BIOZONE

VCE | BIOLOGY UNITS 1&2

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We pay our respects to ancestors and to all First Nations elders: past, present and emerging.

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Cover Photograph

Photo: Adobe Stock /Kuritafsheen

The Australian green tree frog *(Ranoidea caerulea)* have enormous toe pads with partial webbing between fingers and almost complete webbing between toes. The eye has a horizontal pupil; most other tree frogs have vertical pupils. The fatty ridge over the eye is a distinctive feature of the species. https://nationalzoo.si.edu/animals/whites-tree-frog

Disclaimer

Although every care has been taken, Aboriginal and Torres Strait Islander people should be aware that this title may contain images of deceased persons.

The external weblinks (URLs) referenced in this book were correct at the time of publishing. However, due to the dynamic nature of the internet, some addresses may have changed, or cease to exist. While BIOZONE regrets any inconvenience that this may cause readers, no responsibility for any such changes or unforeseeable errors can be accepted by BIOZONE.

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Contents

Activity is marked: ☐ to be done; ☑ when completed ● Includes practical investigation ● Assessment task

Contents

UNIT 2: How does inheritance affect diversity?

Activity is marked: ☐ to be done; ☑ when completed ● Includes practical investigation ● Assessment task

Using BIOZONE's Resource Hub

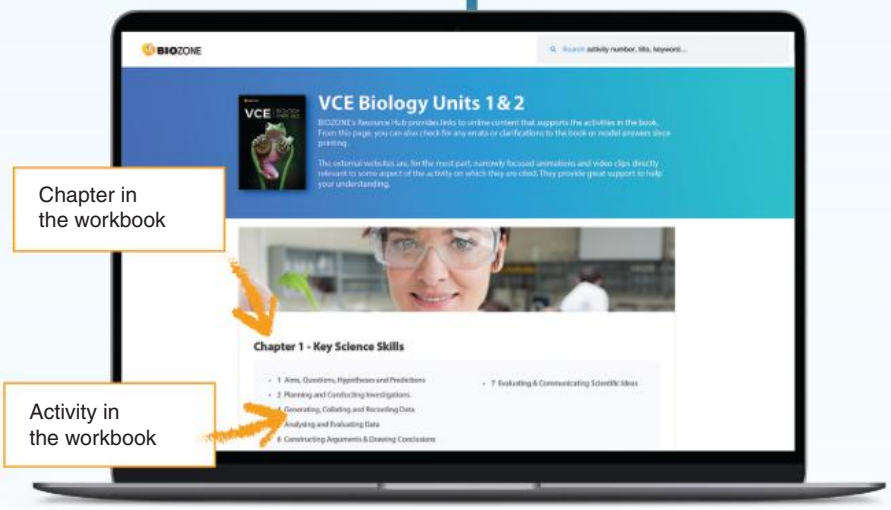
- BIOZONE's **Resource Hub** provides links to online content supporting the activities in the book. From this site (below), you can also explore BIOZONE's collection of annotated 3D models and check for any errata or clarifications to the book or model answers since printing. Activities with Resource Hub support are indicated by a **grey tab** (below) at the bottom of the activity page. Most activities have resources to support them.
- The external websites are generally narrowly focussed animations, illustrated content, or video clips relevant to some aspect of the activity on which they are cited. They provide great support to help your understanding.

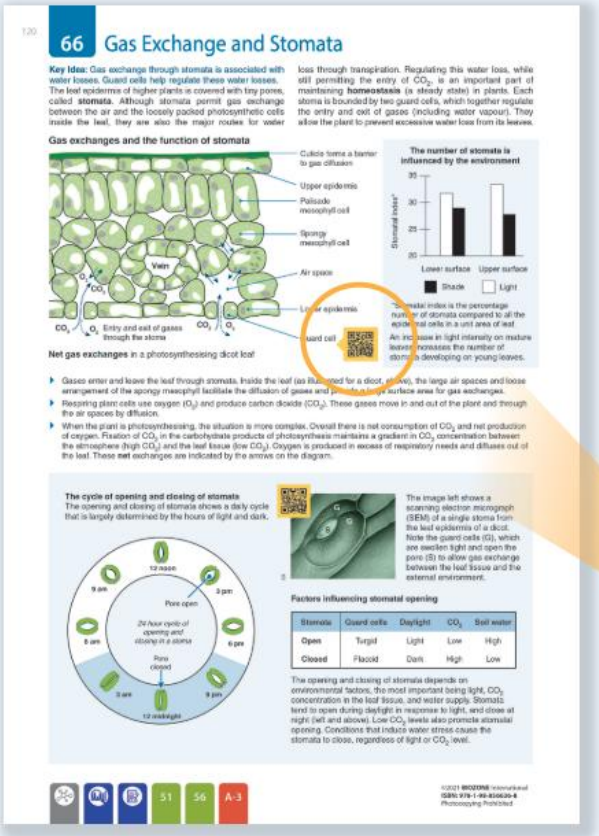
www.BIOZONEhub.com

Then enter the code in the text field

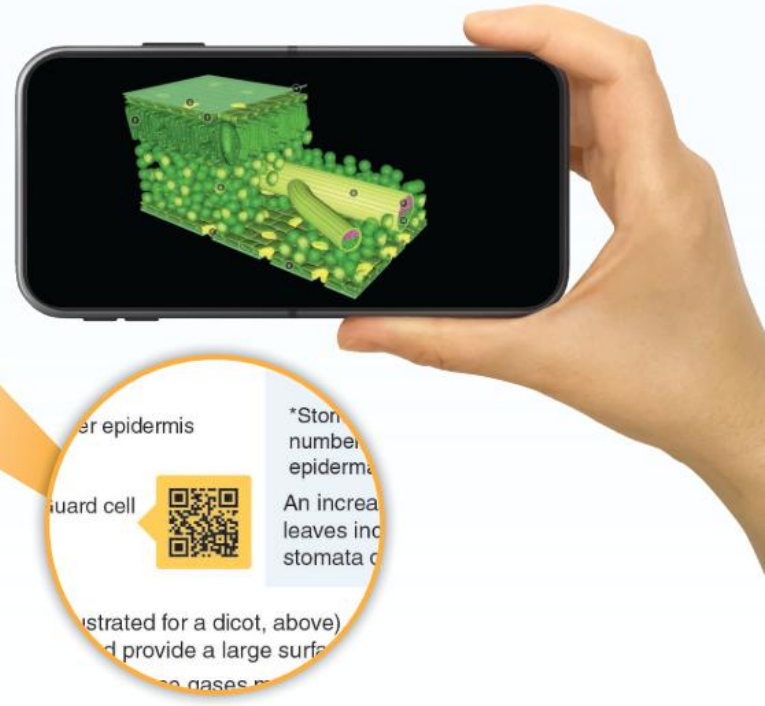
VCE11-2-6368

Or scan this QR code





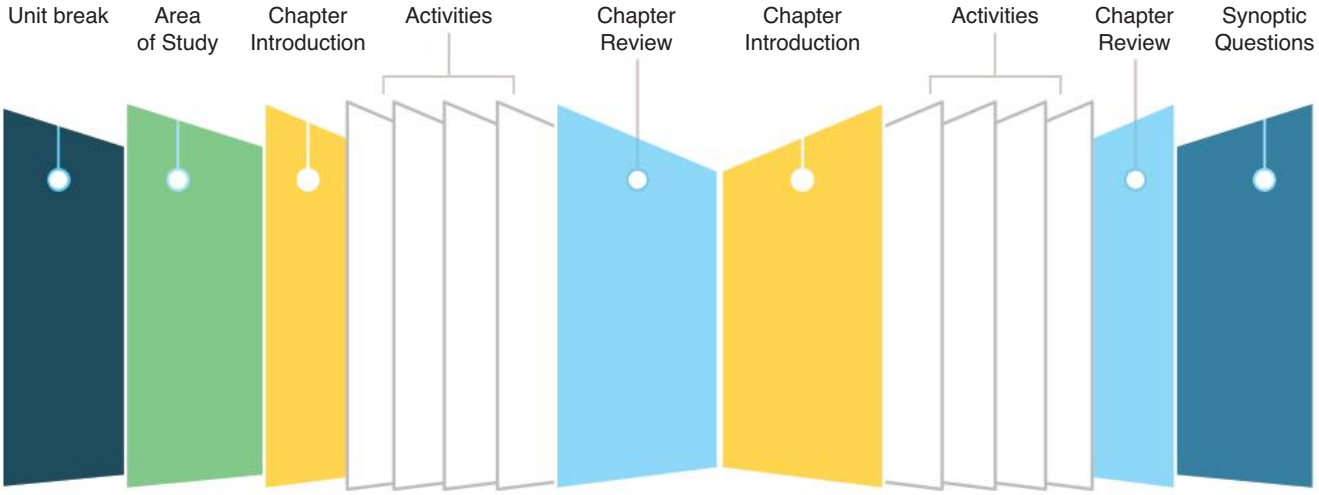
Scan the **QR codes** on the activity pages. These link directly to informative and engaging 3D models. All models can be rotated and zoomed, and some contain informative annotations.



Using This Book

This edition of Biology for VCE Units 1 & 2 has been specifically written to meet the content and skills requirements of the Victorian Certificate of Education, Biology, Units 1 and 2. The workbook follows the unit structure outlined in the Study Design, so it is easy for you to know where you are in the course. Unit and Area of Study breaks help you navigate through the content. Each chapter has an introduction page so you can see the key knowledge and skills requirements for each chapter. You can review and test your understanding, and prepare for assessments and exams by carrying out the Chapter Review and Synoptic Question activities.

- A structure of a unit is outlined below, it will help you identify the features within each unit.



Chapter introduction

- A check list of key knowledge.
- A list of key terms.

Activity pages

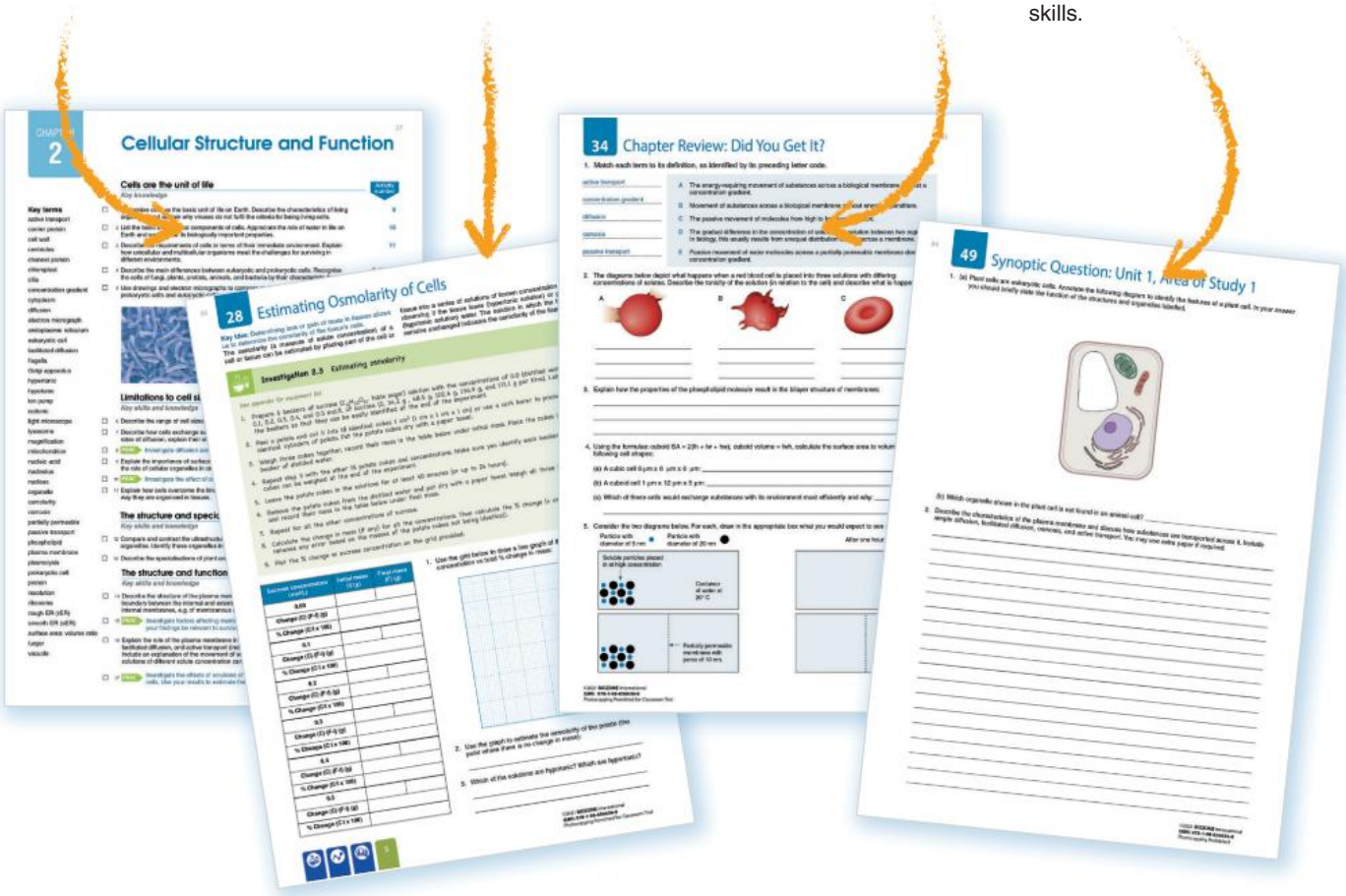
- Contain essential knowledge.
- Questions review the content of the page.

Chapter review

- Test your understanding of the chapter content.
- Develop your scientific literacy.

Synoptic questions

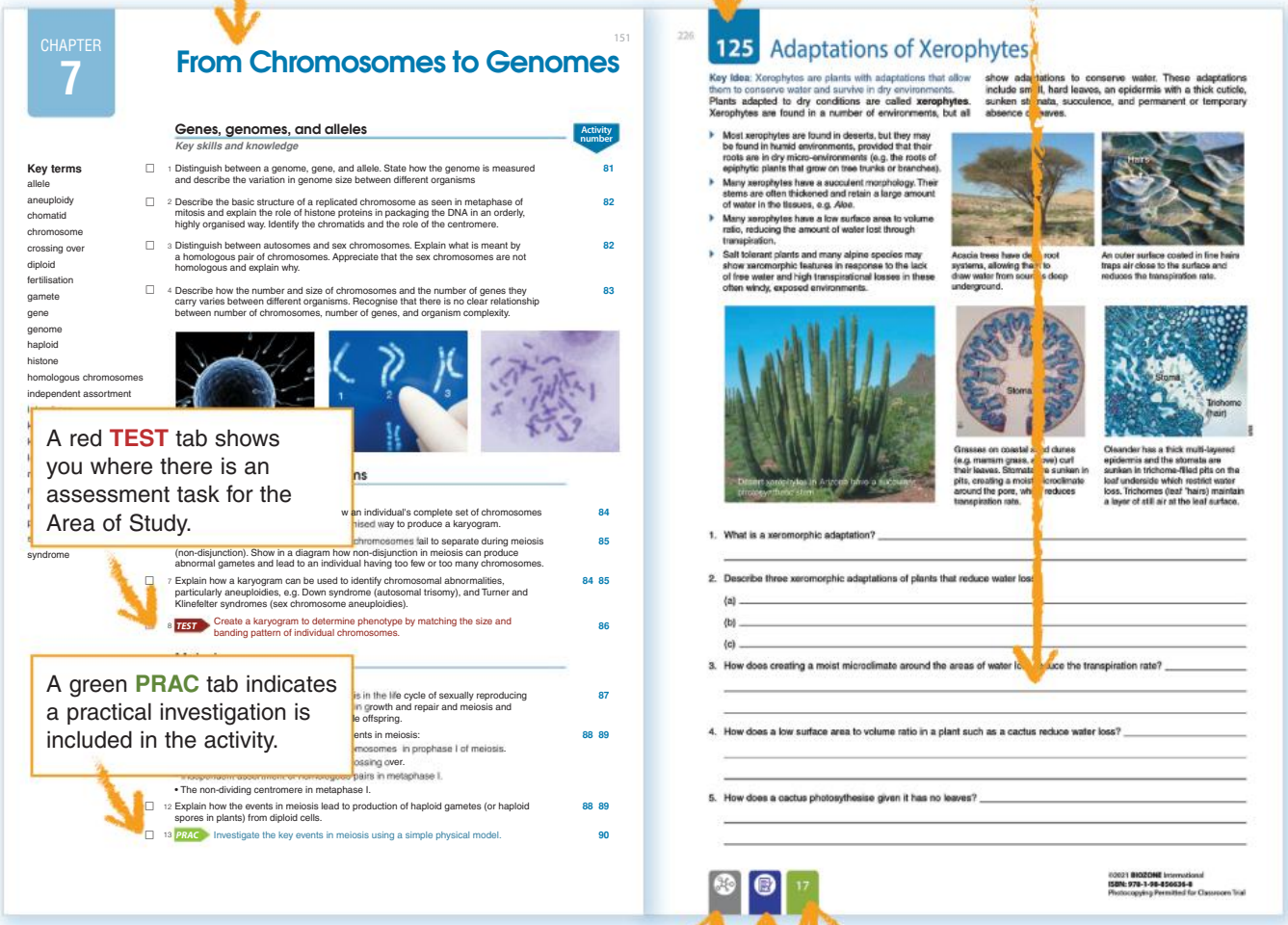
- Synoptic questions conclude the unit and area of study covered in the workbook.
- Practise your written exam skills.



The **chapter introduction** provides you with a summary of the knowledge and skills requirements for the topic, phrased as a set of learning outcomes. Use the check boxes to identify and mark off the points as you complete them. The chapter introduction also provides you with a list of key terms for the chapter, to help you practise using scientific language.

The **ac**tivities form most of this workbook. The activity number is found at the to of the first page. Each activity has a short introduction with a key idea identifying the main message of the page. Most of the information is associated with pictures and diagrams.

Free response questions allow you to use the information on the page to answer questions about the content of the activity, either directly or by applying the same principles to a new situation. In some cases, an activity will assume understanding of prior content.



Resource Hub tabs at the bottom of the activity page show where external, online support material is provided for an activity. The types of resources vary and include animations, video clips, photo libraries, articles, or quizzes. Bookmark the link to Resource Hub (see next page) and visit it often as you progress through the workbook.

Pictograph tabs identify where a **Key Science Skill** is covered. A full description of the pictograph codes is given on the following page.

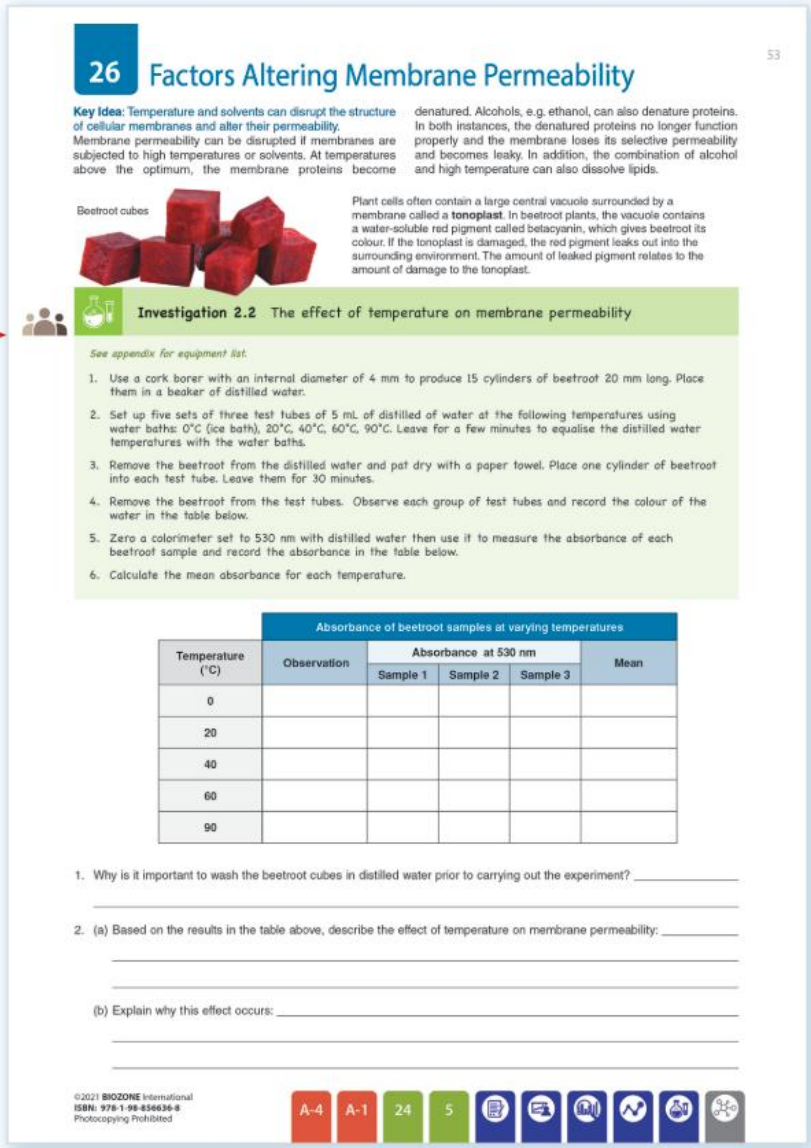
Connect tabs at the bottom of the activity page identify activities that are related in that they build on content or apply the same principles to a new situation.

Using the Tab System

- The tab system is a useful way to identify important parts of the VCE Biology course. The tabs also allow you to see at a glance if online support is provided and if there are content links with other activities.

A group icon in the margin shows where you can work in pairs or small groups to complete a task or activity.

Working in groups allows you to experience the benefits of collaboration. Scientific vocabulary is extended as you listen to the ideas of others and share and discuss your own ideas.



26 Factors Altering Membrane Permeability

53

Key Idea: Temperature and solvents can disrupt the structure of cellular membranes and alter their permeability.

Membrane permeability can be disrupted if membranes are subjected to high temperatures or solvents. At temperatures above the optimum, the membrane proteins become denatured. Alcohols, e.g. ethanol, can also denature proteins. In both instances, the denatured proteins no longer function properly and the membrane loses its selective permeability and becomes leaky. In addition, the combination of alcohol and high temperature can also dissolve lipids.

Beetroot cubes

Plant cells often contain a large central vacuole surrounded by a membrane called a **tonoplast**. In beetroot plants, the vacuole contains a water-soluble red pigment called betacyanin, which gives beetroot its colour. If the tonoplast is damaged, the red pigment leaks out into the surrounding environment. The amount of leaked pigment relates to the amount of damage to the tonoplast.

Investigation 2.2 The effect of temperature on membrane permeability

See appendix for equipment list.

1. Use a cork borer with an internal diameter of 4 mm to produce 15 cylinders of beetroot 20 mm long. Place them in a beaker of distilled water.
2. Set up five sets of three test tubes of 5 mL of distilled of water at the following temperatures using water baths: 0°C (ice bath), 20°C, 40°C, 60°C, 90°C. Leave for a few minutes to equalise the distilled water temperatures with the water baths.
3. Remove the beetroot from the distilled water and pat dry with a paper towel. Place one cylinder of beetroot into each test tube. Leave them for 30 minutes.
4. Remove the beetroot from the test tubes. Observe each group of test tubes and record the colour of the water in the table below.
5. Zero a colorimeter set to 530 nm with distilled water then use it to measure the absorbance of each beetroot sample and record the absorbance in the table below.
6. Calculate the mean absorbance for each temperature.

Temperature (°C)	Absorbance of beetroot samples at varying temperatures				
	Observation	Absorbance at 530 nm			Mean
		Sample 1	Sample 2	Sample 3	
0					
20					
40					
60					
90					

1. Why is it important to wash the beetroot cubes in distilled water prior to carrying out the experiment? _____

2. (a) Based on the results in the table above, describe the effect of temperature on membrane permeability: _____

(b) Explain why this effect occurs: _____

A-4 A-1 24 5

Page tabs show where Key Science Skills are specifically addressed. Some activities may incorporate using more than one skill. Other activities may be informational and no specific skill is identified. The tabs also indicate where is online support, links to activities with related or background content, or useful reference material in an appendix.

Grey hub tabs indicate the activity is supported on the Resource Hub. See page v for details.

Green tabs make connections to related activities elsewhere in the book

Blue tabs indicate the activity covers the following key skills (L → R):

- Develop aims and questions, formulate hypotheses, make predictions
- Plan and conduct investigations
- Comply with safety and ethical guidelines
- Generate, collate, and record data
- Analyse and evaluate data and investigation methods
- Construct evidence-based arguments and draw conclusions
- Analyse, evaluate and communicate scientific ideas

Red tabs indicate appendices (L → R):

- A-1: Which graph to use?
- A-2: Basic mathematical formulae
- A-3: Glossary
- A-4: Equipment list

See pages 276-283

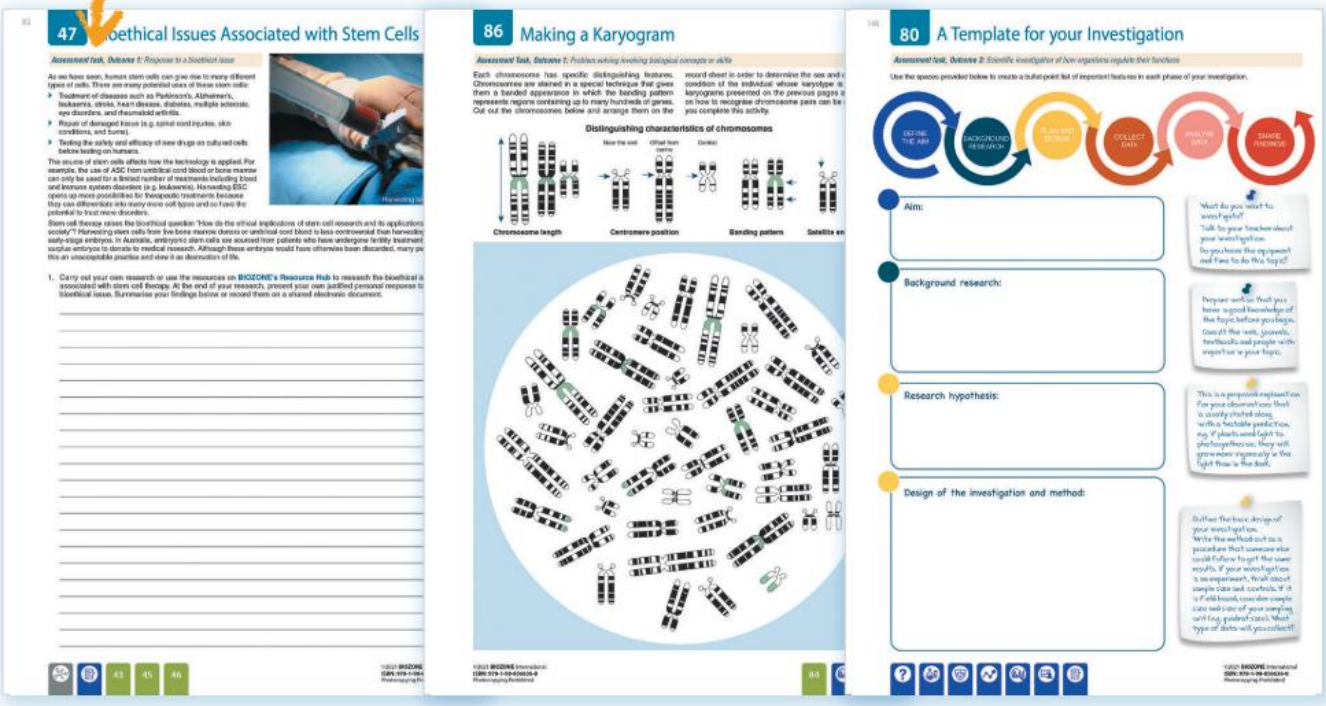
Assessment Tasks and Key Science Skills

Assessment Tasks

Assessment Tasks form an important component of the VCE Biology Study Design. BIOZONE's *VCE Biology* contains material in each Area of Study to support you in preparing for and completing these mandatory Outcome assessments. *Assessment Tasks* are identified in the table, right.

Unit 1		
Outcome 1	Bioethical Issues Associated with Stem Cells	Activity 47
Outcome 2	Investigating Stomatal Density	Activity 67
Outcome 3	Investigating Organism Function	Chapter 6
Unit 2		
Outcome 1	Making a Karyogram	Activity 86
Outcome 2	Tasmanian Devil: Disease and Populations	Activity 140
Outcome 3	Exploring Bioethical Issues	Chapter 12

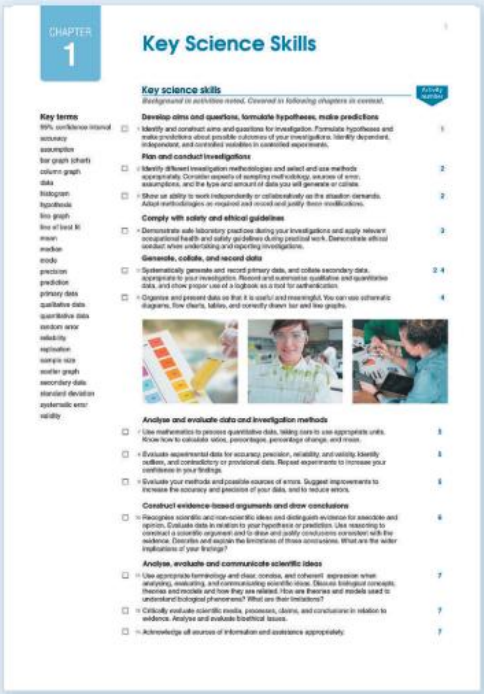
The assessment task is clearly identified on the page.



Key science skills

Developing and using science skills is an important component of the VCE study design. You should be able to use a variety of key science skills, and see their relevance in scientific inquiry and real world applications. Many of the skills you need are explained first in the "*Key Science Skills*" chapter at the beginning of this book. Specific scientific support and guidance relating to Area of Study 3 in Units 1 & 2 are also provided (Chapters 6 and 12). Refer to these chapters at any time to review the skills covered there. These include:

- Forming hypotheses
- Safety and ethical considerations
- Collecting and collating data
- Experimental design
- Recording data
- Analysis and evaluation
- Graphing
- Mathematical skills
- Descriptive statistics
- Argumentation



BIOZONE's *VCE Biology* provides many opportunities to practise and develop mathematical skills. By completing activities, practicals, and synoptic questions you can practise and develop confidence in data analysis and evidence-based argumentation. Tasks include measuring and recording data, using formulae, interpreting graphical and numerical information, and using mathematics to justify conclusions.

Answering Exam Questions

- Exams require you to demonstrate your understanding of a particular concept by providing a written paragraph or essay.
- Open answer questions (meaning there is no definitive answer) are designed so that you can demonstrate your level of understanding. The question may give you some guidance as to what you should include in your answer, such as definitions of certain terms or to provide specific examples.
- In order to gain the highest possible mark in these questions, you need to lay out your answer in a clear and logical way so that the examiner can easily see how you have demonstrated your understanding of the topic.
- The difference between you obtaining a low, mid, or high grade depends on how well you demonstrate your understanding of a concept.
  - Defining, drawing, annotating, or giving a description demonstrates a basic understanding of the material.
  - Explaining how a process works, why it works, and how changes to it may affect an outcome shows a deeper understanding of how the system works in that situation.
  - Linking biological ideas, comparing and contrasting, analysing, or justifying ideas shows both a deep understanding and an ability to translate that understanding to a new situation.
- The following example shows how an answer can be built up from a simple definition, through explanation, to comparisons and linking of ideas.

The human digestive system consists of specialised cells, tissues, and organs. Provide an overview of the digestive system and use a specific example to discuss how the specialisation and organisation of the cells, tissues, and organs contributes to its overall function and efficiency.

A brief description of the overall function of the digestive system is provided.

The digestive system is responsible for the ingestion and breakdown of food, nutrient absorption, and elimination of undigested material. The main components of the digestive system are the teeth and digestive glands in the mouth, stomach, small and large intestines and associated organs (pancreas, gall bladder and liver). Each is specialised to carry out a specific role.

The main components of the digestive system are identified.

The digestive system is a collection of specialised cells, tissues, and organs.

The human digestive system is essentially a one-way tube divided into regions. Each region is specialised to perform a particular task (or group of tasks) associated with digestion. A hierarchy of organisation (cells form tissues and tissues form organs) and specialised roles of the system's components improve the overall efficiency of the digestive process.

The stomach is used as an example to show how specialisation contributes to functionality and efficiency. Other examples (e.g. alkaline environment and increased surface area of the small intestine) could also be used.

This is illustrated by the stomach. In the stomach, ingested food is mixed with HCl in a very acidic environment (pH 1.5 - 2.0). The low pH has two purposes:
1) it begins the chemical breakdown of some food particles into smaller molecules,
2) the main digestive enzyme in the stomach (pepsin) is activated. This enables pepsin to digest (break down) protein molecules in the ingested food.

Specialisation improves efficiency (food molecules, especially protein, are partially digested before moving to the small intestine).

Several specialisations allow the stomach to carry out this role.
- Muscular layers allow efficient mixing of the stomach contents with the acid to maximise chemical pre-digestion.
- Goblet cells secrete mucus to protect the stomach lining from being digested and damaged by the highly acidic HCl.

Specialised cells in the stomach (and their roles) are clearly stated.

Gastric glands in the stomach contain specialised cells to aid digestion:
- Chief cells secrete pepsinogen (a precursor to pepsin) into the stomach
- Parietal cells, produce HCl (allows for some chemical digestion and also converts pepsinogen into the active enzyme pepsin)
- Endocrine cells secrete the hormone gastrin (gastrin promotes HCl production)

A concluding statement summarises the role of regional specialisation and sequential processing of food.

Regional specialisation and sequential digestion in the digestive system enable the most is gained from the nutrients contained in the food eaten.

CHAPTER 1

Key Science Skills

Key terms

accuracy
anecdote
argumentation
assumption
data
histogram
hypothesis
line of best fit
mean
median
mode
precision
prediction
primary data
qualitative data
quantitative data
random error
reliability
replication
sample size
scientific evidence
secondary data
standard deviation
systematic error
validity

Key science skills

Activity number

Background in activities noted. Covered in following chapters in context.

Develop aims and questions, formulate hypotheses, make predictions

☐ 1 Identify and construct aims and questions for investigation. Formulate hypotheses and make predictions about possible outcomes of your investigations. Identify dependent, independent, and controlled variables in controlled experiments. **1**

Plan and conduct investigations

☐ 2 Identify different investigation methodologies and select and use methods appropriately. Consider aspects of sampling methodology, sources of error, assumptions, and the type and amount of data you will generate or collate. **2**

☐ 3 Show an ability to work independently or collaboratively as the situation demands. Adapt methodologies as required and record and justify these modifications. **2**

Comply with safety and ethical guidelines

☐ 4 Demonstrate safe laboratory practices during your investigations and apply relevant occupational health and safety guidelines during practical work. Demonstrate ethical conduct when undertaking and reporting investigations. **3**

Generate, collate, and record data

☐ 5 Systematically generate and record primary data, and collate secondary data, as appropriate to your investigation. Record and summarise qualitative and quantitative data, and show proper use of a logbook as a tool for authentication. **2 4**

☐ 6 Organise and present data so that it is useful and meaningful. You can use schematic diagrams, flow charts, tables, and correctly drawn bar and line graphs. **4**

Analyse and evaluate data and investigation methods

☐ 7 Use mathematics to process quantitative data, taking care to use appropriate units. Know how to calculate ratios, percentages, percentage change, and mean. **5**

☐ 8 Evaluate experimental data for accuracy, precision, reliability, and validity. Identify outliers, and contradictory or provisional data. Repeat experiments to increase your confidence in your findings. **5**

☐ 9 Evaluate your methods and possible sources of error. Suggest improvements to increase the accuracy and precision of your data, and to reduce errors. **5**

Construct evidence-based arguments and draw conclusions

☐ 10 Recognise scientific and non-scientific ideas and distinguish evidence from anecdote and opinion. Evaluate data in relation to your hypothesis or prediction. Use reasoning to construct a scientific argument and to draw and justify conclusions consistent with the evidence. Describe and explain the limitations of those conclusions. What are the wider implications of your findings? **6**

Analyse, evaluate and communicate scientific ideas

☐ 11 Use appropriate terminology and clear, concise, and coherent expression when analysing, evaluating, and communicating scientific ideas. Discuss biological concepts, theories, and models and how they are related. How are theories and models used to understand biological phenomena? What are their limitations? **7**

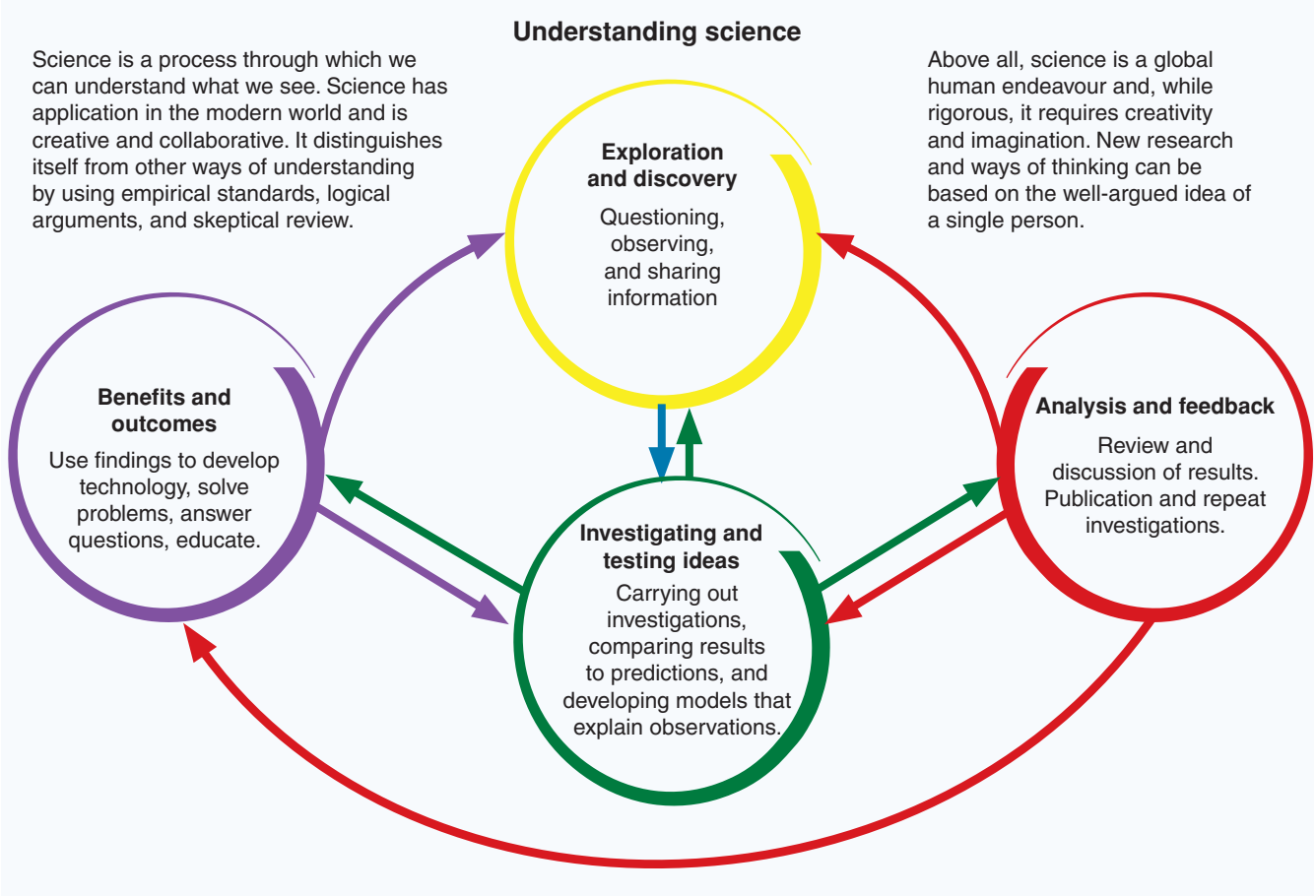
☐ 12 Critically evaluate scientific media, processes, claims, and conclusions in relation to evidence. Analyse and evaluate bioethical issues. **7**

☐ 13 Acknowledge all sources of information and assistance appropriately. **7**

1 Aims, Questions, Hypotheses, and Predictions

Key Idea: Hypotheses are tentative, testable explanations for observed phenomena. Hypotheses can be used to generate predictions about a system or its behaviour.

Science is the pursuit and application of knowledge and understanding of natural phenomena following systematic evidence-based methods. The practice of science involves asking questions and posing testable and falsifiable hypotheses about the things we see around us. A hypothesis leads to one or more predictions about the way a system will behave. Like all of science, hypotheses are not fixed, but can be modified as we gather more information about the system or the phenomenon we are interested in.



