown adipose tissue
tissue that stores large amounts of high-energy lipids, the cells of which contain large numbers of mitochondria

kleptothermy
any form of thermoregulation by which an animal shares in the metabolic thermogenesis of another animal

torpor
a short-term state of decreased physiological activity in an animal, usually with a reduced body temperature and metabolic rate, as a result of cold conditions

Behavioural responses to cold conditions

Behavioural mechanisms that are used to reduce heat loss include diurnal (daytime) activity, huddling in groups to share body heat (**kleptothermy**) and delayed reproduction that ensures that young are born at a time when food will be available at weaning time.

FIGURE 7 A thermographic image of small bats using trapped air as insulation to maintain core body temperature while staying close together to share body heat.

In cold areas where food supply is extremely limited in winter, many animals enter a state of **torpor**. They decrease their metabolic rate, slow their heart and respiratory rate, and are less responsive to external stimuli. This is a controlled state that may involve an initial period of fattening and the preparation of an insulated nest area (e.g. a cave, burrow or hollow tree). Many small Australian mammals (e.g. the feathertail glider and microbats) undergo short-term torpor. This may last for a day (temporarily conserving energy by reducing their metabolic rate) or for several days.

Hibernation is a state of long-term torpor in which body temperature is kept at a lower level than normal when environmental temperatures are very low. Less energy is needed to maintain this decreased body temperature. To remain in this state for a long time (up to six months), an animal builds up large reserves of brown fat in the muscles and liver. This brown fat can be readily metabolised at low temperatures. As its body temperature drops, there is strong peripheral vasoconstriction. This ensures that blood flow is redirected away from the limbs and maintains warm blood flow in the brain, heart and lungs. During arousal (waking up), blood is also sent to the brown fat and adrenal glands. Adrenaline from the adrenal glands causes the brown fat to produce a great deal of heat, which is carried to the heart. The heart rate increases and so more brown fat metabolises to produce further heat. This continues until the animal's normal body temperature is reached.

One of the dangers of hibernation is that of the body temperature falling too low and the animal freezing. It appears that temperature receptors in many species are set off if the core temperature drops below a certain level. This instigates arousal, even if for only a short period. The animal then drops its temperature and re-enters hibernation.

hibernation
a long-term state of inactivity and decreased metabolic rate associated with redirection of blood flow in animals during winter

structural feature
an arrangement or organisation of parts of an organism

Study tip

When answering questions on thermoregulation, always check if you need to provide examples of heat loss or heat production. There are different features that are responsible for each of these.

Structural features to reduce heat loss

Structural features also assist in preventing heat loss. A high surface area to volume ratio in cold climates would result in a high heat loss. Metabolic heat production could outstrip food supplies. Active animals in these habitats tend to have a large torso (in this way reducing the surface area to volume ratio) with short extremities. Ear pinnae, which are thin, are reduced in size and rounded. Tails tend to be stumpy.

CHECK YOUR LEARNING 10.3

Describe and explain

1 **Describe** two ways in which heat is lost from surface blood vessels.
2 **Explain** why a counter-current arrangement of blood vessels in the fluke of a hump-back whale would help their survival.
3 **Describe** two ways in which heat is generated in endotherms.
4 **Explain** how brown adipose tissue is different to other fat-storing tissue.

Apply, analyse and interpret

5 Finches kept in an aviary seem larger in cold weather and spend most of their time sitting on a perch very close together. **Interpret** these observations.
6 Most mice are nocturnal (active at night). In the alpine moorlands of Mt Kilimanjaro (4000 m above sea level) where the daytime temperate reaches 30°C, but the night-time temperature can be as low as –10°C, there lives a species of large brown mouse. This animal is diurnal, has a large body covered in thick hair, and its legs, ears and tail are almost non-existent.
Analyse the features of this mouse to explain why they would be present based on the information provided.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 10.3

» Video weblink
Penguins huddle for warmth

» Weblink
Dinosaurs had feathers

» Weblink
Animals with blubber

10.4 Endothermic survival in hot environments

KEY IDEAS

- Some of the physiological mechanisms used to increase heat loss
- How animals assist temperature control through their behaviour
- The process of aestivation

It is often more difficult to live in a hot environment than a cold environment. Environments with very high temperatures may require organisms to reduce their energy production, reduce their heat absorption and find ways to lose the heat their body generates. This is not easy to do when the surrounding air temperature is warmer than the organism's body. Endotherms that live permanently in warm temperatures have a range of adaptations to increase their chances of survival. Many of these adaptations are the opposite of those found in animals living permanently in cooler climates. Such adaptations include the following:

vasodilation the widening of blood vessels

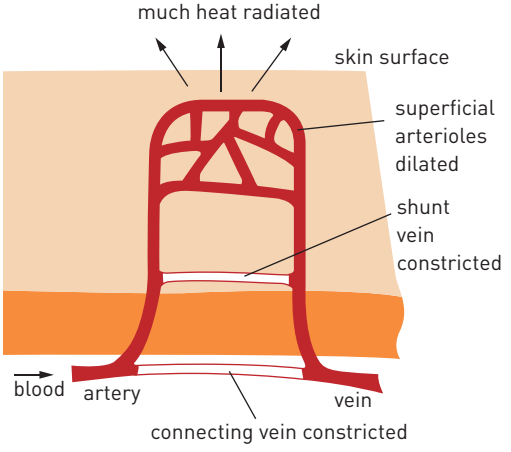


FIGURE 1 Vasodilation of cutaneous arterioles

FIGURE 2 Kangaroo licking its forelegs to increase evaporative heat loss

- **Vasodilation** of the arterioles leading into the skin's capillaries ensures that a large amount of blood is carried to the skin's surface where heat is lost. A greater proportion of blood in the extremities is returned to the body in surface veins rather than in deeper lying ones to aid heat loss by convection and radiation.
- **Sweating** from glands in the skin cools the body. The conversion of sweat from a liquid to a gas requires a great deal of heat energy. This means the heat energy of the organism decreases (2.5 kJ of energy is required for the evaporation of 1 g of water). With such a small amount of body hair, the human skin has sweat glands over the whole body, and this provides a very efficient means of cooling. Most mammals, however, are covered in fur. Sweat glands are therefore restricted to a few areas of the skin where fur is absent, such as the pads of the dog's feet. Birds do not have sweat glands.

  Sweating is only effective, however, if there is an adequate supply of water and salts to replace those lost in the process. When the air is very humid, there is already a large amount of water vapour in the air, making it difficult for more sweat to evaporate.
- **Panting** and **licking** achieve a similar result to sweating. When the animal pants, saliva evaporates from the mouth and nose, cooling the animal. Kangaroos assist evaporative heat loss by licking their forelimbs in very hot conditions to help lose heat.
- **Insulation** using fur or subcutaneous fat can help to reduce heat gain from the environment. The hair erector muscles can also relax so that the fur lies closer to the surface, thereby reducing the layer of warm air trapped in the fur and increasing the heat lost from the body.

- **Fluctuation of core temperature** is achieved by some desert animals (e.g. the camel). By allowing their temperature to rise a few degrees during the day, they decrease the temperature gradient and so decrease the amount of heat gained from radiation or convection from the environment.
- **Fat storage** is limited to specific areas (e.g. the hump of the camel) to reduce its insulating effect and increase heat loss.
- **Behavioural mechanisms** such as nocturnal activity when temperatures are cooler and retreating to burrows and other similar shaded areas and inactivity during the heat of the day, assist temperature control. Prolonged torpor in summer (**aestivation**) may occur during the hottest or driest months in some animals, particularly in insects, fish and amphibians.
- **Structural features** such as a slim torso and large extremities assist in conduction of heat from the body. Ears that are thin and highly vascularised are especially good at increasing heat loss.

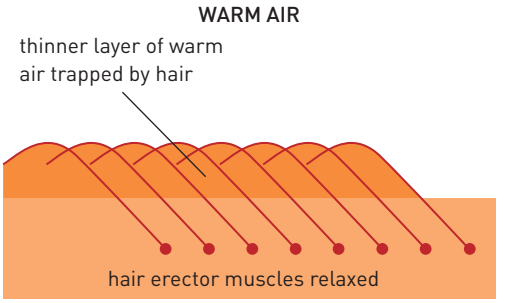


FIGURE 3 Reduction of the thickness of insulating air trapped by fur

aestivation
prolonged torpor in response to high environmental temperature and low water availability

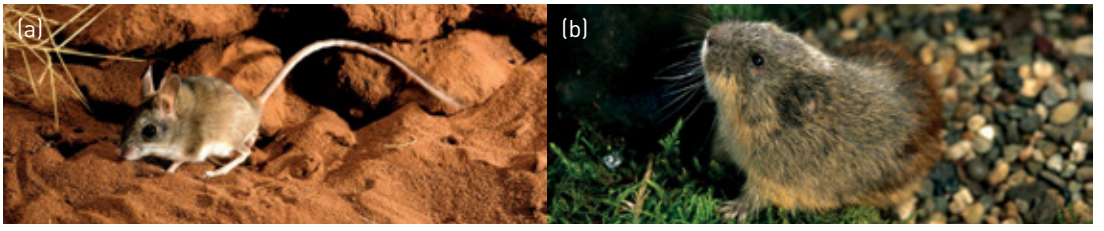


FIGURE 4 (a) The large ears and long limbs and tail of the nocturnal spinifex hopping mouse (*Notomys alexis*) are adaptations to living in a hot climate – a larger surface area to volume ratio results in increased heat radiation from the body. (b) The Northern Hemisphere lemming shows structural adaptations for overwintering in a snow-covered habitat.

CHECK YOUR LEARNING 10.4

Describe and explain

1 **Describe** how vasodilation of the arterioles in the skin results in greater heat loss from the body.
2 In hot weather, humans sweat copiously but the body fur of other mammals and feathers of birds remain dry. **Explain** this observation.
3 Kangaroos and wallabies are often seen sitting in the shade, licking their forearms on a hot day. **Explain** what this behaviour achieves.
4 **Describe** some behavioural strategies of warm-climate endotherms that are opposite to those of cold-climate endotherms.
5 **Explain** how subcutaneous fat acts as insulation in both warm and cold climates.

Apply, analyse and interpret

6 The brolga is a bird adapted to tropical grasslands and woodlands. Although it is a bird of flight, it has extremely long, thin legs. **Apply** your knowledge to suggest reasons for this.

Investigate, evaluate and communicate

7 A person living in a place that reaches 40°C with 90% air humidity experiences much higher heat stress than in a place with the same temperature but only 10% air humidity. **Discuss** this situation.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 10.4

» Weblink
Dogs and heat

» Weblink
Desert animal adaptations

» Weblink
Nocturnal animals

10.5 Homeostatic control of body temperature

KEY IDEAS

- The role of hot and cold temperature receptors in temperature regulation
- Centres in the hypothalamus that determine the conscious awareness of body temperature and therefore behavioural changes
- Stimulation of the posterior gland of the pituitary by the hypothalamus to release thyroid stimulating hormone (to increase metabolic rate) in cold climates

The ability of endotherms to regulate and maintain a constant body temperature is another example of a negative feedback mechanism. If the body temperature is too hot, the body acts to decrease the temperature. This means heat production and conservation is blocked (inhibited), while heat loss is increased. If the body temperature is too cold, the body will act to increase the temperature.

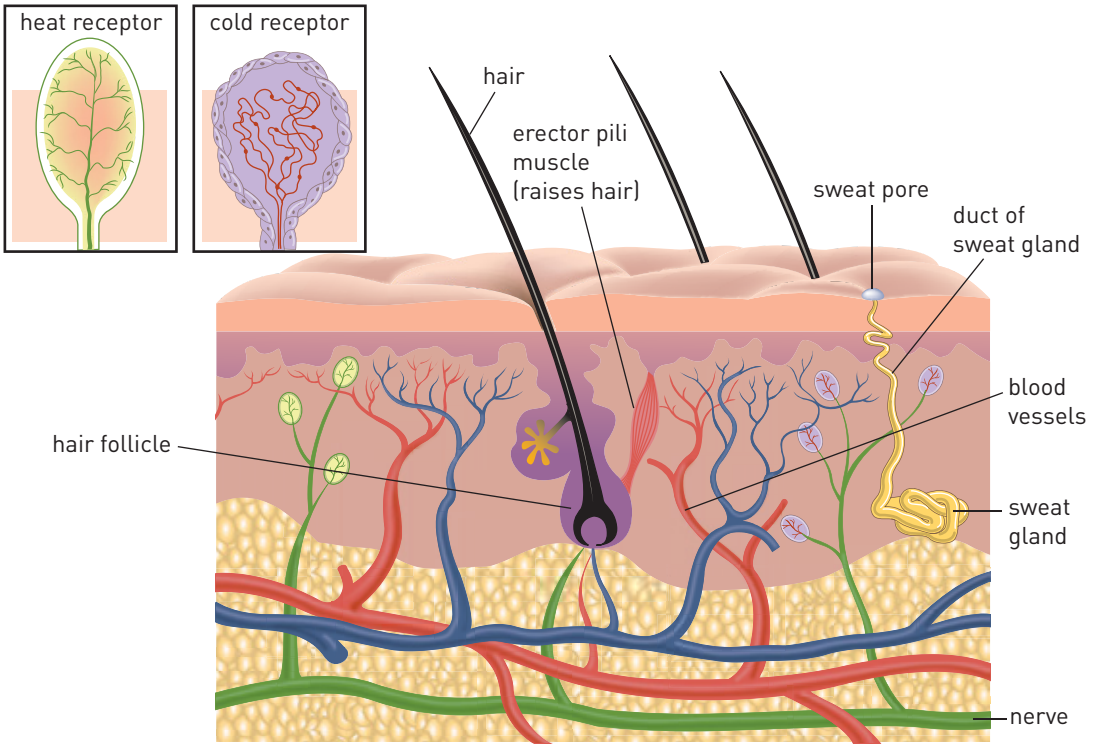


FIGURE 1 Heat and cold receptors in the skin

Hot and cold temperature receptors are found in the skin (see Figure 1), certain veins, the spinal cord and hypothalamus of the brain. Information from all of these receptors is sent to the temperature control centres of the hypothalamus in the brain. Two separate areas, the anterior **heat loss centre** and the posterior **heat production** and **conservation centre**, exist. The anterior centre appears to be activated by an increase in hypothalamus temperature and inhibited by peripheral cold receptors. The posterior centres, on the other hand, are stimulated by peripheral cold receptors and inhibited when the heat loss centre is active. The

heat centres of the hypothalamus act as a thermostat. Information from these centres passes to conscious centres of the brain. This results in an awareness of temperature, which may result in changes in the animal's behaviour.

Being too cold for a long period of time stimulates the cold centres of the hypothalamus and causes the release of thyroid stimulating hormone from the pituitary gland. This acts on the thyroid gland, causing the release of the hormone thyroxine and ultimately an increase of metabolic rate and heat production.

This is the reason humans and endothermic animals can acclimatise to hot or cold weather.

Figure 2 summarises the responses brought about by activation of the heat centres of the hypothalamus.

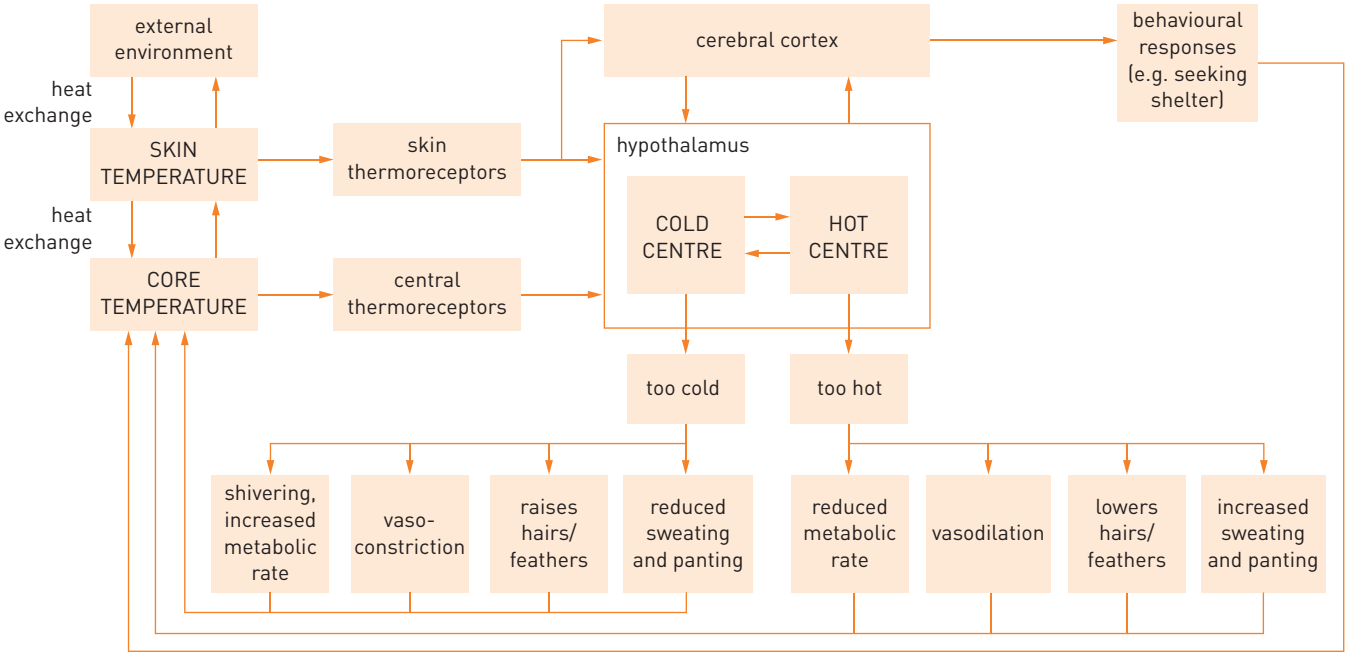


FIGURE 2 Summary of temperature regulation

CHECK YOUR LEARNING 10.5

Describe and explain

1 **Explain** how heat regulation in an endotherm is a negative feedback system.

2 **Describe** the results of stimulation of the anterior heat centre of the hypothalamus during hot weather.

3 **Describe** how an increase in metabolic rate is achieved in a cold environment.

Apply, analyse and interpret

4 The central thermoreceptors register the core body temperature and the responses are reduced body temperature and vasodilation. Using Figure 2, **interpret** the exact stimulus and the pathway to achieve these responses.

5 **Compare** the anterior and posterior heat control centres of the hypothalamus.

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 10.5

» **Weblink**
Skin temperature

» **Weblink**
Core temperature

» **Weblink**
Thyroid hormones

10.6 Regulation of body fluids

KEY IDEAS

- The need to maintain chemical concentrations within cells within a certain range
- The significance of the body fluids exhibiting many features of the marine environment
- The terms 'osmoregulation' and 'excretion'
- The interaction between osmoregulation and excretion in animals
- The distribution of body fluids in a multicellular organism

osmoregulation maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations

excretion removal of the waste products of metabolism

During metabolic reactions, substrates are used and products are made. Some products are wastes and may be very toxic if allowed to accumulate in living cells. At all times the concentrations of chemicals must be maintained within certain set ranges if the cell is to remain functional. This involves three main mechanisms: osmoregulation, excretion and transport.

Evidence suggests that life originated in the sea. Of all the environments of living organisms, seawater is least likely to have big fluctuations in conditions, particularly over long spans of time. Because of the vast volume of the constantly moving oceans, changes in temperature, acidity and salt concentrations take place very gradually.

The constant interactions between organisms and their environments has resulted in life processes that have evolved with a close dependence on the stable conditions that exist in seawater. This is supported by the many features of the body fluids that are similar to that of a marine environment.

Movement onto land involved adaptation to a diverse range of environments, resulting in different ways of carrying out life functions. The capacity to maintain a constant internal fluid environment, regardless of the changes in external environment, is a critical factor for survival.

FIGURE 1 Because of the ideal conditions of the marine environment, life forms originated in the oceans.

Regulation of body fluids involves:

- **osmoregulation** – the maintenance of a constant solute and water balance
- **excretion** – removal of metabolic waste material.

In many animals, the two processes occur simultaneously.

In animals, a certain amount of water is lost during excretion. Since heterotrophs can move from place to place, they use energy for more than just general life functions. They need extra energy to locate and process food. The proportion of protein in the body of an animal is therefore high.

As discussed in Chapter 2, molecules of protein provide important functions such as structure, enzymes and chemical messengers in plants and animals. The functional monomer units of proteins, amino acids, are released when the protein is no longer needed by the animal or in excess of requirements.

Most commonly the nitrogen-containing amino group of the amino acid is converted into toxic ammonia.

Ammonia is highly toxic to animal cells and must be either rapidly removed from the body or converted to a less toxic compound such as urea or uric acid. The availability of water will usually determine if the animal needs to expend energy to convert the ammonia into the less toxic molecules. Aquatic invertebrates, bony fish and larvae and permanently aquatic amphibians are surrounded by water and therefore can excrete mainly ammonia. Urea is less toxic than ammonia and requires less water for its elimination, but energy is required to convert ammonia to urea. Mammals and most adult amphibians excrete urea. Terrestrial insects, molluscs, birds and most reptiles excrete uric acid, which is non-toxic and virtually insoluble in water. The use of large amounts of energy to produce uric acid is an adaptation to water conservation.

Osmoregulation is closely connected with an organism's environment. In general, water is distributed in three main areas within the body of multicellular organisms:

1 the transport medium (e.g. blood plasma in most animals, fluids in the vascular system of plants)
2 extracellular fluid in interstitial spaces between cells
3 intracellular fluid of the cytoplasm.

The transport medium accounts for the least amount of water, while the intracellular fluid accounts for the most.

TABLE 1 Nitrogenous excretory products of animals

Nitrogenous excretory product	Toxicity	Energy requirements to produce	Water required for excretion
Ammonia	High	Low	High
Urea	Medium	Medium	Medium
Uric acid	Non-toxic	High	Very low

CHECK YOUR LEARNING 10.6

Describe and explain

1 **Explain** why the composition of the body fluid of organisms has features in common with seawater.
2 Animals produce nitrogenous waste that must be excreted. **Explain** the reasons for this.
3 **Describe** osmoregulation and excretion.

Apply, analyse and interpret

4 **Determine** why osmoregulation is important for the survival of an organism.

Investigate, evaluate and communicate

5 **Propose** why osmoregulation and excretion commonly occur simultaneously in animals.
6 **Apply** your knowledge to determine in which type of environment you would expect to find an animal that excretes:
   a ammonia
   b urea
   c uric acid.
   For each, give a reason for your response.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 10.6

» Weblink
Osmoregulation

» Weblink
Excretion

» Weblink
The Cambrian Explosion

10.7 Osmoregulation in animals

KEY IDEAS

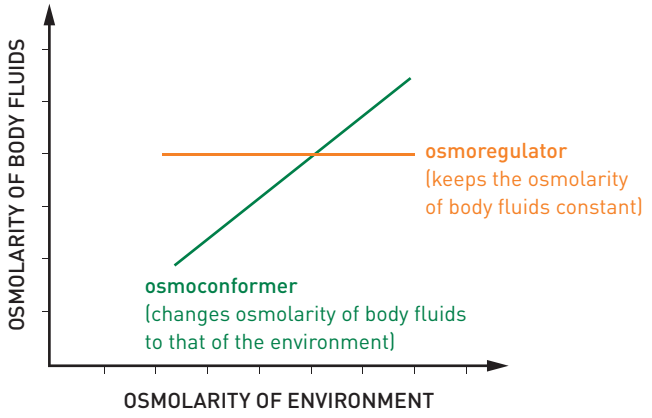
- Means by which water enters and leaves the body
- The difference between an osmoconformer and osmoregulator
- Adaptations of marine, freshwater and terrestrial animals for osmoregulation

Water can move into and out of an animal in response to osmotic gradients between its internal and external environments. Similarly, salts (solutes) can diffuse into and out of aquatic animals in response to diffusion gradients. They can be lost from terrestrial species by way of the kidneys, intestine and skin. Both water and salts can be ingested as part of the diet of both aquatic and terrestrial animals. These passive movements of water or salts into or out of the body cannot be regulated physiologically or are subject to minimal regulation. For example, the air leaving the lungs is always saturated with water. If the absolute humidity of the atmosphere is high, water loss from the lungs will be low. At a very low atmospheric humidity, the water loss from gas exchange surfaces can be considerable. Similarly, water and salt loss through the skin of terrestrial species is unavoidable, especially in those animals which control body temperature through sweating. There will always be some water lost in faeces.

osmoconformer a marine organism that maintains an internal environment that is isotonic with its external environment

osmoregulator an organism that actively controls internal salt concentrations independently of the salt concentrations in the environment

The kidney and its invertebrate precursors are the only organs that have any real control over salt and water balance. From the point of view of osmoregulation, animals fall into two groups: those that cannot regulate their osmotic pressure at all (**osmoconformers**), and those that can do so to some degree (**osmoregulators**). Osmoregulators will manipulate the water or solute levels so that the overall solute concentration is kept constant. Osmoconformers will allow their water and solute levels to become the same as the external environment (isotonic).



Osmolarity = total concentration of all osmotically active solute particles in solution

Osmoregulator

- Keeps the osmolarity of body fluids constant
- Needs to be able to get rid of excess salts or actively promote uptake of salts from the environment
- Must expend energy to maintain the osmotic gradients via active transport

Osmoconformer

- Changes osmolarity of body fluids to that of the environment
- Synthesises substances (e.g. amino acids) upon a rise in external salt concentration, to keep internal and external osmolarity equal
- Does not expend energy regulating body fluids

FIGURE 1 Distinguishing features of osmoregulators and osmoconformers

Marine organisms

Many marine animals, especially invertebrates, have body fluids that are isotonic with seawater. As a consequence, they have little need to osmoregulate. However, if their environment changes, they may need to engage in specific ion regulation if there are differences between the internal and external environments

Some marine species live in a more inhospitable estuarine environment. In these habitats, the concentration of the external environment may change dramatically from very high solute concentration (saline) to low solute levels (fresh water) within short periods of time. Many of these animals have some powers of osmoregulation but this requires energy. Animals in these environments tend to allow the solute concentrations of their body fluids to vary slightly with the external environment. The wider the tolerance range of solute concentration allowed in the cell, the less energy that is needed to osmoregulate. The shore crab, *Carcinus*, controls solute concentrations by eliminating excess water through a pair of glands found at the base of the antennae. These sac-like glands take up nitrogenous waste and excess water from the surrounding blood and excrete these to the exterior. There is no control of salt excretion by these glands. As a result, salt uptake by the gills is very important in maintaining ion concentrations.

Other species, the osmoconformers**,** allow the concentration of their body fluids to fluctuate with external salinity (e.g. the spider crab *Maia* and the lugworm *Arenicola*).

The true brackish-water dwellers have well-developed osmoregulatory powers and can maintain a relatively constant internal environment over a wide range of external salinities.

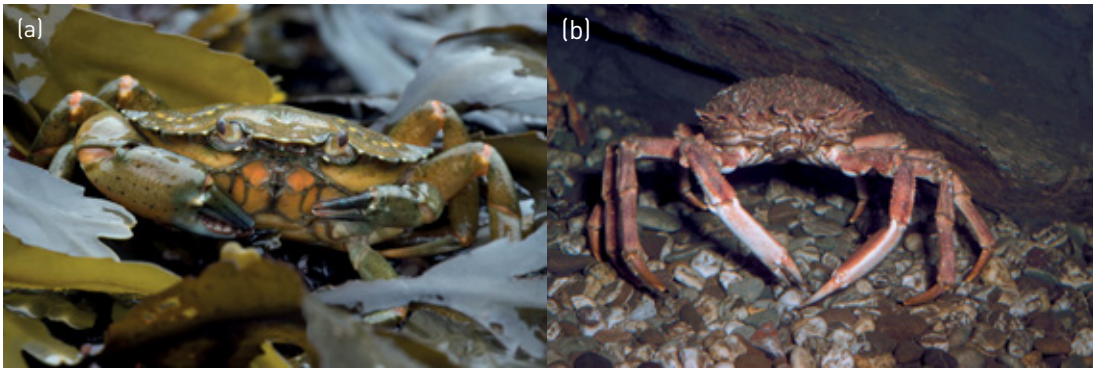


FIGURE 2 (a) A partial osmoregulator, the shore crab *Carcinus*; (b) an osmoconformer, the spider crab *Maia*

Marine bony fish are believed to have evolved in fresh water and then returned to the sea. These animals have a body fluid that is hypotonic (lower solute concentration) to the hypertonic (higher solute concentration) environment and thus there is a tendency for water to leave the tissues, leading to dehydration. These marine fish also drink large amounts of sea water whenever they open their mouth. Three processes are involved in maintaining the correct water and ion concentrations:

- an impermeable coating of scales restricts major water loss to areas such as the gut and the gills
- a very low kidney filtration rate, which results in very little urine containing highly concentrated non-toxic nitrogenous waste
- active secretion of the increased salts that are taken into the body by the drinking of seawater by special glands in the gills.

Freshwater organisms

Animals in freshwater (hypotonic) environments are faced with water continually moving in, causing dilution of their salts. An impermeable body covering, such as fish scales or the arthropod cuticle, restricts water intake to permeable areas such as the gills and gut.

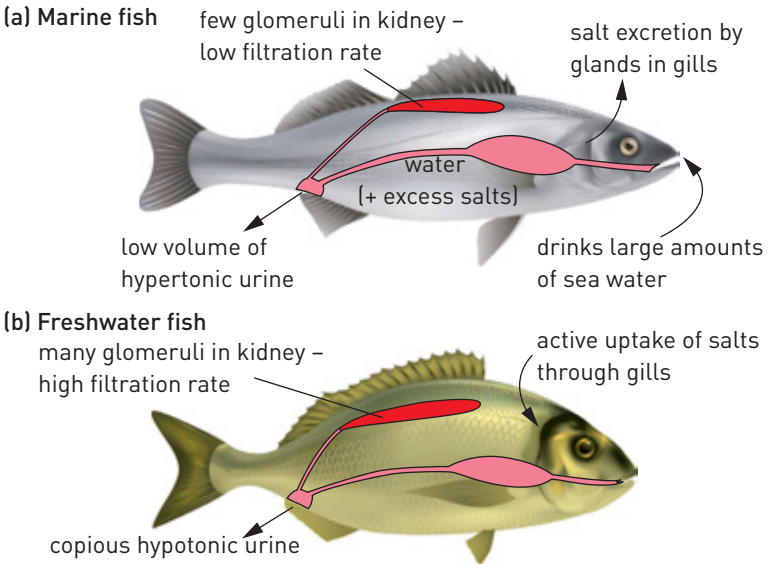


FIGURE 3 Comparison of the osmotic controls exhibited by (a) marine and (b) freshwater bony fishes

Excretory organs, such as the antennal glands of crustaceans and vertebrate kidneys, eliminate excess water and usually reabsorb ions that would otherwise pass out with the water. Replacement of important ions is usually accomplished by active absorption by the gills or intestines.

The freshwater crayfish is able to produce a watery, hypotonic urine. Unlike *Carcinus*, its antennal glands are able to reabsorb salts. Freshwater bony fishes, unlike their marine counterparts, have a very high kidney filtration rate and thus a large volume of dilute urine is produced. Due to the release of this volume of water, toxic ammonia can be safely washed from the body. No further energy need be expended in converting it to a less toxic form.

Terrestrial organisms

Terrestrial animals must take in water to replace that which is continually lost in the processes of eliminating wastes, and by evaporation from the respiratory tract and body surface. Adaptations that reduce water loss include:

- **Waterproof outer surface**: examples include the keratinous scales of reptiles, the dead layers of epithelium in mammals and the waxy cuticle on the exoskeleton of insects.
- **Reduction of kidney filtration rate**: this is accompanied by reabsorption of water from urine in vertebrates, or by the rectal gland of insects.
- **Modification of behaviour**: this includes burrowing during the heat of day and going into aestivation during drought periods to conserve water.
- **Using metabolic water produced during cell respiration**: the yield of metabolic water from aerobic cellular respiration is greater from fat than from carbohydrates. Many desert animals utilise fat to a large extent for water needs.
- **Tissues tolerant to water loss**: in the camel, for example, fat storage in the hump allows a high level of production of metabolic water through aerobic cellular respiration. The capacity of the camel to survive long periods without water (up to 2 months) is related to the ability of its tissues to withstand higher levels of dehydration than can other animals – 10% more than humans, for example.

TABLE 1 Some water conservation mechanisms shown by terrestrial animals

Organisms	Water conservation mechanisms
Insects	Impermeable cuticle Gas exchange structures Primitive kidney Uric acid as nitrogenous waste Shelled egg
Reptiles	Scales and keratinised skin Lungs Kidney Uric acid as nitrogenous waste Cloacal reabsorption Shelled egg Behavioural responses to heat Physiological tolerance to dehydration
Birds	Feathers Lungs Kidney Uric acid as nitrogenous waste Shelled egg Cloacal reabsorption
Mammals	Keratinised skin and hair Lungs Kidney Hypertonic urine containing urea Internal development of young Behavioural response to heat Restricted ecological range Physiological tolerance to dehydration

CHECK YOUR LEARNING 10.7

Describe and explain

1 **Describe** the difference between an osmoregulator and an osmoconformer. Give an example of each to explain your answer.

2 Many marine organisms are said to be isotonic to their environment. **Explain** what this means.

3 Marine bony fish must conserve water. **Explain** why. **Describe** the methods they use to conserve water.

4 **Identify** and **describe** three adaptations of terrestrial animals that enable them to conserve water.

Apply, analyse and interpret

5 **Analyse** and **compare** osmotic regulation in marine and freshwater bony fish.

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 10.7

» **Video**
Kidney function

» **Weblink**
Osmoregulation in marine mammals

» **Weblink**
Water balance

10.8 Hormonal control of water balance in mammals

KEY IDEAS

- Hormones involved in controlling water balance
- The action of the hormones on the collecting ducts of the kidney
- Negative feedback between these hormones

The structure and function of the human kidney was examined in Chapter 7. The main component of the kidney, the nephron, filters the blood, reabsorbs water and nutrients, and secretes excess waste molecules. Water is absorbed from both the loop of Henle and the collecting duct. A long loop of Henle provides a greater opportunity for water to be reabsorbed. Mammals living in dry regions will often have a much longer loop of Henle than those living in areas where there is a more plentiful supply of water. This ensures most of the water is reabsorbed before the highly concentrated urine is eliminated.

Several different hormones help to control the body's reabsorption of water. The most important is antidiuretic hormone (ADH). When an animal in a hot dry environment has lost a lot of water, the amount of intercellular and extracellular fluid decreases. This will also cause the animal to have low blood pressure. This is detected by the **osmoreceptor cells** in the hypothalamus of the brain. When the water level of blood and thus of tissue surrounding the osmoregulator cells is low, it stimulates the pituitary to release ADH. This released ADH is carried by the blood to the kidneys, where it increases the permeability of the distal convoluted tubules and collecting ducts to water. This increased level of reabsorbed water is retained in the body until a normal water balance is attained.

osmoreceptor cell
a cell that detects changes in osmotic (blood) pressure

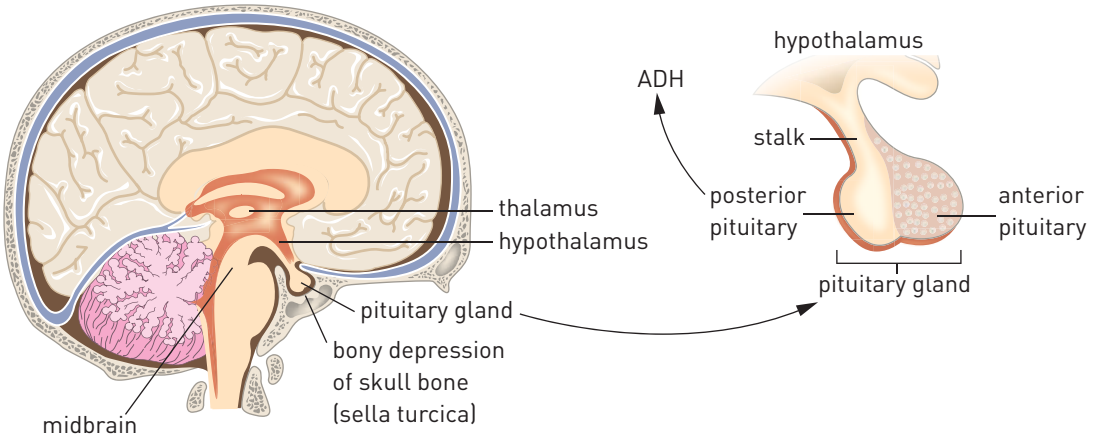


FIGURE 1 Osmoreceptor cells in the hypothalamus stimulate the pituitary gland to release ADH.

If the fluid bathing the osmoreceptor cells has a higher-than-normal water content and the blood pressure is high, less ADH will be released. The permeability of the distal convoluted tubules and collecting ducts to water will decrease, causing less water to be reabsorbed, and a more dilute urine will be excreted. The release of the extra water removes the initial stimulus of higher-than-normal water levels.

Figure 2 shows the negative feedback system involved in osmoregulation.

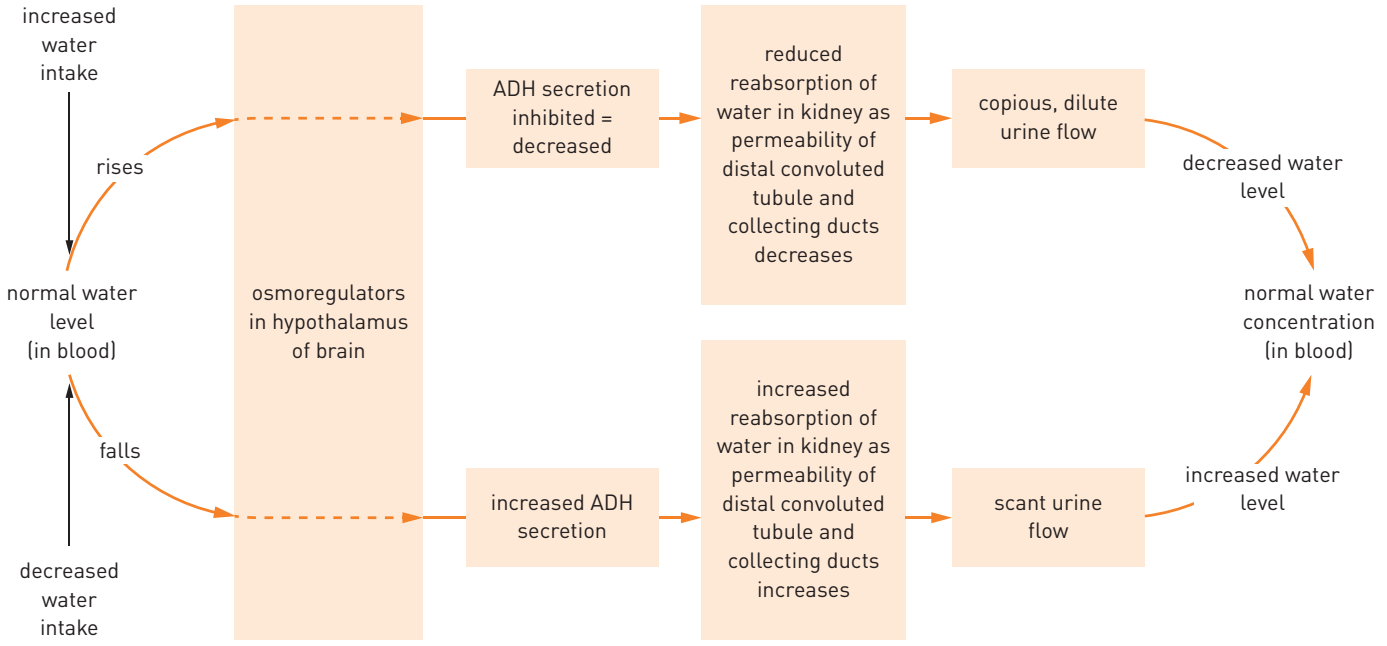


FIGURE 2 Hormonal feedback control of water balance

CHECK YOUR LEARNING 10.8

Describe and explain

1 Fully **explain** the effect that each of the following will have on the quantity and composition of urine.
   - **a** Drinking a large amount of water
   - **b** Eating a very salty meal
   - **c** A hot dry day
   - **d** Low arterial pressure

2 **Describe** the role of the kidney in osmoregulation.

Investigate, evaluate and communicate

3 **Construct** a flow chart to demonstrate the body's responses when 2 litres of water are consumed, at one time, as a dare.

4 **Predict** how the kidney structure of the Australian desert bandicoot might differ from that of an American beaver that lives in a freshwater environment. Provide a reason to support your answer.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 10.8
- » Weblink
  Hormones and water balance
- » Weblink
  Collecting duct on kidneys
- » Weblink
  Negative feedback

10.9 Osmoregulation in plants

KEY IDEAS

- The effect of different osmotic media on plant cells
- The function of the guard cells in controlling water loss
- Factors affecting transpiration rate

Plants have few specific osmoregulation mechanisms. Water intake and loss are mainly controlled by internal and external factors that affect the rate of transpiration. Some plants have structural adaptations that can alter the amount of water lost through evaporation.

Plant cells can tolerate a much wider range of osmotic concentrations bathing their cells than animals can. This is associated with their cell structure. Plant cells are surrounded by a cell wall that exerts a pressure on the cell contained within it and so maintains cell shape.

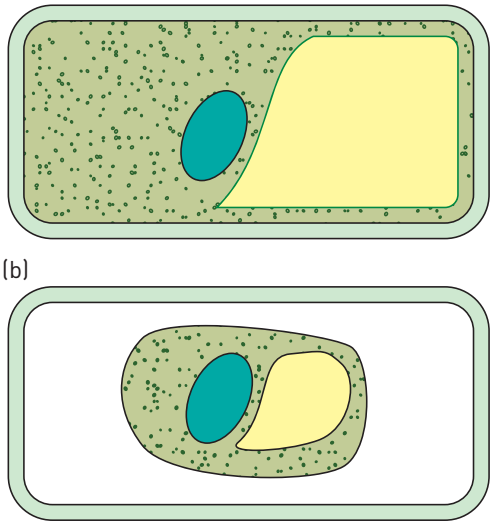


FIGURE 1 The effect of (a) hypotonic and (b) hypertonic extracellular fluid on plants

When plant cells are placed in a hypotonic solution, the uptake of water is limited by the wall pressure. Plant cells cannot continue to take up water until they burst, as animal cells would. In a hypertonic solution, however, water loss causes cell shrinkage similar to that in animals. The resulting high concentration of solutes in the cytoplasm often has profound effects on the well-being of the plant. Since they are surrounded by water, marine and freshwater plants do not have osmoregulatory problems. Terrestrial plants, however, can be subject to conditions that may cause severe water loss.

The epidermis of the leaf is thin and transparent. It is nearly waterproof and airproof because of its waxy outer surface of cutin which covers both surfaces of the leaf.

Within the epidermis are the stomata, which close when water levels in the plant are low. The stomata may be found on both leaf surfaces or only on one surface (usually the lower), depending on the species of plant and/or its habitat. They are also found in the epidermis of young stems, in flowers and in fruit.

Transpiration

The carbon dioxide needed for photosynthesis enters the leaf through the stomata along a diffusion gradient, and diffuses into the cells from the air spaces in the mesophyll layer. Because the stomata are open for gas exchange, moisture is lost by evaporation from the wet cell walls surrounding the intercellular spaces. The sun's rays provide the heat energy for evaporation.

transpiration the process by which plants absorb water through the roots and then give off water vapour through stomata in their leaves

Water loss from the plant by evaporation from its surfaces is called **transpiration**. Unless this water is continually replaced, the stomatal guard cells will collapse, and the stomata will close, preventing further diffusion of carbon dioxide into the leaf. If this happens, the supply of carbon dioxide for photosynthesis is restricted to what is produced by the cellular respiration of the leaf cells. In this case, glucose will no longer be produced, resulting in less ATP. For photosynthesis to occur, plants must continually take in water through their root systems to compensate for water lost through transpiration.

The function of guard cells

Each stoma is surrounded by two modified epidermal cells called guard cells, which are supported by the surrounding epidermal cells (see Figure 2 on page 228 and Figure 4 on page 230). They occupy a very small proportion of the leaf's surface, but diffusion through the stomata is extremely efficient.

The opening and closing of stomata involves variations in the water content of the guard cells. Their cell walls are thicker next to the pore than next to the surrounding epidermal cells. When they are full of water (turgid), their thin walls stretch more than the thick ones, causing the two cells to curve away from each other and the pore to open. As the guard cells lose water and their turgor pressure decreases, the guard cells become straighter and the pore closes.

Factors affecting transpiration rate

Transpiration rate has been shown to be affected by a range of external factors.

- **Light**: stomata usually open in the light and close in the dark.
- **Temperature**: an increase in temperature increases the rate of evaporation and therefore increases transpiration.
- **Humidity**: an increase in humidity causes a decrease in transpiration. This is due to a decreased diffusion gradient between the cells and the atmosphere, which reduces evaporation.
- **Wind**: wind increases transpiration by the removal of water vapour around the stomatal pore. Because the water vapour is removed, the concentration gradient is maintained, and water continues to evaporate.
- **Soil water**: if the supply of soil water is reduced, less water is taken up by the roots and the transpiration rate falls as a result.

CHECK YOUR LEARNING 10.9

Describe and explain

1 **Describe**, with the aid of diagrams, the structure of a stoma. **Explain** how stomata open and close.

2 **Summarise** factors affecting transpiration rate.

Apply, analyse and interpret

3 The photosynthetic activity of desert plants is often greatly reduced during the middle of the day. **Determine** the best explanation for this.

- **A** The enzymes controlling the light reaction are destroyed by the high temperatures inside the plant.
- **B** Insufficient water is available for the plant.
- **C** Most of the light is reflected by the thick cuticle and is unavailable for photosynthesis.
- **D** The stomata of these plants tend to close at this time.

4 **Identify** which of the following conditions of air will speed up the rate of transpiration from a leafy shoot:

- **A** cold, dry and moving
- **B** still, warm and moist
- **C** moving, warm and dry
- **D** still, cold and dry

Investigate, evaluate and communicate

5 **Discuss** why stomata are involved in a compromise situation in the life of a plant.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 10.9
- » Weblink
  Transpiration
- » Weblink
  Function of guard cells
- » Weblink
  Transpiration rate

10.10 Plant adaptations for osmoregulation

KEY IDEAS

- Plants found in different environments – hydrophytes, mesophytes, xerophytes and halophytes
- Adaptations of plants to different environmental conditions
- The influence of the hormone abscisic acid in controlling water loss in plants

Hydrophytes

hydrophyte
any plant adapted to grow wholly or partly submerged in water or wet habitats

Plants that live in fresh water (fully or partly submerged) or in permanently saturated soil are termed **hydrophtyes**. Since light is absorbed by water, these plants are not found in deep water but are close to or on the water's surface, so they can still photosynthesise. They have many adaptations for their habitat:

- Hydrophytes generally have reduced roots, or they can be entirely absent from the plant. The main function of hydrophytic roots is for anchorage.
- Stems of hydrophytes are mostly flexible and thin. The water provides them with the support required to maintain a straight profile.
- Hydrophytes generally do not have a well-developed vascular system because the plants are constantly surrounded by water and can absorb it through their leaves and stems.
- Leaves of hydrophytes can differ depending on their degree of submergence. In fully submerged plants:
  - the leaves are usually thin and divided to create a large surface area for the direct absorption of nutrients, gases such as CO_2 for photosynthesis and water
  - stomata are invariably absent as gases are usually exchanged directly with the water
  - leaves are flexible to prevent damage in moving water
  - a waxy cuticle is very thin or not present as there is no need to conserve water.
  - there are few air pockets to prevent the leaf rising to the water's surface.
- Leaves that are floating on the water's surface:
  - are generally wide, broad and lie flat on the water to increase the surface area
  - have numerous stomata, without guard cells, on the upper leaf surface and are absent on the lower surface; there is a constant need to lose water by transpiration and uptake of CO_2 for photosynthesis
  - have an upper epidermis (waxy cuticle) for protection and to roll water off the leaf to prevent algal adhesion.
- Aerial leaves from partly submerged plants are similar to leaves of terrestrial plant groups.
  - Some hydrophytic leaf and stem tissues have intercellular air spaces, called aerenchyma. These small air pockets assist in the exchange of gases by providing a low resistance pathway, making it easier for gases to diffuse throughout the whole plant.

FIGURE 1 Examples of hydrophytes: (a) partly submerged; (b) floating; (c) fully submerged

Mesophytes

If the plant is growing in a well-watered soil, evaporative loss of water does not present a problem because it can be rapidly replaced by uptake from the soil. These plants, called **mesophytes**, therefore have no special means for conserving water, and include most plants found in rainforests, wet sclerophyll (sclerophyll refers to leathery leaves) and along permanent water courses in Australia.

Mesophytes living in humid habitats must get rid of excess water. Some species (e.g. many rainforest plants) are able to actively secrete water from special structures called hydathodes. This action is known as **guttation**. The removal of the excess water is aided in some of these species by the presence of a pointed, drooping tip on the leaves called a **drip tip**.

mesophyte
a plant adapted to growing in well-watered soil

guttation
the active secretion of excess water by leaf hydathodes

drip tip
an elongated leaf tip from which excess water is expelled by special glands, and drips off

FIGURE 2 Two examples of guttation

Xerophytes

Most of the Australian continent either does not have a high annual rainfall or the soil does not retain moisture. The vegetation types that are dominant in these areas of decreasing soil moisture are dry sclerophyll forests, woodlands and grasslands.

For plants living in dry conditions, transpirational water loss can lead to drastic dehydration. These plants (**xerophytes**) have either evolved to avoid adverse conditions or have adaptations that enable them to resist dry conditions. Some plants have tissues that are capable of withstanding extremes of desiccation. Their protoplasm can be almost totally dried out and yet resume normal functioning when water again becomes available (e.g. some desert plants and many mosses and ferns such as resurrection plants). In hot conditions, some xerophytes will produce a hormone, abscisic acid (ABA), that controls the opening and closing of stomata. High levels of ABA will cause the stomata to close, preventing further water loss.

xerophyte
a plant that has adaptations to survive in an environment with little liquid water

ephemeral
a plant that has a very short life cycle

transpiration check
a process whereby a plant reduces transpirational water loss

halophyte
a plant that grows in waters of high salinity

salt excluder
a halophyte plant that uses root mechanisms to prevent uptake of salt

salt excretor
a halophyte that removes salt through glands in the cuticle located on each leaf

Ephemeral desert plants complete their life cycle in an extremely short time immediately after a wet season. They pass the drought periods as hard fruits or seeds that lie dormant in the soil. These seeds contain high levels of ABA, which inhibits germination. A large amount of water is required to wash out the ABA and so germination will only occur when there is adequate water for the plant to complete its life cycle. Some of these ephemerals may take only 10 days between germination and seed production.

Some xerophytic adaptations include:

- the possession of a very extensive, shallow root system (e.g. mulga) and/or deep 'water-seeking' roots to increase water uptake
- the presence of special water-storage tissues – when these fleshy areas make up a large part of the plant, they are described as succulents (e.g. pigface)
- the presence of one or more **transpirational checks** such as:
  - leaves with low surface area to volume ratio (e.g. small and/or succulent leaves
  - reduction in the number of stomata (e.g. prickly pear)
  - sunken stomata, which increase humidity around the pore
  - hairs on the leaf surface, which increase humidity close to the leaf
  - rolling and/or folding of leaves, therefore increasing humidity in the central core
  - reduction in the length of time that stomata remain open
  - presence of phyllodes (flattened leaf stalks) instead of leaves
  - stems modified to take on the function of leaves – cladodes – that have small-scale leaves on their surfaces
  - flowers reduced in size or flowers with no petals

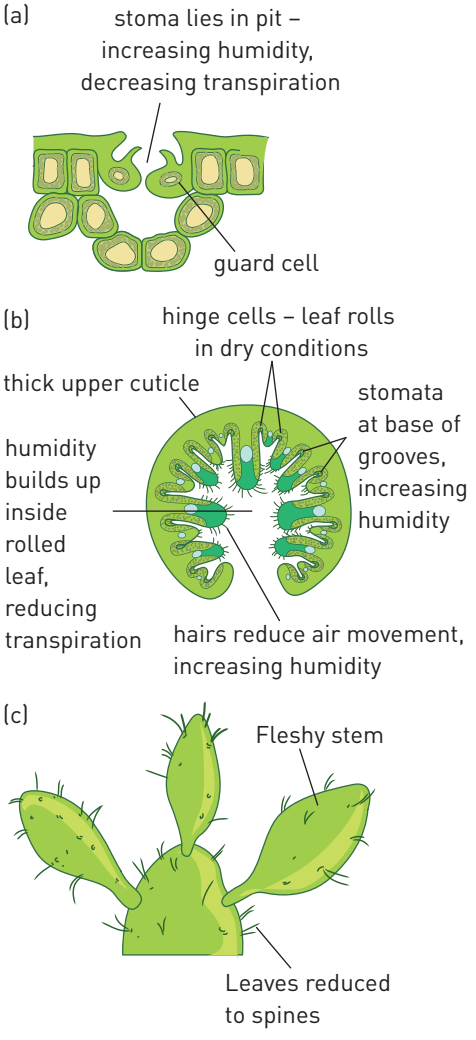


FIGURE 3 Some adaptations of xerophytes

Many plants of cooler temperate regions effectively suffer drought conditions when the soil water freezes and becomes unavailable to them. Herbaceous plants may survive winter conditions as seeds or storage organs. Conifers reduce transpiration because they have a reduced leaf surface area and a thick cuticle.

Trees may become deciduous when low water availability is prolonged. When a plant is water stressed, a special layer of cells is formed at the leaf base (the abscission layer) that results in leaf fall. The remaining scar tissue of the abscission layer seals the cells on the plant body. This prevents 'leakage' from the vessels and bacterial or fungal attack.

Halophytes

Many plants suffer physiological drought because, although water is present in the habitat, it is not readily available. Plants living in saltmarshes or estuaries may suffer water loss due to the osmotic effects resulting from the hypertonic environment. These plants, called **halophytes**, have root cells that contain high levels of salts. This exerts a higher than normal osmotic pressure, allowing roots to take in water by osmosis. The epidermis of root hairs is able to exclude much of the salt in the water. Further salt is excluded by the waxy Casparian strip of the endodermis of the root. Some store water in their tissues. Many can totally block the uptake of sodium ions from the saltwater (**salt excluders**) and others do not block the uptake but have the ability to secrete salt from the leaves (**salt excretors**). Mangrove trees and saltbushes are halophytes.

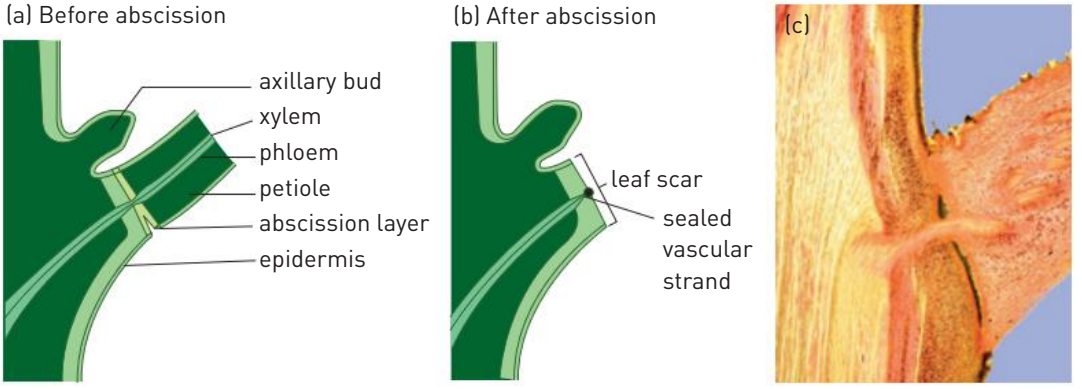


FIGURE 4 The abscission zone of a leaf: (a) before leaf fall: (b) after leaf fall; (c) microscopic view of (a)

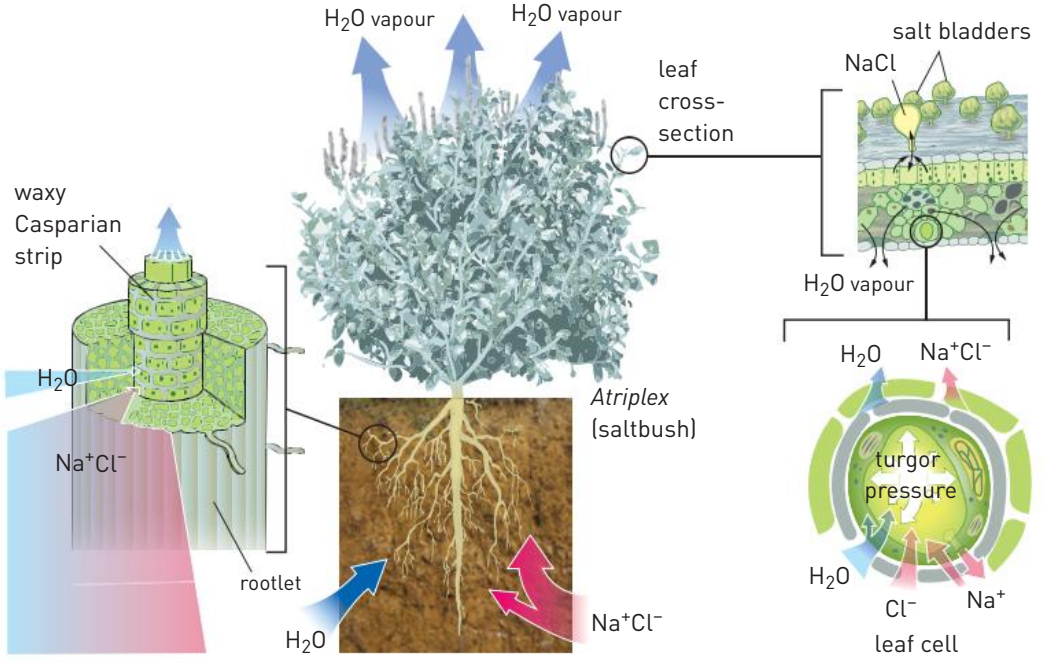


FIGURE 5 Features of saltbush, a halophyte

CHECK YOUR LEARNING 10.10

Describe and explain

1 **Explain** the difference between a hydrophyte, mesophyte, xerophyte and halophyte.
2 **Describe** two adaptations used by plants to reduce water loss in hot, dry conditions.
3 **Explain** the meaning of the term 'physiological drought'. Give examples of how plants cope with physiological drought.

Investigate, evaluate and communicate

4 Hydrophytes have many features atypical of terrestrial plants. **Construct** a table to compare the root, stem and leaf structure of a hydrophyte and xerophyte.
5 **Construct** a table of plant structures (roots, stems, leaf stalks, leaves and flowers) to communicate the adaptations they may exhibit to minimise water loss.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 10.10
- » Mandatory practical
  10.10 The role of the leaf in plant osmoregulation
- » Weblink
  Plant adaptations
- » Weblink
  Halophytes

CHAPTER 10

Review

Chapter summary

10.1 Abiotic conditions, such as temperature, water availability, soil pH, amount of light and soil nutrients vary considerably in different habitats. Each species of organism thrives best within a certain range of each of these conditions (the optimal range).