Observations, hypotheses, and predictions

- An observation is watching or recording what is happening. Observation is the basis for forming hypotheses and making predictions. An observation may generate a number of hypotheses (tentative explanations for what we see). Hypotheses should have a sound theoretical basis and should be testable and falsifiable (able to be refuted by evidence).
- A hypothesis will lead to one or more predictions. These are statements of what you expect to happen under certain conditions. Predictions can be tested by investigation.
- Hypotheses are written as statements, e.g. "*Higher temperatures increase water loss in plants*". For every hypothesis, there is a corresponding **null hypothesis**: a hypothesis of no difference or no effect, e.g. "*Higher temperatures have no effect on water loss in plants*". A null hypothesis allows a hypothesis to be tested statistically. A hypothesis can then be rejected if the experimental results do not support it.
- A research hypothesis is often written as a statement to include the prediction: "If X is true, then if I do Y (the experiment), I expect Z (the prediction)".
- Any biological investigation requires you to make **assumptions** about the system you are working with. Assumptions are features of the system (and investigation) that you assume to be true but do not (or cannot) test. They are usually based on prior knowledge.


Shining bronze cuckoo with woolly bear caterpillar

Duncan McCaskill cc 3.0

Observations: The shining bronze cuckoo has been observed to selectively feed on caterpillar species known for their toxicity to vertebrates, including brightly coloured monarch caterpillars and the hairy woolly-bear caterpillars of the magpie moth. These caterpillars are avoided by other bird species.
Question: How are cuckoos able to eat toxic prey without being affected by the toxins?
Assumptions: Cuckoos can see the bright warning colours. The toxins in the caterpillars would affect the cuckoos if absorbed.

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1. Generate a hypothesis for the question " How are cuckoos able to eat toxic prey without being affected by the toxins?"

2. Generate a prediction about shining bronze cuckoos fed on toxic caterpillars: _____

- For the example of the shining bronze cuckoo, the investigation would involve a careful observational field study to collect data about how birds behave after eating toxic prey (photograph right). In fact, shining bronze cuckoos, like other cuckoos, have a number of adaptations to avoid being poisoned, including shaking the gut out of the prey and trapping toxic caterpillar "hairs" in the inner mucous lining of the stomach, which is periodically vomited out.
- However, many of our questions in science are investigated using controlled experiments in which we manipulate a variable of interest to determine the outcome of this manipulation.
- These experiments are conducted for a purpose or aim, i.e. to test the predictions generated by our hypothesis. The aim is a brief statement of purpose, usually beginning with "*To determine…*". Use the examples below to practice.

3. When preparing cultures of an unidentified bacterial species (X) isolated from the field, a laboratory assistant noticed that cultures left overnight on the end of a bench near a heating unit grew faster than those left on the opposite side of the bench. They decided to investigate this observation further by carrying out an investigation in which 10 plates are incubated for 24 hours at a controlled 37°C and 10 plates are incubated for 24 hours at a controlled 20°C:

   (a) Write an aim for the investigation: _____

   (b) Write a hypothesis for the investigation:

   (c) Write your null hypothesis for the investigation: _____

   (d) Rewrite your hypothesis as a working (research) hypothesis to include your prediction for the investigation:

   (e) Are your hypothesis and its prediction testable? Explain: _____

   (f) What assumptions are being made in this investigation? _____

   (g) Is your hypothesis and its prediction falsifiable? Explain: _____

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2 Planning and Conducting Investigations

Key Idea: Carefully executed, well planned investigations are more likely to produce reliable, valid data.

A major part of any practical investigation is collecting the data. Practical work may be laboratory or field based. Typical laboratory based experiments involve investigating how a biological response is affected by manipulating a particular **variable**, e.g. temperature. The data collected for a quantitative practical task should be recorded systematically, with due attention to safe practical techniques, a suitable quantitative method, and accurate measurements to an appropriate degree of precision. If your quantitative practical task is carried out well, and you have taken care throughout, your analysis of the experimental results will be much more straightforward and less problematic.

Carrying out your practical work

Preparation

Familiarise yourself with the equipment and its set up. Calibrate equipment if necessary to give accurate measurements.

Read through the methods and identify key stages and how long they will take.

Execution and recording

Know how you will take your measurements and how often. Use a logbook to record results systematically as you go. You could record results as a hand-written table or in a spreadsheet. If using a datalogger, data will be logged.

Analysis and reporting

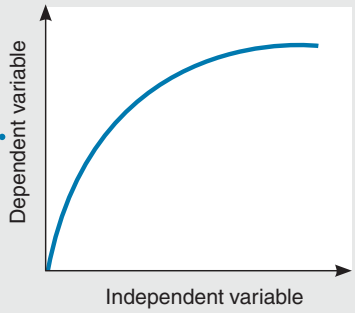
Analyse the data. Tables can summarise data. Graphs present the data to show patterns and trends. Statistical tests can determine the significance of results. Present your findings, e.g. as a poster, a digital presentation, or an oral report.

Identifying variables

A **variable** is any characteristic or property able to take any one of a range of values. Investigations often look at the effect of changing one variable on another. It is important to identify all variables in an investigation: independent, dependent, and controlled, although there may be nuisance factors of which you are unaware. In all **fair tests**, only one variable is changed by the investigator.

Dependent variable

- Measured during the investigation.
- Recorded on the y axis of the graph.



Controlled variables

- Factors that are kept the same or controlled.
- List these in the method, as appropriate to your own investigation.

Independent variable

- Set by the experimenter.
- Recorded on the graph's x axis.

Experimental controls

A **control** refers to a standard or reference treatment or group in an experiment. It is the same as the experimental (test) group, except that it lacks the one variable being manipulated by the experimenter. Controls are used to demonstrate that the response in the test group is due a specific variable (e.g. temperature). The control undergoes the same preparation, controlled conditions, observations, measurements, and analysis as the test group. This helps to ensure that the responses observed in the treatment groups can be reliably interpreted.

- The experiment above tests the effect of a certain nutrient on microbial growth. All the agar plates are prepared in the same way, but the control plate does not have the test nutrient applied.
- Each plate is inoculated from the same stock solution, incubated under the same conditions, and examined at the same set periods. The control plate sets the baseline; any growth above that seen on the control plate is attributed to the nutrient.

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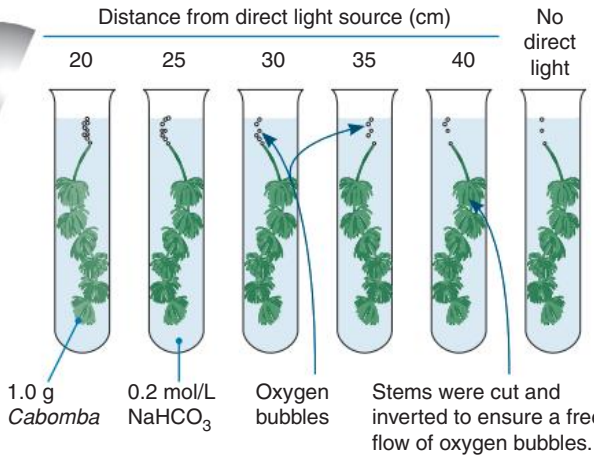
Investigation: Effect of light on rate of photosynthesis

Background

The aquarium plant, *Cabomba aquatica*, will produce a stream of oxygen bubbles when illuminated. The oxygen bubbles are a waste product of the process of photosynthesis (overall equation below right), which produces glucose ($C_6H_{12}O_6$) for the plant. The rate of oxygen production provides an approximation of photosynthetic rate.



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

The method

- 6 x 1.0 g of *Cabomba* stems were placed into each of 6 test-tubes filled with 10 mL room temperature solution of 0.2 mol/L sodium hydrogen carbonate (to supply CO_2).
- Test tubes were placed at distances (20, 25, 30, 35, 40 cm) from a 60W light source (light intensity reduces with distance at a predictable rate). One test tube was not exposed to the light source.
- Before recording, the *Cabomba* stems were left to acclimatise to the new light level for 5 minutes. The bubbles emerging from the stem were counted for a period of three minutes at each distance.

1. Write a suitable aim for this experiment: _____

2. Write a possible hypothesis for this experiment: _____

3. (a) What is the independent variable in this experiment? _____

   (b) What is the range of values for the independent variable? _____

   (c) Name the unit for the independent variable: _____

   (d) How could you better quantify the independent variable? _____

4. (a) What is the dependent variable in this experiment? _____

   (b) Name the unit for the dependent variable: _____

   (c) What equipment might have made it easier to record the response of the dependent variable accurately? Predict when it would have been most needed:

   _____

   (d) What is the sample size for each treatment? _____

   (e) What could you change in the design of the experiment to guard against unexpected or erroneous results?

   _____

5. Which tube is the control for this experiment? _____

6. Identify two assumptions being made about this system:

   (a) _____

   (b) _____

7. Identify one variable that might have been controlled in this experiment, and how it could have been monitored:

   _____

8. How might you test the gas being produced is oxygen: _____

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3 Safety and Ethical Guidelines

Key Idea: In practical work, research, and reporting you should act in accordance with safety and ethical guidelines.

Scientific research, no matter what the level, should be carried out in accordance with ethical and safety guidelines. These guidelines apply to health and safety in the laboratory and field, risk assessment, and correct use of equipment, as well as the ethical issues associated with animal welfare, privacy and personal information, and environmental impact. Ethical considerations also apply to reporting of data and honest use and acknowledgement of reference material.

Heath and safety in the laboratory

Laboratory hazards fall into three general categories: chemical, biological, and physical. Depending on the hazard, they have potential to cause harm to people, other organisms, or the environment.

- **Chemical**: Chemicals could be ingested, absorbed through the skin, or inhaled. Examples include cleaning agents, disinfectants, and reagents (powdered and liquid). Some chemicals can cause fires or explosions if not handled correctly.
- **Biological**: All biological material should be treated as potentially hazardous to avoid contamination and possible harm. Examples include microbial samples, animal tissue, fluid samples, and plant samples.
- **Physical**: There are numerous potential physical hazards ranging from the laboratory environment itself to the equipment you are using. Common hazards include injury caused by not using the equipment correctly (electrical, thermal, or sound hazards), cluttered working spaces, and tripping or slip hazards (e.g. wet floor).

Assessing and reducing risk in the lab

- Identify potential hazards before you start and use risk assessments informed by safety data sheets (SDS) held by your school.
- Wear appropriate personal protection equipment (PPE) such as lab coat, gloves, safety glasses, ear protection, and a mask as necessary.
- Ensure all chemicals and solutions are clearly labelled. Respect warnings and hazard notices.
- Know how to correctly use all equipment and machinery before you begin.
- Maintain clean work spaces and floors to reduce the risk of slips and spills. Keep access ways to emergency equipment clear.

1. (a) Identify potential health and safety issues associated with the dissection of the pig kidney being carried out in the photo (left):

(b) What has been done to reduce potential risks?

2. (a) Identify two potential safety or health hazards associated with the inspection of bacterial colonies in the photo (bottom left):

(b) What could be done to reduce these risks?

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Health and safety in fieldwork

Field studies present their own their own set of ethical and safety considerations. The Australian environment can be harsh, and bushland may contain wildlife, plants, and geographic features that can be hazardous.

- Assess the potential hazards of the area before beginning any field studies. Field studies may also require some follow-up laboratory work, especially if samples found in the field need to be identified of processed. In these cases, follow lab health and safety guidelines.
- Identify potential hazards before you start and become knowledgeable about their risks. In the field, this includes the weather as well as your surroundings. Be aware of hidden hazards such as wasp nests, stinging plants or animals, or territorial birds!

Honesty and ethical issues

- If you are sampling or collecting live organisms, you must consider the environmental impact of any sampling procedures, return live organisms to the same place if possible, respect the natural environment, and handle animals in a way that minimises stress or damage to them. Plan your study to minimise your impact on the natural environment.
- Report your true data and findings, even if they are not the results you were expecting. Changing results to fit your hypothesis is misleading and unethical.
- Acknowledge the intellectual property of others (e.g. photographs, data) and do not to copy directly from sources. Representing the work of others as your own is plagiarism.

Be meticulous in maintaining an accurate logbook, acknowledge all your sources, and reference cited works accurately. Act ethically and responsibly in all aspects of your research, including in the disposal of biological material.

3. Describe the potential ethical issues associated with each of the following investigative scenarios:

   (a) A vegetation survey in a sensitive ecological area: _____

   _____

   _____

   (b) A lab-based experimental investigation of salinity tolerance in shore crabs: _____

   _____

   _____

   (c) Deriving values in a set of experimental measurements by interpolation because you missed a day of recordings:

   _____

   _____

4. Describe two reasons why acknowledgement of sources and correct reference of cited works is important:

   (a) _____

   _____

   _____

   (b) _____

   _____

   _____

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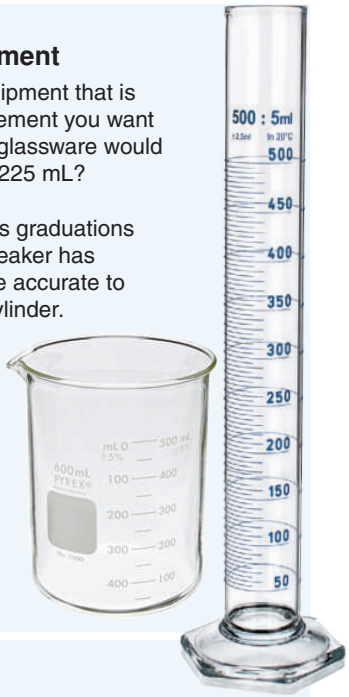
4 Generating, Collating and Recording Data

Key Idea: Research and investigation in science rely on data being collected and recorded systematically, collated carefully, and organised and presented clearly.
Doing your own investigations or researching a topic of interest involves collecting, collating, and recording information (data). Keeping accurate records and presenting data appropriately in tables, graphs, schematics, or flow charts will help you when it comes to communicating your findings to others.

Selecting the correct equipment

It is important that you choose equipment that is appropriate for the type of measurement you want to take. For example, which of the glassware would you use if you wanted to measure 225 mL?

The 500 mL graduated cylinder has graduations every 5 mL whereas the 500 mL beaker has graduations every 50 mL. It is more accurate to measure 225 mL in a graduated cylinder.



Different types of **graduated glassware** have different accuracies. A beaker is less accurate than a measuring cylinder and a measuring cylinder is less accurate than a pipette. Volumetric glassware is the most accurate.

Percentage errors

Percentage error is a way of mathematically expressing how far out your result is from the ideal result. The equation for measuring percentage error is:

$$\frac{\text{experimental value - ideal value}}{\text{ideal value}} \times 100$$

For example, to determine the accuracy of a 5 mL pipette, dispense 5 mL of water from the pipette and weigh the dispensed volume on a balance.
The mass (g) = volume (mL). The volume is 4.98 mL.

$$\frac{\text{experimental value (}\mathbf{4.98}\text{) - ideal value (}\mathbf{5.0}\text{)}}{\text{ideal value (}\mathbf{5.0}\text{)}} \times 100$$

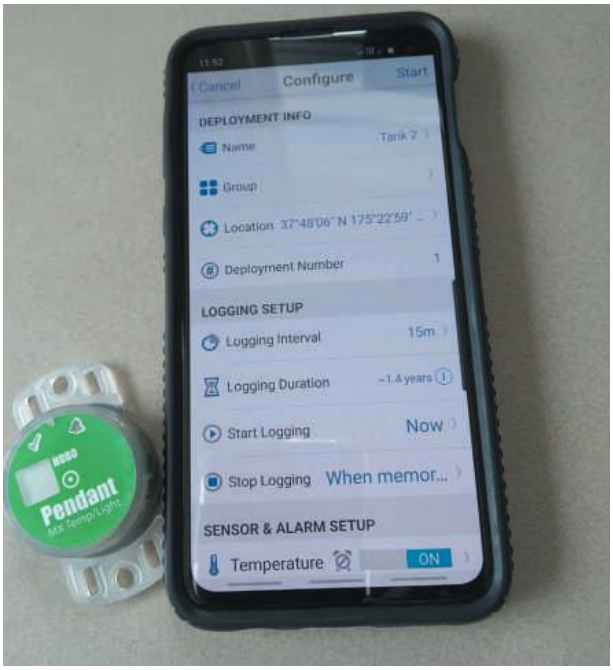
The percentage error = –0.4% (the negative sign tells you the pipette is dispensing **less** than it should).

Data loggers and field equipment

Equipment for collecting data in the field ranges from very general (quadrats and measuring tapes) to highly specific (electronic tags, pH and conductivity meters). Select the equipment that is appropriate to your investigation and know how to use it correctly (including calibration if required).

Data loggers are increasingly used both in the lab and in the field. A data logger is an electronic device that records data over time, either with built-in instrumentation or via a plug-in sensor. Most interface with a computer or phone so that the collected data can be viewed and analysed.

Data loggers enable data to be collected automatically. They are typically deployed and left unattended to measure and record data over the set period of monitoring. In the field, they can provide data on the physical environment alongside a study of biological populations. Many, such as the temperature logger pictured below, are simple to use, and the data can be easily accessed via a smartphone app.



Common lab instruments and equipment in biology and use	Common field equipment and use
Balance (triple beam or electronic): used to measure mass	**Anemometer**: used to measure wind speed
Colorimeters and spectrophotometers: used to measure absorbance o determine concentration of a substance.	**Calipers**: used to measure the dimensions of small objects (e.g. stones) or the diameter of tree trunks
Dissecting kit: used for sectioning plant material and dissecting	**Secchi disc**: used to measure water transparency or turbidity
Dissecting microscope: for examining live or macroscopic specimens	**Quadrat**: to quantify species abundance or cover in an area
Compound microscope: for examining mounted, microscopic specimens	**Nets** (sweep nets, hand nets): to collect aquatic organisms
Standard lab glassware, including flasks, test tubes, and pipettes	**Clinometer**: Used to measure the angle of a slope.
Water baths: maintain set temperature	**pH meter**: used to measure acidity/alkalinity
Thermometer: used to measure temperature	**Thermometer**: used to measure temperature

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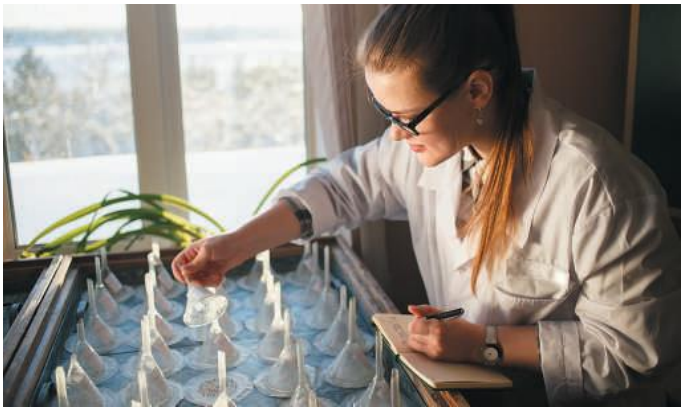
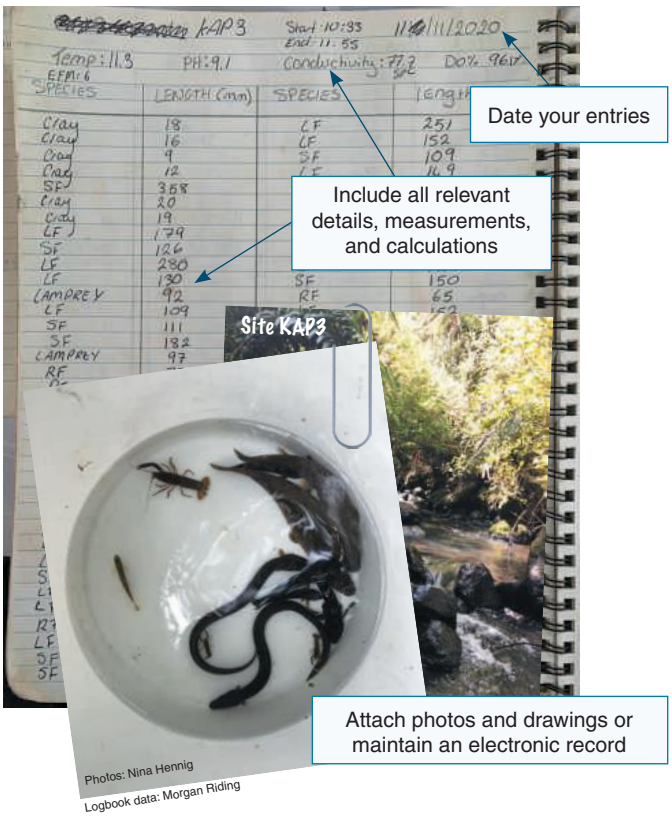
Keeping a log book

Keeping an accurate logbook is an essential part of investigative work. It provides a record of your methods and all results and can be used to used to verify the authenticity and originality of your work.

- Find a notebook to use that will suit your purposes (e.g. a waterproof logbook and pen are useful for fieldwork). A hardback A4 lined exercise book is a good choice. Anything smaller will make it difficult to include photos or extra pages later on.
- Name your logbook in a prominent location and number the pages so you can create a good table of contents. Creating sections in your logbook with tabs helps you keep track of ideas, methods, and results easily.
- Date and sign **every entry**. Entries should be concise, but contain enough information that you can understand them later on. Short notes and bullet points are often used. You must be able to read your entries at a later date, but don't worry too much about presentation. Logbooks have a purpose as an accurate, legible record of your work, not the final report.
- Your logbook should be used in all phases of your investigation, from planning to write up. Record ideas on methods or analysis, as well as results.
- Attach any loose paper or photos into your logbook so they are not displaced or lost.
- Include any mishaps, failed experiments, or changes in methodology in your logbook. Where possible, explain the reasons for the failure or change. Sometimes failed experiments can be just as valuable as successful experiments in understanding a result.
- Include all observations made during your investigation and any calculations and transformations of the data.
- Remember that recording your ideas, observations, and analyses **systematically** during your investigation will help when you come to organise the material for your write up. It will also help to clarify any parts of your study that your teacher may find confusing or incorrect, meaning you could still get credit for your work.





1. Assume that you have the following measuring devices available: 50 mL beaker, 50 mL graduated cylinder, 25 mL graduated cylinder, 10 mL pipette, 10 mL beaker. What would you use to accurately measure:

   (a) 21 mL: _____ (b) 48 mL: _____ (c) 9 mL: _____

2. Calculate the percentage error for the following situations (show your working):

   (a) A 1 mL pipette delivers a measured volume of 0.98 mL: _____

   (b) A 10 mL pipette delivers a measured volume of 9.98 mL: _____

   (c) The pipettes used in (a) and (b) above both under-delivered 0.02 mL, yet the percentage errors are quite different. Use this data to describe the effect of volume on percentage error:

   _____

   _____

3. Why is it important to keep a detailed logbook during a scientific investigation? _____

   _____

   _____

   _____

   _____

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Tally charts and tables

- If collating some types of data from a logbook, such as data for organisms measured in the field (as pictured on the previous page), it can be useful to create a **tally chart**, grouping the measurements into classes and recording the number in each class. This is a useful way to organise the data and get an early idea of any trends or patterns.
- **Tables** provide a way to systematically record and condense a large amount of information. They provide an accurate record of numerical data and allow you to organise and summarise your data.
- Table titles and row and column headings must be clear and accurate. In a **fair test**, where only one variable is manipulated, the independent variable is recorded in the left column, with control values at the top and rows for each treatment. Calculations such as rates and summary statistics (such as mean or standard deviation) may be included on a table.
- Summary statistics make it easier to identify trends and compare different treatments. Rates are useful in making multiple data sets comparable, e.g. if recordings were made over different time periods.

Table 1: Tally chart of size classes of yabbys from stream site A

Size class (cm)	Tally	Number
0 – 4.9	𝍸	3
5.0 – 9.9	𝍸	5
10.0 – 14.9	𝍸 𝍸	9
15.0 – 19.9	𝍸	7
20.0 – 24.9	𝍸	2

Table 2: Mass (g) of radish plant roots under six different fertiliser concentrations (data given to 1dp).

Fertiliser concn (g/L)	Mass of radish root (g) †						
	Sample (*n*)					Total mass	Mean mass
	1	2	3	4	5		
0	80.1	83.2	82.0	79.1	84.1	408.5	81.7
0.06	109.2	110.3	108.2	107.9	110.7	546.3	109.3
0.12	117.9	118.9	118.3	119.1	117.2	591.4	118.3
0.18	128.3	127.3	127.7	126.8	DNG*	510.1	127.5
0.24	23.6	140.3	139.6	137.9	141.1	558.9**	139.7
0.30	122.3	121.1	122.6	121.3	123.1	610.4	122.1

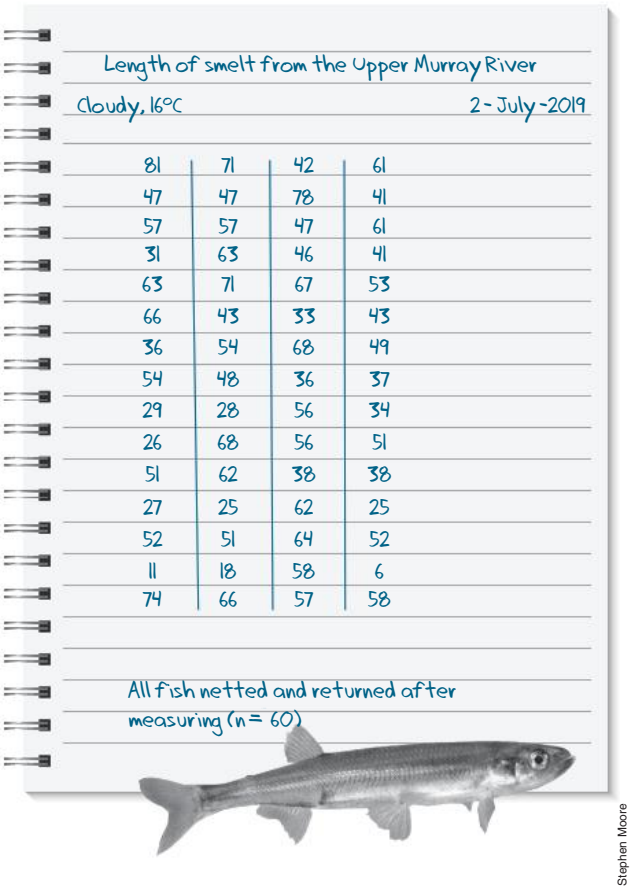
*DNG = Did not germinate
** Calculation excludes sample #1

† Based on data from M S Jilani, *et al* Journal Agricultural Research

4. Using evidence from Table 2 above, explain the value in having a sample size (n) of more than 1 at each treatment:

5. A page from a student logbook is presented right. Using the data presented, create a tally chart size classes of 10 mm:

Size class (mm)	Tally	Total



Stephen Moore

6. What sort of plot is suggested by the tally chart as appropriate for this data set? Explain your answer:

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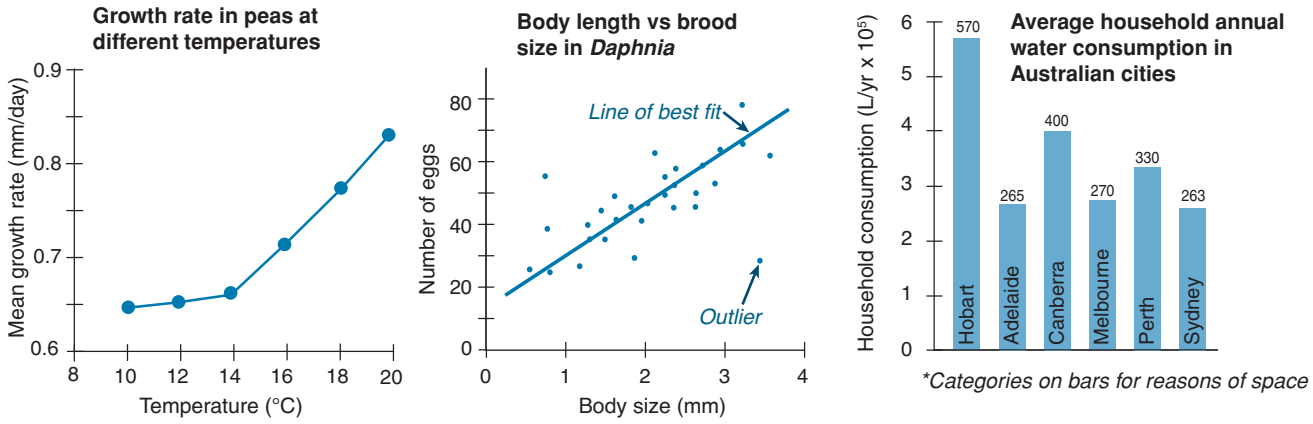
Presenting data in graphs

- Graphs are a good way to show trends, patterns, and relationships visually without taking up too much space. Complex data sets tend to be presented as graphs rather than tables, although the raw data can sometimes be tabulated as an appendix.
- Presenting graphs properly requires attention to a few basic details, including correct orientation and labelling of the axes, accurate plotting of points, and a descriptive, accurate title.
- Before representing data graphically, it is important to identify the kind of data you have. Common graphs include scatter plots and line graphs (for continuous data), and bar charts (for categorical data). For continuous data with calculated means, points can be connected. On scatter plots, a line of best fit is often drawn. If fitting by eye, 50% of the points should fall above the line and 50% below. A lne of best fit is also easily fitted using a spreadsheet program such as Microsoft Excel.



Guidelines for line graphs

- **Line graphs** are used when one variable (the independent variable or treatment) affects another, the dependent variable (the response variable).
- The data must be continuous for both variables. The relationship between two variables can be represented as a continuum and the plotted data points are connected directly (point to point).
- A double axis allows two independent variables with different measurement scales to be plotted on the same graph.

Guidelines for scatter graphs

- A **scatter graph** is used to plot continuous data where there the two variables are interdependent.
- There is no independent (manipulated) variable, but the variables are often correlated, i.e. they vary together in a predictable way.
- The points on the graph are not connected, but a line of best fit (fitted by eye or by computer) is often drawn through the points to show the relationship between the variables.

Guidelines for bar/column graphs

- **Column graphs** (above) are appropriate for data that are non-numerical and categorical for one variable. Data is discontinuous so the bars do not touch.
- Multiple data sets can be displayed side by side for comparison using a key (e.g. males and females).
- A **histogram** is superficially similar to a column graph but is used when one variable is continuous and the other is a frequency (counts). These plots produce a frequency distribution.

7. Use the tally chart to plot the smelt data as a frequency histogram on the grid right. The continuous variable occupies the X axis and the counts are entered on the Y axis.

8. What sort of information is provided by a frequency histogram?

_____

_____

_____

9. (a) What sort of graph would you choose to display the data in Table 2 (opposite). Explain your choice:

_____

_____

(b) The total mass calculated for fertiliser concentration 0.24 g/L excludes sample #1 and the mean is calculated from 4 values. Explain why:

_____

_____

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5 Analysing and Evaluating Data

Key Idea: A ability to use mathematics to analyse and describe your data is important to drawing valid conclusions. The analysis and evaluation of data generated through investigation usually involves the application of mathematical routines. Appropriate data transformations and use of descriptive statistics will help you draw valid conclusions.

Conversion factors and expressing units

Measurements can be converted from one set of units to another by the use of a **conversion factor**.

A conversion factor is a numerical factor that multiplies or divides one unit to convert it into another. Conversion factors are commonly used to convert non-SI units to SI units (e.g. converting pounds to kilograms). Note that mL and cm^3 are equivalent, as are L and dm^3.

1. Convert 5.6 cm^3 to mm^3 (1 cm^3 = 1000 mm^3):

_____

The value of a variable must be written with its units where possible. SI units or their derivations should be used in recording measurements: volume in cm^3, dm^3, or litre (L), mass in kilograms (kg) or grams (g), length in metres (m), time in seconds (s). For example the rate of oxygen consumption would be expressed as $cm^3g^{-1}s^{-1}$ using inverse notation or $cm^3/g/s$ using a solidus.

Estimates

When performing mathematical calculations, typing the wrong number into your calculator can put your answer out by several orders of magnitude. An **estimate** is a way of roughly calculating what answer you should get, and helps you decide if your final calculation is correct.

Numbers are often rounded to help make estimation easier. The rounding rule is, if the next digit is 5 or more, round up. If the next digit is 4 or less, it stays as it is.

For example, to estimate 6.8 x 704 you would round the numbers to 7 x 700 = 4900. The actual answer is 4787, so the estimate tells us the answer (4787) is probably right.

Use the following examples to practice estimating:

2. 43.2 x 1044: _____

3. 658 ÷ 22: _____

Probability

Probability is how likely something is to happen. It is an important part of biology. Its uses include calculating the statistical significance of a difference between means or the probability of an event occurring. The probability of an event ranges from 0 to 1. The sum of all probabilities = 1.

Product rule: for independent events A and B the probability (P) of A and B occurring is P(A) x P(B). For example, the probability two children born one after the other both being male is 0.5 x 0.5 = 0.25.

Sum rule: For mutually exclusive events Y and Z the probability that one will occur (Y or Z) is P(Y) + P(Z). E.g. in an Aa x Aa cross the probability a person will have a dominant phenotype = 0.25 + 0.5 = 0.75.

Rates

Rates are expressed as a measure per unit of time and show how a variable changes over time. Rates are used to provide meaningful comparisons of data that may have been recorded over different time periods.

Often rates are expressed as a mean rate over the duration of the measurement period, but it can be useful to calculate the rate at various times to understand how rate changes over time. The table below shows the reaction rates for gas production during a chemical reaction. A worked example for the rate at 4 minutes is provided below the table.

Time (minute)	Cumulative gas produced (cm^3)	Rate of reaction (cm^3 / min)
0	0	0
2	34	17
4	42	4*
6	48	3
8	50	1
10	50	0

* Gas produced between 2 - 4 min: 42 cm^3 – 34 cm^3 = 8 cm^3
Rate of reaction between 2 - 4 min: 8 ÷ 2 min = 4 cm^3 /min

4. Complete the table to calculate the rate of plant water loss.

Time (min)	Pipette reading (cm^3)	Water loss (cm^3/min)
0	9.0	–
5	8.0	0.2
10	7.2	
15	6.2	
20	4.9	

Fractions

Fractions express how many parts of a whole are present. They are expressed as two numbers separated by a solidus (/) (e.g. 1/2). The top number is the numerator. The bottom number is the denominator, which cannot be zero. Fractions are written in their simplest form, while still being whole numbers. The simplification makes them easier to work with.

In a class of 10 students, two had blonde hair. This fraction is 2/10. To simplify this fraction, divide the numerator and denominator by a common factor (a number which both are divisible by). In this instance the lowest common factor is 2 (1/5). To add fractions with different denominators, obtain a common denominator, add numerators, then simplify.

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Ratios

- Ratios give the relative amount of two or more quantities, and provide an easy way to identify patterns.
- Ratios do not require units.
- Ratios are expressed as **a : b**.
- Ratios are calculated by dividing all the values by the smallest number.

882 inflated

299 constricted

Pea pod shape: Ratio = 2.95 : 1

495 round yellow

152 wrinkled yellow

158 round green

55 wrinkled green

Pea seed shape and colour: Ratio = 9 : 2.8 : 2.9 : 1

Percentages

- To calculate percentage, simply calculate the fraction of the total x 100. For example 2/5 = 0.4 x 100 = 40%
- Percentages will show what fraction (out of 100) falls into any particular category, e.g. for pie graphs.
- Percentages can be used to express concentrations and to allow meaningful comparison between samples with different starting points, e.g. different numbers or masses.

Volume of food colouring (cm^3)	Volume of water (cm^3)	Concentration of colouring (%)
10	0	100
8	2	80
6	4	60
4	6	40
2	8	20
0	10	0

Percentage change

Percentage change shows how much a value has changed (e.g. between time t and time t + 1). Calculating percentage change is easy. Determine the difference between the old and new values, divide by the old value, and multiply by 100.

$$\% \text{ change} = \frac{\text{new value} - \text{old value}}{\text{old value}} \times 100$$

- A positive value = percentage increase. A negative value = percentage decrease.
- Percentage change is useful in studies of natural populations and when analysing mass changes in experiments.

Example: There were 116 mice in a local population, but after a successful breeding season, the number was 160. What was the percentage change?

160 – 116 ÷ 160 = 0.275
0.275 x 100 = 27.5% increase.

5. (a) A student prepared a slide of the cells of an onion root tip and counted the cells at various stages in the cell cycle. The results are presented in the table (right). Calculate the ratio of cells in each stage (show your working):

_____

_____

(b) Assuming the same ratio applies in all the slides examined in the class, calculate the number of cells in each phase for a cell total count of 4800.

Cell cycle stage	No. of cells counted	No. of cells calculated
Interphase	140	
Prophase	70	
Telophase	15	
Metaphase	10	
Anaphase	5	
Total	240	4800

6. Simplify the following fractions:

(a) 3/9: _____ (b) 84/90: _____ (c) 11/121: _____

7. (a) The table on the right shows the nutritional label found on a can of chilli beans. Use the information provided to complete the table by calculating the percentage composition for each of the nutritional groups listed:

(b) How much of the total carbohydrates is made up of:

Dietary fibre? _____

Sugars? _____

(c) Manufacturers do not have to state the volume of water, which makes up the remainder of the serving size. What percentage of the can of beans is water?

_____

Chilli Beans Nutrition Facts Serving size 1 cup (253 g)		
Amount per serving		% Composition
Total Fat	8 g	
– Saturated Fat	3 g	
Total Carbohydrate	22 g	
– Dietary Fibre	9 g	
– Sugars	4 g	
Protein	25 g	

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8. Complete the table right by calculating the percentage of both clover types in two areas.

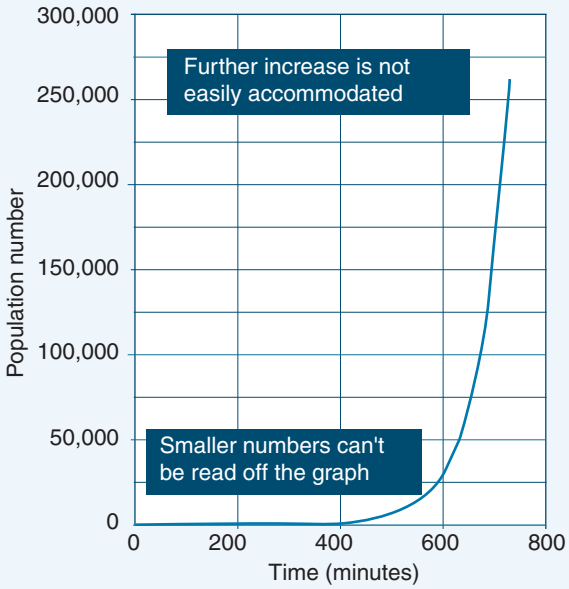
Clover plant type	Frost free area		Frost prone area		Totals
	Number	%	Number	%	
Cyanogenic	124	78	26		
Acyanogenic	35		115		
Total	159				

Interpreting plots with large numbers

- Biological science often deals with very large numbers or scales. Numerical data indicating scale can often increase or decrease exponentially. Large scale changes in numerical data can be made more manageable by using log transformations.
- The plots below compare the same data plotted on a linear and a log-linear scale so that you can recognise these when you come across them. You may see these representations in plots of bacterial growth.

Exponential function

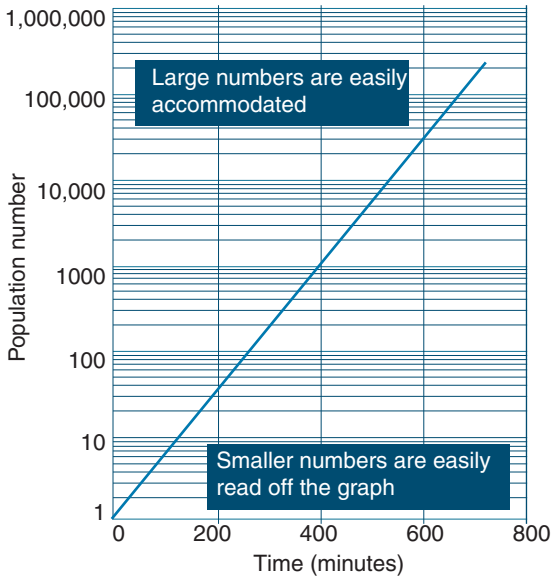
- Exponential growth occurs at an increasingly rapid rate in proportion to the growing total number or size.
- In an exponential function, the base number is fixed (constant) and the exponent is variable.
- The equation for an exponential function is $y = c^x$.
- Exponential growth and decay (reduction) are possible.
- Exponential changes in numbers are easy to identify because the curve has a J-shape appearance due to its increasing steepness over time.
- An example of exponential growth is the growth of a microbial population in an unlimiting, optimal growth environment.



Example: Cell growth in a yeast culture where growth is not limited by lack of nutrients or build up of toxins.

Log transformations

- A log transformation makes very large numbers easier to work with. The log of a number is the exponent to which a fixed value (the base) is raised to get that number. So $\log_{10}(1000) = 3$ because $10^3 = 1000$.
- Both $\log_{10}$ (common logs) and $\log_e$ (natural logs or *ln*) are commonly used.
- Log transformations are useful for plotting data that show an exponential increase or decrease. The log transformation of the data will produce a straight line plot.
- In biology, it is common to plot untransformed data directly on a log-linear scale (below). This means you don't have to worry about doing the transformations yourself. This is not difficult. You just need to remember that the log axis runs in exponential cycles. The paper makes the log for you.