10.2 Most organisms live within an environmental temperature range of 10–30°C.

Organisms gain or lose heat to the environment by conduction, convection and radiation. Heat can also be gained through metabolic reactions and lost through evaporation of water from their surfaces.

Thermoregulation is the ability to have some control over body temperature. Thermoconformers allow their body temperature to equalise with the environment.

Ectotherms (single-celled organisms, fungi, plants, invertebrate animals, fish, amphibians and reptiles) vary their core body temperature with the environmental temperature.

Endothermic animals (birds and mammals) generate most of their heat internally. Most are able to maintain a constant core temperature regardless of environmental temperature and so are termed homoeothermic.

10.3 Endotherms deploy a variety of mechanisms to reduce heat loss when the environmental temperature is below their core temperature. By changing the blood supply to their extremities, the temperature gradient between the animal's surface and the external environment is reduced and so there is less heat loss.

Hair and feathers can be raised and trap a layer of air (a poor conductor) between the skin and environment.

Increased heat generation can be achieved by greater movement and shivering or by increased metabolism. In cold climates, many mammals have deposits of brown fat tissue, the cells of which are rich in special lipids and mitochondria.

Behavioural strategies include kleptothermy, torpor or hibernation.

Structural features, such as decreasing surface area to volume ratio, are also significant in cold-environment endotherms.

10.4 Endotherms living permanently in warm climates often employ strategies that are the reverse of those found in their cold climate counterparts. Cutaneous vasodilation ensures a greater blood flow to skin and therefore increased heat loss. In all but the most humid conditions, secretion from sweat glands, panting and licking result in evaporative water loss.

The shape of endothermic animals tends to result in a high surface area to volume ratio to increase both conduction and radiation of heat from the body.

10.5 Temperature receptors in the skin, some veins, the spinal cord and hypothalamus respond to either heat or cold. The hypothalamus acts as a thermostat. Physiological and behavioural changes associated with decreasing heat loss are activated by stimulation of the posterior heat centre.

10.6 Osmoregulation is the maintenance of a constant solute and water balance whereas excretion is the removal of metabolic wastes.

Animals have a higher proportion of protein in their bodies than plants. Proteins cannot be stored, so any intake in excess of immediate requirements is broken down. The nitrogen of the amino acids making up the protein is converted into either ammonia (highly toxic), urea (less toxicity) or uric acid (non-toxic) and excreted. The energy required for these conversions is lowest for ammonia and highest for uric acid. The form excreted depends on water availability with large amounts needed

for ammonia through to virtually none for uric acid. In animals, osmoregulation and excretion often occur simultaneously.

Body fluids are found, from lowest to highest proportion, in circulating fluids, extracellular fluid and inside cells.

10.7 Osmoconformers are animals that cannot regulate their solute and water levels whereas osmoregulators can. Osmoregulation requires the expenditure of energy.

Many marine organisms, especially invertebrates, have body fluids isotonic to seawater.

Marine bony fish have body fluid that is hypotonic to their environment and thus have a tendency for osmotic water loss.

10.8 Osmoreceptor cells in the hypothalamus detect water levels in the blood surrounding them. These cells stimulate the posterior pituitary to release antidiuretic hormone (ADH) into the blood stream if the levels fall below normal. ADH acts on the distal convoluted tubules and collecting ducts of the kidney to increase their permeability to water, so a more concentrated urine is released.

In a negative feedback response, the release of ADH is limited if the water levels of the blood exceed the normal.

10.9 As plant cells have a cell wall, they can withstand a wider range of osmotic media than animal cells. Water moves through the plant from the roots to the leaves in the transpiration stream. Open stomata, necessary for gas exchange and thus photosynthesis, result in the escape of water vapour from the plant (transpiration). The transpiration rate is affected by light, temperature, humidity, wind and the availability of soil water.

10.10 Plants can be classified according to their ability to live in environments with different levels of available water. Halophytes have special features that enable them to survive fully or partially submerged in fresh water. Mesophytes live in habitats where water availability is not a problem whereas xerophytes are adapted to dry conditions.

Mesophytes living in conditions of high humidity are able to actively secrete water from glands at the ends of leaf veins in the process of guttation. Some of these plants have elongated drip tips at the ends of the leaves to maximise water loss.

Plants have evolved adaptations to prevent water loss or to maximise water uptake. Adaptations to reduce transpirational water loss include:

- leaves with low surface area to volume ratio
- reduced number of stomata
- sunken stomata
- hairs on leaf surface
- folding of leaf
- reduction in time the stomata are open.

Key terms

- abiotic
- adaptation
- aestivation
- arteriole
- brown adipose tissue
- contraction
- counter-current system
- drip tip
- ectotherm
- endotherm
- ephemeral
- erector muscle
- excretion
- guttation
- habitat
- halophyte
- hibernation
- homeotherm
- homoeothermic
- hydrophytes
- insulation
- kleptothermy
- mesophyte
- niche
- optimal range
- osmoconformer
- osmoreceptor cell
- osmoregulation
- osmoregulator
- physiological stress
- salt excluder
- salt excretor
- shunt vessel
- structural feature
- thermoconformer
- thermogenesis
- thermoregulation
- tolerance range
- torpor
- transpiration
- transpiration check
- vasodilation
- xerophyte

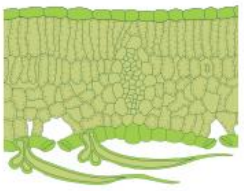
Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

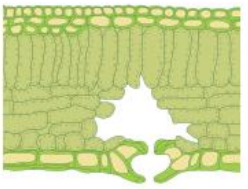
Multiple choice

1 Which of the following diagrams of sections of leaves is **not** from a plant adapted to dry environments?

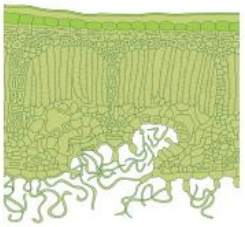
A



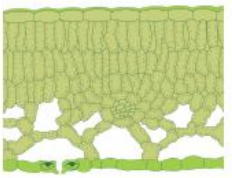
B



C



D



2 Through which of the following processes is water lost from the mammalian body?

- **A** Urination, defaecation, inspiration, sweating
- **B** Urination, defaecation, expiration, sweating
- **C** Urination, defaecation, expiration, increased metabolism
- **D** Urination, defaecation, inspiration, lowered metabolism

3 Kleptothermy is a process that decreases heat loss. It refers to:

- **A** animals huddling close together
- **B** the onset of aestivation
- **C** increased body insulation
- **D** the counter-current system in extremities

4 Which of the following is correct?

	Excretory product	Toxicity	Energy required to produce	Water required for excretion
A	Ammonia	Low	Low	High
B	Urea	Medium	Medium	Medium
C	Uric acid	High	High	Very low
D	Urea	Non-toxic	Low	Low

5 The hormone ADH affects:

- **A** the ability of the glomerus to filter the blood
- **B** the permeability of Bowman's capsule to salts
- **C** the permeability of the distal convoluted tubule and collecting duct to water
- **D** the permeability of the proximal convoluted tubule to glucose

Short answer

Describe and explain

★ **6** **Explain**:

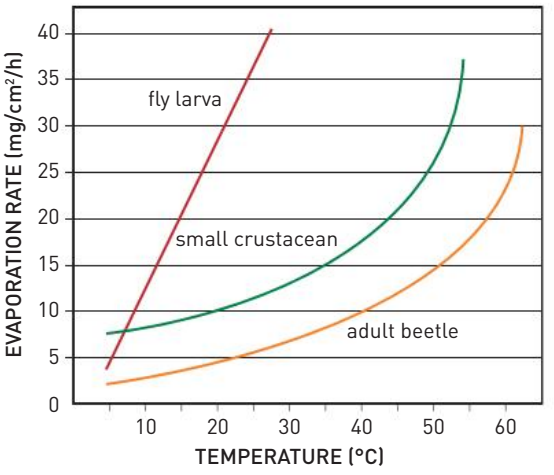
- **a** four advantages of endothermy
- **b** two disadvantages of endothermy.

★ **7** **Describe** how negative feedback controls operate in mammals with respect to:

- **a** maintenance of body temperature
- **b** osmoregulation.

Apply, analyse and interpret

★★ **8** The graph below shows the relationship between the temperature of the environment and the evaporation of water from three different organisms. Given that evaporation decreases with increasing humidity, and that all three organisms are terrestrial, **suggest** the most likely habitat for each of these animals.



Investigate, evaluate and communicate

★★ **9** People who drink large amounts of alcohol urinate frequently. Although this is associated with the volume of fluid intake, the main cause

is the effect of the alcohol, which reduces the release of ADH from the pituitary gland.

Propose, with reference to kidney function, why headaches associated with a 'hangover' are due to dehydration.

★★ **10** The relative length of the loop of Henle differs greatly between different species of mammals. **Predict** the type of environment in which you might expect to find species with relative long loops, giving reasons for your answer.

★★★ **11** Water loss from the leaves of two different species of plants, species A and species B, was compared. One leafy shoot was taken from each plant. The leaves were weighed, hung in air and reweighed at 15-minute intervals. The results are shown in the table (a dash indicates that a result was not available).

Time after start of experiment (minutes)	Mass of leafy shoot (g)	
	Species A	Species B
0	210.0	240.0
15	195.3	–
30	184.4	–
45	176.4	–
60	170.1	–
75	166.3	213.1

a **Sketch** a graph of mass against time for species A. Account for the shape of this curve.

b **Calculate** the percentage of change in mass for each species after 75 minutes.

c **Predict**, with reasons, which of these two species you would expect to be more successful in an arid region.

★★★ **12** **Investigate** the type of clothing used by Scott and Amundsen in their race to be the first to reach the South Pole in the early twentieth century. **Compare** the clothing each wore with respect to their ability to maintain body temperature.

Consider the clothing worn by scientists in Antarctica today. **Discuss** the thermoregulatory features of this modern clothing.

★★★ **13** Biomimicry involves using inspiration from animals and plants in nature to design a new product. Use biomimicry, **design** a set of clothing that would be suitable in:

a an equatorial rainforest environment

b desert conditions.

In your designs, consider the type of material used in construction, as well as the possible effects of insect infestations and hooked, barbed and stinging plants, since these factors could affect thermoregulation.

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- » Student book questions
  Chapter 10 review
- » Revision notes
  Chapter 10
- » assess quiz
  Chapter 10 auto-correcting multiple-choice quiz
- » Flashcard glossary
  Chapter 10 glossary

CHAPTER 11

Disease and its causes

Disease is a physiological abnormality or significant disruption in the health of an individual. It is caused by a variety of factors, such as genetic predisposition, environmental conditions, poor nutrition and by pathogens. Diseases caused by pathogens are termed infectious diseases and these can be non-contagious or contagious, depending on the causative agent and its mode of transmission. Pathogens are parasitic organisms. Some infectious diseases are caused by non-living organic particles such as prions and viruses.

Plants and animals have a number of natural defence mechanisms to pathogens. These are both physical and chemical in nature. In vertebrates, the immune response is both innate and non-specific (e.g. barriers to pathogen prevent entry and the inflammatory response). They also have adaptive immune responses to specific pathogens that result in the production of antibodies and memory cells. Immunity can be passive or acquired.

OBJECTIVES

- → Identify the difference between infectious diseases (invasion by a pathogen and can be transmitted from one host to another) and non-infectious diseases (e.g. genetic and life-style diseases)
- → Identify the following pathogens: prions, viruses, bacteria, fungi, protists and macroparasites
- → Describe the following virulence factors that aid in pathogenesis: adherence factors, invasion factors, capsules, toxins and lifestyle changes.
- → Identify from given data and describe the following modes of disease transmission: direct contact, contact with body fluids, contaminated food, and water and disease-specific vectors.
- → Understand how pathogens can cause both physical and chemical changes in the host cells that stimulate the host immune responses (introduction of foreign chemicals via the surface of the pathogen, production of toxins, and recognition of self and non-self)
- → Recognise that all plants and animals have innate immune responses (general/non-specific) and that vertebrates also have adaptive (specific) immune responses
- → Recall that the innate immune response in vertebrates comprises surface barriers (skin, mucus, cilia), inflammation and the complement system.

FIGURE 1 Coloured scanning electron micrograph (SEM) of bone tissue affected by osteoporosis

→ Describe the inflammatory response (prostaglandins, vasodilation, phagocytes) and the role of the complement system.

→ Explain the adaptive immune responses in vertebrates – humoral (production of antibodies by B lymphocytes) and cell-mediated (T-lymphocytes) – and recognise that memory cells are produced in both situations.

→ Interpret long-term immune response data.

→ Analyse the differences and similarities between passive immunity (antibodies gained via the placenta and via antibody serum injection) and active immunity (acquired via natural exposure to a pathogen or through the use of vaccines) of both naturally and artificially acquired immunity.

→ Recall examples of physical defence strategies (barriers and leaf structures) and chemical defence strategies (plant defensins and production of toxins) of plants in response to the presence of pathogens.

Source: *Biology 2019 v1.2 General Senior Syllabus*
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PRACTICALS

MANDATORY PRACTICAL

11.4 The effect of an antimicrobial on the growth of a microbial organism

A Preparation of a bacterial lawn

B The effect of antibiotics on bacterial growth

C The effect of handwashing liquids on microbial growth

D Assessing the effectiveness of the antibacterial agents

11.1 Health and disease

KEY IDEAS

+ Factors involved in the health of an individual
+ Causes for disease

A healthy individual is considered to function well physically, mentally and socially. The standards for health can depend on age, vulnerability to disease, sensitivity to pain, physical activity and emotional state. The maintenance of health is assisted by the following:

- Genes control the process of protein synthesis and they contain the instructions for maintaining normal functioning of the body.
- Mitosis, or cell division, produces identical cells as part of the cell cycle. Every day, millions of cells die and are replaced in the process of mitosis, which is regulated by genes. Mitosis and the cell cycle are illustrated in Figure 1 in Section 5.2 (page 135).
- Cell differentiation follows mitosis and is the process where particular genes are switched on and off so that the cell is specialised for a certain function.
- Cell specialisation ensures that all of the functions of a multicellular organism are carried out efficiently and that all cell types work together to maintain a healthy organism. Unspecialised cells can form tumours that interfere with the operation of an organ or system.

disease
an abnormal condition of an organism which interrupts the normal bodily functions

infectious
able to be passed from one individual to another

non-infectious
cannot be passed from individual to individual

Disease can very broadly be defined as any physiological abnormality or significant disruption in the 'normal' health of an organism. It can result from both non-living (abiotic) environmental factors such as mineral nutrient deficiency, drought, lack of oxygen, excessive temperature and pollution, and living (biotic) factors that may be within the individual organism or caused by another organism. Although both terms, health and disease, are difficult to define absolutely, it is generally obvious when an individual is demonstrating some form of disease – there is dysfunction in the body or part of the body. Diseases are either **infectious** (i.e. they are caused by another organism or organic agent and can be passed from one individual to another either directly or indirectly) or **non-infectious** (they cannot be spread from one individual to another). To a large extent, infectious diseases have been eliminated or controlled in developed countries although they are rife in poorer areas of the world. Non-infectious diseases, however, present a different picture and many are more prevalent in developed countries.

CHECK YOUR LEARNING 11.1

Describe and explain

1 **Explain** why it is difficult to exactly define a disease.
2 **Identify** three causes for disease.

Apply, analyse and interpret

3 **Compare** an infectious and a non-infectious disease.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 11.1
- » Interactive
  Mitosis
- » Video weblink
  Healthy human body
- » Weblink
  Centre for disease control

11.2 Non-infectious disease

KEY IDEAS

- The underlying causes of non-infectious disease
- Some examples of non-infectious disease

malfunctioning
not functioning correctly

inherited condition
a condition that can be passed from parent to offspring

genetic disease
a disease that results from a change in a gene and may be inherited

environmental condition
a factor in the external surroundings (biotic and abiotic) that surrounds and affects the survival and development of an organism or population

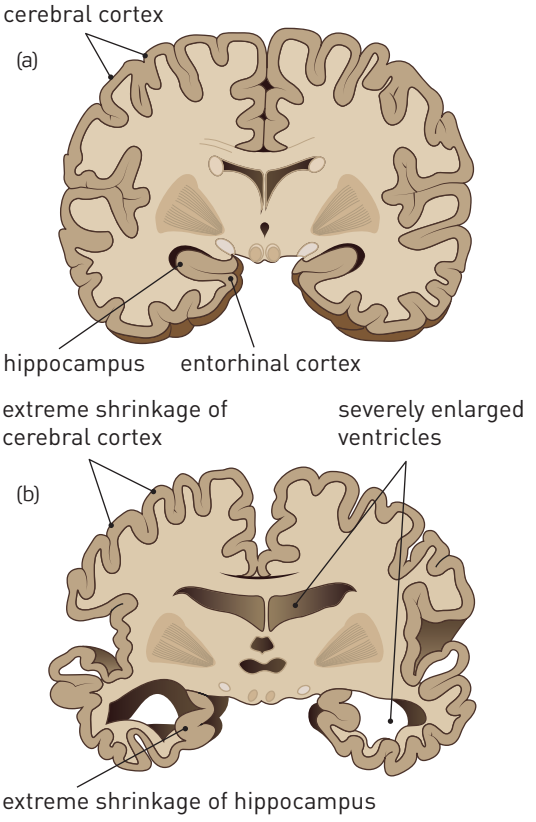

FIGURE 1 Brain sections: (a) normal; (b) with mercury poisoning

FIGURE 2 Old paint often contains lead. Scraping this off without proper protective measures (e.g. gloves, face mask) can result in lead poisoning.

Non-infectious diseases are diseases that cannot be spread. There are many causes for such diseases:

- **malfunctioning** of the physiology and metabolism (which may disrupt homeostatic mechanisms) or structures of the body e.g. cancer, diabetes and cardiovascular disease
- **inherited conditions** that are passed from parent to offspring. These diseases are called **genetic diseases** (e.g. sickle-cell anaemia and cystic fibrosis)
- **environmental conditions** (e.g. heavy metal poisoning, electromagnetic radiation, industrial pollution and drug abuse, including the sniffing of petrol, aviation fuel and glues). Heavy metals that are particularly dangerous are lead and mercury. Mercury poisoning usually results from industrial waste washing into the sea where it is taken up in the food web. People who continuously eat contaminated seafood can develop paralysis, brain damage and widespread neurological effects. Lead poisoning can come from a variety of sources and results in vomiting, cramps, paralysis and brain damage. Other industrial pollution can result in carbon dioxide or carbon monoxide poisoning or mesothelioma due to inhalation of asbestos dust. High levels of electromagnetic radiation have been linked to the development of different forms of cancer. Alcohol can potentially lead to death due to liver damage. It has been shown that babies born to women who drank heavily during pregnancy have a range of conditions (foetal alcohol syndrome) which may include

developmental and learning problems. Tobacco has been linked to a higher incidence of lung cancer. Other drugs can result in severe behavioural changes.

nutritional disease
a disease resulting from deficiencies or excesses in the diet

undernutrition
a diet in which the individual is not getting enough calories, protein or micronutrients

overnutrition
a form of malnutrition in which one or more nutrients is oversupplied

malnutrition
health problems caused by poor diets where nutrients are either deficient or excessive

- **Nutritional diseases** can occur as a result of an inadequate diet. **Undernutrition** occurs when an insufficient amount of one or more essential nutrients is being taken in the daily diet or the amount of food is insufficient (e.g. when a person suffers from anorexia nervosa or bulimia). **Overnutrition** occurs in many Western societies where there is an abundance of food. An increase in fats and carbohydrates in the diet can lead to obesity (which is linked to heart disease and diabetes), whereas an increase in salt and high levels of protein may result in kidney failure.

Malnutrition, on the other hand, results from an adequate daily intake of food that does not have the correct balance of essential nutrients. Table 1 lists some of the major human deficiency diseases.

FIGURE 3 Extremes of nutrition: (a) overnutrition; (b) undernutrition – the swollen belly is an indication of protein deficiency

FIGURE 4 Classic posture of an elderly person with osteoporosis, a condition associated with malnutrition and/or the body's inability to metabolise calcium

TABLE 1 Human nutrient requirements

Nutrient	Function	Source	Deficiency disease
Carbohydrate	Energy source	Cereals	Malnutrition
Protein	Formation of cell membrane, antibodies, enzymes, growth, energy source	Meat, fish, milk, beans	Kwashiorkor; degeneration of liver and pancreas
Fat	Energy source, insulation	Butter, oils, nuts	Malnutrition
Vitamin A	Pigment production in retina of eye, healthy cells lining respiratory tract	Egg yolk, fish oil, carrot	Night blindness, infections of respiratory lining
Vitamin B group (up to 12 vitamins)	Involved in many chemical reactions (e.g. respiration)	Whole grain, cereals, liver	Beriberi; muscular weakness and paralysis
Vitamin C	Keeps tissues in good repair	Citrus fruits, berries, raw vegetables, potato	Scurvy; pain in joints and muscles; bleeding gums
Vitamin K	Blood clotting	Green vegetables	Haemorrhage
Calcium	Bone and teeth formation, blood clotting, nerve conduction, muscle contraction	Dairy products, bread, beans, almonds, some green vegetables	Brittle bones and teeth
Phosphorus	Bone and teeth formation	Milk	Brittle bones and teeth
Iodine	Thyroxine production (hormone that controls metabolic rate)	Seafood, sea salt or iodised salt	Goitre (swelling in the neck); slow metabolic rate, cretinism in infants
Iron	Haemoglobin production	Liver, egg yolks, some green vegetables	Anaemia; not enough red blood cells; oxygen shortage
Sodium	Osmotic balance, nerve conduction	Most foods	Muscle cramps
Potassium	Muscle contraction, nerve conduction, osmotic balance	Most foods	Muscle cramps

CHECK YOUR LEARNING 11.2

Describe and explain

1 **Describe** inherited disease and give an example.

2 **Explain** why non-infectious diseases cannot be spread.

Apply, analyse and interpret

3 Until fairly recent times, lead was a component of petrol in Australia. **Consider** why this additive is now banned.

4 The disease diabetes results from the body being unable to adequately control blood sugar levels. Type 1 diabetes is thought to be caused by the body attacking its own pancreas, preventing the release of the hormone insulin. **Classify** this disease, giving reasons for your choice.

Check your obook assess for these additional resources and more:

- » **Student book questions**
  Check your learning 11.2
- » **Weblink**
  Lead poisoning
- » **Weblink**
  Overnutrition
- » **Weblink**
  Cancer Council Australia

11.3 Infectious disease

KEY IDEAS

- Definition of a pathogen
- Features of parasites
- Distinctions between non-contagious infectious and contagious diseases (epidemic and pandemic)

pathogen
a biological agent that causes disease or illness to its host

parasite
an organism that lives in or on another organism and derives its nourishment from it

host
an organism that harbours a parasite

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)

endoparasite
a parasite that lives in the internal organs or tissues of its host and derives its nourishment from the host

primary host
a host in which the parasite reaches maturity and, if possible, reproduces sexually

vector
any agent that carries and transmits an infectious pathogen into another living organism

secondary host
a temporary host for a parasite

reservoir host
an organism that can harbour a pathogen indefinitely with no ill effects

Infectious diseases are caused by **pathogens** (from the Greek *pathos* = suffering and *gignomai* = cause). A pathogen is an agent that causes disease. Most pathogens are cellular – that is, they are organisms (e.g. bacteria, fungi, protozoans and different types of worms) – but others are caused by organic particles (e.g. prions and viruses).

Cellular pathogens are **parasites**. Parasites obtain their nutrients from their **host** and in doing so invariably cause some form of damage. Parasites that live on the outside of their host are called **ectoparasites**. Fleas are an example of this type of parasite. They are insects that have a piercing mouthpart that can penetrate the skin and enter the blood capillaries. In this way they feed on their host's blood. Parasites that live within the body of the host are called **endoparasites**. A tapeworm living in the alimentary canal is an example of an endoparasite. Regardless of whether the parasite lives inside or on the outside of the host, it is usually an advantage to keep its host alive. If the host dies, it is highly likely that the parasite will also die unless it has some means of moving to another host.

Parasites are found among all of the kingdoms of life. There is also a large array of host organisms. A **primary host** is the organism in which the parasite reaches maturity and undergoes sexual reproduction (in those species that sexually reproduce). Some parasites use another organism to move from one host to another. The organism used in this transfer is called a **vector**. This vector may be a **secondary host** in the parasite's life cycle, and thus essential for its survival, or may be an inadvertent means of transport – a **reservoir host**. It is very common for endoparasites to have a secondary host in their life cycle. A **carrier** is an individual that is infected by a pathogen but does not exhibit disease symptoms.

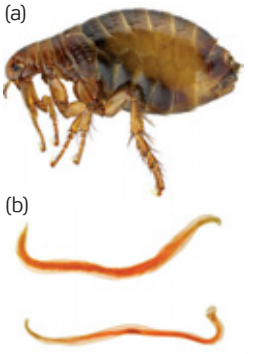

FIGURE 1 (a) Flea (ectoparasite); (b) hookworm (intestinal endoparasite)

Being an endoparasite has some great advantages. There is a constant food supply in a well-protected environment. Among the animal kingdom many endoparasites have special adaptations for their mode of life. These may include one or more of the following features:

- **Attachment devices**: the tapeworm, for example, which lives in the gut of its host, uses hooks and suckers to prevent it being washed out of its host with undigested food.
- **Thickened cuticle**: a thickened outer layer, the cuticle, is resistant to digestive enzymes, acids and alkalis produced by the host.
- **Reduction of feeding organs**: many endoparasites do not have their own digestive system since their host provides all their nutrients in a form that can simply be absorbed by the parasite's cells.
- **Reduction of locomotory powers**: locomotion is unnecessary for most endoparasites.

- **Hermaphroditism**: the chance of encountering another member of their own species within a host is slight, so in some species each individual has a set of both male and female reproductive organs and reproduces by self-fertilisation.
- **An excess of fertilised eggs**: endoparasites produce large numbers of fertilised eggs, which are released into the outside environment. These eggs depend upon chance dispersal to the correct host organism, and so many are lost.

Many parasites do not cause disease – they are not in themselves pathogens. For example, the ectoparasitic mosquito is not a pathogen. It is, however, the vector for many pathogens (e.g. malaria and Zika virus).

Most pathogens are host-specific – they live only in one type of host. Recently, however, some pathogens have been found that can cross species (e.g. Ebola virus).

An infectious disease that can pass directly between two individuals of the same species is termed **contagious** (e.g. the influenza virus in people). Many diseases exist in low levels in a community at all times. For example, influenza (the flu) moves through a population at regular low levels. This pattern of infectious disease is called **endemic**. An **epidemic** of a particular disease occurs when a larger than normal number of individuals in a particular locality is infected at a particular time. If the disease spreads to other countries, it is termed **pandemic**.

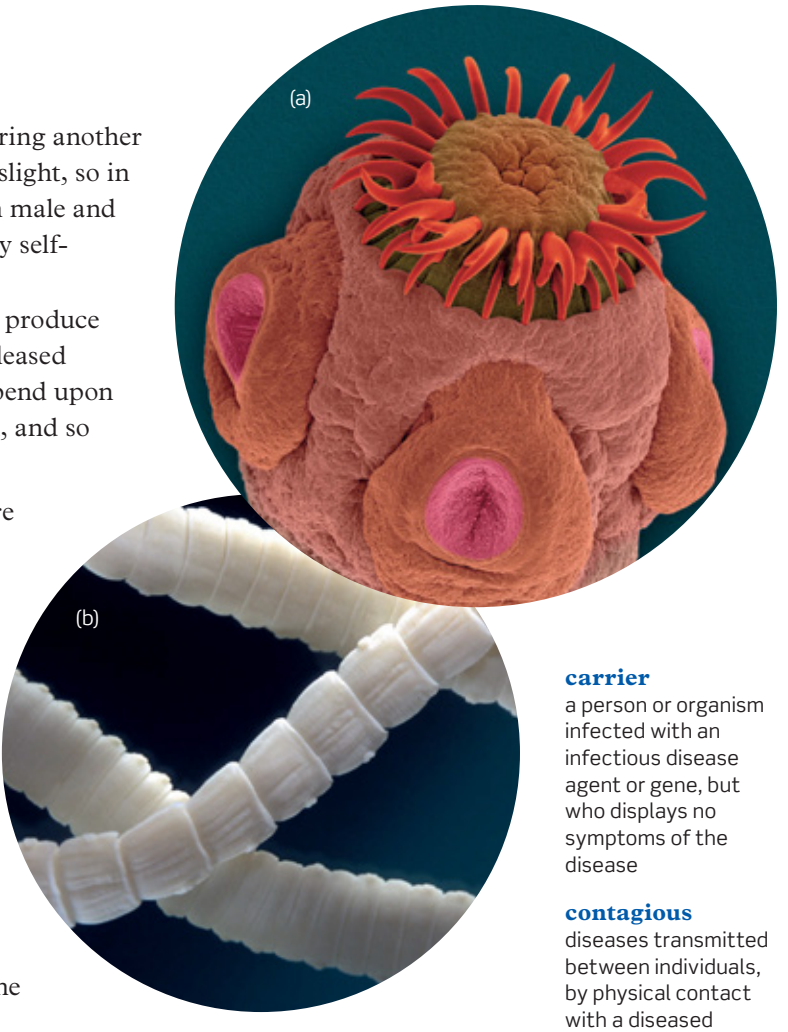

FIGURE 2 (a) The 'head' (scolex) of the tapeworm has both hooks and suckers to attach itself to the intestinal wall; (b) the body has no alimentary canal or means of locomotion, and each section (proglottid) contains male and female reproductive organs.

Diseases can be classified according to the schema in Figure 3.

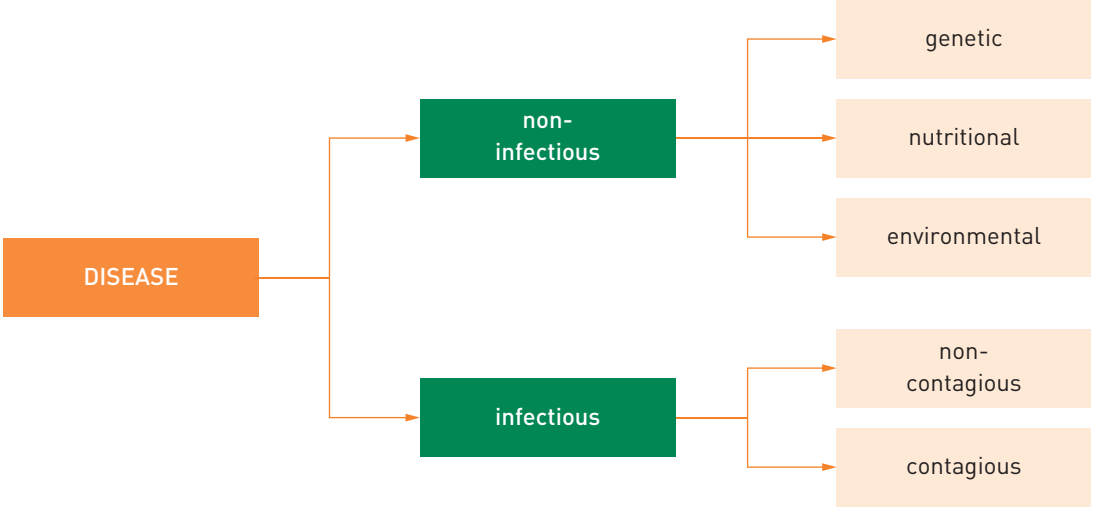

FIGURE 3 Classifying disease

carrier
a person or organism infected with an infectious disease agent or gene, but who displays no symptoms of the disease

contagious
diseases transmitted between individuals, by physical contact with a diseased individual, or by casual contact with their secretions or objects touched by them, or by an airborne route

endemic
describes a disease that is constantly present to a greater or lesser degree in organisms of a certain group or living in a particular location

epidemic
the occurrence of more cases of a disease than would be expected in a community or region during a given period

pandemic
an epidemic of infectious disease that has spread across a large region (e.g. multiple continents) or even worldwide

Table 1 gives some examples of human diseases.

TABLE 1 Some types of human disease

Type of disease	Pathogen	Example
Infectious		
Disease caused by non-living organic particles	Prion	Creutzfeldt–Jakob disease (CJD)
Diseases caused by microorganisms	Virus	Measles, rabies
	Bacterium	Cholera, tuberculosis
Diseases caused by larger organisms	Protozoan	Malaria, trypanosomiasis
	Fungus	Ringworm, athlete's foot
	Roundworm	Ascarisis, onchocerciasis
	Flatworm	Schistosomiasis, tapeworm
Non-infectious		
Nutritional deficiency diseases		Beriberi, pellagra, kwashiorkor
Metabolic disorders		Diabetes
Degenerative diseases		Coronary heart disease, arthritis
Cancer		Skin cancer, breast cancer
Inherited diseases		Sickle-cell anaemia
Occupational or industrial diseases		Silicosis
Mental disorders		Depression, alcoholism

CHECK YOUR LEARNING 11.3

Describe and explain

1 Using an example, **describe** a pathogen.

2 Many endoparasites exhibit special adaptations for their mode of existence. **Identify** two possible adaptations and **explain** their significance to the organism.

Apply, analyse and interpret

3 **Distinguish** between an epidemic and pandemic of a disease. Can either occur in non-infectious diseases?

4 **Contrast** an ectoparasite and an endoparasite.

5 A fly may be a vector to a certain parasite but is not a host for that parasite. Other organisms may be both a vector and a host to the disease. **Compare** the meanings of the terms 'secondary host' and 'vector'.

Investigate, evaluate and communicate

6 All pathogens are parasites, but not all parasites are pathogens. **Discuss** this statement, giving examples.

7 **Explore** the disease measles and **explain** the symptoms.

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 11.3

» **Weblink**
Malaria

» **Weblink**
Typhoid

» **Weblink**
Parasites

MANDATORY PRACTICAL
11.4 The effect of an antimicrobial on the growth of a microbial organism
Go to page 426 »

11.4 Pathogen virulence

KEY IDEAS

- The meaning of pathogen virulence
- Virulent factors and their effects on host cells

virulence
the ability of a pathogen to cause disease

The **virulence** of a pathogen refers to its ability to cause disease. It can be measured by how many individuals the microorganism infects, how quickly it spreads through the body and how many hosts die due to the infection. Influenza is more virulent than the common cold virus because more people are sicker or die as a result of the 'flu'.

For an organism to cause disease it must:

- enter the host
- multiply in host tissues
- resist, or not stimulate, the host defence mechanisms, and
- damage the host.

Virulent factors

virulent factor
a molecule that can contribute to the survival of the pathogen

Virulent factors are molecules that can contribute to the survival of the pathogen. They are typically proteins and include adhesion, colonisation factors, invasion factors, toxins and immune response blockers.

Adhesion

Before a pathogen can cause a disease, it must first enter the host. For this to occur, the pathogen must adhere (stick) to a molecule on the membrane of the host cell. This provides a starting point for the microorganism to penetrate tissues and colonise the host.

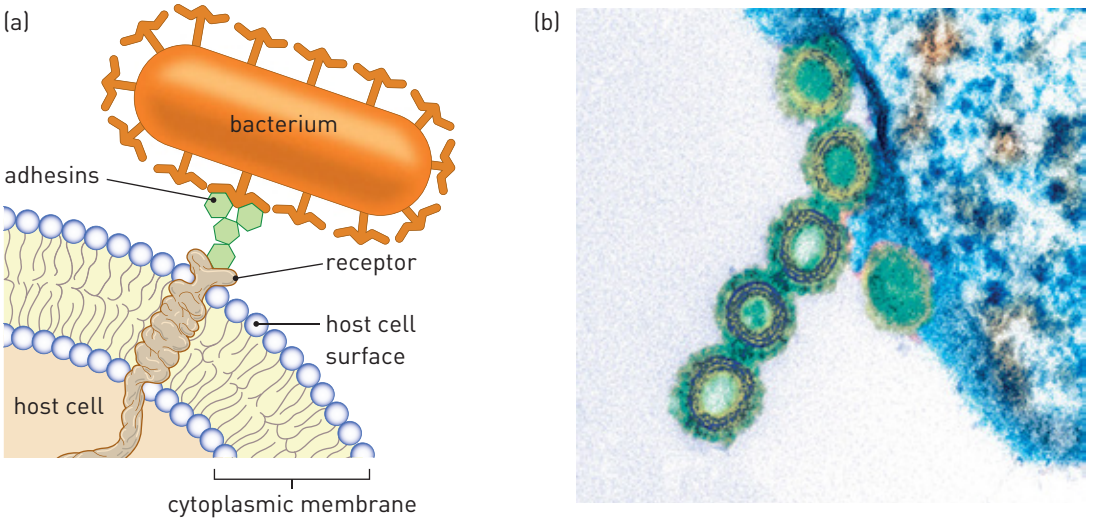

FIGURE 1 A bacterium attaching to the host cell by adhesins, shown (a) diagrammatically and (b) in an electron micrograph

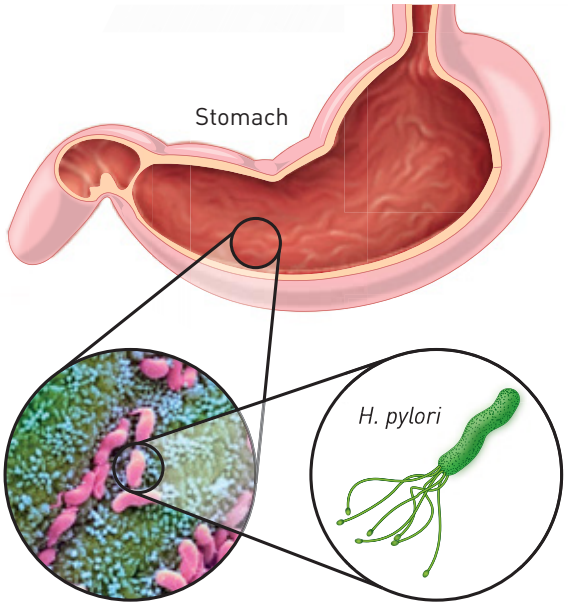

FIGURE 2 *Helicobacter pylori* releases an enzyme that allows it to colonise the human stomach.

One method used is for the pathogen to produce small surface glycoprotein molecules, called **adhesins**, which attach to specific receptors on the host cell's membrane. Some bacteria (e.g. the streptococci) have fine structures (fibrillae) that bind to human epithelial cells while other bacteria (e.g. *Escherichia coli*) have specific adhesive organelles (pili) that allow them to bind to almost all human cells.

Colonisation factors

Colonisation factors are proteins that allow the pathogen to colonise the host's body. The bacterium that results in gastric ulcers, *Helicobacter pylori*, produces an enzyme (urease) that allows it to survive the acidic conditions of the stomach and thus colonise it. Several fungi produce heat-shock proteins that allow them to grow and reproduce at the body temperatures of mammals.

Other pathogens will have a life cycle with different stages, each with different surface molecules, to help them colonise their host. The host's immune system has difficulty in recognising these, enabling the survival of the pathogen.

Invasion factors

Invasion factors are proteins that allow pathogens to enter cells. Many microorganisms must actually enter the host cells. This is especially so for viruses. They produce proteins that either disrupt host cell membranes or stimulate endocytosis into the host cells.

Toxins

Toxins are proteins that poison host cells and cause tissue damage. A large number of bacteria and fungi produce toxins. The damaged tissue provides nutrients for their survival.

- **Endotoxins** are lipopolysaccharides bound to the outer membrane of the pathogen. When the pathogen is damaged or destroyed by the host, the endotoxin is released and causes an inflammatory response in the host.
- **Exotoxins** are proteins produced and released by the pathogen. Different toxins are secreted by different species and are named descriptively to show where the toxin acts (e.g. neurotoxins affect the nervous system, and haemolysin causes red blood cells to rupture). The two most potent known exotoxins are the tetanus toxin secreted by the bacterium *Clostridium tetani*, and the botulinum toxin produced by *Clostridium botulinum*.

  Exotoxins act in several different ways. They can:
  - damage cell membranes by altering the movement of ions into or out of the cell or inhibiting protein production and so causing cell death
  - interfere with cell signalling by disrupting the cell cytoskeleton (and thus membrane), disrupting the proteins involved in transduction or by blocking or altering the signalling pathways
  - affect the immune response by provoking the release of enormous amounts of inflammatory chemicals, which can result in toxic shock syndrome.

adhesin
the component or appendage on the surface of bacteria that helps their adhesion to other cells or to inanimate surfaces

colonisation factor
a protein that allows a pathogen to colonise the host's body

invasion factor
a protein that allows pathogens to enter cells

toxin
a protein produced by pathogens and that poisons host cells

endotoxin
a pathogen toxin bound to its outer membrane and not freely liberated into the surrounding medium

exotoxin
a protein produced and released by a pathogen

Immune response blockers

Some bacteria and fungi have a capsule that blocks or switches off the host's immune system. Yet other bacteria can form a slime layer that protects them from chemical messengers in the host's immune system or antibiotics. The slime layer (**biofilm**) assists large numbers of bacteria to congregate in an area, such as around medical devices (intravenous catheters, prostheses and sutures) or, in the case of the bacterium *Pseudomonas aeruginosa*, in the lungs of patients with cystic fibrosis.

biofilm
an aggregation of microorganisms in which cells that are frequently embedded within a self-produced matrix of extracellular substances adhere to each other and/or to a surface

Some viruses and bacteria produce super-antigens (surface identification proteins) that bypass the host's immune system although they cause an increase in the number of non-specific immune cells produced. In this process, an excessive and potentially destructive inflammatory response may occur.

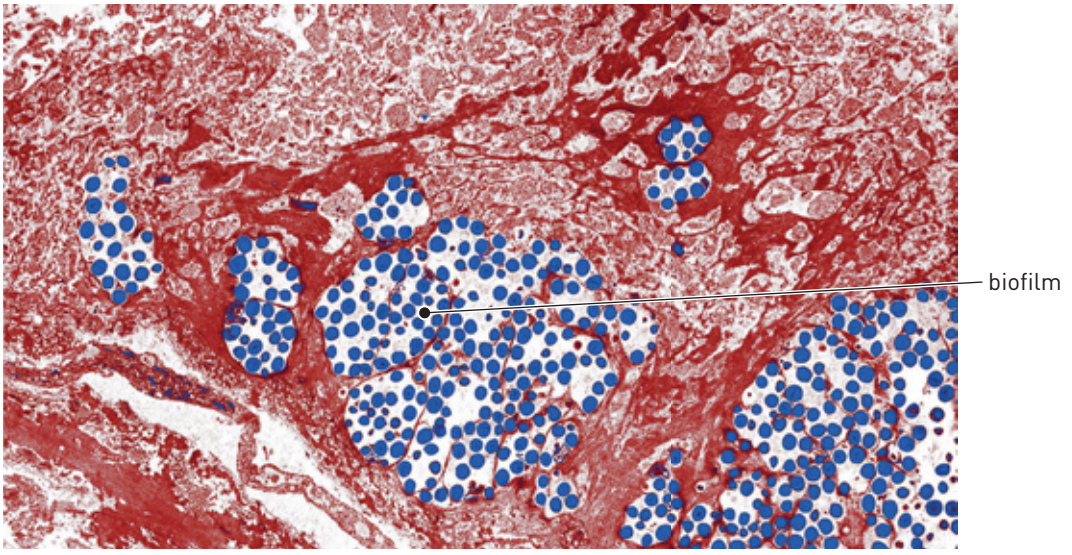

FIGURE 3 The biofilm of bacteria on a heart valve makes them highly resistant to the immune system and antibiotics.

CHECK YOUR LEARNING 11.4

Describe and explain

1 **Describe** three ways in which a pathogen can become more virulent.

2 **Identify** and explain three virulent factors.

Investigate, evaluate and communicate

3 Some winter seasons, a more virulent strain of influenza will affect the human population than normal. **Discuss** this statement, using an example to support your answer.

4 A highly virulent pathogen will often not infect as many people as a mildly virulent pathogen. **Propose** reasons for this.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 11.4
- » Mandatory practical
  11.4 The effect of an antimicrobial on the growth of a microbial organism
- » Weblink
  Escherichia coli
- » Weblink
  Staphylococcus

SCIENCE AS A HUMAN ENDEAVOUR

11.5 Understanding pathogens

KEY IDEAS

- Early experiments
- Koch's postulates

Diseases caused by pathogens have been around throughout human history. Because many pathogens are microscopic, in the past the cause of disease was a mystery. However, people knew that infectious diseases could be passed between individuals.

Three thousand years ago, the Chinese and Hebrew people promoted cleanliness in food preparation, water and personal hygiene to reduce or prevent the spread of infectious disease. Central European hospitals did not practice such precautions until much later. Doctors routinely moved from dissecting corpses to examining new mothers or from one surgical procedure to another without thoroughly washing hands between cases. In the 1840s, Ignaz Semmelweis demonstrated the relationship between a decrease in fatal 'childbed' fever in his maternity ward and rigorous 'scrubbing up'. The cause of disease was not, however, known.

It was once thought that many living things grew from non-living matter (abiogenesis); for example, flies came from rotting meat and frogs grew from moist earth. Although such ideas were based on observed phenomena, the ability to accurately record what was happening was limited to what could be seen by the eye. Two key scientists responsible for dispelling the myth of spontaneous generation were Francesco Redi and Louis Pasteur.

Redi's experiments

In the mid-1600s, Redi carefully observed the process of decay in snakes. He noticed the presence of flies hovering around the dead carcasses, the appearance 3 days later of maggots that consumed the dead snake flesh, the change of maggots into pupae and eventually the emergence of flies (similar to those originally observed) from the pupal cases. Although the eggs were too small to be seen, Redi proposed that the flies had laid eggs, which hatched and finally changed into adult flies.

Going against all prior beliefs, Redi hypothesised that the maggots came **to** the rotting meat, not **from** it. He designed a controlled experiment in which meat was placed in jars

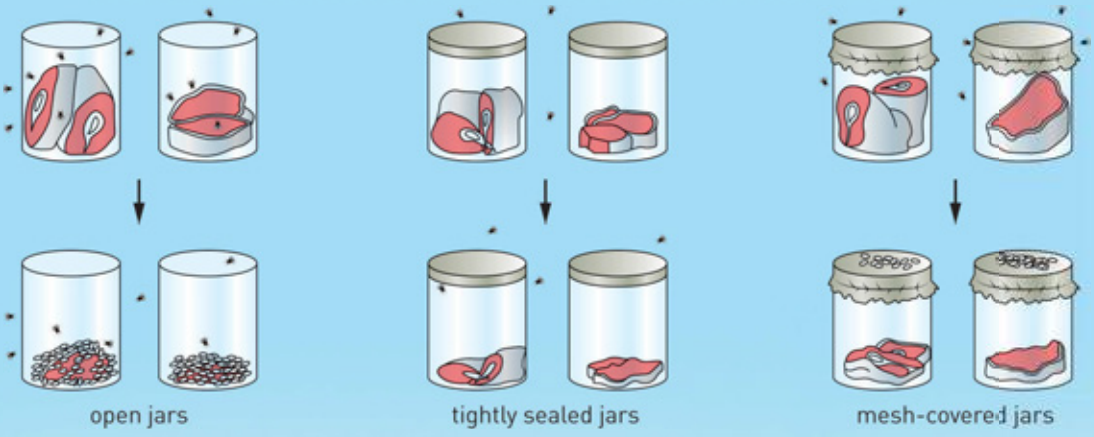

FIGURE 1 Redi's experiment. Fly maggots and flies were found only in the unsealed jars.

that were fully sealed, covered with a fine screen or unsealed. The jar with the screen cover was included to allow fresh air to come in contact with the meat, since it was claimed that air contained the 'active principle' for life. Flies were present in the experimental area. After observing the jars for several weeks, Redi found that maggots developed only on the meat in the unsealed jars. Others repeated his experiments with the same results. Thus, abiogenesis of the fly was no longer supported.

The development of the microscope in the 1600s (see page 70) allowed microscopic organisms to be observed and the debate was reopened. Very small organisms could now be observed. Biologists examining fresh broth could see no signs of life, but after exposure to air for a few days many microorganisms were found living in the broth. There is little doubt that many of the organisms described by Leeuwenhoek were bacteria, although he termed them 'animalcules' and supposed they were some form of worm-like animals. It was not until 1845 that microscopists realised that many of these small organisms were unicellular in nature.

Pasteur's experiments

In 1856, French industrial chemist Louis Pasteur was approached by a fermented beet juice producer who was concerned that some batches of his product were contaminated and acidic. Pasteur examined samples of the beet juice under the microscope. He found small budding yeast cells in the alcoholic samples and small rod-shaped organisms (bacteria) in the acidic samples. Similar bacteria were found in sour milk.

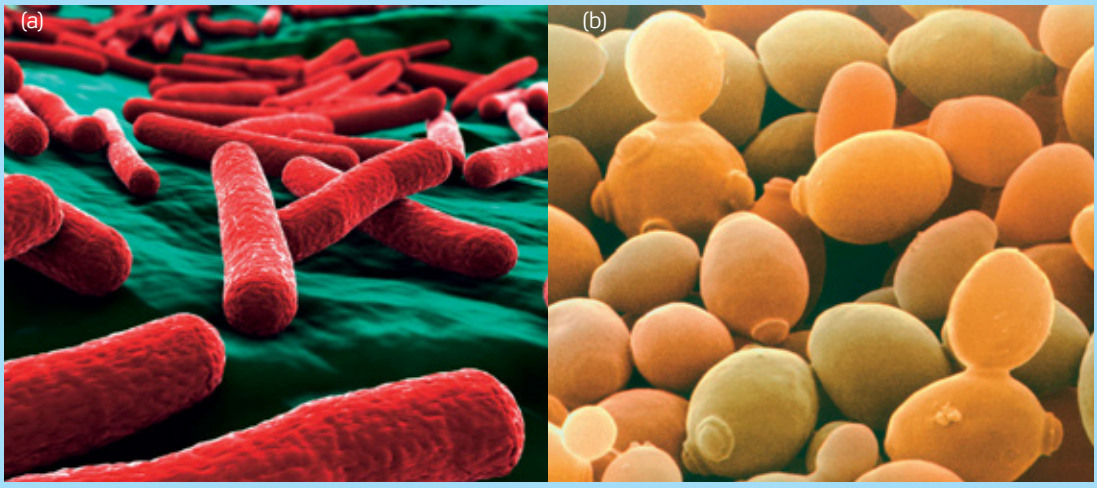

FIGURE 2 (a) Rod bacteria (lactobacilli); (b) yeast cells

At that time, it was thought that production of alcohol was a purely chemical reaction, but Pasteur proposed that alcohol was produced as the yeast cells consumed the sugar of the beet juice and that the acidic product (lactic acid) was the result of the bacteria (lactobacilli) being present. With experimental evidence, he showed that alcohol could not be produced without yeast and that lactic acid was produced from sugar by bacteria. He also showed that heating wine to a temperature between 50°C and 60°C killed the bacteria and so prevented the lactic acid from being formed. This process, known as **pasteurisation**, is still used today.

pasteurisation the process of heating, and then rapidly cooling, liquids or food in order to kill microbes

Using a controlled method similar to that of Redi, Pasteur was able to show that bacteria are carried in the air. He used a swan-necked flask that, in the upright position, prevented air coming into contact with heated broth. This broth did not develop microbes, however any liquid exposed to air had microbes present.

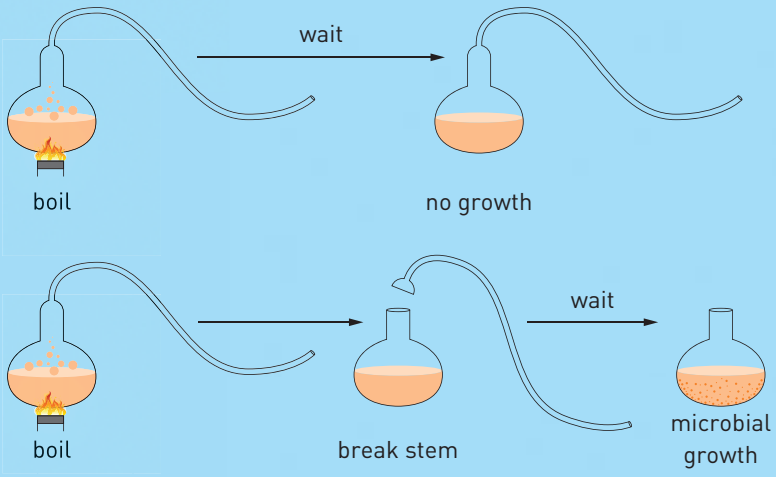

FIGURE 3 Pasteur's experiments

Pasteur defined the spoiled alcohol as diseased and showed that the spoilage was a result of contamination by microorganisms. In this way, the germ theory of disease was established. This view stimulated investigations by Robert Koch, Ferdinand Cohn, Joseph Lister and others, and the science of bacteriology blossomed during the latter part of the nineteenth century.

Sir Joseph Lister, an English surgeon, initiated antiseptic procedures in the operating room, ensuring all operating instruments, hands and patients were washed in carbolic acid, and the room itself sprayed with germicide. As with Semmelweis before him, he demonstrated a radical decrease in infection with such procedures.

Koch's postulates

German doctor Robert Koch (1843–1910) built on Pasteur's work and developed a method to test if a specific microorganism was the cause of a disease. His original work was on the cause of anthrax (foot and mouth disease). He discovered that the bacterium *Bacillus anthraci* was present in the tissues of sheep suffering anthrax. He extracted and cultured the bacteria. When he injected a mouse with the cultured bacteria, the mouse developed the disease. He repeated this process many times with the same results and thus was able to show that the bacterium was the cause of anthrax disease. Using the same technique, he was able to establish the bacterial cause of tuberculosis.

Among his credits is the use of agar as a culture medium for microorganisms. With his team, the Petri dish was developed, along with ways of staining bacteria in order to better identify the type of bacterium responsible for a specific disease. Adopting his techniques, other scientists were able to identify the bacteria that caused such diseases as typhus, tetanus and the plague.

The process Koch used to establish the link between a bacterium and disease, known as **Koch's postulates**, is still used today:

Koch's postulates the criteria required to establish a microorganism as the cause of a disease

- The microbe must be present in organisms with the disease but not in healthy organisms.
- The microbe must be isolated from the diseased organism and cultured in pure form (i.e. with no other microorganisms present).
- When this cultured microbe is injected into a healthy organism, the organism will develop the disease symptoms.
- The microbe should be re-isolated from the experimentally infected organism and again cultured. This new culture should show only the original form of microbe.

Both Koch and Pasteur continued to work, unfortunately as rivals rather than colleagues, attempting to establish the link between particular microbes and a disease. Pasteur was able to produce a weakened culture of anthrax bacteria to successfully make a vaccination against this disease. He also studied chicken pox and rabies. Koch's attempts to develop a **vaccination** against tuberculosis were unsuccessful.

vaccination injection of a killed microbe in order to stimulate the immune system against the microbe, thereby preventing disease

The work of these two men established the study of infectious diseases, their causes and the development of vaccinations that are used today.

Case study 11.5

Using Koch's postulates to win a Nobel Prize

Robin Warren was a clinical pathologist in Western Australia when he noticed spiral-shaped bacteria were present in most of his specimens of stomach ulcers. Barry Marshall, a microbiologist, became interested in the bacteria and hypothesised with Warren that the bacteria caused the stomach ulcer. This was very different to the idea at the time that stomach ulcers were caused by stress and that no bacteria could grow in the acidic stomach. Together, Warren and Marshall were able to isolate and grow the new species of bacteria (*Helicobacter pylori*). They were able to confirm that the *Helicobacter* was always present in ulcerated stomachs. Determined to confirm the cause of the disease and Koch's third and fourth postulate, Marshall decided to drink a culture of the bacteria. He developed a severe stomach ulcer that contained the *Helicobacter*, which he was able to treat successfully. As a result of their discovery, Warren and Marshall won a Nobel Prize in 2005, and the treatment of stomach ulcers was changed.

CHECK YOUR LEARNING 11.5

Apply, analyse and interpret

1 Koch's experimental work in the late nineteenth century led to postulates that are still used today to identify the pathogen causing a specific disease. From these postulates **identify**:
   - **a** the working hypothesis
   - **b** the experimental variable
   - **c** what was measured and observed
   - **d** the control situation.

2 **Identify** each of Koch's postulates from the case study of the Australian Nobel Prize winners Warren and Marshall.

Investigate, evaluate and communicate

3 In order to complete the identification of the causative pathogen, a healthy organism has to be injected with the suspected microbe. Throughout most of the twentieth century, experimental animals were used for this. Primates, being closely related to humans, were the preferred experimental animals. Bioethics regulations were established in the latter part of last century to ensure that experimental animals were treated appropriately. **Investigate** and **summarise** how the reduction in use of experimental animals is now achieved. Does research that may save countless human lives justify the possible harm that may be caused to experimental animals? **Justify** your response.

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  Check your learning 11.5
- » **Weblink**
  Francesco Redi
- » **Weblink**
  Louis Pasteur
- » **Weblink**
  Robert Koch

11.6 Non-living biological agents of disease in animal

KEY IDEAS

- Infectious diseases caused by non-living pathogens
- Prions and their effects
- The structure of a virus and its impact on a host cell
- Transmission of viral infections
- The changing nature of viruses with reference to the influenza virus
- Viral diseases in Australia

While many infectious diseases of animals are a result of parasitic pathogens, there are many diseases caused by non-living agents. Viruses are considered non-living because they do not have ribosomes of their own and cannot reproduce alone. Instead they must invade a cell and use their host cell's ribosomes to construct new viruses. A different type of pathogen that causes degenerative brain diseases is the group of molecules called **prions**.

prion
an abnormal form of a normally harmless protein found in the brain that is responsible for a variety of fatal neurodegenerative diseases of animals, including humans

Case study 11.6

Virus structure and function

Viruses do not have a cellular structure and cannot carry out life processes. They are 'crystalline' when not invading a host cell. These inactive particles are transmitted to cells from the air, in water and in food, as well as by direct contact with an infected host organism. Many are transmitted by other (vector) organisms such as mosquitoes and ticks. Inside the host cell they can 'switch off' the host's DNA and, using their own nucleic acid, instruct the cell to make copies of themselves. Release of the new viral particles causes the host cell to rupture. Viruses have been found to parasitise all known living organisms.

About 20 times smaller than a bacterium, a virus has a very simple structure consisting of a length of genetic material (either DNA or RNA) forming a core, surrounded and protected by a coat of protein. The composition of the protein coat determines the type of cells that the virus can invade. A few viruses, such as herpes and influenza viruses, have an additional lipoprotein envelope, which is derived from its host's cell membrane.

Most viruses have one of two basic shapes: rod-shaped or with 20 triangular sides. The most complex viruses are those which attack bacteria. They are called bacteriophages and are composed of a 'head' and a 'tail'. The head contains the DNA and the tail acts like a hypodermic syringe, penetrating the host's cell membrane and injecting the DNA into it.

Because their structure is so simple, it was once thought that viruses were the first life forms on Earth. Since they cannot reproduce by themselves and can multiply only by parasitising a host cell, however, this theory is no longer considered possible and viruses are no longer considered to be organisms.

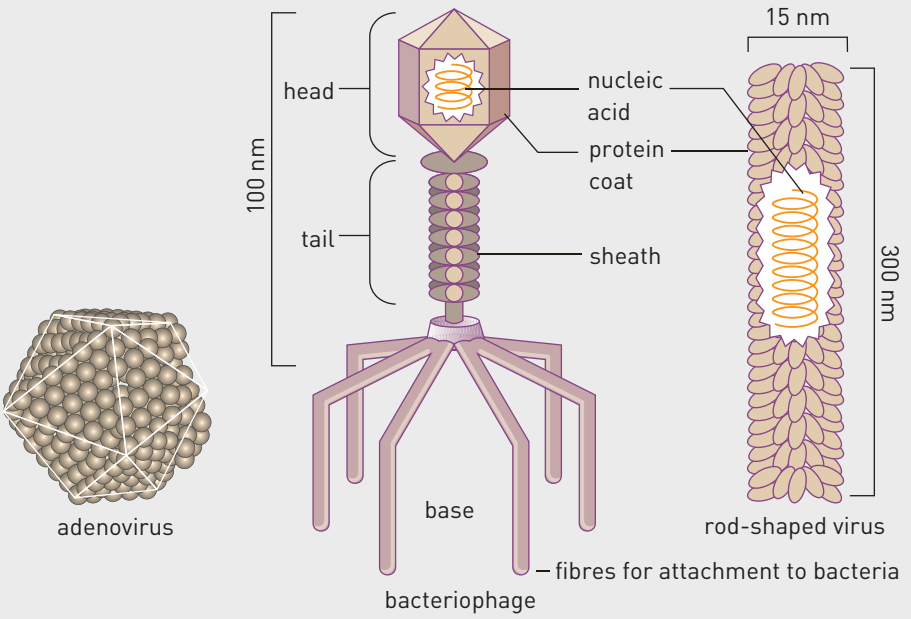

FIGURE 1 Structures and sizes of some viruses

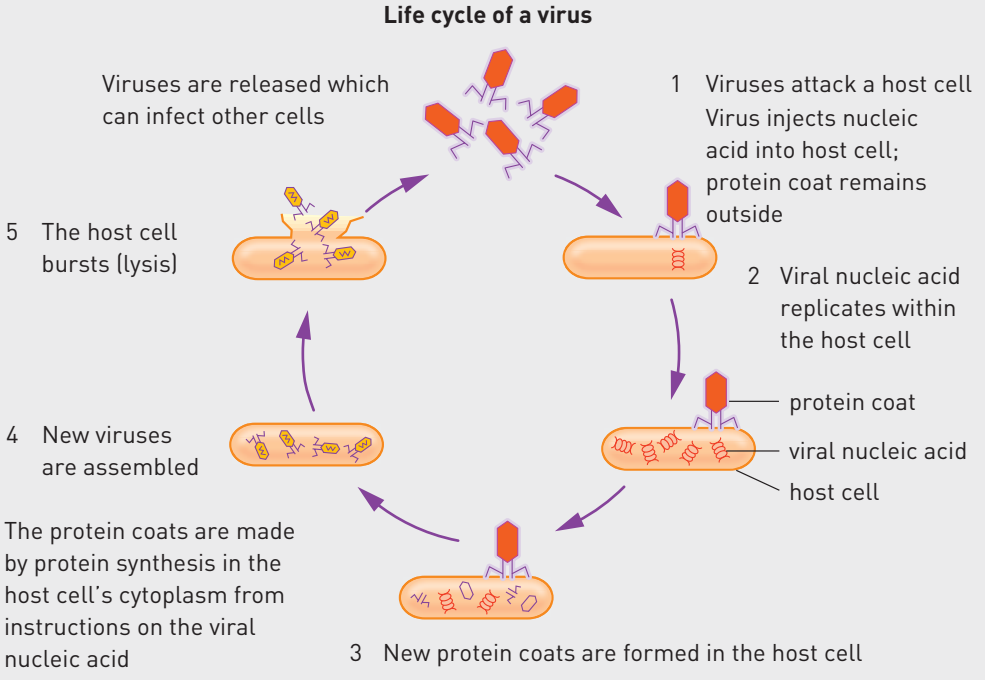

FIGURE 2 Replication phases of a bacteriophage

Prions

Transmissible spongiform encephalitis (TSA) is a group of diseases in which the brains of the affected organisms gradually develop holes (like a sponge). This group of diseases in mammals (including humans) has been known about for more than 250 years. The cause of the disease was unknown until Tikvah Alper in London started working on scrapie, an infectious brain disease in sheep. She found that destroying the nucleic acid (DNA and RNA)

in the affected tissue did not decrease the infectiousness of scrapie. Further testing revealed that it was individual proteins in the tissue that were responsible for the disease.

Normal cells in the brain contain a protein called PrP^{C}. Prions (proteinaceous infectious particles – PrP^{SC}) are proteins that have the same amino acid sequence as PrP^{C}, however the prions are folded to form a different structure. It is thought that the prions are able to 'rearrange' the structure of the normal PrP^{C} proteins so that their structure also becomes abnormal. The abnormally structured PrP^{SC} proteins then group together to form plaques (called amyloids) that disrupt the normal brain tissue function.

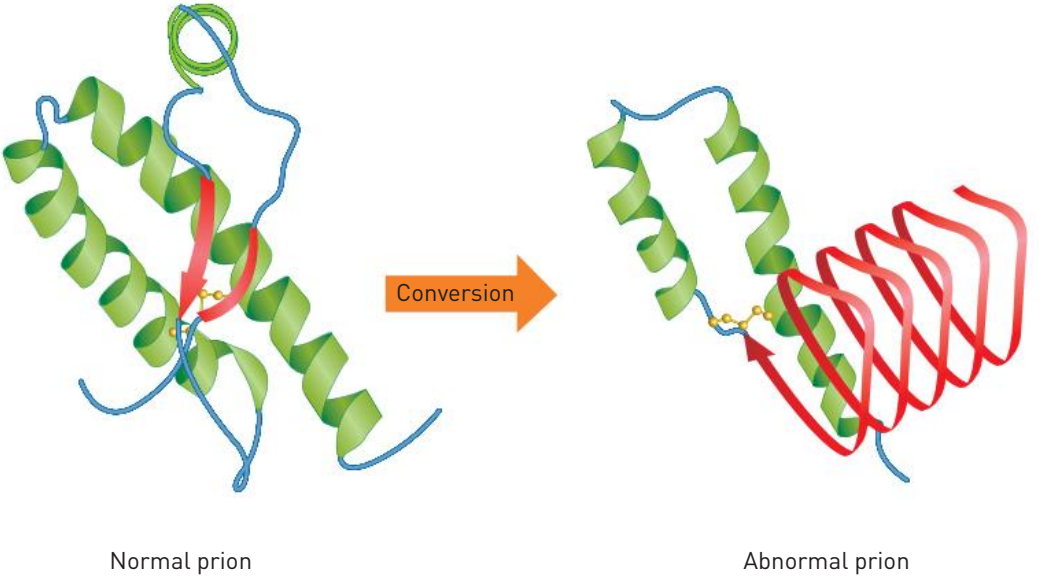

FIGURE 3 Normal prions (green) are infected by abnormal prion pieces (red), which convert the entire prion to the abnormal form.

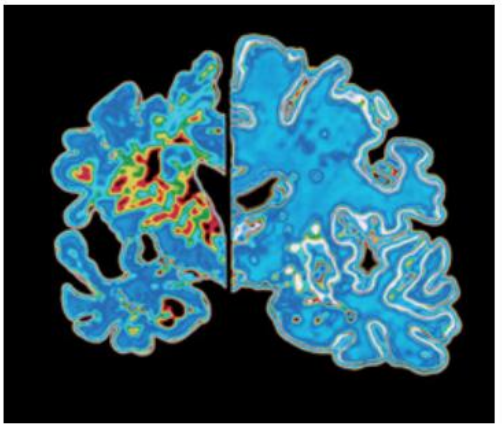

FIGURE 4 Comparison of section of normal brain tissue (right) and that infected with CJD (left).

The disruption results in a spongy appearance of brain tissue, as seen in Figure 4 of an individual with Creutzfeldt–Jakob disease (CJD). Many of the diseases associated with prions bear a name reflecting its effect on the brain, for example bovine spongiform encephalopathy (mad cow disease, BSE). Symptoms of the diseases can include convulsions, poor balance and coordination, and behaviour changes. All known prion diseases are untreatable and fatal.

Since the normal prion protein is very similar in all mammals, a large variety of mammals exhibit prion diseases (Table 1). There are, however, slight differences between the proteins in different species so it is considered unlikely that a disease will spread from one species to another. A notable exception was found during the BSE epidemic in the United Kingdom and parts of Europe between 1986 and 2000.

High protein feed has been produced to supplement grass for cattle in developed parts of the world. This protein came from ground up meat and offal. During the 1980s the method of production of this cattle feed was altered. It is thought that this somehow allowed the scrapie disease agent from infected sheep to survive and contaminate the cattle. At the time neither scrapie nor BSE were thought to affect humans. Brain tissue from BSE-infected cattle, therefore, made its way into the human food supply, particularly as sausages and hamburger meat. In the 1990s at the height of the BSE infection, over 200 young people died of a new variation of CJD (vCJD). CJD is an uncommon, degenerative disease that occurs in

TABLE 1 Diseases in mammals caused by prions

Animal affected	Disease
Sheep, goat	Scapie
Cattle	Bovine spongiform encephalopathy (BSE, mad cow disease)
Mink	Transmissible mink encephalopathy (TME)
White-tailed deer, elk, mule deer, moose	Chronic wasting disease (CWD)
Cat	Feline spongiform encephalopathy (FSE)
Nyala, oryx, greater kudu	Exotic ungulate encephalopathy (EUE)
Human	Creutzfeldt–Jakob Disease (CJD) Variant Creutzfeldt–Jakob Disease (vCJD) Familial Creutzfeldt–Jakob Disease (fCJD) Iatrogenic Creutzfeldt–Jakob Disease (iCJD) Sporadic Creutzfeldt–Jakob Disease (sCJD) Gertsmann–Straussler–Scheinker Syndrome (GSS) Fatal familial insomnia (FFI) Kuru* Familial spongiform encephalopathy

*Kuru is a disease that was common in a tribe from New Guinea that practised ritualistic cannibalism. They ate the bodies of their own dead in the belief that this would immortalise the deceased person. Only the women and children ate the brains and only they were affected by kuru, which has similar symptoms to CJD.

middle-aged people. Those that contract the disease show increasing signs of memory loss, have difficulty in controlling movement and become comatose. They usually die within 3 to 6 months.

This new variation of CJD was found to contain the same prion strain as BSE and occurred in the lymphatic tissues as well as the brain of affected people. It was proposed that the ingested abnormal prions were taken up by lymphoid tissues of the digestive tract and passed to the central nervous system via the **autonomic nervous system**. Once in the brain the process of converting normal protein to abnormal prion protein was accelerated.

autonomic nervous system the system controlling the actions of the inner (visceral) body tube, not under conscious control. Two types of motor nerves are present: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action

Until 2015, it was thought that all known mammalian prion diseases were caused by abnormal strains of the same membrane protein (PrP^C). It was then discovered that multiple system atrophy (MSA) was likely to be caused by an abnormal folding of a different membrane protein (alpha-synuclein). MSA results from deterioration of the parts of the brain that regulate internal body functions, digestion and motor control.

Many other neurological diseases may be shown to be the result of dysfunction of brain cell proteins.

Viral infections

A virus is a large molecule of protein forming a coat surrounding a nucleic acid (either DNA or RNA) core. It is considered as non-living because it cannot perform any of the metabolic activities characteristic of living things. Inside the cell of another organism, however, it can direct the host cell's nucleic acid to produce more virus particles. Ultimately, so many virus particles are produced by the cell that it ruptures and releases the viruses to infect new cells. The process is described more fully in Case study 11.6 (page 330). When not in a host cell many viruses, which are a tiny 30–300 nanometres in size, form a crystal that can survive extreme conditions for many years.

Each virus must first adhere to a cell before entering it. This means different types of viruses can only infect particular types of cells of specific organisms. For example, a virus that infects dogs is unlikely to infect a person. Similarly, the virus that causes cold sores in people (Herpes simplex type 1) does not result in chicken pox, another viral infection of the skin caused by Varicella zoster. Viral nucleic acid can, however, undergo mutations. When this occurs, a disease that was found only in one type of organism can pass to another type of organism. Mutation also results in a variety of related infections such as influenza.

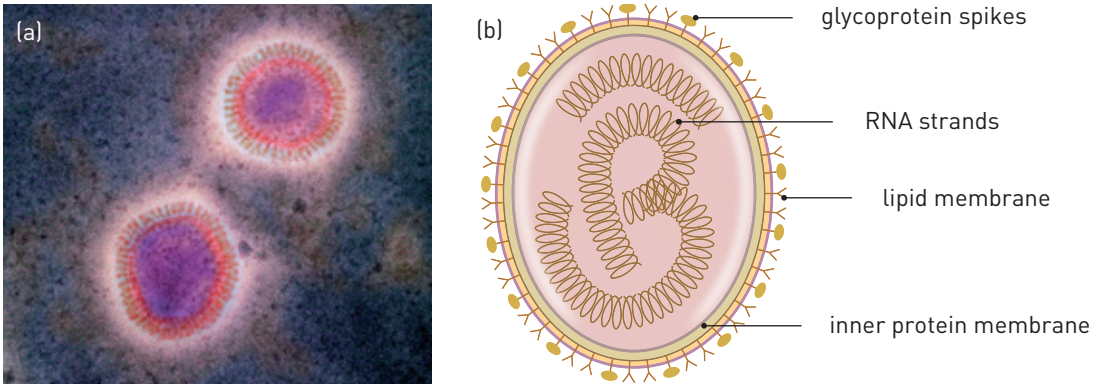

FIGURE 5 Influenza virus: (a) an electron micrograph; (b) structure of the virus

Prior to the development of farming, humans were hunter-gatherers who travelled large areas in search of game and other food in small groups. If a particular group was infected by a virus, the disease did not spread to other groups due to their isolation. About 10 000 years ago, some bands took up growing crops and domesticating certain animals. People settled in one place and the population of some areas started to increase. Records in fossil bones indicate that these people were far more susceptible to disease than their hunting relatives. The close association between humans and their animal stock allowed for the mutations and transfer of animal viruses to humans. The animals had, over time, developed immunity to these viruses and so did not exhibit diseases. The human population, however, did not have this resistance and the subsequent diseases were able to rapidly kill large numbers of people. The viruses responsible for measles, tuberculosis and smallpox were transferred from cattle. Influenza and whooping cough viruses came from domesticated pigs and ducks.

incubation period the time for a pathogen to build up sufficient numbers to produce symptoms of the disease

Outbreaks of new viral strains originating from domestic ducks in Asian countries continue to occur. Travel between countries is now a regular occurrence. Since many influenza viruses have an **incubation period** (the time for the viral numbers to build up sufficiently to produce the symptoms of disease) of up to 14 days, an infected person can contract the disease in one country and travel to several other countries before becoming aware of the disease. This person could, in their daily contact with others, infect thousands of people all of whom could take the infection to another part of the world. They in turn will be in contact with new individuals, many of whom could also become infected. In the first 6 months of 2003 an estimated 8500 people became infected with the pneumonia-like SARS (severe acute respiratory syndrome), of whom almost 800 died. It is believed that this virus is a mutated form of a similar virus found in wild civets (a wild cat), which are captured and sold for food in the Chinese village in which the disease originated.

Records of viral infections in past ages are not accurate and the causes can often only be gauged by the symptoms described at the time. Prior to the nineteenth century most viral epidemics were attributed to yellow fever, smallpox and measles. The first pandemic of influenza

was recorded in 1847. Since then, probably related to greater (and faster) mobility between countries, many more viral pandemics, resulting in large numbers of deaths, have occurred.

TABLE 2 Major epidemic and pandemic viral outbreaks

Disease	Location	Date	Estimated death toll
Influenza	Worldwide	1887–90	1 000 000
Spanish influenza (H1N1)	Worldwide	1918–20	75 000 000
Asian influenza (H2N2)	Worldwide	1957–58	2 000 000
Hong Kong influenza (H3N2)	Worldwide	1968–69	1 000 000
HIV/AIDS	Congo Basin	1960–present	> 30 000 000
SARS coronavirus	Asia, Canada	2002–03	775
Swine influenza (H4N1)	worldwide	2009	14 289
Measles	Congo	2011–present	4 500
Dengue fever	Pakistan	2011–present	350
Yellow fever	Darfur, Sudan	2012–13	847
Middle East Respiratory Syndrome	Worldwide	2012	449
Ebola	West Africa	2013–16	> 11 300
Zika virus*	Worldwide	2015–17	
Yellow fever	Africa	2016	Hundreds

*Although not directly resulting in death, this virus has been linked to microencephaly in babies whose mothers contracted the disease during pregnancy. This has been reported only in South America.

As can be seen in Table 2, the greatest number of deaths due to viruses can be attributed to influenza. The influenza viruses, HIV virus and other viral diseases in Australia are described in the obook.

CHECK YOUR LEARNING 11.6

Describe and explain

1 The proposal that some diseases, such as spongiform encephalitis, are transmitted via an abnormal protein has been very controversial in the scientific world. **Explain** why biologists (at first) struggled with this concept.
2 **Describe** how viruses differ from bacteria.
3 **Explain** why a viral infection can rapidly become pandemic.

Investigate, evaluate and communicate

4 The virulence of influenza A viruses is greater than that of influenza B viruses. **Discuss** in a report:
- a definition of virulence
- the means by which virulence is achieved in pathogens in general
- virulence factors in influenza viruses
- an explanation for the differential virulence of influenza A and B.

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Check your learning 11.6

» **Weblink**
Viral infections

» **Weblink**
Influenza

» **Weblink**
HIV/AIDS

11.7 Living agents of disease in animals

KEY IDEAS

- Bacteria – their types and significance in the environment
- Pathogenic bacteria and their effects on the host
- Protozoans that cause disease
- The life cycle of malaria-causing *Plasmodium*
- Parasitic fungi
- Some flatworms and roundworms that cause disease

Parasites are living, reproducing organisms that may cause disease. There are many different types of pathogenic parasites. These include the microorganisms, bacteria, protozoa and fungi as well as macroparasitic worms.

Bacteria

Bacteria are some of the smallest living organisms (they are between 0.5 and 10 μm in diameter). Although some forms exist as groups of cells or in long strands, there is no specialisation of the cells for a particular function. Instead the cells are only loosely held together. They are so small that their internal structure can only be determined using very high-powered electron microscopes.

These prokaryotic cells have no true nucleus or other membrane-bound structures typical of other organisms. They have a single, circular strand of DNA and several small segments of DNA called plasmids. Metabolic activities occur in the cytoplasm. The entire cell is enclosed by a wall composed of the glycoprotein **murein**.

murein
a glycoprotein forming the cell wall in bacteria

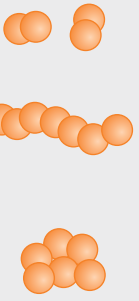
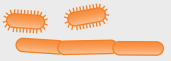
In spite of their small size, bacteria have continued to dominate all environments throughout the existence of life on Earth. It has been estimated that:

- a single handful of soil contains more bacteria than the total number of people who have ever lived
- the skin of an average person has 10^5 bacterial cells per square centimetre
- the human gut contains 10^{11} bacterial cells per gram of contents (the large intestine normally holds 1 kg of material).

Different types of bacteria have different forms of cellular respiration (aerobic, anaerobic or a combination) and methods of gaining nutrition (chemosynthetic, photosynthetic or heterotrophic). This allows them to live in very diverse environments. Most bacteria are harmless and many are essential for the continued existence of life on Earth.

Bacteria can be identified by being grown on a culture medium such as agar jelly or a nutrient broth under controlled environmental conditions. Individual bacteria can grow and divide rapidly, producing colonies of millions of bacteria. The colonies for many bacteria have a characteristic colour and shape which assists in their identification. This process can be used to distinguish between the different groups of bacteria.

TABLE 1 Basic shapes of bacteria

Bacterial shape		Examples
Cocci are spherical (singular, coccus)		Diplococci join together in pairs – *Diplococcus pneumoniae* causes pneumonia. Streptococci join to form a chain – many *Streptococcus* species infect the upper respiratory tract: • *Streptococcus pyogenes* – scarlet fever • *Streptococcus thermophilus* – gives yoghurt its creamy texture. Staphylococci join together in bunches. *Staphylococcus aureus* (golden staph) – different strains cause boils, pneumonia, food poisoning and other infections.
Bacilli are rod-shaped (singular, bacillus)		*Bacillus typhosus* causes typhoid fever. *Bacillus anthracis* causes anthrax. *Escherichia coli* lives in symbiosis in gut.
Spirilla are spiral-shaped (singular, spirillum)		The spirochete (a fine spirilla) *Treponema pallidum* causes syphilis.
Vibrio are comma-shaped		*Vibrio cholerae* causes cholera.
Rickettsiae are rod-shaped		Rickettsiae cause typhus and are often carried on the body louse (a vector). (Note: They are similar in size to the smallest bacilli and cocci, but they are classified into a different group because they cannot survive outside living cells; they are actually the smallest known cell.)

A number of bacteria have been found to be harmful to humans, their domesticated animals and to cultivated plants. Pathogenic bacteria may spread in many ways (see Table 1). When they enter the body, they may cause disease by producing poisonous chemicals (toxins), by changing the host's metabolism, or by damaging tissues. Some *Clostridium* species, for example, can cause food poisoning by releasing a toxin into the food. If this food is then eaten, the toxins affect the nervous system, causing problems in vision, paralysis and often death (botulism).

Many bacteria, like viruses, only affect particular parts of the body. The bacterium that causes bacterial dysentery produces a powerful toxin that affects the cells of the large intestine. This results in loss of blood with the faeces as well as diarrhoea. Other bacteria can affect many different tissues. The bacterium *Treponema pallidum*, which causes syphilis, initially causes inflammation of the penis (or vulva of the female) but can travel to, and affect, all parts of the body, including the brain.

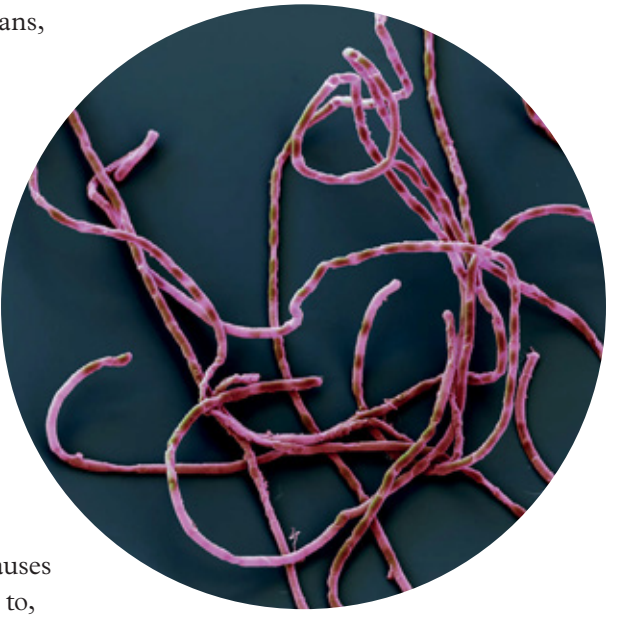


FIGURE 1 Chains of anthrax bacilli in the blood

Case study 11.7

Deadly bacterial diseases

The greatest number of deaths resulting from infectious diseases is due to plague. This disease is caused by the bacillus bacterium *Yersinia pestis*, found in fleas that feed on human and rats. The disease passes between organisms through flea bites. Plague affects people in three different ways:

1 **Bubonic plague** (the most common form) occurs when the bacteria infect the lymphatic system. This causes painful swelling of the lymph glands, which begin to bleed and so become purple-black and rupture into foul-smelling lesions. Eventually the victim's nervous system collapses, and death follows. Modern antibiotics are effective against bubonic plague if it is treated early.

2 **Pneumonic plague** occurs when the bacteria infect the lungs and is the most serious form of the plague. It does not respond readily to antibiotics.

3 **Septicaemic plague** occurs when the bacteria multiply in the blood. This can occur from a direct flea bite or from untreated bubonic or pneumonic infection.

Plague epidemics and pandemics have occurred for thousands of years. The first recorded case was in China in 224 BCE. Since then there have been many serious outbreaks. Five million people in Europe, Western Asia and Africa died between 165 and 180 CE and up to 50 million in Europe between 541 and 542 CE. The most significant outbreak was in Europe – in the 5-year period between 1347 and 1352 CE between 75 and 100 million people died. Although the disease receded, it never really went away and is still prevalent in 20 countries. Recently, severe outbreaks have occurred in Central Africa and parts of South America. An epidemic is more likely to occur in highly populated, urban areas with poor sanitation. As with other microorganisms with a high reproductive rate, *Yersina pestis* has many mutant forms and some of its genes have been acquired from other bacteria and viruses. There has been rapid evolution of the bacterium, therefore, allowing it to survive in many different environments.

Another significant disease, cholera, which is still prevalent in countries with poor sewage and water treatment, is caused by the vibrio bacterium, *Vibrio cholera*, of which there are several forms. The bacterium causes severe diarrhoea that within hours can lead to dehydration and electrolyte imbalance. Bodies of water are the reservoir for this bacterium. It has been found that frozen seafood shipped long distances can spread the disease from country to country. There have been seven serious pandemics of cholera between 1816 and 1975, resulting in several millions of deaths. Today it is estimated that 3–5 million people are affected worldwide, with about 100 000 deaths a year.

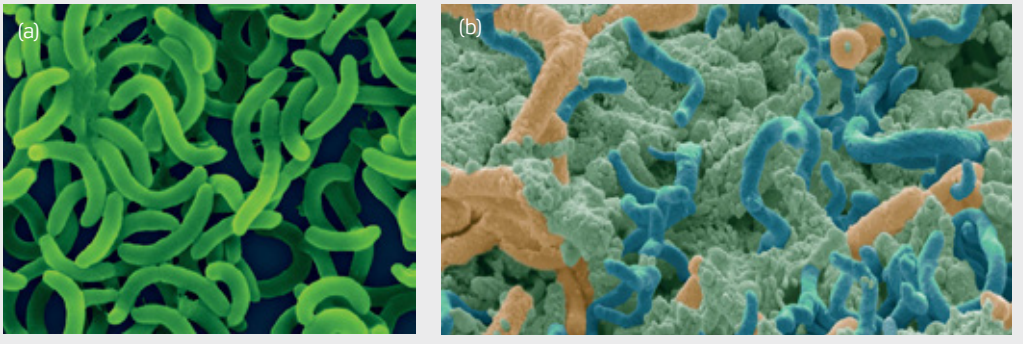


FIGURE 2 Electron micrographs of bacteria that cause (a) plague and (b) cholera

Protozoa

The kingdom Protista comprises a very diverse group of eukaryotes, most of which are unicellular. It is an artificial classification of all those eukaryotic organisms that are not fungi, plants or animals. Protists are divided into the animal-like protozoans, the plant-like algae and the fungus-like slime moulds (Oomycetes). All live in moist environments.

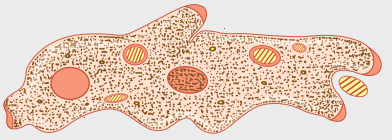
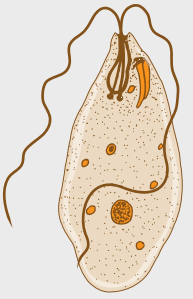
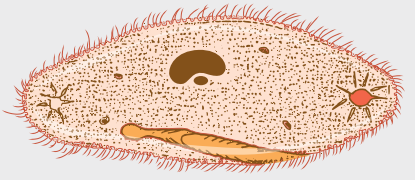
The Protozoa are heterotrophic protists that are divided into four main phyla. Three of these are distinguished by their mode of locomotion – the Rhizopoda move by **pseudopodia**, the Zoomastigina by **flagella** and Ciliophora by **cilia**. They include both free-living and parasitic forms. The Apicomplexa are all parasites of animals and exhibit complex life cycles involving both sexual and asexual phases.

pseudopodium (plural pseudopodia)
a temporary foot-like extension of the cell membrane of some protozoans, resulting in a flowing movement of the protozoan

flagellum
a whip-like extension, containing protein filaments, of the cell membrane of some protozoans

cilium (plural cilia)
a hair-like extension of the cell membrane

TABLE 2 Animal-like protists

Protozoa	Aquatic or endoparasites Unicellular Heterotrophic eukaryote	
Phylum Rhizopoda	Move by pseudopodia Irregular shape Engulf food by phagocytosis anywhere across membrane Mostly free-living	
Phylum Zoomastigina	Move using one or more flagella Definite shape Food intake at base of flagellum only Free-living or parasitic	
Phylum Ciliophora	Move by cilia Definite shape Food intake in one place only, the 'gullet' All free-living	
Phylum Apicomplexa (Sporozoans)	No locomotion Definite shape All parasites Have complex life cycles	

The amoebas and flagellates include some important human parasites. *Entamoeba gingivalis* lives in the human mouth, feeding on bits of food caught in the gums and teeth. As their numbers rise, by-products of their metabolism bring about tooth decay and gum disease. They are transmitted by kissing.

Entamoeba histolytica, which causes amoebic dysentery in humans, is spread via contaminated food or drinking water.

The flagellate *Giardia lamblia* also causes human dysentery. Another flagellate, *Trypanosoma gambiense*, transmitted by the tsetse fly, is a human blood parasite causing

African sleeping sickness. *Trypanosoma cruzi* is transmitted by blood-sucking bugs and affects muscle, particularly that of the heart. It causes the fatal Chagas disease.

Many Apicomplexa require a different host for each phase of the life cycle. Toxoplasmosis, a human brain disease, is caused by *Toxoplasma*. This organism has the domestic cat as one of its hosts. It leaves the cat as spores in the faeces. These spores may remain on the cat's fur and then be transferred to the human host. *Leptospirosis* can be transmitted from native animals to wildlife carers.

Malaria

Malaria is caused by a protozoan that hides inside human cells to avoid the immune system. Humans are the secondary host, while mosquitos are the primary host for the parasite, *Plasmodium* (phylum Apicomplexa). The parasite undergoes sexual reproduction in the digestive tract of the *Anopheles* mosquito, and asexual reproduction in both the human liver and blood cells.

Large-scale insecticide spraying of the watery breeding grounds of the *Anopheles* mosquito during the 1960s successfully eradicated this vector of *Plasmodium* from many parts of Europe. The sprays used, however, were found to have such a devastatingly adverse effect on the environment that their use was discontinued. Malaria, therefore, continues to be endemic in many Mediterranean and tropical regions of the world. Between 200 and 400 million people have malaria, 80% occurring in Africa. Every year 2.5 million people die of the disease, while the survivors are usually subject to a wide range of other infections due to their weakened resistance. Recently, hormonal sprays have been developed that prevent the development of the aquatic mosquito larvae into adults, as have sprays containing viruses that attack the larvae. Sterilised male mosquitoes are also released so that many eggs are unfertilised.

Four different species of *Plasmodium,* generally from different parts of the world, produce malaria in people. The life cycle is similar in each. Infection occurs when a person is bitten by a female mosquito that is carrying the parasite. One stage in the *Plasmodium* life cycle, the **sporozoite**, is injected into the human bloodstream with saliva when the mosquito feeds. The sporozoites travel to the liver cells, where they multiply asexually by binary fission. This takes about a week. Some remain in the liver and continue to divide while others move back into the bloodstream. The parasites invade red blood cells, where they again undergo rapid asexual division to form a stage called the **merozoites**. The red blood cells rupture, releasing the merozoites, infecting more red blood cells and their metabolic waste products. Amazingly, the rupture of the red blood cells by the merozoites appears to be synchronised.

sporozoite
a form of *Plasmodium* resulting from sexual reproduction and produced in the salivary glands of the mosquito

merozoite
a cell produced in large numbers by rapid asexual division during a stage in the life cycle of *Plasmodium* in red blood cells, causing the red blood cells to rupture

It appears that the number of merozoites in the blood must be very high (an estimate of 150 million has been suggested) before the infected person shows the classic symptoms of malaria. These occur approximately 14 days after infection and are initiated by a cold stage that lasts approximately an hour, coinciding with the rupture of the red blood cells. As the parasites enter new cells and as a result of the waste materials, the body temperature rises. This is usually accompanied by a very rapid pulse rate, rapid breathing and headache and may last for 3 to 4 hours. The following 2 to 4 hours are characterised by profuse sweating and decrease in body temperature. This cycle occurs every 2 to 3 days.

Some of the cells produced within the red blood cell may develop into gamete-forming cells or **gametocytes**. This is the only stage that can develop further within the stomach of the female mosquito. The female and male gametocytes develop into gametes, which fuse to form a zygote. Repeated division of the zygote results in the formation of the sporozoites that migrate to the mosquito's salivary glands.

gametocyte
a gamete-forming cell

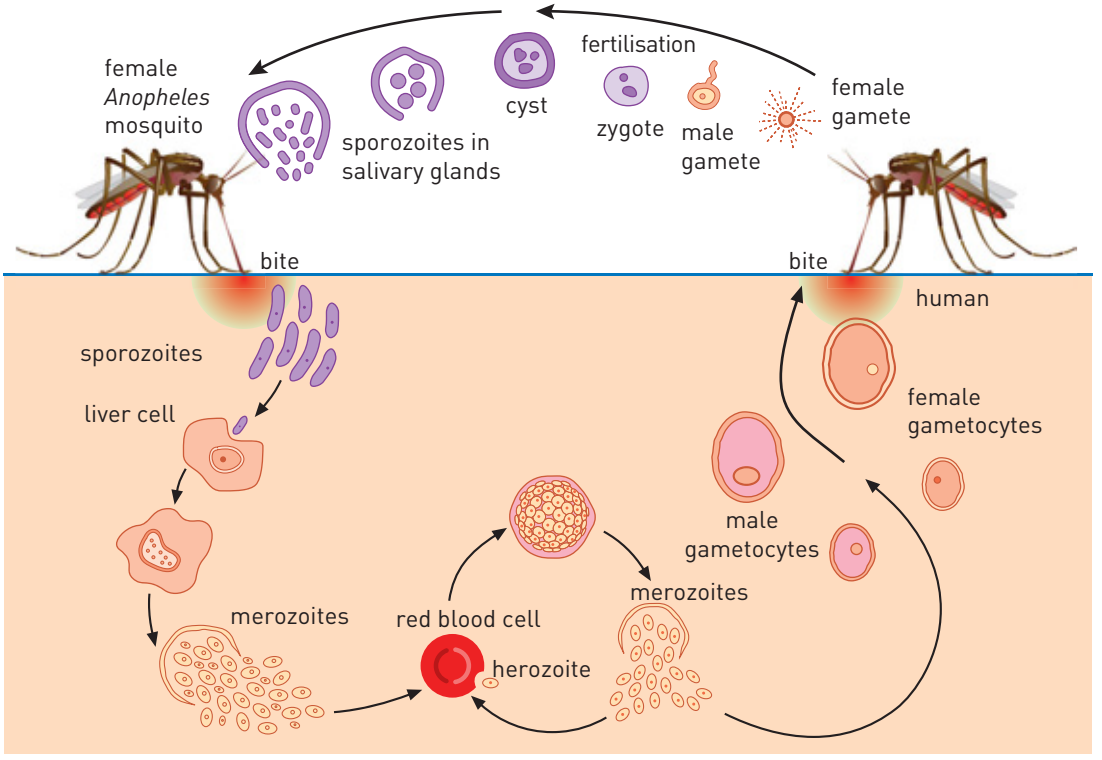


FIGURE 3 The life cycle of *Plasmodium*

TABLE 3 Some common protozoan diseases of humans

Disease	Symptoms	How transmitted
African sleeping sickness	Headache, fever, enlargement of lymph nodes, drowsiness leading to coma	The tsete fly takes up *Trypanosoma* from blood of an infected person. The parasite multiplies in the fly's salivary glands. It is injected into another person as the fly feeds on human blood.
Giardiasis	Diarrhoea, bloating, flatulance, vomiting	Food or water contaminated with *Giardia lamblia*
Vaginitis	Inflammation and irritation of the vagina in women and urethra in men	Usually sexual intercourse, although the disease-causing flagellate, *Trichnomonas vaginalis*, can survive for several days in moisture in towels or in droplets on toilet seats.
Amoebic dysentry	Fever, nausea, vomiting, diarrhoea	Food or water contaminated with *Entamoeba histolytica*
Malaria	Anaemia; fever alternating with shivering	The *Anopheles* mosquito is the primary host of *Plasmodium*.

Fungi

Fungi are eukaryotic heterotrophs whose cells are surrounded with walls composed of chitin. All fungi, except unicellular forms (yeasts), are composed of filaments called hyphae, which penetrate their organic substrate. Parasitic fungi use hyphae to enter host cells. Extracellular digestion is achieved by secreting enzymes into the substrate, and the small molecules thus released are absorbed by the hyphae. Fungi may be decomposers or parasites or found in association with a plant. Fungi are classified on the basis of their spore formation.

Only a few types of fungi are parasitic on humans. The most common fungal infections are:

- **Ringworm**: Usually a single fungal spore from *Trichophyton* or *Epidermophyton* germinates on the skin and hyphae spread out, digesting and absorbing the nutrients from skin cells. This causes inflammation of the skin, which may become very itchy or sore and which is seen as an increasing circle of red tissue as the growth of the fungus proceeds. As fruiting bodies are formed, spores may be transferred directly to another person or via towels or clothing.
- **Athlete's foot (tinea)**: The fungus *Tinea pedis* primarily grows on the skin between the toes, although it may spread to other parts of the foot. It is common in people who wear shoes and socks that do not allow perspiration from the feet to evaporate. Thus, athletes who spend hours training are particularly susceptible to infection. Since they invariably share change rooms and showers, the fungus can spread rapidly from person to person.

FIGURE 4 Athlete's foot or tinea

- **Thrush, *Candida albicans***: Thrush is a yeast that infects the mouth, throat, intestines and vagina, where it grows as a white patch on the moist tissues. In the vagina, the symptoms are intense itchiness and an unpleasant discharge. Vaginal thrush can be transferred from mother to baby during birth. Care should be taken not to share towels, since this could result in transmission from one person to another. Females should also use underwear (pants and stockings) that allows removal of heat and moisture from the vaginal area, since thrush thrives in humid conditions.

  Candida can be kept in check by bacteria that normally inhabit these regions and thus a person may not be aware that they are harbouring the fungus. If these bacteria are killed by antibiotics, or the person's resistance is lowered due to other illness or malnutrition, over 60 different disease conditions can occur. The membranes of the epithelial cells lining the intestine become more permeable. This allows the entrance of larger, partially digested proteins into the bloodstream. An immune reaction to these proteins can result in food allergies. The *Candida* can change from the single-celled shape and produce a mass of hyphae that penetrate the intestinal wall and move throughout the body via the bloodstream. Rapidly growing colonies of this fungus produce toxins. Forms of arthritis, depression, mood swings and severe allergic responses have been attributed to candidiasis infection.

Macroparasites

Most macroscopic endoparasites of humans are either flatworms (phylum Platyhelminthes) or roundworms (phylum Nematoda).

Diseases caused by flatworms

Flatworms are dorsoventrally (top to bottom) flattened animals that include both free-living and parasitic forms. The main human parasites are the flukes and tapeworms. Both have a very complex life cycle involving a vertebrate and an invertebrate host. The flukes have a leaf-like body and two suckers and are generally quite small. The tapeworms have an elongated body, some reaching up to 10 metres in length, and a highly modified head which serves to attach the body to the host's gut wall by suckers and a series of hooks.

The life cycles of many flukes, such as *Schistosoma* (human blood fluke) and *Fasciola*, are very similar. Although *Fasciola* is most common in sheep, it can also occur in humans. In both primary hosts the adult fluke, which is a hermaphrodite, lives in the liver and bile ducts. The eggs are released with the bile into the intestines and pass out with the faeces. If the eggs land on moist grass and are eaten by the appropriate type of water snail, the cycle continues. The eggs hatch and the larvae feed on the snail tissues before undergoing asexual reproduction. Again, a cercarian larva leaves the snail's body. This larva, however, swims to a stalk of grass, climbs above water level and forms a protective cyst. When sheep graze, or humans eat watercress, they may ingest the cysts. Inside the intestine, the cyst coating breaks down to release the larva, which burrows through the intestinal wall into the blood vessels.

In farming communities in Australia, it was common to feed offal from slaughtered sheep to the farm dogs. Since this practice has been outlawed, the incidence of the sheep liver fluke has decreased (Figure 6).

Adult *Taenia* tapeworms are the largest endoparasites of humans, growing to several metres in length in the small intestine. Although their waste products can be absorbed into the human bloodstream causing illness, their main effects are host malnutrition and obstruction of the bowel.

FIGURE 5 (a) Flatworm; (b) roundworm

Most of the organs of the tapeworm have degenerated and the body consists of a series of sections (proglottids) effectively filled with reproductive organs. The proglottids are formed from the head end (scolex) continuously throughout the life of the tapeworm. These

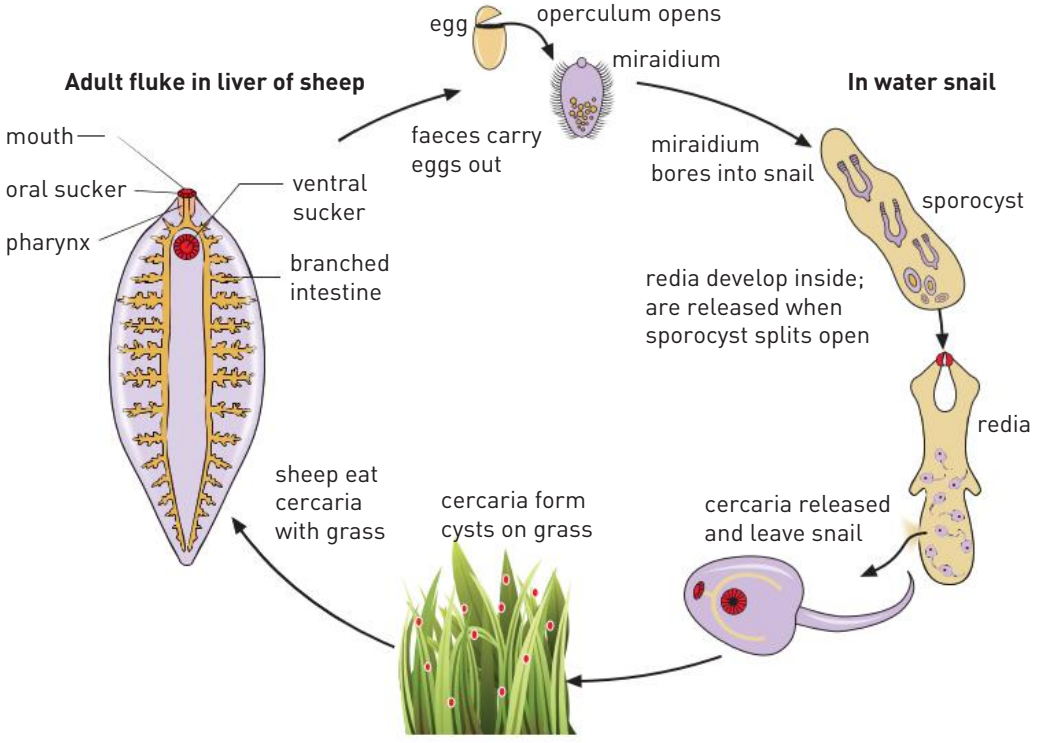


FIGURE 6 Life cycle of a liver fluke (*Fasciola hepatica*) is similar to that of the blood fluke. Since the practice of feeding the intestines of sheep to farm dogs has decreased, the number of cases of liver fluke has decreased.

FIGURE 7 *Taenia* scolex, immature and mature proglottids

new proglottids are pushed back as still more are formed. The scolex is an attachment organ, firmly fixed to the intestinal wall with suckers and, in some species, hooks. A thick, mucus-covered cuticle covers the entire body, preventing digestion by the host's enzymes while still absorbing the digested food in which it is bathed.

Diseases caused by roundworms

The roundworms, phylum Nematoda, occur in enormous numbers in a great variety of habitats. Most are free-living in moist soil and decomposing organic matter on the bottom of lakes and oceans; others are parasites of plants and animals. Humans are hosts to about 50 species of roundworms. Few people have escaped contracting pinworms during their childhood. Due to its low virulence, this infection has more annoyance than disease value. More serious diseases caused by roundworms occur in tropical and subtropical regions and include elephantiasis (with a mosquito vector), onchocercariasis (with a water-breeding fly as vector), ascariasis and hookworm, which are spread directly from person to person through faecal contamination of food or water.

CHECK YOUR LEARNING 11.7

Describe and explain

1 **Describe** how bacteria may cause disease in their host. Use an example to illustrate your answer.
2 **Describe** how bacterial diseases are transmitted.
3 **Identify** two macroparasites that are transmitted via contaminated water and describe the symptoms of the infected person.
4 **Explain** whether thrush is caused by an ectoparasite or an endoparasite.

Apply, analyse and interpret

5 One group of Protozoans, Phylum Apicomplexa, is only found as parasites of animals. **Determine** which feature of these organisms is compatible with this mode of living.
6 The blood fluke *Schistosoma* is very common in areas where there is canal irrigation of farmland. **Apply** your knowledge to **deduce** why this is the case.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 11.7
- » Viedo weblink
  Bacterial shapes
- » Weblink
  Malaria
- » Weblink
  Fungal infections

11.8 Animal defence mechanisms against pathogens

KEY IDEAS

- Ways pathogens enter the body
- Distinction between the innate and acquired (adaptive) immune systems
- Barriers inhibiting entry of pathogens into the body
- Types of white blood cells and their role in the innate immune system
- How complement proteins are activated and act on pathogens
- The two components of the acquired immune system (humoral B-lymphocytes and cell-mediated T-lymphocytes)
- The action of antibodies on antigens
- Interaction between B-lymphocytes and T-lymphocytes
- Allergic reactions

immune system
a host defence system, comprising many biological structures and processes within an organism, that protects against disease

innate immune system
the system of non-specific defence mechanisms that includes physical barriers such as skin, chemicals in the blood, and white blood cells that attack foreign cells in the body

acquired (adaptive) immune system
immunity that is not present at birth but is 'learned'; the learning process starts when a person's immune system encounters foreign invaders and recognises non-self substances (antigens) – the system then generates special chemicals (antibodies) that neutralise the pathogen

In order for a pathogen to cause disease, it must first gain entry into the appropriate host cells and then, in most cases, multiply. To do this, it must overcome defences the host has evolved to prevent this.

Entering the body

Pathogens may enter the body through natural openings or via wounds and breaks in the skin. Each of the natural openings leads to a tube lined with soft, moist membranes that are safe breeding havens for many pathogens:

- **eyes**: through contact and dust – conjunctivitis
- **nose**: airborne organisms – tuberculosis, cold, influenza, measles
- **mouth**: contaminated food, drink, utensils – cholera, bacillary dysentery, tapeworm, salmonella food poisoning
- **urinary, reproductive and anal passages**: by contact, gonorrhoea, HIV, syphilis, candidiasis.

When there is no break present, the human skin has a remarkable protective ability against microorganisms. The larvae of *Schistosoma*, hookworm, and the fungi that produce tinea and ringworm are among the few pathogens that can enter unbroken human skin. As has been seen, many pathogens can enter from vectors that penetrate the skin. Contaminated needles used for injection can spread HIV and hepatitis. Many pathogens, such as bacteria-causing tetanus and septicaemia, enter the body via scratches and abrasions.

The body has many defences against disease that constitute the **immune system**. There are two parts of the immune system, each of which plays a role in defending the body:

1. the **innate immune system**
2. the **acquired (adaptive) immune system**.

The innate immune system

The innate immune system is present in all organisms and is always working. It does not require any special preparation to prevent infection. It includes physical barriers to prevent entry of pathogens and components of the blood (white blood cells and complement proteins).

First line of defence – barriers to entry of pathogens

Physical and chemical barriers to the entry of pathogens are show in Table 1.

TABLE 1 Defence barriers to prevent the entry of pathogens into the mammalian body

Barrier	Method of defence
Skin	Tough, physical barrier Dry outer layer of cells inhibits bacterial growth. Oil and sweat glands produce anti-bacterial and anti-fungal substances. Beneficial bacteria live off the oil secreted by sebaceous (oil) glands and produce acids that prevent pathogen growth.
Mucous membranes	Pathogens get caught in mucus, which is coughed up or swallowed. Contain antibodies to prevent pathogens attaching. Harmless microbes produce substances that inhibit growth and entry of pathogens.
Cilia	Move mucus-containing pathogens out of the lungs.
Urinary and vaginal tracts	Acidic conditions inhibit growth and entry of pathogens.
Alimentary canal	Saliva contains chemicals to destroy microbes (e.g. the enzyme lysozyme destroys some bacterial cells). Stomach acid is intolerable to many pathogens. Other pathogens cannot tolerate the basicity of the intestines.
Tears	Wash pathogens away from the eyes.
Urine	Acidity prevents growth of pathogens. Flushes and cleans urinary system.

Study tip

'Skin' by itself cannot be used to mean a physical barrier as the skin may have small wounds or breaks. It must be described as 'intact skin' to ensure it provides a barrier to the pathogens.

Second line of defence

If a pathogen penetrates these barriers, the secondary defence system must become activated. This system will react the same way for any pathogenic organism; it is non-specific.

All the cells in an organism have special protein molecules called the MHC (major histocompatibility complex) on their outer membrane. It is a kind of self-marker or identity tag. The immune system can therefore recognise 'self' (all body cells of an individual have exactly the same MHC I on their surface). MHC II proteins are found only on certain cells, such as macrophages and B-lymphocytes, and are used in the recognition of foreign cells. Cells not containing the specific MHC I for the individual are not recognised and therefore attacked by the immune system. Pathogens such as viruses, parasites, fungi and bacteria do not contain the specific host identification marker. Any non-self-marker is known as an **antigen** (Ag) to the host organism, and it will initiate the immune response.

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

basophil
a white blood cell involved in inflammatory reactions

mast cell
a type of granular basophil cell in connective tissue that releases heparin and histamine during inflammation and allergic reactions

White blood cells

White blood cells (leucocytes) play a very significant role in the immune process. They are found in the blood, tissue fluids surrounding cells and in the lymphatic system. All leucocytes are formed in the bone marrow and have a nucleus.

There are five different types of leucocytes: neutrophils, eosinophils, basophils, monocytes and lymphocytes.

Each type of leucocyte either performs the same function in different parts of the body (e.g. in tissue fluids or lymphatic fluid) or has different functions.

- **Basophils** and **mast cells** are important in **inflammatory reactions**. When tissue is damaged and pathogens enter the body, chemicals (chemokines – a type of cytokine)

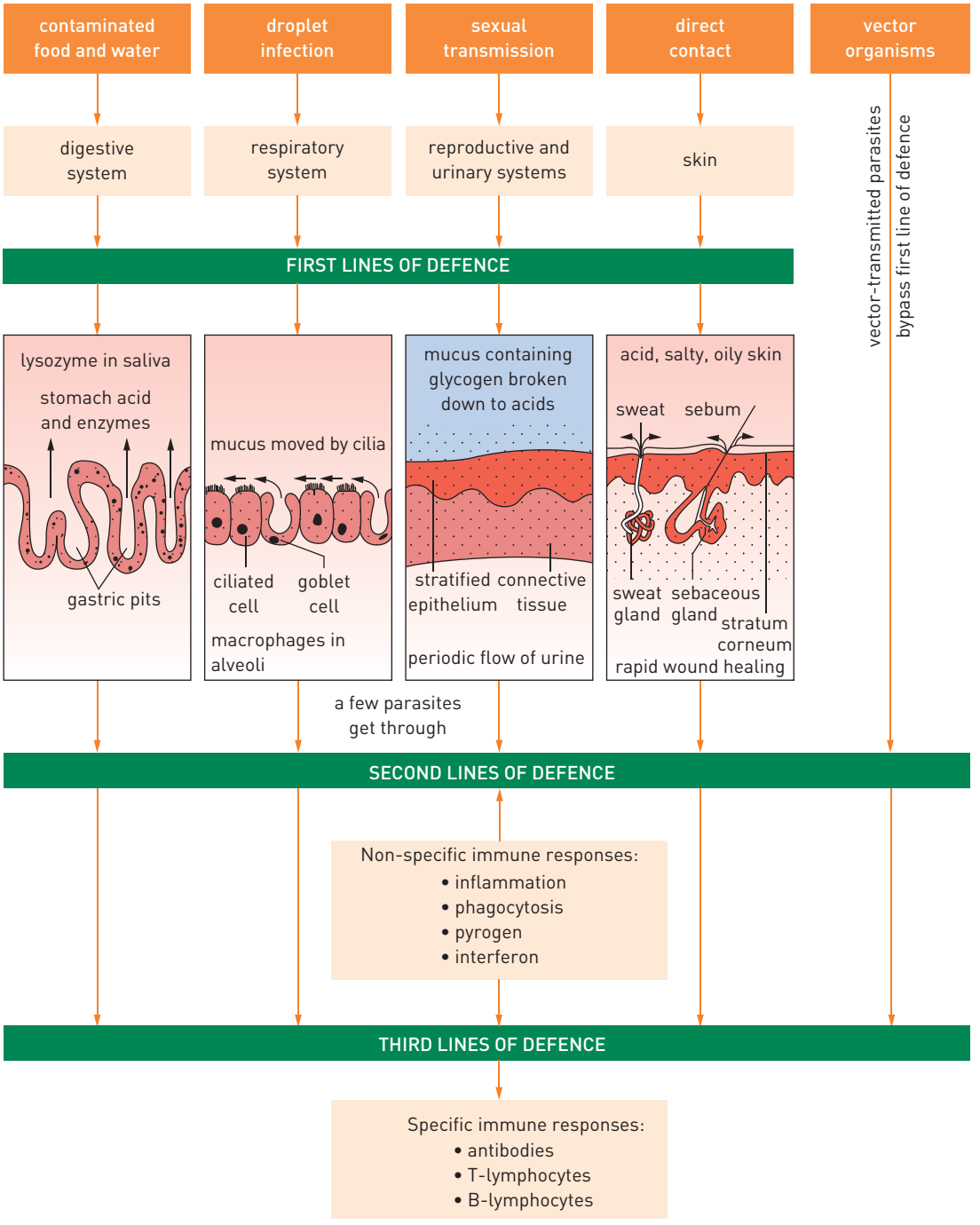


FIGURE 1 The body's defences against disease

are released. These chemicals stimulate the basophils and mast cells to produce and release the chemical called **histamine**. This chemical messenger redirects blood flow to the injured area where the vessels dilate. Increased numbers of phagocytes, therefore, flow into the area to destroy any pathogens. Because of the increase in the amount of blood present, the area becomes red and swollen. The basophils also secrete the chemical heparin, which prevents the blood clotting. In more severe infections, the inflammation can be more widespread and accompanied by a fever. The fever is brought about by chemicals called **pyrogens** and aids in the destruction of the pathogens. Also involved

inflammatory reaction
a response of the body to an injurious agent, characterised by swelling, pain or heat

histamine
a chemical secreted by basophils and mast cells to direct blood flow to an injured area

pyrogen
a chemical released by activated immune cells that induces fever

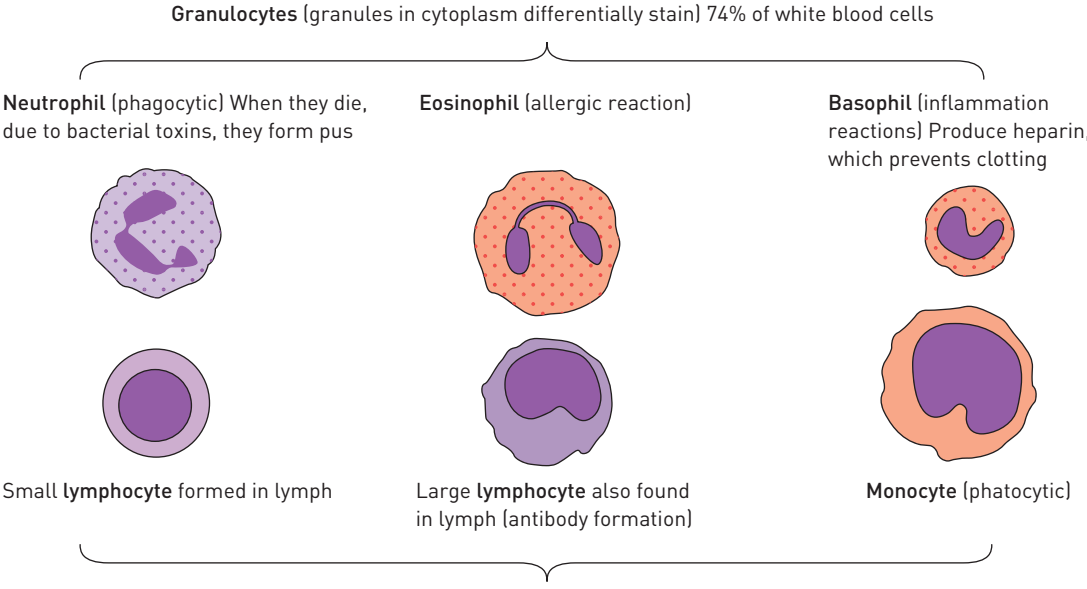


FIGURE 2 Types of white blood cells

prostaglandin
a chemical released from damaged cells that directs blood flow to an injured area

neutrophil
a phagocytic, granulocytic white blood cell

monocyte
a large white blood cell that is formed in the bone marrow, circulates in the blood, and destroys pathogenic bacteria by phagocytosis; monocytes develop into macrophages in various body tissues

macrophage
a large, white blood cell, occurring principally in connective tissue and in the bloodstream, that ingests foreign particles and infectious microorganisms by phagocytosis

eosinophil
a white blood cell that is involved either in the breakdown of macroparasites or in allergic reactions

lymphocyte
a white blood cell found in the lymphatic system

in the inflammatory response is another group of chemicals: **prostaglandins**. These are released from cells damaged by the pathogen and act with the histamine to redirect the flow of blood to the injured area.

- **Neutrophils** and **monocytes** are phagocytes that ingest foreign matter. Monocytes pass through the capillary walls and enter tissue fluid where they mature into large phagocytic cells called **macrophages**. A sac of enzymes (a lysosome) within the phagocytic cell fuses with the engulfed pathogen, causing it to be digested. When neutrophils die, due to bacterial toxins, they form pus.
- **Eosinophils** have two major functions. They can help in the destruction of macroparasites such as worms, by secreting digestive enzymes into them. Eosinophils also take part in allergic reactions.