Example: The same yeast cell growth plotted on a log-linear scale. The y axis present 6 exponential cycles

9. Why is it useful to plot exponential growth using semi-log paper? _____

_____

_____

10. What would you do to show yeast exponential growth (left plot above) as a straight line plot on normal graph paper?

_____

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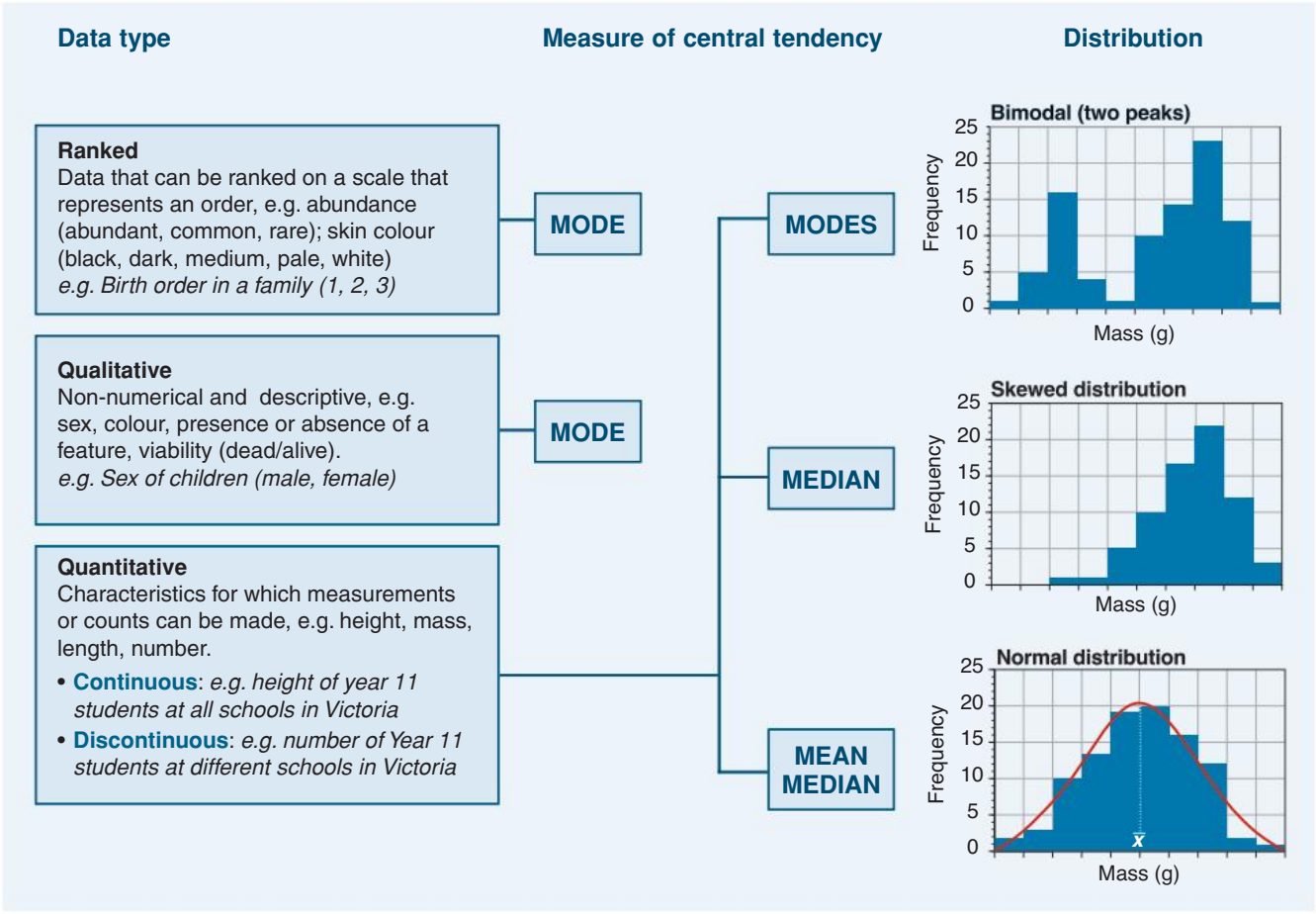
Describing quantitative data using descriptive statistics

- Descriptive statistics, such as mean and standard deviation, are used to summarise a set of data values and its features. These values can be calculated for an entire population, e.g. mean condition score of koalas in VIC, or from a sample, e.g. mean condition score of koalas on Phillip Island. When we talk about descriptive statistics, we are usually talking about a sample of the entire population. In experimental studies, the mean is often used to "average out" the different values obtained for samples undergoing the same treatment (e.g. the mean of 5 samples of enzyme reaction rate at pH 7).
- When we describe a set of data, it is usual to give a measure of **central tendency**. This is a single value (a mean, a median, or a modal value) identifying the central position within that set of data. The type of statistic calculated depends on the type of data (quantitative, qualitative) and its distribution (normal, skewed, bimodal).
- The sample mean ($\bar{x}$) is calculated by summing all the data values (x) and dividing them by the total number of data points (n). **Outliers** (very extreme values) are usually excluded from calculations of the mean. For very skewed data sets, it is better to use the median (the middle value) as a measure of central tendency. Qualitative data are described using mode (the most common value or values).



11. In a class of 20 students, the individual heights of the students in cm are: 135, 139, 141, 146, 147, 149, 156, 151, 158, 155, 156, 159, 161, 167, 162, 163, 161, 172, 171, 170.

(a) Calculate the mean height of the students: _____

(b) A person takes a sample of five of the students: 139, 151, 162, 172, 170. Calculate the mean of the sample and comment on its accuracy:

_____

_____

(c) A second person takes a sample of ten of the students: 135, 146, 147, 156, 155, 156, 161, 167, 162, 170. Calculate the mean of the sample and comment on its accuracy:

_____

_____

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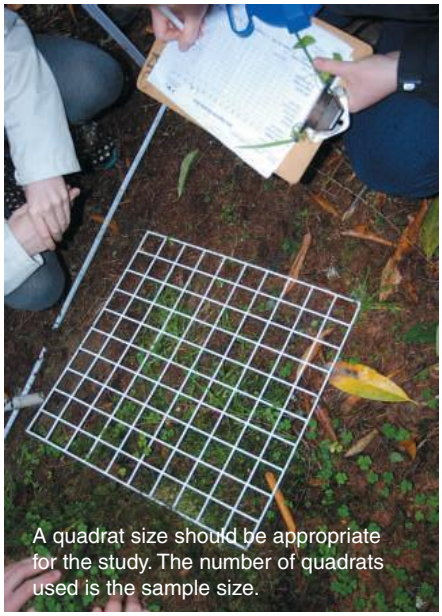
Accuracy, precision, reliability, and validity

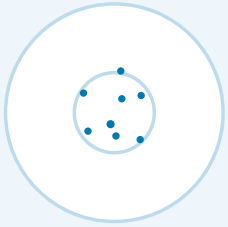
- How do we describe the confidence we have in the primary data we collect? If the data are accurate and reliable, we can be more confident that the conclusions we draw based on the data are valid.
- In its broadest sense, **validity** is a measure of how well your investigation measures what it sets out to measure. Validity is increased by controlling more variables, improving measurement technique, reducing sampling bias, increasing sample size, and replication (repeating the entire experiment at the same time).
- **Accuracy** refers to how close a measured or derived value is to its true value. **Precision** refers to how close repeated measurements are to each other, i.e. **repeatability**. A balance with a fault in it could give very precise (repeatable) but inaccurate (untrue) results. This is an example of a systematic error.
- **Systematic errors** are consistent, repeatable errors associated with faulty equipment or a flawed experiment design. They differ from **random errors** caused by unknown or unpredictable changes in the experimental conditions.
- For student investigations, increasing sample size and minimising systematic errors are easy ways to improve validity. In field studies, choosing an appropriate size of sampling unit (e.g. quadrat) is also important in collecting sufficient, unbiased data.



A quadrat size should be appropriate for the study. The number of quadrats used is the sample size.

sagt, Flickr

Accurate but imprecise



The measurements are all close to the true value but quite spread apart.
Analogy: The arrows are all close to the bullseye.

Inaccurate and imprecise

The measurements are all far apart and not close to the true value.
Analogy: The arrows are spread around the target.

Precise but inaccurate

The measurements are all clustered close together but not close to the true value.
Analogy: The arrows are close together but not near the bullseye.

Accurate and precise

The measurements are all close together and also very close to the true value.
Analogy: The arrows are clustered close together near the bullseye.

Increasing precision

The accuracy of a measurement refers to how close the measured value is to the true value. The **precision** of a measurement relates to its **repeatability** and is synonymous with reliability. In most laboratory work, we usually assume a piece of equipment (e.g. a pipette) performs accurately, so making precise measures is the most important consideration.

Increasing accuracy

Population studies present us with an additional problem. When a researcher makes measurements of some variable (e.g. fish length), they are usually trying to obtain an estimate of the true value for a parameter of interest (e.g. the mean size of fish). Populations are variable, so we can more accurately estimate a population parameter if we take a large number of random samples from the population.

A digital device such as the pH meter will deliver precise measurements, but its accuracy will depend on correct calibration. The precision of measurements taken with instruments such as calipers will depend on the skill of the operator. Precise measurements provide reliable data.

12. A researcher is trying to determine the temperature at which an enzyme becomes denatured. Their temperature probe is incorrectly calibrated. Discuss how this might affect the accuracy and precision of the data collected:

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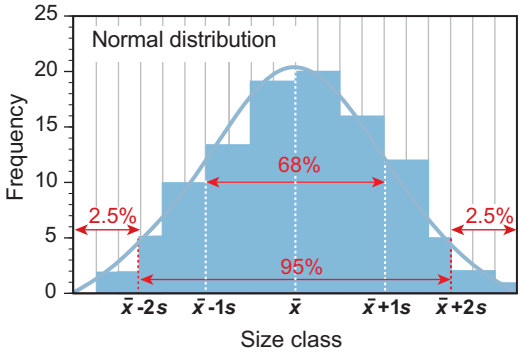
Expressing confidence in your data

- When we take measurements (e.g. fish length) from samples of a larger population, we are using the samples as indicators of what the whole population looks like. Therefore, when we calculate a sample mean for a variable, it is useful to know how close that value is to the true population mean for that same variable. If you are confident that your data set fairly represents the entire population, you are justified in making inferences about the population from your sample.
- You can start by calculating a simple measure of dispersion called standard deviation. Standard deviation is a measure of the amount of variation in a set of values. Are the individual data values all close to the mean, or are the data values highly variable? Standard deviation provides a way to evaluate the confidence of your conclusions about your data.

Standard deviation

- Sample standard deviation (s) is presented as $\bar{x} \pm s$.
- In normally distributed data, 68% of all data values will lie within one standard deviation (1s) of the mean. 95% of all values will lie within two standard deviations (2s) of the mean (see the distribution plotted right).
- The lower the standard deviation, the more closely the data values cluster around the mean.
- The formula for calculating standard deviation is shown in the green box (below).



Calculating standard deviation

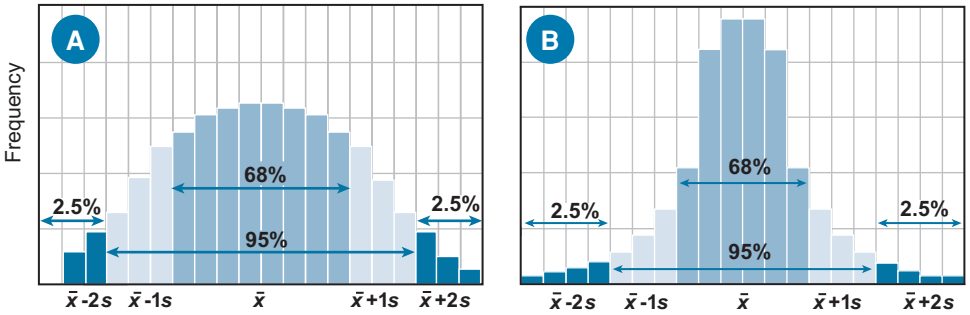
$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

$\sum(x - \bar{x})^2$ = sum of squared deviations from the mean

n = sample size.

$n - 1$ provides a unbiased s for small sample sizes (large samples can use n).

Both of the histograms below show a normal distribution of data with the values spread symmetrically about the mean. However, their standard deviations are different. In histogram A, the data values are widely spread around the mean. In histogram B, most of the data values are close to the mean. Sample B has a smaller standard deviation than sample A.



13. Two sample data sets of rat body length have the same mean. The first data set has a much larger standard deviation than the second data set. What does this tell you about the spread of data around the mean in each case? Which data set is likely to provide the most reliable estimate of body length in the rat population being sampled and why?

14. The data on the right shows the heights for 29 male swimmers.

    (a) Calculate the mean for the data: _____

    (b) Use manual calculation, a calculator, or a spreadsheet to calculate the standard deviation (s) for the data:

    (c) State the mean ± 1s: _____

    (d) What percentage of values are within 1s of the mean? _____

    (e) What does this tell you about the spread of the data? _____

Raw data: Height (cm)

178	177	188	176	186	175
180	181	178	178	176	175
180	185	185	175	189	174
178	186	176	185	177	176
176	188	180	186	177	

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95% confidence intervals

- So how can you tell if your sample is giving a fair representation of the entire population? We can do this using the **95% confidence interval**. This statistic allows you to make a claim about the **reliability** your sample data. The mean ± the 95% confidence interval (95% CI) gives the **95% confidence limits** (95% CL). This tells us that, on average, 95 times out of 100, the true population mean will lie within the confidence limits. Having a large sample size greatly increases the reliability of your data.
- You can plot the 95% CL on to graphs to determine if observed differences between sets of sample data (e.g. between field plots or treatments) are statistically significant. If the 95% CL do not overlap it is likely that the differences between the sample sets is significant. The 95% CI is very easy to calculate (below). You can also use the spreadsheet on **BIOZONE's Resource Hub**.

Step 1 is to calculate the standard error of the mean (SE). It is simple to calculate and is usually a small value.

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

Step 2 is to calculate the 95% confidence interval (95% CI). It is calculated by multiplying SE by the value of t at P = 0.05 for the appropriate degrees of freedom (df) for your sample.

$$95\%\ CI = SE \times t_{(P=0.05)}$$

An experiment was carried out to see how different types of feed affected the growth of newly weaned rats. Rats were placed into four different groups and each group was fed a different type of feed. There were 10 rats in each group. They were weighed after a further 28 days of growth. The results are shown right.

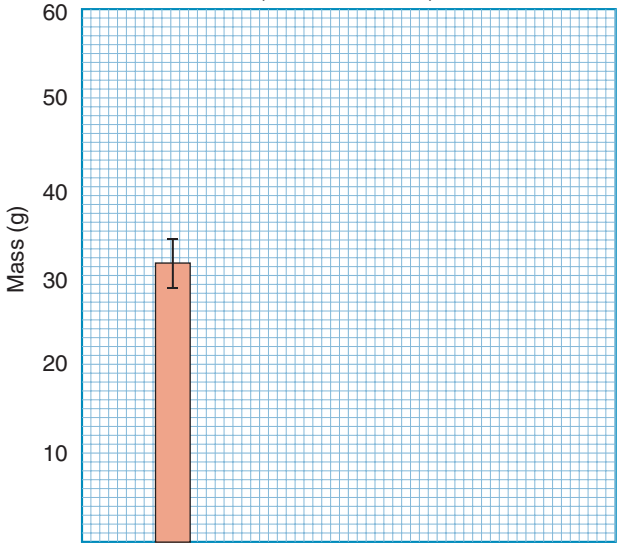
Individual	Mass (g) of rats after 28 days on four feeds			
	Feed type			
	Feed 1	Feed 2	Feed 3	Feed 4
1	28.0	28.5	25.6	48.6
2	36.0	31.2	28.6	51.2
3	36.2	30.9	27.1	55.3
4	28.5	35.0	33.0	42.7
5	27.9	27.2	40.0	40.5
6	32.6	26.9	25.9	49.8
7	35.0	34.0	32.9	47.9
8	27.2	29.0	33.1	50.8
9	26.9	34.8	33.6	39.9
10	35.0	23.9	35.0	47.0
Sum (∑)				
Mean ($\bar{x}$)				
Std dev. (*s*)				
Std error (SE)				
95% CI				

15. Complete the table by calculating the sum (∑), mean ($\bar{x}$), standard deviation (*s*), standard error (SE), and 95% confidence interval (95% CI) for each group. You can do this using a calculator or a spreadsheet. The t value at P=0.05 for 9 df = 2.262

16. (a) Plot a column graph of the mean mass of the rats in each group. Add the 95% CL bars ($\bar{x}$ ± 95% CI) to your graph. To do this, add the 95% CI value to the mean to get the upper value and subtract it to get the lower value. Feed 1 is completed for you.

    (b) Is there any significant difference between the groups? Explain your answer:

Mass of rats after 28 days on 4 different feeds (mean ± 95% CL)



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6 Constructing Arguments & Drawing Conclusions

Key Idea: Argumentation in science is about evidence-based justification of explanations (claims). It involves use of empirical evidence and logical reasoning.

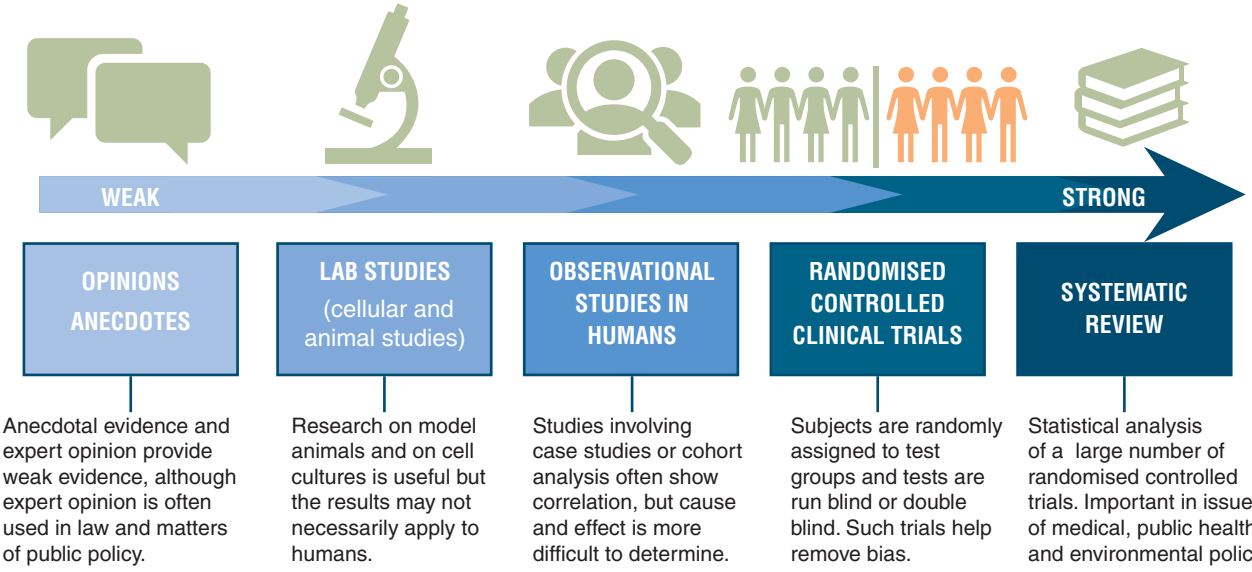
An important part of your studies in biology is developing skills in argumentation. This means using evidence-based reasoning to support a claim or explanation that you make with respect to your own investigations or second hand data collected by others.

Opinion, anecdote, and scientific evidence

As well as collecting primary data from your own investigations, much of your study of biology will involve collating and interpreting the results of others (secondary data) or evaluating the claims they have made based on their findings.

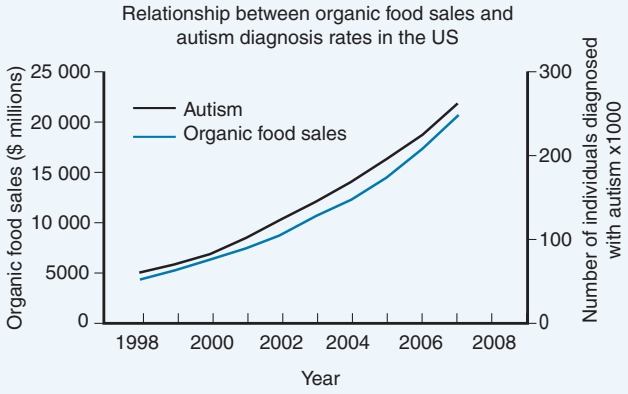
The validity of scientific claims depends on the evidence used to support the claim. The schematic below shows a hierarchy of evidence as might apply to developing a new pharmaceutical drug. Although this applies to a particular case, the concepts are applicable across all science. Keep this in mind when you come to respond to a bioethical issue at the end of your course.

ANECDOTAL EVIDENCE	SCIENTIFIC EVIDENCE
Uncontrolled, therefore very susceptible to bias	Controlled for subject and experimenter bias
Very small sample size	Large sample sizes
Only exceptional cases reported	Everything is reported
Vague outcomes	Defined outcomes
Claim from memory	Claim from data



Correlation does not imply causation

- You may come across the phrase "correlation does not necessarily imply causation". This means that even when there is a strong correlation between variables (they vary together in a predictable way), you cannot assume that change in one variable caused change in the other. We might assume that A causes B, but B might cause A, or the correlation between A and B might be caused by another variable C.
- Example: When data from the Organic Food Association and the Office of Special Education Programmes is plotted over 10 years, there is a strong correlation between the increase in organic food sals and rates of diagnosed autism. However, there is no evidence of a causative effect here.



1. (a) Explain why it is important not to imply causation just because there is a correlation between two variables:

(b) Suggest how you could determine if a relationship between two variables involved cause and effect?

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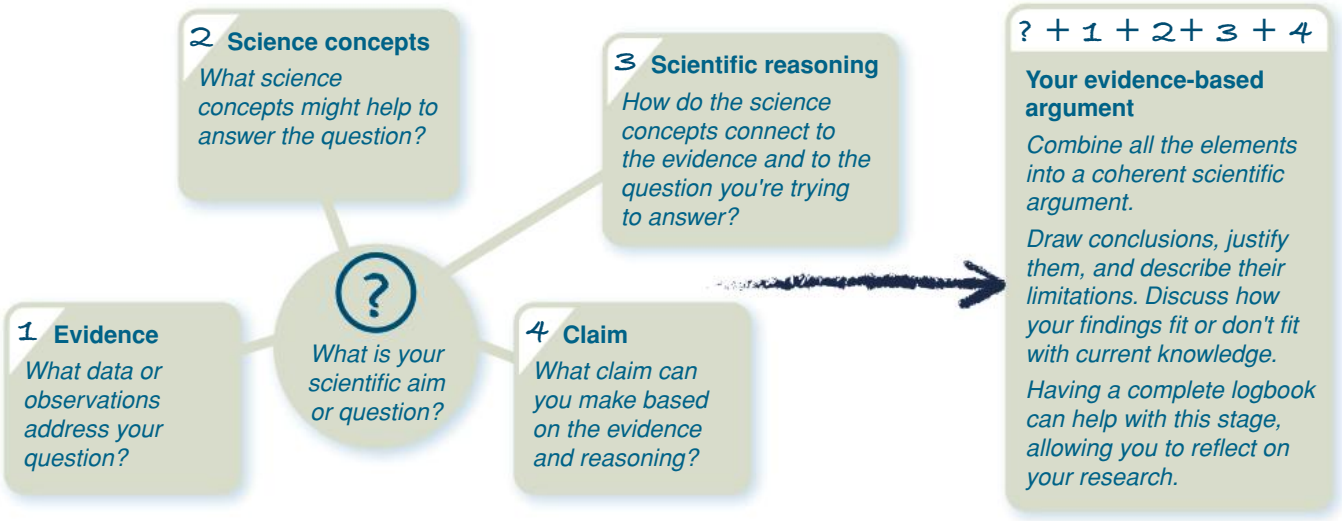
Constructing an evidence-based argument

Once you have planned your investigation, collected and analysed your data, and justified your methodology, you will be ready to make an evidence-based argument. To do this, you need to determine the degree to which the evidence (the data you have collected or collated) supports the aim of your investigation (the question you asked). The evidence might raise further questions, or support an alternative explanation (hypothesis). This doesn't mean your investigation was a failure. Sometimes unexpected findings are the most exciting!

You can use the graphic organiser below to help in constructing a scientific argument. A scientific argument makes a claim based on evidence (data, statistical analysis, anecdotal evidence, expert opinion), and justified by logical reasoning. Bear in mind, the more you rely on opinion and anecdote, the weaker your argument will be. Any evidence-based argument should address the reliability of the data and the limitations of the study. Acknowledging strengths as well as weaknesses is important to planning future research.

If you have been careful about the design of your experiment and collection of data, you can then draw and justify conclusions that are consistent with the evidence. Argumentation is not the same as arguing! It is about presenting a case with evidence to support it.



2. Suggest why opinion and anecdote are weak forms of evidence for constructing an evidence-based argument

3. The table (below) outlines some common problems students encounter when presenting a scientific argument. For each of the examples below, describe how the problem could result in a weak or flawed argument

(a) Scientific misconceptions: _____

(b) Discounting evidence that does not support your claim:

Some problematic patterns in scientific argumentation…	
Value judgments (normative reasoning)	Making an argument based on social norms
Fallacious reasoning	Not distinguishing between opinion and scientific evidence
	Fusion of scientific facts and personal beliefs
	Scientific misconceptions
Claims unsupported by data	Can be the result of extrapolation
Disregarding evidence contrary to the claim	Lack of critical thinking and dishonesty
Check during your work that you don't fall into these traps!	

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7 Evaluating & Communicating Scientific Ideas

Key Idea: The analysis, evaluation, and communication of scientific information are skills requiring an understanding of the science and a critical approach to the claims made.

Some of your studies in biology involve you gathering, analysing, and evaluating primary data, and then communicating your findings to others. However, you will also need to critically evaluate and interpret a range of published material, both in scientific publications and in popular media. To analyse and evaluate the science you read about or see online you must think critically and have a good understanding of the concepts, theories, and models involved. When communicating scientific ideas to others you must be able to express them clearly and concisely in a way that is appropriate to your audience.

Analysis and evaluation of scientific ideas

A text analysis and critique may involve:

- Describing the article:
  - Stating the main points in article.
  - Describing the author's perspectives and assumptions.
  - Identifying any claims made by the author and any evidence presented to justify them.
- Evaluating the article:
  - Identifying and describing any bias in the article. How might this have affected the article's accuracy?
  - Describing the article's conclusions or claims.
  - Describing the limitations of an investigative article.

What can be trusted?

- Biological science covers some contentious or emotive topics. Many new ideas about biology may not be compatible with traditional views or people's own personal belief systems. As a result, people may have certain views they feel invested in. This leads to people putting forth information to support their own view, lobbying to a certain extent.
- When reading biological information, especially on the internet, it is important that you take note of where the information comes from and whether it makes sense in a wider context. This will help you identify biased or flawed information.
- Note the site from which you obtained information. Is it reputable or just someone's blog with their own unverifiable ideas? Be cautious with video clips, which can present an unsubstantiated personal view. Comments may identify errors.

Evaluating scientific information

- In order to communicate scientific ideas, you must be able to critically evaluate the information. Points to consider include:
- Validity of the information.
  - The currency of the information. Is it up to date?
  - Is the information peer reviewed? Has it been accepted by the scientific community?
- Does the information present an unbiased view?
  - Is information presented in a fair, unbiased way? Is it based on fact and not emotion?
  - Is the information presented clouded by the attitudes, beliefs, or values of the person, group, or organisation supplying the information?
- Scientific journals are peer-reviewed, meaning the information is checked by experts in the area before publication. This makes the information much more reliable. However, journals can be very technical, requiring a high level of in-area expertise to understand.
- Newspaper articles are a good starting point as a source of generally reliable information, but beware of the newspaper's particular leaning. Tabloids often sensationalise stories, while some newspapers may have left or right political leanings, which can skew the focus of a story.
- Online sites that are specific for a topic need to be carefully scrutinised for validity. Avoid conspiracy sites as these misreport the science. Government sites usually have current and reliable data based on information from skilled advisers.

- Periodicals or technical magazines, e.g. National Geographic, Scientific American, or New Scientist, are useful sources of reliable information. As they are written for the general public they make understanding the technical information easier.

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Communicating scientific ideas

The purpose of your research, the type of data involved, and your target audience will all play a part in determining the best method by which you can effectively communicate your findings or your response to an issue. A presentation of qualitative data to an audience with no science background will probably be very different to a report on a controlled experiment to your teacher. You can start by planning the structure of your report by using bullet points and build your presentation from there. Some things to consider are illustrated by the cartoon right.
Common presentation formats include:

- Formal written report
- Practical report
- Scientific poster
- Slideshow (e.g. Powerpoint)
- Multimedia presentation
- Oral presentation
- Video
- Visual representation, e.g. model

Tips for presenting to a non-scientific audience

- ☑ Get to the point quickly.
- ☑ Use your data to tell a story.
- ☑ Don't overload the audience with information.
- ☑ Use conversational wording.
- ☑ Use analogies to help understanding.
- ☑ Acknowledge all sources of information.

Tips for a written report to a scientific audience

- ☑ Clearly state your aim and hypothesis.
- ☑ Keep your methodology clear and brief.
- ☑ Report your results and present data clearly.
- ☑ Keep a discussion of results to the discussion section.
- ☑ Clearly state your conclusions.
- ☑ Acknowledge all sources of information.

1. Explain why it is important to tailor your communication to your target audience:

_____

_____

_____

2. Briefly describe the communication problems that could arise with each of the following scenarios:

(a) An overlong Powerpoint presentation to a Year 10 biology class: _____

_____

(b) Submitting a written report of a field study with in-text citations but no reference section: _____

_____

(c) Including all the raw data in a report without any processing: _____

_____

(d) Making a presentation on a bioethical issue on the basis on one person's blog: _____

_____

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8 Chapter Review: Did You Get It?

1. (a) A balance used throughout the course of an experiment has a calibration error of +0.04 g. A student weighs out 11.71 g of sodium hydroxide. Calculate the percentage error (show your working):

_____

(b) What sort of error is represented by this? _____

2. Determine what type of graph is appropriate for each of the following examples:

(a) Arm span vs height in humans: _____

(b) Daily energy requirement for different species of deer: _____

(c) Number of fish of each size in a population: _____

(d) Volume of water used per person per day in different North American cites: _____

(e) Mean catalase reaction rate at different temperatures: _____

(f) Number of eggs per brood in different breeds of chickens: _____

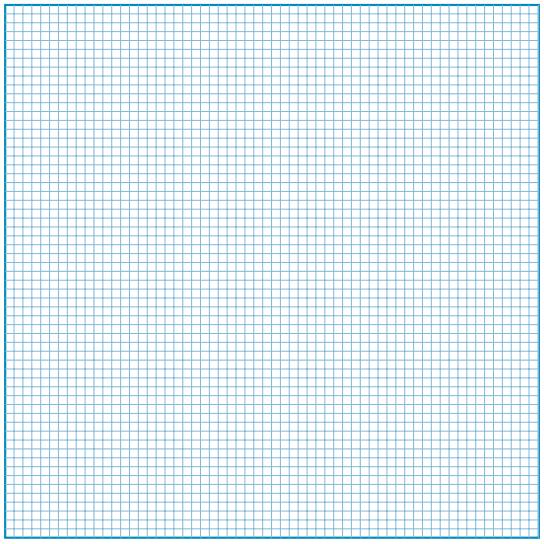
(g) Mean monthly rainfall vs mean monthly temperature: _____

4. The table below shows the rate of sweat production in an athlete on a stationary cycle.

(a) Complete the table below to determine the rate of sweat loss in cm^3/min:

(b) Choose an appropriate graph type and plot both cumulative sweat loss and rate of sweat loss on the grid below.

Time (minutes)	Cumulative sweat loss (cm^3)	Rate of sweat loss (cm^3/min)
0	0	
10	50	
20	130	
30	220	
60	560	



(c) Describe how the rate of sweat loss changes over time:

_____

_____

_____

_____

5. A student investigated the effect of nitrogen fertiliser on the growth of plants. They grew 10 plants at each of 4 fertiliser concentrations in a controlled environment:

(a) What measure of central tendency and dispersion would be best to summarise the results at each treatment?

_____

(b) What calculation could they use to determine if differences between the treatments were significant?

_____

(c) What choice of graph is best to display the results? _____

(d) The student had some outlier values in each of their treatments and wanted to repeat the investigation. Briefly describe two ways they could they increase the validity of their findings, assuming plentiful resources and time:

_____

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UNIT

01

How do organisms regulate their functions?

Area of Study 1

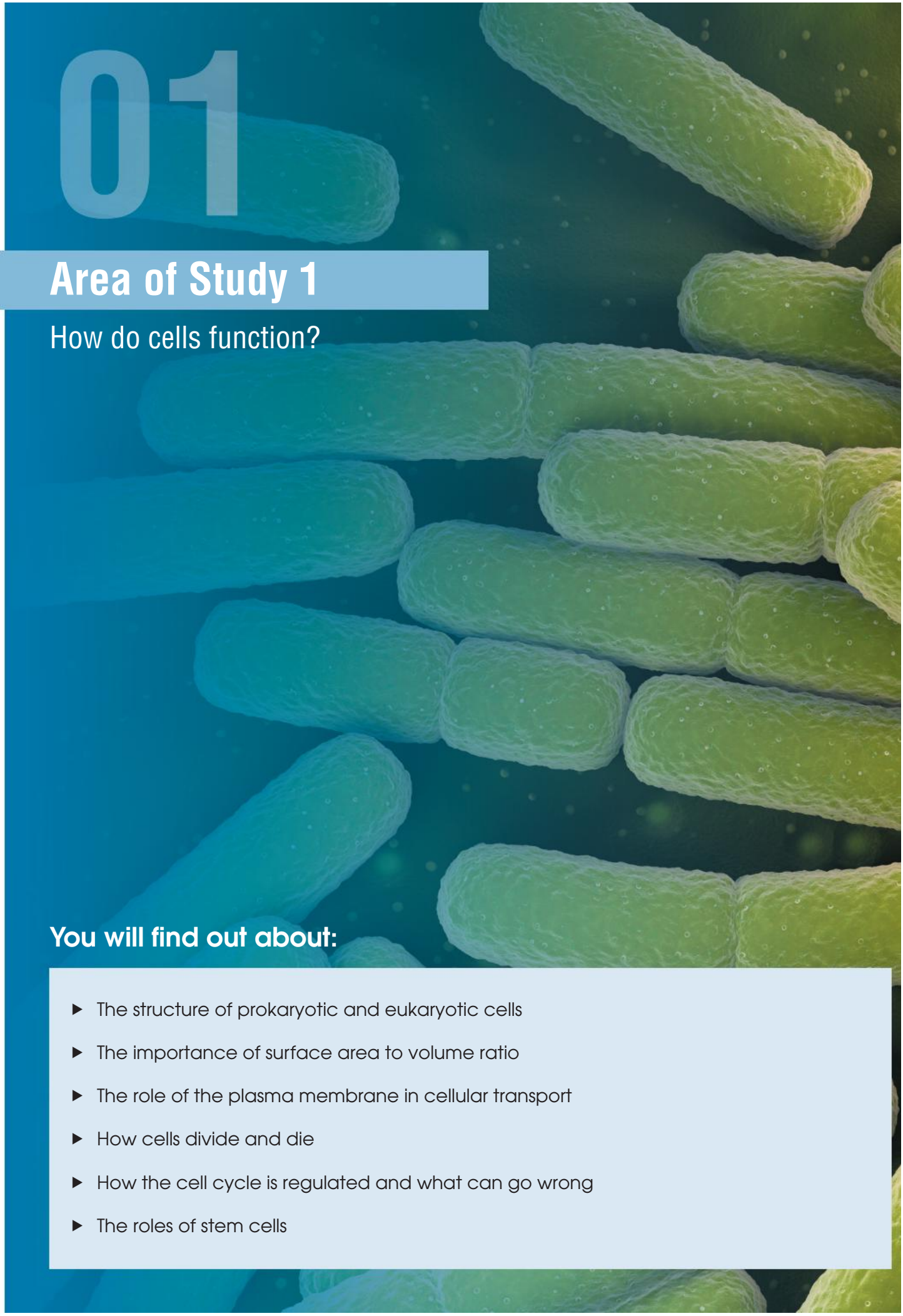
How do cells function?

Area of Study 2

How do plant and animal systems function?

Area of Study 3

How do scientific investigations develop understanding of how organisms regulate their functions?



01

Area of Study 1

How do cells function?

You will find out about:

- The structure of prokaryotic and eukaryotic cells
- The importance of surface area to volume ratio
- The role of the plasma membrane in cellular transport
- How cells divide and die
- How the cell cycle is regulated and what can go wrong
- The roles of stem cells

CHAPTER 2

Cellular Structure and Function

Key terms

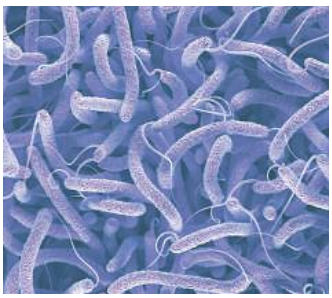
active transport
carrier protein
cell wall
centrioles
channel protein
chloroplast
cilia
concentration gradient
cytoplasm
diffusion
electron micrograph
endoplasmic reticulum
eukaryotic cell
facilitated diffusion
flagella
Golgi apparatus
hypertonic
hypotonic
ion pump
isotonic
light microscope
lysosome
magnification
mitochondrion
nucleic acid
nucleolus
nucleus
organelle
osmolarity
osmosis
partially permeable
passive transport
phospholipid
plasma membrane
plasmolysis
prokaryotic cell
protein
resolution
ribosome
rough ER (rER)
smooth ER (sER)
surface area: volume ratio
turgor
vacuole

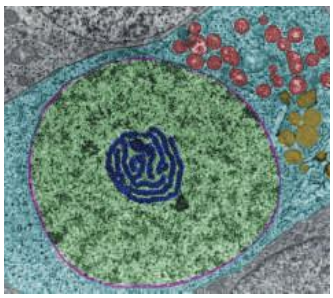
Cells are the unit of life

Key skills and knowledge

Activity number

- ☐ 1 Recognise cells as the basic unit of life on Earth. Describe the characteristics of living organisms and explain why viruses do not fulfil the criteria for being living cells. — 9
- ☐ 2 List the basic biochemical components of cells. Appreciate the role of water in life on Earth and summarise its biologically important properties. — 10
- ☐ 3 Describe the requirements of cells in terms of their immediate environment. Explain how unicellular and multicellular organisms meet the challenges for surviving in different environments. — 11
- ☐ 4 Describe the main differences between eukaryotic and prokaryotic cells. Recognise the cells of fungi, plants, protists, animals, and bacteria by their characteristic features. — 9 12 14
- ☐ 5 Use drawings and electron micrographs to compare and contrast the structure of prokaryotic cells and eukaryotic cells. — 13 14





Limitations to cell size: surface area to volume ratios

Key skills and knowledge

- ☐ 6 Describe the range of cell sizes. Express cell sizes in different units of measurement. — 15
- ☐ 7 Describe how cells exchange substances by diffusion. Identify the factors affecting rates of diffusion, explain their effect, and relate these to biological systems. — 16
- ☐ 8 PRAC Investigate diffusion across membranes using a model system. — 16
- ☐ 9 Explain the importance of surface area to volume ratio in limiting cell size and describe the role of cellular organelles in creating cellular compartments with specific functions. — 17
- ☐ 10 PRAC Investigate the effect of cell size on the rate and efficiency of diffusion. — 18
- ☐ 11 Explain how cells overcome the limitations to cell size by changes in shape and by the way they are organised in tissues. — 19

The structure and specialisation of cell organelles

Key skills and knowledge

- ☐ 12 Compare and contrast the ultrastructure of plant cells and animal cells in terms of their organelles. Identify these organelles in drawings and in light and electron micrographs. — 20-22
- ☐ 13 Describe the specialisations of plant and animal cellular organelles for specific functions. — 20-22

The structure and function of the plasma membrane

Key skills and knowledge

- ☐ 14 Describe the structure of the plasma membrane and its role as a partially permeable boundary between the internal and external environments of the cell. Recognise that internal membranes, e.g. of membranous organelles, have the same basic structure. — 23-25
- ☐ 15 PRAC Investigate factors affecting membrane structure and permeability. How might your findings be relevant to survival in different environments? — 26
- ☐ 16 Explain the role of the plasma membrane in the movement of substances by diffusion, facilitated diffusion, and active transport (including ion pumps, cotransport, and cytosis). Include an explanation of the movement of water by osmosis. Explain the effects that solutions of different solute concentration can have on plant and animal cells. — 16 27 29-33
- ☐ 17 PRAC Investigate the effects of solutions of different solute concentration on plant cells. Use your results to estimate the osmolarity of a cell, e.g. a potato cell. — 28

9 The Cell is the Unit of Life

Key Idea: All living organisms are composed of cells. Cells are broadly classified as prokaryotic or eukaryotic.

The cell theory is a fundamental idea of biology. This idea, that all living things are composed of cells, developed over many years and is strongly linked to the invention and refinement of the microscope in the 1600s.