1. Damage to tissue; invasion by pathogens.
2. The entry of pathogens triggers the release of chemokines from surrounding tissue.
3. The chemokines act on basophils and mast cells (types of leucocytes), causing them to release the chemical histamine; prostaglandins are also released.
4. Histamine and prostaglandins redirect blood flow to the site of injury, bringing heat, fluid and phagocytes, which destroy the pathogens.

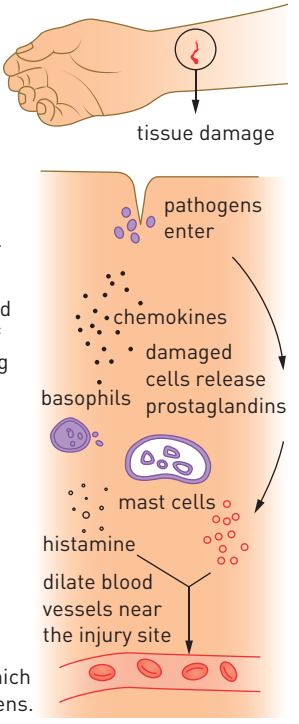
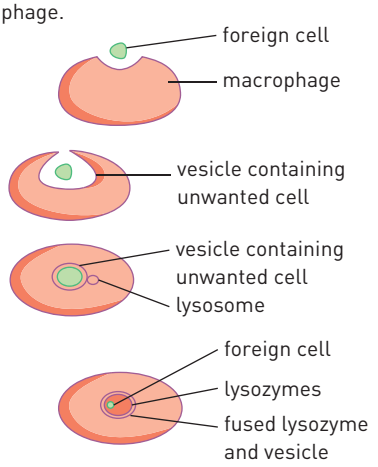


FIGURE 3 The inflammatory response

(a) **Phagocytosis**

Phagocytosis is the ingestion and destruction of foreign or infected cells by phagocytes.
Consider a typical phagocyte – a macrophage.

1. The phagocyte forms a groove, which engulfs the foreign cell.
2. The phagocyte ingests the foreign cell, forming a package or vesicle around it.
3. A lysosome and the vesicle containing the unwanted cell fuse together.
4. The unwanted cell is 'lysed' or broken down by lysozymes (enzymes) within the lysosome.



(b)

FIGURE 4 Phagocytosis: (a) the process; (b) fibril-like pseudopodia of the macrophage attaching to the rod-shaped bacterium, which will be ingested and destroyed

- **Lymphocytes** are found in the lymphatic system and are responsible for the acquired immune system. The lymphatic system is a series of vessels that pass tissue fluid through lymph nodes before returning it to the blood circulatory system. Pathogens become trapped in the lymph nodes where they are systematically attacked by both lymphocytes and macrophages.

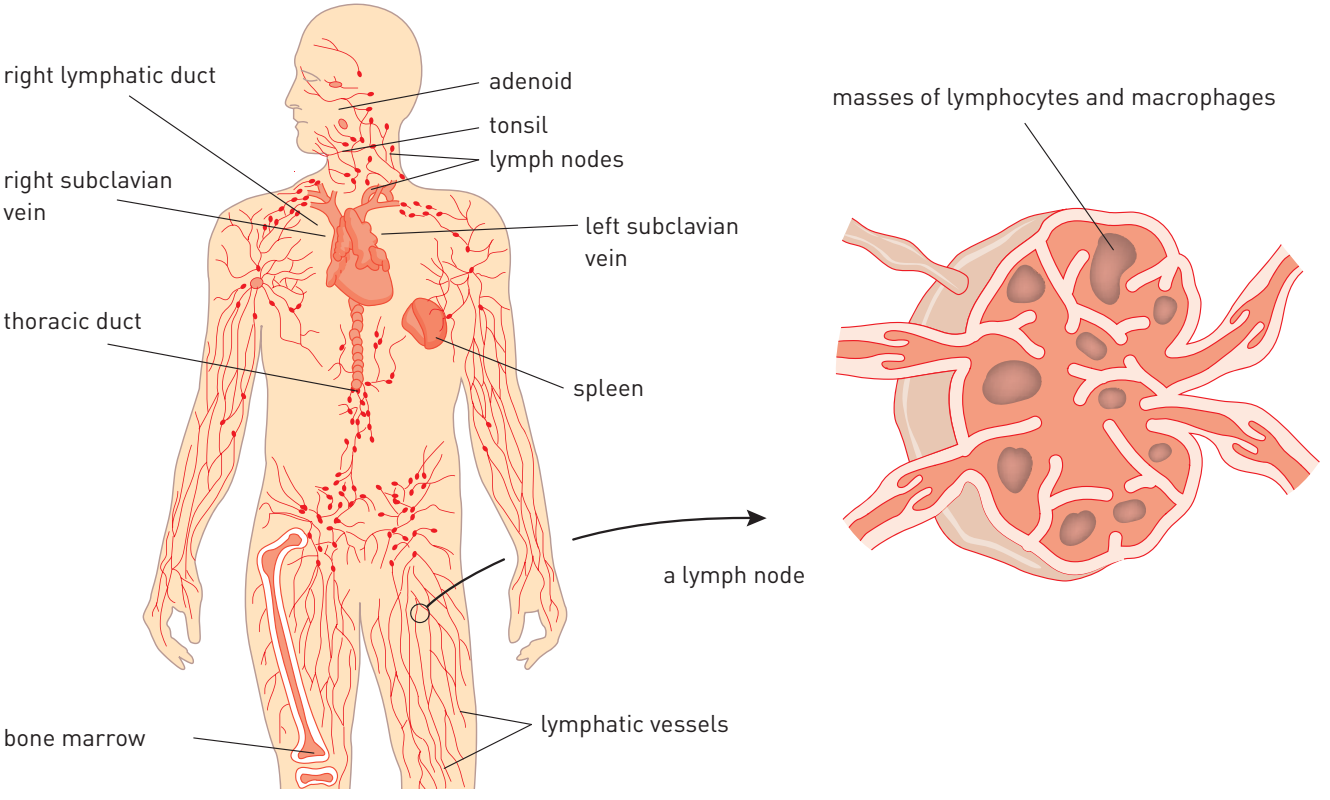


FIGURE 5 The human lymphatic system

The complement system

complement system
a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter

The **complement system** consists of about 20 proteins that are formed in the liver. They are normally found in the blood plasma and intercellular spaces. Each type is produced in an inactive form and, when activated, can undergo a series of changes (termed a cascade) that results in parts of the protein being removed. Each step in the cascade produces a chemical that may react with a specific chemical on the foreign matter.

There are three distinct pathways through which the protein complement can be activated on pathogen surfaces. The first pathway is activated by antibodies attaching to a pathogen's antigen. In the second pathway, a chemical, lectin, attaches to the pathogen and this attachment activates the complement protein. Lastly, a complement protein recognises specific chemicals on the bacterial surface.

In each case, the complement may trigger:

- phagocytosis by signalling phagocytes (opsonisation)
- direct destruction, by the cascade's terminal enzyme 'punching' holes in a bacterium's wall and causing it to burst
- agglutination by altering the bacterial surface and causing them to stick together and thus aiding phagocytosis
- neutralisation of viruses by direct attack
- cell signalling, causing neutrophils and macrophages to move to the pathogen
- activation of mast cells and basophils to release substances that lead to increased blood flow and increased leakage of complement proteins to help inactivate or immobilise bacteria
- inflammation.

The complement system has the potential to cause damage to the body's own cells. Therefore, its activation needs to be tightly regulated. This is achieved by complement control proteins that are present at a higher concentration in the plasma than the complement proteins themselves. Some of these control proteins are also present on the membranes of self-cells to prevent them being targeted.

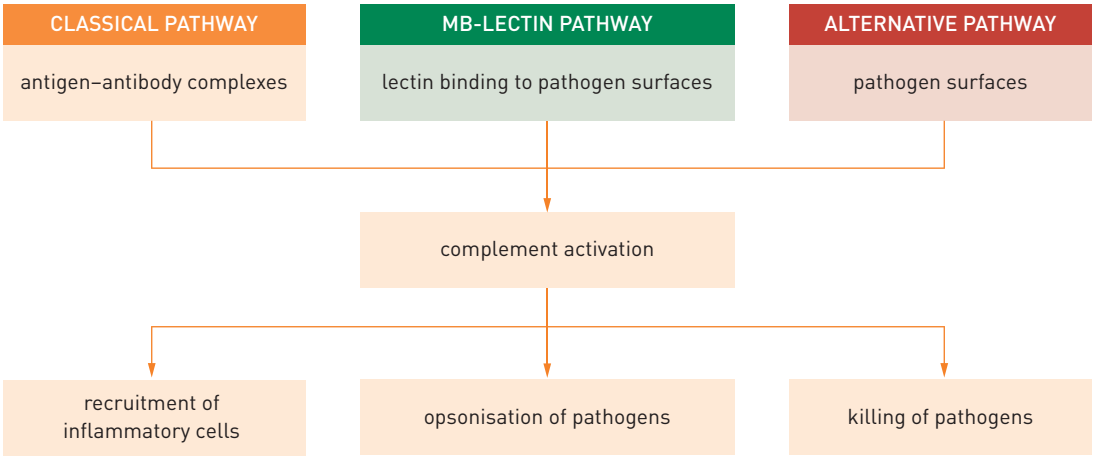


FIGURE 6 The three pathways of complement activation

Acquired (adaptive) immune system

The acquired (adaptive) immune system needs to be 'primed' before it can be fully effective (i.e. it forms a record of past exposure of the body to potentially dangerous molecules and pathogens).

The acquired immune system distinguishes two groups of foreign substances:

1. antigens: molecules on the surface of viruses and foreign cells
2. self cells that display abnormal MHC self-marker proteins (from antigens that have been engulfed and broken down, or from virus-infected and tumour cells that are actively synthesising foreign proteins).

These two groups of molecules are detected as foreign to the body by specialised white blood cells called lymphocytes. They enter the bloodstream from the bone marrow and follow one of two separate pathways as they mature. Those that pass through the thymus gland become sensitised and form **T-lymphocytes** or T-cells. Lymphocytes that do not pass through the thymus are termed **B-lymphocytes** or B-cells.

The humoral response

The activation of the B-lymphocytes is a **humoral** (or **antibody-mediated**) **response**. B-lymphocytes congregate in lymph nodes, the tonsils, spleen, appendix and in specialised areas (Peyer's patches) in the gut. When they encounter a particle with a non-self antigen on its surface, the B-lymphocytes produce a gammaglobulin molecule. The gammaglobulins contain five classes of immunoglobulin or **antibodies** that differ in the amino acid sequence of one part of the gammaglobulin molecule. The specific sequence is initiated by the B-lymphocyte in response to a particular antigen. The antibodies produced by each B-lymphocyte will recognise the shape of only one antigen molecule.

The presence of an antigen stimulates B-lymphocytes to divide rapidly and produce many identical cells. Some of these cells turn into **plasma cells**. The mature plasma cells produce and secrete antibodies that have combining sites complementary to the particular antigen. Other B-lymphocytes become **memory cells**. These cells persist long after the original antigen has been removed or destroyed and become new antibody-producing plasma cells in reinfection.

When an antibody binds with the antigen, it may:

- block parts of the pathogen needed to survive (neutralisation)
- cause the foreign matter to agglutinate (stick together) to facilitate phagocytosis
- cause the foreign matter to break up and dissolve (precipitation)
- produce an antitoxin to the pathogen's toxins (complement activation).

The cell-mediated response

The **cell-mediated response** involves mostly T-lymphocytes. Antigens stimulate the production of T-lymphocytes in the thymus gland. On contact with the complementary antigen of foreign matter, these sensitised cells release soluble proteins (lymphokines – a type of cytokine) into the body fluids. These proteins may:

- attract phagocytes to the foreign matter
- prevent the foreign matter from leaving a site
- activate monocytes and so increase phagocytosis
- kill the pathogenic cell by punching holes in its membrane.

Some T-lymphocytes also become memory cells. T-lymphocytes are responsible for reactions such as graft rejections, delayed hypersensitivity and resistance to cancer. Although

T-lymphocyte
a lymphocyte that has passed through the thymus during maturation

B-lymphocyte
a white blood cell that does not pass through the thymus as it matures; involved in antibody formation

humoral response
the response of the acquired immune system

antibody-mediated response
immunity conferred to an individual through the activity of B-lymphocytes and their progeny, which produce circulating antibodies in response to the presence of an antigen and recognise the substance upon renewed exposure

antibody
a gamma globulin protein found in the blood or lymph, and produced by B-lymphocytes as an immune defence against foreign agents (antigens)

plasma cell
a cell, developed from activated B-lymphocytes, that makes large amounts of a specific antibody

memory cell
a small, long-lived lymphocyte (B or T) that has previously encountered a given antigen and that, on re-exposure to the same antigen, rapidly initiates the immune response

cell-mediated response
antigen activation of T-lymphocytes in the thymus to release soluble proteins to inactivate a pathogen

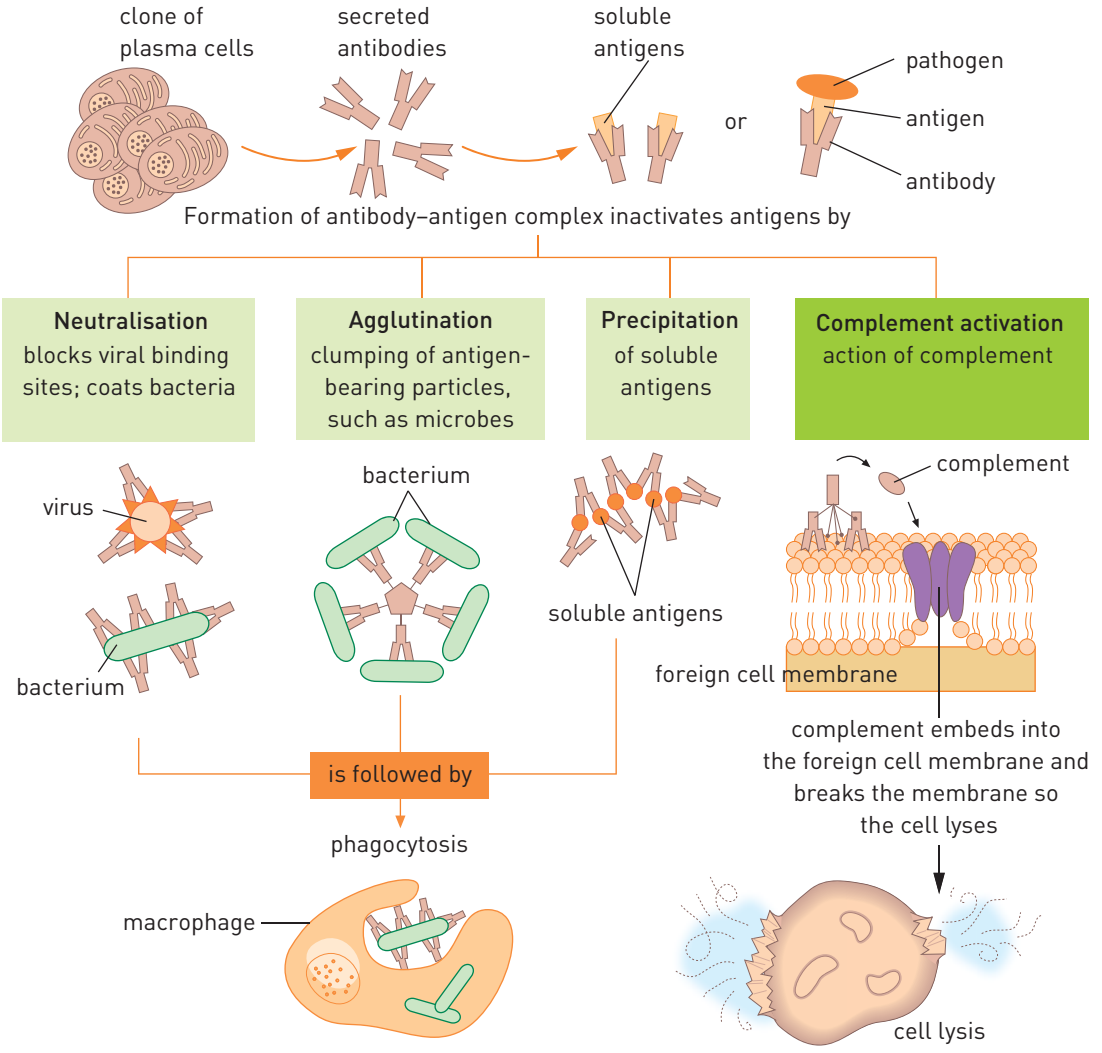
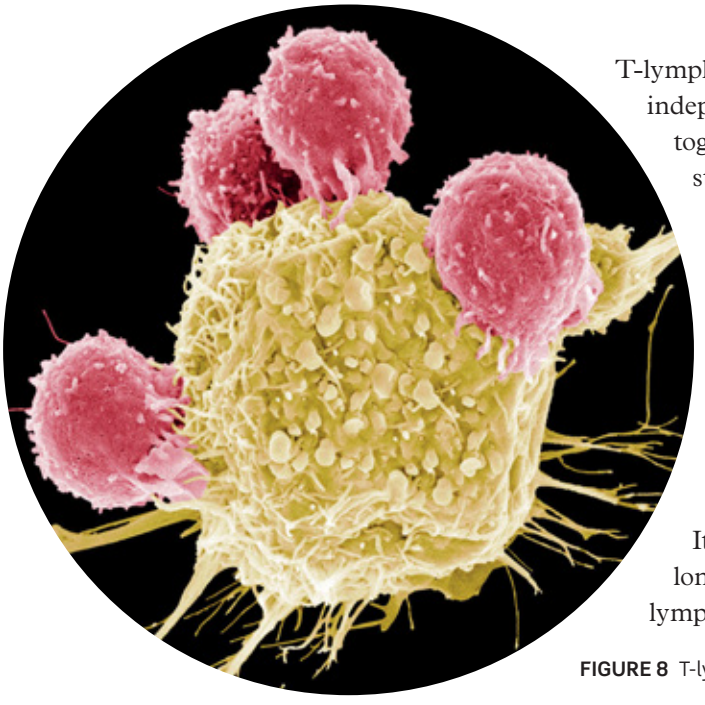


FIGURE 7 The action of B-lymphocytes in antibody production and the action of antibodies in destroying antigens and pathogens



T-lymphocytes and B-lymphocytes are capable of producing independent immune responses, they sometimes work together. Some T-lymphocytes have a 'helper' function, stimulating the production of antibodies. Other T-lymphocytes suppress antibody formation when helper T-lymphocytes and B-lymphocytes have carried out the immune response. Another type of T-lymphocyte (cytotoxic T-lymphocyte) induces toxicity in the cytoplasm of the pathogen, which kills it.

The HIV virus attacks helper T-lymphocytes, thus inhibiting the whole immune system. The AIDS victim is therefore vulnerable to all sorts of diseases. It has also been found that mental stress, bereavement, loneliness and depression affect the operation of the lymphocytes and reduce T-lymphocyte activity.

FIGURE 8 T-lymphocytes attacking a cancer cell

TABLE 2 Components of the acquired immune system

Name	Description	Role
Antibodies	Proteins that the body produces when it detects specific antigens. Different antigens stimulate the productions of different corresponding antibodies	Bind with antigens, causing them to clump together to form an antibody–antigen complex. Antibody–antigen complex is more easily recognised and destroyed by macrophages than antigens alone.
B-lymphocytes	Special kind of lymphocyte. Produced in bone marrow. Control (humoral) antibody-mediated immunity.	When a B-lymphocyte recognises an antigen, it is cloned to produce a mass of identical cells. The B-lymphocytes work as antibody producers (plasma cells) or memory cells, which provide long-term immunity.
T-lymphocytes	Special kind of lymphocyte. Produced in the bone marrow. Mature in thymus gland. Control cell-mediated immunity.	**Cytotoxic T-lymphocytes** produce toxic substances that destroy cells that have been invaded by a pathogen. They defend the body from cancer cells and transplant tissue. **Helper T-lymphocytes** help B-cells divide rapidly. **Suppressor T-lymphocytes** turn off the immune response and supress the production of antibodies when they are not needed. **Memory T-lymphocytes** recognise the antigen if it is re-introduced, providing long-term immunity.

CHECK YOUR LEARNING 11.8

Describe and explain

1 **Describe** ways in which pathogens can enter the body.

2 **Define** the immune system. Explain the difference between the innate and acquired immune systems.

3 One of the body's responses to tissue damage is an inflammatory reaction. **Explain** how this is achieved and its purpose.

4 The human body is said to have three lines of defence against invading pathogens:
- The first line involves physical and chemical barriers to pathogen entry.
- The second line of defence is a non-specific response of the immune system.
- The third line of defence is a specific response of the immune system to the particular pathogen.

Describe how each of these mechanisms operates.

Investigate, evaluate and communicate

5 **Discuss** the differences between an antigen and an antibody.

6 **a** **Discuss** why B-lymphocytes and T-lymphocytes are considered part of the acquired immune system rather than the innate immune system.

b **Predict** how these cells would be involved in response to:
- **i** an infected cut on a finger
- **ii** virus-infected cells
- **iii** a grafted kidney.

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 11.8

» **Video**
Inflammatory response

» **Video worksheet**
Inflammatory response

» **Weblink**
Antibodies

SCIENCE AS A HUMAN ENDEAVOUR

11.9 Transplant rejection

KEY IDEAS

- Organ compatibility
- Use of immunosuppressant drugs
- Graft vs host disease

Medical technology has advanced to such a high level that it is possible to replace a diseased organ from one individual with a healthy organ from another individual. In kidney transplants, this usually involves the transfer of a single kidney from a healthy living donor. Both recipient and donor are able to survive with a single kidney. A similar situation occurs in bone marrow transplants. For most other organ transplants, however, the donor must have very recently died. For example, a living donor cannot donate their heart or lungs.

The success of the transplant depends on the compatibility of the donor and recipient cells. Only identical twins have exactly the same MHC I markers on their cells. Closely related individuals will generally have similar antigens due to their similar genetic backgrounds; however, inheriting different sets of genes from each of their parents will result in some differences. The tissues of the potential recipients are carefully examined to ensure their markers are as closely matched as possible to that of the donor. The closer the MHC I compatibility between donor and recipient, the smaller the immune response and vice versa, which can result in tissue or organ rejection (graft vs host disease). Most recipients are treated with **immunosuppressant drugs** to prevent the action of the immune system. This delays rejection for many years.

immunosuppressant drug
a drug used to prevent the body from rejecting a transplanted organ

Immunosupression

Suppression of T-lymphocytes has been found to be the most effective means of maintaining the transplant. Early immunosuppressant drugs completely blocked the immune system, making the recipient vulnerable to infection.

Because B-lymphocyte activation can overcome most bacterial invasions, blocking the T-lymphocytes with drugs like cyclosporine provides a compromise between supressing the immune system so that the graft survives and allowing the immune system to protect the recipient.

Graft vs host disease

Occasionally the transplanted graft tissue, for example transplants of bone marrow or other organs with lymphatic tissue, contains immune cells from the donor. When this occurs, the donor B- and T-lymphocytes will leave the transplanted tissue and start a humoral or cell-mediated immune response against the rest of the host's body. This may result in damage to the liver, skin and digestive tract. The main treatment is suppression of the immune system.

CHECK YOUR LEARNING 11.9

Describe and explain

1 **Describe** why your identical twin would be the safest option for an organ transplant.

Investigate, evaluate and communicate

2 **Investigate** the ethical considerations around organ donation. Based on your findings, conduct an in-class debate on the topic 'Organ donation should be compulsory for all Australian citizens'.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 11.9
- » Video weblink
  Preparing for a transplant
- » Weblink
  Bone marrow transplant
- » Weblink
  Graft versus host disease

11.10 Immunity

KEY IDEAS

- Development of immunity
- Immunological effects

natural active immunity
immunity which occurs when a person is exposed to a live pathogen and develops a primary immune response, which leads to immunological memory

natural passive immunity
antibody-mediated immunity conveyed to a foetus or infant by its mother

colostrum
the first form of milk produced by the mammary glands of mammals (including many humans) immediately following delivery of a newborn

artificial active immunity
an active immunity acquired by vaccination with a vaccine containing active antigens to prevent the development of the disease in the future

Individuals may recover from disease caused by pathogens as a result of the immune responses of the B-lymphocytes and T-lymphocytes. Due to the formation of memory cells for a particular pathogen, the body builds up resistance or immunity to further attacks by the same type of organism. This is termed **natural active immunity**. 'Natural' refers to the individual being exposed to the living pathogen, and 'active' refers to the production of the memory cells.

Natural passive immunity is obtained when a mother is exposed to the living pathogen (natural) and then passes her antibodies to the foetus through the placenta. As the baby does not produce memory cells, the immunity is termed passive. These antibodies are also present in the first 'milk' (**colostrum**) secreted after birth. This immunity lasts for only a short time after birth, but further antibodies are contained in the mother's milk. Breastfeeding of babies is therefore desirable.

Immunity can also be acquired artificially. Injection of an individual with parts of or deactivated antigens can induce the immune system to react and ultimately produce memory cells. This vaccination or immunisation is called **artificial active immunity**. Three general types of antigens used in vaccines are:

1. sterile bacterial exotoxins
2. sterile, dead microorganisms
3. living infectious microorganisms whose ability to cause serious infection has been altered.

Vaccines

A vaccine is produced to target a specific pathogen, usually from a cultured sample. The pathogen is either killed or genetically altered so that it is no longer harmful. Once injected into an individual, the immune system reacts to the foreign antigen on the pathogen surface and forms memory cells that last for a period of time. The body's defence system is thereby 'sensitised' and immunity is achieved without the individual having to suffer the effects of infection by the pathogen. If the person or animal immunised becomes infected by the pathogen during that time, the memory cells quickly recognise it and the immune reaction is rapid enough to prevent the disease developing.

Vaccines against viruses are more difficult to produce than those for bacteria. They undergo rapid changes to their protein

FIGURE 1 The vaccine for influenza is not effective permanently.

coats and, as a result, their antigens. So, an influenza vaccination from one year could be totally ineffective in preventing people from contracting a different form of flu in the following year. Also, because viruses are not living organisms they cannot be killed. They require a living host or tissue culture in order to produce adequate numbers for a vaccination program. Their nucleic acid core must then be removed or chemically destroyed to leave just the antigenic protein coat and thus prevent the particle causing a host cell to produce more viral particles. Once produced, the vaccine must undergo rigorous testing to ensure it is effective.

TABLE 1 Types of vaccines and their effectiveness

Disease	Type of vaccine	Effectiveness	Possible complications if the disease is contracted
Diphtheria (bacterial)	Toxoid	Almost 100% for 10 years	Nerve, heart problems, death
Influenza (viral)	Altered	One season	Respiratory, cardiac problems, death
Measles (viral)	Weakened	95% for at least 21 years	Blindness, deafness, encephalitis, death
Mumps (viral)	Weakened	90% for 12 years	Sterility in males, inflammation of male and female sex organs
Poliomyelitis (viral)	Weakened (Sabin), and nucleic acid destroyed (Salk)	95% for 10 years	Paralysis, lameness
Rubella (viral)	Weakened	95% for 16 years	Possible foetal deafness and/or blindness if pregnant woman contracts the disease in the first 12 weeks of pregnancy
Human papillomavirus (viral)	Synthesised viral particles	Long term if given to 12- to 13-year-old boys and girls	Cervical cancer in females and penile cancer in males, also throat and/or anal cancer
Tetanus (bacterial)	Toxoid	100% for 10 years	Respiratory, cardiac problems, death
Whooping cough (pertussis) (bacterial)	Killed	70–80% for 2–10 years	Pneumonia, convulsions, encephalitis, death in infants
Meningococcal C disease (meningitis) (bacterial)	A conjugate vaccine composed of a carrier protein attached to an antigen made from the coat of the bacteria*	There is long-term immunity from one dose for individuals 1–19 years. Infants 6 weeks to 4 months need three doses of the vaccine for long-term immunity. Infants 1–12 months need two doses of the vaccine for long-term immunity.	Meningitis (inflammation/swelling of the lining of the brain) Septicaemia (blood poisoning)

It is important to note:

1 Weakened pathogens are altered to decrease infection. Many bacterial pathogens are killed for vaccination. A toxoid is an inert toxin of the type produced by the bacterium in question.

2 Viruses are not considered to be living. Vaccines are produced by destroying or altering the nucleic acid but retaining the viral surface coat that contains antigens.

3 Effectiveness is for adults or from teenage years on.

*This vaccine has been introduced as a free vaccine for 1–19-year-old individuals in response to the increased incidence of meningococcal C disease in recent years.

Serums

Serums that contain antibodies to specific antigens have been developed. In the case of serious infections, such as diphtheria and tetanus, the reaction to the bacterial toxin may be too fast for the individual to develop antibodies. Specific antibody serums are administered to counteract the infection and produce immediate resistance. In the case of most snake or spider bites, serums containing the antibodies to the specific toxins found in the venom are produced (antivenom). This is termed **artificial passive immunity**. This type of immunity invariably lasts for a year or so.

artificial passive immunity
immunity acquired by means of injection of serum containing antibodies into an individual who may have been infected with a particular pathogen

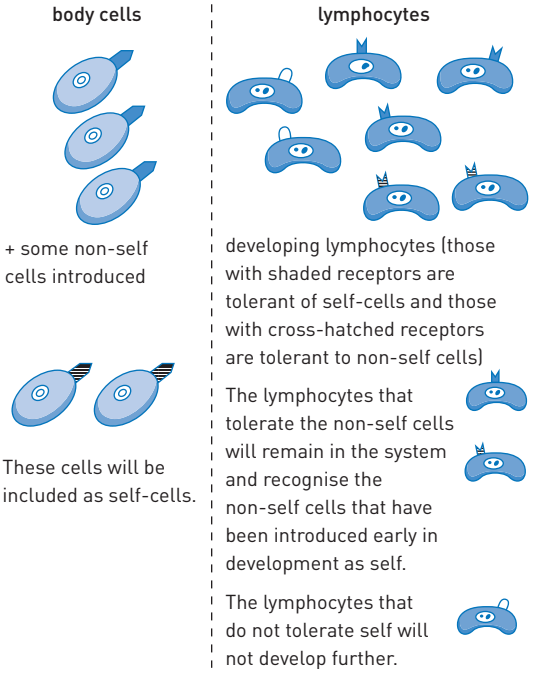


FIGURE 2 The development of immunological tolerance

allergen
an antigen that causes an allergic reaction in an organism

Immunological tolerance

Experimental evidence indicates that the ability of lymphocytes to recognise 'self' from 'non-self' is learned over a period. This principle has been applied to some people that have an allergy to bee stings. Under medical supervision, it has been possible to introduce very small amounts of the bee venom to the allergic individual. Over time, the immune system learns that the **allergens** in the bee venom are not dangerous and starts producing a special type of T-lymphocyte that supresses the rest of the immune cells. This condition is known as **immunological tolerance**. It is possible to develop this tolerance if the:

- animal is very young
- dose of antigen is high
- antigen has a low molecular weight
- dose of antigen is prolonged or repeated.

immunological tolerance
the failure to mount an immune response to an antigen

Diseases of the immune system

Autoimmune disease occurs if an organism loses its ability to recognise 'self' from 'non-self'. As a result, the individual's immune system manufactures antibodies against certain of its own cells. Cells of the blood, liver, kidneys, endocrine glands and stomach lining are most susceptible. Some autoimmune diseases can be treated with immune-suppressive drugs to prevent destruction of healthy cells. These drugs are similar to those used in grafting when a tissue or organ comes from another individual.

autoimmune disease
a disease in which the body produces antibodies that attack its own tissues

Haemolytic anaemia occurs when antibodies are formed against the individual's own red blood cells. The red blood cells break down after only a few days in circulation instead of the normal 100–120 days. The body cannot produce enough red blood cells to compensate for the high levels of breakdown. This results in a much-depleted oxygen supply to the cells.

haemolytic anaemia
a form of anaemia due to haemolysis, the abnormal breakdown of red blood cells

Interferons

Many animals, including humans, produce a group of substances in response to viral infections.

These small protein molecules, collectively termed **interferons**, prohibit further increase in viral numbers. Interferon prevents viral DNA instructing the host cell to produce more virus particles. Each species produces a specific interferon. Unlike other proteins, interferons are resistant to excessive heat and acidity.

interferon
a small protein- and glycoprotein-signalling molecule produced by lymphocytes, in response to infection and other biological stimuli

CHECK YOUR LEARNING 11.10

Describe and explain

1 **Explain** how B or T memory cells are formed. What is the function of a memory cell?

2 **Describe** two ways in which a person can become immune to a pathogen.

3 **Describe** what a vaccine is. **Explain** using an example.

Apply, analyse and interpret

4 An individual has been vaccinated with a particular antigen. Three weeks later the vaccination is repeated. **Determine** what one would expect after the second vaccination. Antibodies specific to the antigen are:

- **A** produced more quickly and in greater quantity than after the first vaccination
- **B** produced more quickly but in smaller quantity than after the first vaccination
- **C** produced more slowly but in greater quantity than after the first vaccination
- **D** not produced in any quantity as the antibodies from the first vaccination are still present in abundance.

5 Travellers to Africa are given immunoglobulin injections against hepatitis A infection. **Deduce** the type of immunity that has been conferred.

Investigate, evaluate and communicate

6 The cells of a developing foetus will have MHC I recognition proteins, unique to themselves, derived from the types found on each parent's gametes. Antibodies can pass across the placenta. **Investigate** and **discuss** your findings by writing a short report on why the mother's immune system does not reject her foetus.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 11.10
- » Video Weblink
  Immunisation for Queenslanders
- » Video Weblink
  Vaccinations for Vietnam
- » Weblink
  Autoimmune disease

11.11 Infectious diseases in plants

KEY IDEAS

- The variety of pathogens that infect plants
- Passive defence mechanisms (physical and chemical) utilised by plants to prevent infection
- Active plant defence mechanisms against pathogens

Plant pathogens

viroid
an RNA molecule without a protein coat

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)

Plants, like animals, can be infected with pathogens. Humans almost exclusively depend, either directly or indirectly, on plants for food. Plants also provide many non-food products such as wood, dyes, textiles, medicines, cosmetics, soaps and industrial chemicals. Pathogenic infections of plants, therefore, directly affect the human population. The main plant pathogens are **viroids** (RNA molecules without a protein coat), viruses, bacteria, fungi, fungus-like oomycetes, protozoa, nematodes (roundworms) and parasitic plants. **Ectoparasites**, like insects and mites, affect plant growth by eating the tissues. This may make the plant more susceptible to pathogen entry through wounds. Some ectoparasites are vectors for pathogens.

FIGURE 1 Bananas exhibiting bunchy top disease

FIGURE 2 Panama disease in bananas

In Australia, diseases of bananas have resulted in financial loss to growers and food shortage for consumers. Bunchy top is a viral infection that attacks conducting tissue in newly emerging leaves in plants in south-east Queensland and northern New South Wales. It results in short, narrow leaves that stand more upright than normal. A sap-sucking aphid is the vector for the virus. All plants in the area have to be destroyed to prevent further spread.

Panama disease also affects bananas. It is caused by a fungus (*Fusarium* sp. TR4 variety) and results in wilting of the plant by blocking water-conducting vessels. This disease destroyed a large proportion of commercial Cavendish banana crops in the Northern Territory in 1997 and in a plantation in Tully, North Queensland, in 2015. Since the fungus can remain in the soil for decades, the plants must be destroyed, and the property quarantined to prevent soil movement to other properties.

Two types of oomycetes also affect Australian growers. *Phytophthora cinnamomi* causes die-back in avocadoes and eucalypts (particularly the jarrah forests of Western Australia) as well as affecting the flowering rhododendrons, azaleas and camellias. *Phytophthora citrophthora* causes collar rot in a variety of fruit trees, resulting in cracking and oozing of sap from the bark at the base of the trunk.

TABLE 1 Some additional plant pathogens and their effects

Pathogen	Plant affected and symptoms
Viroids	Potato spindle-tuber disease Twisted leaves and stunted growth in tomatoes
Viruses	
Tobacco mosaic virus	Large number of species – stunted growth
Squash mosaic virus	Affects members of the melon family – distorted fruit; mosaic leaf pattern
Rice mosaic virus	Rice plants with mottled and stunted leaf growth
Bacteria	More prevalent in tropics and subtropics
Erwinia	Soft rot
Agrobacterium	Tumours (e.g. stems of stone fruit); scabs on gladioli bulbs
Pseudomonas syringae	Decreased fruit production in tomatoes
Fungi	A large range cause black spot on roses, gerberas and strawberries, grey mould on flowering annuals, dollar spot in lawns, downy mildew and powdery mildew on leaves.
Thielaviopsis	Cancer root, black root rot
Sclerotmia sclerotiorum	Cotton rot
Claviceps purpurea	Dutch elm disease
Urstilago	Smut
Puccinia	Rusts on cereals and grasses
Armillaria	Ringbarks roots of trees
Slime moulds	
Plasmodiophora	Club root in cabbages
Spongospora	Powdery scab in potatoes
Nematodes (roundworms)	Affect roots (e.g. tomato) and bulbs (e.g. daffodil)
Globodera	Potato cyst
Root knot	Affects uptake of water and nutrients for normal growth in a wide variety of host plants
Parasitic plants	
Mistletoe	Competes for nutrients of host plant
Dodder	Extracts nutrients from host plant; transmits viruses

CASE STUDY 11.11

The potato blight

Perhaps the most devastating plant disease recorded is the potato blight. Potatoes were spread by humans from the Andes (their country of origin) throughout the Americas, Europe and the United Kingdom after their discovery by the Spanish. Since the tubers are highly nutritious and rich in starch, the potato became the staple food for many. This was particularly so in Ireland where potatoes formed the major part of the diet. During the 1800s the oomycete *Phytophthora infestans* started to infect some potato varieties in the highlands of Central Mexico. The spores were spread with the tubers to other parts of the world. Since only one variety of potato was grown in Ireland, and it was susceptible to the disease, the impact was disastrous. First, the plant foliage forms a soggy mush and the oomycete travels down the stem to the tubers, which also rot. Between 1845 and 1857 over a million Irish died of starvation and 2 million emigrated. Although new, resistant varieties of potatoes have since been developed, as have a variety of means to control the disease, it is estimated that $2 billion each year is lost in revenue across the world due to this infection. This oomycete also affects tomatoes, pineapples, strawberries, apple and citrus fruit.

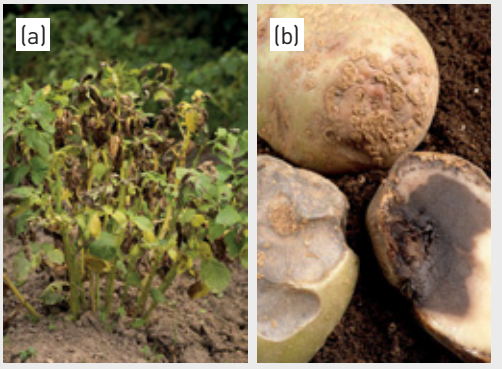


FIGURE 3 Potato blight: (a) effect on foliage; (b) effect on tubers

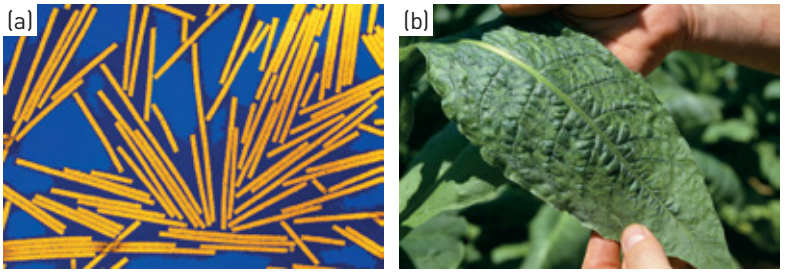


FIGURE 4 Tobacco mosaic virus: (a) virus particles (b) effect on the leaf. This virus was the first one to be identified (1930) although its effects were first noticed in tobacco crops in the 1800s. The virus affects over 350 different species of plants, resulting in stunting, mosaic pattern of light and dark green (or yellow and green), with yellow streaking or spotting on the leaves and malformation of leaves or growing points.

Plant defences to pathogens

Although lacking an adaptive immune system, plants exhibit a large array of innate mechanisms to inhibit entry, detect invading organisms and stop them before they are able to cause extensive damage. Most plant pathogens are host-specific or only infect a related group of plants; for example, the family Solanaceae includes tobacco, potato and tomato plants and all can be infected by the tobacco mosaic virus. Other groups of plants are not susceptible to this virus. Some pathogens have evolved mechanisms to overcome or avoid the plant's defences. Plant defence mechanism may be passive or active. Different plants utilise different strategies and combinations of strategies.

Passive defence mechanisms

Physical

Many plants have impenetrable barriers, such as bark, waxy cuticles and cell walls, which are resistant to many pathogens, although some can infect young leaves that have thin cuticles. Since plants are subject to attack by herbivores, many have leaf hairs (often containing chemicals) to defend them against insect pests. Others have thorns (modified branches), spines (modified leaves) or prickles (outgrowths of the epidermis) to protect against grazing animals. These features also act as barriers to pathogens. Some plants have a thick waxy cuticle on their leaves, which hang vertically down. This prevents the formation of a moisture film on the leaf surface. Dry surfaces inhibit infection by bacteria, fungi and nematodes as these organisms need water to survive while they adhere to the cell's surface. Vertical surfaces, however, are more prone to 'capture' windborne pathogens.

Stomata are natural openings in the plant for both pathogens and their vectors. Stomatal size relative to the size of the pathogen may be important. For example, mandarins are resistant to citrus cancer because their stomata are too small for the causative agent to enter.

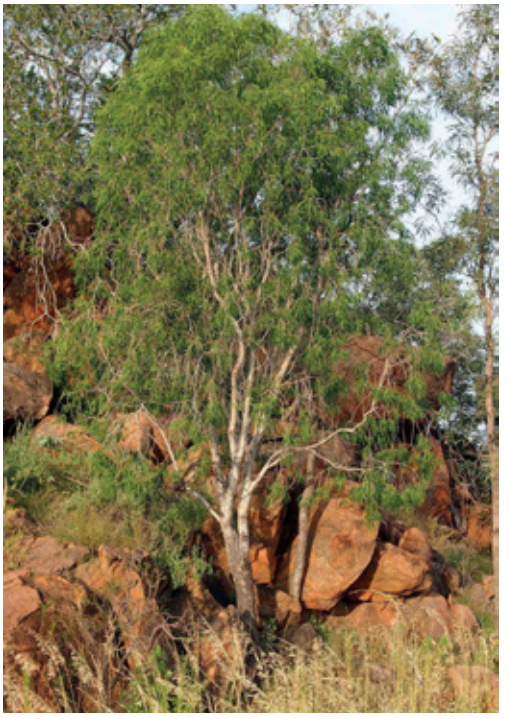


FIGURE 5 The pendulous foliage (e.g. of the weeping pittosporum) inhibits pathogen invasion, as well as reducing water loss.

Chemical

Each plant species has an optimal pH range for the soil in which it grows, and this acidity or alkalinity can exclude some pathogens. Similarly, the nutrients present in both the soil and plant cells can dictate the survival of particular pathogens. Iron depletion, for example, prevents the growth of certain fruit-rotting bacteria. Exudates on plant surfaces or compounds in their cells inhibit some pathogens.

Phytoanticipins are chemicals that may be excreted into the external environment, accumulated in dead cells (e.g. brown onion skins) or stored in vacuoles in an inactive form. They inhibit the germination of some fungal spores. For example, avocado root stock secretes an antimicrobial chemical, making it resistant to root rot caused by *Phytophthora cinnamomi*. Pyrethrin, produced by members of the chrysanthemum group, is an insect neurotoxin (many commercial insecticides are synthetic forms of pyrethrin). Marigold and asparagus roots secrete a nematode-inhibiting substance. Another group of these chemicals, the saponins, destroy the membrane integrity and function of certain fungal pathogens, but do not affect the oomycetes.

phytoanticipin
a chemical produced by plants to inhibit fungal spore germination

Some plants produce **plant defensins**. These are proteins that inhibit the development of fungi, bacteria and viruses. Some plant defensins accumulate during normal development while others are induced by a plant wound.

plant defensin
a protein produced by a plant to inhibit development of fungi, bacteria and viruses

Active defence mechanisms

Plants are able to recognise pathogens as 'non-self' from a large array of pathogen signals. The signal may be non-specific (e.g. fragments of cell wall from fungi, bacteria or damaged self-cells). The cell wall fragment may even be their own due to pathogen damage. A particular pathogen gene, or its product, may act as the signal. This can trigger a change in the host cell's metabolism, priming the plant against further infections.

Rapid active defences

Different plant species utilise different individual or combinations of strategies or different sequences of actions. These include:

- Changes in the membrane permeability can cause the osmotic pressure inside the cell to change, making it unsuitable for the pathogen.
- Rapid increase in cellular respiration – an oxidative burst – can lead to the death of the pathogen either directly or indirectly through host cell death.
- Cell wall reinforcement may occur with the attempted penetration by a pathogen. There is increased cytoplasmic streaming followed by an accumulation of host cytoplasm under the site of attempted invasion. This results in strengthening of the cell wall and possibly the deposition of lignin and/or a waxy substance.
- Hypersensitive cell death may occur when the host cells are extremely sensitive to a particular pathogen. The suicides of the infected cells or those surrounding them prevents further spread of the infection. Although this phenomenon is widespread in plants (e.g. cereal plant response to leaf rust fungi), it is not universal.
- Some plants produce **phytoalexins**. These chemicals are antibiotic and are produced by the plant in response to infection. They are non-specific although 350 phytoalexins have been identified in more than 100 plant species. Different 'organs' accumulate different types of this chemical. They are thought to be synthesised in cells adjacent to the infected site in response to a signal by either the pathogen or host cell. This produces a toxic microenvironment for the pathogen.

phytoalexin
antifungal or antibacterial compounds synthesised in plants in response to infection

FIGURE 6 'Shot hole' response by a leaf. The brown sections are the damaged host cells containing pathogens that have been encapsulated and released from the plant.

Delayed active defence

Wounds can be repaired (e.g. the secretion of gum to seal wounds on tree trunks) or the pathogen can be contained within damaged host tissues to restrict spread. Fleshy tissues, roots, fruit and bark may be sealed in layers of bark. Sometimes a special layer of cells, which causes that part of the plant to break off, is formed around the infected area. This can result, for example, in sealed holes in leaves – 'shot hole' symptoms.

Pathogenesis-related proteins may be produced by the plant. A massive shift in cell metabolism and gene expression occurs due to pathogen invasion, resulting in many novel proteins being produced. These proteins may be enzymes capable of dissolving fungal cell walls, or protein-digesting enzymes that are antiviral or antibacterial.

Systemic acquired resistance may occur if the plant survives the infection. The whole plant becomes protected against subsequent attacks. This protection, unlike the specific antigen–antibody-mediated immune responses of vertebrates, provides the plant with immunity to a wide range of pathogens.

CHECK YOUR LEARNING 11.11

Describe and explain

1 **Explain** why diseases in plants can have large impacts on human survival.
2 **Describe** a viroid. **Explain**, with reasons, whether it is considered a living organism.
3 **Identify** and **describe** a plant pathogen. Include the method of infection and the effects of the disease.
4 **Identify** two plant diseases that are of economic significance to humans. For each, name the pathogen causing the disease and how it affects the plant.
5 **Describe** how passive mechanisms of defence operate against a large variety of pathogens.
6 **Identify** what ability of the plant is necessary for active defence mechanisms to operate.

Apply, analyse and interpret

7 Plant defence mechanisms to pathogens can be considered as passive or active. **Contrast** the difference between these two modes of defence.
8 **Compare** the ways in which the active defence mechanism of the plant is similar to the immune response of vertebrates. How is it different?

Investigate, evaluate and communicate

9 **Identify** a plant disease. **Manipulate** the following information in a report or presentation:
- **identify** the plant species
- **identify** the pathogen causing the disease
- **explain** how the pathogen reaches the plant
- **identify** measures taken by the plant to resist the pathogen
- **explain** how the pathogen overcomes the plant defence mechanisms
- **describe** the effects of the disease on the plant
- **describe** any socio-economic implications of the disease.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 11.11

» Weblink
Queensland crop diseases

» Weblink
Crop rotation

» Weblink
Phytoanticipins

CHAPTER 11

Review

Chapter summary

11.1 A disease is a condition that causes dysfunction of an organism. Disease can be caused by genetic factors, infectious factors (factors that can be transmitted from host to host) or non-infectious lifestyle factors (e.g. lack of nutrition, smoking).

11.2 Non-infectious diseases have been linked to a variety of causes such as malfunctioning of body structure and/or function, and inherited, environmental and nutritional conditions.

11.3 Parasites are organisms that live in or on, and gain their nutrition from, another organism. Endoparasites usually have special adaptations associated with living in a host. Pathogens cause disease in another organism. Not all parasites are pathogens, but all pathogens are parasites. Diseases that can be spread from individual to individual as a result of pathogens are termed infectious diseases.

Many pathogens use a vector organism to transfer from host to host. The vector may be a reservoir organism or a secondary host.

An infectious disease that can be passed directly to another individual of the same species is termed contagious (e.g. influenza). A disease that affects a large number of individuals in an area at any particular time is considered to be an epidemic. If the disease spreads to many countries, it is termed pandemic.

11.4 The virulence of a pathogen is determined by its ability to enter the host, multiply in host tissues, resist or not stimulate, the host defence mechanisms and damage the host (i.e. cause disease). This is largely determined by proteins on the surface of the pathogen or by proteins it produces (toxins).

11.5 Science as a Human Endeavour: Development of the understanding of infectious diseases progressed with the microscope. Major steps were made by Pasteur, Koch, Cohn and Lister. Koch's postulates are still used to establish the link between a disease and its pathogenic cause.

11.6 Some diseases result from abnormal prion proteins that cause normal prions to become abnormal.

Viruses are non-living particles composed of nucleic acid covered in a protein coat. When they invade a cell, they cause the host cell to produce more virus particles. Many human diseases are caused by viruses, with influenza being the most virulent. Many viruses are able to cross hosts from animals to humans.

11.7 Pathogens may be microbes (bacteria, protozoans or fungi) or macroorganisms (such as flukes, tapeworms or roundworms). A great number of microbes and macroorganisms are pathogens of humans, their domesticated animals and cultivated plants. Some pathogens are transmitted via the air, in contaminated food or water, or by a vector.

Bacteria are single-celled prokaryotic organisms. Although the majority are non-pathogenic, some are the cause of highly infectious diseases (e.g. plague and cholera). Similarly, some fungi can also cause disease. If probiotic intestinal bacteria cannot control the fungus causing thrush, *Candida albicans*, spores can enter the bloodstream and result in a variety of other afflictions such as arthritis and depression. Protozoans are animal-like, unicellular eukaryotes, some of which are the cause of fatal diseases such as malaria and African sleeping sickness.

Most macroscopic endoparasites of humans are flatworms (e.g. tapeworms) or roundworms (hookworm, *Ascaris*). Left untreated, diseases from these worms can be fatal.

11.8 The human body has a variety of mechanisms to prevent or reduce the effects of pathogens. External barriers may provide both physical (e.g. skin, hair) and chemical (mucous membranes, secretions such as saliva and tears) defences against invading pathogens. If these barriers are breached, the immune system comes into action. White blood cells in the tissues and blood respond in a non-specific manner to pathogens, engulfing and destroying them by phagocytosis. This is accompanied by an inflammation reaction. Along with special proteins, the complement system, they constitute the innate immune system.

Each organism is able to distinguish its own cells from those of another organism, of the same or different type, or its own cells that have been changed in some way (e.g. infected with a pathogen or tumour cell). Specific responses occur against the 'marker' proteins or antigens that identify a particular type of pathogen. These responses involve the lymphocytes found in the lymphatic system and form the acquired immune system. Those lymphocytes that pass through the thymus gland are called T-lymphocytes (cell-mediated immune system) and those that do not are termed B-lymphocytes (humoral immune system).

There are three types of T-lymphocytes – helper T-lymphocytes, cytotoxic (killer) T-lymphocytes and suppressor T-lymphocytes. Helper T-lymphocytes activate cytotoxic T-lymphocytes and B-lymphocytes. Cytotoxic T-lymphocytes destroy infected or foreign cells. Each of the T- and B-lymphocytes can be either active cells or produce memory cells that can become active if reinfection of the particular pathogen occurs at a later date. Once the particular immune response is completed, suppressor T-lymphocytes destroy the antibodies.

11.9 Science as a Human Endeavour: Success of organ transplants depends upon the compatibility between donor and recipient cells. The closer this compatibility, the less likely it is that the transplant will be rejected. Drugs can be administered to suppress immune system responses to the donor cells.

11.10 Immunity is the ability to resist disease. Natural immunity is acquired either passively or actively. Active natural immunity can occur when memory T-lymphocytes and B-lymphocytes have formed. Passive immunity results from the intake of antibodies. This may come from placental diffusion, breast milk when a baby feeds (natural) or by vaccination of antibodies from a previously infected individual (artificial). Artificial active immunity can be achieved by vaccination of inactivated antigens.

Immunological tolerance is the ability of some organisms to tolerate cells other than their own provided they are introduced to the organism during the early stages of its development or in supervised, minute amounts at later stages.

11.11 Plants are subject to pathogenic attack by viroids, viruses, bacteria, fungi, oomycetes, slime moulds, roundworms and parasitic plants. Although ectoparasites, such as insects and other grazing animals, feed on plants, they stunt growth rather than cause disease. They may, however, be vectors for, or create a point of entry for, pathogens.

Since plants are significant in the survival of humans, providing food for themselves and their domestic animals, shelter, clothing, medicines and other commodities, infectious diseases in plants are of economic importance.

Plants have a number of defence mechanisms against disease-causing organisms:

- Many plants have impenetrable barriers, such as bark and waxy cuticles.
- If pathogens breach a plant's barriers, the plant can respond with secondary metabolites, which are often toxic compounds that may harm the pathogen.
- Plants produce antimicrobial chemicals, antimicrobial proteins, and antimicrobial enzymes that are able to fight the pathogens.
- Plants are able to seal off damaged tissues to prevent the spread of many pathogens.
- If a plant survives an infection, it may develop resistance to that and other pathogens.

Key terms

- acquired (adaptive) immune system
- adhesin
- allergen
- antibody
- antibody-mediated response
- antigen
- artificial active immunity
- artificial passive immunity
- autoimmune disease
- autonomic nervous system
- B-lymphocyte
- basophil
- biofilm
- carrier
- cell-mediated response
- cilium
- colonisation factor
- colostrum
- complement system
- contagious
- disease
- ectoparasite
- endemic
- endoparasite
- endotoxin
- environmental conditions
- eosinophil
- epidemic
- exotoxin
- flagellum
- gametocyte
- genetic disease
- haemolytic anaemia
- heparin
- histamine
- host
- humoral response
- immune system
- immunological tolerance
- immunosuppressant drugs
- incubation period
- infectious
- inflammatory reaction
- inherited condition
- innate immune system
- interferon
- invasion factor
- Koch's postulates
- leucocyte
- lymphocyte
- macrophage
- malfunctioning
- malnutrition
- mast cell
- memory cell
- merozoite
- monocyte
- murein
- natural active immunity
- natural passive immunity
- neutrophil
- non-infectious
- nutritional disease
- overnutrition
- pandemic
- parasite
- pasteurisation
- pathogen
- phytoalexin
- phytoanticipin
- plant defensin
- plasma cell
- primary host
- prion
- prostaglandin
- pseudopodium
- pyrogen
- reservoir host
- secondary host
- sporozoite
- T-lymphocyte
- toxin
- undernutrition
- vaccination
- vector
- viroid
- virulence
- virulent factor

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 The lymph nodes:

A are places where red corpuscles are made

B are places where iron is stored

C are places where iodine is manufactured

D contain white blood cells that combat disease

2 Phagocytes are best described as:

A complex chemical compounds, consisting of molecules with large numbers of atoms

B arrangements of protein molecules with digestive properties similar to enzymes

C living cells that reproduce rapidly at points of bacterial invasion

D living cells able to ingest bacteria and cell pieces

3 Which one of the following statements about antibodies is correct?

A They are molecules on the outer surface of a pathogen that can initiate an immune response.

B They combine with phagocytes to form cells resistant to invading particles.

C They are produced in response to the stimulus of bacteria and viruses entering the body.

D They are produced by antigens present in the body.

4 A non-infectious disease may be caused by all of the following **except**:

A an inherited condition

B drug abuse

C prions

D malnutrition

5 Infectious diseases may be:

A caused by over or under nutrition

B contagious or non-contagious

C a dysfunction of the body due to environmental pollution

D a result of poor lifestyle choices

6 The virulence of a pathogen refers to:

A its ability to infect a variety of different organisms

B the independence of its ability to resist the host's immune system

C its ability to cause damage in its host's tissues

D the variety of toxins all pathogens can produce

7 Viruses:

A are large molecules of protein surrounding a nucleic acid core

B can be considered to be living because they can reproduce

C can infest other organisms but only cause disease in humans

D can only be transmitted through direct contact from an infected to a non-infected individual

8 Which of the following is correct?

	Barrier	Method of defence
A	Skin	Oil and sweat glands produce anti-viral substances.
B	Mucous membranes	The cells produce substances that inhibit the growth of pathogens.
C	Vagina	Alkaline conditions inhibit entry and growth of pathogens.
D	Alimentary canal	Many pathogens are intolerant of the acidity of the stomach and alkalinity of the intestines.

9 The difference between the innate and acquired immune systems is that the innate but not acquired system:

A needs the stimulation of a pathogen to bring about a response

B is always working and does not require any special preparation to prevent infection

C involves T-lymphocytes that engulf and destroy pathogens

D is stimulated by the complement system of proteins

10 An example of natural passive immunity is:

A diffusion of antibodies across the placenta from foetus to mother

B diffusion of antibodies across the placenta from mother to foetus

C injection of sterile, dead pathogens

D formation of memory cells to an antigen

11 The blood types of humans are classified according to two major blood group systems, the ABO system and the rhesus (Rh) system. These groups are identified by the presence or absence of antibodies in the plasma and antigens on the surface of the red blood cells.

The table gives the proportion of Australians who have each of the blood groups.

Blood group	Percentage of Australian population (%)
A+	31
A-	7
B+	8
B-	2
AB+	2
AB-	1
O+	40
O-	9

Which antibodies and antigens would be present in the blood of people in the Australian population with the rarest blood group?

	Antibodies present	Antigens present
A	Anti-A only	B only
B	Anti-B only	A and D only
C	No antibodies	A, B and D
D	No antibodies	A and B only

Short answer

Describe and explain

★★ **12 a** **Explain** why a tapeworm in a human does not require a digestive system.

b **Describe** which structural features of a tapeworm enable it to survive in its host.

★ **13** **Explain** why application of Koch's postulates is difficult for identifying a virus as the causative agent for an infection.

★ **14** **Explain** why it is useful for B-lymphocytes to be highly variable, but essential that helper T-lymphocytes do not change.

★ **15** **Explain** why an injection of ready-made antibodies is called 'passive' immunity.

Apply, analyse and interpret

★ **16** Many women suffer high blood pressure during pregnancy. **Consider** why this increase in blood pressure would not be considered a disease whereas it is in non-pregnant people.

★ **17** Many ectoparasites, such as the mosquito and leech, contain an anaesthetic in their saliva. **Consider** why this is an adaptation that enables these parasites to survive.

★★ **18** The graph below was obtained from experimental results of two pairs of rats.

Effect of protein ingestion of weight gain in rats

a **Interpret** the data to draw conclusions about the rats on full protein diet.

b **Analyse** the weight of the female rat on a full protein diet at 2 weeks.

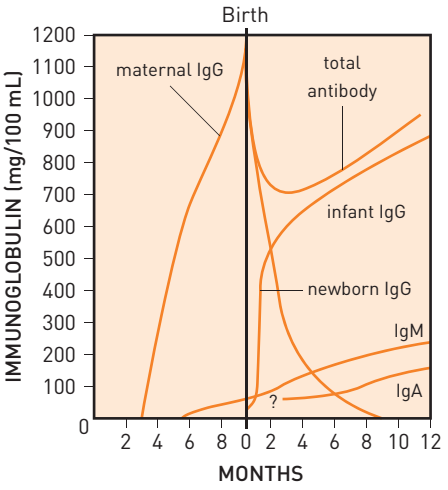
c The two rats on a low protein diet were given full protein at a certain age. **Identify** the age at which this was administered.

★ **19** **Suggest** reasons why the evidence that prions caused infectious disease was contested in the scientific world.

★★★ **20** The following table shows some of the characteristics of the different types of antibodies found in body fluids.

	Type of antibody				
	IgG	IgA	IgM	IgD	IgD
Ability to cross placenta	Yes	No	No	No	No
Present in saliva and tears	No	Yes	No	No	No
Present in milk	Yes	Yes	No	No	No
Active against viruses	Yes	Yes	Some	No	No
Active against some bacteria	Yes	Yes	Yes	No	No
Involved in allergy reactions	No	No	No	No	Yes

The figure below shows the changes in the levels of these immunoglobulins during pregnancy and for a period after birth.



Changes in immunoglobulin levels

a **Interpret** the graph to **determine** when the newborn infant suffers the greatest chance of infection by bacteria.

b Information about the levels of IgA have been deleted from the graph until 2 months after the birth. In terms of the efficient use of available resources and the information provided, **deduce** a logical explanation for the starting point of IgA production. (Your response need not be correct, but it must be a logical deduction based upon your understanding of the immune system and the information supplied.)

★**21** **Construct** a table to **compare** passive and active immunity.

★★**22** As seen in Table 1 in Section 11.10 (page 357), some vaccines provide long-term immunity while others are only effective for a short period.

a **Suggest** reasons for this.

b **Discuss** why immunity may not last for the life of an individual after infection or vaccination.

Investigate, evaluate and communicate

★**23** During any one season, an individual may suffer from influenza more than once. **Propose** reasons for this.

★★**24** Infectious diseases caused by macroparasites are more prevalent in countries with small economies. Using an example of a pathogenic macroparasite, **propose** (with justification) why this is the case.

★★★**25** Scientists wanted to test the hypothesis that a given B-lymphocyte makes only one specific antibody against an antigen. They injected an animal simultaneously with two different antigens. After waiting for the immune system to respond, they took a sample of blood. From the blood, they isolated single plasma cells and tested whether each one produced antibodies to one or both of the antigens.

Predict the results you would expect for the B-lymphocytes based on your knowledge of the immune system. **Justify** your predictions.

Check your obook assess for these additional resources and more:

» Student book questions
Chapter 11 review

» Revision notes
Chapter 11

» assess quiz
Chapter 11 auto-correcting multiple-choice quiz

» Flashcard glossary
Chapter 11 glossary

CHAPTER 12

Identifying, monitoring and controlling disease

In order to control and prevent disease, the causative agent for the disease must first be identified. Identification of non-infectious diseases is achieved through epidemiological studies. The method used to identify the pathogens causing infectious disease varies according to the organic particles or organisms causing it. Monitoring diseases at local, national and global levels is important in determining vector control measures, predicting spread of the disease and establishing vaccination programs. A variety of means are available to control disease within a community. Quarantine and border control are significant in preventing the entry and spread of disease within and between countries. Treatment of disease is mainly chemical-based with most active ingredients being derived from plants or animals (natural or synthesised). Antibiotics are produced by a number of different fungi and bacteria, and are used to treat bacterial infections only. With misuse of these antibiotics, strains of bacteria can become resistant to them.

OBJECTIVES

→ Recognise that the transmission of disease is aided by the regional and global movement of organisms.

→ Identify the interrelated factors affecting immunity (persistence of pathogen within host, transmission mechanism, the proportion of population that is immune or have been immunised, mobility of individuals in the affected population).

→ Analyse these factors to predict potential outbreaks.

→ Interpret data for the modelling of the spread of disease using secondary data or computer simulations.

→ Evaluate strategies to control the spread of disease:

- personal hygiene measures
- community level: contact tracing and quarantine, school and workplace closures, reduction of mass gatherings, temperature screening and travel restrictions.

→ Make decisions and justify them in regard to best practice for the prevention of disease outbreaks based on the critical analysis of relevant and current information.

Source: *Biology 2019 v1.2 General Senior Syllabus*
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FIGURE 1 Laboratory scientists are vital in identifying and controlling diseases.

12.1 Transmission and the spread of disease

KEY IDEAS

- Transmission of infectious pathogens by air, water and vector organisms
- Movement of many vector organisms both regionally and globally during migrations
- Increase in the spread of infectious diseases by human trade and travel
- Defining epidemiology
- Factors considered in an epidemiological study
- Features of an epidemiological conclusion

FIGURE 1
A mosquito is a vector organism because it can carry and transmit diseases to other organisms.

pathogen
a biological agent that causes disease or illness to its host

vector
any agent that carries and transmits an infectious pathogen into another living organism

As seen in Chapter 11, there is no single model to describe the transmission of **pathogens** from one individual to another. Some, like the influenza virus, pass from an infected person in small water droplets into the air, that may then be inhaled by an uninfected person, by hand-to-mouth transmission from a contaminated surface or by via direct contact with an infected person. Water contaminated with bacteria (e.g. cholera) can infect anyone drinking that water. **Vector** organisms play a major role in passing pathogens from one host to another.

Transmission of disease through movement of organisms

Vector organisms may also contribute to the spread of disease as they move over large distances and interact with local organisms. These local organisms then become vectors for disease also. The flyways of migrating aquatic birds, which are vectors for influenza A, and the flying fox, which is the vector for Hendra, Menangle and Nipah viruses respectively, are shown on the obook.

The patterns of human travel and trade of goods has changed dramatically over the last century. It was once very unusual for the general population to move from their local area. There were, however, some significant trade routes (e.g. the Silk Road, and shipping between China and Europe in the fourteenth century). Diseases such as the plague were widely spread as a result of these trade movements.

Regional travel within and between areas of a country are now common for recreation and work. Tourists can return to their home countries and inadvertently bring back pathogens picked up from overseas. Large numbers of people travel overseas on business. Huge volumes of goods are transported between countries in large shipping containers, inadvertently carrying new vectors for disease.

The virulence factors of individual pathogens (Section 11.4) and their persistence (occasionally symptomless) in a host are also significant, not only host-to-host transmission, but also in the ability of the host's immune system to overcome them. All of these factors have the ability to spread pathogens.

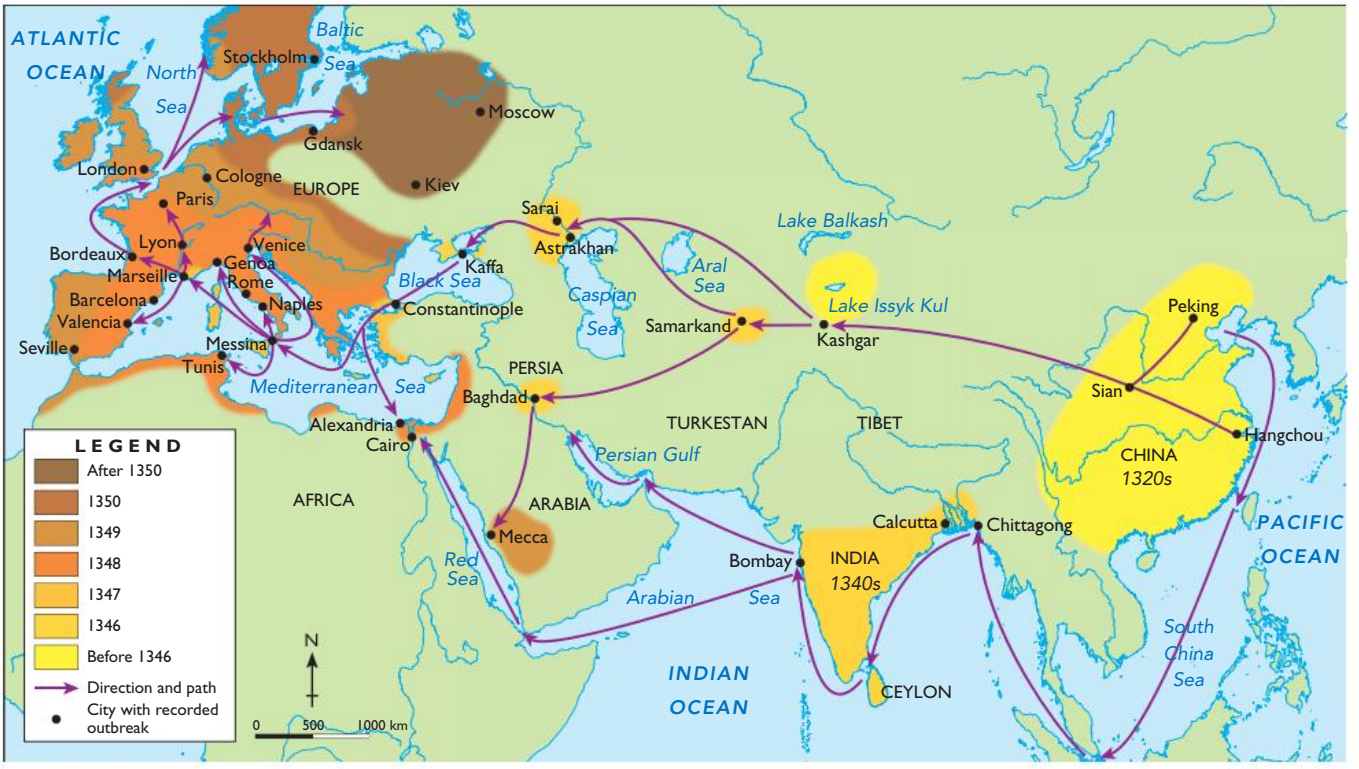


FIGURE 2 The fourteenth century land and sea routes that resulted in the spread of the plague from China to Europe

Preventing, treating and controlling disease

Governments and scientists concerned about the global spread of diseases first met at the International Sanitary Conference in 1851. Over the next 70 years the participants developed programs to deal with pandemics of cholera, yellow fever and bubonic plague. After the Second World War, this group of governments and people expanded and become the World Health Organization.

World Health Organization data shows that, in 2015, 26.6% of the 56.4 million deaths worldwide were attributed to heart disease and stroke. These diseases have remained the leading cause of death globally since 2000 regardless of socio-economic status, although death due to stroke is lower in high-income economies, probably as a result of better medical facilities. Non-infectious diseases cause 70% of the deaths globally. It is therefore crucial that the causes of these diseases be identified, so treatments or preventative measures can be developed.

In the past, many connections were made between a disease and a possible cause, but the evidence was not scientific. In the nineteenth century, for example, people embarking on long sea voyages often suffered from scurvy. It was found that a daily intake of lime juice (high in vitamin C) reduced this illness. Now, studies involving the collection and careful statistical analysis of data assist the causal identification of diseases.

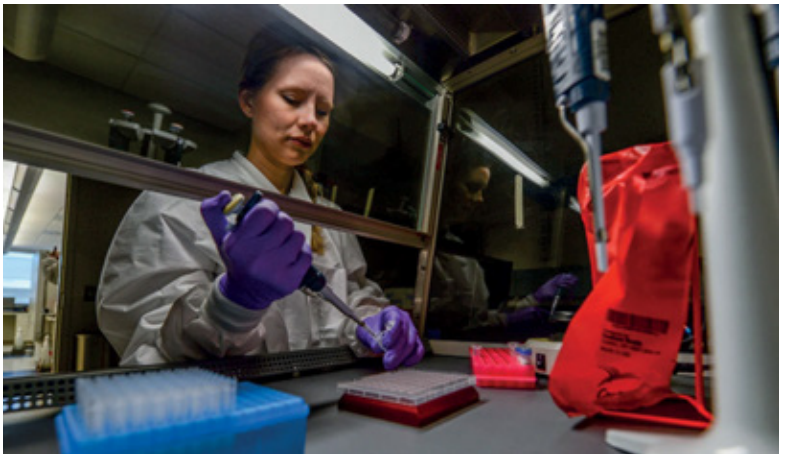


FIGURE 3 Epidemiologists study the distribution and causes of health-related states or events (including disease), to develop ways of controlling these problems.

Epidemiology

Epidemiology is the scientific study of factors determining and influencing the frequency and distribution of disease, injury and other health-related events in a defined human population. Its purpose is to establish programs to prevent and control their development and spread. It can be used to evaluate health services and preventative programs or to identify individuals who are at high risk of contracting disease.

All epidemiological studies include how common the disease is (the number of people affected), what proportion of the population is affected, how many people in the population died as a result of the disease, and what other factors might have affected their chances of survival (e.g. age, gender, race, diet, geographic location, lifestyle, and family history of the disease).

epidemiology the study and analysis of the distribution (who, when, and where) and determinants of health and disease conditions in defined populations

random sample one of many statistically possible samples where all have an equal chance of happening

Epidemiological conclusions

The conclusions from any study regarding risk cannot be drawn from purely clinical data (i.e. the number of sick people seen) but must relate to all members of a population. In most cases the entire population cannot be studied so a large **random sample** of the whole population is used. This allows comparisons to be made – for example, the incidence of lung cancer in people who smoke cigarettes versus non-smokers or the rate of mesothelioma in people with and without exposure to asbestos.

Similar to Koch's postulates, a number of steps must be satisfied before it can be determined if key factors in a population contribute to the cause and spread of a disease. These steps include:

- Is there a **significant statistical correlation** between a proposed cause and the disease? For example, it has been shown that deaths due to lung cancer are significantly higher

FIGURE 4 Comparison of the lungs of a smoker and non-smoker

in smokers than in non-smokers, implying a high correlation between smoking and lung cancer. With further information, it can be concluded that smoking is a cause of lung cancer.

- Is the cause–effect relationship **consistent** across all other variable characteristics such as age, occupation, gender, geographical location and race? The trend that smoking correlates with a higher incidence of lung cancer should be observed across all variables.
- Is there a **temporal sequence** or direct timeline – that is, does the proposed cause occur before the onset of the disease? For example, incidences of lung cancer began to rise 10 years after cigarette smoking began to rise. This typically corresponds with the time between exposure to cancer-causing chemicals (in cigarette smoke) and the onset of cancer.
- Does an increase in exposure to the proposed cause mean an increased risk of the disease? It has been found that the death rate due to lung cancer is higher in heavy smokers than in less regular smokers.
- Do the trends observed have a **plausible relationship** or explanation of why this factor causes clinical symptoms? The chemicals in cigarette smoke have been identified as carcinogens. Therefore, it is plausible that they cause lung cancer.

Using such studies, the cause, whether inherited, environmental or nutritional, has been determined for many non-infectious diseases.

CHECK YOUR LEARNING 12.1

Describe and explain

1 **Define** the term 'epidemiology'.
2 **Explain** why clinical studies alone are inadequate to determine the cause of non-infectious diseases.
3 Random samples from a population are used in an epidemiological study. **Explain** what a random sample is and why they are used.
4 One of the criteria for drawing a conclusion from an epidemiological study is that the cause–effect relationship must be temporal. **Explain** this statement.

Investigate, evaluate and communicate

5 Recently a number of miners have exhibited black lung disease. **Design** an epidemiological study to determine the cause of this disease.
6 Over the past 100 years, the spread of infectious disease has increased dramatically and globally. **Discuss** factors that have contributed to this spread.
7 **Investigate** an infectious disease that has spread around the world. Compile a report outlining the following details:
   - Where did the disease begin?
   - How was it transmitted?
   - What is being done to control the disease?

Check your obook assess for these additional resources and more:

» **Student book questions**
Check your learning 12.1

» **Weblink**
The Black Plague

» **Weblink**
World Health Organization

» **Weblink**
How to become an epidemiologist

12.2 Identifying the cause of infectious disease

KEY IDEAS

- Techniques used in the identification of pathogens
- Basic morphological features of bacterial colonies
- The use of antibiotic testing and staining techniques used in bacterial identification
- Features of yeast and mould colonies that distinguish them from bacterial colonies
- Tests used to identify bacteria and fungi to species level

Macroparasites and protozoa can be readily seen either visually or through a light microscope. Intestinal worms lay uniquely shaped and sized eggs that can be identified from a faecal smear. Intestinal protozoans can be identified in a similar way. Other pathogens can be easily identified from microscopic examination of blood samples. Micropathogens (prions, viruses, bacteria and many fungi), on the other hand, need more specialised methods of identification. Once a pathogen has been isolated and identified, techniques using Koch's postulates (Section 11.5, page 328) are employed to ensure that the organism is responsible for the disease. Prions are identified using chemical analysis of blood proteins.

Identifying a virus

Viruses are difficult to identify in a laboratory because they cannot survive on their own. Instead they must be grown in a liquid culture with possible host cells. Because each virus can only bind to the host cell that contains the correct adhesion molecule, trial and error may be required to determine a suitable host cell.

Once the virus can be grown in a host cell, different strategies are used in its identification, depending on the purpose for identification. Often a virus causes specific changes to its host cells – a **cytopathic effect** – that can be seen under a light microscope. If these changes are seen in the cultured host cells, then the virus can be identified. Other techniques used include X-ray diffraction, electron microscope examination or DNA analysis.

cytopathic effect a degenerative change in the appearance of cells

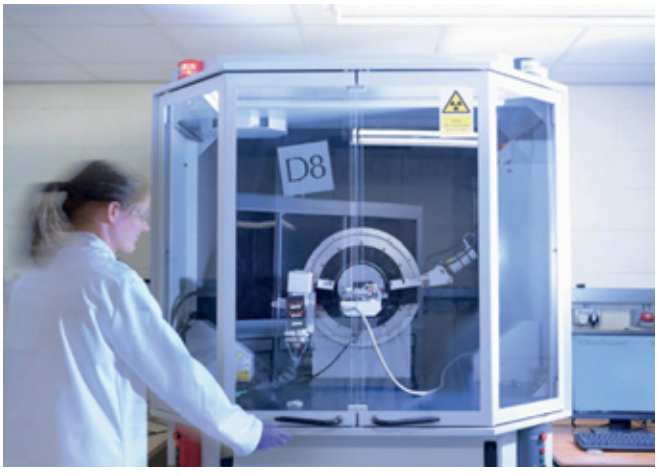


FIGURE 1 An X-ray diffraction machine

FIGURE 2 Electron microscopes can be used to physically detect a virus.

Identifying bacterial and fungal pathogens

Bacterial and fungal pathogens can be isolated from host cells by centrifugation of tissue samples and filtering the smaller pathogens from the host cells. The pathogenic cells are then cultured on nutrient agar jelly in a Petri dish. Similarly, the plates can be smeared with blood serum or scrapes of tissue. Sterile conditions are employed to ensure that the cultivar is not contaminated with airborne organisms.

Bacteria and fungi (including moulds and yeasts) grow well on nutrient agar plates. Single cells of these organisms reproduce and form colonies. Different types of cells produce colonies with distinctive features or colony morphology. Basic characteristics of this morphology include their colour or shape, the elevation or surface of the colony, the smoothness of the edges or even the odour of the colony. Figure 3 shows some examples of shape, elevation and edge margin.

Most bacterial colonies have a fairly circular shape and are coloured white, cream or yellow.

Antibiotics are molecules that block the growth, or kill some types, of bacteria. Each antibiotic works in a different way, depending on the presence of specific antigens on the bacteria. When special filter papers, each impregnated with a different antibiotic, are laid over the bacterial colonies, particular antibiotics will inhibit the growth of the bacteria. This can be seen by a zone clear of bacteria around that specific antibiotic (see Figure 5). This allows the identification of the bacteria by noting their susceptibility to the antibiotic.

Further identification can be achieved by staining the colonies. Gram-staining determines two major groups – Gram-positive and Gram-negative bacteria – depending on the chemicals present in the outer cell wall. The shape of the bacterium

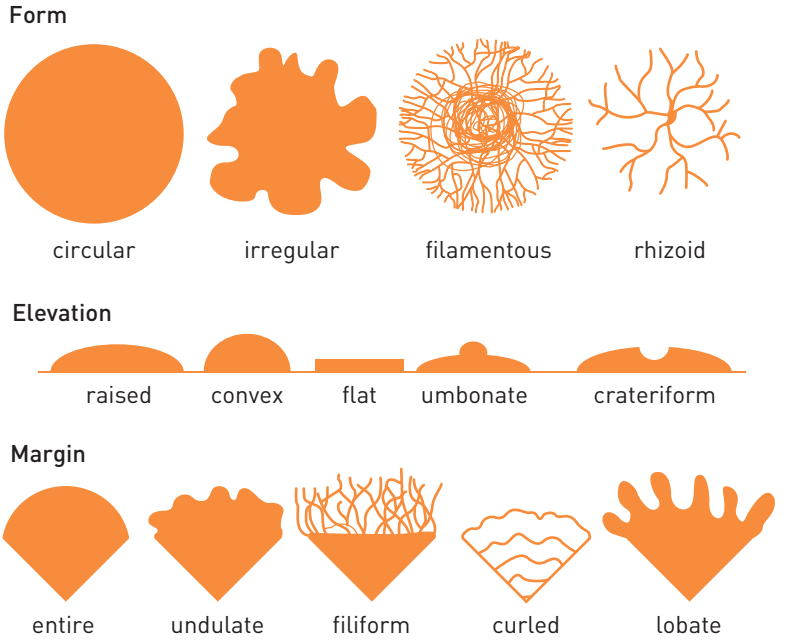
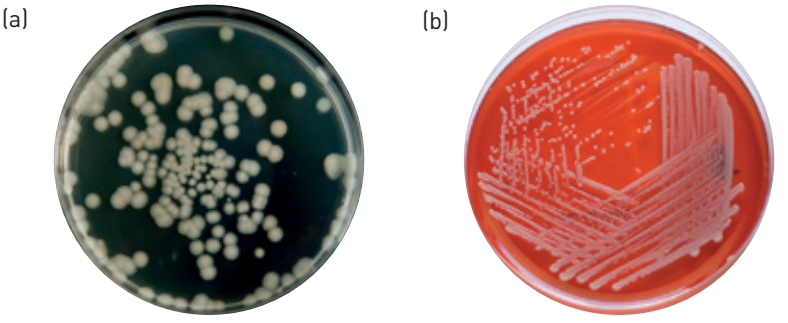


FIGURE 3 Some morphological features of colonies of bacteria and fungi



Bacillus subtilis *Staphylococcus aureusa*

FIGURE 4 Some bacterial colonies growing on agar plates

FIGURE 5 The clear zones around all of the antibiotic-impregnated discs indicate inhibition by bacterial growth.

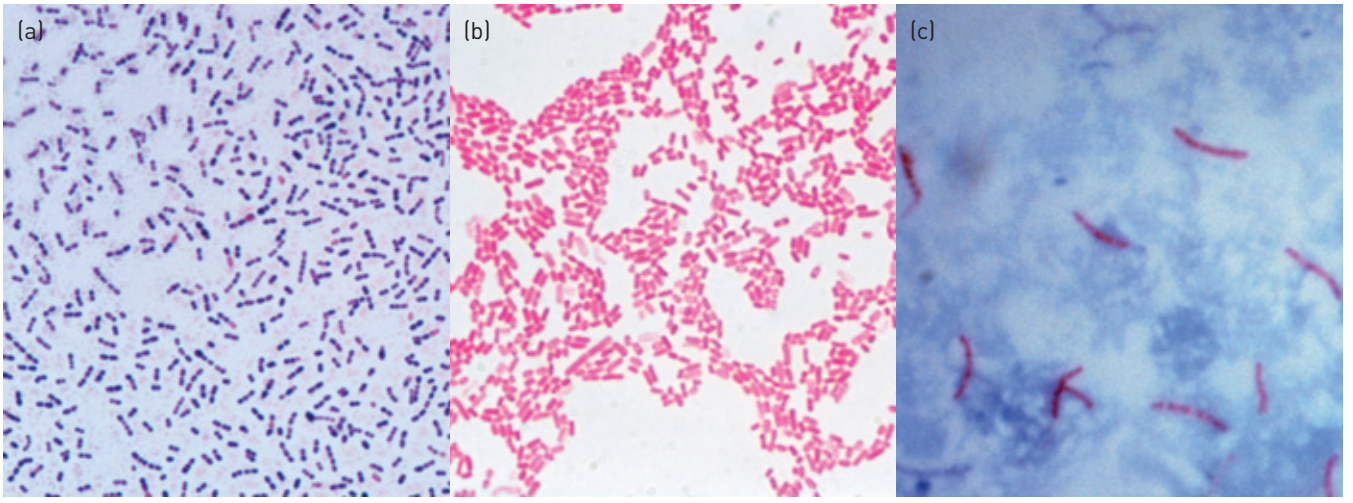


FIGURE 6 (a) Gram-positive (purple) *Streptococcus pneumoniae*; (b) Gram-negative (pink) *Escherichia coli*; (c) fast-acid staining of *Mycobacterium tuberculosis*

(cocci – single cells, in pairs or as a chain of cells; rod-shaped; spiral or comma-shaped) along with the Gram reaction are important identifiers. Some fungus-like bacteria, the Mycobacteria, have a Gram-negative result because they have a waxy surface on their cell walls preventing the uptake of the stain. These bacteria need an alternative fast-acid (pink) stain so they can be identified.

These staining techniques are useful for identification of the genus of the bacterium, but not its species within the genus. This means a mycobacterium can be differentiated from a streptococcus. Differentiation of the exact species involves DNA analysis.

Yeast colonies also have a circular shape and some look remarkably like bacterial colonies. For example, *Candida albicans*, which causes thrush, has white, round colonies. Microscopic examination of individual cells will determine if they are prokaryotic (no nucleus and therefore bacteria) or eukaryotic (nucleus present and therefore fungi).

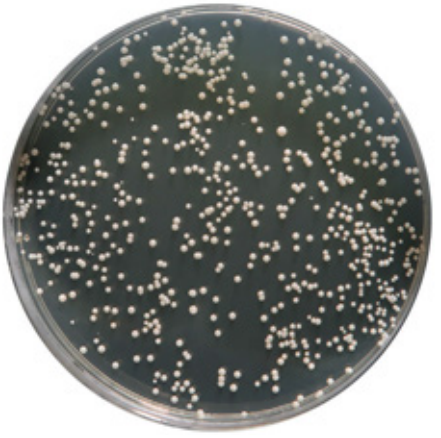


FIGURE 7 *Candida albicans* colonies on an agar plate

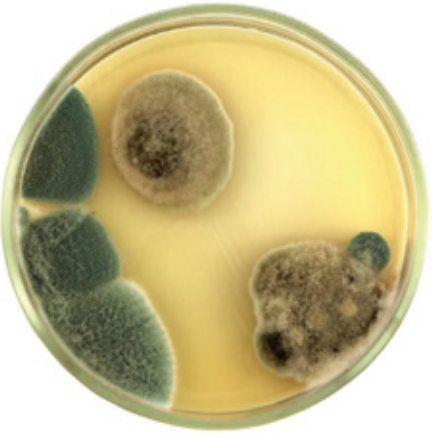


FIGURE 8 Mould colony of *Aspergillus* sp.

Moulds often appear whitish grey with fuzzy edges when grown on an agar plate. They usually turn a different colour from the centre outwards. The cell structure, method of spore formation, and general body function can be determined using a microscope. Fungi can be further tested by growths on selected media or by enzymatic reactions.

CHECK YOUR LEARNING 12.2

Describe and explain

1 **Identify** which of the following *cannot* be used to culture viruses. **Explain** your choice.
   - **A** Tissue culture
   - **B** Liquid medium only
   - **C** Embryo
   - **D** Animal host

2 **Explain** a cytopathic effect and how it is used.

3 **Describe** how a colony of bacteria or microscopic fungi is produced.

4 **Identify** some of the morphological features of a bacterial colony that are used to identify bacteria.

5 **Explain** what causes the different reaction of certain bacteria to Gram stain.

6 **Explain** why Gram-negative bacteria need to be further tested with fast-acid stain.

7 Certain bacteria and the yeast *Candida* both form smooth, white colonies. **Describe** the differences between them.

8 **Identify** which colony features are used to differentiate between a bacterial and mould colony.

9 **Describe** the ultimate test for identifying a bacterium or fungal pathogen.

Investigate, evaluate and communicate

10 A bacterial sample can be collected from surfaces of objects using a sterile cotton bud that is then placed in a sterile container until it is used to smear the sample over nutrient agar in a Petri dish. The sample can then be cultured in a laboratory oven at an appropriate temperature.

Design an experiment to test which surfaces around the school grounds harbour bacteria. In your design, state:
   - **a** the control for this experiment
   - **b** safety precautions involved
   - **c** a method to determine the most contaminated zones
   - **d** methods for distinguishing between bacterial and fungal colonies
   - **e** methods to determine the types of bacteria present
   - **f** methods of disposal of the cultures when the experiment is completed.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 12.2
- » Video weblink
  Electron microscope
- » Video weblink
  Preparing agar plates
- » Weblink
  Gram staining

12.3 Monitoring disease

KEY IDEAS

- How disease is monitored
- The need for disease surveillance
- How data collected from surveillance is used
- The use of the data to predict spread of disease
- How the proportion of a population needed to be vaccinated to prevent spread of disease is calculated

Diseases, whether infectious or non-infectious, are monitored by health authorities and agricultural departments around the world. In Australia, for example, it is mandatory to report certain identified infectious diseases to local, state and federal authorities as well as to the World Health Organization (WHO). Diseases that rapidly spread from animals to humans or human to human must be reported to WHO so that control measures worldwide can be put into place to prevent pandemics occurring.

An outbreak of Ross River fever in a particular locality, for example, would be reported to the appropriate authority, and a particular hormone could be sprayed into waterways to prevent mosquito larvae developing into adults to minimise the spread of the disease. Although Ross River fever is not a World Health Organization notifiable disease, at the local level it is significant. The disease can have debilitating effects on the individual that may last for a long time. This affects the ability to work and, as a result, the family income. If many individuals in an area contract the disease, the welfare of the community could be in jeopardy.

As seen in Chapter 11, the occurrence of certain commercial plant and animal diseases is also monitored, and appropriate measures are taken to control the expansion of the disease range.

Drug use in particular areas can be monitored in a variety of ways. A 2017 analysis of sewage in southern Queensland treatment works was able to identify not only the incidence of drug use in certain centres, but also the prevalence and types of drugs most used. This information is used to inform better social education regarding drug use (particularly of extremely harmful drugs like 'ice') and to provide better community support to those in high use areas.

FIGURE 1 Some of the measures taken by workers in food preparation areas to minimise spread of disease – workers wear special coats, headwear, gloves and face masks.

Monitoring of disease is an epidemiological practice that aims to predict and minimise the harm caused by an outbreak. It also improves knowledge about factors that contribute to outbreak.

Surveillance may, for example, focus on food-borne diseases. The data could identify new or emerging food pathogens, where the contamination was occurring and how it was being spread.

CASE STUDY 12.3

Typhoid Mary

Mary Mallon was born in Northern Ireland in 1869. At the age of 15, she migrated to New York (US) where she eventually found work as a cook for well-to-do families. It is not known where Mary was first exposed to typhoid, but in 1900 she started cooking for a new family. Within two weeks, family members became sick with typhoid. Mary herself did not show any symptoms of the disease (fevers and diarrhoea). Within a year, Mary needed to move on (as family members started dying). The family members of her new employers also contracted typhoid, and the laundress died. In the third family Mary cooked for, seven out of eight members of the family contracted the disease. This pattern of asymptomatic (no symptoms) Mary cooking for new families who then contracted the disease continued for seven years before a typhoid researcher named George Soper investigated the outbreak.

Despite several confrontations by the health authorities, Mary denied that she was the cause (carrier) of the typhoid outbreaks. Mary was jailed several times for refusing to stop cooking and spreading the disease. Eventually, she was placed in quarantine at the Riverside Hospital for the last 23 years of her life. It is thought that 'Typhoid Mary' was responsible for at least three deaths and over 50 infections as a result of being a typhoid carrier.

Surveillance of this type can also help to identify **carriers** of a disease (e.g. typhoid fever). Although these individuals do not exhibit any symptoms of the disease, they are infected with causative pathogens and are able to pass these on to other individuals.

In many countries, detailed data on vaccine-preventable diseases are collected and analysed to guide public health activities. It is an important component of any immunisation program.

carrier
a person or organism infected with an infectious disease agent or gene, but who displays no symptoms of the disease

Modelling infectious diseases

Most models for determining the spread of an infectious disease are mathematical in nature.

Two measures used in analysing disease are:

1. **Mortality rate** – the rate of death per population size. This is usually represented as a proportion (e.g. per 1 000 000 individuals).
2. **Case fatality ratio** – the number of deaths amongst those who have contracted the disease. This is usually expressed as a percentage.

mortality rate
the ratio of deaths in an area to the population of that area; expressed per 1000 per year

case fatality ratio
the proportion of deaths within a designated population of 'cases' (people with the disease) over the course of the disease

For example, in a population of 3.5 million, if 70 of the 210 reported cases die of a particular infectious disease:

$$\text{The mortality rate} = \frac{70 \times 1\,000\,000}{3\,500\,000} = 20 \text{ per million}$$

$$\text{And the case fatality ratio} = \frac{70 \times 100}{210} = 33.3\%$$

Since case fatality ratios do not depend upon actual population size, health organisations can make some predictions on the severity of any particular outbreak. By comparing these figures across country groups, they can work out the likely spread to other countries, and whether or not to impose travel restriction advice to particular countries.

SIR model
a method that models or tracks the numbers of susceptible, infected and recovered individuals during an epidemic

The **SIR model** is the basic model used to analyse spread of disease. It uses an advanced mathematical formula that examines:

- the proportion of a population that is susceptible to a particular infection (**S**),
- how many of these people go on to become infectious (**I**), and
- the proportion of these that then recover (**R**), and in what time frame.

This model assumes that the population being investigated does not change (i.e. births, deaths, immigration and emigration are not taken into account) and that a single infected person introduces the disease into the population and that there is no incubation period.

With the advent of complex computer programming and access to a massive amount of processing power, this basic model can now generate models that also take into account such factors as weather, human travel and trade patterns and warfare.

One of the important features of the SIR model is to work out the levels of vaccination needed to protect a population. Figure 2 shows the relationship between vaccination rate and the spread of disease through a population.

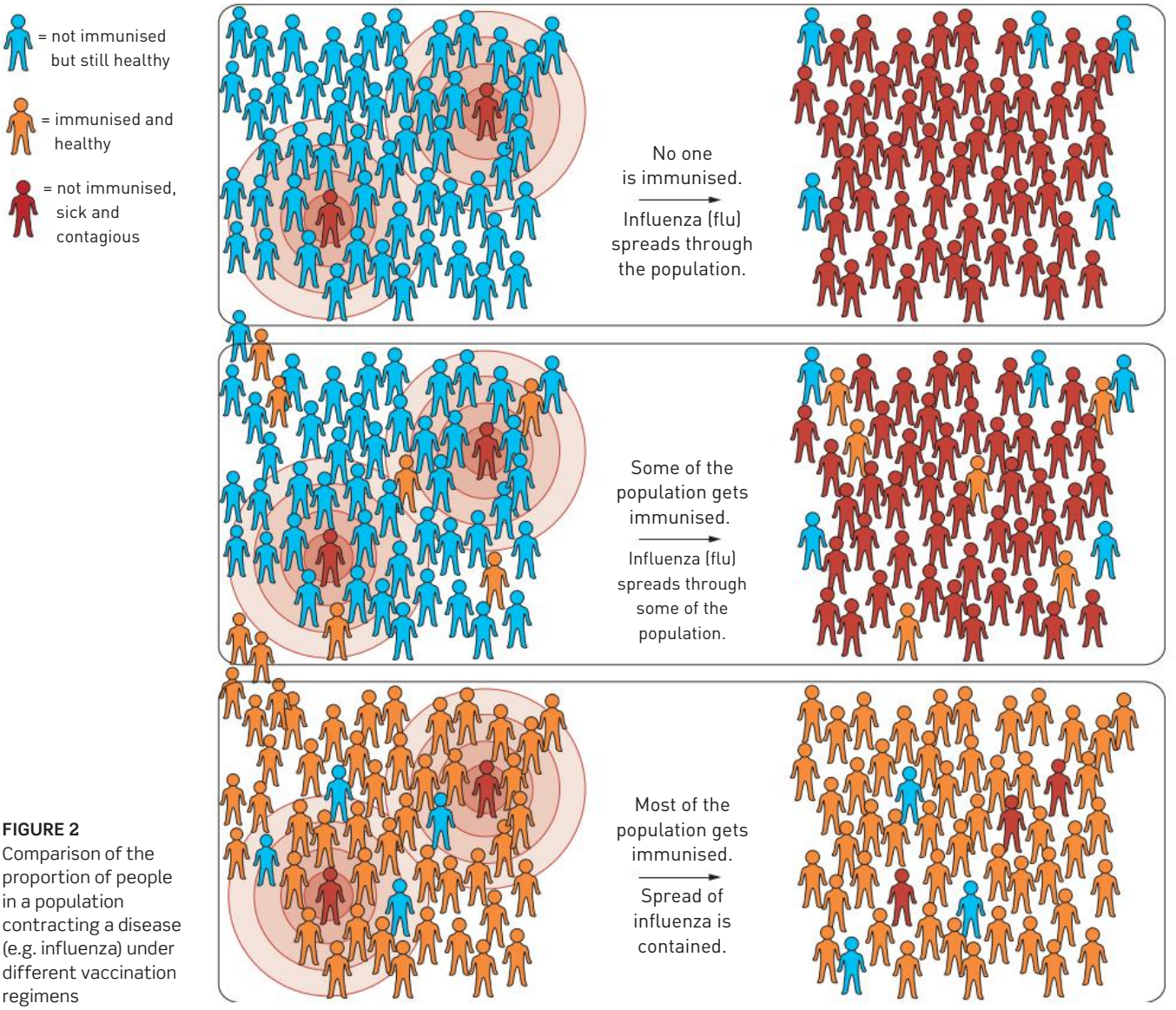


FIGURE 2
Comparison of the proportion of people in a population contracting a disease (e.g. influenza) under different vaccination regimens

One of the aspects of a SIR model is the ability to predict the spread of an infectious disease in a totally susceptible population (i.e. no one is vaccinated against the pathogen). R_0 is a measure of the number of people who become infected by a single person with the disease. This varies from disease to disease and mode of transmission. Malaria, for example, is transmitted by mosquitoes, and one mosquito can transfer the pathogen from one infected person to a large number of people in a short time. AIDS, which is transferred from person to person only in body fluids, will have a lower transmission rate among a particular contact group of individuals.

For a disease with an R_0 of 2 (e.g. hepatitis C and Ebola), each infected person is likely to infect two other people, whereas one person with mumps (R_0 of 10) will infect 10 other people.

The proportion of the population that needs to be vaccinated to prevent the spread of the pathogen can be worked out using the formula

$$VT = 1 - 1/R_0$$

where VT is the proportion of the population that needs vaccination.

Disease	R_0
AIDS	2 to 5
Smallpox	3 to 5
Measles	16 to 18
Malaria	> 100

TABLE 1 The value of R_0 for some common diseases

Herd immunity

There are always a few people in a population who are especially vulnerable to an infectious disease. Individuals who are immunosuppressed (e.g. individuals with AIDS or transplanted tissue), very young children, the elderly or individuals who are unable to be vaccinated due to allergies are at high risk of severe complications if they become infected. As a result, they rely on everyone around them to protect them from the disease. **Herd immunity** is a way to protect these individuals by ensuring a large percentage of the population is immune to an infection. This can be done through vaccination. The greater the number of people in a population that are vaccinated against a disease, the less likely the disease will spread. (See Figure 2.) To prevent the spread of smallpox a vaccination rate of 80% would be effective, but 95% of the population needs to be vaccinated to prevent the spread of measles. This is because measles (R_0 = 18) is more contagious that smallpox (R_0 = 5).

herd immunity a form of indirect protection from infectious disease that occurs when a large percentage of a population has become immune to an infection, thereby providing a measure of protection for individuals who are not immune

CHECK YOUR LEARNING 12.3

Describe and explain

1 **Explain** why monitoring of disease is important.
2 **Describe** how data from disease monitoring is used.
3 **Explain** why it is mandatory for some diseases to be reported to the World Health Organization.

Apply, analyse and interpret

4 **Explain** why the value of R_0 varies according to the type of pathogen and its mode of transmission.
5 **Describe** the characteristics of a carrier of a disease.
6 **Predict** the likelihood of an epidemic occurring in a population in which:
   a no one is vaccinated against the disease
   b most people are vaccinated against the disease.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 12.3

» Weblink
Monitoring diseases in Queensland

» Weblink
SIR model

» Weblink
Herd immunity

12.4 Preventing and controlling disease

KEY IDEAS

- Ways in which diseases are spread and preventative and control measures
- Quarantine at local, federal and international levels
- Vaccination

Disease can be minimised by undertaking prevention and control measures.

Preventative measures

People continually touch objects that have been previously touched by others, such as doors and seats of public toilets, money, pets and taps. All have the potential to transfer pathogenic organisms. Personal hygiene is important in decreasing the risk of contracting pathogens. Sneezing into an elbow instead of hands prevents the bacteria or virus from being spread to others. Regular washing of hands with soap and water after using the toilet and before eating can significantly reduce transfer of pathogens. Many microorganisms stick to small droplets of oils released by skin glands. Water alone will not remove these. Soap affects the surface tension so that the area of contact between the oil and the skin is smaller and allows the oil to be washed away.

Both contagious and non-contagious diseases can result from contaminated food. Food poisoning often occurs because food is kept too long or stored incorrectly. Some decomposing bacteria in the food release toxins which then affect the person eating the spoilt food. Several contagious diseases can be unwittingly transferred from people preparing food as they can be carriers of disease without displaying any of the symptoms. Strict laws govern cleanliness of commercial food preparation areas. All people involved in the industry must wear special protective clothing and disposable gloves. The actual premises must also be kept clear of all vermin such as cockroaches, flies and rats that may be vectors in disease. Similar controls should be implemented in all homes.

FIGURE 1 Poor kitchen hygiene is responsible for food poising and increasing the populations of vectors of disease (e.g. cockroaches, flies and rats).

Meat bought in Australia and in most other Western countries is subject to strict meat inspection at the abattoirs for parasites. It is still important that meats such as pork are thoroughly cooked. The heat generated in the cooking process kills the larvae of tapeworms and other flatworm parasites that can be passed on to humans.

Many diseases are spread by water, either directly or via a vector. In Australia, clean drinking water is taken for granted. All major towns and cities have strict treatment and quality control of household water supplies. This is not the case in many parts of the

world, particularly in developing countries, where people must use the local streams or wells for water. Contamination of these waters by human and domestic animal wastes frequently occurs. Moving water can swiftly transport microorganisms over large distances. Even in places where there is sterilised, reticulated water, defects in pipes, flooding and other factors can result in recontamination of water supplies. In areas where intestinal diseases are common, it is important that people are educated in methods of disposal of human wastes to prevent spread of disease.

FIGURE 2 Many parts of the world do not have access to clean drinking water.

Cholera, an intestinal disease common in tropical Africa and Asia, is caused by a bacterium that enters the person in drinking water or from contaminated food. It produces toxins that result in both diarrhoea and vomiting. Even after all food contents have been voided, there is constant elimination of digestive juices. The fluid to produce these juices is withdrawn from other body tissues. Death is a result of dehydration and loss of potassium. In many places where cholera is endemic, human faeces are collected and used as manure for growing vegetables. Bacteria from an infected person are rapidly transferred via the vegetables to other people. Flies move between the house and garden, transferring bacteria from plants to food. In other areas, toilets are built over the banks of streams or rivers. The flowing water carries the wastes away. The cholera bacteria reproduce in these warm waters and water used further downstream for drinking or watering vegetables can be contaminated, resulting in further infections.

Control measures

The control of many diseases can be achieved by minimising the effects of vector organisms. An understanding of the life cycle of the vector can provide different strategies for eradication. In the past, insecticides have been intensively used in an attempt to eliminate **secondary hosts** to a number of human pathogens. Similarly, swamps have been drained to prevent mosquito and snail breeding areas. These strategies, however, have resulted in severe environmental damage since they target a whole range of organisms and so disrupt ecosystems. Years after their use many pesticides have been shown to have a direct negative impact on humans. For example, in addition to a wide range of other effects, DDT has recently been shown to be a hormone mimic that can affect the development of the human foetus.

secondary host
a temporary host for a parasite

Avoiding contact with vectors of disease is the best means of control. Suggested measures include to:

- use personal insect repellents in places and times where vector insects are most likely to be active
- wear clothing that minimises being bitten by insects – long, loose trousers and shirts
- use insect screens in windows and doors of houses
- use mosquito nets to cover beds
- use building materials that do not harbour insect pests
- not wade or swim in waters suspected of being contaminated by pathogens and/or their hosts.

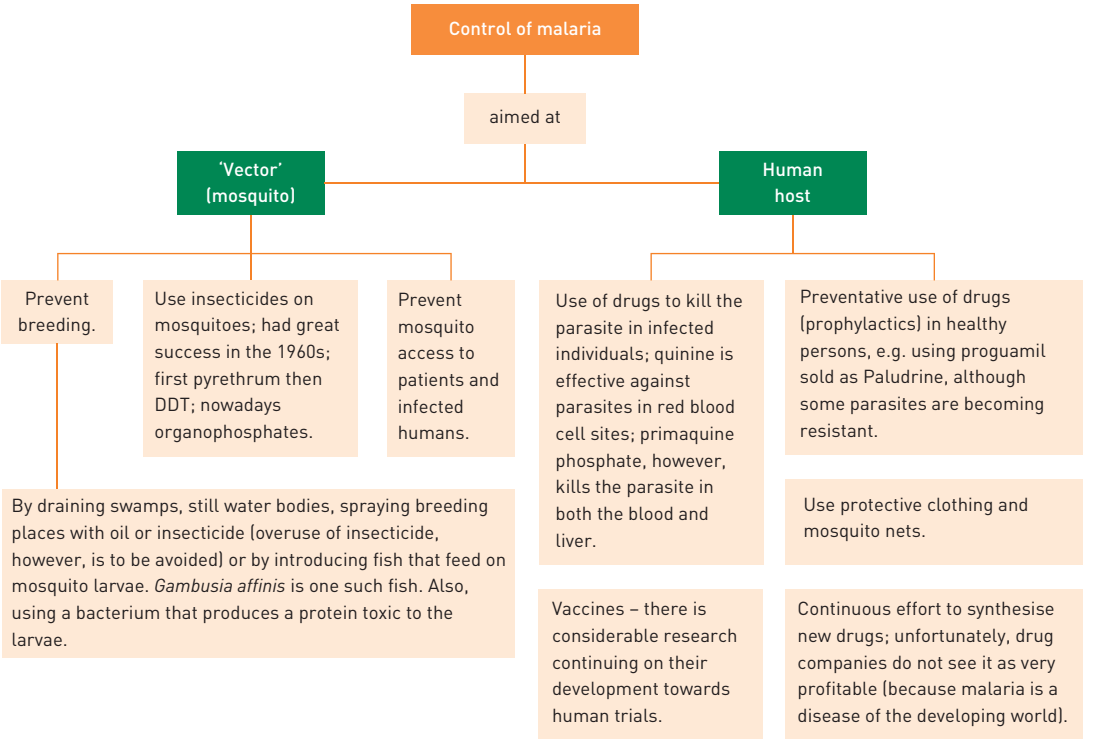


FIGURE 3 Mechanisms to control malaria

Some of these measures may not always be practical all of the time or for all people. In many countries where diseases such as malaria and yellow fever are prevalent, the majority of the population are very poor and have little opportunity for education.

Internal medication may also be used to reduce and prevent the effects of infection. Therefore, antimalarial tablets can be used prior to, during and for a time after possible exposure to *Plasmodium*. These drugs kill the organisms within the human. The cost of such medication is prohibitive for most people in developing countries.

Quarantine

quarantine
a strict isolation imposed to prevent the spread of disease

Quarantine (the word is derived from a phrase meaning 40 days) relates to the idea that a period of 40 days is adequate time for a disease to pass and treatment to be completed. The idea of 40 days is no longer strictly adhered to and varies from disease to disease. Quarantine can be applied locally, nationally and internationally.

Locally, individuals who have a contagious disease should ideally be isolated from other people. Many bacteria and viruses pass from person to person in airborne droplets of water. Isolation reduces the chance of this occurring by minimising the number of people with whom the infected person comes in contact. The period of isolation depends upon the incubation period of the pathogen as well as the length of time of infection. For example, a person infected with chickenpox must be kept isolated until all skin lesions have dried. For serious contagious diseases (e.g. Ebola), patients are kept in special hospital isolation wards. Only hospital staff, usually in special biohazard clothing, can attend the patient and they undergo a sterilisation treatment when they leave the ward to prevent spread of the pathogen.

In serious outbreaks within a community, further action is taken. Schools, aged care facilities and public places may be closed. Quite often, there is a period between contraction of pathogen and symptoms of disease appearing. This means an apparently healthy person could be contagious. By preventing large assemblies of people, the spread of the disease can be minimised.

Quarantine is important at both state and federal levels in Australia. To prevent the spread of exotic plants and animals, and the pathogens they may carry, there are sometimes limitations on what may pass between states or regions within a state. For example, only livestock that have been recently sprayed to destroy ticks can pass from Queensland into New South Wales or from coastal areas of Queensland into western, tick-free areas.

Control of entry also occurs at all sites of international entry – ports, airports and mail exchanges. Aeroplanes are sprayed on arrival. Clearance of passengers, cargo and other effects by quarantine officers is of major importance. Many airports screen arriving passengers for fevers using a thermal camera. Animals imported into Australia, including insects, fish, birds and mammals, and even semen for artificial insemination, are placed into special quarantine stations for a time to ensure they are not carrying any disease. All plants or their parts (e.g. fruit, seeds and honey) must pass quarantine inspection and possibly treatment and a period in isolation, as do objects made from plant material.

FIGURE 4 Tick areas in South-East Queensland. Stock not sprayed prior to transport will be sprayed at the areas labelled with a star (e.g. Helidon) before they can enter a tick-free zone.

As planes arrive in Australia from overseas, the cabins are sprayed in an attempt to kill any aerial pathogens before people can disembark. Passengers travelling from certain countries or at certain times are also given special consideration. For example, during the mad cow epidemic in the United Kingdom, all passengers had to declare whether or not they had been to a farm and if they had, their footwear was sterilised. Similarly, passengers from certain parts of Africa need to have all shoes and boots sterilised. If coming from areas where a disease is rife (e.g. yellow fever in Tanzania), the passenger must have a current vaccination card for that disease, otherwise they are placed in quarantine. People are checked if they exhibit a fever, particularly if they are coming from an area with a virulent influenza epidemic.

Biosecurity stations have been set up along Australia's northern regions where a variety of animals (e.g. horses, cattle, pigs, poultry and insects) are kept. Regular blood tests are performed on these 'sentinel' animals to monitor diseases that may have come from South-East Asia or the Pacific region via migrating animals. A range of other procedures, such as management of ballast water (which may contain disease-causing pathogens or pests) released from international ships, also exist.

FIGURE 5 An Australian quarantine station: (a) plant greenhouses; (b) dog runs; (c) horse stables

Although our border controls have been very effective in preventing the spread of disease and pests, they are not infallible. Not all entry into Australia can be controlled along our thousands of miles of coastland. Many pathogens are carried by birds and flying foxes that migrate between Asia and Australia. Sailing boats moving between the Pacific islands and Australia often pull into small coastal towns. This means they might avoid surveillance and, as a result, biosecurity checks.

Contact tracing

If a disease outbreak occurs, health officials will attempt to trace all contacts of the original infected person. This occurred in 2017 when there was a small outbreak of measles that affected eleven people. Eight of these people were linked to a particular building in Melbourne where they had come into contact with the original infected person. All these people were quarantined to prevent the spread of the disease.

public health program
a program undertaken by organisations to prevent disease, prolong life and promote human health through informed choices

vaccination
injection of a killed microbe in order to stimulate the immune system against the microbe, thereby preventing disease

Public health programs

Public health programs are very important in disseminating information and implementing control measures. **Vaccination** is another measure to prevent both the contraction and spread of disease. Programs that encourage all children to be vaccinated before starting childcare or school improve herd immunity. Needle-exchange centres for drug users have helped prevent the spread of HIV or hepatitis through multiple use of needles between associates. Spread of insect-borne disease is alleviated through programs to advise of breeding sites for vectors.

CASE STUDY 12.4A

Fire ants

Fire ants are small, highly aggressive ants that swarm their victims and bite viciously. The effect on the victim (animal or human) is so severe and painful that it can cause anaphylactic shock and death. These ants originated in South America but have spread throughout the United States and China. They can spread rapidly and even a tiny amount of soil in or on a shipping container can contain enough ants to set up new colonies. Somehow, a few ants evaded biosecurity checks of incoming cargo into Australia. Fire ants were first detected at the port of Brisbane in 2001 and are now found at Port Botany in New South Wales. Eradication programs were set up and movement of soil and pot plants from areas of known infestation stopped. It is thought that these ant colonies are under control, but continued vigilance for their occurrence is necessary. The presence of one undetected colony could result in their rapid spread.

(a) (b)

FIGURE 6 (a) A biting fire ant; (b) the effects of group biting

CASE STUDY 12.4B

Moreton Bay prawns and white spot disease

In 2017, prawn farms in the Logan River in south-east Queensland were closed and all stock destroyed when the viral white spot disease was discovered. Shortly afterwards wild prawns in Moreton Bay were discovered with the disease. Although harmless to humans when cooked, the effect on prawns and the prawning industry is devastating. The disease can only be transmitted from live or uncooked prawns to other live prawns and crabs. In an attempt to prevent further spread of the disease, no uncooked prawns can be moved from region between the New South Wales border and Caloundra or inland of the Moreton Bay area past 30 kilometres.

It is not known how this disease, which occurs in South-East Asia, was transmitted to Australia. One hypothesis is that contaminated raw prawns exported from Asia were used as fishing bait in the Logan River; another is that food produced for the prawn farms contained contaminated raw prawns.

FIGURE 7 A prawn infected with white spot disease

CHECK YOUR LEARNING 12.4

Describe and explain

1 **Explain** why it is important to wash your hands with soap and water rather than just water.

2 Pathogens can be transmitted in a variety of ways. **Identify** three modes of transmission and for each give an example of a transmitted pathogen.

3 **Explain** why animals for human consumption should only be killed at approved abattoirs.

4 Overseas hotels often advise their clients not to use the tap water for drinking or cleaning teeth. **Explain** why.

5 **Define** the term 'quarantine'.

6 Despite stringent federal quarantine control, some diseases still enter Australia from overseas. **Describe** how this could occur.

Investigate, evaluate and communicate

7 During an outbreak of gastroenteritis, a number of schools and aged care facilities were closed for a period of time in a particular locality. **Discuss** the rationale for these closures.

8 **Investigate** an Australian public health initiative that helps control disease. Find out about its purpose and strategy, and **evaluate** how effective you think this initiative is.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 12.4
- » Weblink
  Preventative measures
- » Weblink
  Control measures
- » Weblink
  Customs and quarantine

12.5 Treating diseases

KEY IDEAS

- Definition and common use of the term 'chemotherapy'
- Natural sources of medicines
- The role of antibiotics in the treatment of infectious disease
- Antibiotic resistance

Throughout time animals have used natural remedies to alleviate ill health. The grass eating of domestic cats and dogs, and deliberate ingestion of kaolin clay by birds and primates to cure intestinal upsets, is well recognised. Early humans also developed a knowledge and understanding of curative aspects of particular plants. Even today approximately 60% of the world's population does not have regular access to pharmaceutically produced medicines. They depend primarily on plants for preventing and treating illness. The forest people of the Amazon, for example, use 1300 plant species for medicinal purposes. The number of plant species used in healing in other parts of the world is also staggering – in India 2500 species, in South-East Asia approximately 6500, and in China 5000 species. Some people, even with access to Western medicines, prefer traditional herbal remedies. A number of Chinese herbalists can be found in most cities throughout the world. A large number of plants in Australia were also used by Indigenous people. In recent times, there has been a resurgence in investigating Australian plants for possible drug applications.

chemotherapy the treatment of disease by means of chemicals that have a specific toxic effect upon disease-producing microorganisms (e.g. antibiotics) or that selectively destroy cancerous tissue

FIGURE 1 Chemotherapy is most commonly used as a term to describe the treatment administered to cancer patients; however, it also refers to the use of chemicals to prevent and cure other diseases or disorders.

Chemotherapy

Although the term **chemotherapy** is now applied to the injection of specific chemicals to prevent cell division, and therefore cancer growth, it is defined as the use of chemicals to prevent and cure diseases and disorders. Many of these chemicals have been isolated from living organisms. The active components, once identified, can often then be synthesised in the laboratory. Others, such as sulphonamides, which were widely used in the mid to late 1900s to treat urinary and bowel infections and pneumonia, are purely synthetic.

Plant chemicals

Plant chemicals with healing properties are known as secondary plant products since they are not involved in manufacturing carbohydrates, proteins or lipids. These products are actively made by the plant and at least some are thought to be adaptations to protect the plant. As useful drugs, these plant products act by either mimicking existing chemicals that inhibit or stimulate natural processes, or producing an antibiotic or antiseptic to protect themselves from infection.

Studies of particular plants, isolation of their active ingredients and rigorous testing have resulted in the development of approximately 40% of all prescription drugs. For example, the major surgical muscle relaxant tubocurarine is derived from the plant-based

curare used by some South American Indian tribes on the tips of their blowpipe darts when hunting.

The identification and isolation of the active ingredients from plants have allowed the production of synthetic drugs. However, not all plant chemicals can be synthesised. For example, digitalis, a heart stimulant that slows down and strengthens heartbeat and that has saved millions of lives, is still produced from dried foxglove (*Digitalis purpurea*) leaves. After the Second World War, the anti-malarial drug quinine, produced from the bark of the *Cinchona* tree, was replaced by synthetic products. In recent years, however, malarial parasites have shown increasing resistance to these drugs. Quinine has had a revival as the only effective drug against certain *Plasmodium* strains. Less than 10% of the active higher plant chemicals used in prescriptions are commercially prepared by synthesis. This is either because scientists have not as yet found a way to synthesise them or because they can be more economically produced by growing the plants.