The cell theory

The idea that cells are fundamental units of life is part of the cell theory. The basic principles of the theory are:

- All living things are composed of cells and cell products.
- New cells are formed only by the division of pre-existing cells.
- The cell contains inherited information (genes) that are used as instructions for growth, functioning, and development.
- The cell is the functioning unit of life; all chemical reactions of life take place within cells.

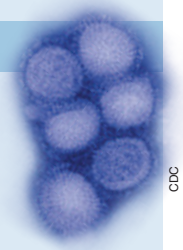
All cells show the functions of life

Cells use food (e.g. glucose) to maintain a stable internal environment, grow, reproduce, and produce wastes. The sum total of all the chemical reactions that sustain life is called metabolism.

- **Movement**
- **Respiration**
- **Sensitivity**
- **Growth**
- **Reproduction**
- **Excretion**
- **Nutrition**

Viruses are non-cellular

- Non-cellular.
- Typical size range: 20-300 nm.
- Contain no cytoplasm or organelles.
- No chromosome, just RNA or DNA strands.
- Enclosed in a protein coat.
- Depend on cells for metabolism and reproduction (replication).



CDC

Influenzavirus

Living things

→ **Cells**

Prokaryotic (bacterial) cells

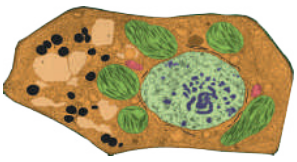
- Autotrophic or heterotrophic
- Single celled
- Lack a membrane-bound nucleus and membrane-bound organelles
- Cells 0.5-10 µm
- DNA a single, circular chromosome. There may be small accessory chromosomes called plasmids.
- Cell walls containing peptidoglycan.

Eukaryotic cells

• Cells 30-150 µm • Membrane-bound nucleus and membrane-bound organelles • Linear chromosomes

Plant cells

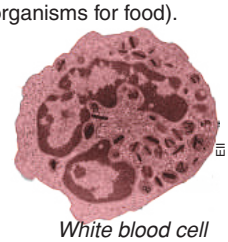
- Exist as part of multicellular organism with specialisation of cells into many types.
- Autotrophic (make their own food): photosynthetic cells with chloroplasts.
- Cell walls of cellulose.



Generalised plant cell

Animal cells

- Exist as part of multicellular organism with specialisation of cells into many types.
- Lack cell walls.
- Heterotrophic (rely on other organisms for food).



EII

White blood cell

Protist cells

- Mainly single-celled or exist as cell colonies.
- Some are autotrophic and carry out photosynthesis.
- Some are heterotrophic.

Amoeba cell

Fungal cells

- Rarely exist as discrete cells, except for some unicellular forms (e.g. yeasts)
- Plant-like, but lack chlorophyll.
- Rigid cell walls containing chitin.
- Heterotrophic.

Yeast cell

1. What are the characteristic features of a prokaryotic cell? _____

_____

2. What are the characteristic features of a eukaryotic cell? _____

_____

3. Why are viruses considered to be non-cellular (non-living)? _____

_____

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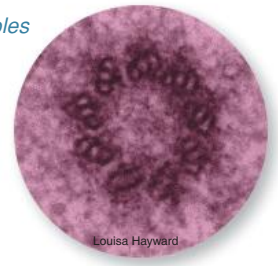
10 What Are Cells Made Of?

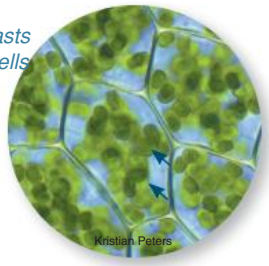
Key Idea: The main components of a cell are water and compounds of carbon, hydrogen, nitrogen, and oxygen.

Water is the main component of cells and organisms, providing an aqueous environment in which metabolic reactions can occur. Apart from water, most other substances in cells are compounds of carbon, hydrogen, oxygen, and nitrogen. Carbon can combine with many other elements to form a large number of carbon-based (or organic) molecules. The organic molecules that make up living things can be grouped into four broad classes: carbohydrates, lipids, proteins, and nucleic acids. In addition, a small number of inorganic ions are also components of larger molecules.

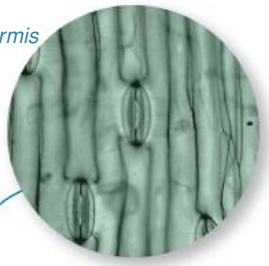
Centrioles



Chloroplasts in plant cells



Plant epidermis

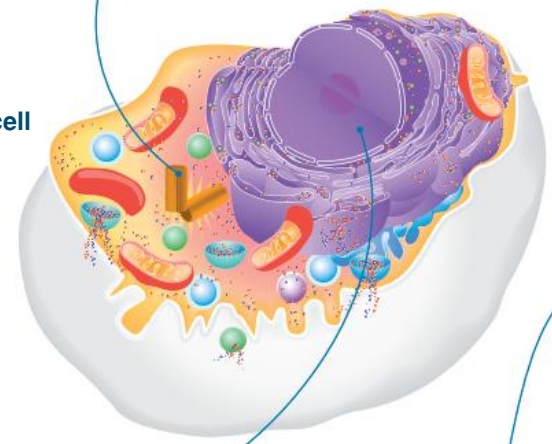


Proteins have an enormous number of structural and functional roles in plants and animals, e.g. as enzymes, structural materials (such as collagen), in transport, and movement (e.g. cytoskeleton and centrioles).

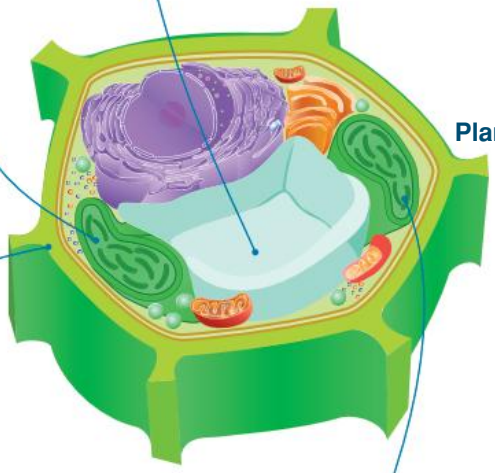
Inorganic ions: Dissolved ions participate in metabolic reactions and are components of larger organic molecules, e.g. Mg^{2+} is a component of the green chlorophyll pigment in the chloroplasts of green plants.

Water is a major component of cells: many substances dissolve in it and metabolic reactions occur in it. In plant cells, fluid pressure against the cell wall provides turgor, which supports the cell.

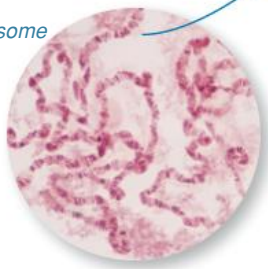
Animal cell



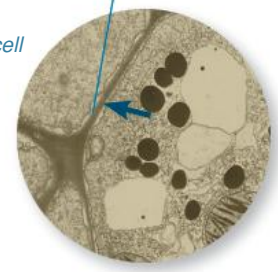
Plant cell



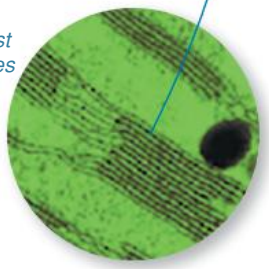
Chromosome



Plant cell wall



Chloroplast membranes



Nucleotides and nucleic acids
Nucleic acids encode information for the construction and functioning of an organism (DNA and RNA). ATP, a nucleotide derivative, is the energy carrier of the cell.

Carbohydrates form the structural components of cells, e.g. cellulose cell walls (arrowed). They are important in energy storage and they are involved in cellular recognition.

Lipids provide a concentrated source of energy. Phospholipids are a major component of cellular membranes, including the membranes of organelles such as chloroplasts and mitochondria.

1. Given the components of cells above, predict some substances they need to remain functioning and the importance of those substances:

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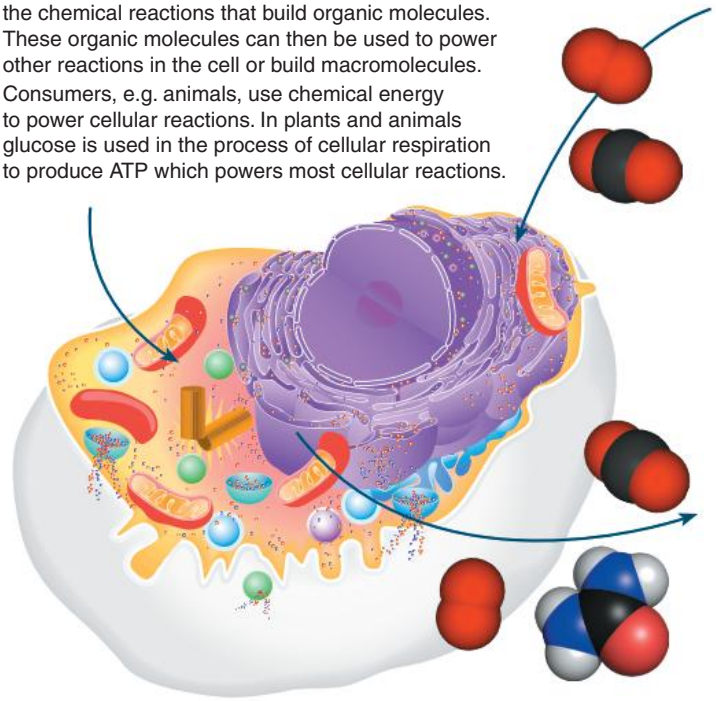
11 What Cells Need for Survival

Key Idea: Cells have specific requirements for survival. These include obtaining nutrients and removing wastes.
Cells require energy to power the reactions that build their structures and maintain their functions. Cells also require a range of molecules and ions to build and maintain these structures and they need to be able to remove wastes.

Cells need energy

Cells have evolved to use two basic forms of energy: light or chemical energy.

- Producers (some bacteria, and plant and algal cells with chloroplasts) use light from the Sun to power the chemical reactions that build organic molecules. These organic molecules can then be used to power other reactions in the cell or build macromolecules.
- Consumers, e.g. animals, use chemical energy to power cellular reactions. In plants and animals glucose is used in the process of cellular respiration to produce ATP which powers most cellular reactions.



Cells require resources

Cells require molecules and ions to build macromolecules and help carry out cellular reactions.

- Carbon dioxide is needed by plants to build organic molecules during photosynthesis.
- Oxygen is needed by plants and animals as an electron acceptor at the end of cellular respiration.
- In plants, nitrates provide nitrogen, which is incorporated into amino acid molecules. Animals use these (by eating plants or plant eaters) to obtain building blocks for their proteins.
- Various metal ions are also needed. Some in relatively large amounts, e.g. Na^+ is needed for nerve cell function in animals, while others are needed only in very small amounts.

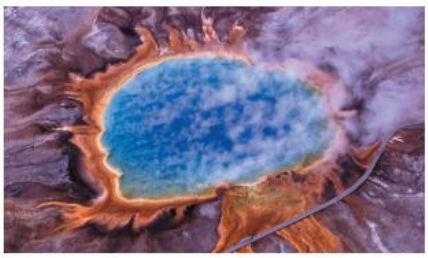
Cells need to remove wastes

Cells need to remove wastes generated during cellular reactions. What is regarded as a waste depends on the type of cell.

- Oxygen is a waste product of photosynthesis, but is required for cellular respiration.
- Other waste products include nitrogen wastes such as urea, ammonia, and uric acid (from metabolic processes).
- Most cellular reactions generate heat, which must be managed so that an organism does not overheat. In animals, metabolic heat is removed from cells by the blood and transferred to places where it can radiate into the environment (e.g. the skin).

Cellular environments

The exact conditions a cell needs depends on many factors including whether the organism is unicellular or multicellular, and what environment it has evolved to survive in.



Jim Peaco, National Park Service PD

Some unicellular organisms (called thermophiles) can survive in temperatures as high as 122°C. Their enzymes can not function at the lower temperatures outside environments such as hot thermal pools.

Halophiles require environments with high salt concentrations (up to five times as concentrated as the sea). These cells are specially adapted to retain water. If placed in fresh water they quickly swell and burst.

Cells in multicellular organisms require the homeostatic environment provided by the organism. The organism provides an internal environment that provides the cells with nutrients, waste removal, and a relatively constant temperature.

1. Why do cells need energy? _____

_____

2. Why must cells be able to remove wastes? _____

_____

3. Describe an example of where waste products of one cellular process can be used as a resource for another:

_____

_____

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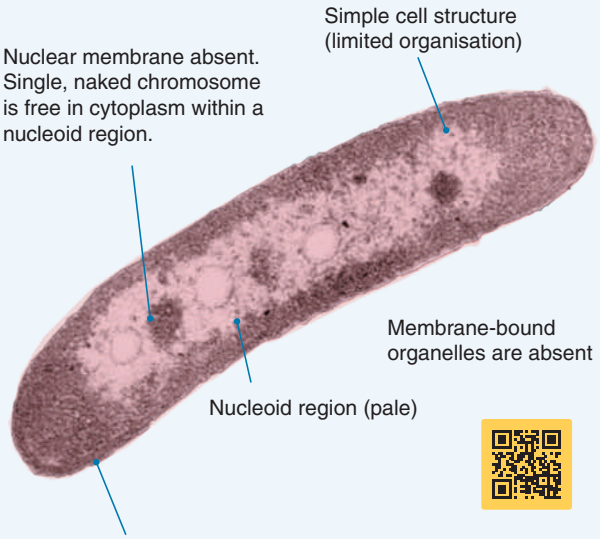
12 Prokaryotic vs Eukaryotic Cells

Key Idea: Cells are classified as either prokaryotic or eukaryotic and are distinguished on the basis of their size, internal organisation, and complexity.

Cells are divided into two broad groups based on their size and organisation. Prokaryotic cells (all Bacteria and Archaea) are small, single cells with a simple internal structure. Eukaryotic cells are larger, more complex cells. All multicellular and some unicellular organisms are eukaryotic.

Prokaryotic cells

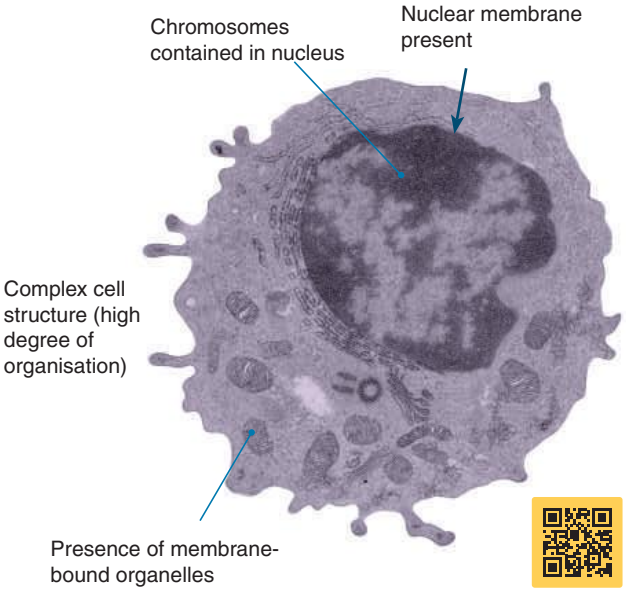
- Prokaryotic cells lack a membrane-bound nucleus or any membrane-bound organelles.
- Prokaryotic cells are often also called bacterial cells. Examples of bacterial cells include *E. coli* and *Staphylococcus aureus*.
- They are small (generally 0.5-10 µm) single cells (unicellular).
- They are relatively unstructured and have little cellular organisation (their DNA, ribosomes, and enzymes are free floating within the cell cytoplasm).
- Single, circular chromosome of naked DNA.
- Prokaryotes have cell walls, but it is different to the cell walls that some eukaryotes have.



The image above shows a bacterium called *Escherichia coli*

Eukaryotic cells

- Eukaryotic cells have a membrane-bound nucleus, and other membrane-bound organelles.
- Plant cells, animal cells, fungal cells, and protists are all eukaryotic cells.
- Eukaryotic cells are large (30-150 µm). They may exist as single cells or as part of a multicellular organism.
- Multiple linear chromosomes consisting of DNA and associated proteins.
- They are more complex than prokaryotic cells, with more structure and internal organisation.



A human white blood cell (above) is an example of an animal cell

1. List three features of a prokaryotic cell:

   (a) _____

   (b) _____

   (c) _____

   (d) Name an example of a prokaryote: _____

2. List three features of a eukaryotic cell:

   (a) _____

   (b) _____

   (c) _____

   (d) Name examples of eukaryotic cells: _____

   _____

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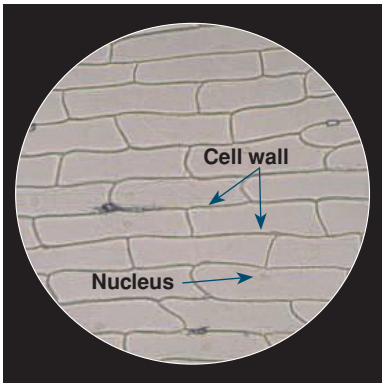
13 Interpreting Images of Cells

Key Idea: Different microscopy techniques produce different views of cells and their features.

The microscope is an important tool in biology for viewing cells and their features, which are far too small to be seen by the human eye. High power compound light microscopes use visible light and a combination of lenses to magnify objects up to several 100 times. Electron microscopes use beams of electrons and computer imaging to capture extremely fine detail of either surface or internal cellular features. They can magnify images up to 500,000 times. Scanning Tunnelling Microscopes (STMs) can magnify object ten times more than that. With a resolution of 0.1 nanometers, STMs operate at the edge of the quantum realm and are able to image some types of atoms.

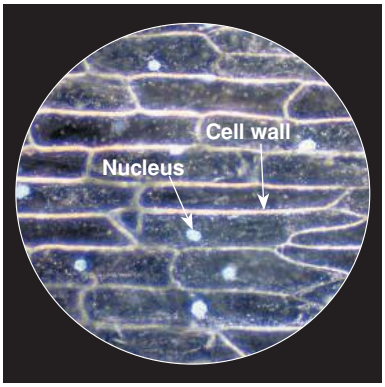
JDG

Dissecting microscopes are used for dissections, observing microbial cultures, and for identifying and sorting organisms, like this small crustacean.



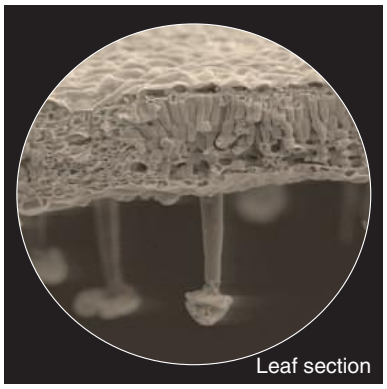
EII

These onion epidermal cells are viewed with standard **bright field** lighting. Very little detail can be seen. The cell nuclei are barely visible.



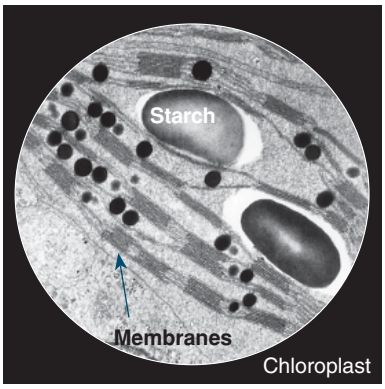
EII

Dark field illumination is excellent for viewing specimens that are almost transparent. The nuclei of these onion epidermal cells are clearly visible.

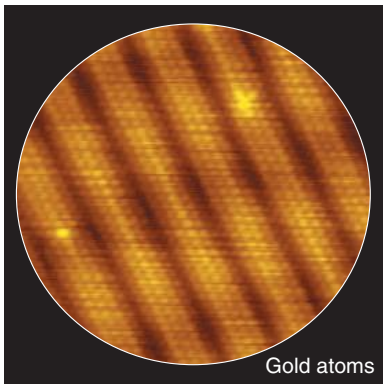


Dartmouth

Scanning Electron Microscopes (SEMs) produce extremely high resolution images of the surface of cells and objects.



Transmission Electron Microscopes (TEMs) produce extremely high resolution images of the interior of cells and transparent objects.

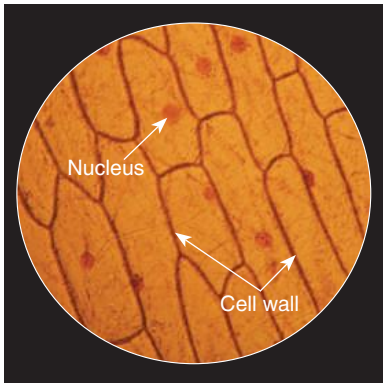


STM Erwinrossen

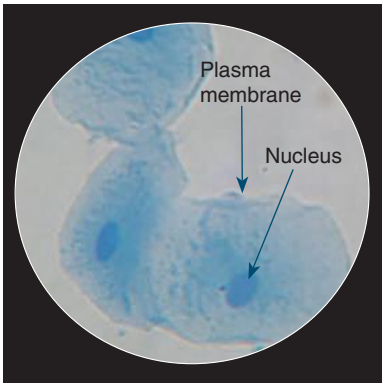
Scanning Tunnelling Microscopes (STMs) produce images based on current variation between an extremely fine needle and the object it moves over.

Staining

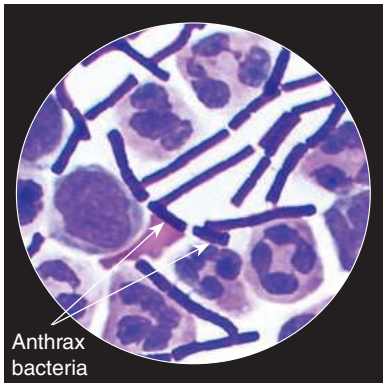
Some parts of the cell take up stains (chemical dyes) better than others. Stains can be used to highlight parts of the cell for better viewing with a microscope or they can improve contrast. A wide range of chemicals act as stains, including iodine and methylene blue.



Iodine is used to increase the contrast in transparent tissues, such as this onion epidermis. Iodine stains are also used to show the presence of starch, binding starch to produce a blue-black colour.



Methylene blue is a positively charged stain commonly used when viewing animal cells. It has a strong affinity for DNA (in the nucleus) and a weaker affinity for RNA (in the cytoplasm).



Some bacteria can be identified and viewed using Gram staining. Bacteria are classed as Gram positive and Gram negative depending on whether or not the stain is retained by the cell wall.

ISBN: 978-1-98-856636-8

What is magnification?

Magnification refers to the number of times larger an object appears compared to its actual size.

$$\text{Magnification} = \frac{\text{measured size of the object}}{\text{actual size of the object}}$$

$$\text{Actual object size} = \frac{\text{size of the image}}{\text{magnification}}$$

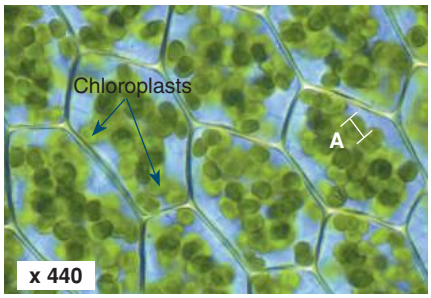
What is resolution?

Resolution is the ability to distinguish between close together but separate objects. Resolution is a function of wavelength of light used to view the object. Examples of high and low resolution for separating two objects viewed under the same magnification are given below.

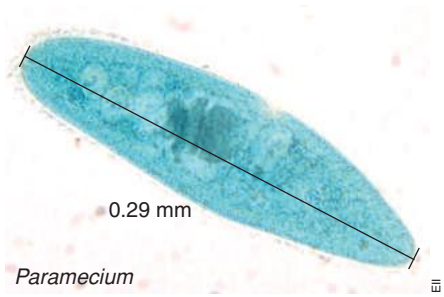
High resolution

Low resolution

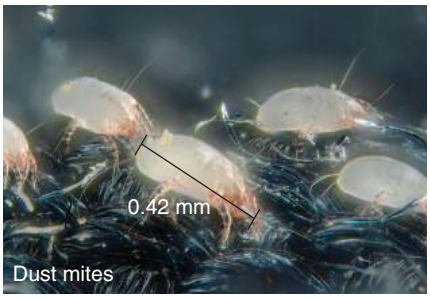
1. Calculate the length or magnification of the object or organism:



Kristian Peters

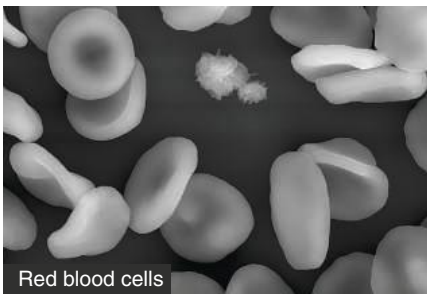


Eli



(a) Length of A: _____ (b) Magnification: _____ (c) Magnification: _____

2. Identify which type of microscope (optical microscope, SEM, or TEM) was used to produce each of the images in the photos below (a to f):



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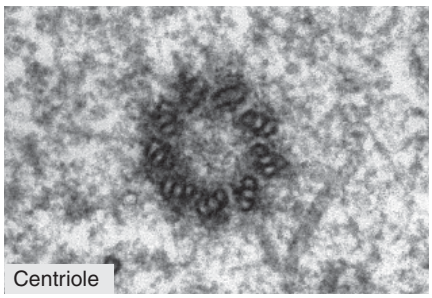
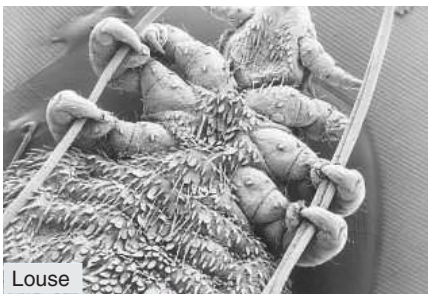
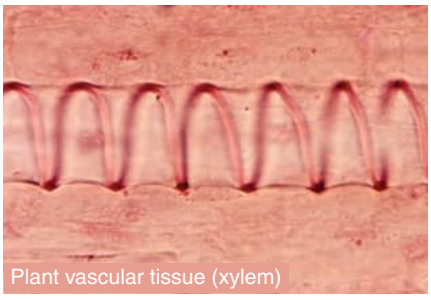


Louisa Howard Dartmouth College



(a) _____ (b) _____ (c) _____



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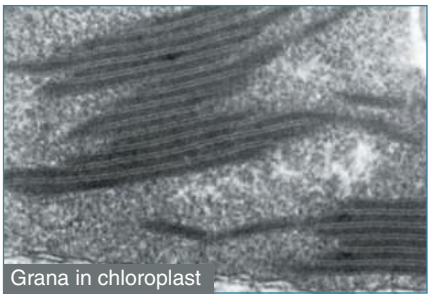

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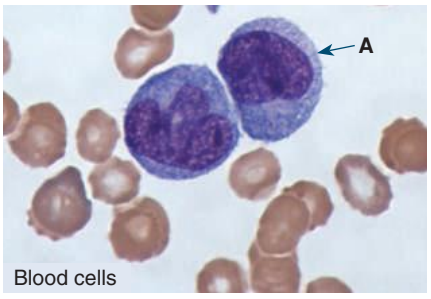
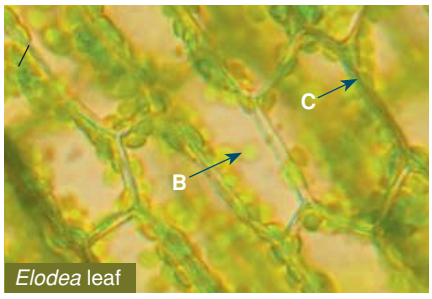
(d) _____ (e) _____ (f) _____

3. Identify the labelled structures:



Dr Graham Beards



tooony

(a) _____ (b) _____ (c) _____ (d) _____

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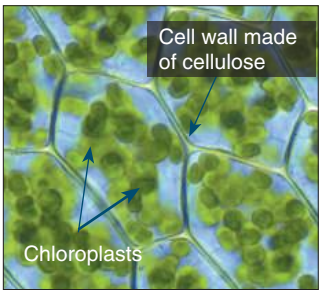
14 Types of Cells

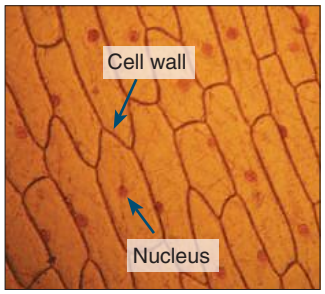
Key Idea: Cells come in a wide range of shapes and sizes. In multicellular organisms, cells are adapted for a specific role.

Cells come in a wide range of types and forms. The images below show a selection of cell types from the five kingdoms. Multicellular organisms typically have many specialised cell types, each of which performs a specific function.

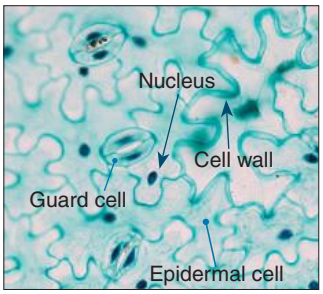
Plant cells



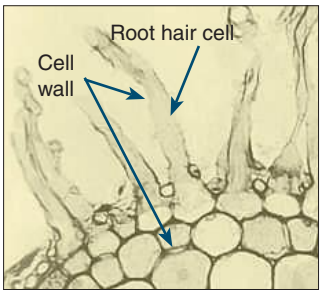
Palisade mesophyll cells



Epidermal cell

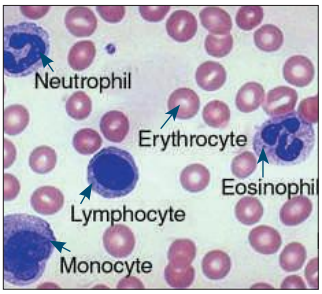


Guard cells and epidermal cells

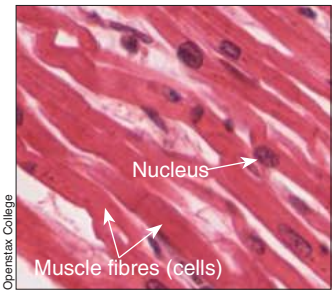


Root hair cell

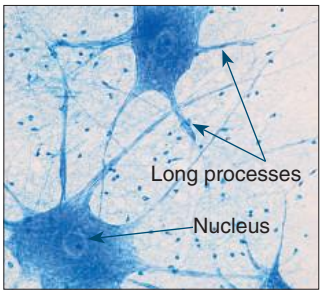
Animal cells



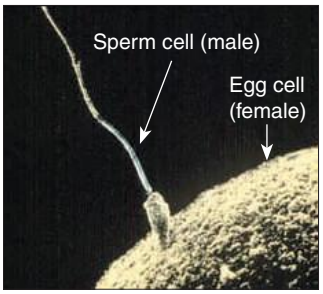
Blood cells



Muscle cells

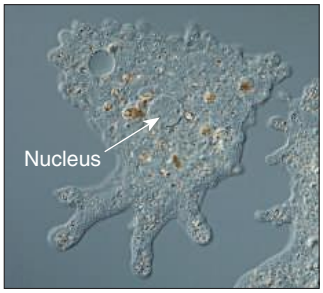


Nerve cells (neurones)

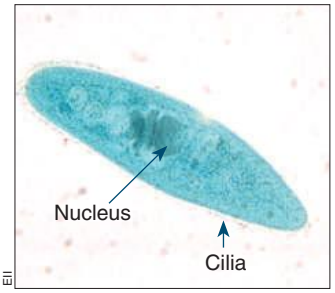


Reproductive cells

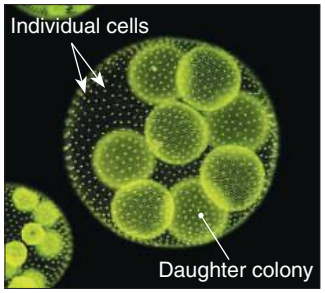
Protists (single cells or colonies)



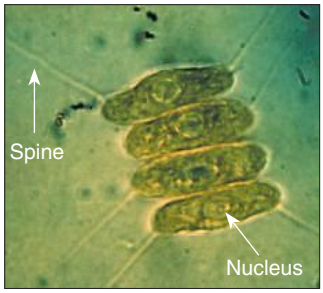
Amoeba



Paramecium

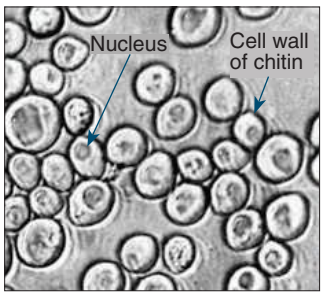


Volvox colony

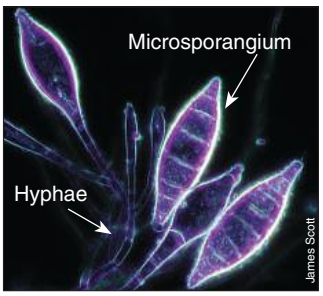


Scenedesmus colony

Fungal cells

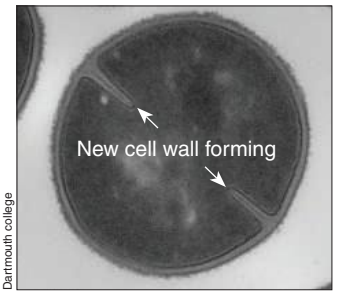


Yeast cells (*Saccharomyces*)

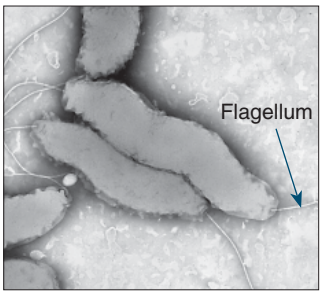


Microsporum cells

Bacterial cells



Staphylococcus cell (dividing)



Campylobacter cell

1. Identify one distinguishing feature of each of the following cell types, based on what is (or is not) labelled above:

   (a) Plant cells: _____ (c) Fungal cells: _____

   (b) Bacterial cells: _____ (d) Animal cells: _____

2. Both plants and animals have a large number of specialised cell types. Why do you think this is? _____

   _____

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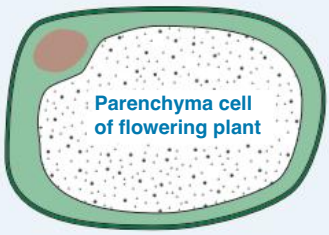
15 Cell Sizes

Key Idea: Cells vary in size (2-100 µm), with prokaryotic cells being approximately 10 times smaller than eukaryotic cells.

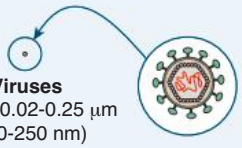
Cells can only be seen properly when viewed through the magnifying lenses of a microscope. The images below show a variety of cell types, including a multicellular microscopic animal and a virus (non-cellular) for comparison. For each of these images, note the scale and relate this to the type of microscopy used.



Human white blood cell

Eukaryotic cells
(e.g. plant and animal cells)
Size: 10-100 µm diameter.
Cellular organelles may be up to 10 µm.

Prokaryotic cells
Size: Typically 2-10 µm length, 0.2-2 µm diameter.
Upper limit 30 µm long.

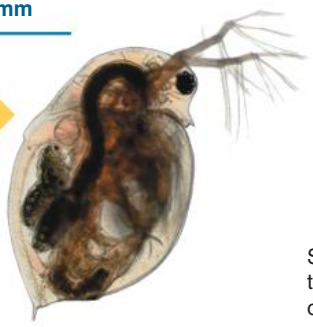


Viruses
Size: 0.02-0.25 µm (20-250 nm)

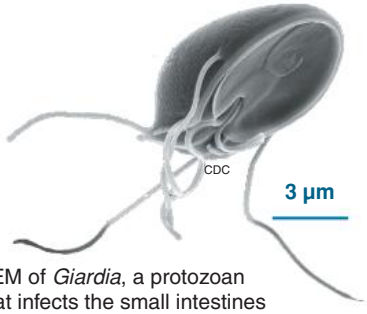
Unit of length (international system)		
Unit	**Metres**	**Equivalent**
1 metre (m)	1 m	= 1000 millimetres
1 millimetre (mm)	10^{-3} m	= 1000 micrometres
1 micrometre (µm)	10^{-6} m	= 1000 nanometres
1 nanometre (nm)	10^{-9} m	= 1000 picometres

Micrometres are sometimes referred to as microns. Smaller structures are usually measured in nanometres (nm) e.g. molecules (1 nm) and plasma membrane thickness (10 nm).

1.0 mm

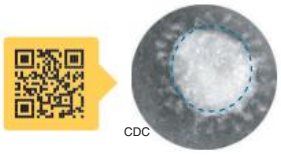


Daphnia is a small crustacean found as part of the zooplankton of lakes and ponds.



SEM of *Giardia*, a protozoan that infects the small intestines of many vertebrate groups.

Paramecium is a protozoan commonly found in ponds.

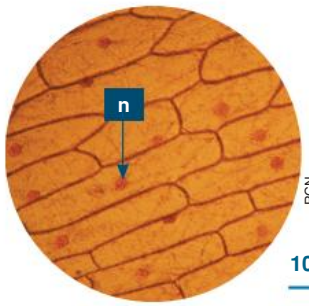


Coronavirus is the virus responsible for SARS.

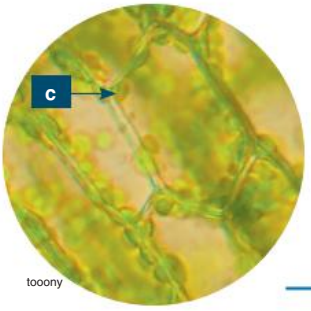
10 nm

10 µm

Salmonella is a bacterium found in many environments and causes food poisoning in humans.



Onion epidermal cells: the nucleus (n) is just visible.

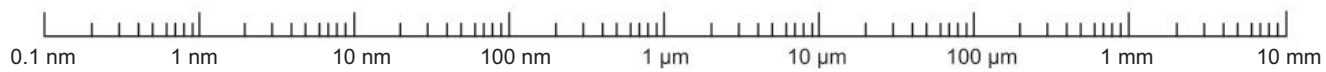


Elodea is an aquatic plant. In these leaf cells, the chloroplasts (c) can be seen around the inner edge of the cells.

1. Using the measurement scales provided on each of the photographs above, determine the longest dimension (length or diameter) of the cell/animal/organelle indicated in µm and mm. Attach your working:

(a) *Daphnia*:	_____ µm	_____ mm	(e) Chloroplast:	_____ µm	_____ mm
(b) *Giardia*:	_____ µm	_____ mm	(f) *Paramecium*:	_____ µm	_____ mm
(c) Nucleus	_____ µm	_____ mm	(g) *Salmonella*:	_____ µm	_____ mm
(d) *Elodea* leaf cell:	_____ µm	_____ mm	(h) *Coronavirus*:	_____ µm	_____ mm

2. Mark and label the examples above on the log scale below according to their size:



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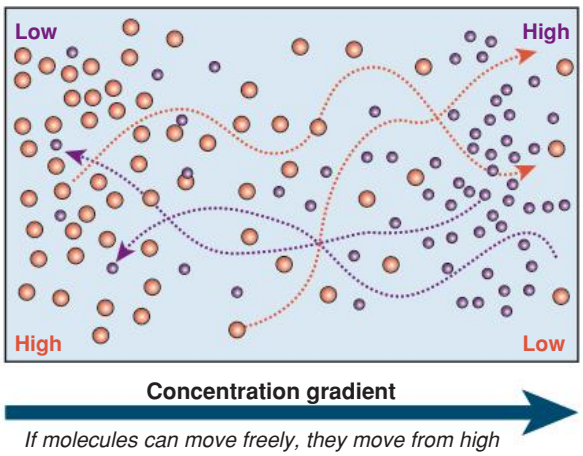
16 Cells Exchange Substances by Diffusion

Key Idea: Diffusion is the movement of molecules down a concentration gradient.

The molecules that make up substances are constantly moving about in a random way. This random motion causes them to disperse from areas of high to low concentration. This dispersal is called **diffusion** and it requires no energy. Each type of molecule moves down its own concentration gradient. In biological systems, most diffusion occurs across membranes. Some molecules move freely (unassisted) across the membrane by simple diffusion. For other molecules, their diffusion is facilitated by proteins in the membrane. Diffusion is important in allowing cells to make exchanges with their extracellular environment (e.g. the blood and fluids that bathe them) and is crucial to the regulation of water content.

What is diffusion?