FIGURE 2 Foxglove (*Digitalis purpurea*)

Antibiotics

Plants are not the only organisms found to have therapeutic effects. Many modern **antibiotics** are either produced by various species of bacteria or fungi, or artificially synthesised from their natural products. Antibiotics are chemicals that interfere with either the metabolism or structure of bacteria. Some ways that antibiotics destroy bacteria are by interfering with:

antibiotic
a drug used to treat bacterial infections

- cell wall structure (e.g. penicillin)
- cell membranes (e.g. amphotericin)
- synthesis of proteins (e.g. streptomycin and tetracycline)
- synthesis of nucleic acids (e.g. rifampicin).

It is probable that production of these chemicals is a defence mechanism of one species to prevent competition for resources. Antibiotics have selective toxicity – they act only on bacteria other than the one producing it. Some antibiotics are broad spectrum and act on a range of bacteria (e.g. tetracycline) while others are very specific to a particular type. This difference has been utilised in the commercial production of these drugs.

The antibiotics streptomycin and aureomycin are produced by bacteria. Several antibiotics are produced from fungi. Penicillin (used to combat many Gram-positive bacteria and staphylococcal infections) is produced from several species of *Penicillium*, notably *P. notatum*.

Much research has been conducted into the production of antibiotics by bacteria and fungi since the discovery of penicillin in 1929, and into their purification and ability to act on specific pathogenic bacteria. Now there is an antibiotic treatment for the majority of diseases caused by bacteria. The success of these treatments over the past century has been responsible for a massive decrease in many lethal infections such as tuberculosis.

Antibiotic resistance

This success has, however, led to a major problem – **antibiotic-resistant** strains of bacteria have developed. Bacteria are able to evolve this resistance since they have

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

- an extremely large population size
- a short generation time
- an unusually flexible genetic system.

Bacteria have a single, circular chromosome composed of DNA. Spontaneous changes (mutations) in sections of the DNA (i.e. genes) that can be neutral (have no effect), harmful to survival or beneficial (e.g. resistance to an antibiotic) occur. Since bacteria can divide rapidly in a favourable environment, any beneficial mutation can spread within a population very quickly. Although bacteria do not reproduce sexually, they have three mechanisms for transferring genes from one individual to another.

Some bacteria can take up segments of naked DNA (e.g. DNA released when the cell wall/membrane from another bacterium or organism has been destroyed) from their environment and incorporate it into their chromosome. Thus, the bacterial DNA has been **transformed**. If a bacterium is infected with a non-lethal virus, some of the bacterial DNA can be incorporated into the viral particles it produces. If these viruses infect a new bacterium, the host can pick up and incorporate the transported bacterial DNA into its chromosome in the process of **transduction**. **Conjugation** is a process where genes can be transferred between two bacterial cells that are temporarily joined by extensions of their membranes, called pili. In addition to the main chromosome, bacteria have other small circular DNA molecules called plasmids. Plasmids replicate separately from the bacterial chromosome and are important in conjugation transfer. One group of plasmids (R-plasmids) carry genes for antibiotic-destroying enzymes. These can be passed to non-resistant individuals of the same or a different species of bacteria.

Bacteria can therefore become resistant to one or more antibiotics by:

- mutations that are passed from generation to generation
- uptake of resistant genes during transformation
- transfer of resistant bacterial genes by viruses in transduction
- exchange of genes during conjugation
- movement of R-plasmids between bacteria.

This resistance has not developed as a cumulative tolerance of the bacteria to the drug, but as a chance mutation. Thus, some bacteria in a population have an enzyme capable of breaking down a drug (e.g. penicillin). In the presence of penicillin, non-resistant forms are destroyed, and resistant forms survive. The greater the quantity and frequency of penicillin use, the higher the proportion of resistant forms left in the population. Because the resistant gene can be transferred between different species, a pathogen can be resistant to the antibiotic even before the antibiotic is used against it.

Taking antibiotics for a non-bacterial infection or as a precaution increases the likelihood of development of antibiotic-resistant forms. Similarly, if an incomplete course of prescribed antibiotics is taken, not all of the invading bacteria will be killed. Since they will continue to reproduce, there is a good chance that a random mutation will occur that is resistant to the drug.

Chemicals produced by other organisms

Other chemicals produced by fungi can be used to treat other pathogens. Griseofulvin, produced from *Penicillium griseofulvum,* has antifungal properties; fumagillin, produced from *Aspergillus fumigatus*, is frequently used against amoebic dysentery.

Although there are some antiviral drugs that cause disruption of the ability of a virus to either adhere to or leave a host cell, most treatment of viral infections rely on boosting the individual's immune system through rest and taking vitamin C and zinc.

Although only a small fraction of marine organisms has been examined, a large number of valuable chemicals have been found in them. A sea squirt, for example, produces a substance

found to be active against a broad range of viruses responsible for such diseases as colds, influenza, herpes and meningitis. Serum from horseshoe crabs is able to isolate tumour cells from the blood of cancer victims. Shark livers contain lipids thought to increase human resistance to cancer. Over 500 marine organisms have been found to produce chemicals that have the potential to combat cancer.

Terrestrial animals have provided fewer chemicals to medicine. Bee venom is used to treat arthritis, and captopril, produced from the venom from a Brazilian snake, aids in controlling hypertension.

CHECK YOUR LEARNING 12.5

Describe and explain

1 **Identify** three plants that produce chemicals that are of medicinal value to humans.
2 **Describe** the ways in which plant and animal chemicals (active ingredients) can act on human pathogens.
3 **Explain** the function of antibiotics and why they are not prescribed for viral infections.
4 **Explain** the term 'antibiotic resistance'.
5 **Describe** the features of bacterial reproduction that enhance the development of antibiotic resistance.

Check your obook assess for these additional resources and more:

- » Student book questions
  Check your learning 12.5
- » Weblink
  Chemotherapy
- » Weblink
  Antibiotics
- » Weblink
  Antivirals

CHAPTER 12

Review

Chapter summary

12.1 Spread of disease is facilitated by migration of vectors and the increased movement of the general population.

Epidemiology is the scientific study of factors determining and influencing the frequency and distribution of disease, injury and other health-related events.

12.2 Viruses are non-living particles that can only be cultivated in living cells.

Bacteria and pathogenic fungi are living cells and can be cultivated on a nutrient agar medium in a Petri dish under sterile conditions.

Different groups of bacteria can be distinguished using growth inhibition by specific antibiotics and staining techniques (Gram stain or fast-acid stain). Identification to species level is achieved by DNA analysis.

12.3 Monitoring of disease is an epidemiological practice that aims to predict and minimise the harm caused by an outbreak.

It is mandatory to report certain diseases to state and federal authorities. Other diseases are notifiable to the World Health Organization to reduce pandemic outbreaks.

Mathematic models, developed from surveillance data, can predict the likely outcomes of disease outbreak.

12.4 Pathogens are transmitted in air, water, soil, from individual to individual, and via vector organisms.

Good personal hygiene and rigid standards at food preparation outlets are significant deterrents to the spread of infectious disease.

Quarantine isolates infected organisms until the disease has run its course or been treated.

Vaccination prevents the contraction and spreading of a disease.

Public health program rules to reduce the spread of infectious disease include:

- Do not get bitten by a vector or infected individual.
- Do not urinate or defecate in or near water supplies.
- Do not use fresh human faeces as fertiliser in gardens.
- Maintain good hygiene.
- Isolate sources of infection.

12.5 Chemotherapy is used in the treatment of cancerous growths and prevents cells from reproducing.

Traditional treatments for human diseases have been derived from plant extracts. Although medicinal drugs have been isolated and extracted from a large variety of organisms, plants are the main source of prescription medicines.

Antibiotics are medications against bacteria. They are naturally produced by bacteria and fungi.

Bacteria can become resistant to antibiotics. Viruses can transfer genes between microorganisms.

Key terms

- antibiotic-resistant strain
- antibiotics
- carrier
- case fatality ratio
- chemotherapy
- cytopathic effect
- epidemiology
- herd immunity
- mortality rate
- public health program
- quarantine
- random sample
- SIR model
- vaccination

Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Multiple choice

1 Factors that aid in the transmission of pathogens would *not* include:
- **A** small droplets of water in the air
- **B** decreased flyways of birds and flying foxes
- **C** direct contact with an infected individual
- **D** contaminated food and water

2 Pandemics have *not* been caused by:
- **A** regional travel within a country
- **B** increased tourism
- **C** movement of goods between countries
- **D** migration of certain animals

3 Epidemiology is the scientific study of:
- **A** identification of species from their genome
- **B** the use of X-ray diffraction to determine the molecular structure of pathogens
- **C** the ability to rapidly make multiple copies of segments of DNA
- **D** identification of the causes of disease

4 Globally, the leading cause of death is:
- **A** non-infectious diseases, of which the prime cause is smallpox
- **B** non-infectious diseases, of which the prime cause is heart disease and stroke
- **C** infectious diseases, of which the prime cause is influenza
- **D** infectious diseases, of which the prime cause is cholera

5 R_0 is a measure of the number of people who become infected by each person with a disease. This parameter:
- **A** varies from disease to disease and mode of transmission
- **B** varies from disease to disease but not mode of transmission
- **C** is the same for all diseases that have the same mode of transmission
- **D** is the same for all diseases irrespective of the mode of transmission

6 Quarantine refers to:
- **A** the 40-day period of isolation of a person with a disease to ensure that the disease is no longer viable
- **B** the 40-day period of isolation of a diseased person to ensure treatment is completed
- **C** the isolation period for a person, animal or plant required to ensure non-transmission of an infectious disease or a potential infectious disease
- **D** the isolation of all people with a contagious disease in a special hospital ward

7 As planes arrive in Australia from overseas, the passenger cabins are sprayed prior to disembarkation. The purpose of this procedure is to:
- **A** provide deodorant to passengers after being in stagnant air for a long time
- **B** reduce stress in the passengers before they pass through quarantine
- **C** attempt to reduce ectoparasites harbouring on a passenger
- **D** attempt to eliminate airborne pathogens

8 Antibiotics:
- **A** can be used to treat all the effects brought about by pathogens
- **B** are restricted in their effectiveness to bacterial and viral infections
- **C** have selective toxicity to all bacteria
- **D** each have selective toxicity to specific bacteria

Short answer

Describe and explain

★**9** **Explain** what is meant by a cytopathic transformation.

★**10** **Explain** how public health programs control and/or prevent disease.

★**11** **Discuss** the roles of the Australian Quarantine and Inspection Service.

★★**12** People who were in England during the mad cow epidemic are not permitted to donate blood in Australia. **Explain** the rationale behind this.

★★**13** The bacterium *Staphylococcus aureus*, or 'golden staph', causes a range of pus-forming

Group of countries	Total population	Reported cases	Fatalities	Mortality rate (per 100 000 000)	Case fatality ratio (%)
A Cambodia, Thailand and Vietnam	164 326 409	123	66		
B Indonesia	234 693 997	96	76		
C Azerbaijan, Djibouti, Egypt, Iraq, Nigeria, Turkey	322 641 106	59	26		
D China, Laos	1 328 373 886	26	17		

infections through the production of toxins. Some strains of this bacterium are highly adapted to hospital environments because they are resistant to a large number of antibiotics and are highly dangerous in individuals recovering from surgery. Strains of this bacterium found outside the hospital environment are sensitive to antibiotics. **Suggest** how this different sensitivity to antibiotics has occurred in these strains.

Apply, analyse and interpret

★ **14** Gather, process and analyse information to **identify** the cause and effect relationship between asbestos exposure and mesothelioma.

★★ **15** In 1957, scientists in England discovered a natural substance, now known as interferon, which interferes with viral replication. Interferon is produced in infected human (and closely related species such as the chimpanzee) cells within 2 hours of viral infection. Antibody production takes 7–10 days after infection. Nearly all cell types can synthesise interferon, but it cannot be synthesised in embryos less than 3 months old. The production of interferon is variable among different people.

- **a** The mosquito-borne Zika virus may not have serious effects on a pregnant woman. Her unborn child, however, may die or suffer microencephaly where the brain is highly undeveloped. **Explain** this occurrence.
- **b** Some people in the population rarely suffer viral infections while others constantly contract diseases such as colds and influenza. **Identify** what factors might contribute to this difference.

Investigate, evaluate and communicate

★★ **16** In March 2017, a vaccine against malaria, developed by researchers at Queensland's Griffith University, passed early human trials.

- **a** Assuming that the R_0 for malaria is 100, **determine** what percentage of any given population would need to be vaccinated to prevent the spread of this disease.
- **b** **Propose**, with reasons, impediments to undertaking such a vaccination program in those countries in which malaria is most prevalent.

★★★ **17** The table above shows the incidence of avian influenza A (H5N1) in humans at a particular time.

- **a** **Calculate** the mortality rate and case fatality rate for each group of countries to complete the table.
- **b** **Contrast** the mortality rates and case fatality ratios for the groups of countries.
- **c** **Propose** two possible explanations for the differences in mortality rates in the country groups.
- **d** **Determine** whether you would recommend travel warnings to tourists for any of the countries listed. **Justify** your answer.

★★ **18** Many people are worried about contracting a disease, such as lyssavirus, from flying foxes. As a consequence, submissions to local councils for the destruction of colonies are regularly made. The flying fox is a protected species and so the most a council can legally achieve is to use methods to move the colony from its camp.

Investigate the positive and negative effects of a flying fox colony and the means by which colonies are forced to move from an area. Write a justified report in response to a submission to move or kill a colony.

★ **19** **Investigate** foot and mouth disease and the world locations in which it is most prevalent. Outline the ways in which Australia controls this disease.

★★ **20** Coastal regions from the New South Wales border north to Broome are tick infested. Movement of stock from Queensland into New South Wales or west of the Great Dividing Range is controlled and can occur only if the stock has been sprayed to kill any ticks they may be harbouring. **Propose** two reasons for this control.

★★ **21** Process, analyse and present information from secondary sources to **evaluate** the effectiveness of vaccination programs in preventing the spread and occurrence of once common diseases, such as smallpox, diphtheria and polio.

★★★ **22** In recent years a large number of people in developed countries have consciously decided not to be vaccinated or have their children vaccinated against diseases. Much of the objection is related to the carrier chemicals in the vaccine. **Investigate** the reasons for and against vaccination, and **construct** a table summarising your findings. Draw a justifiable scientific conclusion.

★★ **23** Using information from the previous two questions, **predict** the effects of a reasonable proportion of the Australian population refusing any vaccinations. **Justify** your response.

★★ **24** **Design** an experiment to determine the minimum length of time required to wash clean hands, using a liquid soap that purports to kill 99% of germs, to remove all bacteria from them. State your control and other variables.

★★ **25** Biomedical researchers often examine the herbal medicine practices of communities who do not have access to Western medicines. Discuss the significance of research into chemicals produced by plants and animals to combat disease and testing done to validate their effectiveness. **Investigate** and **describe** new findings of medicinal properties found in Australian plants.

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- » Student book questions
  Chapter 12 review
- » Revision notes
  Chapter 12
- » assess quiz
  Chapter 12 auto-correcting multiple-choice quiz
- » Flashcard glossary
  Chapter 12 glossary

CHAPTER 13

Practical manual

The QCAA Biology General Senior Syllabus outlines a number of mandatory and suggested practicals for completion in Units 1 and 2. All mandatory practicals and four manipulative skill practicals are included in this chapter. The remaining suggested practicals can be found online in your obook. Suggestions for methodology and materials have been supplied in this chapter and the practicals are listed in the tables here. However, the following is not prescriptive; schools may complete the mandatory or suggested practicals in any other form suited to their resources.

The experiments in this chapter have been trialled and cautions of obvious hazards given; however, it is the legal obligation of the individual teacher to carry out their own risk assessment prior to undertaking any practical activity.

In all of the practicals it is required for all participants to wear safety glasses, gloves, lab coats (or aprons) and enclosed footwear. Long hair must be tied back and lab rules must be followed.

UNIT 1 PRACTICALS

MANDATORY PRACTICAL	**3.2**	The effect of surface area to volume ratio on the rate of diffusion
MANDATORY PRACTICAL	**3.3B**	Preparation and examination of wet mount specimens
MANDATORY PRACTICAL	**7.2A**	The effect of temperature on the rate of reactions of an enzyme
MANIPULATIVE SKILL	**3.3A**	Use of the light microscope
MANIPULATIVE SKILL	**4.2B**	Separation of chloroplast pigments by paper chromatography
MANIPULATIVE SKILL	**8.5B**	The passage of water through flowering plants
MANIPULATIVE SKILL	**8.5C**	Stomatal function
SUGGESTED PRACTICAL	**2.5**	The effect of enzyme concentration on the rate of reaction
SUGGESTED PRACTICAL	**3.3C**	Identifying organelles from electron micrographs
SUGGESTED PRACTICAL	**3.5**	Modelling the selectively permeable cell membrane

SUGGESTED PRACTICAL	**4.2A**	Conditions necessary for photosynthesis
SUGGESTED PRACTICAL	**4.3**	Respiration
SUGGESTED PRACTICAL	**5.5**	Organisation of cells into tissues, organs and systems
SUGGESTED PRACTICAL	**7.2B**	The effect of pH on the rate of enzyme reactions
SUGGESTED PRACTICAL	**8.5A**	Investigation of plant leaves, stems and roots
SUGGESTED PRACTICAL	**8.6**	Factors affecting the rate of transpiration

UNIT 2 PRACTICALS

MANDATORY PRACTICAL	**10.10**	The role of the leaf in plant osmoregulation
MANDATORY PRACTICAL (either part B or part C)	**11.4**	The effect of an antimicrobial on the growth on a microbial organism **A** Preparation of a bacterial lawn **B** The effect of antibiotics on bacterial growth **C** The effect of handwashing liquids on microbial growth **D** Assessing the effectiveness of the antibacterial agents
SUGGESTED PRACTICAL	**9.1**	Tolerance limits for water or salt balance in plant growth
SUGGESTED PRACTICAL	**9.6**	A simple reflex arc – pupil response

FIGURE 1 A student adding oil to a biological sample on a microscope slide

Unit 1 Mandatory practicals and manipulative skills

3.2 MANDATORY PRACTICAL — The effect of surface area to volume ratio on the rate of diffusion

HYDROCHLORIC ACID, EVEN IN DILUTED CONCENTRATIONS, IS CORROSIVE AND AN IRRITANT. IF IT COMES IN CONTACT WITH YOUR SKIN OR EYES, IMMEDIATELY WASH IT OFF OR USE THE EYE WASH STATION. WEAR SAFETY GLASSES AND GLOVES WHEN HANDLING CHEMICALS. USE AN ACID SPILL KIT IF THE ACID SPILLS ON THE BENCH.

Investigate the effect of surface area to volume ratio on cell size. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1 To determine the influence of the surface area to volume ratio on the effectiveness of diffusion
2 To relate the findings to the size and shape of cells and living organisms

Theoretical basis

The cell membrane determines what substances can diffuse into and out of a cell. This characteristic of a cell membrane is called permeability. Membranes are semi-permeable; that is, they only allow the passage of certain materials. Nutrients and oxygen need to diffuse into the cell and waste materials need to diffuse out. Other chemical components, however, need to remain in the cell.

Gelatine is permeable and thus can represent a cell. Cresol red dye is an acid/alkali indicator. In the alkali condition, it is red or purple but when exposed to acid it turns a light yellow colour. By cutting differently sized cubes and rectangular blocks of gelatine impregnated with cresol red dye, different surface area to volume ratios are achieved. The time taken for the indicator to turn light yellow when the block is placed in acid represents the time of diffusion.

Surface area to volume ratio calculations:

Cube	surface area = $6 \times \text{side}^2$ volume = side^3
Regular rectangular block	surface area = 2 × (length × width) + 2 × (length × height) + 2 × (width × height) volume = length × breadth × height

Materials

- 6 × 150 mL beakers
- Tray of gelatine containing cresol red dye, 15 mm thick
- 0.1 M hydrochloric acid
- Three stopwatches
- Scalpel
- Ruler
- Cutting mat
- Forceps
- 100 mL measuring cylinder
- Safety glasses

Note

It is recommended that the class be divided into groups, for example:

- group 1 to work with shapes a and b
- group 2 to work with shapes c and d
- group 3 to work with shapes e and f.

Results for all six shapes can then be shared and collated for individual calculations and interpretations.

Replicates of each shape should be done concurrently to save time.

Method

1 Remove the dyed gelatine from the tray onto the cutting mat.
2 Using the scalpel and ruler, carefully cut three each of the following shapes:
   a 5 × 5 × 5 mm
   b 10 × 10 × 10 mm
   c 15 × 15 × 15 mm
   d 10 × 10 × 5 mm
   e 10 × 15 × 5 mm
   f 20 × 5 × 5 mm
3 Put on the safety glasses. Measure 100 mL of 0.1 M hydrochloric acid and pour it into the beaker. Repeat for two other beakers.
4 Using forceps, carefully place one of each of the three replicate shapes into each beaker (to be done simultaneously by three group members) and start the stopwatch.

5 Time how long it takes for all the red dye to disappear in each replicate block. Record the times in the results table.
6 Discard the blocks and acid as instructed by your teacher.
7 Repeat steps 3–6 for the next shape.
8 Calculate the surface area to volume ratio for each shape and record in the results table.
9 Calculate the average time for the dye to disappear and record in the table.

$$\text{Surface area to volume ratio} = \frac{\text{surface area}}{\text{volume}}$$

10 Draw a graph of surface area to volume ratio against time.

Results

Dimensions (mm)	Surface area (mm^2)	Volume (mm^3)	SA:vol	Time taken for all the dye to disappear (min:sec)			
				Test 1	Test 2	Test 3	Average
5 × 5 × 5							
10 × 10 × 10							
15 × 15 × 15							
10 × 10 × 5							
10 × 15 × 5							
20 × 5 × 5							

Discussion

Write a discussion of your results, including the following points:

- difficulties in cutting the shapes accurately and any means used to determine dimensions
- the reason for the three replicates of each shape size
- the reason fresh acid is used for each test
- the relationship between the surface area to volume ratio of the shape and the time taken for the acid to diffuse into the whole block
- the shape of the block related to diffusion rate
- explain how the surface area to volume ratio affects cell size
- the relationships between cell size and shape and the ability of the cell to function efficiently
- the necessity for organisms to increase cell numbers in order to become larger.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

3.3B MANDATORY PRACTICAL
Preparation and examination of wet mount specimens

METHYL BLUE AND METHYL CELLULOSE ARE IRRITANTS. IF THEY COME IN CONTACT WITH SKIN OR EYES, IMMEDIATELY WASH THEM OR USE THE EYE WASH STATION. WEAR SAFETY GLASSES AND GLOVES WHEN HANDLING CHEMICALS.
MOVING THE STAGE UP AND DOWN AT HIGH MAGNIFICATIONS CAN CAUSE THE LENS TO BREAK THE GLASS SLIDE. BE CAREFUL WHEN ZOOMING IN AND OUT.

Prepare wet mount slides and use a light microscope to observe cells in microorganisms, plants and animals to identify nucleus, cytoplasm, cell wall, chloroplasts and cell membrane. The student is required to calculate total magnification and field of view. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1. To prepare wet mounts of cells in microorganisms, plants and animals
2. To use the light microscope to observe the nucleus, cytoplasm, cell membrane, cell wall and chloroplasts
3. To calculate total magnification and field of view to determine cell size of the specimens

Theoretical basis

The kingdom Protista comprises a very diverse group of eukaryotes, most of which are unicellular. Some are animal-like (e.g. *Paramecium caudatum*), some are plant-like (e.g. *Spirogyra* sp.) and some are fungi-like. Fungi (e.g. bread mould), plants (e.g. moss) and animals are multicellular eukaryotes. All eukaryotes have cytoplasm enclosed by a cell membrane and membrane-bound organelles. The largest organelle, and the one most easily seen in a light microscope, is the nucleus. The cells of plants and plant-like protists are further bound by a cell wall. In those cells exposed to sunlight, chloroplasts in which photosynthesis occurs are also present and can be readily detected using a light microscope. These organelles contain the green pigment chlorophyll. Fungi, like plants, have a cell wall, but do not have chloroplasts. Special stains can be used to enhance the visibility of the nucleus. Methyl cellulose slows down the movement of organisms.

Materials

- Microscope
- Clean slides and coverslips
- Cavity slides
- Absorbent paper
- Millimetre graph paper on overhead transparent paper or a microscope mini grid
- Plastic pipettes
- Forceps
- Methyl cellulose
- Methylene blue
- Glass stirring rod
- Mortar and pestle
- *Paramecium caudatum* culture
- Pond water
- Filamentous algae
- Moss 'leaves'
- Fresh kidney
- Prepared slide of human cheek cell

Method

1. Determine the total magnification of your microscope at all eye pieces and objective lens magnifications (see the table in Practical 3.3A Part 1B 'The magnification and nature of the image', page 410). Record your calculations.
2. Determine the diameter of field of view for each microscope magnification (Practical 3.3A Part 2 'A: Diameter of field of view', page 412). Record your results.
3. Using the cavity slide, place a drop of methyl cellulose into the well. Using a clean pipette, place a small sample of the *Paramecium caudatum* culture over the methyl cellulose. Gently mix the two solutions using a clean glass stirring rod. Cover with a coverslip (see Figure 1 in Practical 3.3A and preceding instructions). Examine the slide under low power but make sure the iris diaphragm is almost closed to reduce the amount of light passing through the slide. When a *Paramecium caudatum* is located, change to a higher power. Identify the cell membrane,

cytoplasm and nucleus. Sketch (keeping the proportions correct) and label these parts in the results table. Using the diameter of field of view for this magnification, determine the cell length and width. Record them.

4 Place a few stands of filamentous algae onto a drop of water on a slide. Gently lower a coverslip over the specimen. Examine the stands under low power and then high power magnification. Sketch a few representative cells of each type present, paying attention to:
   - the size and shape of the chloroplasts
   - the size and position of the nucleus.

5 Identify the cell wall and cell membrane and label these on the sketch(es). Determine the length and width of each cell type.

6 Place a drop of methyl cellulose into the well of a cavity slide. With a clean pipette, add a drop of pond water and gently stir with a glass stirring rod. Cover with a coverslip and examine under low power magnification. When you have located an organism, change to high power. Observe cell features. Determine whether the organism is animal-like or plant-like (give reasons) and its actual size. Observe further organisms. Record your observations.

7 Make a wet mount of a small piece of bread mould and examine it under low power. Focus on several cells and move to high power. Identify the cell wall, cell membrane, cytoplasm and nucleus. Sketch and record the cell length and width. Using the technique for staining (see Figure 2 in Practical 3.3A and preceding instructions), stain the specimen with methylene blue. Record if any of the cell structures are more visible.

8 Place a drop of water in the centre of a clean slide. Carefully remove one 'leaf' from the moss and lay it flat (with top side uppermost) on the drop of water. Gently lower a coverslip over the specimen and examine it under low power. When clear cells have been focused, move to high power. Identify the cell wall, cell membrane, cytoplasm, chloroplasts and nucleus. Sketch and label a cell, keeping the proportions correct. Determine the cell length and width and record.

9 Cut a small segment of kidney and macerate it using the mortar and pestle. When it is finely ground up, place a small amount onto a drop of water in the centre of a slide. Gently lower a coverslip over the specimen. Place the slide on a piece of folded absorbent paper on the bench top. Place another piece of folded absorbent paper over the coverslip. Press down gently on this paper with your thumb, making sure to keep an even pressure, to squash the specimen thinly over the slide. Examine under low power. When a few cells are in focus, move to high power. Identify the cell membrane, cytoplasm and nucleus. Sketch and label a cell, and determine and record its length and width. Stain the slide with methylene blue and comment on any differences seen.

10 Examine the prepared slide of human cheek cells. Sketch and record the cell length and width.

Results

1 Draw a table as below and record your results, allowing enough space for the sketches.

TABLE 1 Similarities and differences between cells of various organisms

Organism	Magnification	Diameter of field of view (mm)	Cell length (mm)	Cell width (mm)	Labelled sketch
Paramecium caudatum					
Filamentous alga A					
Filamentous alga B					
Filamentous alga C					
Bread mould cell					
Kidney cell					
Human cheek cell					

2 Draw a table as below and record your results, allowing enough space for the sketches.

TABLE 2 Observations of pond water

Organism	Cell length (mm)	Cell width (mm)	Labelled sketch of cell	Plant-like or animal-like (with reasons)
A				
B				
C				

Discussion

Write a discussion of the results, including the following points:

- features common to all eukaryotic cells
- differences between plant (and plant-like), fungal and animal (and animal-like) cells
- relative sizes of different types of cells and possible explanations for any size differences
- differences seen when the cells are stained.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

7.2A MANDATORY PRACTICAL
The effect of temperature on the rate of reactions of an enzyme

TEMPERATURES ABOVE 50°C MAY CAUSE BURNS. HANDLE THE TUBES WITH HEAT RESISTANT GLOVES.

Investigate the effect of temperature on the rate of reaction of an enzyme. (Source: QCAA Biology General Senior Syllabus 2019)

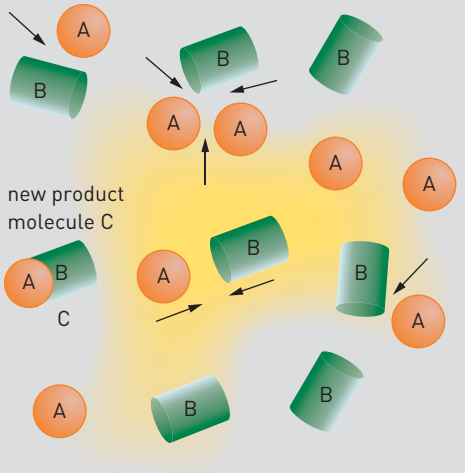
Aim

To investigate the effect of temperature on the rate of reaction of an enzyme

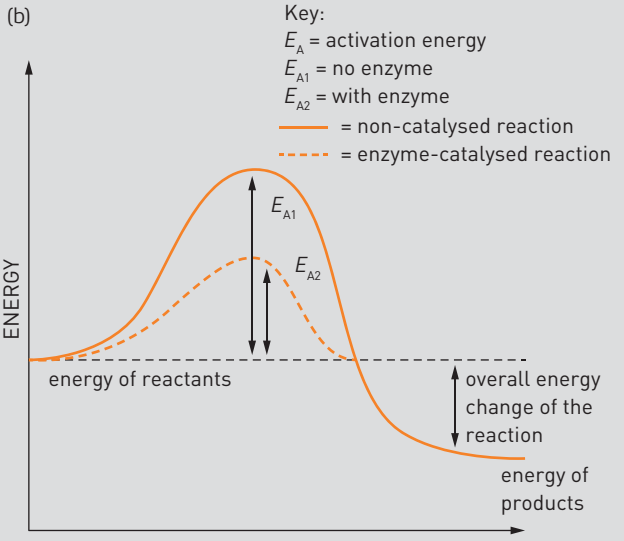
Theoretical basis

Nearly every chemical reaction that takes place in a living organism is catalysed by an enzyme. Enzymes greatly speed up the rate of reaction and lower the activation energy required for the reaction to occur. As the enzymes themselves are not consumed during these reactions, they can be used over and over again and are considered to be organic or biological catalysts. Enzymes are globular proteins and their properties are therefore the properties of proteins. Each enzyme has a specific active site, the nature of which allows that enzyme to only control one specific reaction or type of reaction.

(a)



(b)



Being proteins, enzymes are readily inactivated by heat. Heat increases molecular motion; the reactants move more quickly and chances of their bumping into each other are increased, and therefore there is a greater probability of a reaction being caused. The temperature that promotes maximum activity is referred to as the **optimum temperature**. If the temperature is increased above this point, then a decrease in the rate of reaction occurs. This is because the structure of the enzyme has been disrupted and the enzyme is said to be **denatured**. If temperature is reduced to near or below freezing point, enzymes are **inactivated**, not denatured. They will regain their catalytic influence when higher temperatures are restored.

The enzyme rennin is found in the gastric juice of young mammals and acts on milk proteins. It turns the soluble protein caseinogen in milk to the clumps of insoluble curds of casein. Although it does not bring about the digestion of these proteins, it is responsible for bringing them out of solution and so being more readily available for the action of the other enzymes that can digest casein. Rennin acts best at body temperature. Junket is a dessert that is based on this enzymatic reaction in the presence of the commercially available substance rennet.

Materials

- Test tubes
- Test-tube rack
- Junket tablets
- Beakers for junket
- 'UHT' or homogenised milk
- Equipment for heating milk
- Beakers for water baths
- Thermometers
- Equipment for maintaining temperatures of water baths
- Stirring rods
- Safety glasses and apron

Method

1. Label the three test tubes A to C and add the group name.

Tube A	Less than 15°C
Tube B	36–37°C
Tube C	50–60°C

2. Each class group is to prepare a water bath at one of the given temperatures and maintain it for the duration of the practical.
3. Each class group is to prepare the junket, using half a tablet and half the volume of milk as shown on the packet instructions. The milk used is to be at refrigeration temperature.
4. Place 10 mL of the milk solution at the appropriate temperature in each of the labelled test tubes and then place the test tubes in the appropriate water baths. This will require one member of the group to take the test tube to the appropriate water bath.
5. After 10 minutes collect the three tubes and very quickly assess and record the degree of setting in each test tube. This must be done quickly before the temperature changes and alters the results.

Results

Record your results in a table. You may need to devise a method to describe the degree of setting of the junket.

Discussion

Write a discussion of your results, including the following points:

- the best temperature of milk for the action of rennin
- the range of temperatures over which rennin acts
- reasons for the optimum temperature found
- a reason for the fact that there was no setting in some cases.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

3.3A MANIPULATIVE SKILL Use of the light microscope

MOVING THE STAGE UP AND DOWN AT HIGH MAGNIFICATIONS CAN CAUSE THE LENS TO BREAK THE GLASS SLIDE. BE CAREFUL WHEN ZOOMING IN AND OUT.

Construct a wet mount slide, using a light microscope. (Source: QCAA Biology General Senior Syllabus 2019)

Part 1

Aims

1 To get familiar with the parts and use of the light microscope
2 To prepare a wet mount of the letter 'e'
3 To determine the nature and magnification of the image

Theoretical basis

The light microscope is an important tool in biological studies. Knowledge of its parts and their functions, and the accurate use of the instrument, are essential for this course. The material that can be examined ranges in size from small whole organisms (e.g. a water flea) through to cells and their structures, including cell organelles (e.g. nucleus or chloroplast). Because this instrument depends upon its ability to transmit light through the material being examined, all specimens must be very thin. This may involve special sectioning techniques. Stains may be used to enhance differentiation of parts of the section or organism. This practical should be repeated over several periods until students are conversant with microscope techniques.

Materials

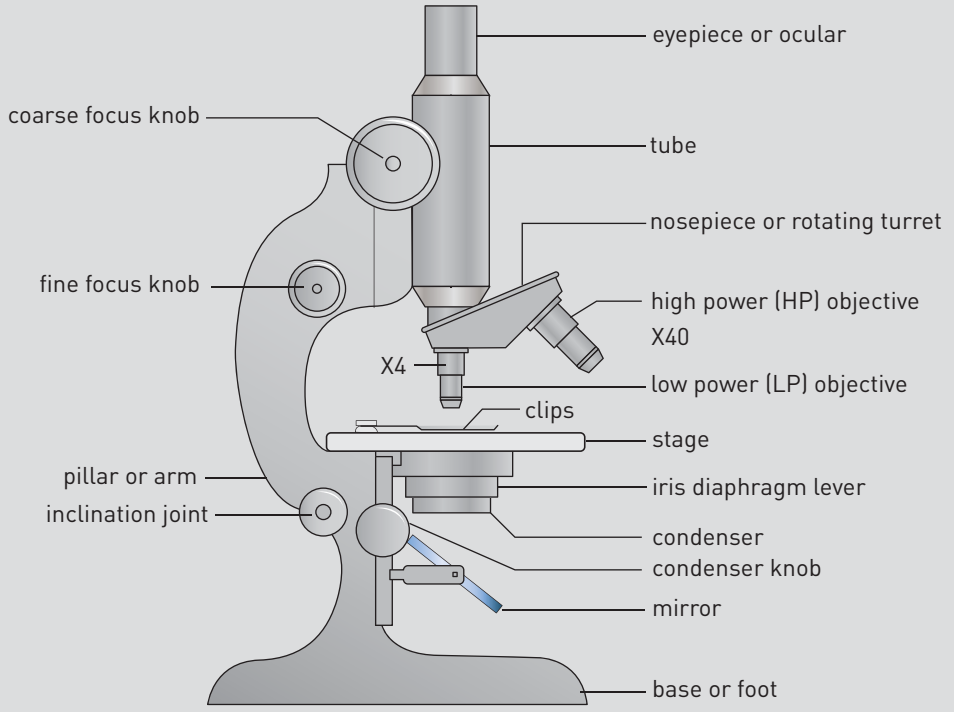
- Light microscope
- Light source
- Clean slides and coverslips
- Printed letter 'e' – can be from a newspaper, magazine or on an overhead transparency sheet
- Pipette or squeeze bottle
- Absorbent tissue paper
- Forceps
- Dissecting needles

Method

A The structure and use of the light microscope

Students may need to use separate lights for some microscopes, while other microscopes have built-in lights.

1 Get out the microscope and place it on the desk in front of you. Using the diagram below, identify the parts of the instrument, noting the functions of each. When you feel familiar with this, proceed to the next step.



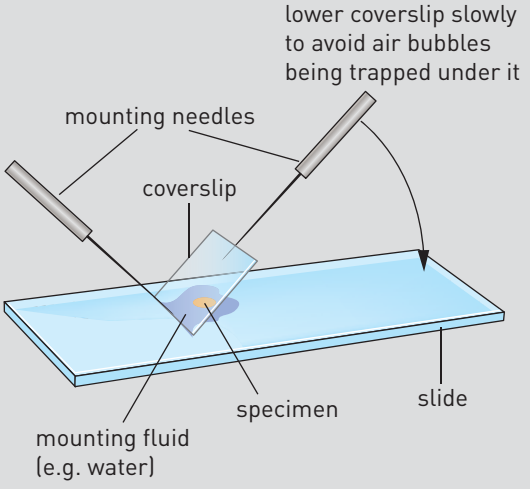
Microscope

Name of part	Function of part
Base or foot	Heavy horseshoe-shaped support
Pillar or arm	Supports the tube, stage, condenser and mirror
Inclination joint	Allows tilting of the microscope and the stage. Any time that the microscope is being used, be sure that the microscope is **not** at an angle to the vertical and that the stage is level.
There are three groups of components carried on the pillar.	
a Stage	A square area on which specimens are placed for examination. (The central hole allows the passage of light.)
Clips	Hold the object being examined on the stage
b Condenser	A lens system that focuses light on the specimen on the stage
Condenser knob	A milled adjustment knob, located just below the stage; used to alter the distance between the stage and the condenser
Iris diaphragm	Regulates the amount of light passing through the condenser. It is opened or closed by means of a lever. With lower powers or with transparent objects, the diaphragm should be partly closed.
Mirror	Attached to the pillar under the condenser. It can be twisted to any angle. Its function is to reflect light into the microscope. The plane mirror is used with very low magnifications in microscopes without condensers, and with condensers in microscopes that have these. The concave mirror is only used in microscopes without condensers in the higher powers. If the microscope does not have a condenser, most of the work will be done with the concave mirror. Some microscopes have an inbuilt light source and there will be no mirror. **DO NOT TOUCH THE MIRROR SURFACES WITH FINGERS.**

Name of part	Function of part
c Tube	Attached to the pillar, above the stage; may be graduated and has the eyepiece lens system at the top and the objective lenses system at the bottom = the microscope. If the tube is graduated, pull it up to 160 mm for the objectives supplied.
Eyepiece or ocular	A removable lens system; is inserted in the upper part of the tube. In most cases the eyepiece is a X10 magnification.
Nosepiece	A rotating turret, at the bottom of the tube, into which is screwed the objective lens systems. This may be such that it can only be rotated in **one direction**.
Objectives lens systems	The microscopes are fitted with three objectives: low power objective = X4, medium power objective = X10, and high power objective = X40. Compare the length and the diameter of the lens in the outer (lower) end. The one that is the longest and that has the smallest diameter lens is the strongest magnifier.
Coarse focus knob	On the pillar, nearest the eyepiece. It can be operated with either hand and is used to move the tube up or down. It should only be used with the low power objectives to obtain the initial focus of the object being examined.
Fine focus knob	On the pillar above the stage. It is used after the object is approximately focused with the coarse knob. **It is the only focusing knob to be used with the high power objective**.

2 Prepare a wet mount of the printed letter 'e'.

- **a** Make sure that the microscope slides and coverslips are clean.
- **b** Always handle the glass slides and coverslips by their edges.
- **c** Place the glass slide and coverslip on a small piece of paper towel.
- **d** Using a dropper bottle or a pipette, add one or two drops of distilled water to the centre of the slide.
- **e** Pick up the cut-out image of the letter 'e' with forceps and place it carefully on the centre of the slide so that the letter is read correctly facing you.
- **f** The specimen is then covered with a thin coverslip to exclude air and dust, and to protect the high power microscope objectives. This is done by holding the coverslip by the edges, and then placing it on the slide at an angle of about 45° so that the angle includes the specimen and the drop of water or mounting medium.
- **g** Gently and slowly lower the coverslip, using a dissecting needle. If this is done with care and very slowly, there should be few (if any) air bubbles trapped on the specimen. Air bubbles will be seen under the microscope as perfect circles with distinct dark edges. Look at the specimen under low power and if there are too many air bubbles in the specimen, then mount another specimen.
- **h** If specimens begin to dry out, add a drop of water to the edge of the coverslip and then draw it under the coverslip using a piece of absorbent paper on the opposite edge.



Mounting a specimen and lowering a coverslip onto a glass slide

B The magnification and nature of the image

1 Using the prepared wet mount of the letter 'e', note the orientation of the letter before placing the slide on the microscope stage under **the lowest objective power**.

2 Move the slide so that the specimen is centred above the condenser.

Fasten the slide in position under the stage clips.

Looking from the side and using the coarse focus knob, lower the low power objective lens until it is about 6 mm above the glass cover strip of the slide.

Keeping both eyes open, look through the eyepiece and **raise** the tube by means of the coarse adjustment until the specimen comes into focus. Use the fine focus adjustment knob for critical focus.

With the magnification of the microscope on this setting, the magnification of the image of the letter 'e' will be:

microscope magnification = power of the eyepiece × power of the objective lens

3 Construct a table similar to the table below and complete it by determining all magnifications possible on your microscope.

Your table may vary from the one below; for example, your microscope may have only one eyepiece magnification or you may not have oil immersion available, so adjust your table to suit your microscope.

Objective lens	Eyepiece power	Objective power	Microscope magnification
Low power X4	A X5 B X10	A X4 B X4	A X20 B X40
Medium power X10	A B		A B
High power X40	A B		A B
Oil immersion X100	A B		A B

4 Draw the letter 'e' as viewed through the eyepiece.

5 Comment on the letter's orientation relative to its placement on the microscope stage.

6 Move the slide away from you. Record your observations. Move the slide towards you. Record your observations. Move the slide to your right. Record your observations. Move the slide to your left. Record your observations.

7 Make a summarised statement concerning the nature and movement of the image of an object viewed through a light microscope.

Part 2

Aims

1 To measure the field of view at a low microscope magnification and calculate the field of view for other magnifications

2 To draw accurately scaled biological drawings of microscopic specimens using field of view diameter by means of the following steps:

- **a** Prepare a wet mount of onion epidermal cells.
- **b** Use irrigation techniques to stain the cells.
- **c** Draw an accurate representation of three of these cells under high power and their contents.
- **d** Label the drawing.
- **e** Determine the magnification of the drawing.

Materials

- Light microscope
- Light source (if the microscope doesn't have a built-in one)
- Slides and coverslips
- Pipette or squeeze bottle
- Absorbent tissue paper
- Onion
- Stain
- Pencil, rubber and ruler
- Millimetre graph paper on overhead transparency (OHT) or a microscope mini grid
- White paper

Method

A Diameter of field of view

1 The engraved mini-grids are very accurate and should be used if available.

Alternatively, place **one** drop of water in the centre of a clean microscope slide. Carefully centre a 20 mm square of the OHT millimetre graph paper over the drop and gently lower this as if it were a coverslip.

2 Focus this grid under a low power of the microscope. **Record the magnification used**.

3 Move the slide so that this grid can be used to measure the diameter of the field of view of the magnification.

Note: If printed grids are used, the grid lines may appear fuzzy, disjointed and wide. The centre of one line to the centre of the other line is 1 mm.

4 Measure and **record the diameter of the field of view** for this magnification.

5 Leaving the grid in place, change to the next highest objective magnification. **Record your observations**.

6 Calculate and record in the table the diameter of the field of view for each possible magnification of your microscope using the formula found in the **formula box** on the next page. Examples are given.

For the microscope used, complete the table.

Objective lens	Eyepiece power	Objective power	Microscope magnification	Diameter of field of view
Low power	X10	X4	X40	
Medium power	X10	X10	X100	
High power	X10	X40	X400	
Oil immersion	X10	X100	X1000	

The above data may vary between different microscopes.

B Scaled microscope drawings

1 Place a clean, dry slide on a piece of absorbent paper on the desk. Put one drop of water on the centre of the slide. Remove a piece of epidermis from a small segment of onion. The teacher will demonstrate how this is done.

2 Carefully place this strip of cells on the drop of water on the slide with the outer surface upwards. Add a second drop of water to the top of the strip. Complete the wet mount preparation as for the letter 'e' using either the mini-grid or the millimetre OHT as a coverslip.

3 Observe the cells under low power. Move the slide until the cells are lengthwise across the field of view. Count and record the number of cells across the diameter. Calculate and record the average length of these onion cells, using the length of cell formula.

$$\text{length of cell} = \frac{\text{diameter of the field of view at this magnification}}{\text{number of cells across the diameter}}$$

4 Refocus under higher magnification and make notes or sketch the details of the cells observed.

5 Stain the strip of onion epidermis as shown in the diagram below.

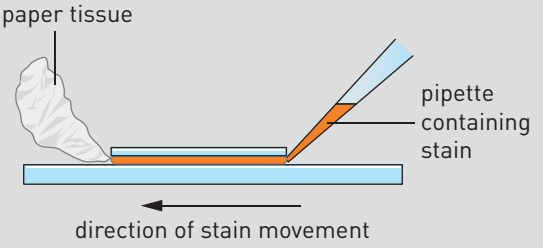


FIGURE 2 Staining a strip of onion epidermis

Re-examine the specimen.

6 Draw **three** onion cells showing details seen under high power, ensuring the correct length and width proportions.

- **a** Draw **large** enough to clearly represent all necessary details (at least half a page).
- **b** Use simple **pencil** lines on **plain** white paper. (Do **not** shade or colour.)
- **c** Give an explicit **title** at the top right-hand side of the page (e.g. 'Onion epidermis cells').
- **d** Labels of observed structures should be printed or neatly written horizontally on one side of the drawing arranged neatly in a vertical column.
- **e** Draw **straight lines** (as short as possible) from the labels, **not crossing** any other label lines, and terminating **on** the structure indicated (without arrowheads or crosses)

7 Calculate the **drawing magnification** using the following formula:

$$\text{Drawing magnification} = \frac{\text{linear dimension of the drawing}}{\text{linear dimension of the object (cells)}}$$

For example, drawing magnification

$$= \frac{8\text{ cm}}{4\text{ mm}} = \frac{80\text{ mm}}{4\text{ mm}} = 20$$

This is recorded as 'X20'.

It is placed after title '**Onion epidermis cells X20'.**

In this case, the linear dimension of the object is the length of the cell as calculated in step 3. The formula on the previous page is used to determine all drawing magnification, remembering that the smallness of microscopic objects requires calculation of size using the diameter of field of view method.

Discussion

Write a discussion of the results for parts 1 and 2, including the following points:

- the nature and movement of the image (viewed with a light microscope) with reference to the object
- the diameter of the field of view with changing magnifications
- comparison of cellular details seen:
  - **a** with changing magnification
  - **b** with staining
- the necessity of calculating the size of microscopic objects
- the desirability of always including a drawing magnification or scale on biological presentations.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

Formula box

$$\text{Field of view diameter (for the new magnification)} = \frac{\text{recorded low power microscope magnification}}{\text{new microscope magnification}} \times \text{recorded field of view diameter at low power}$$

Microscope magnification (low power) = Power of the eyepiece × Power of the objective lens

Recorded low power microscope magnification = X10 × X4 = X40

New microscope magnification = X10 × X10 = X100

Recorded field of view diameter at low power = previously measured = [ ] mm

$$\text{Field of view diameter (for objective X10 eyepiece X10)} = \frac{\text{low power magnification}}{\text{new magnification}} \times \text{field of view diameter at low power}$$

$$\textbf{Field of view diameter (for objective X10 eyepiece X10)} = \frac{\mathbf{40}}{\mathbf{100}} \times \textbf{[ ] mm = ? mm}$$

4.2B MANIPULATIVE SKILL Separation of chloroplast pigments by paper chromatography

BOILING WATER MAY CAUSE BURNS. HANDLE BEAKER WITH HEAT-RESISTANT GLOVES.
ETHYL ALCOHOL IS HIGHLY FLAMMABLE – DO NOT HANDLE NEAR AN OPEN FLAME.

Extract chlorophyll from leaves. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1. To remove pigments from plant material
2. To separate the pigments using paper chromatography
3. To identify the pigments by their colours and relative positions on the chromatograph
4. To determine relative amounts of each pigment

Theoretical basis

Various pigments found in the chloroplasts of plants are used in the process of photosynthesis. The specific pigments used depend to some extent upon the amount of light normally present and the wavelengths of the light that normally falls on the plant. Other pigments are not used in photosynthesis. There are five pigments commonly found in chloroplasts. Although leaves usually appear green, the chlorophylls present may mask the appearance of other pigments. Some leaves are red and in those leaves a red pigment is masking the chlorophylls. Variegated leaves, those which are green with white areas, only photosynthesise in the green areas, and the white areas are devoid of chlorophylls.

The chloroplast pigments can be separated and identified by paper chromatography. Absorptive paper containing a concentrated spot of chloroplast extract is dipped into a suitable solvent. The various pigments have differently-sized molecules, with the result that as the solvent ascends the absorptive paper it carries the pigments with it at different rates, the smaller molecules being more mobile than the larger ones. In this way, they become separated from each other and can be identified by their different colours and positions.

Materials

- Test-tube holder
- Drawing pin
- Glass rod
- Glass pipette
- Hot plate
- Small container
- Parsley or spinach
- Water
- Tweezers
- Beakers (600, 400 mL)
- Large test/boiling tube
- Cork or rubber stopper
- Solvent
- Metric ruler
- Scissors
- Ethyl alcohol
- Chromatography paper
- Mortar and pestle
- Centrifuge
- Centrifuge tube

An alternative solvent is 1 part of 90% acetone to 9 parts of petroleum ether (boiling point = 80–100°C).
Check chemical restrictions and workplace health and safety rules.

Method

A Preparation of leaf pigments

1. Bring about 150 mL of water to the boil in a 600 mL beaker on the hot plate. Place the leaves in the boiling water and bring to the boil again. Boil for several minutes.
   Remove the beaker from the hot plate and drain the water from the leaves.
2. Transfer the boiled leaves to a 400 mL beaker containing 80 mL ethyl alcohol.
   Place this beaker on the hot plate and when it begins to bubble remove it and allow to cool.
   Repeat this heating and cooling of the alcohol-leaf mixture several times.

3 Remove the beaker from the hot plate. Squash the leaves with a glass rod.
Reheat and squash until the alcohol solution becomes a dark green colour.

This preparation of pigments can also be achieved by the following method:

1 Quickly immerse leaves in boiling water.
2 Place killed leaves in mortar and pestle and grind these up with a small amount of alcohol.
3 Decant the dark green liquid produced into a centrifuge tube and settle it out using a centrifuge.

B Preparing the chromatograph chamber

1 Cut a length of chromatograph paper of sufficient length to almost reach the bottom of a large test tube (the width should be less than that of the tube so that the paper does not touch the sides of the tube).
2 Rule a pencil line across the strip of paper 30 mm from one end. Make a cut from each side of the line to the centre bottom to form an arrow head. Fold the other end through 90° and, by means of a drawing pin, attach it to the cork stopper. The bottom tip of the strip should almost reach the bottom of the tube when the cork is inserted.
3 Place the chromatography paper on the desk, dull side up. Add the chloroplast extract to the centre of the drawn line by dipping the fine glass pipette into the extract and then quickly touching it to the centre spot on the paper. Allow the spot to dry. Add more pigment to the same spot. Repeat this procedure (allowing the spot to dry before adding more pigment) about 20 times, until there is a small spot of concentrated pigment.

C Separating the pigments

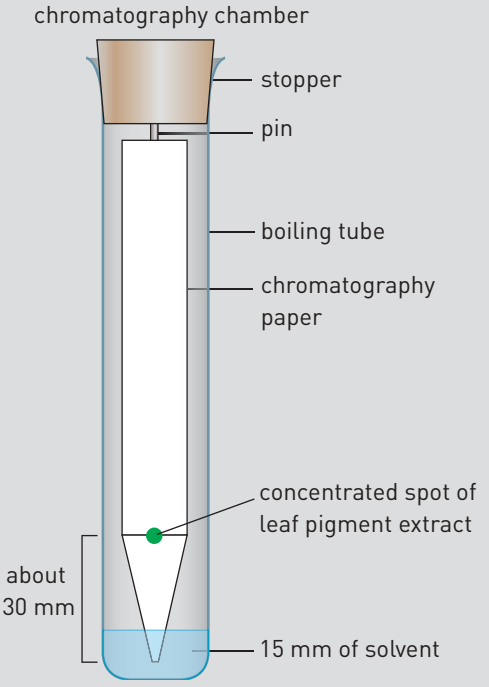


FIGURE 1 Chromatography chamber

FIGURE 2 Appearance of pigments

Make sure all flames are turned off and the room is well ventilated.

1 Add the solvent to a height of 15 mm in the test tube. Carefully place the tube into the test tube holder.
2 Place the chromatography paper into the tube. Do not let the spot of extract touch the solvent.
3 Do not shake or move the tube for at least 15 minutes. Remove the chromatograph from the tube when the solvent has almost reached the top of the paper.

D Analysis of the chromatograph

1 Quickly measure the distance travelled by the solvent. Record it. (The solvent rapidly evaporates in air.)
2 Examine the chromatograph for the presence of different bands of colour. Each colour band will be a different pigment. Some bands are very faint.
3 Measure the distance from the pencil line to the leading edge of each clearly detectable pigment. Record it.

   The ratio of the rate of movement of the pigment to solvent (the R_f value) can then be calculated for each pigment.

$$Rf = \frac{\text{distance moved by the substance from the original position}}{\text{distance moved by solvent from the same position}}$$

4 Using the information opposite, identify the pigments found in the leaf examined.

Name	Colour	R_f
Carotene	Yellow	0.95
Pheophytin	Yellow-Grey	0.83
Xanthophyll	Yellow-Brown	0.71
Chlorophyll a	Blue-Green	0.65
Chlorophyll b	Green	0.45

5 Measure the width and depth of each of the pigment bands.

   Estimate the relative quantities of each pigment present.

Results

Present your results in an appropriate form.

Discussion

Write a discussion of your results, including the following points:

- the pigments present in the leaf
- possible functions for pigments such as phaeophytin, a breakdown product of chlorophyll
- possible changes in leaf colour change in deciduous trees in autumn (chlorophyll a and b are easily broken down in cool temperatures)
- possible differences in types and/or concentrations of pigments present between plants with very dark green leaves and those with light green leaves
- a scientific reason (based on pigments present) that could explain why some rainforest trees and ferns have young leaves that are red in colour as do the red algae that are found at greater depths of seawater than the green and brown algae.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

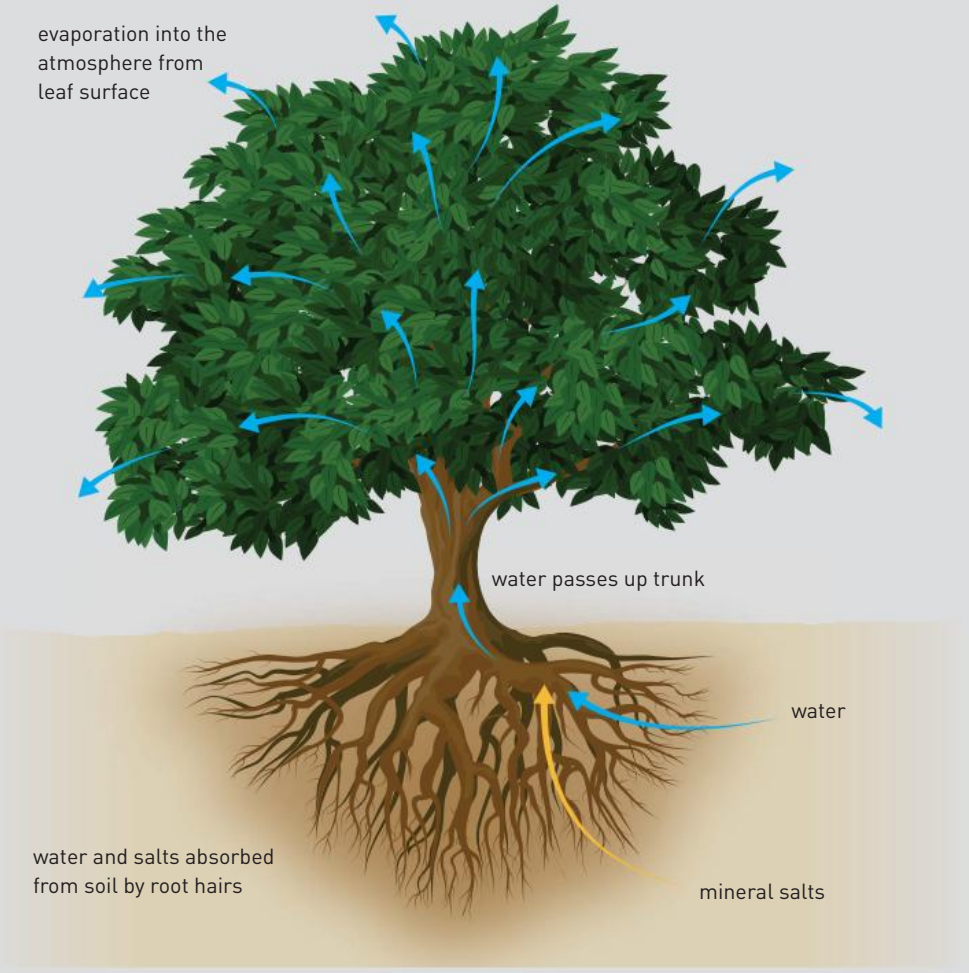
8.5B MANIPULATIVE SKILL The passage of water through flowering plants

MOVING THE STAGE UP AND DOWN AT HIGH MAGNIFICATIONS CAN CAUSE THE LENS TO BREAK THE GLASS SLIDE. BE CAREFUL WHEN ZOOMING IN AND OUT.

Using different diameter capillary tubing, demonstrate cohesion and adhesion forces in water. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1. To demonstrate movement of water through a plant
2. To prepare wet mounts of transverse sections through root tips, main root and stem
3. To identify xylem tissue from both wet mounts and prepared slides of longitudinal sections of plant tissue
4. To prepare a three-dimensional diagram of xylem tissue from transverse and longitudinal sections
5. To demonstrate that transpiration is necessary for movement of water in the plant
6. To determine the effect of root pressure on water transport
7. To demonstrate the effects of cohesion and adhesion on a thin column of water



Theoretical basis

Water and dissolved inorganic ions pass from the soil water into root hairs and through the cortex to the root xylem by osmosis. The inward movement of water creates a root pressure, which forces water up the xylem until counteracted by the downward force of gravity. Transpirational loss of water from the leaves pulls the thin water columns in the xylem vessels and tracheids upwards. This can occur due to the strong forces of cohesion between water molecules and adhesion between the water molecules and the plant cell walls. Since the water columns are extremely narrow, the forces of adhesion result in capillarity.

Materials

- Herbaceous plants (e.g. balsam) at least 30 cm tall
- Large beakers
- Razor blade
- Microscope slides
- Distilled water
- Coverslips
- Microscope
- Vaseline
- Different-sized capillary tubing
- Retort stand
- Absorbent paper
- Hypodermic syringe
- Toothpick
- Rubber band
- Petri dish
- Sticky tape
- Tissue
- Eosin stain or food colouring
- Prepared slides of longitudinal sections – stem and root

Method

Prepare parts A and B together.

A The passage of water through the flowering plant

1. Half-fill the beaker with water and add drops of the eosin (pink/red) dye or food colouring until the solution is very dark in colour. Stir the solution to ensure even distribution of the dye.
2. Wash the plant roots with water and then place the plant with its roots in the solution. Leave for a day.
3. Record your observations of the plant.
4. Remove the plant from the solution and wash thoroughly with water. Cut thin transverse sections (TS) of each of the following – the root tip, main root and stem. Add a drop of water to the centre of three clean microscope slides and carefully place the sections (one type per slide) onto the water. Add another drop of water and cover with a coverslip. Label the slides with the name of the specimen type (e.g. TS of root tip).
5. Examine each section under the microscope.
   Draw and label each section.
6. Examine the prepared longitudinal sections of the root and stem under the microscope.
   Draw and label each section.
7. Construct a three-dimensional model (diagram) of the xylem.

B Transpiration, root pressure and water movement in the flowering plant

1. Set up a beaker containing aqueous eosin or food colouring as in part A.
2. Completely coat the stem, petioles and leaves of a young plant with a thin, even smear of Vaseline and then, after washing the roots in water, place the plant with its roots in the solution. Leave for a day.
3. Make serial transverse sections of the stem to determine the extent of movement of the dye.
4. Record your observations of the plant.
5. In tabular form, compare the observations of the two plants in parts A3 and B4.

C(I) Cohesion and adhesion in water

1. Take two clean microscope slides. Stand them together vertically. Select a rubber band and a toothpick.
2. Place the thin end of the toothpick between the two slides close to their tops.
3. Wind the rubber band around the top of the two slides to hold the two slides and the toothpick together.
4. Put a small amount of water that is well coloured with food colouring into the Petri dish.
5. Stand the slides vertically in the water.
6. Observe and record the level of coloured water between the slides.

C(II) Cohesion and adhesion in water

1. Run a strip of sticky tape from the bottom of a Petri dish across its top and down to the bottom.
2. Put water that is well coloured with food colouring into the Petri dish.
3. Take a selection of fine, differently-sized capillary tubing.
4. With a pin, put an equivalent number of pinpoint holes in the sticky tape.
5. Place one fine capillary tube into each hole in the sticky tape.
6. After a few minutes observe and record the size of the hole in the capillary tubing and the level to which the water has risen in the tubing.

C(III) Cohesion and adhesion in water
Teacher demonstration

1. Stand two test tubes in a test-tube rack and fill these with aqueous eosin solution or food colouring solution so that the level is just below the top of the test tubes. Place a piece of sticky tape from one side over the top and onto the other side of one test tube. Repeat for the other test tube. This should effectively close the top of the tubes. Use the drawing pin to make a small hole in the tape in the centre of each test tube. Fill a piece of capillary tubing with water by holding it under a running tap. When water is seen running from the end of the tubing, place a finger over the end furthest from the tap. Check that there are no air bubbles in the tube. Keeping a finger over the bottom opening of the tube, move until the tubing is near one of the test tubes, invert the tubing and then slowly move the tubing through the hole in the tape until only about 1 cm of tubing is above the tape. Slowly remove the finger from the tubing. The level in the tubing should not drop. Repeat this procedure for the other test tube.
2. Cut a corner about 6 cm long from the corner of a tissue. Separate the tissue into two pieces. With your fingers, carefully roll the corner into a fine point so that it will fit into the end of the capillary tubing. Loosely roll one of these pieces of tissue. With the other, only roll the corner and leave the rest flat.
3. Place the rolled corner of one of the tissues into the top, open end of the capillary tube. Repeat with the other into the other capillary tube. Record your observations.
4. Leave overnight and again record your observations.

Discussion

Write a discussion of your results, including the following:

- the structure of xylem in flowering plants
- the necessity for washing the plant roots with water before and after placing in the solution
- evidence that water moves through the plant in an upward direction from roots to leaves
- evidence that water moves in the xylem
- evidence that transpiration is important in the transport of water in flowering plants
- the extent to which root pressure is responsible for the transport of water
- the necessity for coating stems and petioles with Vaseline in part B.
- the control for part B
- the relationship between the results of part C and the transpiration stream
- the causes of the results observed in part C
- the analogy of the different arrangements of the tissue to leaf structure and function
- the cohesion and adhesion of water in plants.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

8.5C MANIPULATIVE SKILL Stomatal function

MOVING THE STAGE UP AND DOWN AT HIGH MAGNIFICATIONS CAN CAUSE THE LENS TO BREAK THE GLASS SLIDE. BE CAREFUL WHEN ZOOMING IN AND OUT.

Create models to demonstrate the action of guard cells of stoma. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1. To prepare wet mounts of upper and lower epidermis of a plant leaf
2. To identify, draw and label stomata, guard cells and epidermal cells
3. To make 'moulds' of the upper and lower epidermis of a variety of plant leaves
4. To determine differences in number of stomata in the upper and lower epidermis and between different species
5. To produce models to demonstrate the action of the guard cells of the stoma

Theoretical basis

The main functions of the epidermis are to **cover** and **protect** stems, leaves and young roots. The epidermal cells of the leaves produce the cuticle and hairs. Leaf epidermis contains stomata (pores or holes). A single pore is called a stoma while many pores are called stomata. Although the epidermis protects and waterproofs the leaves it also allows gaseous exchange to occur. The gases that diffuse into and/or out of the stomata are water vapour from transpiration, carbon dioxide needed by the photosynthetic tissue of the leaf, and the oxygen from photosynthesis that is not required for respiration. Two modified epidermal cells, called guard cells, surround each stoma. These are the only cells in the epidermis to have chloroplasts. The opening and closing of the stomata involves variation in the water content of the guard cells. Their cell wall is thicker next to the pore than next to the other epidermal cell. When they are full of water, their thin walls stretch more than their thick ones, causing the cells to curve away from each other and the pore to open. As the guard cells lose water the pressure in the cells decreases, and the guard cells become straighter and the pore closes.

Materials

- Microscope
- Slides and coverslips
- Fresh clear nail varnish
- Long balloons
- Sticky tape
- Cotton thread
- Strong sugar solution
- Scissors
- Visking (dialysis) tubing
- Leaf samples (e.g. *Tradescantia*, pansy)

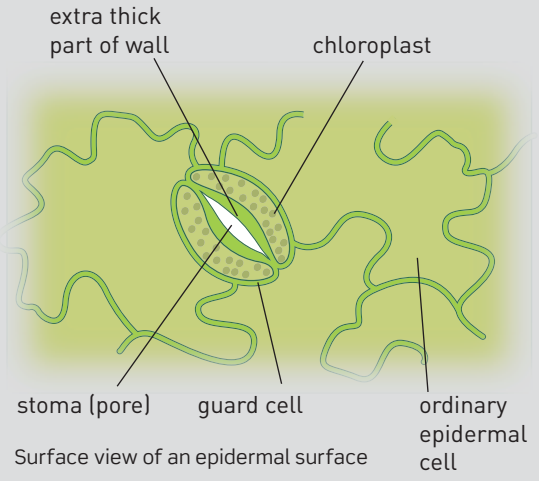
Method

A Viewing stomata

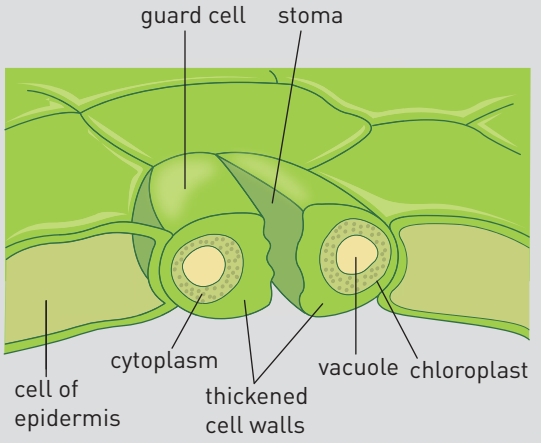
1. Place a drop of water on the centre of a clean microscope slide. Remove a small strip of the lower epidermis of the *Tradescantia* leaf provided (the teacher will demonstrate the process). Carefully lower this onto the drop on the slide with the outer surface upward. Place a coverslip over the epidermis and examine under the microscope. Locate the stomata under lower power.

   It often helps to place the leaves in cold water for about five minutes, allowing them to become turgid. When the leaf is bent and breaks the epidermis is left intact and a small section on it can then be cut.
2. Under high power, draw and label a stoma with its guard cells and a few surrounding epidermal cells.

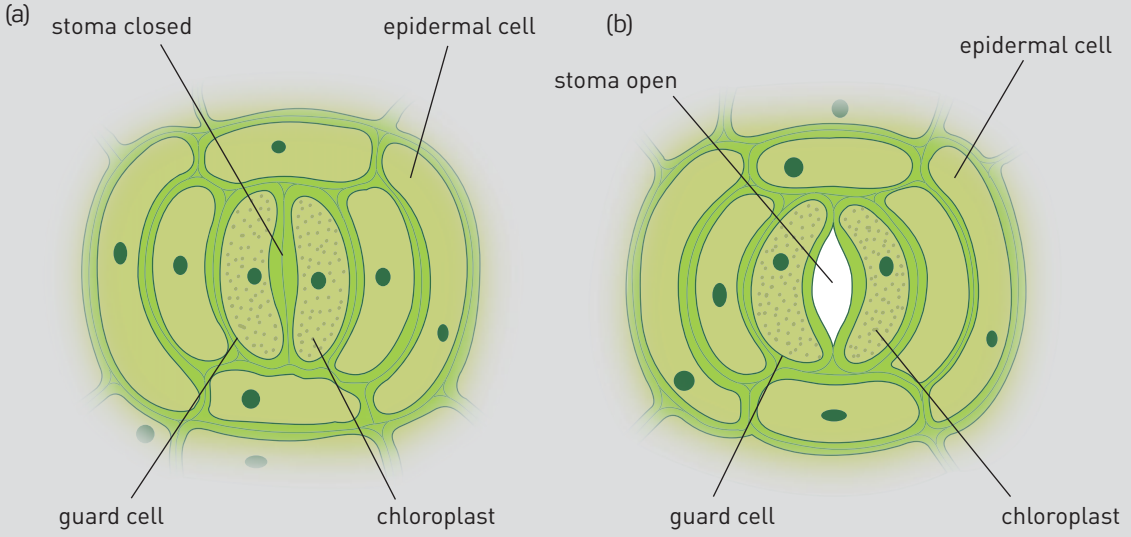
3 Repeat steps 1 and 2 using the upper epidermis of the leaf.



Surface view of an epidermal surface



Appearance of stoma in leaf surface



Structure of a stoma when (a) closed; (b) open

4 Apply several coats of nail varnish to the leaf surface of a variety of different leaves in strips. Allow to dry. For each leaf type, strip away the lower epidermis dried coat and mount on a slide **with the side in contact with the leaf upward**. Repeat for the upper epidermis. Examine under low power.

5 Under high power, count the number of stomata in the field of view for upper and lower epidermis of each leaf type. Estimate the area of the field of view (see Practical 3A Part 2A 'Diameter of field of view') and determine the number of stomata per unit area. Record your results in tabular form.

B Models to demonstrate the action of the guard cells of the stoma

Balloon model

1 Inflate a long balloon and record its shape.

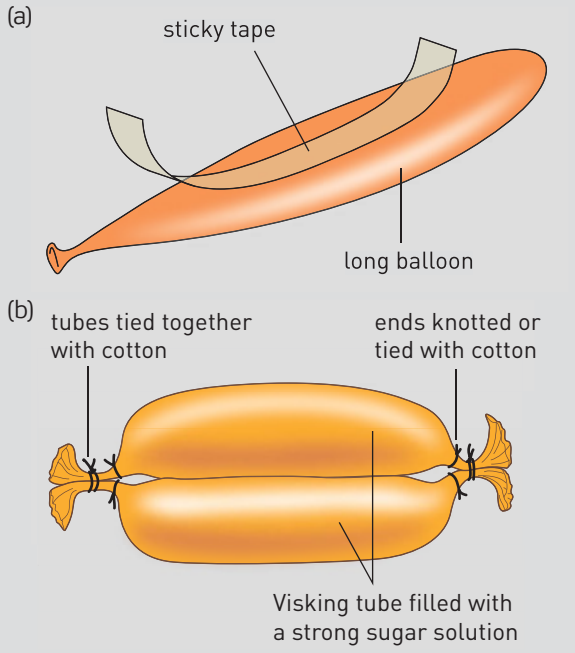
2 Deflate the balloon and lay it flat on the desk. Cut off a section of sticky tape that is shorter than the balloon. Place this down one side of the balloon and make sure that it is firmly attached to the balloon. Very slowly inflate the balloon again. Record the shape that the balloon assumes. Compare it with the shape in step 1.

3 Hold the inflated balloon with the sticky tape beside another balloon with sticky tape. Draw this and label it with what you consider that it represents from your drawings in A.

Visking tubing model

4 Cut two lengths of Visking tubing of about 20 cm. Open the tubing under running water by rubbing it between your fingers. When both lengths are open, tie a knot in one end of each piece of tubing. Fill each tube with a strong sugar solution and then tie a knot in the other end of each of the tubes. Tie the two tubes together with cotton as shown below. If you have any difficulty tying the knots in the tube, then tie them with cotton but make sure that they are securely tied and sealed.

5 Place the two tubes in a large beaker, then cover with distilled water so that the tubes are totally immersed. Leave the tubes in the water for 25 to 30 minutes. Remove from the water and record what has occurred.



(a) Preparing the balloon; (b) Visking tubing model

Results

Record your results as a table, written description and diagrams as requested.

Discussion

Write a discussion of your results, including the following points:

- differences and similarities (numbers, shape and other factors) of the stomata on the upper and lower epidermis of the leaf
- differences and similarities of stomata (numbers, shape other factors) between different types of leaves
- the function of the thicken cell wall on the guard cells

For the two models above, explain what is occurring.

Are the two models demonstrating the same thing?

Propose a hypothesis that could explain the occurrences in the two models.

Relate the structure of the guard cells to the opening and closing of the stomata.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

Unit 2 Mandatory practicals and manipulative skills

10.10 MANDATORY PRACTICAL — The role of the leaf in plant osmoregulation

MOVING THE STAGE UP AND DOWN AT HIGH MAGNIFICATIONS CAN CAUSE THE LENS TO BREAK THE GLASS SLIDE. BE CAREFUL WHEN ZOOMING IN AND OUT.

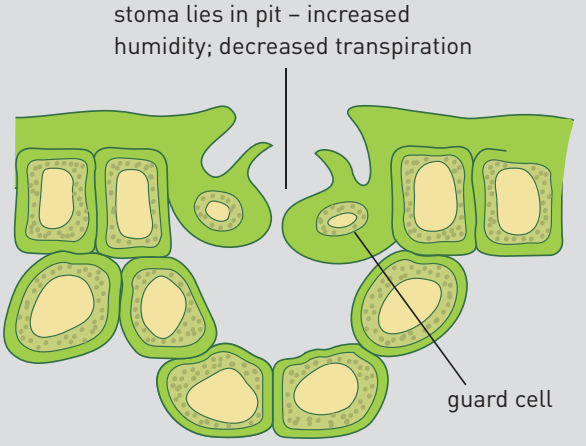
Compare the distribution of stomata and guard cells in plants adapted to different environments (aquatic, terrestrial) as an adaptation for osmoregulation in plant tissue. (Source: QCAA Biology General Senior Syllabus 2019)

Aims

1. To make wet mount slides of a leaf epidermis
2. To compare the distribution of stomata and guard cells on the upper and lower epidermis of a leaf
3. To compare the distribution of stomata and guard cells on the leaves of plants adapted to a range of different environmental conditions
4. To examine leaf adaptive features (leaf dimensions, colour, presence of hairs, sunken stomata, drip tip and other factors) and relate these to the natural environment in which the plant lives

Theoretical background

In most terrestrial plants, the stomata are mainly on the lower epidermis. Since the leaves tend to overhang each other, this creates a higher humidity between the leaves that further reduces water loss from the stomata while still allowing intake of carbon dioxide, release of oxygen and access to sunlight. The drier the environment in which the plant lives, the fewer the number of stomata. Some terrestrial plants in very dry conditions (e.g. marron grass) roll their leaves when water is short. Their stomata are on the upper surface. When rolled the upper surface forms a humidity chamber. Floating aquatic leaves (e.g. water lily) also have stomata on the upper surface only. Since they do not have to conserve water, there are no guard cells and the stomata are permanently open.



Sunken stoma

Plants in hot, dry conditions tend to have leaves that are light in colour (to reflect heat) while those in high rainfall forest conditions have leaves that are darker green in colour (usually a response to low light conditions). Hairs on the surface of leaves create a humid layer that decreases water loss by evaporation. In the same way, stomata sunk into the epidermis of the leaf also create a humid chamber between each stoma and the outside surface of the epidermis.

Materials

- Microscope
- Slides and coverslips
- Fresh clear nail varnish
- Magnifying glass, hand lens or stereomicroscope
- Class set of shoots from a variety of dry-adapted terrestrial plants (e.g. most banksias, most eucalypts, kurrajongs, hakea, wattle, emu bush, marron grass)
- Class set of shoots from a variety of moist-adapted terrestrial plants (e.g. paperbark, blueberry ash, bottlebrush, grevillea, native frangipani, swamp mahogany)
- Leaves from the above examples in addition to snake plant (*Sansevieria trifasciata*) submerged water plants (e.g. water milfoil – *Myriophyllum* sp.,

Tristicha sp.) and floating water plants (e.g. water lily or *Centella cordifolia*)

- Prepared slide of epidermis of *Hakea* sp. (microscope images can be found online)

Method

A Viewing stomata

1 Place a drop of water on the centre of a clean microscope slide. Remove a small strip of the lower epidermis of the snake plant leaf provided (the teacher will demonstrate the process). Carefully lower this onto the drop on the slide with the outer surface upward. Place a coverslip over the epidermis and examine under the microscope. Locate the stomata under lower power.

   It often helps to place the leaves in cold water for about five minutes, which allows the leaves to become turgid. When the leaf is bent and breaks, the epidermis is left intact and a small section on it can then be cut.

2 Viewing under high power, draw and label a stoma with its guard cells and a few surrounding epidermal cells.

3 Repeat steps 1 and 2 using the upper epidermis of the leaf.

4 Apply several coats of nail varnish in strips to the lower leaf surface of a variety of different leaves. Allow to dry. For each leaf type, strip away the dried varnish coat on the lower epidermis and mount on **a slide with the side that was in contact with the leaf upward**. Repeat for the upper epidermis. Examine under low power.

5 Under high power, count the number of stomata in the field of view for the upper and lower epidermis of each leaf type. Estimate the area of the field of view (see Practical 3A Part 2A 'Diameter of field of view') and determine the number of stomata per unit area. Record your results.

6 Examine the prepared slide of the transverse section of a hakea leaf. Locate, draw and label a sunken stoma, its guard cells and a few surrounding epidermal cells.

B Examination of leaf surface features

1 Observe the shoots of the plants provided. For each species, note the leaf size (length and width), colour and the manner in which it is positioned on the stem.

2 Using the magnifying glass, hand lens or stereomicroscope, examine the upper and lower surfaces of each leaf. Note the presence of any hairs. Record your results.

Results

Tabulate your findings for sections A and B.

Discussion

Write a discussion of your results, including the following points:

- the distribution and abundance of stomata and guard cells in leaves of different plants
- the relationship between distribution and abundance of stomata and guard cells, and the environment in which the plant naturally lives
- the relationship between gross leaf features of a plant and its natural environment
- the role of the leaf in plant osmoregulation.

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

11.4* MANDATORY PRACTICAL The effect of an antimicrobial on the growth of a microbial organism

ALCOHOL IS HIGHLY FLAMMABLE – DO NOT HANDLE NEAR AN OPEN FLAME.
BUNSEN BURNERS AND MATCHES MAY CAUSE BURNS. HANDLE THEM WITH CARE.

Investigate the effect of an antimicrobial on regrowth of a microbial organism (via the measurement of zones of inhibition). (Source: QCAA Biology General Senior Syllabus 2019)

*Parts B and C are mandatory practicals, while parts A and D offer students an extra challenge.

Aims

1. To follow aseptic procedures to inoculate nutrient agar plates to produce a bacterial lawn of the supplied RG1 (Risk Group 1) bacteria
2. To use this bacterial lawn to test the effectiveness of antibiotics and/or hand disinfectants in reducing or preventing the growth of the bacteria under investigation
3. To relate the size of the zone of inhibition of bacterial growth to the susceptibility or resistance of the different types of RG1 bacteria used and to the different types of antibiotics and/or hand disinfectants being assessed
4. To assess the effectiveness of the procedures used to reduce contamination of the plates produced

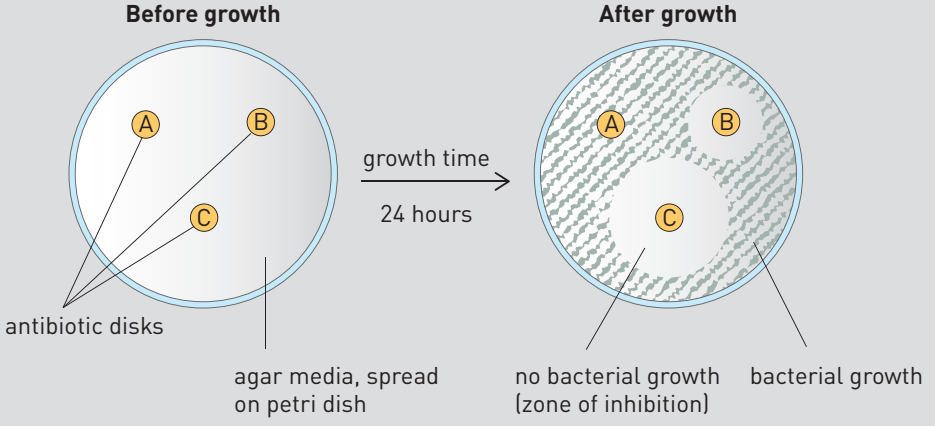
Theoretical background

A microorganism is any organism that is too small to be viewed by the unaided eye, such as bacteria, protozoa, and some fungi and algae. These practicals only involve Risk Group 1 (RG1) bacteria. These bacteria are classified by the World Health Organization as not being associated with disease in a healthy adult and include *Escherichia coli* K-12 strain, *Micrococcus luteus*, *Bacillus subtilis*, and *Staphylococcus epidermidis*.

The **disk diffusion method** involves having different types of antibiotics or disinfectants on sterile filter paper disks placed on an inoculated but not incubated agar plate covered by a 'lawn' of an RG1 bacteria. As this 'lawn' is incubated, the bacteria grow while the chemicals diffuse out of the disks. If the bacteria are susceptible to the chemical, then a **zone of inhibition** of bacterial growth is seen as a clear area around the disk. The size of this zone is an indication of the effectiveness of the chemical being tested. The diameter of each clear zone is measured in millimetres. If there is no cleared area around the disk, it is an indication that the bacterium is resistant to that chemical. Factors such as whether the chemical being tested is water-soluble and able to diffuse into the agar may limit these zones.

A **Mastring** is a ring device carrying six or eight antibiotic impregnated tips, each of which performs as a single susceptibility-testing disk. Single antibiotic-infused disks are commercially available, but it is advisable that no more than six disks (including a control, if needed) are used on a single plate.

* **Teacher note**: It is recommended that preparation of parts A, B and C be done simultaneously.



Zones of inhibition show where there is no bacterial growth in a bacterial 'lawn'.

Materials

Personal protection items for parts A to D:

- Laboratory coat or disposable apron
- Gloves and safety goggles
- 70% alcohol or strong disinfectant
- Bunsen burner and matches
- Absorbent paper
- Antibacterial handwash
- Contaminated waste bag
- Bleach solution for cleaning benches

Additional requirements

For A

- Two or three types of Risk 1 (RG1) bacteria in broth culture
- Two or three sterile nutrient agar plates
- Two or three sterile plastic dropping pipettes
- Two or three sterile hockey stick spreaders
- Fine permanent marker
- Sticky tape or Parafilm M sealing film
- Incubator
- Autoclave bag

For B

- Bacterial lawns produced in part A
- Sterile plastic forceps
- Fine permanent marker
- Sticky tape or Parafilm M sealing film
- Filter paper impregnated with known antibiotics **or**
- Antibiotic susceptibility Mastring discs
- Incubator

For C

- Bacterial lawns produced in part A
- Sterile plastic forceps
- Fine permanent marker
- Sticky tape or Parafilm M sealing film
- Pure distilled water
- Alcohol-based hand cleaner
- 99.9% antibacterial handwash
- Normal dishwashing liquid
- Incubator

For D

- Incubated plates from parts B and/or C
- Measuring ruler or callipers
- Autoclave bag

Method

A Preparation of a bacterial lawn

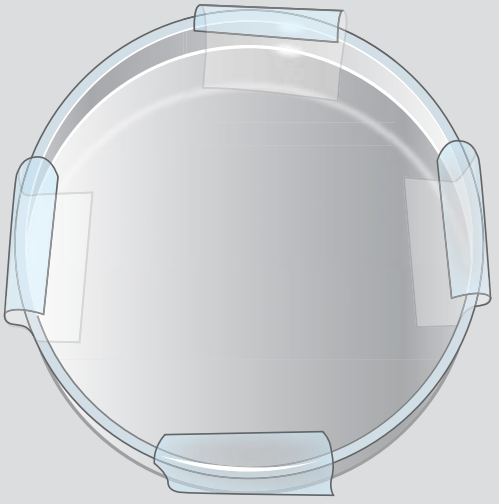
1. Reduce draughts by closing the doors and windows and turning off fans. This will also prevent unwanted entrances while the practical is proceeding.
2. Remove all unwanted books, computers and other things that are not needed from the working surfaces.
3. Wash hands with an antibacterial soap and water before and after working with microorganisms.
4. Wearing full protective gear of coat, gloves and safety goggles, wipe down the entire working surface with either 70% alcohol or a strong disinfectant.
5. Collect a Bunsen burner, matches, two or three RG1 bacteria in nutrient broth, two or three sterile dropping pipettes, two or three sterile agar plates, 0.5–1% bleach solution in beaker, a sterile L-shaped spreader (hockey-stick spreader), clean sticky tape or Parafilm M strips, and permanent marking pen.
6. Light the Bunsen burner only after it is certain that all the alcohol fumes from cleaning the bench have dissipated.
7. Turn the Bunsen burner to a blue flame that will create convection air currents so that air that may contain microbes is drawn into flame and destroyed.
8. **Always** work within 25 cm of the flame of the Bunsen burner to ensure that this occurs.
9. Turn the agar plate so that the base is uppermost. With a permanent marker on the bottom edge in small letters, write the day's date, the group initials and the RG1 that will be used to inoculate the plate.
10. Select one of the RG1 bacteria supplied. Open the lid near the blue flame and pass the lid of the glass container through the flame once.
11. Turn the plate over so that the lid is on top. **Never** open the lid of the agar plate more than 45° and always open it near the flame.
12. Using a sterile dropping pipette, transfer two or three drops of the liquid culture containing an RG1 microbe in nutrient broth to a sterile agar plate.
13. Immediately place the used pipette into the bleach and do not use it again.
14. With the lid still at 45°, take a sterile L-shaped spreader and gently spread the drops of RG1 culture evenly over the agar to create a consistent 'lawn' of microbe.
15. Immediately place the spreader into the bleach solution and do not use it again.

16 This agar plate is now ready for parts B or C. This is considered to be a 'seeded lawn'.

17 Repeat the above instructions to prepare 'lawns' for the other RG1 cultures for parts B or C.

18 If the lawn is **not** to be used in parts B or C, then the agar plate can be sealed in either of two different ways in order to incubate the plates:

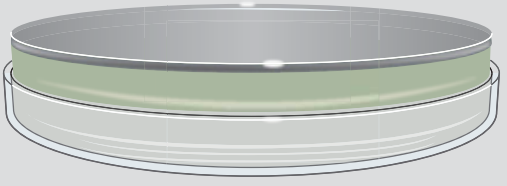
a Cut four pieces of sticky tape that are about 3–4 cm long and place at the 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock positions (see diagrams below). This will allow oxygen to diffuse into the plate and so any wanted anaerobic bacteria cannot form.



Placement of sticky tape at intervals around the agar plate

or

b Take a 2 cm wide strip of Parafilm M that is of sufficient length to go around the edge of the plate and overlap by about 2 cm. Stretch the Parafilm M around the edge to seal the lid to the base. Do not double-wrap the Parafilm M, as this will prevent oxygen getting into the microbe. One layer allows oxygen diffusion.



Placement of Parafilm M

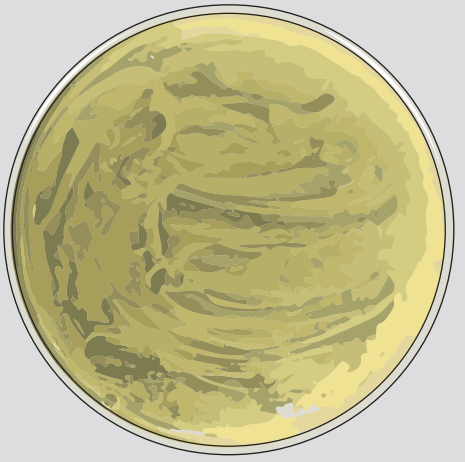
19 Repeat these procedures to produce inoculated plates for all other RG1 bacteria supplied.

20 Place the plates with the lid downwards and the agar surface uppermost in the incubator or a suitable area for incubation that is isolated, away from sunlight and at a temperature of 24–30°C for 24–48 hours. **Any incubated plates may not be opened by students under any circumstances.** Therefore, any incubated plates may not be used in parts B and C.

21 If not proceeding to parts B and C at this time, follow the teacher's instructions as to the disposal of all contaminated items used in this practical.

22 Clean the desks and all surrounding surfaces. Place any absorbent paper used to achieve this in the contaminated-waste bag supplied and not in the normal waste bin. Do not remove any items from the beaker containing bleach.

23 On completion of all tasks, place the gloves in the contaminated-waste bag supplied and then wash hands with antibacterial soap.



Appearance of a lawn culture *Micrococcus luteus* on nutrient agar that has been incubated for 24 hours at 28°C

B The effect of antibiotics on bacterial growth

1 Following all aseptic procedures in part A:

a Prepare an inoculated bacterial lawn as described in part A for each of the RG1 bacteria to be tested.

b Alternatively, inoculated but **not** incubated bacterial lawns are supplied for each of the RG1 bacteria to be tested.

2 Turn the agar plate so that the base is uppermost. With a permanent marker, write the day's date, the group initials and the RG1 that is inoculating the plate on the bottom edge in small letters.

3 Working within 25 cm of the Bunsen burner, open the lid of the inoculated plate by approximately 45°.

4 Using the sterile disposable plastic forceps, select the antibiotic susceptibility Mastring and place it as centrally as possible.

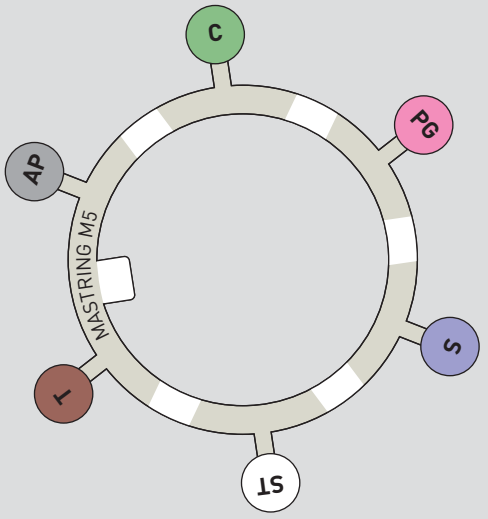
5 Immediately place the used forceps into the bleach and do not use them again.

6 If using metal forceps, they must be placed into the flame before and again after use.

7 The Mastring, if commercially supplied, will have letters or numbers to indicate the antibiotic on each spoke of the ring.

8 Seal the plate as indicated in part A.

9 Incubate the plates with the lids downwards and the bases uppermost in an incubator at 24–30°C for 24–48 hours, or in a suitable isolated area for incubation that is away from sunlight.



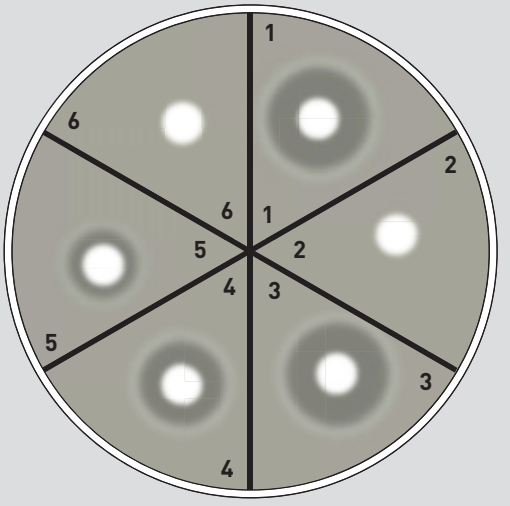
Mastring-M5 contains the following antibiotics:

C	CHLORAMPHENICOL	GREEN
PG	PENICILLIN G	PINK
S	SULPHATRIAD	MAUVE
ST	STREPTOMYCIN	WHITE
T	TETRACYCLINE	BROWN
AP	AMPICILLIN	GREY

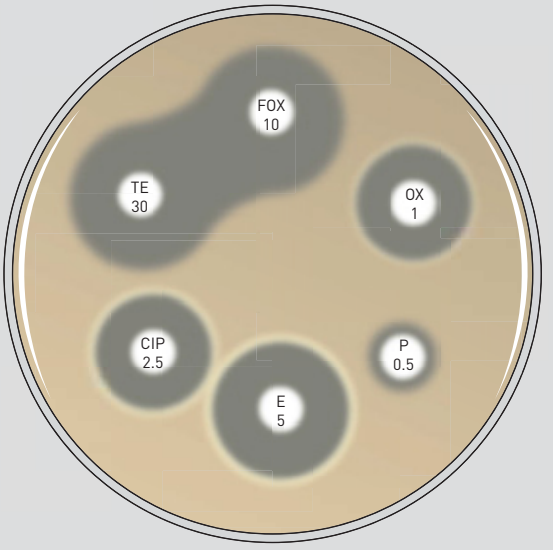
10 If separate discs impregnated with antibiotics are used, then separate disposable plastic forceps must be used for each disc. After use, immediately place the used forceps into the bleach and do not use them again.

11 Arrange the disks so that they are separated evenly and away from the edge of the plate. No more than six disks are to be placed on the surface of the agar.

12 On the base of the agar plate, write a code to indicate the antibiotic used.



Unmarked disks after incubation. Lines are drawn to divide the base into the required divisions, which are labelled with numbers related to antibiotic used.



Marked disks after incubation

13 Seal the plate as indicated in part A.

14 Repeat this procedure for all the plates inoculated with RG1 bacteria.

15 Incubate the inoculated plates with the Mastring or single disks with the lid downwards and the agar surface uppermost at 24–30°C for 24–48 hours. This can best be achieved in a thermostatically controlled incubator. If an incubator is not available,

then select a suitable area for incubation that is isolated, away from sunlight and not accessible to students during the incubation period.

16 The Mastring and disks should adhere to the agar and bacterial lawn when the plates are inverted.

17 Follow steps 22 and 23 of part A.

18 Ensure that teacher aseptic instructions are followed.

19 After 24–48 hours, proceed to part D for the instructions for measuring the effectiveness of the antibiotics being tested on the chosen bacteria.

C The effect of handwashing liquids on bacterial growth

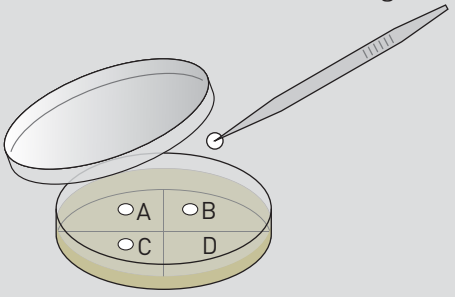
1 Following all aseptic procedures in part A:
   - **a** Prepare an inoculated bacterial lawn as described in part A for each of the RG1 bacteria to be tested.
   - **b** Alternatively, inoculated but **not** incubated bacterial lawns are supplied for each of the RG1 bacteria to be tested.

2 If the inoculated 'lawns' are supplied, ensure that the agar plates are labelled on the bottom edge in small letters, with the day's date, the group initials and the RG1 that is inoculating the plate.

3 If any of the above labelling is absent when the agar plate is observed with the base uppermost, then with a permanent marker on the bottom edge in small letters, complete the data set so that the day's date, the group initials and the RG1 that is inoculating the plate are present.

4 Using the permanent marker, divide the base into four quadrants and label them A, B, C and D.

5 Separate disks have been placed in the four solutions to be tested: A, tap water; B, alcohol-based hand cleaner; C, 99.9% antibacterial handwash; and D, normal detergent.



System for labelling handwashes:

A PLAIN TAP WATER

B ALCOHOL-BASED HAND CLEANER

C 99.9% ANTIBACTERIAL HANDWASH

D NORMAL DISHWASHING LIQUID

6 Working within 25 cm of the Bunsen burner and, using sterile forceps, remove disc A from the solution and shake off excess liquid.

7 Still working within 25 cm of the Bunsen burner, open the lid of the inoculated plate by approximately 45° and place this disc A in the middle of its labelled quadrant.

8 Immediately close the plate lid and place the forceps into the bleach container.

9 Using separate disposable plastic forceps, repeat steps 6 to 8 for discs B to D. Immediately place the used forceps into the bleach and do not use them again.

10 The aim is to arrange the disks so that they are separated evenly and away from the edge of the plate. Repeat this procedure for all the plates inoculated with RG1 bacteria supplied.

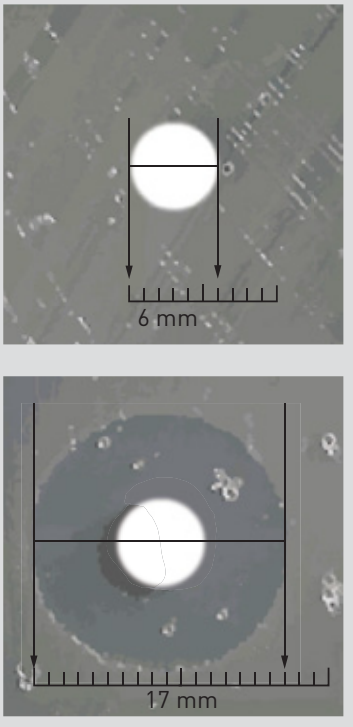
11 Seal all plates as indicated in part A.

12 The treated disks should adhere to the agar and bacterial lawn when the plates are inverted.

13 Incubate as in step 15 of part B.

14 Follow steps 22 and 23 of part A.

15 Ensure that teacher aseptic instructions are always followed.



Examples of disk (top) without and (bottom) with a zone of inhibition

16 After 24–48 hours proceed to part D for the instructions to measure of the effectiveness of the handwashes being tested on the chosen cultures.

D Assessing the effectiveness of the antibacterial agents used in parts B and C

1 Follow all aseptic procedures in part A.
2 Collect the incubated plates.
3 **Do not open these incubated plates for any reason.**
4 Prepare a table to record the diameter of the zones of inhibition.
5 Measure the diameter of the zones of inhibition, if present, using a fine millimetre rule or callipers as in Figure 9.
6 After the measurements on each plate are completed, carefully place the plates into the supplied autoclave bag.
7 Clean the desks and all surrounding surfaces. Place any absorbent paper used to achieve this in the contaminated-waste bag supplied and not in the normal waste bin.
8 On completion of all tasks, place the gloves in the contaminated-waste bag supplied and then wash hands with antibacterial soap.
9 Ensure that teacher aseptic instructions are always followed.
10 In the results table and using the diameter of the zone of inhibition, classify the sensitivity of each RG1 to the antibiotic or hand liquids as 'resistant to', 'sensitive to' or 'intermediate' between these two.
11 Add any other items to the result table that the group considers to be of assistance to the discussion of the interpretation of the results.

Discussion

Write a discussion of your results, including the following points:

- a summary of the results, comparing the different antibiotics and hand-washes, and the effects on the different bacterial cultures
- whether the inhibition zones are circular and, if not, what would be a sensible measuring strategy
- the factors that determine the diameter of the inhibition zones
- any failures in this experiment, and how they could have been avoided or eliminated
- contamination of any of the plates. How could you tell? If any were contaminated, suggest reasons why this occurred and methods to prevent this in future experiments.
- the successes in this experiment
- If class data are shared, consider:
  - the overall spread of the data
  - whether all individual results show the same trends
  - reasons for any variability and how this could be represented on your graphs.

Application of results

If you were working in a hospital laboratory and you had just carried out this test on bacteria isolated from sick patients, would you always choose the antibiotic that gave the biggest inhibition zone? Are there any other factors you would need to consider?

Conclusion

Write a concise statement (a few sentences only) that links the interpretation of the results to the aim(s) or, where appropriate, that links the independent and dependent variables.

UNIT 1

Practice Examination

This exercise is designed for you to practice examination skills. You should take 10 minutes to read through all of the questions. Allow a total of 90 minutes to complete the test. Initially spend no more than 10 minutes on the multiple choice questions and 45 minutes on the short answer questions. 30 minutes has been allowed for the extended answer questions. If you do not immediately know the answer to a question, leave it and go on to complete all questions with which you feel confident. When these are completed, go back to the questions you have left.

Perusal time: 10 minutes
Writing time: 90 minutes

Multiple choice

Select the alternative (A, B, C or D) that **best** answers the question or completes the statement.

The **next two questions** refer to the following information.

The enzyme succinicate dehydrogenase normally catalyses a reaction involving succinic acid. Another substance, malonic acid, sufficiently resembles succinic acid to form temporary complexes with the enzyme, although malonic acid itself cannot be catalysed by succinicate dehydrogenase.

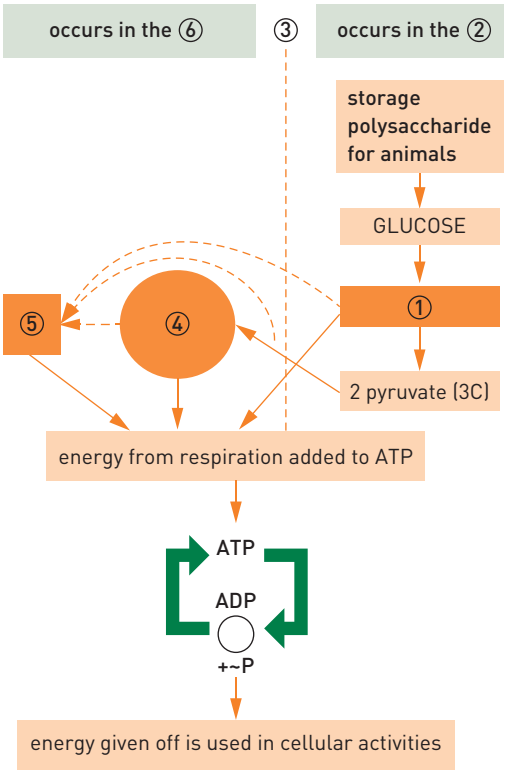
1 In this example succinic acid is:

A the substrate
B the active site
C a competitive inhibitor
D the product

2 Malonic acid is:

A the substrate
B the active site
C a competitive inhibitor
D the product

3 Below is a simplified diagram for cellular respiration. Use it to answer the following question.



The correct labels for 1 to 6 are:

	①	②	③	④	⑤	⑥
A	Anaerobic stage	Inside the cell	Cell membrane	Krebs cycle	Hydrogen chain	Outside the cell
B	Glycolysis	Cytoplasm	Membrane of mitochondrion	Krebs cycle	Electron transport chain	Mitochondria
C	Addition of phosphate	Mitochondria	Membrane of an organelle	ATP producing cycle	Respiratory chain	Cytoplasm
D	Glycolysis	Outside the cell	Phospholipid of the cell membrane	TCA Cycle	Hydrogen chain	Inside the cell

4 At night, a plant normally has a:
- **A** net uptake of carbon dioxide and a net release of water
- **B** net uptake of oxygen and a net increase of carbon dioxide
- **C** net uptake of nitrogen and net release of oxygen
- **D** net uptake of carbon dioxide and net release of oxygen

5 Coloured translucent plastic can be used as a material for roofing a fern house. Even at very low light intensities, the ferns would be able to carry out a significant amount of photosynthesis if the light they received passed through plastic that was coloured:
- **A** orange
- **B** green
- **C** blue
- **D** yellow

6 Cell differentiation:
- **A** involves the loss of certain genes from cells during meiosis
- **B** results in two cells being formed from a single cell
- **C** results from the regulation of specific genes within each cell type
- **D** results in cells in different parts of the body having the same structure and function

7 The cells of individual multicellular plants and animals are linked together. In animals, this may occur by all of the following *except*:
- **A** a thin layer of polysaccharide cementing adjoining cells
- **B** a non-cellular matrix of fibres in an intercellular fluid
- **C** fusion of adjoining cells by proteins on each membrane
- **D** localised thickenings containing filaments that penetrate the membranes of both cells

8 The Bohr effect refers to:
- **A** the amount of oxygen that can be carried by oxyhaemoglobin
- **B** the shift of the oxygen dissociation curve downwards and to the right at high carbon dioxide levels
- **C** the shift of the oxygen dissociation curve upwards and to the left by myoglobin
- **D** the ability of foetal haemoglobin to take up oxygen at lower levels than adult haemoglobin

9 **Select** which letter has correct statements about transpiration.

	Energy supply	Where occurs	Status of vessels	Direction of flow
A	By the plant root cells	Tracheids and vessels	Living	Leaves to roots and roots to leaves
B	Solar	Tracheids and vessels	Dead	Roots to leaves
C	Solar	Sieve tubes	Dead	Leaves to roots
D	Respiration in companion cells	Sieve tubes	Living	Leaves to roots and roots to leaves

10 Which of the following comparisons between aerobic and anaerobic respiration is true?

		Aerobic respiration	Anaerobic respiration
1	Energy released	Less	More
2	Raw materials	Organic compounds and oxygen	Organic compound only
3	End products	Carbon dioxide and lactic acid	Carbon dioxide and alcohol
4	Occurrence	In animals only	In plants only
5	Time of occurrence	All day long	At night only

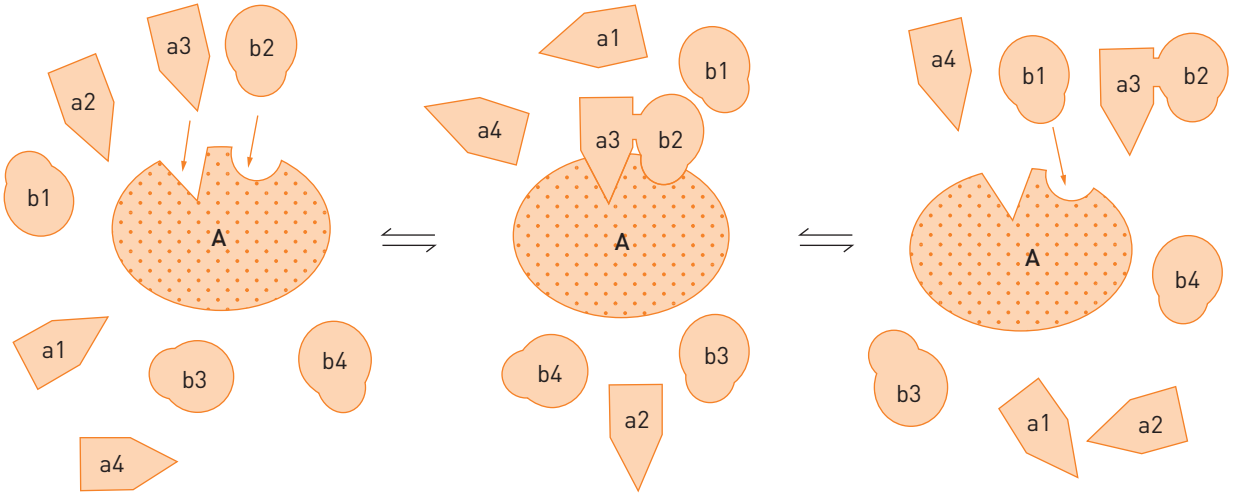
- **A** 1, 3, and 4 only
- **B** 1 and 5 only
- **C** 4 only
- **D** 2 only

Short answer

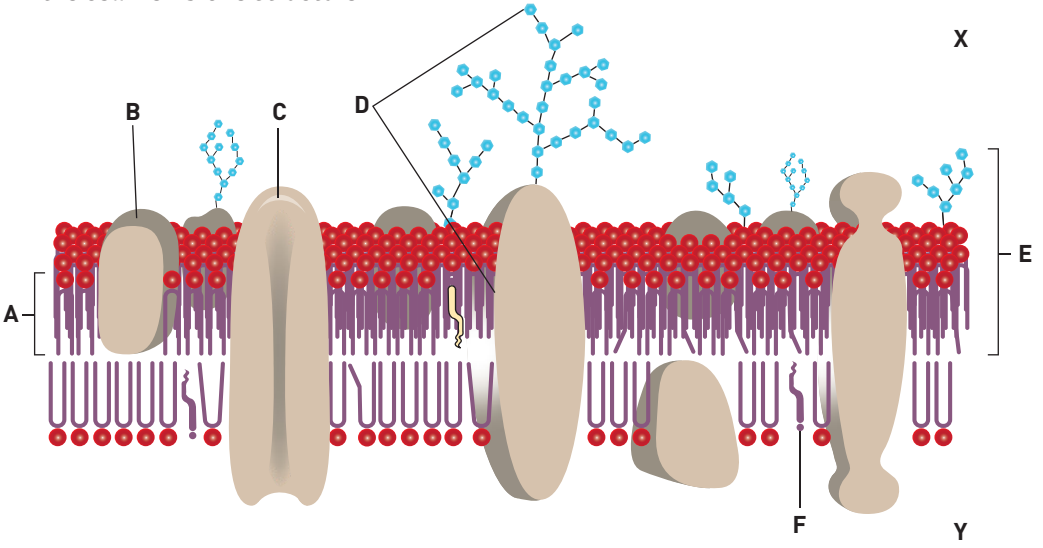
The numbers to the right of each question are an indication of the maximum time, in minutes, that should be spent on the question.

1 **Define** a protein. Explain why proteins are so important to life. **2**

2 Using the diagrams below, **explain** how an enzyme works. **3**



3 The diagram shows the fluid mosaic model of the cell membrane structure.

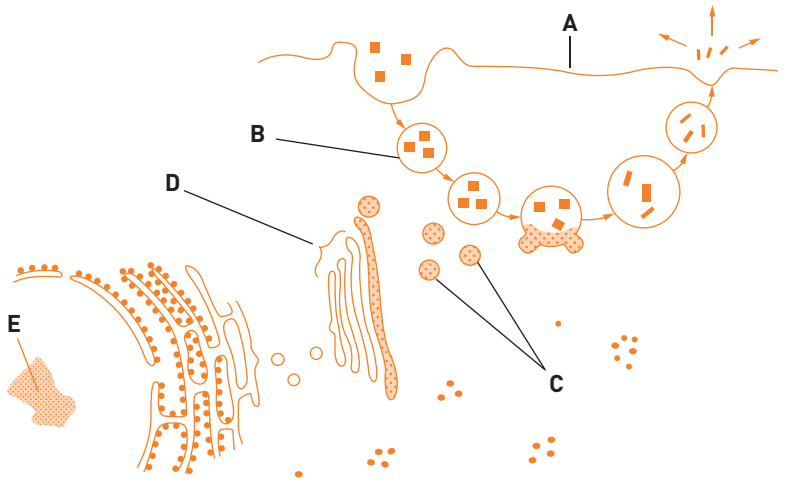


a **Identify** the molecules labelled A and B. **1**

b **Explain** why A is present as a double layer. **2**

c **Deduce** whether the cell cytoplasm would be found on side X or Y. Justify your answer using evidence from the diagram. **2**

4 The diagram below shows part of an animal cell and is based on a series of electron micrographs.



a **Identify** the structures A, B, C, D, E. **2**

b **Identify** the structure in which the protein contents of D are synthesised. **1**

c **Identify** the process illustrated in the diagram which results in large particles entering the cell. Is energy required for this process? **2**

5 Photosynthesis occurs in two major sets of reactions. **Identify** these two stages and state specifically where each occurs in the eukaryotic cell. **3**

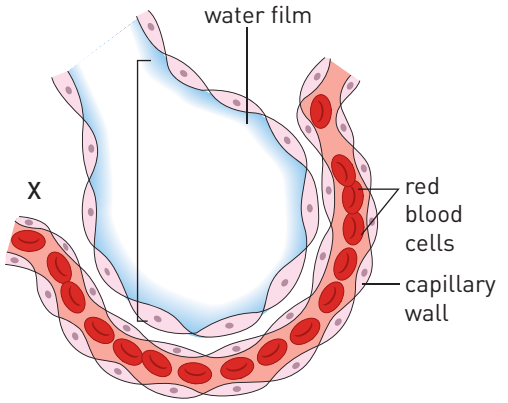
6 The diagram opposite shows the structures involved in gaseous exchange in humans.

a **Identify**

i the structure labelled X. **1**

ii the process by which gases cross the exchange surface. **1**

b Using the labelling on the diagram, **describe** gas exchange between the capillary and X. **4**



7 The leaf shows many adaptations for photosynthesis. **Identify** *four* of these features and explain how *one* of them is an adaptation for photosynthesis. **5**

8 Phloem sap can be collected by aphids. Aphids are sucking insects that use their mouthparts (stylets) to penetrate phloem sieve tubes for sugar. The stylet is a hollow, syringe-like structure. If the stylet of a feeding aphid is cut, samples of phloem sap run out and can be collected for analysis.

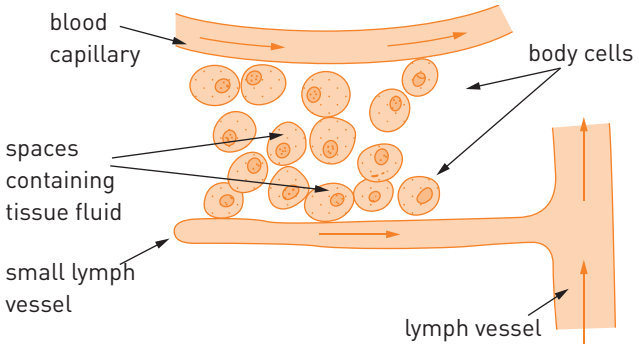
Deduce what this method of collecting phloem sap indicates about:

a the pressure of the fluid in the phloem. **1**

b the amount of energy expended by the aphid in obtaining its food. **1**

9 Briefly **describe** four processes in which the digestive tract is involved. **4**

10 The diagram below shows the relationship between a blood capillary, cells of the body and the lymph system in a mammal. The arrows show the direction of blood and lymph flow.



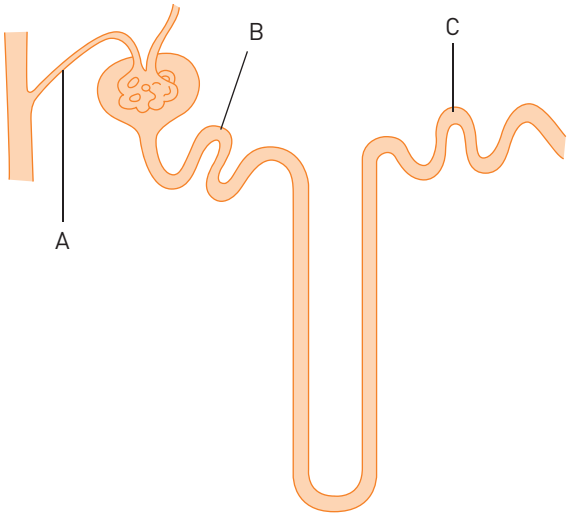
a **Describe** the structure of a blood capillary. **2**

b **Identify** the process by which the exchange of materials occurs between blood and the cells. **1**

c **Contrast** tissue fluid and blood. **2**

d **Explain** the role of lymph in the exchange process. **1**

11 The diagram below shows a single nephron from a mammalian kidney together with some associated blood vessels.



a **Identify** a chemical substance present in the fluid in A but absent from the fluid in B and give a reason for its absence in B. **2**

b **Identify** a chemical substance present in the fluid in B but absent from the fluid in C and give a reason for its absence in C. **2**

Extended answer

Select **one** of the following questions. **20**

1 Jane designed an experiment to study osmosis. She cut five blocks of potato and measured the mass of each block and then placed each block in a different concentration of table sugar (sucrose) solution.

The table below shows her results.

Test tube	Amount of sugar in 100 cm^3 of sucrose solution (g)	Mass of potato block (g)		Increase (+) or decrease (–) in mass (g)	% change in mass
		Before soaking	After soaking		
A	0.0	4.9	5.51	+ 0.61	12.4
B	5.0	4.7	5.10	+ 0.40	8.5
C	10.0	4.8	4.85	+ 0.05	1.0
D	15.0	4.8	4.66	– 0.14	–2.9
E	20.0	5.2	4.81	– 0.39	

TABLE 1 Osmosis experiment on five potatoes

a **Calculate** the percentage change in mass for the potato block in the 100 cm^3 sucrose solution made with 20 g of sugar. **Justify** your answer by showing all working.

b **Construct** a graph of all of the results. Don't forget to include a title.

c **Sketch** a *straight line of best fit*.

d Use the graph to **determine** how many grams of sugar in 100 cm^3 of sucrose solution would be required to maintain a constant mass of a raw potato cube.