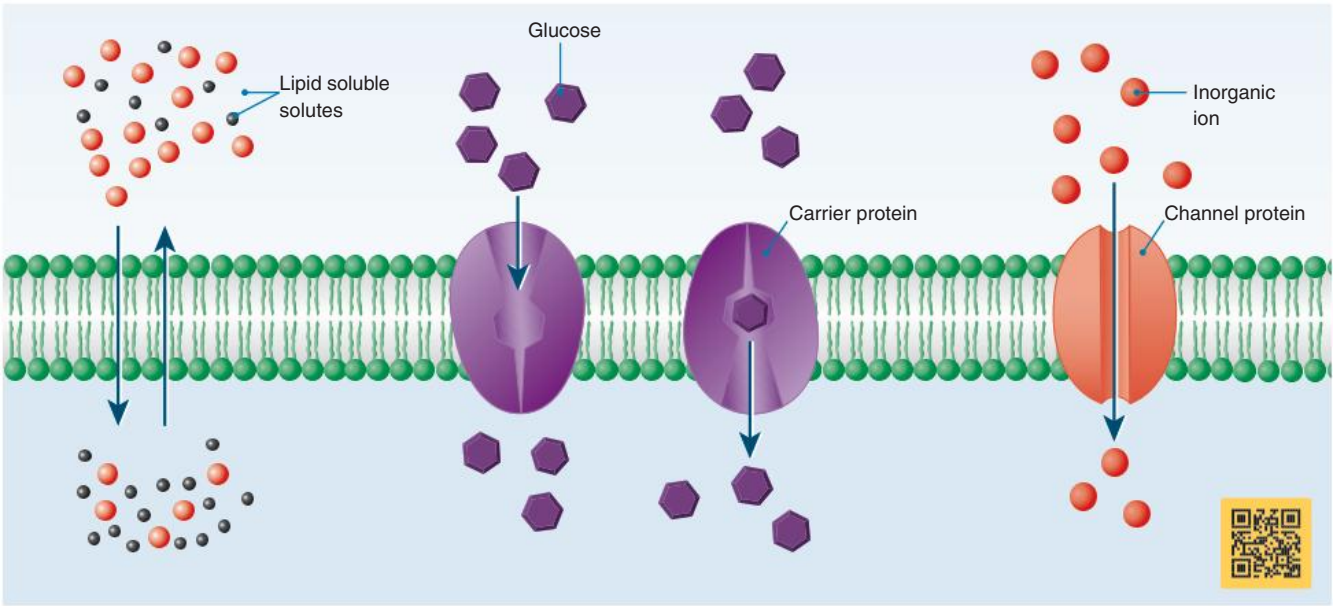
Diffusion is the movement of particles down a concentration gradient. Diffusion is a **passive process**, meaning it needs no input of energy to occur. During diffusion, molecules move randomly about, eventually becoming evenly dispersed.



If molecules can move freely, they move from high to low concentration (down a concentration gradient) until evenly dispersed. Each molecule moves down its own concentration gradient independent of the concentration gradients of other molecules.

Factors affecting the rate of diffusion

Concentration gradient	The rate of diffusion is higher when there is a greater difference between the concentrations of two regions.
The distance moved	Diffusion over shorter distance occurs at a greater rate than over a larger distance.
The surface area involved	The larger the area across which diffusion occurs, the greater the rate of diffusion.
Barriers to diffusion	Thick barriers have a slower rate of diffusion than thin barriers.
Temperature	Particles at a high temperature diffuse at a greater rate than at a low temperature.
Solubility	Lipid-soluble or non-polar molecules pass across membranes more easily than polar materials, so their rates of diffusion are faster.
Solvent density	As the density of a solvent increases, the rate of diffusion decreases. Cellular dehydration adversely affects diffusion rates within cells.



Simple diffusion

Molecules move directly through the plasma membrane without assistance. Example: O_2 diffuses into the blood and CO_2 diffuses out. Diffusion gradients are maintained because substances are constantly being imported, made, or used by the cell.

Facilitated diffusion involving carrier proteins

Carrier proteins in the membrane allow large lipid-insoluble molecules that cannot cross the membrane by simple diffusion to be transported into the cell. Example: the transport of glucose into red blood cells.

Facilitated diffusion involving channel proteins (hydrophilic pores)

Channel proteins (water-filled pores) in the plasma membrane allow inorganic ions to pass through. **Aquaporins** are special channel proteins for rapid diffusion of water. Example: K^+ ions exiting nerve cells to restore resting potential.

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1. What do the three types of diffusion described above all have in common?

2. How does facilitated diffusion differ from simple diffusion?

3. Why is carbon dioxide able to continually diffuse out of cells?

4. Why would a thin flat cell have a greater rate of diffusion to and from its centre than a thick spherical cell?

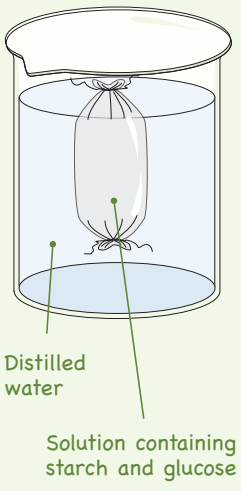
Observing diffusion

Diffusion through a partially permeable membrane can be modelled using dialysis tubing. The pores of the dialysis tubing determine the size of the molecules that can pass through. In the experiment described below, you will investigate how glucose will diffuse down its concentration gradient from a high glucose concentration to a low glucose concentration and demonstrate, via the model, the selective permeability of the plasma membrane.

Investigation 2.1 Simple diffusion across a membrane

See appendix for equipment list.

1. Add 200 mL of distilled water to a clean 200 mL beaker. Remove a 1 mL sample and place in a clean test tube. Use a glucose dipstick to test for the presence and concentration of glucose in the 1 mL sample. If glucose is present, the indicator window will change colour. The colour change can be compared against a reference to determine the concentration of glucose present.
2. Now add a few drops of Lugol's indicator to test for the presence of starch. Lugol's indicator contains iodine, and turns blue/black in the presence of starch.
3. Obtain a short section of dialysis tubing, approximately 10 cm long. Use thread or nylon line to tie off one end (or tie a knot in the tubing if long enough).
4. You may need to rinse the tubing under water to make it pliable enough to open.
5. Fill the dialysis tubing with 5 mL each of a 1% starch solution and a 10% glucose solution.
6. Remove a 1 mL sample and place in a clean test tube. Tie off the top of the dialysis tubing, rinse well with distilled water, then place in the beaker of distilled water.
7. Test for the presence and concentration of glucose and then starch in the sample from the dialysis tubing as in steps 1 and 2.
8. Leave the dialysis tubing in the distilled water for 30 minutes.
9. Remove 1 mL of water from the beaker and place in a clean test tube. Use a glucose dipstick to test for the presence and concentration of glucose. Test for the presence of the starch using Lugol's indicator.
10. Remove a 1 mL sample from the dialysis tubing and place in a clean test tube. Use a glucose dipstick to test for the presence and concentration of glucose. Test for the presence of the starch using Lugol's indicator.



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5. What is the aim of the experiment? _____

_____

6. What part of a cell does the dialysis tubing represent? _____

7. Why was it important to wash the dialysis tubing before placing it into the beaker of distilled water? _____

_____

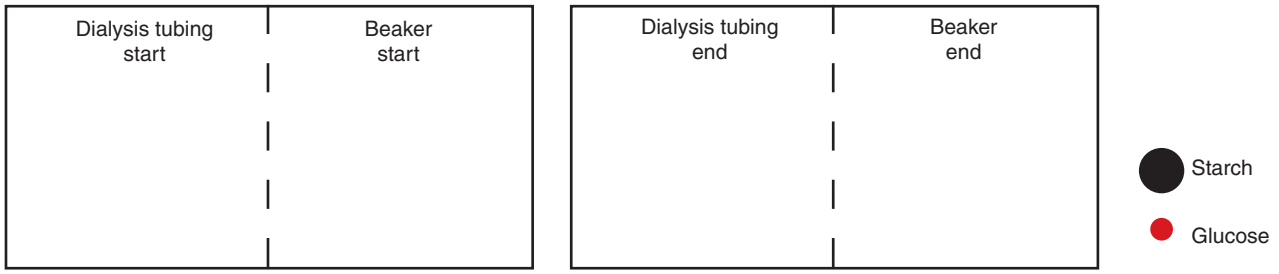
_____

8. Complete the result table right:

   For relative concentration of glucose, use **+** for relatively low concentration and **++** for relatively high concentration.

	Beaker start	Dialysis tubing start	Beaker end	Dialysis tubing end
Starch (+/–)				
Glucose (relative concentration)				

9. In the spaces provided (below) draw the distribution of starch and glucose at the start and at the end of the experiment. Use the coloured symbols shown under the table to represent starch and glucose:



10. Explain your results: _____

_____

_____

_____

11. Suggest how a cell could regulate the rate of facilitated diffusion of specific molecules? _____

_____

_____

12. Why is glucose able to continually diffuse into a cell? _____

_____

_____

_____

13. Study the images below. Place them in order of first event to last event. Explain your order of events in terms of diffusion:

_____

_____

_____

_____

_____

_____

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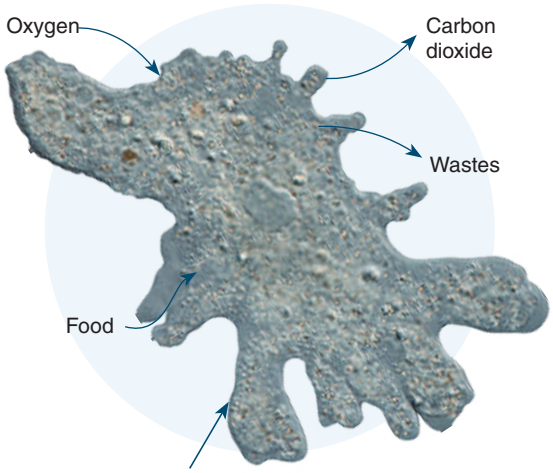
17 Diffusion and Cell Size

Key Idea: Diffusion is less efficient in cells with a small surface area relative to their volume than in cells with a large surface area relative to their volume.

Small objects, such as cells, have a large surface area relative to their volume and diffusion is an effective way to move materials in and out. As an object becomes larger, its surface area to volume ratio is smaller and diffusion is no longer an effective way to transport materials to the inside. The effectiveness of diffusion is therefore the controlling factor determining how big an individual cell can become. In large, multicellular organisms, specialised systems deliver materials to the many cells that make up the tissues of the body.

Single-celled organisms

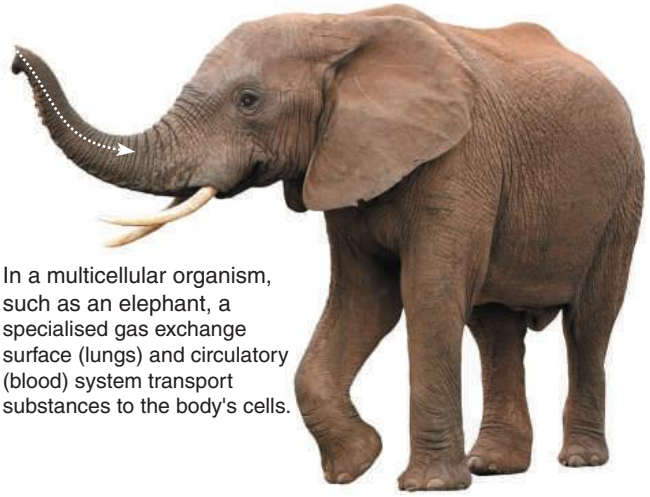
Single-celled organisms (e.g. *Amoeba*), are small and have a large surface area relative to the cell's volume. The cell's requirements can be met by the diffusion or active transport of materials into and out of the cell (below).



The **plasma membrane**, which surrounds every cell, regulates movements of substances into and out of the cell. For each square micrometre of membrane, only so much of a particular substance can cross per second.

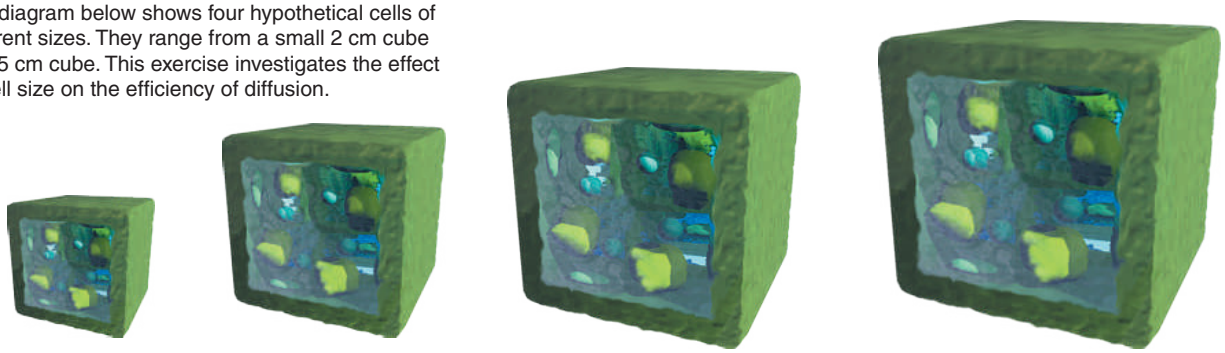
Multicellular organisms

Multicellular organisms (e.g. plants and animals) generally have a small surface area compared to their volume. They require specialised body systems to transport the materials they need to and from the cells and tissues in their body.



In a multicellular organism, such as an elephant, a specialised gas exchange surface (lungs) and circulatory (blood) system transport substances to the body's cells.

The diagram below shows four hypothetical cells of different sizes. They range from a small 2 cm cube to a 5 cm cube. This exercise investigates the effect of cell size on the efficiency of diffusion.



2 cm cube **3 cm cube** **4 cm cube** **5 cm cube**

1. Calculate the volume, surface area and the ratio of surface area to volume for each of the four cubes above (the first has been done for you). When completing the table below, show your calculations.

Cube size	Surface area (cm^2)	Volume (cm^3)	Surface area to volume ratio
2 cm cube	2 x 2 x 6 = 24 cm^2 (2 cm x 2 cm x 6 sides)	2 x 2 x 2 = 8 cm^3 (height x width x depth)	24 to 8 = 3:1
3 cm cube			
4 cm cube			
5 cm cube			

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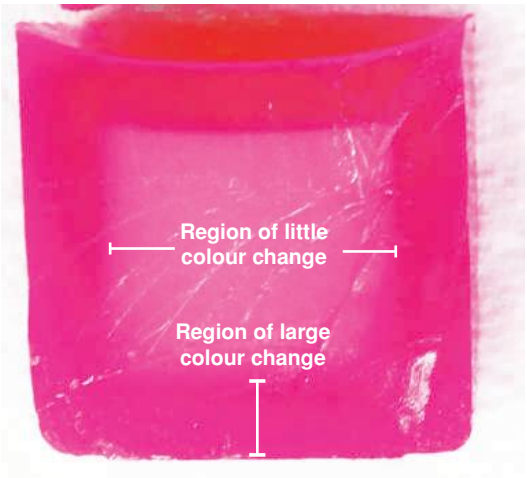
18 Investigating the Effect of Cell Size

Key Idea: The effect of cell size on the efficiency of diffusion can be investigated using model agar "cells" of different sizes. As described in the previous activity, the efficiency of diffusion decreases as cell size increases. This can be demonstrated easily in a model system. In this activity you will design an experiment to demonstrate the effect of surface area: volume ratios on diffusion in model cells. Think about how you will plan your investigation and analyse your data to obtain meaningful results. This will help you to make valid conclusions about your findings.

Background information

Oxygen, water, cellular waste, and many nutrients are transported into and out of cells by diffusion. However, at a certain surface area to volume ratio, diffusion becomes inefficient. In this activity you will create model cells of varying sizes from agar and use them to test the relationship between cell size and rate or efficiency of diffusion.

- The diffusion of molecules into a cell can be modelled by using agar cubes infused with phenolphthalein indicator and soaked in sodium hydroxide (NaOH).
- Phenolphthalein is an acid/base indicator and turns pink in the presence of a base.
- As the NaOH diffuses into the agar, the phenolphthalein changes to a pink colour and thus indicates how far into the agar block the NaOH has diffused (right).
- By cutting an agar block into cubes of various sizes, it is possible to investigate the effect of cell size on diffusion.



A phenolphthalein-infused agar cube after exposure to NaOH.

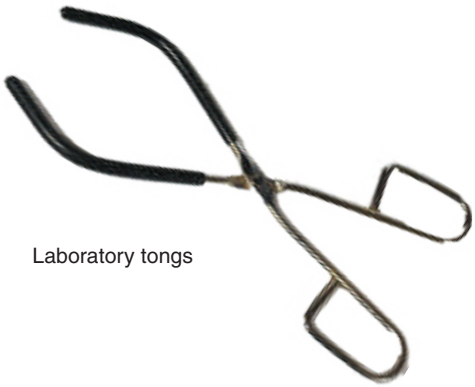
Equipment list

Glass beaker

Paper towel

Timer

Agar blocks infused with phenolphthalein



Laboratory tongs

Scalpel

Sodium hydroxide (NaOH) solution

Ruler

ISBN: 978-1-98-856636-8

Based on the aim of this experiment "To investigate the effect of cell size on diffusion in a model cell", the background information provided, and the equipment list provided, design your own experiment using the questions below to guide you.

1. State an hypothesis for your experiment: _____

2. Write your method as step by step instructions: _____

3. In the space below draw a table to record your results. Remember to record cell volume and include space to work out how much diffusion has occurred.

4. Write your conclusions here: _____

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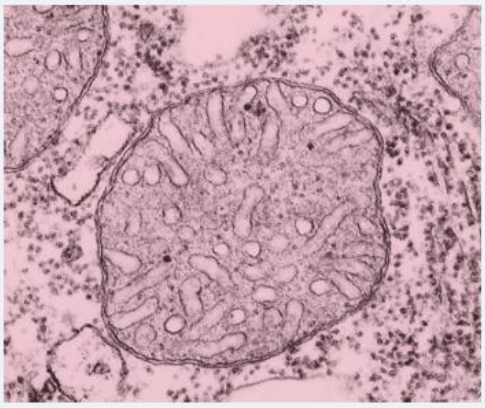
19 Overcoming Limitations to Cell Size

Key Idea: Larger cells can maintain high surface area to volume ratios by having a non-spherical shape and membrane extensions. Organelles also increase functional efficiency.

We have seen that cells must exchange materials with the extracellular environment in order to survive. The efficiency of these exchanges, which must occur across the plasma membrane, is limited by the cell's surface area to volume ratio. Larger cells can maintain higher SA:V ratios by having a non-spherical shape and extensions of the membrane. Within the cell, the presence of organelles specialised to perform particular functions creates cellular compartments, which also improve functional efficiency in a larger cell.

Cell size and functional efficiency

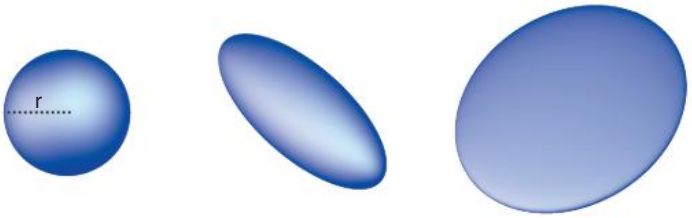
Cells have a wide range of sizes. Large eukaryotic cells may reach 100 µm in diameter, whereas bacteria typically only reach a tenth of that. Eukaryotic cells can remain efficient at larger sizes in part because they contain **organelles**, which concentrate associated materials (such as the reactants and enzymes in a metabolic pathway) into specific regions for specific purposes. These cellular compartments enable efficiency of function.



Cellular respiration occurs within the mitochondria, which has regions in which different reactions occur.

Solving the size problem

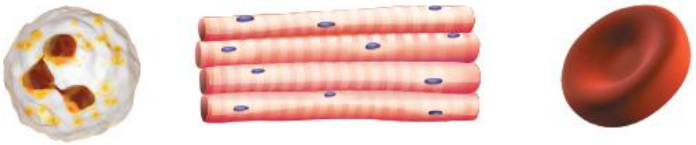
One way of increasing a cell's surface area while retaining the same volume is to elongate the cell. An elongated sphere (an ellipsoid, e.g. a rod shaped cell) has a greater surface area than a sphere of the same volume. In this way, a cell can grow larger while still gaining the materials it needs. The cells of multicellular organisms are often highly specialised to maximise SA: V. The three images below are all to scale.



Sphere
V = 2 cm^3
SA= 7.65 cm^2

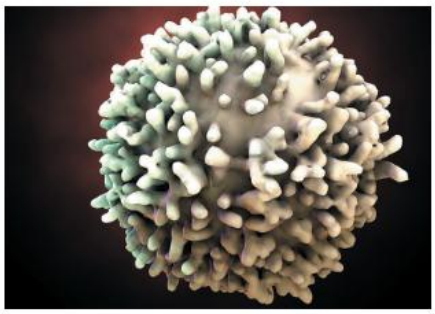
Ellipsoid
V = 2 cm^3
SA= 8.8 cm^2

Disc shaped ellipsoid
V = 2 cm^3
SA= 14.98 cm^2



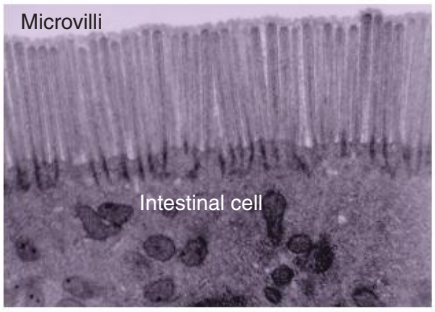
White blood cell *Skeletal muscle cells* *Red blood cell*

By flattening the ellipsoid along one axis and stretching it along the other two to form a disc, surface area increases while the volume remains the same.



Animal cells, such as this B cell (a type of white blood cell), often have extensions of the cell membrane providing a high surface area for transfer of materials.

Tissues are organised to increase surface area. Here, the intestinal wall is folded into projections called villi. Column-shaped intestinal cells line the surface of the villi.



The cell membrane of each intestinal cell is folded into numerous microvilli. These increase the surface area for absorbing nutrient and binding digestive enzymes.

1. Use the formulae surface area = $4\pi r^2$ and volume = $(^4/_3)\pi r^3$ (where $\pi = 3.14$) to calculate surface area, volume, and SA:V of a spherical cell with a radius (r) of (a) 2 µm and (b) 10 µm:

   (a) 2 µm, SA: _____ V: _____ SA:V: _____

   (b) 10 µm, SA: _____ V: _____ SA:V: _____

2. (a) What happens to the SA:V ratio of a spherical cell as its volume increases? _____

   (b) How can eukaryotic cells overcome the restrictions of reduced SA:V as they become larger: _____

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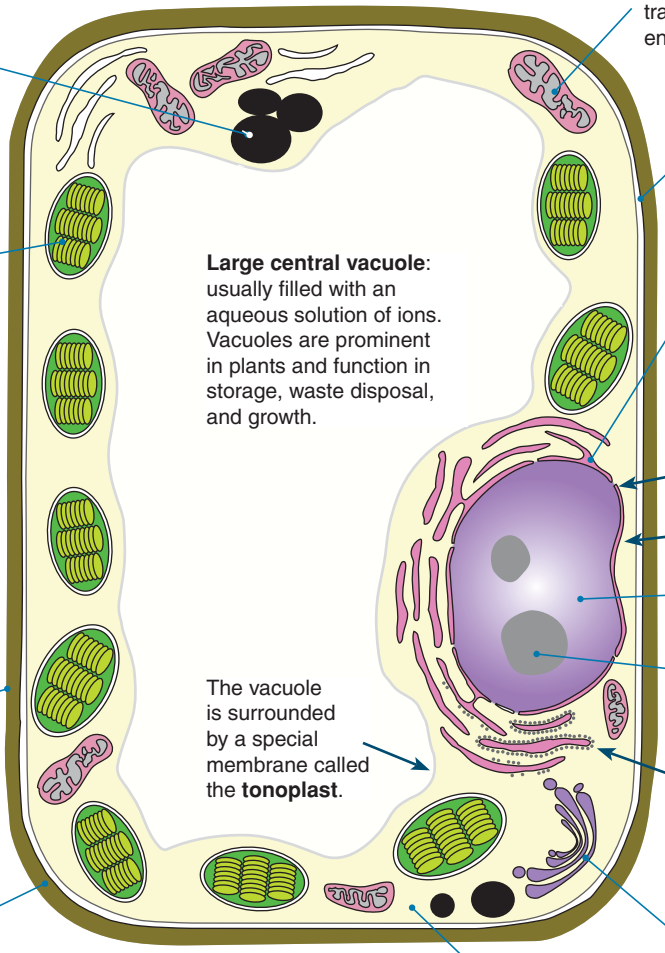
20 Plant Cells

Key Idea: Plant cells are eukaryotic cells. They have features in common with animal cells, but also several unique features.

Eukaryotic cells have a similar basic structure, although they may vary tremendously in size, shape, and function. Certain features are common to almost all eukaryotic cells, including their three main regions: a nucleus, surrounded by a watery cytoplasm, which is itself enclosed by the plasma membrane. Plant cells are enclosed in a cellulose cell wall, which gives them a regular, uniform appearance. The cell wall protects the cell, maintains its shape, and prevents excessive water uptake. It provides rigidity to plant structures but permits the free passage of materials into and out of the cell.

Generalised plant cell



Starch granule: Carbohydrate stored in **amyloplasts** (specialised storage organelles).

Chloroplast: Specialised organelles, 2 µm x 5 µm, containing the green pigment chlorophyll. Chloroplasts contain dense stacks of membranes within a fluid which is much like cytosol. They are the sites for photosynthesis and are found mainly in leaves. Chloroplasts are one of a group of double membraned organelles called **plastids**, which include amyloplasts (see above).

Cell wall: A semi-rigid structure outside the plasma membrane, 0.1 µm to several µm thick. It is composed mainly of cellulose. It supports the cell and limits its volume.

Middle lamella (seen here between adjacent cells left): The first layer of the cell wall formed during cell division. It contains pectin and protein, and provides stability. It allows the cells to form **plasmodesmata (P)**, special channels that allow communication and transport to occur between cells.

Large central vacuole: usually filled with an aqueous solution of ions. Vacuoles are prominent in plants and function in storage, waste disposal, and growth.

The vacuole is surrounded by a special membrane called the **tonoplast**.

Mitochondrion: 1.5 µm X 2–8 µm. They are the cell's energy transformers, converting chemical energy into ATP.

Plasma membrane: Located inside the cell wall in plants, 3 to 10 nm thick.

Endoplasmic reticulum (ER): A network of tubes and flattened sacs. ER is continuous with the nuclear membrane and may be smooth or have attached ribosomes (rough ER).

Nuclear pore: 100 nm diameter

Nuclear membrane: a double layered structure.

Nucleus: A conspicuous organelle 5 µm diameter.

Nucleolus

Ribosomes: These small (20 nm) structures manufacture proteins. They may be free in the cytoplasm or associated with the surface of the endoplasmic reticulum.

Golgi apparatus

Cytoplasm: A watery solution containing dissolved substances, enzymes, and the cell organelles and structures.

1. (a) What are the functions of the cell wall in plants? _____

   _____

   (b) Why is the middle lamella of the cell wall important? _____

   _____

2. What distinguishes the tonoplast and the plasma membrane? _____

   _____

3. (a) What structure takes up the majority of space in the plant cell? _____

   (b) What are its roles? _____

4. Identify two structures in the diagram that are not found in animal cells: _____

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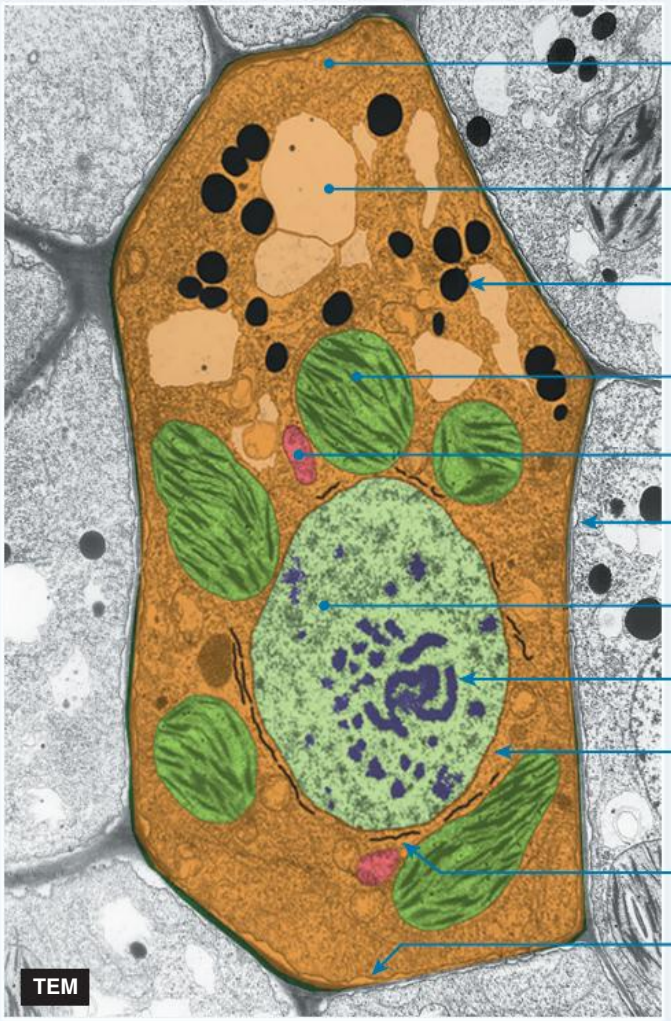
5. Study the diagrams on the other pages in this chapter to familiarise yourself with the structures found in eukaryotic cells. Identify the 11 structures in the cell below using the following word list: *cytoplasm, smooth endoplasmic reticulum, mitochondrion, starch granule, chromosome, nucleus, vacuole, plasma membrane, cell wall, chloroplast, nuclear membrane*



(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)

6. State how many cells, or parts of cells, are visible in the electron micrograph above: _____

7. Describe the features that identify this cell as a plant cell: _____

_____

_____

8. (a) Explain where cytoplasm is found in the cell: _____

_____

(b) Describe what the cytoplasm is made up of: _____

_____

9. Describe two structures, pictured in the cell above, that are associated with storage:

(a) _____

_____

_____

(b) _____

_____

_____

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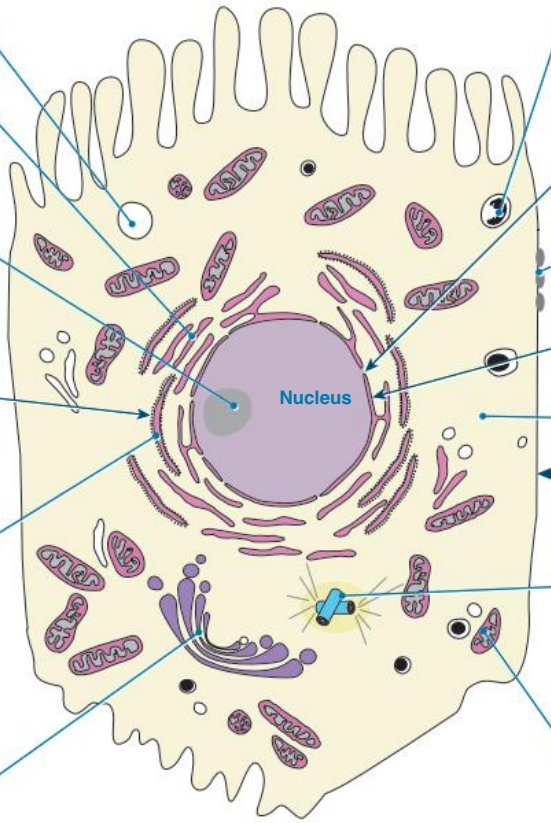
21 Animal Cells

Key Idea: Animal cells are eukaryotic cells. They have many features in common with plant cells, but also have a number of unique features.

Animal cells, unlike plant cells, do not have a regular shape. In fact, some animal cells (such as phagocytes) are able to alter their shape for various purposes (e.g. engulfing foreign material). The diagram below shows the structure and organelles of a liver cell. It contains organelles common to most relatively unspecialised human cells. Note the differences between this cell and the generalised plant cell. The plant cells activity provides further information on the organelles listed here but not described.

Generalised animal cell



Vacuoles: Smaller than those found in plant cells. In animal cells, vacuoles have minor roles in exocytosis and endocytosis.

Smooth endoplasmic reticulum: ER without ribosomes. It is a site for lipid and carbohydrate metabolism, including hormone synthesis.

Nucleolus: A dense, solid structure composed of crystalline protein and nucleic acid. They are involved in ribosome synthesis.

Ribosomes: These small structures may be free in the cytoplasm or associated with the endoplasmic reticulum (ER). Ribosomes in animal cells are 80S ribosomes

Rough endoplasmic reticulum: A site of protein synthesis.The rough ER also synthesises new membranes, growing in place by adding proteins and phospholipids.

Golgi apparatus (20-200 nm): A series of flattened, disc-shaped sacs, stacked one on top of the other and connected with the ER. The Golgi stores, modifies, and packages proteins. It 'tags' proteins so that they go to their correct destination.

Lysosome: A sac bounded by a single membrane. They are pinched off from the Golgi apparatus and contain and transport enzymes that break down food and foreign matter. Lysosomes show little internal structure but often contain fragments of material being broken down. Specialised lysosomes are generally absent from plant cells.

Nuclear pore: A hole in the nuclear membrane allowing the nucleus to communicate with the rest of the cell.

Tight junctions: Join cells together in the formation of tissues.

Nuclear membrane: Double layered

Cytoplasm

Plasma (cell surface) membrane

Centrioles: Structures within a centrosome associated with nuclear division. They are composed of microtubules, but appear as small, featureless particles, 0.25 μm diameter, under a light microscope. They are absent in higher plant cells and some protists.

Mitochondrion (*pl.* mitochondria): An organelle bounded by a double membrane system. The number in a cell depends on its metabolic activity.

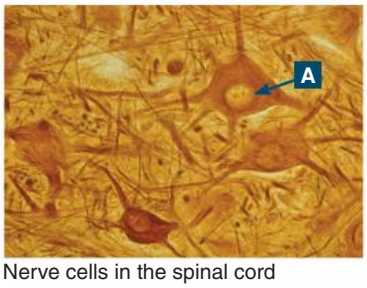
1. What is the difference between vacuoles in plant and animal cells? _____

_____

_____

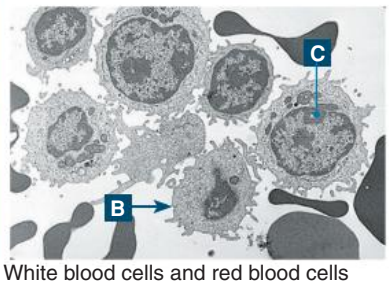
2. Name one structure or organelle present in generalised animal cells but absent from plant cells and describe its function:

_____



Photos: Ell

Nerve cells in the spinal cord



White blood cells and red blood cells

3. The two photomicrographs below show several types of animal cells. Identify the features indicated by the letters A-C:

(a) _____

(b) _____

(c) _____

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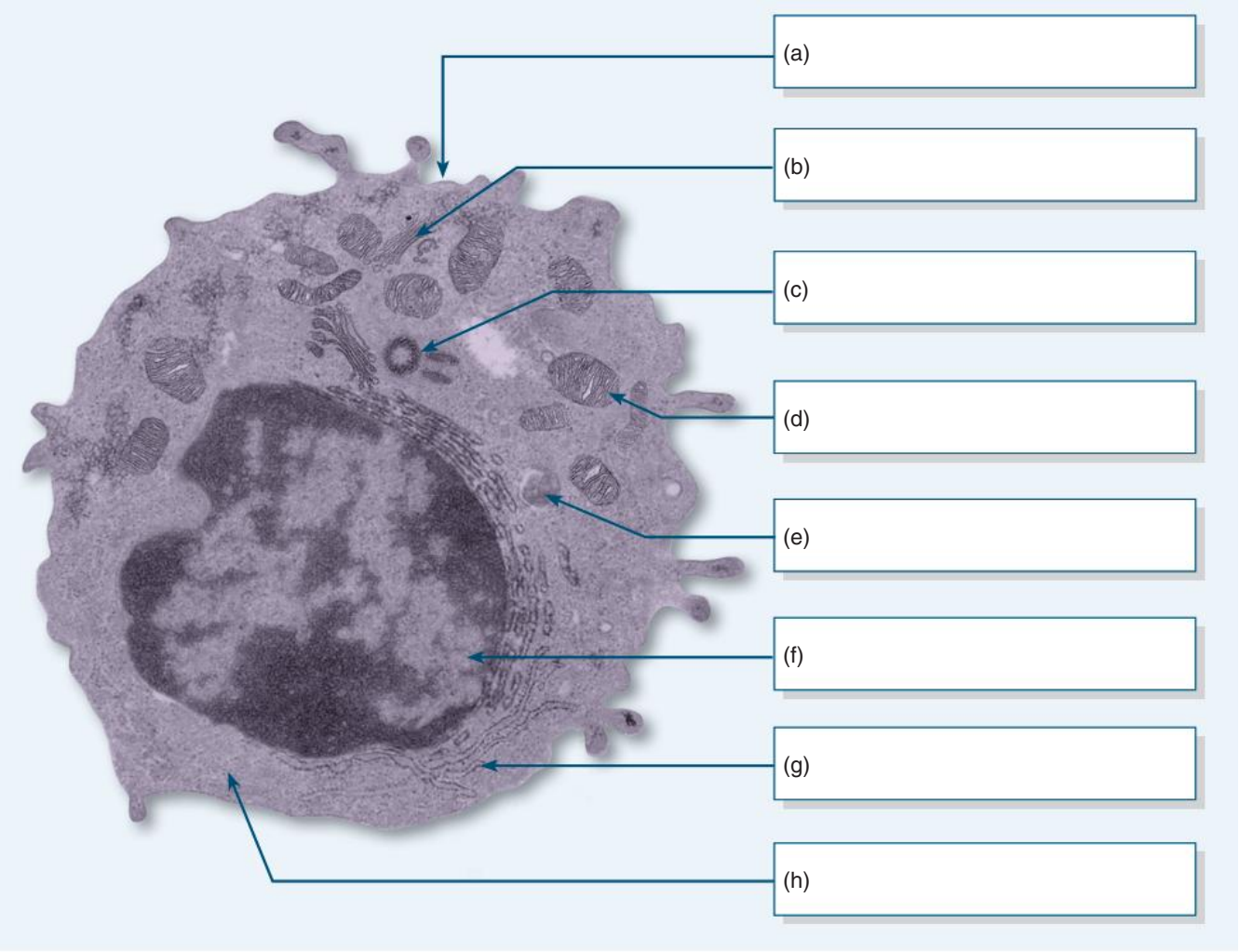
4. Identify and label the structures in the TEM of the animal cell below using the following list of terms: *cytoplasm, plasma membrane, rough endoplasmic reticulum, mitochondrion, nucleus, centriole, Golgi apparatus, lysosome*



5. Which of the organelles in the TEM above are obviously shown in both transverse and longitudinal section?

_____

6. Why do plants lack any of the mobile phagocytic cells typical of animal cells? _____

_____

_____

7. The animal cell pictured above is a lymphocyte. Describe the features that suggest to you that:

   (a) It has a role in producing and secreting proteins: _____

   _____

   (b) It is metabolically very active: _____

   _____

8. What features of the lymphocyte cell above identify it as eukaryotic? _____

_____

_____

9. If you were to see the cell above with no other references, how would you be able to identify it as an animal cell?

_____

_____

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22 Cell Structures and Organelles

Key Idea: Each type of organelle in a cell has a specific role. Not all cell types contain every type of organelle.
The diagram below provides spaces for you to summarise information about the organelles found in eukaryotic cells. The log scale of measurements (top of next page) illustrates the relative sizes of some cellular structures.

1. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

2. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

3. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

4. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

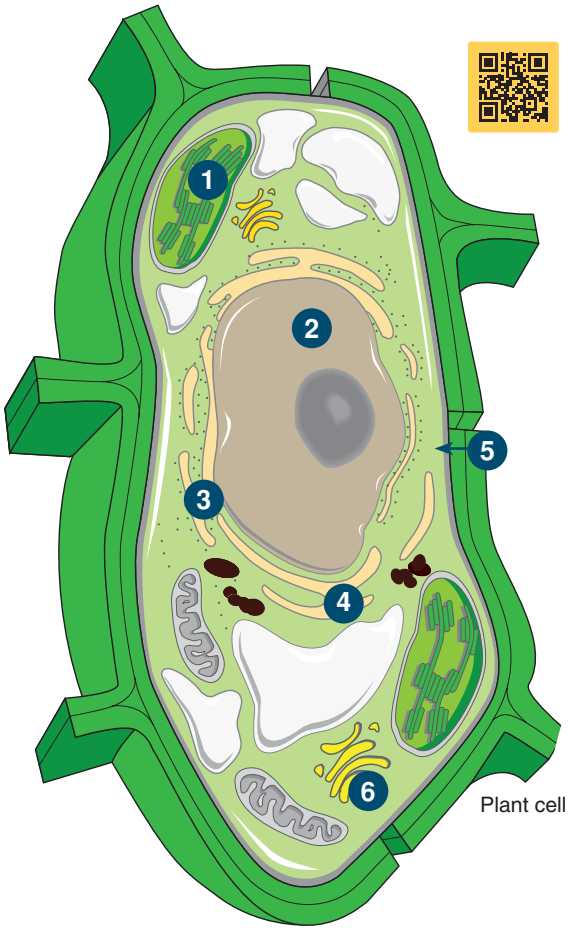
   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

5. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells



Plant cell

6. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

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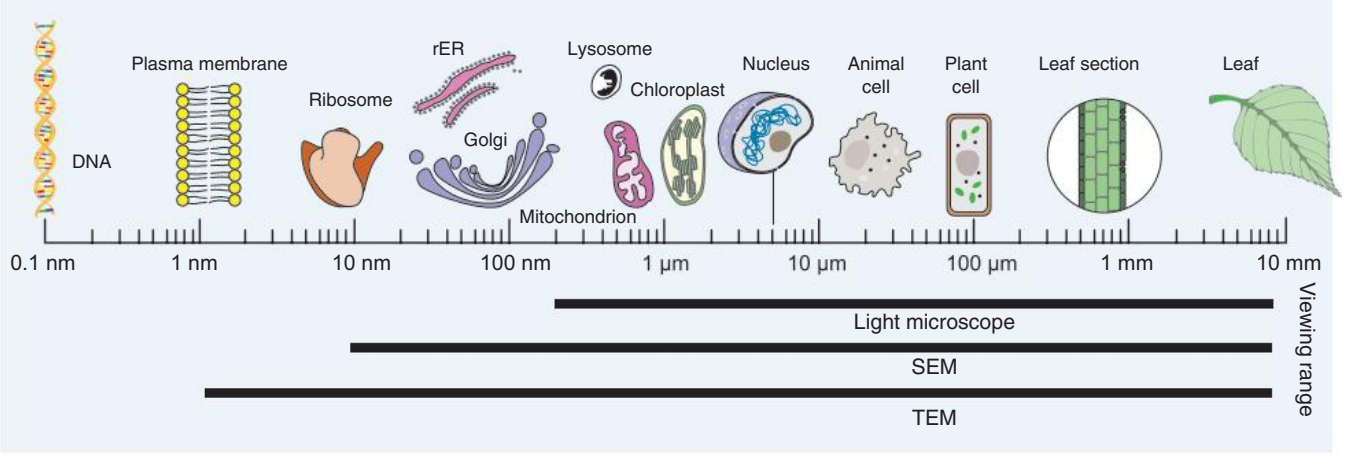

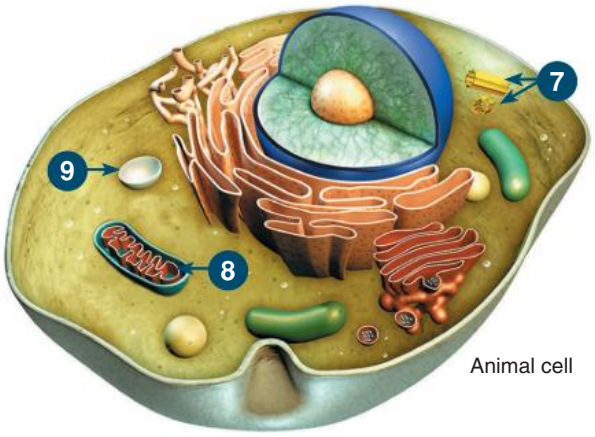

Animal cell

7. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

8. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

9. (a) Name this organelle:

   (b) Structure and location:

   (c) Function:

   (d) This organelle is found (circle the correct answer): only in plant cells / only in animal cells / in both plant and animal cells

10. Use the scale at the top of the page and the information on previous activities to identify which of the organelles (1-9) can be seen through a light microscope:

11. Identify which of the organelles (1-9) require a TEM (transmission electron microscope) to be seen: _____

12. Identify one other structure in the plant cell not labelled opposite and describe its function: _____

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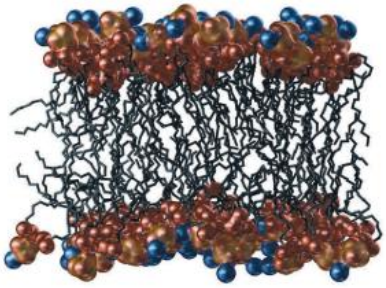
23 The Plasma Membrane

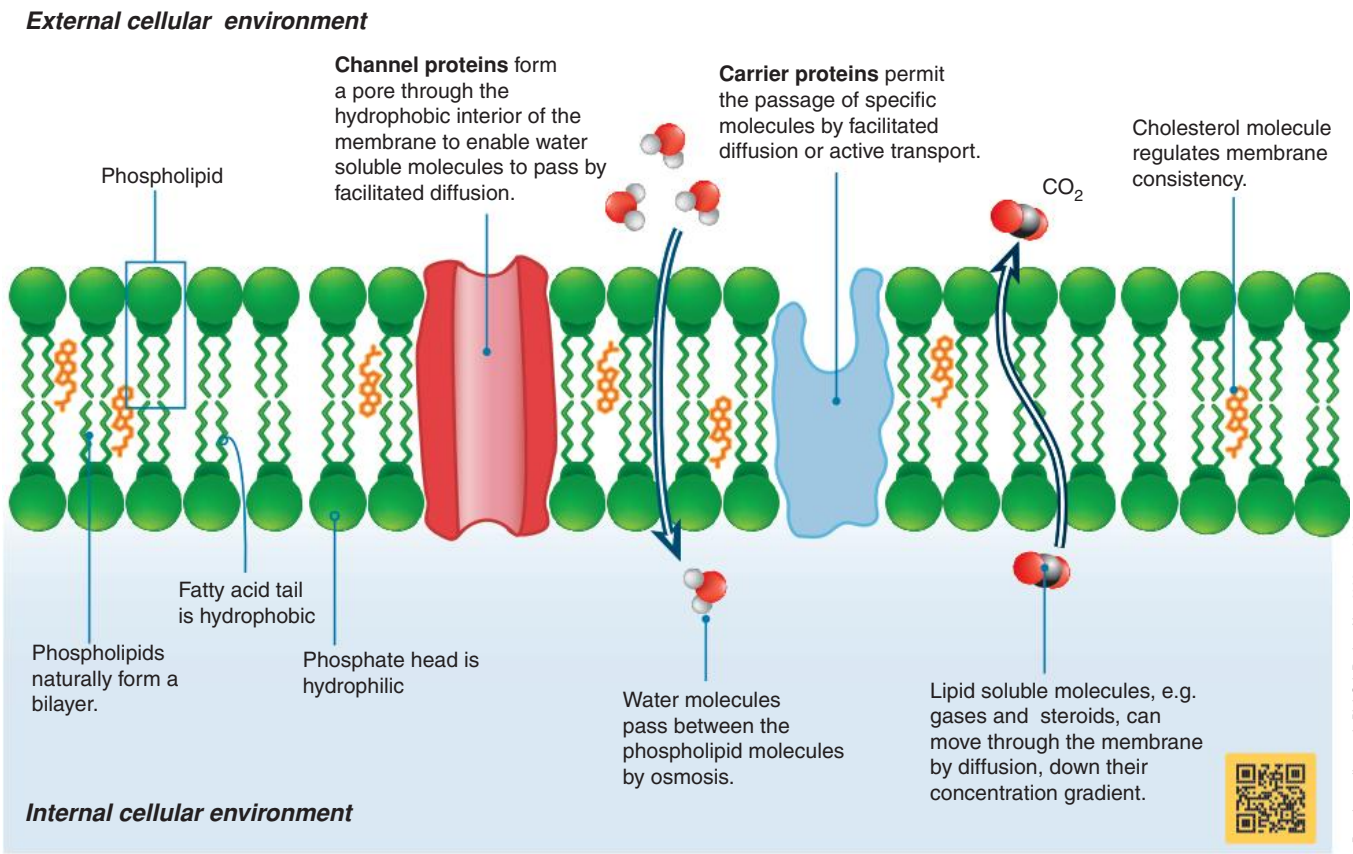
Key Idea: The plasma membrane is composed of a lipid bilayer with proteins moving freely within it. It is the partially permeable (also called semi-permeable or selectively permeable) boundary between the internal and external cell environments.

All cells have a plasma membrane, which forms the outer limit of the cell. A cell wall, if present, lies outside this, and it is quite distinct from it. Cellular membranes are also found inside eukaryotic cells as part of membranous organelles. The currently accepted model of the plasma membrane describes a lipid bilayer with proteins embedded within it, called the **fluid-mosaic model** (below). This model was devised by Singer and Nicolson in 1972. The plasma membrane is a partially permeable barrier. It allows the passage of some molecules but not others. Many of the proteins embedded in the membrane are involved in the movement of molecules by transporting specific molecules (often large molecules or ions) across the membrane, often against their concentration gradients.



Molecular model showing how phospholipid molecules naturally orientate to form a bilayer.

Simple membrane structure



Based on a diagram in Biol. Sci. Review, Nov. 2009, pp. 20-21

1. List the important components of the plasma membrane: _____

   _____

2. Identify the kind of molecule on the diagram above that can:

   (a) Move through the plasma membrane by diffusion: _____

   _____

   (b) Form a channel through the membrane: _____

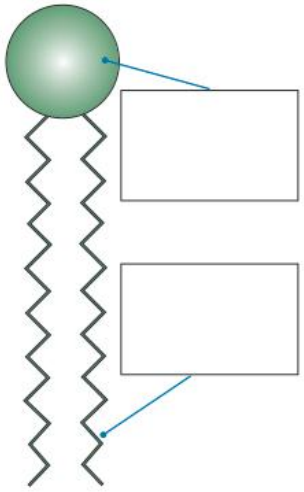
3. (a) On the diagram (right) label the hydrophobic and hydrophilic ends of the phospholipid and indicate which end is attracted to water:

   (b) How does this structure make the phospholipid molecule behave?

   _____

   _____

   _____



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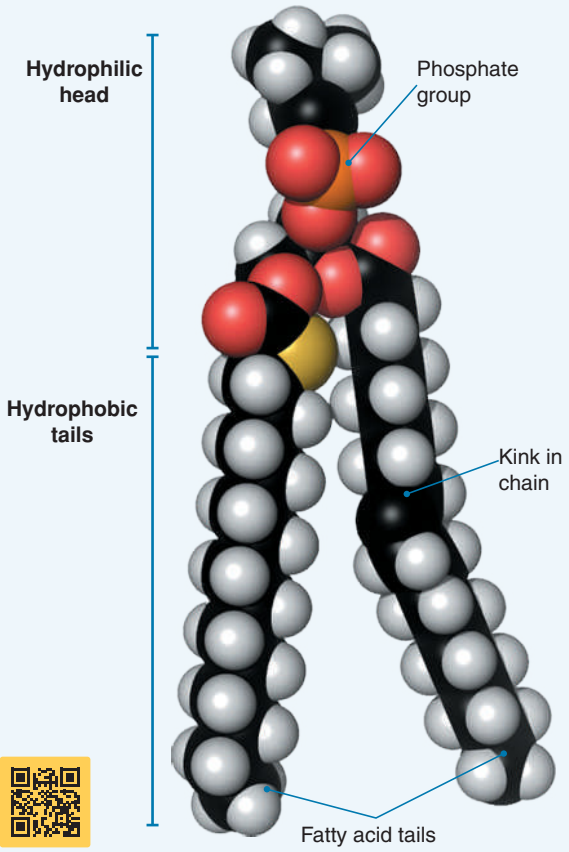
24 Phospholipids and the Properties of Membranes

Key Idea: Phospholipids are important components of cellular membranes. They are made up of a hydrophilic head region and a hydrophobic tail region, making them amphipathic.

Phospholipids consist of a glycerol attached to two fatty acid chains and a phosphate (PO_4^{3-}) group. Phospholipids naturally form bilayers in aqueous solutions and are the main component of cellular membranes. The fatty acid tails can be saturated (forming straight chains) or unsaturated (kinked chains). The level of phospholipids with saturated or unsaturated tails affects the fluidity of the phospholipid bilayer.

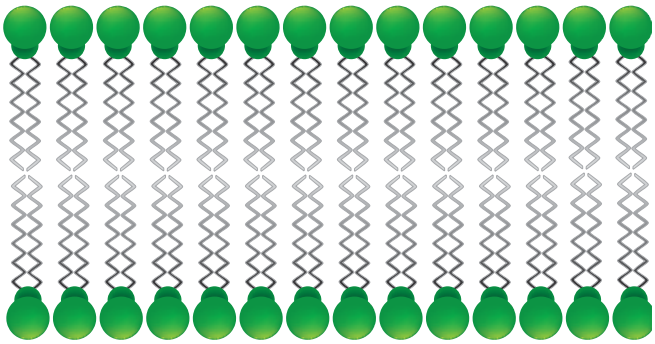
Phospholipids

The phosphate end of the phospholipid is attracted to water (it is hydrophilic) while the fatty acid end is repelled (hydrophobic). In an aqueous environment, the hydrophobic ends turn inwards in the membrane to form a bilayer. Fatty acids containing double C=C bonds are unsaturated. This causes a "kink" in the chain.

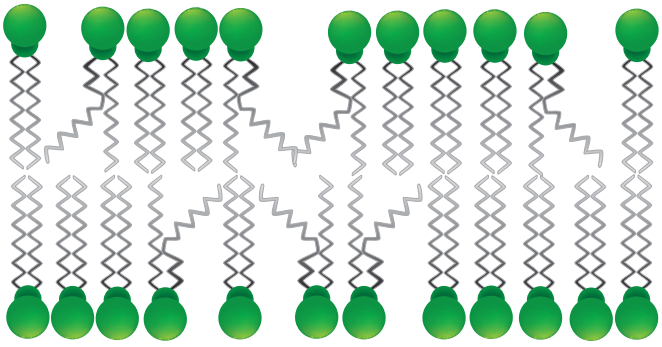


Phospholipids and membranes

Phospholipids are amphipathic (have hydrophobic and hydrophilic regions). This means that they will spontaneously form bilayers when in aqueous environments and so form the outer boundary of cells and organelles. Modifications to the hydrophobic ends of the phospholipids regulate the fluidity of the bilayer. The greater the number of double bonds in the hydrophobic tails, the greater the fluidity of the membrane.



Membrane containing only phospholipids with saturated fatty acid tails.



Membrane containing phospholipids with unsaturated fatty acid tails. The fact that the phospholipids do not stack neatly together produces a more fluid membrane that may remain fluid even at low temperatures.

1. (a) How do the properties of phospholipids contribute to their role in forming the structural framework of membranes?

(b) Explain why phospholipid bilayers containing many phospholipids with unsaturated tails are particularly fluid:

2. Suggest how the cell membrane structure of an Arctic fish might differ from that of tropical fish species:

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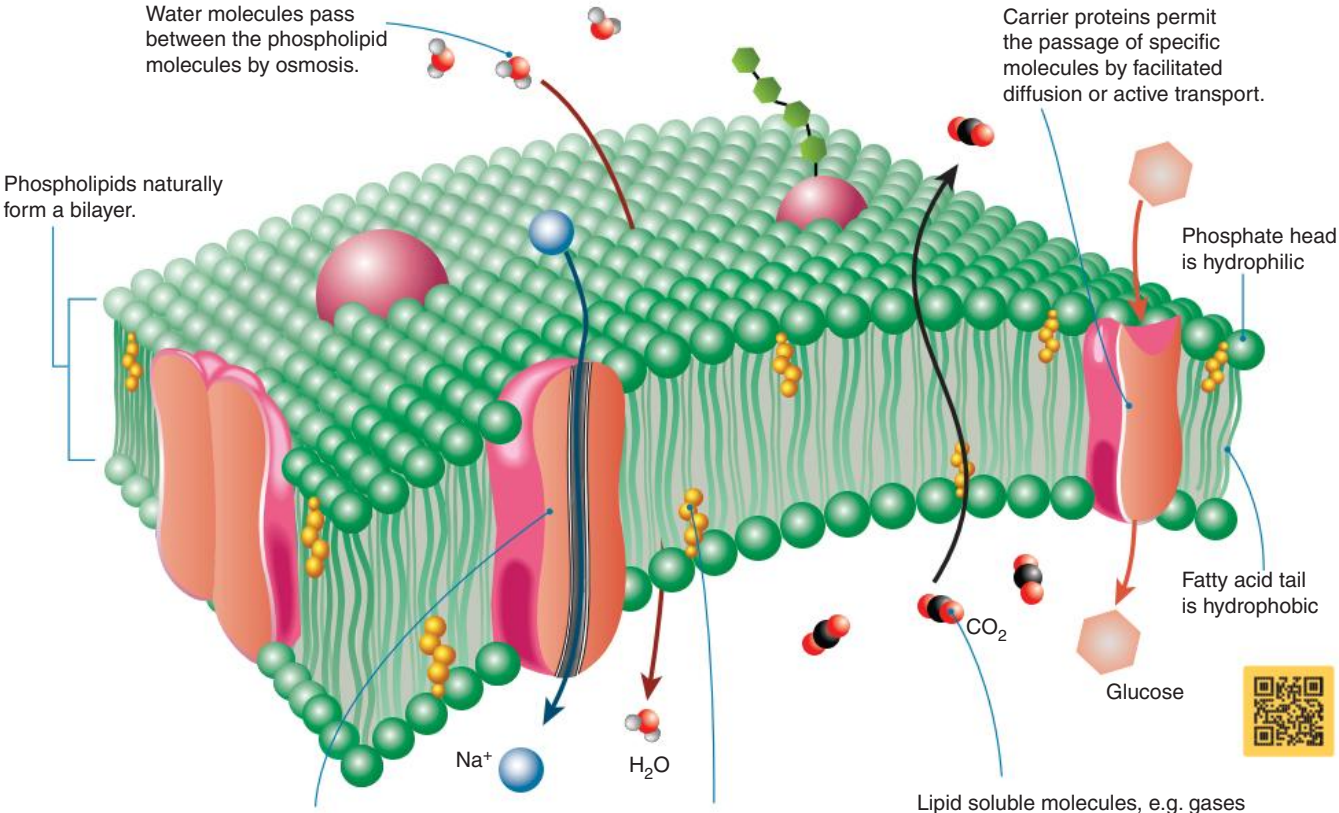
25 The Structure of the Plasma Membrane

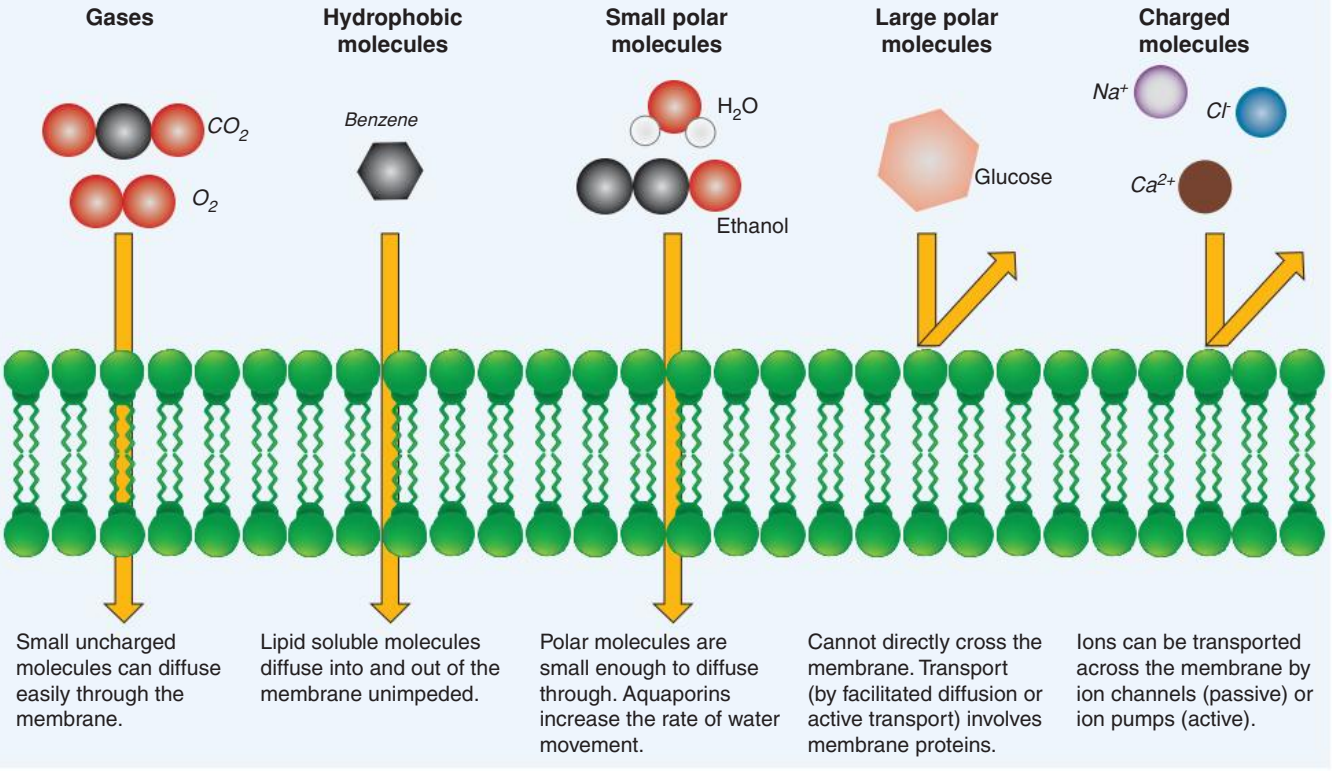
Key Idea: A cellular membrane is made of a phospholipid bilayer with proteins of different sorts embedded in it.

The plasma (or cell surface) membrane encloses the cell's contents and regulates many of the cell's activities. Importantly, it controls what enters and leaves the cell by the use of carrier and channel proteins.

Fluid mosaic model of membrane structure



What can cross a lipid bilayer?



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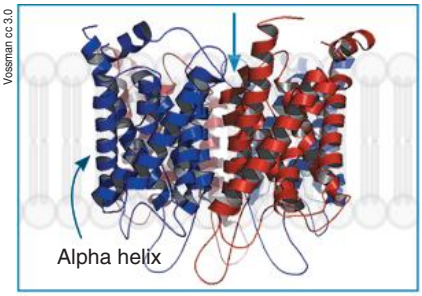
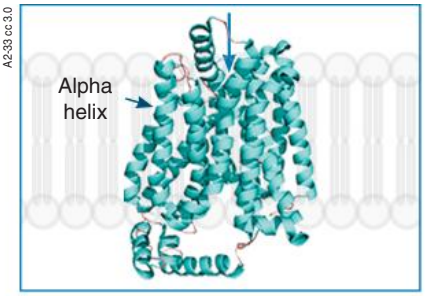
What do proteins in the cell surface membrane really look like?

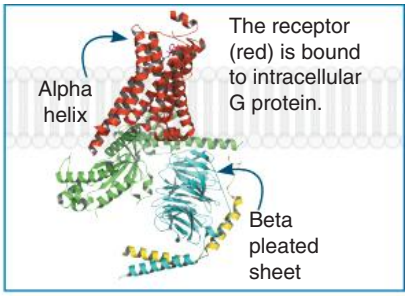
The structure of membrane proteins enables them to perform their particular function in transport, cell signalling, or cell recognition. The proteins are integral to the membrane, and often have parts of their structure projecting from both internal and external sides of the membrane. Note the two types of folding structure in membrane proteins: the alpha helix and the beta pleated sheet.



Aquaporins are a special type of channel protein that speed up the passage of water molecules across the membrane. Their tertiary structure creates a pore through the centre of the protein through which molecules can pass (arrow).



The GLUT1 glucose transporter is a carrier protein that facilitates the transport of glucose across the plasma membranes of mammalian cells. It increases the rate of glucose transport by 50,000X (high enough to supply the cell's energy needs).



G-protein coupled receptors are proteins involved in signalling pathways. A signal molecule binds to the receptor protein outside the cell to trigger a reaction involving intracellular G protein. In this example, the receptor binds to adrenaline.

1. What is the purpose of carrier proteins in the membrane? _____

2. What is the purpose of channel proteins in the membrane? _____

3. Identify the molecule(s) that:

   (a) Can diffuse through the plasma membrane on their own: _____

   (b) Can diffuse through the membrane via channel proteins: _____

   (c) Must be transported across the membrane by carrier proteins: _____

4. Describe the role of the following proteins in the plasma membrane:

   (a) Aquaporins: _____

   (b) GLUT1 protein: _____

   (c) G protein: _____

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26 Factors Altering Membrane Permeability

Key Idea: Temperature and solvents can disrupt the structure of cellular membranes and alter their permeability.

Membrane permeability can be disrupted if membranes are subjected to high temperatures or solvents. At temperatures above the optimum, the membrane proteins become denatured. Alcohols, e.g. ethanol, can also denature proteins. In both instances, the denatured proteins no longer function properly and the membrane loses its selective permeability and becomes leaky. In addition, the combination of alcohol and high temperature can also dissolve lipids.

Beetroot cubes

Plant cells often contain a large central vacuole surrounded by a membrane called a **tonoplast**. In beetroots, the cell vacuoles contain a water-soluble red pigment called betacyanin, which gives beetroot its colour. If the tonoplast is damaged, the red pigment leaks out into the surrounding environment. The amount of leaked pigment relates to the amount of damage to the tonoplast.

Investigation 2.2 The effect of temperature on membrane permeability

See appendix for equipment list.

1. Use a cork borer with an internal diameter of 4 mm to produce 15 cylinders of beetroot 20 mm long. Place them in a beaker of distilled water.
2. Set up five sets of three test tubes of 5 mL of distilled of water at the following temperatures using water baths: 0°C (ice bath), 20°C, 40°C, 60°C, 90°C. Leave for a few minutes to equalise the distilled water temperatures with the water baths.
3. Remove the beetroot from the distilled water and pat dry with a paper towel. Place one cylinder of beetroot into each test tube. Leave them for 30 minutes.
4. Remove the beetroot from the test tubes. Observe each group of test tubes and record the colour of the water in the table below.
5. Zero a colorimeter set to 530 nm with distilled water then use it to measure the absorbance of each beetroot sample and record the absorbance in the table below.
6. Calculate the mean absorbance for each temperature.

	Absorbance of beetroot samples at varying temperatures				
Temperature (°C)	Observation	Absorbance at 530 nm			Mean
		Sample 1	Sample 2	Sample 3	
0					
20					
40					
60					
90					

1. Why is it important to wash the beetroot cubes in distilled water prior to carrying out the experiment? _____

_____

2. (a) Based on the results in the table above, describe the effect of temperature on membrane permeability: _____

_____

_____

(b) Explain why this effect occurs: _____

_____

_____

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Method for determining effect of ethanol concentration on membrane permeability

Beetroot cubes were prepared the same way as described on the previous page. The following ethanol concentrations were prepared using serial dilution: 0, 6.25, 12.5, 25, 50, and 100%. Eighteen clean test tubes were divided into six groups of three and labelled with one of the six ethanol concentrations. Three cm^3 of the appropriate ethanol solution was placed into each test tube. A dried beetroot cube was added to each test tube. The test tubes were covered with parafilm (plastic paraffin film with a paper backing) and left at room temperature. After one hour the beetroot cubes were removed and the absorbance measured at 477 nm.
Results are given in the table, right.

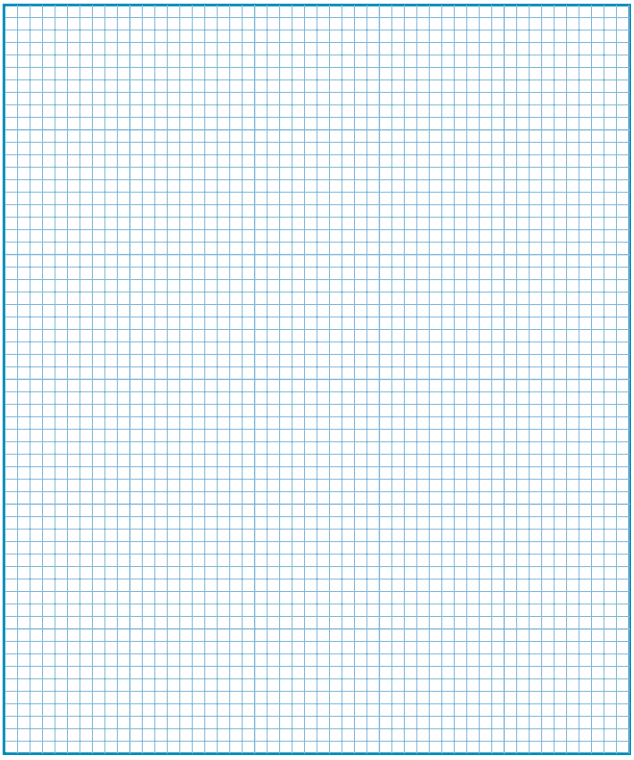
Absorbance of beetroot samples at varying ethanol concentrations

Ethanol concentration (%)	Absorbance at 477 nm			Mean
	Sample 1	Sample 2	Sample 3	
0	0.014	0.038	0.038	
6.25	0.009	0.015	0.023	
12.5	0.010	0.041	0.018	
25	0.067	0.064	0.116	
50	0.945	1.100	0.731	
100	1.269	1.376	0.907	

3. What was the purpose of the 0% ethanol solution in the experiment described above?

4. (a) Why do you think the tubes were covered in parafilm?

   (b) How could the results have been affected if the test tubes were not covered with parafilm?



5. (a) Complete the table above by calculating the mean absorbance for each ethanol concentration:

   (b) Plot a line graph of ethanol concentration against mean absorbance on the grid (above):

   (c) Describe the effect of ethanol concentration on the membrane permeability of beetroot: _____

6. How does ethanol affect membrane permeability? _____

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27 Osmosis

Key Idea: Osmosis is the diffusion of water molecules from a lower solute concentration to a higher solute concentration across a partially permeable membrane.

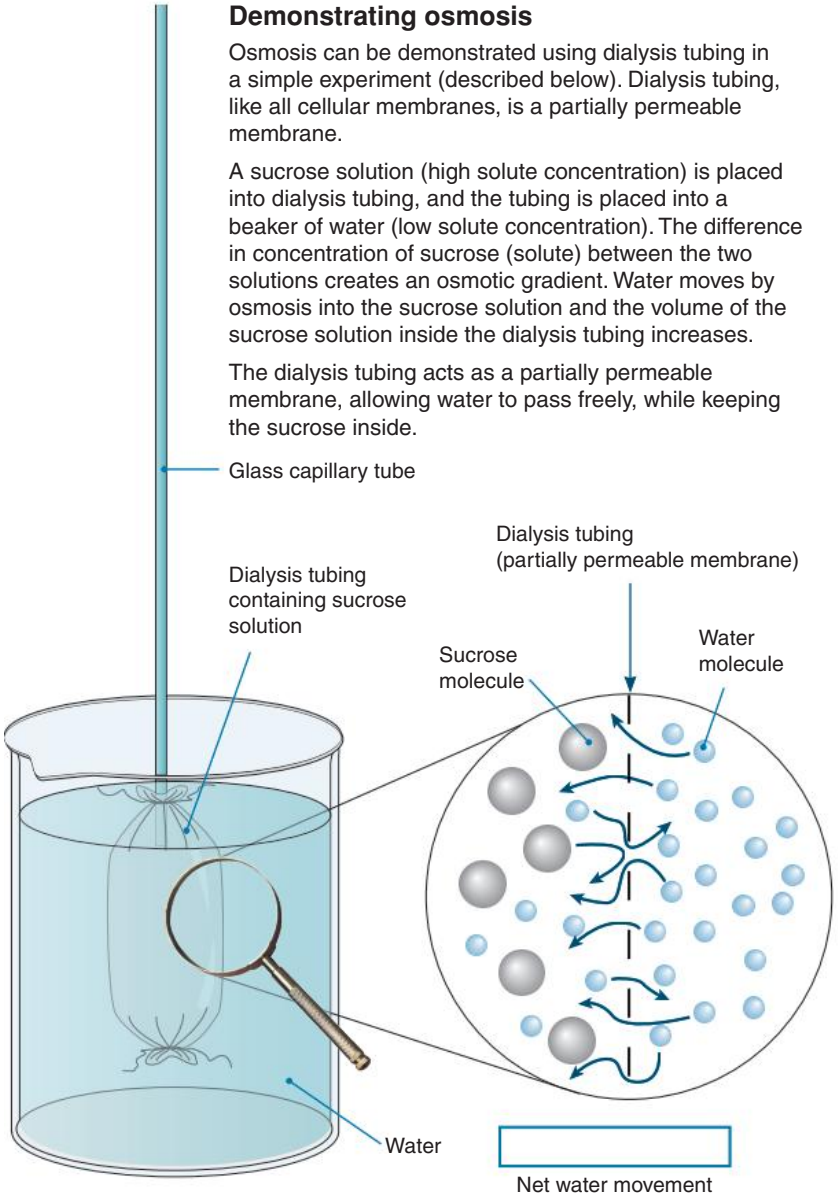
Osmosis is the diffusion of water molecules from regions of lower solute concentration (higher free water concentration) to regions of higher solute concentration (lower free water concentration) across a partially permeable membrane. A partially permeable membrane allows some molecules, but not others, to pass through. Water molecules will diffuse across a partially permeable membrane until an equilibrium is reached and net movement is zero. The plasma membrane of a cell is an example of a partially permeable membrane. Osmosis is a passive process and does not require any energy input.

Demonstrating osmosis

Osmosis can be demonstrated using dialysis tubing in a simple experiment (described below). Dialysis tubing, like all cellular membranes, is a partially permeable membrane.

A sucrose solution (high solute concentration) is placed into dialysis tubing, and the tubing is placed into a beaker of water (low solute concentration). The difference in concentration of sucrose (solute) between the two solutions creates an osmotic gradient. Water moves by osmosis into the sucrose solution and the volume of the sucrose solution inside the dialysis tubing increases.

The dialysis tubing acts as a partially permeable membrane, allowing water to pass freely, while keeping the sucrose inside.



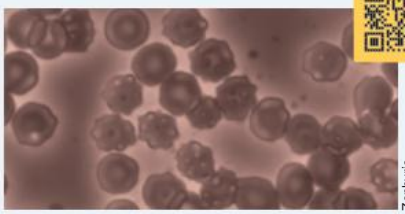
Osmotic potential

The presence of solutes (dissolved substances) in a solution increases the tendency of water to move into that solution. This tendency is called the osmotic potential or osmotic pressure. The more total dissolved solutes a solution contains, the greater its osmotic potential.

Describing solutions

Osmosis is important when handling body tissues for medical transport or preparation. The tissue must be bathed in a solution with an osmolarity (a measure of solute concentration) equal to the tissue's to avoid a loss or gain of fluid in the tissue. Solutions separated by a partially permeable membrane are often described in terms of their solute concentration concentrations relative to one another.

Isotonic solution: Having the same solute concentration relative to another solution (e.g. the cell's contents).
Hypotonic solution: Having a lower solute concentration relative to another solution.
Hypertonic solution: Having a higher solute concentration relative to another solution.



The red blood cells above were placed into a hypertonic solution. As a result, the cells have lost water and have begun to shrink, losing their usual discoid shape.

1. What is osmosis? _____

2. (a) In the blue box on the diagram above, draw an arrow to show the direction of net water movement.

   (b) Why did water move in this direction? _____

3. What would happen to the height of the water in the capillary tube if the sucrose concentration was increased?

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28 Estimating Osmolarity of Cells

Key Idea: Determining loss or gain of mass in tissues allows us to determine the osmolarity of the tissue's cells.

The osmolarity (a measure of solute concentration) of a cell or tissue can be estimated by placing part of the cell or tissue into a series of solutions of known concentration and observing if the tissue loses (hypertonic solution) or gains (hypotonic solution) water. The solution in which the tissue remains unchanged indicates the osmolarity of the tissue.

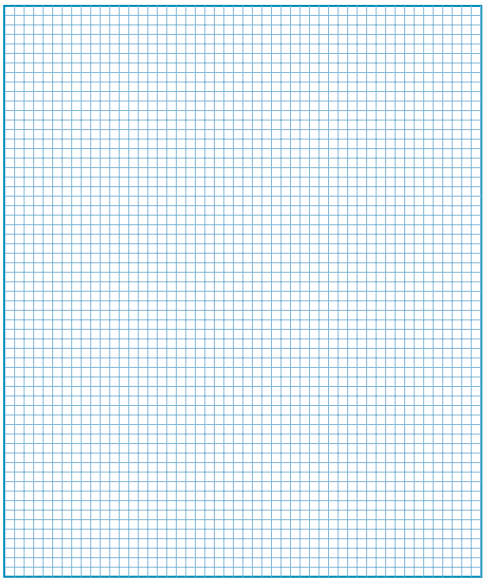
Investigation 2.3 Estimating osmolarity

See appendix for equipment list.

1. Prepare 6 beakers of sucrose ($C_{12}H_{22}O_{11}$, table sugar) solution with the concentrations of 0.0 (distilled water), 0.1, 0.2, 0.3, 0.4, and 0.5 mol/L of sucrose (0, 34.2 g , 68.5 g, 102.6 g, 136.9 g, and 171.1 g per litre). Label the beakers so that they can be easily identified at the end of the experiment.
2. Peel a potato and cut it into 18 identical cubes 1 cm^3 (1 cm x 1 cm x 1 cm) or use a cork borer to produce 18 identical cylinders of potato. Pat the potato cubes dry with a paper towel.
3. Weigh three cubes together, record their mass in the table below under initial mass. Place the cubes in the beaker of distilled water.
4. Repeat step 3 with the other 15 potato cubes and concentrations. Make sure you identify each beaker so the cubes can be weighed at the end of the experiment.
5. Leave the potato cubes in the solutions for at least 40 minutes (or up to 24 hours).
6. Remove the potato cubes from the distilled water and pat dry with a paper towel. Weigh all three together and record their mass in the table below under final mass.
7. Repeat for all the other concentrations of sucrose.
8. Calculate the change in mass (if any) for all the concentrations. Then calculate the % change (+ or -) (this removes any error based on the masses of the potato cubes not being identical).
9. Plot the % change vs sucrose concentration on the grid provided.

Sucrose concentration (mol/L)	Initial mass (I) (g)	Final mass (F) (g)
0.00		
Change (C) (F-I) (g)		
% Change (C/I x 100)		
0.1		
Change (C) (F-I) (g)		
% Change (C/I x 100)		
0.2		
Change (C) (F-I) (g)		
% Change (C/I x 100)		
0.3		
Change (C) (F-I) (g)		
% Change (C/I x 100)		
0.4		
Change (C) (F-I) (g)		
% Change (C/I x 100)		
0.5		
Change (C) (F-I) (g)		
% Change (C/I x 100)		

1. Use the grid below to draw a line graph of the sucrose concentration vs total % change in mass:



2. Use the graph to estimate the osmolarity of the potato (the point where there is no change in mass):

_____

3. Which of the solutions are hypotonic? Which are hypertonic?

_____

_____

5 A-1 A-4

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29 Water Relations in Plant Cells

Key Idea: Plant cells in a hypertonic solution lose water and undergo plasmolysis. In a hypotonic solution, they gain water creating turgor pressure.

Osmosis across the partially permeable cell membrane is the main way by which water enters and leaves the cell. When the external concentration of free water molecules is the same as that of the cytoplasm there is no net movement of water. Changing the tonicity of the external environment will cause a net movement of water into or out of the cell as water moves down its concentration gradient.

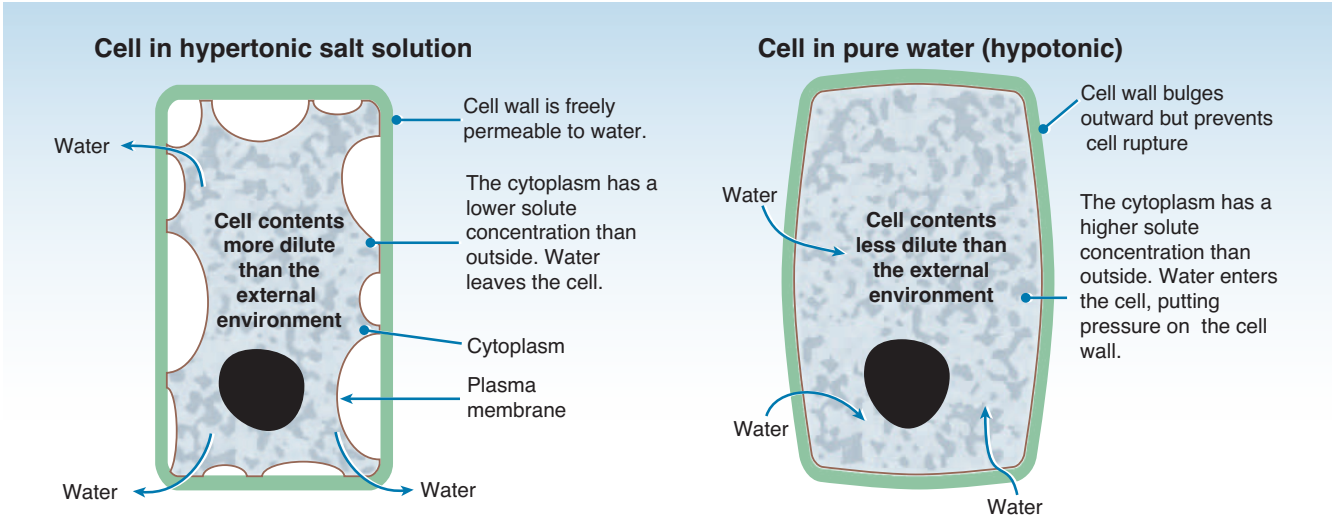
Osmosis and tonicity

When the watery contents of a plant cell push against the cell wall they create **turgor** (tightness) which helps to provide support for the plant body. When cells lose water, there is a loss of cell turgor and the plant will wilt. Complete loss of turgor from a cell is called plasmolysis and is irreversible. Two systems (cell and environment) with the same effective osmotic pressure are termed isotonic and there is no net movement of water molecules. However, when there is an osmotic gradient between the cell and environment there will be a net movement of water molecules down their concentration gradient. The diagram below shows two different situations: when a plant cell is in a hypertonic solution and when it is in a hypotonic solution.