The above experiment has implications in the human body cells.

e **Summarise** the results of this experiment.

f Three photographs of human red blood cells are shown on the next page. Cells A and B have been placed in two different solutions.

From the solutions prepared for the experiment, **predict** the solution that has most likely caused the change of shape of cells A and B. **Justify** your choice by giving an accurate explanation of what has occurred.

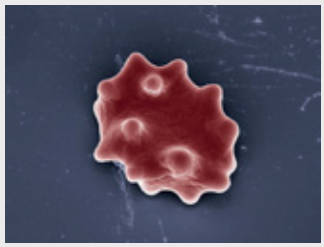
Normal appearance of human red blood cells	Cell A	Cell B
		

TABLE 2 Shapes of human red blood cells

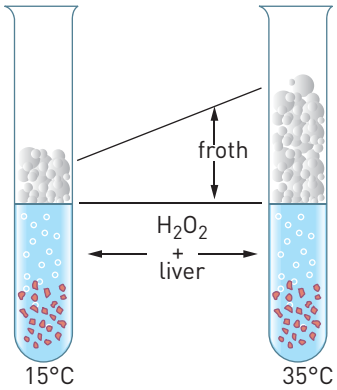
2 A student observed the effect of temperature on the action of the enzyme catalase in chopped liver on hydrogen peroxide.

Catalase

hydrogen peroxide → water + oxygen

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

Test tubes containing equal amounts of hydrogen peroxide and chopped liver were set in beakers of warm water at various temperatures. A drop of detergent was used to observe the varying rates of reaction, which were recorded as the depth of froth produced by the oxygen bubbles.



Temperature (°C)	Depth of bubbles after 2 minutes (cm)
10	0.8
15	1.5
20	3.2
25	5.4
30	6.8
35	8.1
40	7.4
45	1.1

TABLE 3 Temperature changes with respect to depth of froth

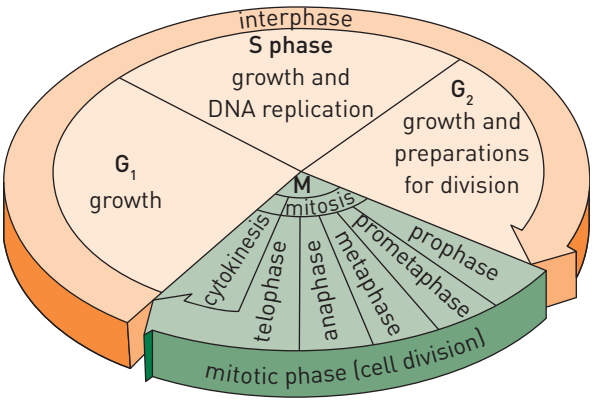
a **Summarise** the experiment, including:
- **i** the hypothesis
- **ii** controls used
- **iii** the dependent and independent variables
- **iv** possible extraneous variables.

b **Construct** a graph of the results.

c **Justify** a conclusion from the results, fully explaining the variations in reaction rates.

3 The diagram on the next page shows the cell cycle. It does *not* represent the actual time taken in each phase.

When a population of cells is dividing, the percentage of cells in the mitotic phase (M) is called the *mitotic index*. The greater the proportion of cells that are dividing, the higher the mitotic index. The duration of a phase is proportional to the number of cells in that phase at any time.



Cells from a culture were spread out on a slide and 100 cells were examined.

- Nine cells were in prophase.
- Five cells were in metaphase.
- Two cells were in anaphase.
- Four cells were in telophase.
- 80 cells were in interphase.

a The average duration for the cell cycle in this culture is 20 hours. **Calculate** the duration of anaphase for these cells. Show your working.

In a dividing cell the mitotic phase (M) alternates with interphase. During interphase the cell grows and the DNA is replicated. So, by the end of the S phase the cell contains twice the normal quantity of DNA. During M phase, the nucleus and cell divide to form 2 cells, each with the normal amount of DNA.

The average quantity of DNA in the living culture of these cells was measured. Of the cells in interphase

- 50% contain 10 ng of DNA per cell ($1\ ng = 10^{-9}\ g$)
- 20% contain 20 ng of DNA per cell
- 30% contain between 10 and 20 ng of DNA per cell

b Based on these data, **determine** the approximate duration (in hours) of the G1, S and G2 phase of the cell cycle. Fully explain how you determined this.

4 Multicellular organisms have different types of stem cells that operate at different stages of the organism's life. **Discuss** the role of different types of stem cells in the differentiation of embryonic cells into tissues, organs and systems and in the continued life of the organism.

5 The descending and ascending limbs of the loop of Henle in the mammalian nephron have different permeabilities to water and sodium ions. As a consequence, it acts as a counter-current system. **Describe** how this system assists in the reabsorption of water by the nephron.

UNIT 2

Practice Examination

Perusal time: 10 minutes
Writing time: 90 minutes

Multiple choice

Select the alternative (A, B, C or D) that *best* answers the question or completes the statement.

1 In maintaining homeostasis, there is often the tendency to overshoot the normal level desired, but the normal level is achieved after some oscillation. The overshoot is mainly the result of:
   - **A** the length of time necessary to elicit the desired response
   - **B** the transmission of nerve impulses to surrounding tissues
   - **C** a sudden upsurge in the amount of hormone in the blood
   - **D** a 'miscalculation' by the organism when detecting the stimulus

2 A synapse is the connection between:
   - **A** two axons
   - **B** two dendrites
   - **C** a dendrite and an axon
   - **D** the central and peripheral nervous systems

3 Which of the following is not a difference between sweating in a mammal and transpiration in a plant?

	Sweating	Transpiration
A	Water lost in liquid form	Water lost in vapour form
B	Size of sweat pores not affected by light	Size of stomata is affected by light
C	Removes some salts	Only water lost through the stomata
D	Restricted to the skin	Restricted to areas containing stomata

4 Experimentally it is found that the rate of heat loss from a rat is larger than that of an elephant. The best explanation for this observation is that:
   - **A** small animals eat proportionally more than large animals
   - **B** the simpler structures of smaller mammals compared with large mammals means they are not able to conserve heat
   - **C** small mammals have a larger surface area to volume ratio than large mammals
   - **D** small mammals are more active than large mammals

5 An increase in urine production occurs following the drinking of a large volume of water, but in most humans the increase cannot be detected for about 30 minutes. The best explanation for the delay is that:
   - **A** The drinking of water stimulates nerves, but the kidney is such a distance from the central nervous system that the extra volume is not detected for 30 minutes.
   - **B** The increased water intake enters the circulation, but the blood does not circulate through the renal artery to the kidney for about 30 minutes.
   - **C** Water is not absorbed from the digestive tract immediately, and appreciable amounts only get into the blood stream after about 30 minutes. Increase in urine production then follows very rapidly.
   - **D** The rate of water excretion depends on the release, into the blood, of a hormone, the concentration of which changes relatively slowly.

6 A pandemic occurs when:
- **A** a particular infectious disease spreads through many countries at the same time
- **B** many individuals in a population contract the same disease
- **C** the pathogen is able to multiply rapidly
- **D** a reservoir host is incapacitated

7 Damaged cells release a substance called histamine, which relaxes muscles in the walls of blood vessels, making them more permeable than usual. This:
- **A** facilitates bleeding that washes out the tissue and carries white blood cells to the site of damage
- **B** allows red blood cells to move to the damaged area to release high levels of oxygen to kill pathogens
- **C** causes the familiar reddening and swelling associated with inflammation
- **D** ensures all pathogens present are taken up into the blood stream for destruction

8 Identification of a viral cause of disease is difficult because:
- **A** viruses are too small to be seen through a microscope
- **B** viruses can only be cultured in living tissues
- **C** cytopathic effects are caused only by bacteria
- **D** it can be achieved only by gene sequencing of the viral nucleic acid

9 In the modelling of infectious diseases, mortality rate refers to:
- **A** the number of deaths from the disease
- **B** the rate of death per population size for the disease
- **C** the number of deaths among those who have contracted the disease
- **D** the percentage of individuals that die from the disease

10 Chemotherapy refers:
- **A** specifically to the treatment of cancer
- **B** to the use of a range of treatments for a disease
- **C** to the use of chemicals to prevent and cure diseases and disorders
- **D** to the synthesis of chemicals to treat disease

Short answer

The numbers to the right of each question are an indication of the maximum time, in minutes, that should be spent on the question.

1 **Identify** the essential features of homeostasis. **2**

2 **Define** a pheromone. What is its role? **2**

3 **a** **Identify** *two* broad functions of the nervous system. **2**

b **Explain** the occurrence of a resting membrane potential. **2**

c **Define** the 'all-or-nothing' law in impulse conduction. **1**

d **Identify** the actions at a particular point of an axon as a nerve impulse passes. **4**

e **Contrast** *three* factors in the method of signal transmission between the nervous system and the endocrine system. **3**

4 Different organisms have a specific optimal and tolerance range for any particular environmental condition. **Distinguish** between optimal and tolerance range. **2**

5 Whales are homoeothermic animals. Many, such as the humpback whale, spend considerable time in very cold Antarctic waters. **Describe** *three* features of the whale that reduce loss of core body heat to the environment. **3**

6 **Compare**:

a torpor and aestivation **2**

b osmoregulation and excretion **2**

c ectothermic and endothermic. **2**

7 **Describe** how humidity, wind speed and temperature affect the rate of water loss by a plant during the day. **4**

8 **Contrast** non-infectious and infectious diseases. **2**

9 **Identify** *three* causes of non-infectious disease. **3**

10 **Define** an antigen. **1**

11 **Distinguish** between the cellular-mediated immune response and humoral-mediated immune response. **3**

12 **Contrast** active immunity in plants and animals. 2

13 Yellow fever is a potentially deadly viral disease with an R_0 of 43 and is endemic to tropical Africa and South America. Its vector is the mosquito *Aedes aegypti*, a species that is found in Queensland. Any traveller from these regions is placed in quarantine on entry into Australia unless they have a current vaccination record stamped in their passport. 3

Determine the effects on the population if this international border control was not in place and a person in the incubation phase of this disease returned to Cairns from a holiday in northern Africa.

Extended response

Write a short essay on **one** of the following topics. The length of the essay is not of primary importance. The focus should be on a concise, planned essay that takes into account both general and biological knowledge. 20

1 'Hormones may be likened to a message-in-a-bottle means of communication while nerves act as a kind of landline telephone system of the body.' Fully **discuss** this analogy.

2 Temperature control in mammals is important. **Explain** the biological significance of this phenomenon and the role of the skin in temperature regulation. **Discuss** *two* behavioural adaptations to hot climates, and *two* others to cold climates.

3 Fully **describe** the role of the pituitary gland, and **discuss** subsequent actions, in osmoregulation in mammals.

4 Different species of plants may be found in a variety of habitats – in estuaries, submerged or emergent in freshwater lakes and streams, and in a range of terrestrial conditions from the desert to tropical rainforests. Each species exhibits specific adaptations that allow it to survive in its particular environment. **Select** one group (e.g. hydrophyte, halophyte, xerophyte, mesophyte) and **discuss** the environmental conditions the group of plants is exposed to and its adaptations to contend with each condition.

5 Parasites need at least one host to survive. **Describe** problems that threaten the life of parasites. With reference to a named animal parasite and a named plant parasite, **discuss** how they solve these problems.

6 Write an account of the use of antibiotics in the treatment of infection. In your response, **discuss** which microorganisms antibiotics affect, how they inactivate their growth and why they may fail to work against pathogens that were previously sensitive to them.

7 Epidemiological studies have been significant in determining the cause of non-infectious diseases. Using an example of a disease, **discuss** the features of such a study that are necessary for a conclusion to be drawn.

8 Outline the roles of quarantine and biosecurity services in Australia. **Discuss** the effectiveness of these services in preventing entry (or exit) of disease organisms, giving examples to support your response.

GLOSSARY

A

abiogenesis
the formation of a living organism from non-living matter

abiotic
non-living

absolute refractory period
the period immediately following an action potential when the nerve fibre cannot be stimulated no matter how great a stimulus is applied

absorption spectrum
a graph of the relative absorption of different wavelengths of light by a pigment

acetylcholine (ACh)
a chemical released from nerve endings when nerve impulses arrive there, stimulating the adjacent neuron or effector organ

action potential
chemical impulse that passes along the nerve fibre

action spectrum
a graph of the effectiveness of different wavelengths of light to bring about a particular reaction

activation energy
the energy needed to start a chemical reaction

active site
the portion of an enzyme in contact with the substrate; at this point it will have a specific shape which corresponds to the shape of at least a portion of the substrate molecule

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

acquired (adaptive) immune system
immunity that is not present at birth but is learned; the learning process starts when a person's immune system encounters foreign invaders and recognises non-self substances (antigens) – the system then generates special chemicals (antibodies) that neutralise the pathogen

adaptation
a feature of an organism that enhances its ability to survive and reproduce in a particular environment

adenosine diphosphate (ADP)
the chemical adenine bound to two phosphate groups, each bond requiring an input of energy

adenosine monophosphate (AMP)
the chemical adenosine bound (with an input of energy) to one phosphate group

adenosine triphosphate (ATP)
an organic chemical able to store and release large amounts of energy; consists of the chemical adenosine bound to three phosphate groups

adhesin
the component or appendage on the surface of bacteria that helps their adhesion to other cells or to inanimate surfaces

adult stem cell
a partially differentiated animal cell, responsible for repair and maintenance of the adult body

aerobic respiration
the complete conversion of glucose to carbon dioxide and water in the mitochondria of cells with oxygen present, resulting in a large release of energy (net gain of 36 ATP)

aestivation
prolonged torpor in response to high environmental temperature and low water availability

afferent arteriole
the arteriole leading into a structure, e.g. the glomerulus of the kidney

all-or-nothing response
a type of response in which neuron membranes will respond completely to a stimulus, regardless of its strength, if it is above a threshold intensity, but will not respond if it is below the threshold intensity

allergen
an antigen that causes an allergic reaction in an organism

alveolus
the thin-walled ending of alveolar ducts (end divisions of the bronchioles) in the lung through which gas exchange occurs

amino acid
a building block of protein consisting of an amino group (NH_2), a carboxyl (acid) group (COOH), a variable (R) group and a hydrogen atom attached to a carbon atom

ammonia
an inorganic nitrogen compound; in animals, a toxic product of the breakdown of excess amino acids

amylase
an enzyme that stimulates the conversion of polysaccharides to disaccharides

anabolic reaction
the chemical reaction in which large molecules are built up, usually with a net input of energy

anabolism
chemical reactions in which large molecules are built up, usually with a net input of energy

anaerobic respiration
cellular respiration in the absence of oxygen, resulting in a net gain of 2ATP and lactic acid (in animals), or ethyl alcohol and carbon dioxide (in plants and fungi)

anchoring junction
a cell junction formed from parts of the extracellular matrix that hold adjacent cells together

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

antibiotic
a drug used to treat bacterial infections

antibody
a gamma globulin protein found in the blood or lymph, and produced by B-lymphocytes as an immune defence against foreign agents (antigens)

antibody-mediated response
immunity conferred to an individual through the activity of B-lymphocytes and their progeny, which produce circulating antibodies in response to the presence of an antigen and recognise the substance upon renewed exposure

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

anus
the end of the alimentary canal through which faeces (undigested food) are egested

apical meristem
the growing point of the tip of the root and stem in vascular plants

apoptosis
cell death

arteriole
the branch of an artery that breaks up into capillaries

artery
a thick-walled blood vessel that leaves the heart or aorta and ends in an arteriole

artificial active immunity
an active immunity acquired by vaccination with a vaccine containing active antigens to prevent the development of the disease in the future

artificial passive immunity
immunity acquired by means of injection of serum containing antibodies into an individual who may have been infected with a particular pathogen

assimilation
the incorporation of simple organic molecules, or products of digestion, into complex constituents of the organism

association neuron (interneuron)
the nerve cell within the central nervous system which relays information between sensory input and motor output

autoimmune disease
a disease in which the body produces antibodies that attack its own tissues

autonomic nervous system
the system controlling the actions of the inner (visceral) body tube, not under conscious control. Two types of motor nerves are present: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action

axon
the extension of the nerve cell body through which impulses are passed

B

B-lymphocyte
a white blood cell that does not pass through the thymus as it matures; involved in antibody formation

basophil
a white blood cell involved in inflammatory reactions

biofilm
an aggregation of microorganisms in which cells that are frequently embedded within a self-produced matrix of extracellular substances adhere to each other and/or to a surface

biology
the study of life and living organisms

bladder
the storage organ for urine in vertebrate animals

blastula
a hollow ball of cells resulting from division in the animal zygote

blood
the transporting medium of the animal body; in mammals, it is composed of plasma, platelets, and red and white blood cells

Bohr effect
the shifting of the oxygen-dissociation curve downwards and to the right in the presence of carbon dioxide or hydrogen ions

Bowman's capsule
the area of the mammalian kidney nephron in which ultrafiltration of the blood occurs

brain
the enlarged, anterior part of the central nervous system which coordinates sensory input and responses

brown adipose tissue
tissue that stores large amounts of high-energy lipids, the cells of which contain large numbers of mitochondria

C

Calvin–Benson cycle
the cyclic reactions of the light-independent phase of photosynthesis

cambium
the layer of actively dividing plant cells

capillary
a fine blood vessel with walls one cell thick, permeating tissues; pressure in these vessels causes plasma to pass out into the tissue fluid

carbaminohaemoglobin
a compound formed by the attachment of carbon dioxide to amino acids of the haemoglobin molecule

carbohydrase
the general term for an enzyme that breaks down carbohydrate

carbohydrate
a molecule of carbon hydrated with water; monomer having the general formula of $(CH_2O)n$, i.e. ratio of C:H:O = 1:2:1. Polymers have the general formula $(C_6H_{10}O_5)_nH_{20}$ (there is less hydrogen and oxygen due to formation of glycosidic bonds)

carboxyhaemoglobin
the product of the union of carbon dioxide with haemoglobin in red blood cells

carrier
a person or organism infected with an infectious disease agent or gene, but who displays no symptoms of the disease

case fatality ratio
the proportion of deaths within a designated population of 'cases' (people with the disease) over the course of the disease

Casparian strip
a thickening of waxy, waterproof suberin found in the endodermal cells of the root of angiosperms and which directs the flow of water and dissolved ions into the root xylem

catabolic reaction
a chemical reaction in which large molecules are broken down into smaller ones, usually accompanied by the release of energy

catabolism
chemical reactions in which large molecules are broken down into smaller ones, usually accompanied by the release of energy

causation
the capacity of one variable to influence another

cell body (soma)
the mass of cytoplasm with a nucleus, from which arises the branches of a nerve cell

cell cycle
the continuous cycle of growth and division in cells

cell differentiation
the process by which a cell becomes specialised in order to perform a specific function

cell-mediated response
antigen activation of T-lymphocytes in the thymus to release soluble proteins to inactivate a pathogen

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

cell specialisation
the changes in a cell that allow it to perform a specific function

cell theory
theory that all organisms are made up of cells and their products, and that growth and reproduction are fundamentally due to division of cells

cell wall
a rigid structure surrounding the cells of bacteria (murein), fungi (chitin) and plants (cellulose)

cellular respiration
cellular process in which glucose is broken down to release energy in many small, enzyme-controlled reactions

central nervous system (CNS)
a mass of nervous tissue, comprising the brain and spinal cord in vertebrates, which coordinates the activities of animals

central tendency
the tendency for the values of a random variable to cluster around its mean, mode, or median

centriole
a paired tubular structure found in animals and algae; involved in formation of cilia and flagella and in cell division

centromere
the point of attachment of two chromatids

cerebrospinal fluid
the fluid that fills the cavity inside the vertebrate brain and spinal cord

chemical digestion
the hydrolysis of complex organic molecules to smaller units that are small enough to pass through cell membranes; mediated by enzymes specific to each chemical

chemical transmitter substance (neurotransmitter)
a chemical that passes from one area to another (e.g. from the axonic end of one neuron to the dendritic end of the adjoining neuron) to bring about a change

chemosynthesis
the formation of complex organic molecules from simple organic molecules, using chemical energy derived from oxidation of inorganic molecules

chemotherapy
the treatment of disease by means of chemicals that have a specific toxic effect upon disease-producing microorganisms (e.g. antibiotics) or that selectively destroy cancerous tissue

chlorophyll
a green plant pigment

chloroplast
a plastid found in green plants, containing chlorophyll on membranous grana, and enzymes in the liquid stroma; photosynthetic organelle

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

chromatid
a replicated chromosome, still attached to the original at the centromere

chromatin
the nucleoprotein of chromosomes seen as fine, dispersed threads of genetic material and found in eukaryotic cells in the interphase stage

chromoplast
a plastid found in plants, containing red, yellow or orange pigments

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

chunk feeder
an animal that ingests large pieces of food

chylomicron
small droplets of lipids, glycerol and fatty acids enclosed in a protein coat; involved in the absorption of products of fat digestion in alimentary canal directly into lymphatic system

colonial
an animal composed of the same unicellular organisms joined into a cluster where each individual can carry out all functions necessary for life

cilium
a hair-like extension of the cell membrane

collecting duct
a duct into which waste materials from each nephron in the kidney drain

colonisation factor
a protein that allows a pathogen to colonise the host's body

colostrum
the first form of milk produced by the mammary glands of mammals (including many humans) immediately following delivery of a newborn

column graph
a graph consisting of vertical or horizontal bars whose lengths are proportional to amounts or quantities

compensation period
the time taken, after the onset of daylight, for the rate of photosynthesis to equal that of respiration in plants

compensation point
the point at which the rate of photosynthesis equals the rate of respiration

competitive inhibition
the process where a substance (inhibitor) occupies the active site of an enzyme and prevents the normal substrate from binding

complement system
a system of proteins (formed in the liver) which, when activated by the presence of an antigen, produce chemicals that bring about inactivation of foreign matter

complete anaerobe
an organism that is independent of oxygen for cellular respiration

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

condensation
an enzymatic build-up of monomers into a larger molecule by the removal of a water molecule between each pair of monomers

contagious
diseases transmitted between individuals, by physical contact with a diseased individual, or by casual contact with their secretions or objects touched by them, or by an airborne route

continuous data
values that are not restricted to defined separate values, but can occupy any value over a continuous range

contraction
shortening (e.g. of a muscle)

control centre (hypothalamus)
the group of ganglia in the brain that release hormones that bring about the release or inhibition of hormones by the anterior lobe of the pituitary gland

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

coordination
working together

cortex
the outer part of a structure, e.g. the outer part of the vertebrate kidney in which are found the Bowman's capsule, glomerulus and convoluted tubules of the nephron

counter-current
the movement of two media (usually fluids) parallel to each other but in opposite directions

cristae
the folds of the inner membrane of mitochondria

cuticle
the superficial, non-cellular layer covering a plant or animal

cytokinesis
division of cells after mitosis

cytopathic effect
a degenerative change in the appearance of cells

cytoplasm
cell contents not including the nucleus

cytoplasmic streaming
the flow of cytoplasm around the cell

D

data
quantitative or qualitative information; facts and statistics

dendrite
the branching cytoplasmic projection of a nerve cell; it receives and transmits impulses

deoxyribonucleic acid (DNA)
a double-chained, helical nucleic acid containing the sugar deoxyribose, capable of replicating and determining the inheritance of a cell's proteins

dependent variable
a variable whose value is dependent on another variable

desmosome
an anchoring junction formed by localised thickenings where filaments penetrate the membranes of both cells

diaphragm
the muscular sheet of muscle separating the thorax and abdominal cavity of mammals

differentiation
the process of change in cells, tissues and organs during development, resulting in division of labour within cells or organisms

dipeptide
a molecule formed by the bonding of two amino acids

direct chemoreceptor
a sensory receptor able to detect chemical stimuli with which it is in direct contact

disaccharide
a molecule composed of two chemically bound monosaccharides, e.g. sucrose

discontinuous data
data that can only take particular values and may be numeric (e.g. like numbers of cars) or categorical (e.g. male or female, or good or bad)

disease
an abnormal condition of an organism which interrupts the normal bodily functions

distal convoluted tubule
part of the nephron which joins the loop of Henle to the collecting duct; responsible for the reabsorption of sodium, potassium, phosphate and calcium ions under the control of hormones

distance chemoreceptor
a sensory receptor able to detect chemical stimuli from a source that is not in direct contact

dorsal root of spinal cord
the area emerging from the dorsal region of the spinal cord forming the afferent, sensory part of a spinal nerve

double circulatory system
a system of blood vessels where the blood passes through the heart twice in a single circuit around the body

down-regulation
the process of reducing or suppressing a response to a stimulus by reduction in the number of receptors on the cell surface

drip tip
an elongated leaf tip from which excess water is expelled by special glands, and drips off

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

E

ecology
the study of the relationships between organisms and their environment

ectoderm
the outer primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

ectoparasite
a parasite that lives on or in the skin, but not within the body (e.g. a flea)

ectotherm
any animal whose regulation of body temperature depends on external sources

effector
an organ or cell by which an animal acts, e.g. muscles, glands

efferent arteriole
the arteriole leaving a structure, e.g. the glomerulus of the kidney

egestion
the removal of undigested food (faeces) from alimentary canal

electron micrograph
a photographic image of a sample magnified by an electron microscope

electron transport chain
a series of coenzymes along which high-energy electrons pass, releasing energy to form ATP at each step in the chain; the final stage in aerobic cellular respiration in which most ATP molecules are formed

embryonic stem cell
an undifferentiated, totipotent or pluripotent cell found in the early embryo

emulsify
break up large lipid particles into small droplets

end plate
a thickened and folded part of a muscle fibre membrane which receives nerve impulses

endemic
describes a disease that is constantly present to a greater or lesser degree in organisms of a certain group or living in a particular location

endergonic
describes a chemical reaction requiring input of energy

endocrine glands
ductless gland in animals which secrete hormones into the bloodstream

endocytosis
the movement of materials into the cell

endoderm
the inner primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

endodermal cell
a cell of the central, innermost layer of living cells of the cortex in some land plants

endoparasite
a parasite that lives in the internal organs or tissues of its host and derives its nourishment from the host

endotherm
an animal that can maintain a constant body temperature independent of the environment

endotoxin
a pathogen toxin bound to its outer membrane and not freely liberated into the surrounding medium

environmental condition
a factor in the external surroundings (biotic and abiotic) that surrounds and affects the survival and development of an organism or population

enzyme
an organic catalyst, produced by living cells, that changes the rate of chemical reactions in living organisms

eosinophil
a white blood cell that is involved either in the breakdown of macroparasites or in allergic reactions

ephemeral
a plant that has a very short lifespan

epidemic
the occurrence of more cases of a disease than would be expected in a community or region during a given period

epidemiology
the study and analysis of the distribution (who, when, and where) and determinants of health and disease conditions in defined populations

epidermis
the outermost layer of cells in plants and animals

erector muscle
a muscle composed of bundles of smooth muscle fibres, attached to the deep part of hair follicles, contraction of which erects hairs

erythrocyte
a red blood cell

essential nutrient
a nutrient that must be ingested and absorbed since it cannot be synthesised by the organism

ester bond
a bond formed by condensation between a fatty acid (removal of OH) and glycerol (removal of H)

ethology
the study of animal behaviour under natural conditions

eukaryote
an organism whose cells contain membrane-bound organelles

eukaryotic cell
a cell which contains membrane-bound organelles

evolution
the change in organisms over time due to natural selection, resulting in changes in the gene pool of a population

excretion
the removal of metabolic wastes from the body

exergonic
describes a chemical reaction in which energy is released

exocytosis
the movement of materials out of the cell

exotoxin
a protein produced and released by a pathogen

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

experimental variable (independent variable)
the single factor under investigation in a controlled experiment

expiration
the movement of air out of the lungs in tetrapods (four-'legged' animals)

extracellular
outside the cell

extraneous variable
some factor in an experiment which was unaccounted for and thus was not controlled

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

F

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

fact
information which has been verified by observation or experimentation

faeces
a compacted, undigested food mass that is voided from an animal

fatty acid
a compound (RCOOH) formed between a carboxyl (COOH) group and a chain of hydrocarbons of variable length (R)

feedback
modification or control of a process or system by its results or effects, e.g. in a biochemical pathway or behavioural response

fermentation
the anaerobic breakdown of sugar by bacteria and yeasts to form ethyl alcohol, carbon dioxide and 2 ATP

fibre
the thread-like extension of the nerve cell body – the axon

flagellum
a whip-like extension, containing protein filaments, of the cell membrane of some protozoans

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

foetal haemoglobin
a form of haemoglobin with higher affinity for oxygen than adult haemoglobin

G

gametocyte
a gamete-forming cell

ganglion
area of concentration of nerve cell bodies

gap junction
a junction between animal cells that allows direct passage of ions and small molecules in solution between them

gastrula
the early embryonic stage in the animal formed from the ingrowth of cells at one end of the blastula to produce a double layer of cells from which future tissues and organs develop

gene
a segment of DNA which controls a specific characteristic through protein production

genetic code
the sequence of nucleotides in a DNA molecule, coding for a particular protein

genetic disease
a disease that results from a change in a gene and may be inherited

gill
the gas exchange surface of aquatic animals

gill filament
a thin-walled, highly vascular structure arising from the gill arches of the gill of bony fish; a gas exchange surface

glomerulus
the capillary knot found in Bowman's capsule through which ultrafiltration of blood (plasma minus protein) into the nephron of the mammalian kidney occurs

glycerol
a structural component of lipids

glycolysis
the first stage in cellular respiration; occurs in the cytoplasm and results in the gain of 2 ATP and 2 pyruvate molecules; does not require oxygen

glycoprotein
a protein with attached polysaccharides that reacts predominately as a protein

glycosidic bond
the bond formed by condensation between two monosaccharides

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

grana (singular granum)
stacked portions of membranes found in chloroplasts; sites of light-dependent reactions for photosynthesis

graph
a diagram that exhibits a relationship between two sets of numbers as a set of points having coordinates

grey matter
the part of the central nervous system, associated with coordinating activities, where the fibres are not myelinated

guttation
the active secretion of excess water by leaf hydathodes

H

habitat
a specific locality, with a particular set of abiotic conditions, inhabited by an appropriately adapted community of organisms

haemoglobin
the pigment molecule found in red blood cells; contains four iron-containing (haem) groups, each of which can combine with one oxygen molecule; has a high affinity for oxygen

haemolytic anaemia
a form of anaemia due to haemolysis, the abnormal breakdown of red blood cells

halophyte
a plant that grows in waters of high salinity

heparin
a chemical secreted by basophils that prevents blood clotting

hepatic portal vein
the vein which transports absorbed food molecules directly from the small intestine to the liver

herd immunity
a form of indirect protection from infectious disease that occurs when a large percentage of a population has become immune to an infection, thereby providing a measure of protection for individuals who are not immune

heterotroph
literally, other-feeder; an organism which derives its external source of energy from other living organisms

hibernation
a long-term state of inactivity and decreased metabolic rate associated with redirection of blood flow in animals during winter

histamine
a chemical secreted by basophils and mast cells to direct blood flow to an injured area

histogram
a diagram consisting of rectangles whose area is proportional to the frequency of a variable and whose width is equal to the class interval

homeostasis
maintenance of a constant internal environment, mediated by feedback systems

homoeotherm
an animal that maintains a relatively constant body temperature that is independent of the temperature of the surrounding environment

homoeothermic
the ability to maintain a relatively constant body temperature that is independent of the temperature of the surrounding environment

hormone
a regulatory chemical of the control and coordination system; capable of bringing about a specific response to a particular stimulus

host
an organism that harbours a parasite

humoral response
the response of the acquired immune system

hydrolysis
the enzymatic breakdown of polymers involving the addition of a water molecule when the bond between monomers is broken

hydrophilic
describes substances that dissolve readily in water

hydrophobic
describes substances that are insoluble in water

hydrophyte
any plant adapted to grow wholly or partly submerged in water or wet habitats

hypertonic
a solution having a higher solute concentration than that of the surroundings

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

hypotonic
a solution having a lower solute concentration than that of the surroundings

I

immune system
a host defence system, comprising many biological structures and processes within an organism, that protects against disease

immunological tolerance
the failure to mount an immune response to an antigen

immunosuppressant drug
a drug used to prevent the body from rejecting a transplanted organ

incubation period
the time for a pathogen to build up sufficient numbers to produce symptoms of the disease

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

'induced fit' hypothesis
idea that the active site of an enzyme, after initially attracting a specific substrate, can

change in order to suit the substrate's shape and in doing so affects the shape of the substrate and thus lowers its activation energy requirements

induced pluripotent cells
a differentiated cell that is treated (genetically reprogrammed) back to a pluripotent state

inflammatory reaction
a response of the body to an injurious agent, characterised by swelling, pain or heat

inherited condition
a condition that can be passed from parent to offspring

infectious
able to be passed from one individual to another

innate immune system
the system of non-specific defence mechanisms that includes physical barriers such as skin, chemicals in the blood, and white blood cells that attack foreign cells in the body

inorganic compound
a chemical compound that does not contain carbon (except carbonates and cyanides) or carbon–hydrogen bonds

irritability
the basic property of protoplasm: detection and response to changes in the environment

inspiration
the movement of air into the lungs in tetrapods (four-'legged' animals)

insulation
material used to reduce the rate of heat transfer (e.g. subcutaneous fat, hair and feathers)

intracellular
found within a cell

integral protein
a protein found within the structure of the cell membrane

intercellular
fluid composed of water, electrolytes and proteins that reside inside a cell

interferon
a small, protein- and glycoprotein-signalling molecule produced by lymphocytes, in response to infection and other biological stimuli

interphase
stage in the cell cycle in which the cell grows, stores energy and replicates chromosomes

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

invasion factor
a protein that allows pathogens to enter cells

isotonic
a solution having the same solute concentration as that of the surroundings

K

kinetic energy
energy of motion

kleptothermy
any form of thermoregulation by which an animal shares in the metabolic thermogenesis of another animal

Koch's postulates
the criteria required to establish a microorganism as the cause of a disease

Krebs cycle
the cyclic series of chemical reactions in mitochondria of cells in which 2 molecules of acetyl-CoA are converted to citric acid which, with the addition of 6 water molecules, releases 4 carbon dioxide molecules as waste and 24 hydrogen atoms, which are transferred to carrier molecules; 2 ATP are formed

L

lacteal
a blind-ending lymph vessel that collects tissue fluid

lactic acid
an organic acid formed by the breakdown of glucose during anaerobic cellular respiration in animals

lamina
the leaf blade

lenticel
the specialised area of tissue in the corky bark of woody plant stems which allows gas exchange

leucocyte
white blood cell

leucoplast
a colourless plastid found in plant cells; concerned with starch or oil storage

light-dependent reaction
chemical reactions in the chloroplast, involving excitation of chlorophyll electrons by energy transfer from specific wavelengths of light, and resulting in splitting of water to release hydrogen for the light-independent reactions and formation of ATP

light-independent reaction
the second stage of photosynthesis, in which carbon dioxide is reduced by the hydrogen formed in the light-dependent reactions, with the input of energy from ATP, to form glucose; these reactions do not need the presence of light

line graph
a pictorial representation of data in which specific values of a function are plotted as dots on a coordinate plane. Adjacent pairs of dots are connected by straight lines

line of best fit
a straight line drawn through the centre of a group of data points plotted on a scatter plot

lipase
the general term for an enzyme that is involved in the hydrolysis of lipids

lipid
an ester of fatty acids and glycerol

'lock and key' hypothesis
the hypothesis explaining the interaction between an enzyme and its substrate in terms of the shapes of the molecules

loop of Henle
area between proximal and distal convoluted tubules of the nephron in the mammalian kidney; is a counter-current multiplier whereby high salt concentration in the interstitial fluid is maintained, resulting in diffusion of water from the filtrate to the surrounding blood capillaries

lymph
tissue fluid, containing a high volume of white blood cells, which has been taken up by the lymphatic vessels to be returned to the blood vascular system

lymph node
an organ on the course of major lymph vessels containing cells involved with the immune system

lymphatic vessel
the tubular structure that carries lymph from tissue to the blood circulatory system

lymphocyte
a white blood cell found in the lymphatic system

lysosome
an organelle containing digestive enzymes concerned with intracellular digestion

M

macrophage
a matured monocyte (a type of white blood cell) that destroys foreign matter and bacteria by phagocytosis

malfunctioning
not functioning correctly

malnutrition
health problems caused by poor diets where nutrients are either deficient or excessive

mast cell
a type of granular basophil cell in connective tissue that releases heparin and histamine during inflammation and allergic reactions

mean
the average of a set of arithmetic values

mean variance
the average of the sum of the squared differences of a set of values from the mean

median
the value lying at the midpoint of a frequency distribution of observed values

medulla
the inner layer of a structure, e.g. the medulla of the vertebrate kidney contains loops of Henle and collecting tubules

memory cell
a small, long-lived lymphocyte (B or T) that has previously encountered a given antigen and that, on re-exposure to the same antigen, rapidly initiates the immune response

merozoite
a cell produced in large numbers by rapid asexual division during a stage in the life cycle of *Plasmodium* in red blood cells, causing the red blood cells to rupture

mesoderm
the middle primary germ layer of an animal that undergoes differentiation into particular tissues, organs and systems

mesophyll
plant tissue of two types (palisade and spongy) specialised for photosynthesis

mesophyte
a plant adapted to growing in well-watered soil

metabolism
chemical reactions occurring within a cell

microfilament
a solid rods of actin protein found in the cytoplasm, cilia and flagella of eukaryotic cells

microtubule
a hollow protein strand in cytoplasm; involved in cell transport and structure

microvillus (plural microvilli)
minute finger-like projection from a cell's surface; can form a brush border

mitochondrion (plural mitochondria)
a membrane-bound cellular organelle; has inner membrane forming folds (cristae) on which are found enzymes for aerobic respiration, and a fluid matrix

mitosis
nuclear division resulting in daughter cells with the same number and types of chromosomes as in the parent cell

mode
the value that occurs most often

monocyte
a large white blood cell that is formed in the bone marrow, circulates in the blood, and destroys pathogenic bacteria by phagocytosis; monocytes develop into macrophages in various body tissues

monomer
the basic building block of an organic compound

monosaccharide
a monomer of carbohydrates

morphology
the study of external features of an organism

mortality rate
the ratio of deaths in an area to the population of that area; expressed per 1000 per year

motor (efferent) neuron
a nerve cell which transmits information from the central nervous system to an effector organ

mouth
the opening of the anterior region of the alimentary canal through which food is ingested

multicellular
composed of many cells

multicellular organism
an organism composed of many integrated cells

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

murein
a glycoprotein forming the cell wall of bacteria

myelin sheath
a fatty sheath surrounding some nerve fibres formed by Schwann cells

myoglobin
a variety of haemoglobin found in vertebrate muscles with a high affinity for oxygen

N

natural active immunity
immunity which occurs when a person is exposed to a live pathogen and develops a primary immune response, which leads to immunological memory

natural passive immunity
antibody-mediated immunity conveyed to a foetus or infant by its mother

negative feedback
a change which reverses a particular trend

nephron
the functional unit of the vertebrate kidney

nerve
a fibre (dendrite or axon) or group of fibres which carry impulses between the central nervous system and body parts

neuromuscular junction
the junction between nerve and muscle cells

neuron
a nerve cell consisting of dendrite(s), cell body and axon(s)

neutrophil
a phagocytic, granulocytic white blood cell

niche
the 'role' of an organism in a habitat

node of Ranvier
the regularly repeated constriction of the myelin sheath of neurons between adjacent Schwann cells

non-competitive inhibition
the permanent blockage of the active site of an enzyme to the normal molecule by a poison

non-essential nutrient
a nutrient that can be synthesised by an organism

non-infectious
cannot be passed from individual to individual

noradrenalin
the chemical secreted by nerve endings of sympathetic nerves; closely related to the hormone adrenalin secreted by the adrenal gland in the 'flight or fight' response

nuclease
the general term for an enzyme involved in the hydrolysis of nucleic acids

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

nucleotide
the building block of nucleic acid composed of a 5-carbon sugar, an organic nitrogen base and phosphoric acid

nucleus
control centre of the eukaryotic cell

null hypothesis
a hypothesis written in the negative form

nutrient
any substance used as food by an organism

nutritional disease
a disease resulting from deficiencies or excesses in the diet

O

oligopotent stem cell
a stem cell that can only differentiate into a few cell types

operculum
the bony covering of the gills of bony fish

optimal level
the state of something that is the most advantageous for an outcome

optimal range
the most favourable condition of, for example, temperature, light, and moisture for the growth or reproduction of an organism

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

organic compound
a complex carbon compound formed by living things; usually a macromolecule

osmoconformer
a marine organism that maintains an internal environment that is isotonic with its external environment

osmoreceptor cell
a cell that detects changes in osmotic (blood) pressure

osmoregulation
the physiological regulation of water and salt concentrations within the body

osmoregulator
an organism that actively controls salt concentrations independently of the salt concentrations in the environment

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

outlier
a value that 'lies outside' (is much smaller or larger than) most of the other values in a set of data

overnutrition
a form of malnutrition in which one or more nutrients is oversupplied

oxygen debt
the amount of oxygen required to convert lactic acid, produced during a period of anaerobic respiration, to pyruvate

oxygen-dissociation curve
a graphical representation of the percentage saturation of blood with oxygen at different levels of 'environmental' oxygen

oxyhaemoglobin
haemoglobin that is combined with oxygen

P

palisade cells
photosynthetic mesophyll cells, usually found below the surface of plant leaves

pandemic
an epidemic of infectious disease that has spread across a large region (e.g. multiple continents) or even worldwide

parasite
an organism that lives in or on another organism and derives its nourishment from it

parasympathetic nervous system
the section of the autonomic nervous system involved in the unconscious control of body organs

partial anaerobe
an organism that can undergo a period of anaerobic cellular respiration when oxygen supplies are depleted or oxygen is in short supply

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

pasteurisation
the process of heating, and then rapidly cooling, liquids or food in order to kill microbes

pathogen
a biological agent that causes disease or illness to its host

peptide bond
a bond formed from condensation between two amino acids, where hydrogen (H) is lost from the amino group and a hydroxyl group (OH) from the carboxyl group

peripheral nervous system
the system of nerves between effectors/receptors and the central nervous system; subdivided into somatic (outer body tube) and visceral (inner body tube)

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

peristalsis
the waves of contraction and relaxation in muscular walls of the alimentary canal, aiding in mechanical digestion and moving food forward through its length

petiole
leaf stalk

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

pheromone
a hormone released as an external signal to other members of the species

phloem
a complex tissue composed of living and dead cells; its functional unit consists of a sieve element and a companion cell. Sieve tubes (composed of sieve elements end-to-end) provide the route for the movement of organic solutes in vascular plants

phospholipid
a lipid in which a polar phosphate group replaces one fatty acid

phospholipid bilayer
the main structure of the cell membrane consisting of two layers of phospholipids arranged so that the hydrophilic heads face the internal and external fluid environments

phosphorylation
the addition of a phosphate group to a molecule; can be non-cyclic (e.g. formation of ATP) or cyclic (e.g. the cyclic flow of electrons along electron transport chain from chlorophyll, the energy release being used in the formation of ATP)

photosynthesis
a process whereby radiant energy (in the visible spectrum) is converted to the chemical energy of glucose; requires chlorophyll, carbon dioxide, water and a suitable temperature; occurs in green plants, algae and some bacteria

physical (mechanical) digestion
the breakdown of food into small units by crushing or cutting actions of mouthparts (in invertebrates), teeth, muscles, etc.

physiological stress
an organism's response to a stressor such as an environmental condition

physiology
the study of the way in which organs and systems operate within an organism

phytoalexin
antifungal or antibacterial compounds synthesised in plants in response to infection

phytoanticipin
a chemical produced by plants to inhibit fungal spore germination

pie graph
a circular statistical graphic which is divided into slices to illustrate numerical proportion

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

pituitary gland
the 'master gland' of the human body, the pituitary gland is responsible for the production of a number of hormones in the body and the coordination of hormone production in other glands

plant defensin
a protein produced by a plant to inhibit development of fungi, bacteria and viruses

plasma cell
a cell, developed from activated B-lymphocytes, that makes large amounts of a specific antibody

plasmodesma (plural plasmodesmata)
a junction between plant cells allowing direct communication between the cycltoplasm of each cell

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

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

polarised
a condition in which there is an unequal distribution of charges between two points (e.g. inside and outside the cell membrane)

polymer
a macromolecule formed by the union of many monomers

polypeptide
a macromolecule formed by the union of many amino acids

polysaccharide
a complex carbohydrate composed of many monosaccharides bonded together

positive feedback
a physiological control mechanism in which a change in some variable triggers mechanisms that amplify the change

post-synaptic element
the membrane of the structure (e.g. a dendrite) to which an impulse is transferred across a synapse

potential energy
stored energy

pre-synaptic element
the axon knob and its membrane, from which an impulse will pass across a synapse

prediction
forecast of a future event based on similar known events

primary host
a host in which the parasite reaches maturity and, if possible, reproduces sexually

prion
an abnormal form of a normally harmless protein found in the brain that is responsible for a variety of fatal neurodegenerative diseases of animals, including humans

product
the chemical(s) formed as a result of a chemical reaction

prokaryote
an organism without a membrane-bound nucleus or organelles

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

proprioceptor
a sensory receptor which receives stimuli from within the body, especially one that responds to position and movement

prostaglandin
a chemical released from damaged cells that directs blood flow to an injured area

protease
the general term for an enzyme involved in the hydrolysis of proteins

protein
a macromolecule, consisting of one or more polypeptide chains, which may be folded, branched and/or cross-linked at intervals

protein channel
a channel passing through the centre of a protein, the lining of which is hydrophilic

proximal convoluted tubule
the tubule of the kidney nephron arising from Bowman's capsule and leading to the loop of Henle; responsible for the reabsorption of glucose, sodium chloride and water

pseudopodium (plural pseudopodia)
a temporary foot-like extension of the cell membrane of some protozoans, resulting in a flowing movement of the protozoan

public health program
a program undertaken by organisations to prevent disease, prolong life and promote human health through informed choices

pulmonary circulation
the circulation of deoxygenated blood from the right side of the heart to the lungs and the return of oxygenated blood from the lungs to the left side of the heart

pyramid
the bundle of collecting ducts in the mammalian kidney

pyrogen
a chemical released by activated immune cells that induces fever

Q

qualitative
descriptive

quantitative
measured

quarantine
a strict isolation imposed to prevent the spread of disease

R

random sample
one of many statistically possible samples where all have an equal chance of happening

reactant
a chemical taking part in a chemical reaction

reflex arc
the nervous pathway along which impulses pass from sensory to motor nerves, with little or no coordination by the central nervous system, leading to a reflex behaviour to a specific stimulus

regulator
a substance or process that regulates or controls another

relative refractory period
the period shortly after the firing of a nerve fibre when partial repolarisation has occurred and a greater than normal stimulus can stimulate a second response

reliable
the degree to which an investigation produces stable and consistent results

renal artery
the blood vessel entering the kidney

renal pelvis
the funnel-shaped expansion of the ureter before it leaves the kidney

renal vein
the blood vessel leaving the kidney

repeatability
the ability to get the same measurement as in the original experiment when using the same method and equipment

repolarisation
the change in membrane potential that returns it to a negative value just after the depolarisation phase of an action potential has changed the membrane potential to a positive value

reproducibility
the ability of an entire experiment or study to be duplicated

reservoir host
an organism that can harbour a pathogen indefinitely with no ill effects

resting potential
polarised state of neuron membrane due to a sodium pump, resulting in the inside of the membrane being negative relative to the outside

ribonucleic acid (RNA)
the single-stranded nucleic acid characterised by a ribose sugar in each nucleotide, and the bases adenine, uracil, cytosine and guanine

ribosome
the site of protein synthesis in cells; composed of RNA, produced in nucleolus and found on rough ER (eukaryotes) or in cytoplasm (eukaryotes and prokaryotes)

root pressure
the pressure exerted on water in the roots of plants due to the continued uptake of water from the soil by osmosis; it forces water a certain way up the stem of the plant until counteracted by the force of gravity

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

ruling hypothesis
the most successful hypothesis of a particular investigation

S

salt excluder
a halophyte plant that uses root mechanisms to prevent uptake of salt

salt excretor
a halophyte that removes salt through glands in the cuticle located on each leaf

saturated compound
a compound in which only single electrons are shared between any two atoms in the compound

scatterplot
a graph of plotted points that show the relationship between two sets of data

Schwann cell
a cell, rich in fats, which ensheaths peripheral nerve fibres

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

scientific method
the testing of hypotheses by controlled experimentation

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

secondary host
a temporary host for a parasite

sense organ (receptor)
a cell or group of cells that receives stimuli

sensory (afferent) neuron
a nerve cell which carries information from a receptor to the central nervous system

shunt vessel
a blood vessel that links an artery directly to a vein, allowing the blood to bypass the capillaries in certain areas

sieve tube
the element of phloem functioning to transport organic molecules within the plant; consists of thin-walled, elongated living cells arranged in a longitudinal row and forming a connected series by means of perforations in their end walls through which pass strands of cytoplasm

signal transduction
a set of chemical reactions in a cell that occurs when a molecule, such as a hormone, attaches to a receptor on the cell membrane

signal transduction pathway
a cascade of biochemical reactions inside the cell that eventually reach the target molecule or reaction; it is initiated when a molecule (e.g. a hormone) attaches to a receptor on the cell membrane

simple diffusion
the unaided movement of molecules or ions across a differentially permeable

membrane from an area of high solute concentration to an area of low solute concentration

SIR model
a method that models or tracks the numbers of susceptible, infected and recovered individuals during an epidemic

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

sodium pump
a special transport protein in the membrane of animal cells that transports sodium out of the cell, and potassium into it, against their concentration gradients

somatic nervous system
the system of nerves that are associated with the tissues of the outer body tube (outside the body cavity)

spinal cord
the part of the vertebrate central nervous system within the backbone

spongy mesophyll
parenchyma tissue that has many spaces between cells to facilitate the circulation of air and the exchange of gases

sporozoite
a form of *Plasmodium* resulting from sexual reproduction and produced in the salivary glands of the mosquito

standard deviation
a measure of the dispersion or variation in a distribution

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

stimulus
change in the environment of an organism that brings about a response

stoma (plural stomata)
pore in leaf epidermis, bound by guard cells; allows gas exchange and transpiration

stroma
the fluid matrix of the chloroplast, containing enzymes for the light-independent reactions of photosynthesis

structural feature
an arrangement or organisation of parts of an organism

sympathetic nervous system
the division of the autonomic nervous system involved in the unconscious control of organs

synapse
the position where two adjoining neurons meet

synaptic cleft
the space between the elements in a synapse

synaptic fatigue
the condition that occurs when no more transmitter substance is available to transmit an impulse across a synapse

synaptic terminal or knob
the swollen axonic end of a synapse

system
different organs working together to perform a specific function

systemic circulation
the circulation of blood from the left side of the heart to all body cells and back to the right side of the heart

T

T-lymphocyte
a lymphocyte that has passed through the thymus during maturation

table
a display of information in named rows and/or columns

taxonomy
the science of classifying things

thermoconformer
any organism whose body temperature changes according to the external temperature

thermogenesis
the process of heat production in organisms

thermoregulation
maintenance of a constant internal temperature of an organism independent of the temperature of the environment

threshold potential
the minimum stimulation required to initiate a nerve impulse

thylakoid
the membranous, flattened, disc-shaped sac (groups of which form a granum) found in chloroplasts, on which the light-dependent reactions of photosynthesis occur

tight junction
the fusion of the cell membranes of adjacent cells by proteins

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

tissue fluid (extracellular fluid)
fluid formed from plasma pushed out through the walls of capillaries under arterial pressure; surrounds the cells, providing a medium for exchange between the blood and the cells

tolerance limit
the upper and lower limits to the range of particular environmental (e.g. light, temperature, availability of water) or physiological (particular chemical concentrations) factor within which an organism can survive

tolerance range
a certain range of a particular factor in which an organism can survive

torpor
a short-term state of decreased physiological activity in an animal, usually with a reduced body temperature and metabolic rate as a result of cold conditions

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

toxin
a protein produced by pathogens and that poisons host cells

trans-differentiation
the change of a differentiated cell into another type of cell, bypassing stem cells

translocation
the movement of organic solutes in the phloem in any direction; also a chromosome aberration in which a segment of DNA has been moved to another chromosome

transpiration
evaporation of water from the stomata of leaves

transpiration check
a process whereby a plant reduces transpirational water loss

transpiration stream
the water column from the roots of the plant to the intercellular spaces of a leaf

transport system
a system of vessels responsible for the movement of materials through an organism

trend line (line of best fit)
a line that is used to represent the behaviour of a set of data to determine if there is a certain pattern

triglyceride
a lipid formed from one molecule of glycerol and three molecules of one or more different types of fatty acids

tropic hormone
a hormone which brings about changes in growth patterns

turgor pressure
the inward pressure exerted on plant cells due to presence of the cell wall

U

ultrafiltration
the removal of most of the plasma and its contents from a capillary under high pressure, e.g. in the kidney

undernutrition
a diet in which the individual is not getting enough calories, protein or micronutrients

unicellular
composed of a single cell

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

unsaturated compound
a substance in which two or more electrons are shared between adjoining atoms in a molecule

up-regulation
the process of increasing the response to a stimulus due to an increase in the number of receptors on the cell surface

urea
a water-soluble nitrogenous excretory product of protein breakdown

ureter
the duct which leads from the kidney to the bladder

urethra
the tube running from the bladder to the body's exterior; in human females, it functions to eliminate urine; in human males, the vas deferens joins the urethra, which therefore functions in the elimination of semen as well as urine

uric acid
a complex non-toxic nitrogenous excretory product that is only slightly soluble; present in waste in reptiles and birds

urine
the excretory fluid produced in the kidney, containing metabolic wastes (urea, salts) in a watery solution

V

vaccination
injection of a killed microbe in order to stimulate the immune system against the microbe, thereby preventing disease

vacuole
a cellular inclusion, or space within the cell; small in animals (food storage or digestion); large in plants (storage and osmotic control)

valid
describes an experiment which provides data that refers directly to the hypothesis

variability
the extent to which data points in a data set diverge from the average, or mean, value as well as the extent to which these data points differ from each other

variance
a measure of how far each value in the data set is from the mean

vascular cambium
the layer of actively dividing cells between the xylem and phloem of vascular plants

vasodilation
the widening of blood vessels

vector
any agent that carries and transmits an infectious pathogen into another living organism

vein
a blood vessel that begins in a capillary bed and enters the heart in animals

ventilation
active movement of the passage of air (or water) over gas exchange surfaces

ventral root of the spinal cord
the area emerging from the ventral region of the spinal cord forming the efferent, motor part of a spinal nerve

venule
a thin-walled vessel that directly connects capillaries to veins

villus (plural villi)
a finger-like projection of the lining of the small intestine; increases the surface area available for absorption

virulence
the ability of a pathogen to cause disease

virulent factor
a molecule that can contribute to the survival of the pathogen

viroid
a RNA molecule without a protein coat

visceral nervous system
the system of nerves associated with the organs of the body cavity and the inner body tube (alimentary canal)

W

white matter
the myelinated neurons within the central nervous system

X

xerophyte
a plant that has adaptations to survive in an environment with little liquid water

xylem
a complex tissue composed of living and dead cells; the tracheids and vessels are the non-living components through which water and dissolved mineral nutrients pass from the roots to the leaves in the transpiration stream

Z

zoology
the study of animals

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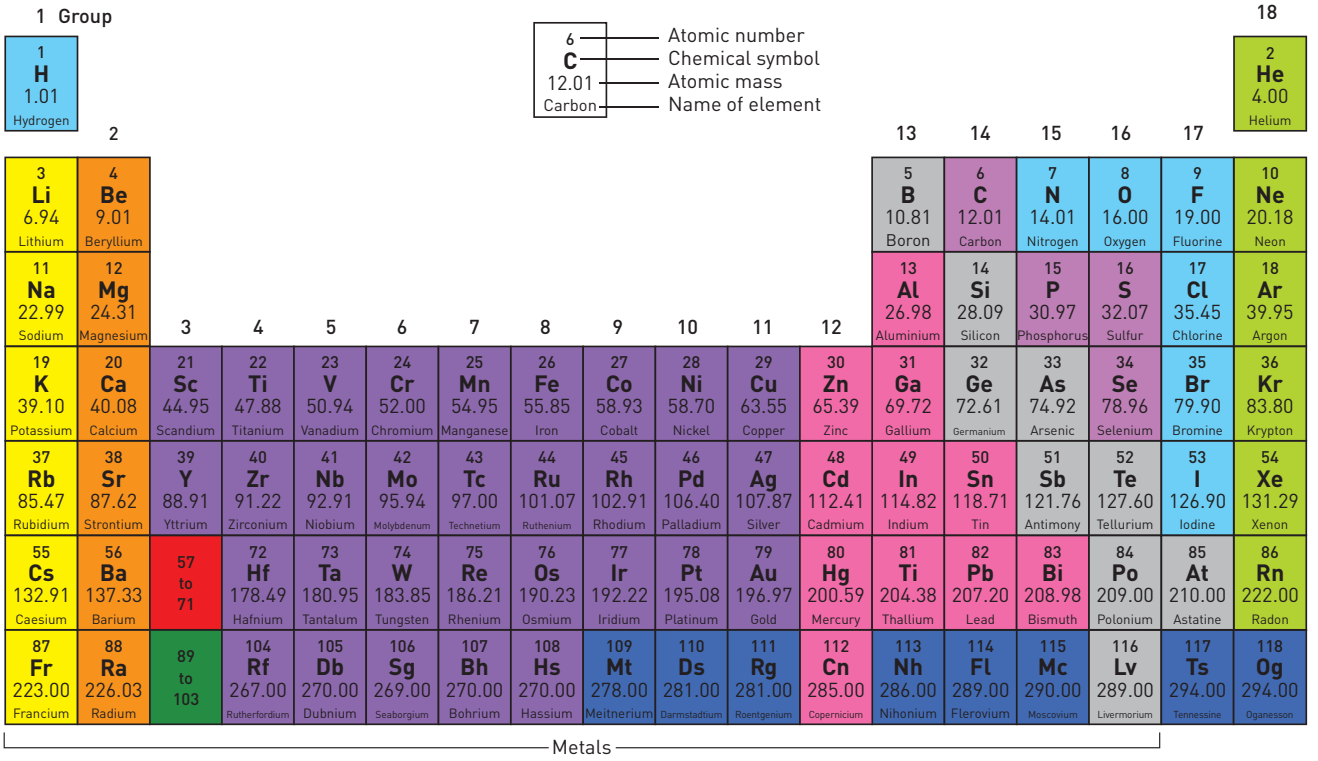
APPENDIX

Appendix 1 Periodic table



The front cover shows a shoal of anthias. Shoals, or groups, of anthias can be found on tropical coral reefs all over the world, including the Great Barrier Reef. These fish feed on zooplankton that floats through the ocean current. Anthias are protogynous hermaphrodites, which means they are all born female but can become male.

OXFORD
UNIVERSITY PRESS
AUSTRALIA & NEW ZEALAND

ISBN 978-0-19-031021-9
9 780190 310219

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