Wilted plant (cells have lost turgor)

Plant cells are turgid

MCC UW



Plasmolysis in a plant cell

Tonicity is a measure of the osmotic pressure of a solution. In a hypertonic solution, the external free water concentration is lower than the free water concentration of the cell. Water leaves the cell and, because the cell wall is rigid, the cell membrane shrinks away from the cell wall. This is called **plasmolysis** and the cell becomes flaccid (limp).

Turgor in a plant cell

In a hypotonic solution, the external free water concentration is higher than the cell cytoplasm. Water enters the cell, causing it to swell tight. A wall (turgor) pressure is generated when the cell contents press against the cell wall. Turgor pressure increases until no more water enters the cell (the cell is **turgid**).

1. Identify the outcome of the following situations:

   (a) A plant cell is placed in a hypertonic solution: _____

   (b) A plant cell is placed in a hypotonic solution: _____

   (c) A plant cell in an isotonic solution: _____

2. (a) Explain the role of cell wall pressure in generating cell turgor in plants: _____

   _____

   _____

   (b) Discuss the role of cell turgor in plants: _____

   _____

   _____

   _____

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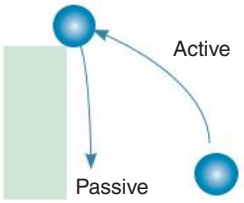
30 Active Transport

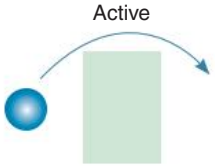
Key Idea: Active transport uses energy to transport molecules against their concentration gradient across a partially permeable membrane.

Active transport is the movement of molecules (or ions) from regions of low concentration to regions of high concentration across a cellular membrane by a transport protein. Active transport needs energy to proceed because molecules are being moved against their concentration gradient.

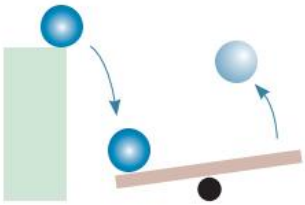
- The energy for active transport comes from ATP (adenosine triphosphate). Energy is released when ATP is hydrolysed (water is added) forming ADP (adenosine diphosphate) and inorganic phosphate (Pi).
- Transport (carrier) proteins in the membrane are used to actively transport molecules from one side of the membrane to the other (below).
- Active transport can be used to move molecules into and out of a cell.
- Active transport can be either primary or secondary. Primary active transport directly uses ATP for the energy to transport molecules. In secondary active transport, energy is stored in a concentration gradient. The transport of one molecule is coupled to the movement of another down its concentration gradient, ATP is not directly involved in the transport process.



A ball falling is a passive process (it requires no energy input). Replacing the ball requires active energy input.

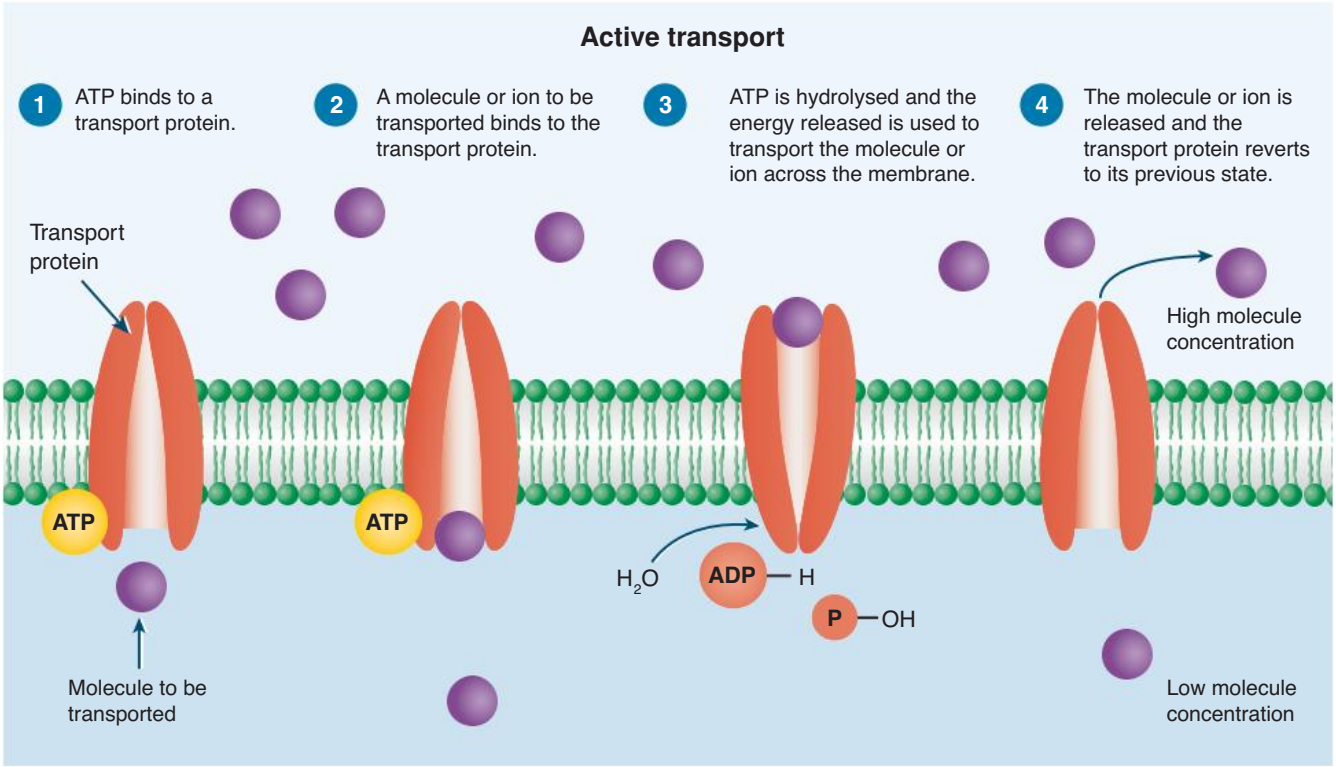


It requires energy to actively move an object across a physical barrier.



Sometimes the energy of a passively moving object can be used to actively move another. For example, a falling ball can be used to catapult another (left).

Active transport



1. What is active transport? _____

_____

_____

2. Where does the energy for active transport come from? _____

3. What is the difference between primary active transport and secondary active transport? _____

_____

_____

_____

_____

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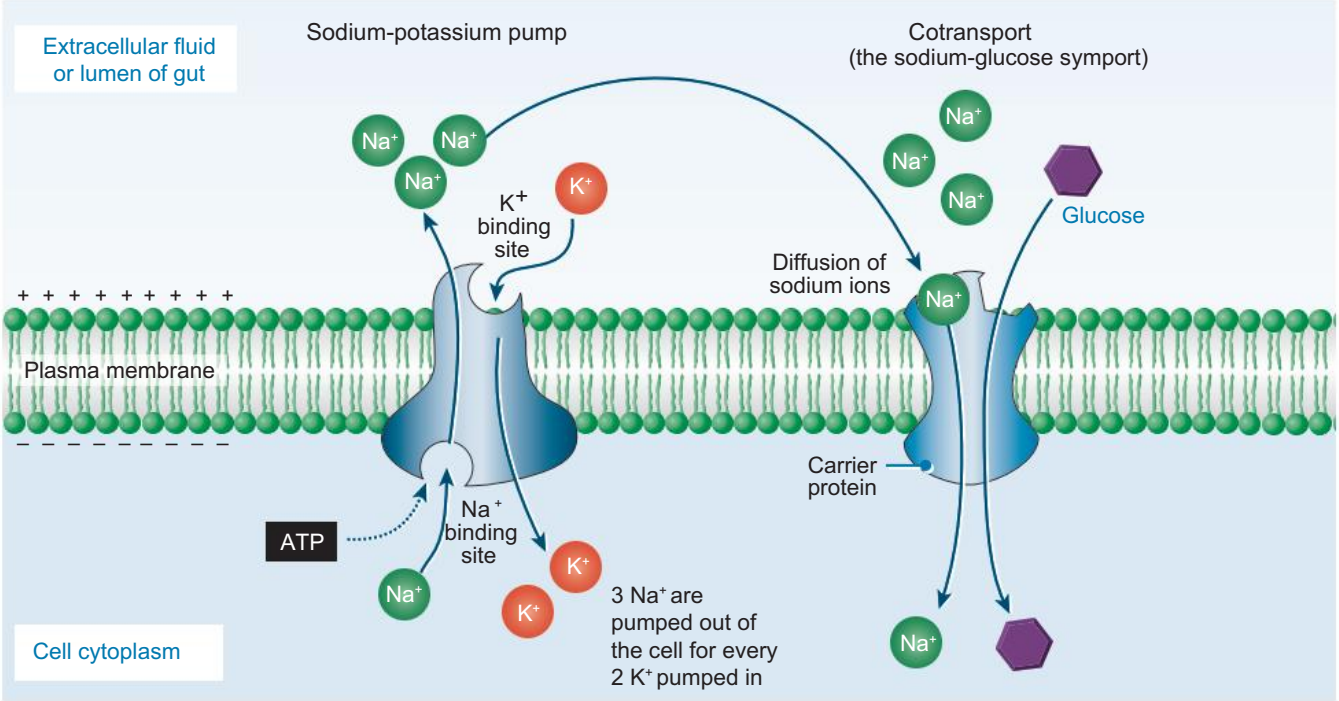
31 Ion Pumps and Cotransport

Key Idea: Ion pumps are transmembrane proteins that use energy to move ions and molecules across a membrane against their concentration gradient.

Sometimes molecules or ions are needed in concentrations that diffusion alone cannot supply to the cell, or they cannot diffuse across the plasma membrane. In this case ion pumps move ions (and some molecules) across the plasma membrane. Proton pumps move H^+ against a concentration gradient to create a potential difference across the membrane that can be used to do work. The sodium-potassium pump (below left) is found in almost all animal cells and is also common in plant cells. The concentration gradient created by ion pumps is often coupled to the transport of other molecules such as glucose across the membrane (below right).



Sodium-potassium (Na^+/K^+) pump

The Na^+/K^+ pump is a protein in the membrane that uses energy in the form of ATP to exchange sodium ions (Na^+) for potassium ions (K^+) across the membrane. The unequal balance of Na^+ and K^+ across the membrane creates large concentration gradients that can be used to drive transport of other substances (e.g. cotransport of glucose). The Na^+/K^+ pump also helps to maintain the right balance of ions and so helps regulate the cell's water balance.

Cotransport (coupled transport)

A gradient in sodium ions drives the active transport of glucose into intestinal epithelial cells. The specific transport protein couples the return of Na^+ down its concentration gradient to the transport of glucose into the intestinal epithelial cell across the cell membrane in contact with the gut lumen. Glucose diffuses from the epithelial cells across the opposite surface and is transported away in the blood. A low intracellular concentration of Na^+ (and therefore the concentration gradient) is maintained by a sodium-potassium pump.

1. Why is ATP required for membrane pump systems to operate? _____

2. (a) Explain what is meant by cotransport: _____

   (b) How is cotransport used to move glucose into the intestinal epithelial cells? _____

   (c) What happens to the glucose that is transported into the intestinal epithelial cells? _____

3. (a) The sodium-potassium pump uses primary/secondary (delete one) active transport.

   (b) The sodium-glucose symport uses primary/secondary (delete one) active transport.

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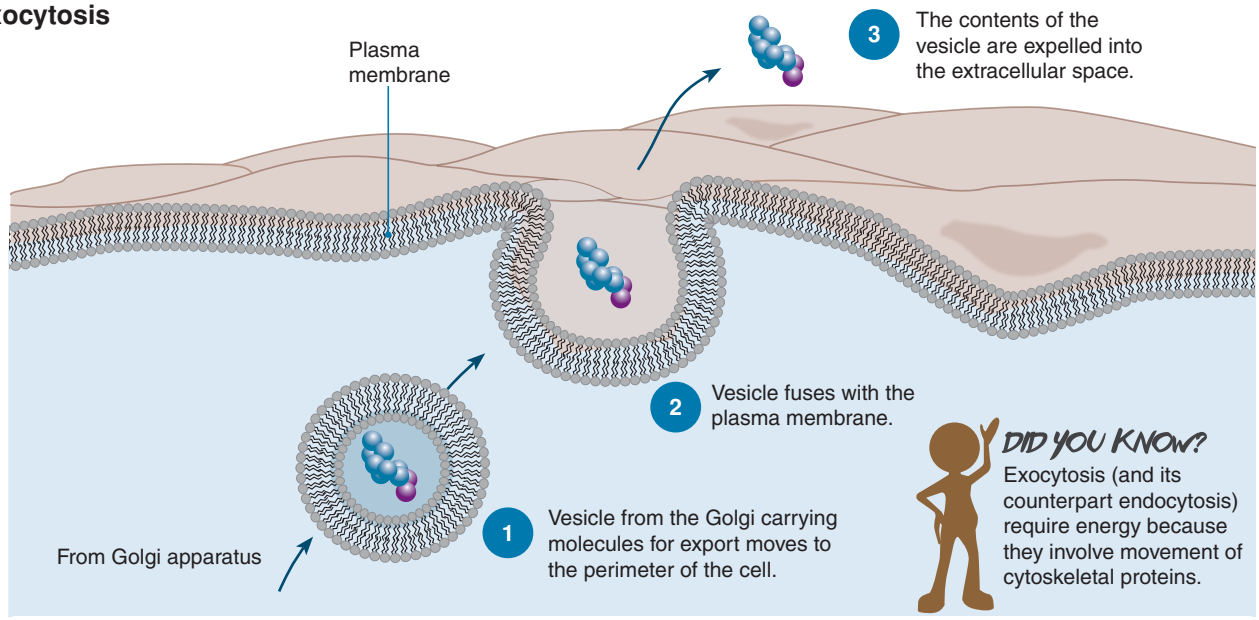
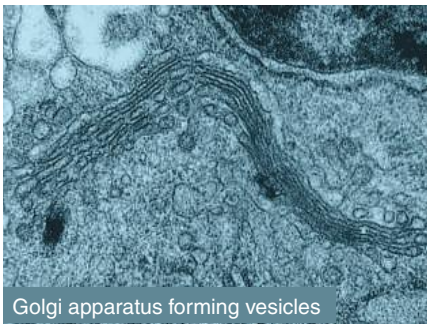
32 Cytosis

Key Idea: Cytosis is an energy demanding (active) transport mechanism involving the folding of the plasma membrane.
Cytosis is an active process involving the plasma membrane. In exocytosis, vesicles merge with the plasma membrane to export material from the cell. Endocytosis is a general term for engulfing of material by infolding of the plasma membrane.

Exocytosis



Exocytosis (above) is an active transport process in which a secretory vesicle fuses with the plasma membrane and expels its contents into the extracellular space. In multicellular organisms, various types of cells (e.g. endocrine cells and nerve cells) are specialised to manufacture products, such as proteins, and then export them from the cell to elsewhere in the body or outside it.



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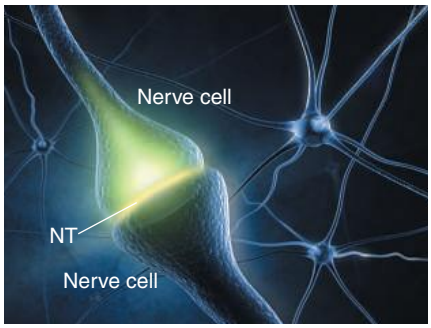
The transport of Golgi vesicles to the edge of the cell and their expulsion from the cell occurs through the activity of the cytoskeleton. This requires energy (ATP).



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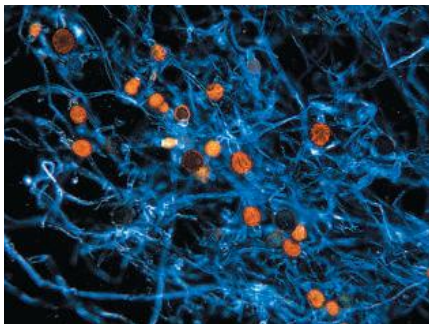
Exocytosis is important in the transport of neurotransmitters (NT) into the junction (synapse) between nerve cells to transmit nervous signals.



Fungi and bacteria use exocytosis to secrete digestive enzymes, which break down substances extracellularly so that nutrients can be absorbed (by endocytosis).

1. (a) What is the purpose of exocytosis? _____

_____

(b) How does it occur? _____

_____

_____

2. Describe two examples of the role of exocytosis in cells:

(a) _____

_____

_____

(b) _____

_____

_____

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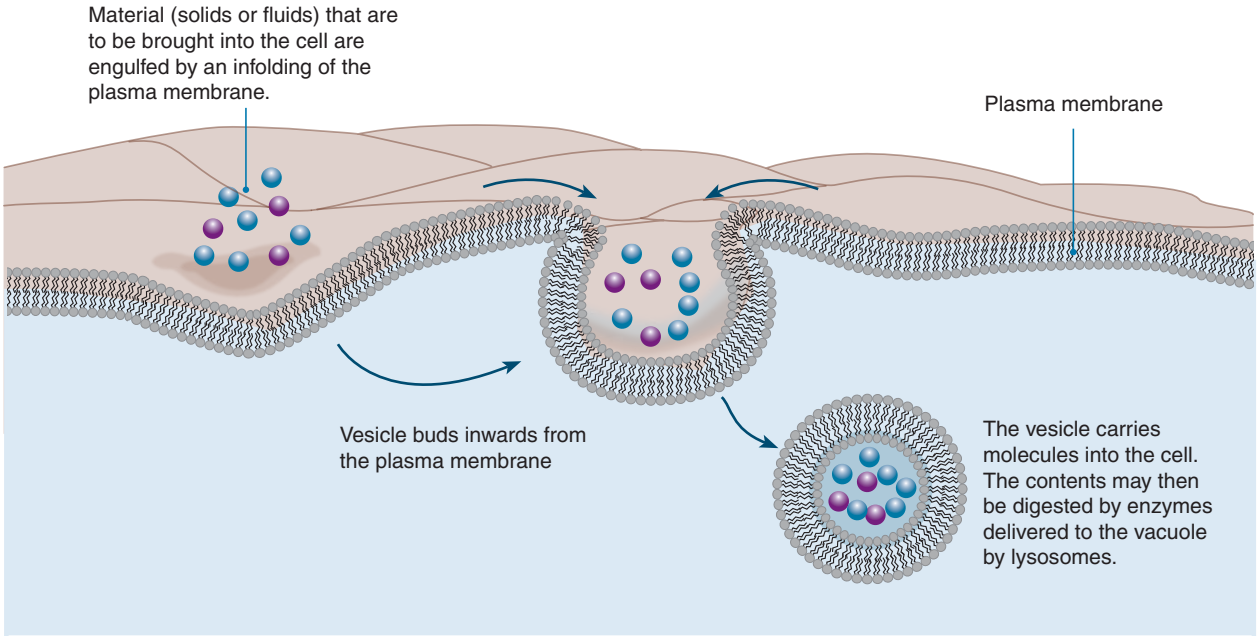
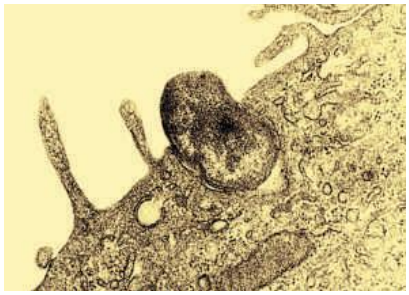
Endocytosis

Endocytosis is a type of active transport in which the plasma membrane folds around a substance to transport it across the plasma membrane into the cell. The ability of cells to do this is a function of the fluid nature of the plasma membrane.

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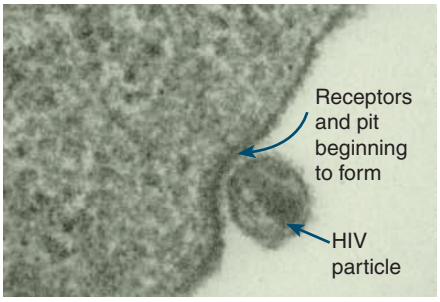

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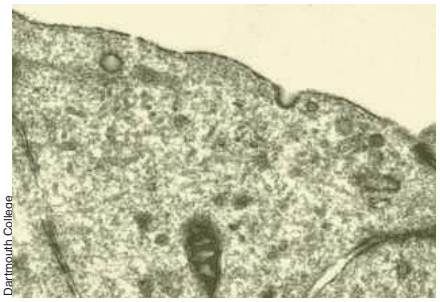
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Phagocytosis (or 'cell-eating') involves the cell engulfing solid material to form large phagosomes or vacuoles (e.g. food vacuoles). It may be non-specific or receptor-mediated. Examples: Feeding in *Amoeba*, phagocytosis of foreign material and cell debris by neutrophils and macrophages.

Receptor mediated endocytosis is triggered when certain metabolites, hormones, or viral particles bind to specific receptor proteins on the membrane so that the material can be engulfed. Examples: The uptake of lipoproteins by mammalian cells and endocytosis of viruses (above).

Pinocytosis (or 'cell-drinking') involves the non-specific uptake of liquids or fine suspensions into the cell to form small pinocytic vesicles. Pinocytosis is used primarily for absorbing extracellular fluid. Examples: Uptake in many protozoa, some cells of the liver, and some plant cells.

3. What is the purpose on endocytosis? _____

_____

4. Is endocytosis active or passive transport? _____

5. Describe the following types of endocytosis:

   (a) Phagocytosis: _____

   _____

   (b) Receptor mediated endocytosis: _____

   _____

   (c) Pinocytosis: _____

   _____

6. Explain how the plasma membrane can form a vesicle: _____

_____

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33 Active and Passive Transport Summary

Key Idea: Cells move materials into and out of the cell by either passive or active transport mechanisms.

The diagram below summarises the movement of material in and out of a cell. Use the information to complete the activity.

A

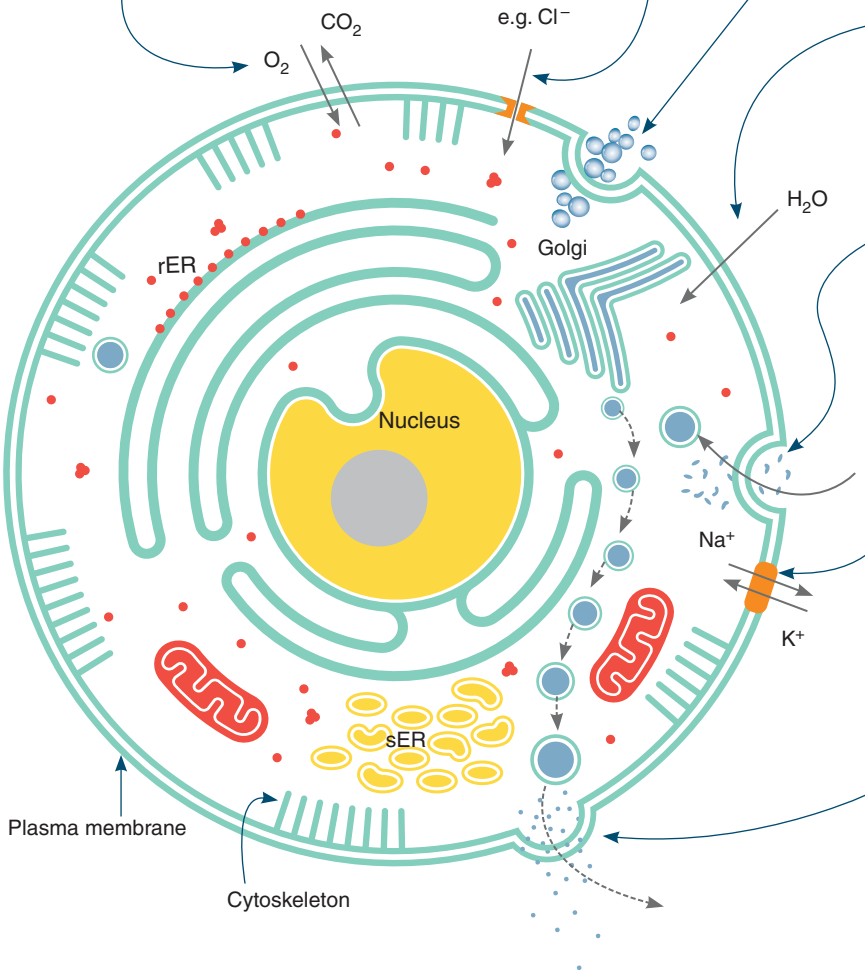
Molecules of liquids, dissolved solids, and gases move into or out of the cell without any expenditure of energy. These molecules move down their own concentration gradients.

B

Diffusion involving a carrier system (channel proteins or carrier proteins) but without any energy expenditure.

C

Fluid or a suspension is taken into the cell. The plasma membrane encloses some of the fluid to form a small vesicle, which then fuses with a lysosome and is broken down.



D

Diffusion of water across a partially permeable membrane. It causes cells in fresh water to take up water.

E

A type of endocytosis in which solids are taken into the cell. The plasma membrane encloses one or more particles and buds off to form a vacuole. Lysosomes fuse with it to digest the contents.

F

A protein in the plasma membrane that uses energy (ATP) to exchange sodium for potassium ions (3 Na^+ out for every 2 K^+ in). The concentration gradient can be used to drive other active transport processes.

G

Vesicles bud off the Golgi or ER and fuse with the plasma membrane to expel their contents into the extracellular fluid.

1. Identify each of the processes (A-G) described in the diagram above in the spaces provided. Indicate whether the transport process is active or passive by using **A** for active and **P** for passive.

2. Identify the transport mechanism involved in each of the following processes in cells:

   (a) Uptake of extracellular fluid by liver cells: _____

   (b) Capture and destruction of a bacterial cell by a white blood cell: _____

   (c) Movement of water into the cell: _____

   (d) Secretion of digestive enzymes from cells of the pancreas: _____

   (e) Moving H^+ against a concentration gradient to do work: _____

3. In general terms describe the energy requirements of passive and active transport: _____

_____

_____

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34 Chapter Review: Did You Get It?

1. Match each term to its definition, as identified by its preceding letter code.

active transport .....

concentration gradient .....

diffusion .....

osmosis .....

passive transport .....

A The energy-requiring movement of substances across a biological membrane against a concentration gradient.

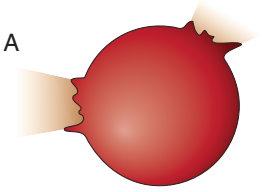
B Movement of substances across a biological membrane without energy expenditure.

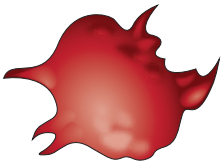
C The passive movement of molecules from high to low concentration.

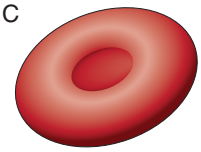
D The gradual difference in the concentration of solutes in a solution between two regions. In biology, this usually results from unequal distribution of ions across a membrane.

E Passive movement of water molecules across a partially permeable membrane down a concentration gradient.

2. The diagrams below depict what happens when a red blood cell is placed into three solutions with differing concentrations of solutes. Describe the tonicity of the solution (in relation to the cell) and describe what is happening:

A 

B 

C 

(a) _____

_____

_____

(b) _____

_____

_____

(c) _____

_____

_____

3. Explain how the properties of the phospholipid molecule result in the bilayer structure of membranes:

_____

_____

_____

4. Using the formulae: cuboid SA = 2(lh + lw + hw), cuboid volume = lwh, calculate the surface area to volume ratio of the following cell shapes:

(a) A cubic cell 6 µm x 6 µm x 6 µm: _____

(b) A cuboid cell 1 µm x 12 µm x 5 µm: _____

(c) Which of these cells would exchange substances with its environment most efficiently and why: _____

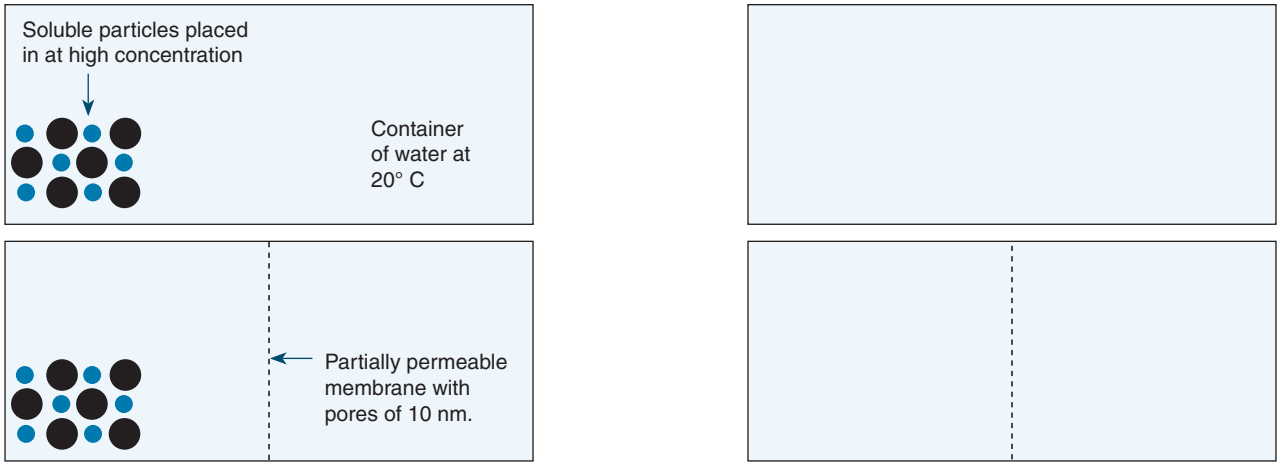
_____

5. Consider the two diagrams below. For each, draw in the appropriate box what you would expect to see after one hour.

Particle with diameter of 5 nm ●

Particle with diameter of 20 nm ●

After one hour:



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CHAPTER 3

Cell Cycle, Growth, and Differentiation

Key terms

adult stem cell
anaphase
asexual reproduction
binary fission
cancer
cell cycle
cell cycle
cell division
cytokinesis
differentiation
DNA replication
ectoderm
embryonic stem cell
endoderm
eukaryote
first gap phase (G1)
germ layer
interphase
M phase
mesoderm
metaphase
mitosis
multipotent
pluripotent
potency
prokaryote
prophase
S phase
second gap phase (G2)
self renewal
stem cell
telophase
totipotent
tumour
zygote

The division of cells

Key skills and knowledge

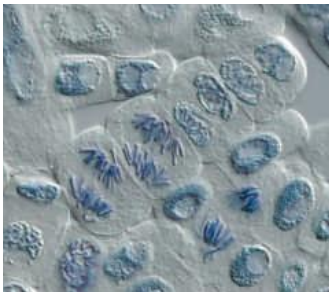
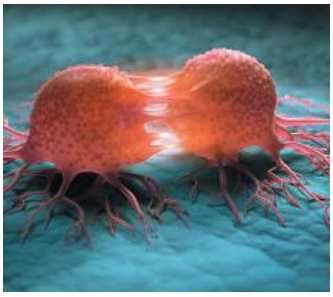
Activity number

- ☐ 1 Describe the various roles of cell division in the life cycles of different organisms, including asexual reproduction, growth, and repair and replacement of tissues. **35**
- ☐ 2 Describe binary fission in prokaryotes. Identify the stages involved including cell elongation, duplication of the DNA, cross wall formation, and division of the cell. **36**
- ☐ 3 Broadly contrast the features of prokaryotic cell division with cell division in eukaryotes. **35 36**

The eukaryotic cell cycle

Key skills and knowledge

- ☐ 4 Describe the cell cycle in eukaryotes, including reference to DNA replication (S), growth (G_1 and G_2), and mitosis (M phase). **37**
- ☐ 5 Describe the events in each of the main stages of mitosis: prophase, metaphase, anaphase, and telophase. **38**
- ☐ 6 Describe and explain cytokinesis in both plant cells and animal cells. **38**
- ☐ 7 Recognise stages of mitosis in light and electron micrographs. Calculate mitotic index (ratio of cells in mitosis vs interphase) in an actively growing tissue, e.g. root tip tissue. How would this compare to a tissue that is not growing? **39**


Apoptosis and regulation of the cell cycle

Key skills and knowledge

- ☐ 8 Describe apoptosis as a regulated process of programmed cell death. Explain the role of apoptosis during development and in the life of an adult organism. **41**
- ☐ 9 Describe how the cell cycle is regulated according to requirements, including the role of specific checkpoints. **40**
- ☐ 10 Explain how disruptions to the cell cycle can occur when cell cycle checkpoints are ignored or bypassed. Explain the consequences of disruptions to the cell cycle and malfunctions in apoptosis, e.g. uncontrolled cell division, cancer, and abnormal embryonic development. **42**
- ☐ 11 Describe the features of cancer cells and relate them to the cell cycle disruptions. **42**

The structure and function of the plasma membrane

Key skills and knowledge

- ☐ 12 Explain what is meant by a stem cell. Describe the properties of stem cells, including self-renewal and potency. Describe the types and functions of stem cells in humans, distinguishing between embryonic stem cells (ESC) and adult stem cells (ASC). **43**
- ☐ 13 Explain how the properties of stem cells allow for differentiation, specialisation, and renewal of cells and tissues. Distinguish between totipotent, pluripotent, and multipotent stem cells. Understand that as cells become more specialised during division of the zygote (fertilised egg) they lose their ability to produce different cell types. **44 45**
- ☐ 14 Discuss the potential use of stem cells in the development of medical therapies. Explain how ESC and ASC could be used, what technical difficulties must be overcome, and what ethical issues are associated with each. **46**
- ☐ 15 TEST Make a response to the bioethical issues associated with the use of stem cells. **47**

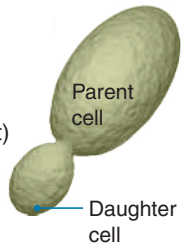
35 Why Cells Need to Divide

Key Idea: Mitotic cell division has three primary functions: growth of the organism, replacement of damaged or old cells, and asexual reproduction (in some organisms).

Mitotic cell division produces daughter cells that are genetically identical to the parent cell. It has three purposes: growth, repair, and reproduction. Multicellular organisms grow from a single fertilised cell into a mature organism that may consist of several thousand to several trillion cells. Repair occurs by replacing damaged and old cells with new cells. Some unicellular eukaryotes (such as yeasts) and some multicellular organisms (e.g. *Hydra*) reproduce asexually by mitotic division.

Asexual reproduction

Some simple eukaryotic organisms reproduce asexually by cell division. Yeasts (such as baker's yeast) can reproduce by budding. The parent cell buds to form a daughter cell (right) which eventually separates from the parent cell. Prokaryotes divide by binary fission, a different but superficially similar process.



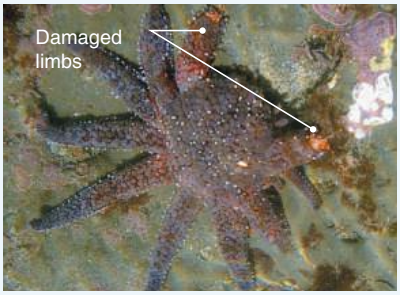
Growth

Multicellular organisms develop from a single fertilised egg cell (zygote) and grow by increasing the number of cells. Cells complete a cycle, in which the cell copies its DNA and then divides to produce two identical cells. During the period of growth, the rate of cell production is higher than the rate of cell deaths. Organisms, such as the 12 day old mouse embryo (above, centre), grow by increasing their total cell number and the cells become specialised as part of development.

Cell growth is highly regulated. Once the mouse reaches its adult size (above, right), physical growth stops and the number of cell deaths equals the number of new cells produced.

Bill Rhodes

Jpbarrass



Brocken Inaglory

Repair of damaged tissues

Mitotic cell division is responsible for the repair and replacement of damaged cells in multicellular organisms. When you break a bone or graze your skin, new cells are generated to repair the damage. Some organisms, like the sea star (above right) are able to generate new limbs if they are broken off.

1. Use examples to explain the role of cell division in:

   (a) Growth of an organism: _____

   _____

   _____

   _____

   (b) Replacement of damaged cells: _____

   _____

   _____

   _____

   (c) Asexual reproduction: _____

   _____

   _____

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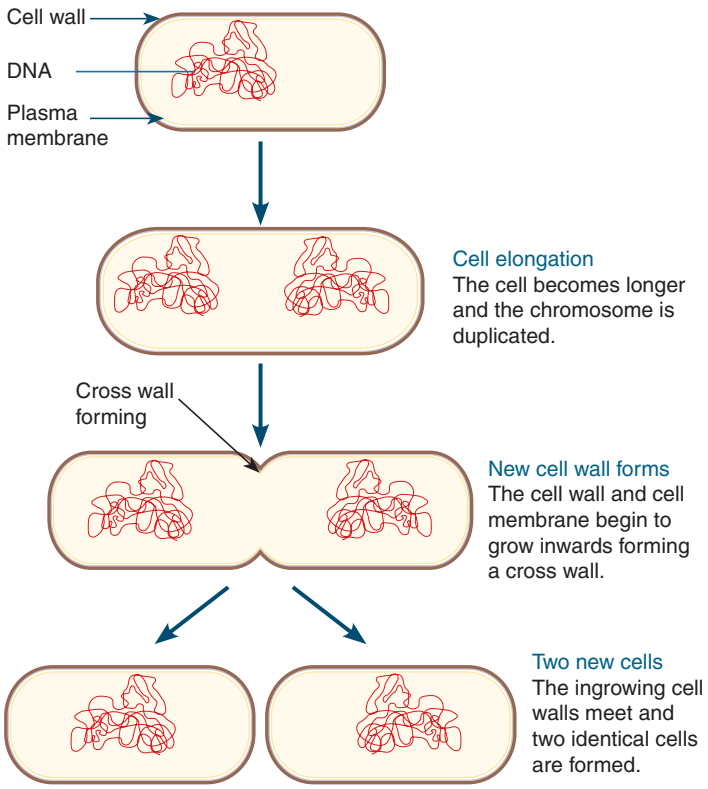
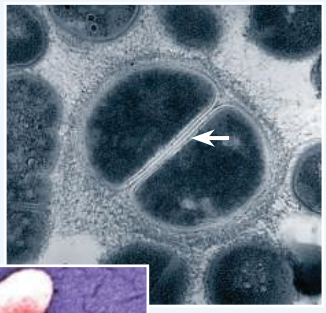
36 Binary Fission in Prokaryotes

Key Idea: Binary fission involves division of the parent body into two, fairly equal, parts to produce two identical cells.

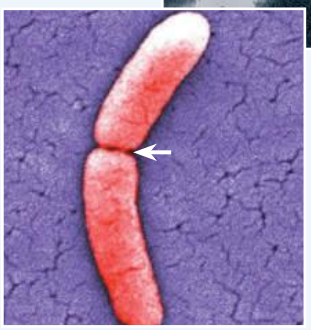
New prokaryotic cells arise through the division of existing ones in a process called **binary fission**. Binary fission is a form of asexual reproduction. It is carried out by most prokaryotes, some eukaryotic organelles, such as chloroplasts, and some unicellular eukaryotes. In eukaryotic cells, fission involves mitosis but in prokaryotes it does not. The time required for a bacterial cell to divide, or for a population of bacterial cells to double, is called the generation time. Generation times may be quite short (20 minutes) in some species and as long as several days in others.



Most bacteria reproduce asexually by binary fission (left). The cell's DNA is replicated and each copy attaches to a different part of the plasma membrane. When the cell begins to pull apart, the replicated and original chromosomes are separated. **Binary fission in bacteria does not involve mitosis or cytokinesis**.



This bacterium (right) is in the process of binary fission. The arrow shows where a cross wall has formed.



CDC

This bacterium (left) has completed cell division. The separation between the two cells can be clearly seen (arrow).

Generation time (minutes)	Population size
0	1
20	2
40	4
60	8
80	
100	
120	
140	
160	
180	
200	
220	
240	
260	
280	
300	
320	
340	
360	

1. What is binary fission? _____

2. Explain why the formation of the cross wall is important in binary fission:

3. Explain the term generation time: _____

4. A species of bacteria reproduces every 20 minutes. Complete the table (left) by calculating the number of bacteria present at 20 minute intervals.

5. State how many bacteria were present after:

   (a) 1 hour: _____

   (b) 3 hours: _____

   (c) 6 hours: _____

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37 The Eukaryotic Cell Cycle

Key Idea: The eukaryotic cell cycle can be divided into phases, although the process is continuous. Specific cellular events occur in each phase.

The life cycle of a eukaryotic cell is called the cell cycle. The cell cycle can be divided into interphase and M phase. Aspects of the cell cycle can vary enormously between cells of the same organism. For example, intestinal cells divide around twice a day, while cells in the liver divide once a year, and those in muscle tissue do not divide at all. If any of these tissues is damaged, however, cell division increases rapidly until the damage is repaired. This variety of length in the cell cycle can be explained by the existence of regulatory mechanisms that are able to slow down or speed up the cell cycle in response to changing conditions.

Interphase

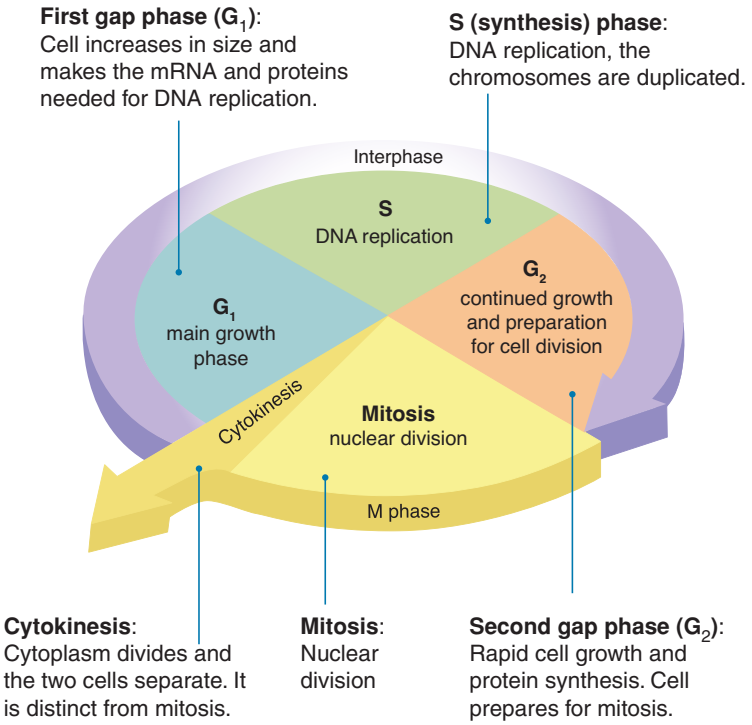
Cells spend most of their time in interphase. Interphase is divided into three stages:

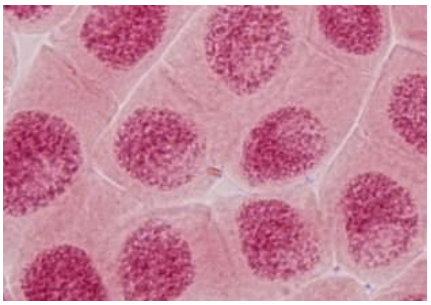
- The first gap phase (G_1).
- The S-phase (S).
- The second gap phase (G_2).

During interphase the cell increases in size, carries out its normal activities, and replicates its DNA in preparation for cell division. Interphase is not a stage in mitosis.

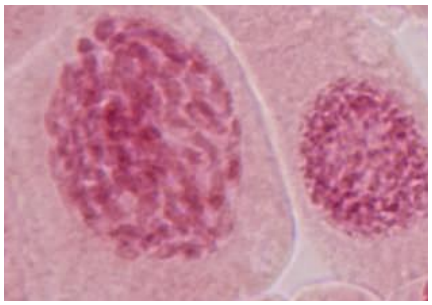
Mitosis and cytokinesis (M-phase)

Mitosis and cytokinesis occur during M-phase. During mitosis, the cell nucleus (containing the replicated DNA) divides in two equal parts. Cytokinesis occurs at the end of M-phase. During cytokinesis the cell cytoplasm divides, and two new daughter cells are produced.

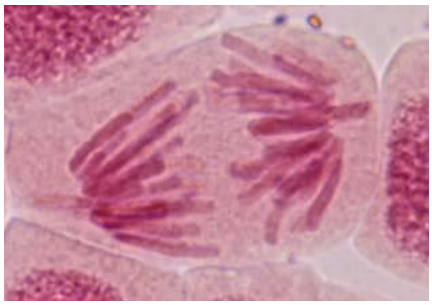




During interphase, the cell grows and acquires the materials needed to undergo mitosis. It also prepares the nuclear material for separation by replicating it.



During interphase the nuclear material is unwound. As mitosis approaches, the nuclear material begins to reorganise in readiness for nuclear division.



During mitosis the chromosomes are separated. Mitosis is a highly organised process and the cell must pass checkpoints before it proceeds to the next phase.

1. Briefly outline what occurs during the following phases of the cell cycle:

(a) Interphase: _____

_____

_____

(b) Mitosis: _____

_____

_____

(c) Cytokinesis: _____

_____

_____

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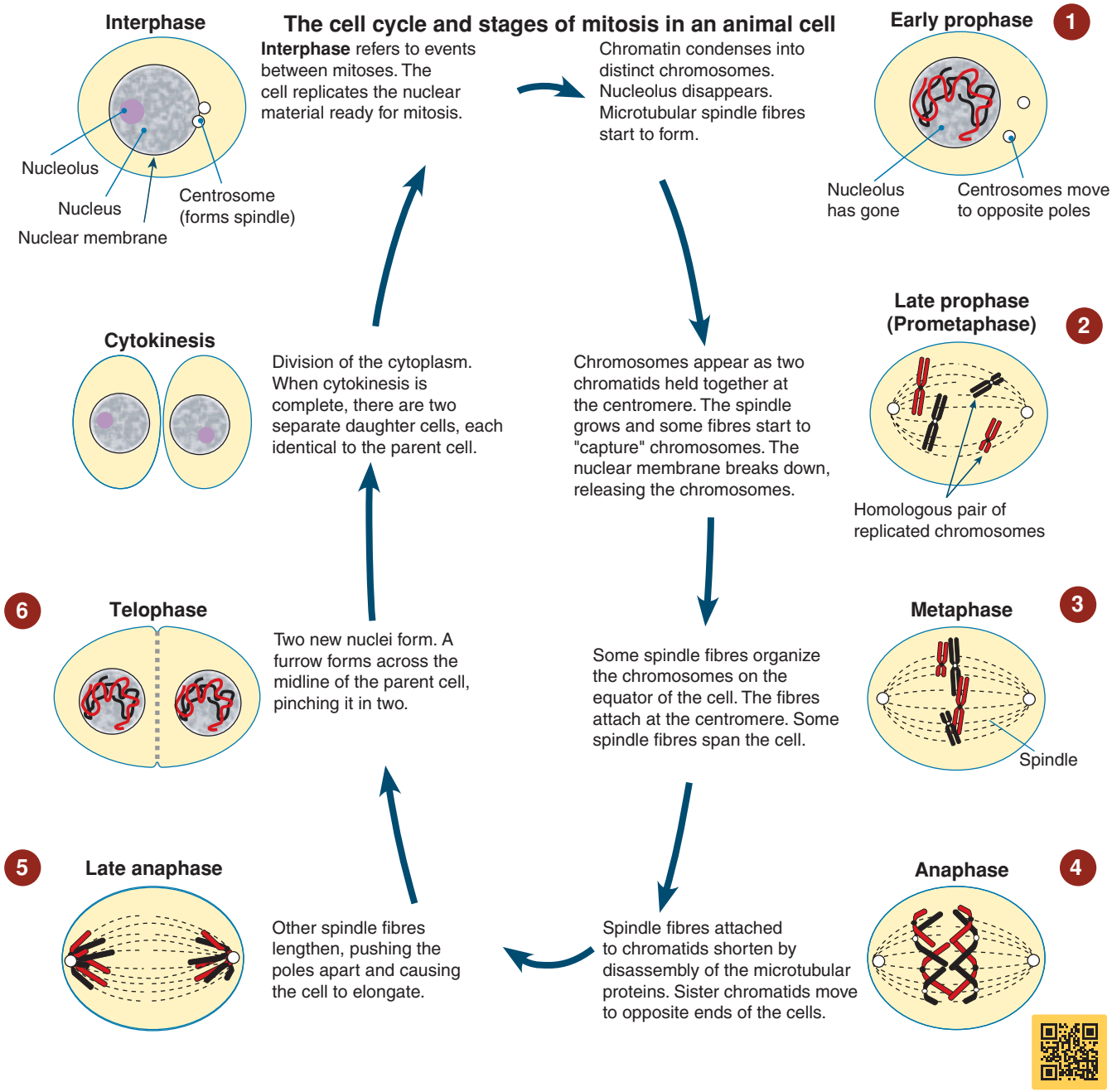
38 Mitosis and Cytokinesis

Key Idea: Mitosis is part of the cell cycle in which an existing cell (the parent cell) divides into two (the daughter cells).

Mitosis refers to the separation (division) of the nuclear material and it precedes division of the cell. There is no change of chromosome number and the daughter cells are identical to the parent cell. Although mitosis is part of a continuous cell cycle, it is divided into stages (prophase, metaphase, anaphase, and telophase) to help distinguish the processes involved. Mitosis is one of the shortest stages of the cell cycle. Cytokinesis (the division of the newly formed cells) is part of M-phase but it is distinct from nuclear division. During cytokinesis the cell divides into two.

The cell cycle and stages of mitosis in an animal cell



1. What is the purpose of mitosis? _____

_____

_____

2. What must occur before mitosis takes place? _____

3. (a) What is the purpose of the spindle fibres? _____

_____

(b) Where do the spindle fibres originate? _____

_____

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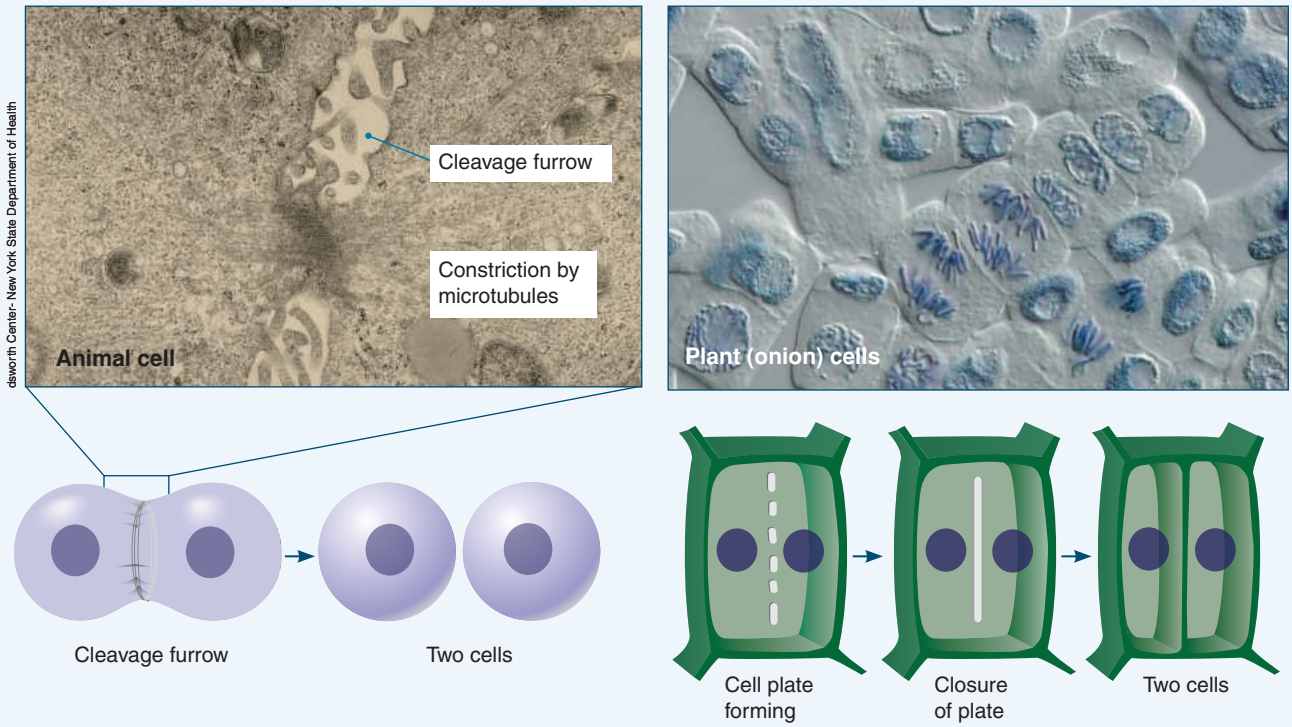
Cytokinesis (division of the cytoplasm)

Animal cells: Cytokinesis (below left) begins shortly after the sister chromatids have separated in anaphase of mitosis. A ring of microtubules assembles in the middle of the cell, next to the plasma membrane, constricting it to form a cleavage furrow. In an energy-using process, the cleavage furrow moves inwards, forming a region where the two cells will separate.

Plant cells (below right): Cytokinesis involves construction of a cell plate (a precursor of the new cell wall) in the middle of the cell. The cell wall materials are delivered by vesicles derived from the Golgi. The vesicles join together to become the plasma membranes of the new cell surfaces.



Cytokinesis in an animal cell

Cytokinesis in a plant cell

4. Summarise what happens in each of the following phases:

   (a) Prophase: _____

   _____

   (b) Metaphase: _____

   _____

   (c) Anaphase: _____

   _____

   (d) Telophase: _____

   _____

   _____

5. (a) What is the purpose of cytokinesis? _____

   _____

   (b) Describe the differences between cytokinesis in an animal cell and a plant cell: _____

   _____

   _____

   _____

   _____

   _____

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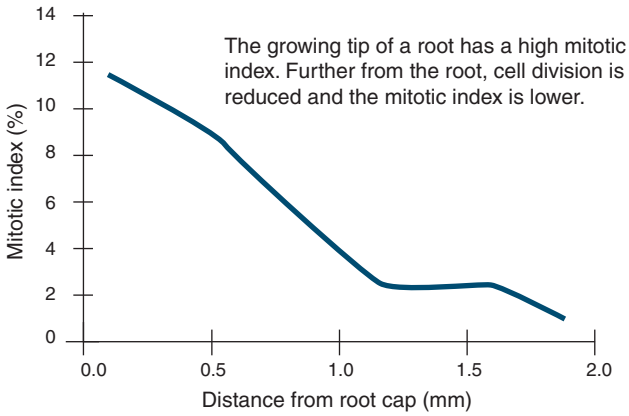
39 Recognising Stages in Mitosis

Key Idea: The stages of mitosis can be recognised by the organisation of the cell and chromosomes.
Although mitosis is a continuous process it is divided into four stages (prophase, metaphase, anaphase, and telophase) to more easily describe the processes occurring during its progression.

The mitotic index

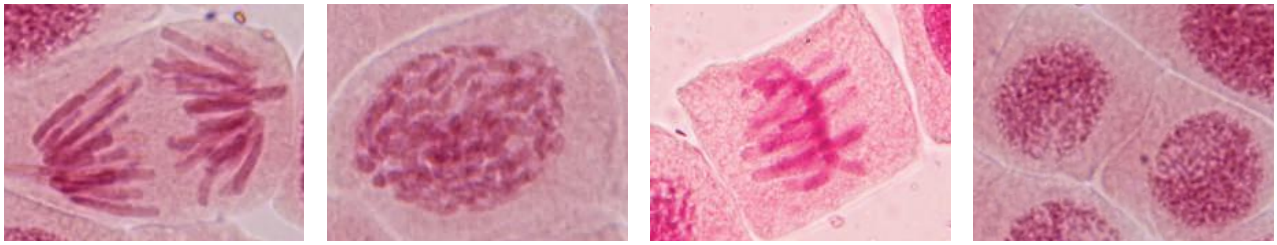
The mitotic index measures the ratio of cells in mitosis to the number of cells counted. It is a measure of cell proliferation and can be used to diagnose cancer (because cancerous cells divide very quickly). In areas of high cell growth the mitotic index is high such as in plant apical meristems or the growing tips of plant roots. The mitotic index can be calculated using the formula below:

$$\text{Mitotic index} = \frac{\text{Number of cells in mitosis}}{\text{Total number of cells}}$$



The growing tip of a root has a high mitotic index. Further from the root, cell division is reduced and the mitotic index is lower.

1. Use the information in the previous activity to identify which stage of mitosis is shown in each of the photographs below:



(a) _____ (b) _____ (c) _____ (d) _____

2. (a) The light micrograph (right) shows a section of cells in an onion root tip. These cells have a cell cycle of approximately 24 hours. The cells can be seen to be in various stages of the cell cycle. By counting the number of cells in the various stages it is possible to calculate how long the cell spends in each stage of the cycle. Count and record the number of cells in the image that are in mitosis and those that are in interphase. Cells in cytokinesis can be recorded as in interphase. Estimate the amount of time a cell spends in each phase.

Stage	No. of cells	% of total cells	Estimated time in stage
Interphase			
Mitosis			
Total		*100*	

(b) Use your counts from 2(a) to calculate the mitotic index for this section of cells.

_____

_____

Onion root tip cells

3. What would you expect to happen to the mitotic index of a population of cells that loses the ability to divide as they mature?

_____

_____

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40 Regulation of the Cell Cycle

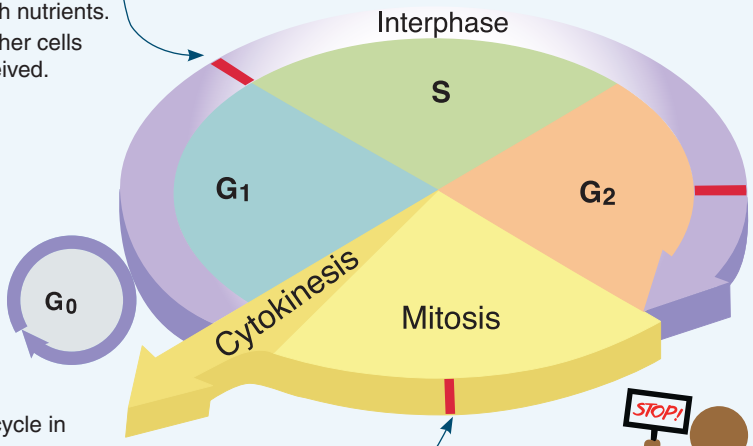
Key Idea: Regulatory checkpoints are built into the cell cycle to ensure that the cell is ready to proceed from one phase to the next. The failure of these systems can lead to cancer.

Cell checkpoints give cells a way to ensure that all cellular processes have been completed correctly before entering the next phase. There are three checkpoints in the cell cycle. At each checkpoint, a set of conditions determines whether or not the cell will continue into the next phase. Cancer can result when the pathways regulating the checkpoints fail. Non-dividing cells enter a resting phase (G_0), where they may remain for a few days or up to several years. Under specific conditions, they may re-enter the cell cycle.

Checkpoints during the cell cycle

G_1 checkpoint

Pass this checkpoint if:
- Cell is large enough.
- Cell has enough nutrients.
- Signals from other cells have been received.



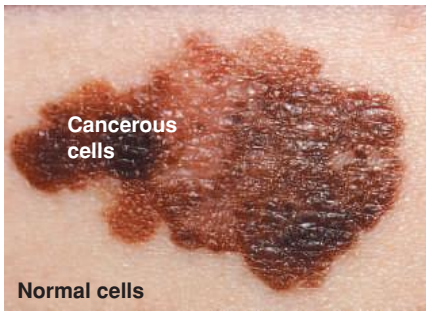
G_2 checkpoint

Pass this checkpoint if:
- Cell is large enough.
- Chromosomes have been successfully duplicated.

Resting phase (G_0)
- Cells may exit the cell cycle in response to chemical cues.
- Cells in G_0 may be quiescent (waiting), differentiated, or senescent (aged).
- Quiescent cells may reenter the cycle in response to chemical cues.

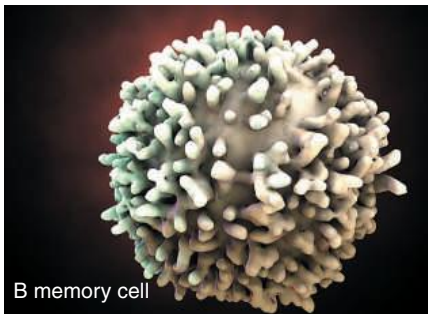
Metaphase checkpoint

Pass this checkpoint if:
- All chromosomes are attached to the mitotic spindle.

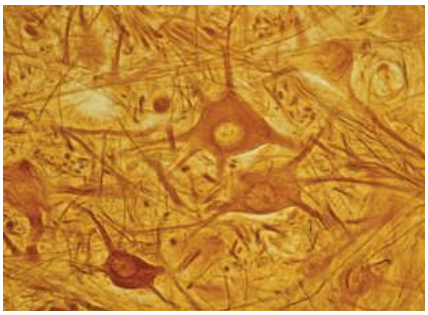


NCI

Skin cancer (melanoma). The cancer cells grow more rapidly than the normal skin cells because normal cell regulation checkpoints are ignored. This is why the cancerous cells sit higher than the normal cells and can rapidly spread (a process called metastasis).



Most lymphocytes in human blood are in the resting G_0 phase and remain there unless they are stimulated by specific antigens to re-enter the cell cycle via G_1. G_0 phase cells are not completely dormant, continuing to carry out essential cell functions in reduced form.



Eli

Many fully differentiated (specialised) cells, e.g. neurones (above), exit the cell cycle permanently and stay in G_0. These cells continue their functional role in the body, but do not proliferate. Senescent cells have accumulated mutations, lose function, and die.

1. Explain the importance of cell cycle checkpoints: _____

2. In terms of the cell cycle and the resting phase (G_0), distinguish between the behavior of fully differentiated cells, such as neurones, and cells that are quiescent, such as B memory cells

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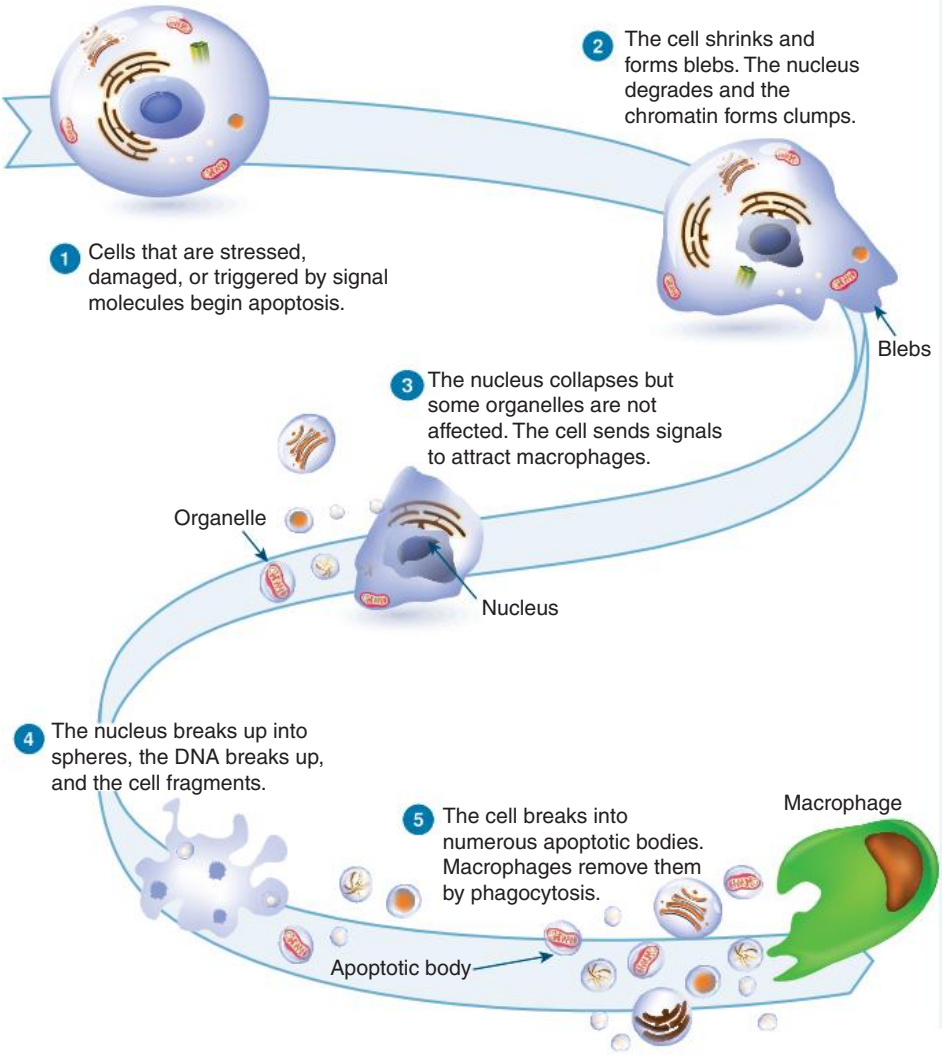
41 Apoptosis: Programmed Cell Death

Key Idea: Apoptosis is a process of programmed cell death. It maintains cell numbers and sculpts body parts during development. It is a tightly regulated process.

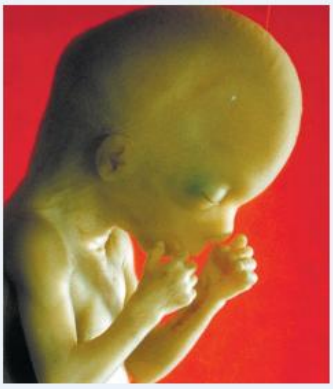
Apoptosis, also called programmed cell death (PCD), is a natural and necessary mechanism in multicellular organisms to trigger the death of a cell. Apoptosis helps to maintain adult cell numbers and stops the multiplication of damaged or dangerous cells, such as virus-infected cells and cells with DNA damage. Apoptosis also has a role in sculpting embryonic tissue during development, e.g. in the formation of digits in developing embryos and resorption of the larval tail during amphibian metamorphosis.

An overview of apoptosis

- Apoptosis is a controlled process of cell suicide. It occurs in response to specific cell signals and involves an orderly series of biochemical events.
- The cell and its nucleus shrink and there is an orderly dissection of chromatin by endonucleases.
- Death is finalised by a rapid engulfment of the dying cell by phagocytosis. This safely disposes of the remains of the cell.



Ed Uhman



In humans, the mesoderm tissue initially formed between the fingers and toes is removed by apoptosis. At 41 days after fertilisation (top), the digits of the hands and feet are webbed, appearing paddle-like. Apoptosis selectively destroys this webbing, sculpting them into digits, which can be seen in later stages of development in the fetus (bottom image).

1. What is apoptosis? _____

_____

_____

2. What is the role of apoptosis in the normal functioning of the body? _____

_____

_____

_____

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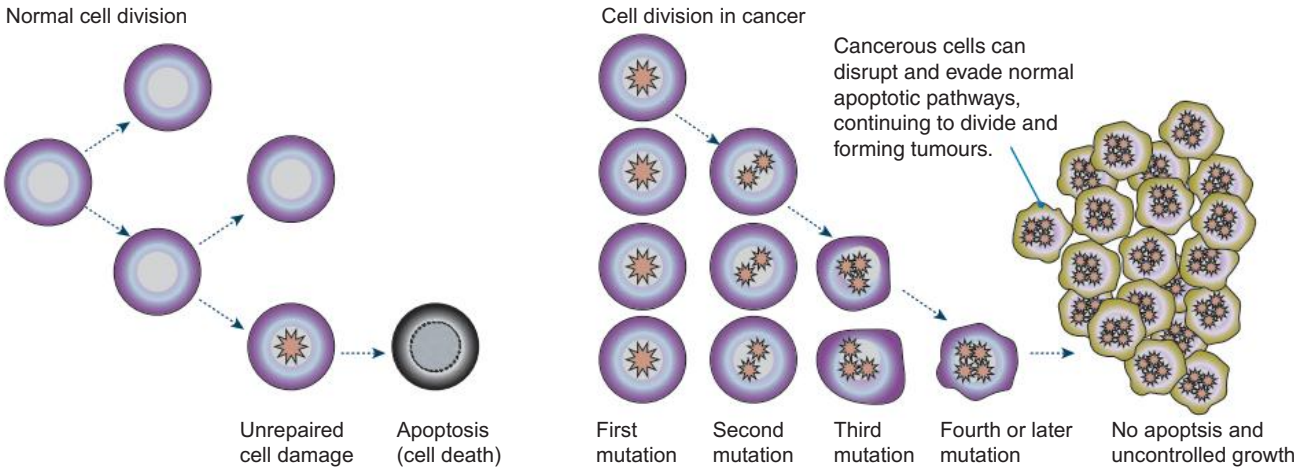
42 Errors in Regulation Can Cause Cancer

Key Idea: An imbalance in the factors controlling apoptosis can alter its normal rate and result in abnormal cell behaviour and disease, such as cancer.

Apoptosis removes damaged or abnormal cells before they can multiply. However, when apoptosis malfunctions it can cause a number of diseases, including cancer. When cell cycle checkpoints fail, the normal rate of apoptosis falls. This allows a damaged cell to divide without regulation and it can lead to the formation of tumours. There are a number of factors that can disrupt the cell cycle and cause a cell to become cancerous. These include defective genes, some viruses, and a number of chemical and environmental factors.

Reduction in rates of apoptosis can cause cancer



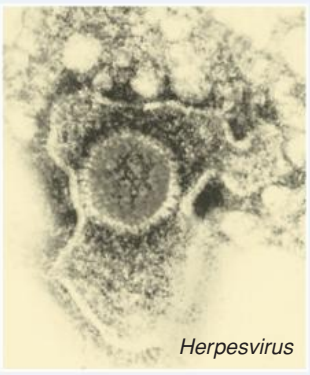
Tumour suppressor genes, e.g. the p53 gene, normally halt cell division of DNA damaged cells until the damage is repaired. If the damage cannot be repaired, apoptosis is triggered.

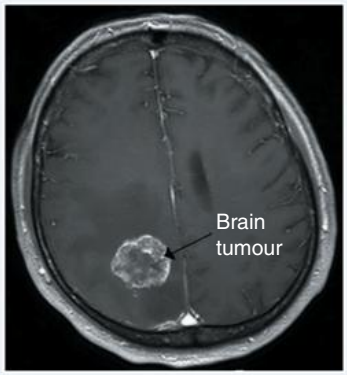
Cancerous cells may inhibit the expression of the p53 gene or increase the expression of signals to halt apoptosis. Around 50% of all human tumours contain p53 gene mutations.

The Herpesvirus inhibits apoptosis

Some viruses, such as the human herpesviruses, invade human cells and can inhibit apoptosis. This prevents the premature death of host cells and allows the virus to hide within the cells and avoid detection by the immune system.

Some human herpesviruses are known carcinogens (they cause cancer). For example, the cytomegalovirus (CMV) is well linked with causing brain tumours (far right). Many other herpesviruses are suspected carcinogens. The ability of the virus to inhibit apoptosis is one mechanism involved in a cell turning cancerous.





Marvin 101 CC2.0

1. How can a decreased rate of apoptosis lead to cancer? _____

2. A number of Herpesviruses are recognised cancer-forming agents. How might they exert this effect? _____

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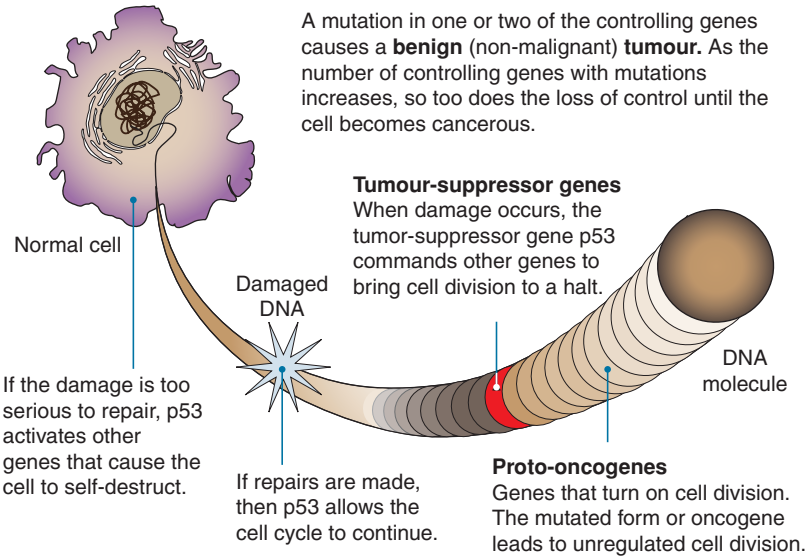
Formation of cancerous cells

The formation of cancerous cells results from changes in the genes controlling normal cell growth and division. The resulting cells become immortal and no longer carry out their functional role.

Two types of gene are normally involved in controlling the cell cycle:

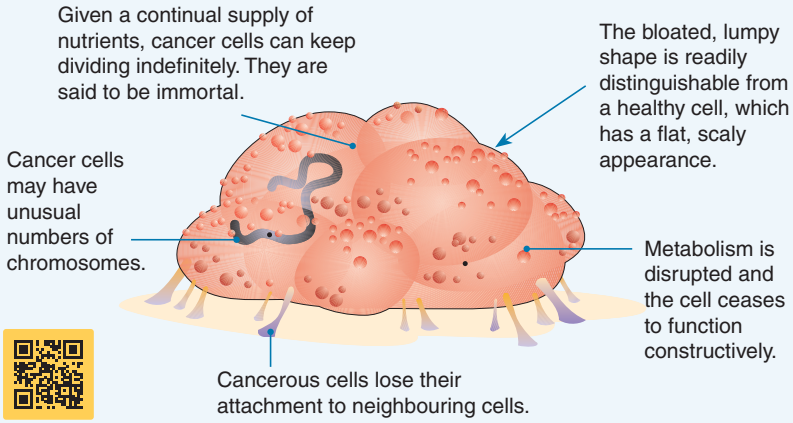
- **Proto-oncogenes**: these start the cell division process and are essential for normal cell development.
- **Tumour-suppressor genes**: these genes switch off cell division.

In their normal form, both kinds of genes work as a team, enabling the body to perform vital tasks such as repairing defective cells and replacing dead ones. But mutations in these genes can disrupt these finely tuned checks and balances. Mutated proto-oncogenes can give rise to oncogenes (genes that lead to uncontrollable cell division). Mutations to tumour-suppressor genes initiate most human cancers. The best studied tumour-suppressor gene is p53, which encodes a protein that halts the cell cycle so that DNA can be repaired before division.



Features of cancer cells

The diagram right shows a single lung cell that has become cancerous. It no longer carries out the role of a lung cell, and instead takes on a parasitic lifestyle, taking nutrients from the body and contributing nothing in return. The rate of cell division is greater than in normal cells in the same tissue because there is no resting phase between divisions.



3. How do cancerous cells differ from normal cells? _____

4. Explain how the cell cycle is normally controlled, including reference to the role of tumour-suppressor genes:

5. With reference to the role of oncogenes, explain how the normal controls over the cell cycle can be lost:

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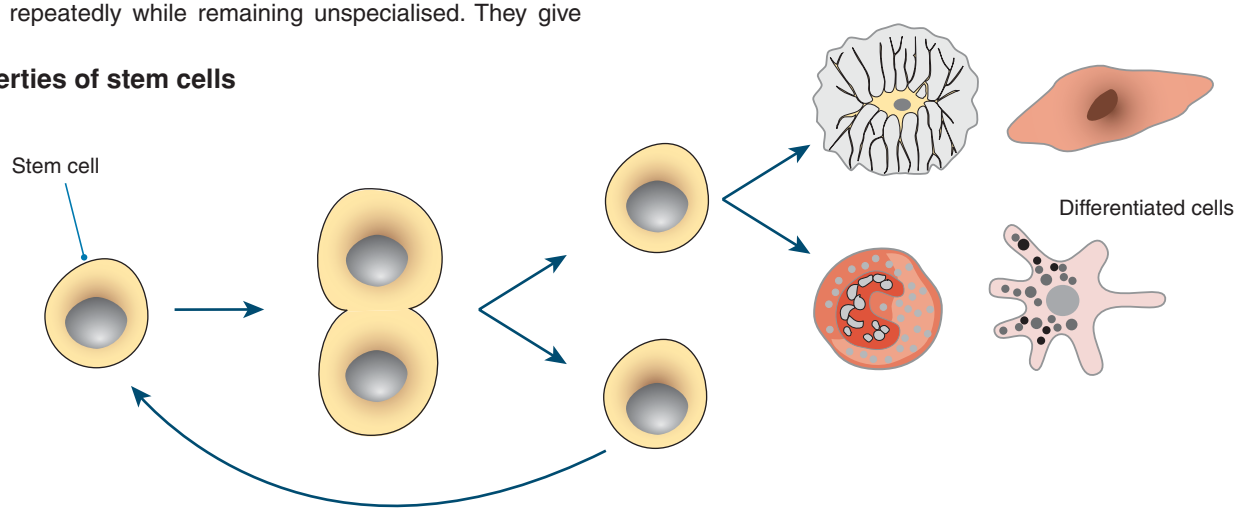
43 What are Stem Cells?

Key Idea: Stem cells are undifferentiated cells found in multicellular organisms. They are characterised by the properties of self renewal and potency.

A zygote (fertilised egg cell) can differentiate into all the cell types of the body because its early divisions produce stem cells. Stem cells are unspecialised cells that can divide repeatedly while remaining unspecialised. They give rise to the many cell types that make up the tissues of a multicellular organism. For example, the stem cells in bone marrow specialise to produce all the cell types that make up blood. These multipotent (or adult) stem cells are found in most organs, where they replace old or damaged cells and replenish cells throughout life.

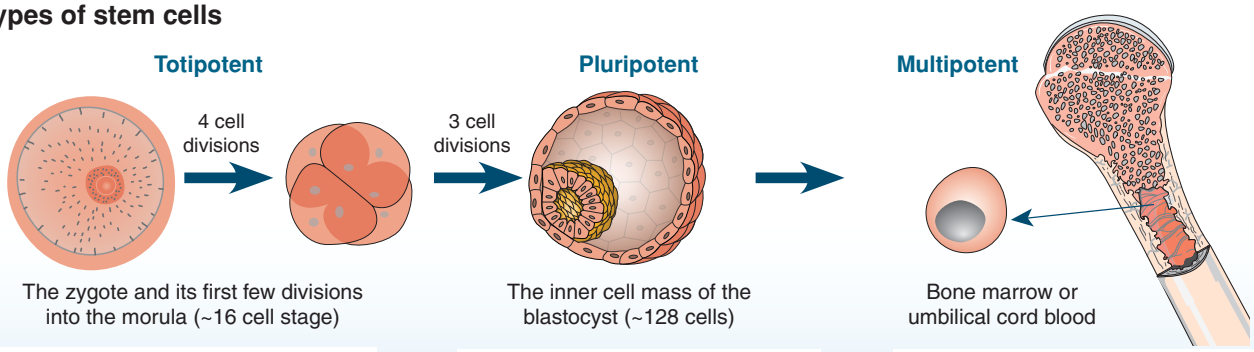
Properties of stem cells



Self renewal: Stem cells have the ability to divide many times while maintaining an unspecialised state.

Potency: The ability to differentiate (transform) into specialised cells. There are different levels of potency, depending on the type of stem cell.

Types of stem cells



Totipotent stem cells
These stem cells can differentiate into all the cells in an organism.
Example: In humans, the zygote and its first few divisions.
In plants, the tissue at the root and shoot tips.

Pluripotent stem cells
These stem cells can give rise to any cells of the body, except extra-embryonic cells (e.g. placenta and chorion).
Example: Embryonic stem cells.

Multipotent stem cells
These adult stem cells can give rise to a limited number of cell types, related to their tissue of origin.
Example: Bone marrow stem cells, epithelial stem cells, bone stem cells (osteoblasts).

1. Describe the two defining features of stem cells:

   (a) _____

   (b) _____

2. Describe the potency of stem cells and where they are found:

   (a) Totipotency: _____

   _____

   (b) Pluripotency: _____

   _____

   (c) Multipotency: _____

   _____

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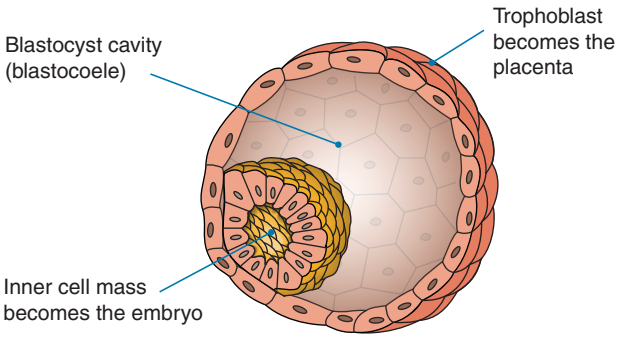
Embryonic stem cells



Blastocyst (5 days old)

- **Embryonic stem cells** (**ESC**) are derived from the inner cell mass of blastocysts (above). Blastocysts are 5 day old embryos consisting of a hollow ball of 50-150 cells.
- Cells derived from the inner cell mass are **pluripotent**. They can become any cells of the body, with the exception of placental cells.
- When cultured without any stimulation to differentiate, ESC retain their potency through multiple cell divisions. This means they have great potential for therapeutic use in regenerative medicine and tissue replacement.
- However, the use of ESC involves the deliberate creation and destruction of embryos and is therefore is ethically unacceptable to many people.

Adult stem cells

- **Adult stem cells** (ASC) are undifferentiated cells found in several types of tissues (e.g. brain, bone marrow, fat, and liver) in adults, children, and umbilical cord blood.
- Unlike ESCs, they are **multipotent** and can only differentiate into a limited number of cell types, usually related to the tissue of origin.
- There are fewer ethical issues associated with using ASC for therapeutic purposes, because no embryos are destroyed. For this reason, ASC are already widely used to treat a number of diseases including leukaemia and other blood disorders.

3. Distinguish between embryonic stem cells and adult stem cells with respect to their potency: _____

4. Suggest how stem cells could be potentially useful for treating diseased or damaged organs: _____

5. Why are there ethical issues with the use of embryonic stem cells in research and medicine? _____

6. New research has produced pluripotent stem cells from differentiated adult cells. These are called **induced pluripotent stem cells**. Suggest why using these cells in medicine generates fewer ethical issues than using other stem cell types:

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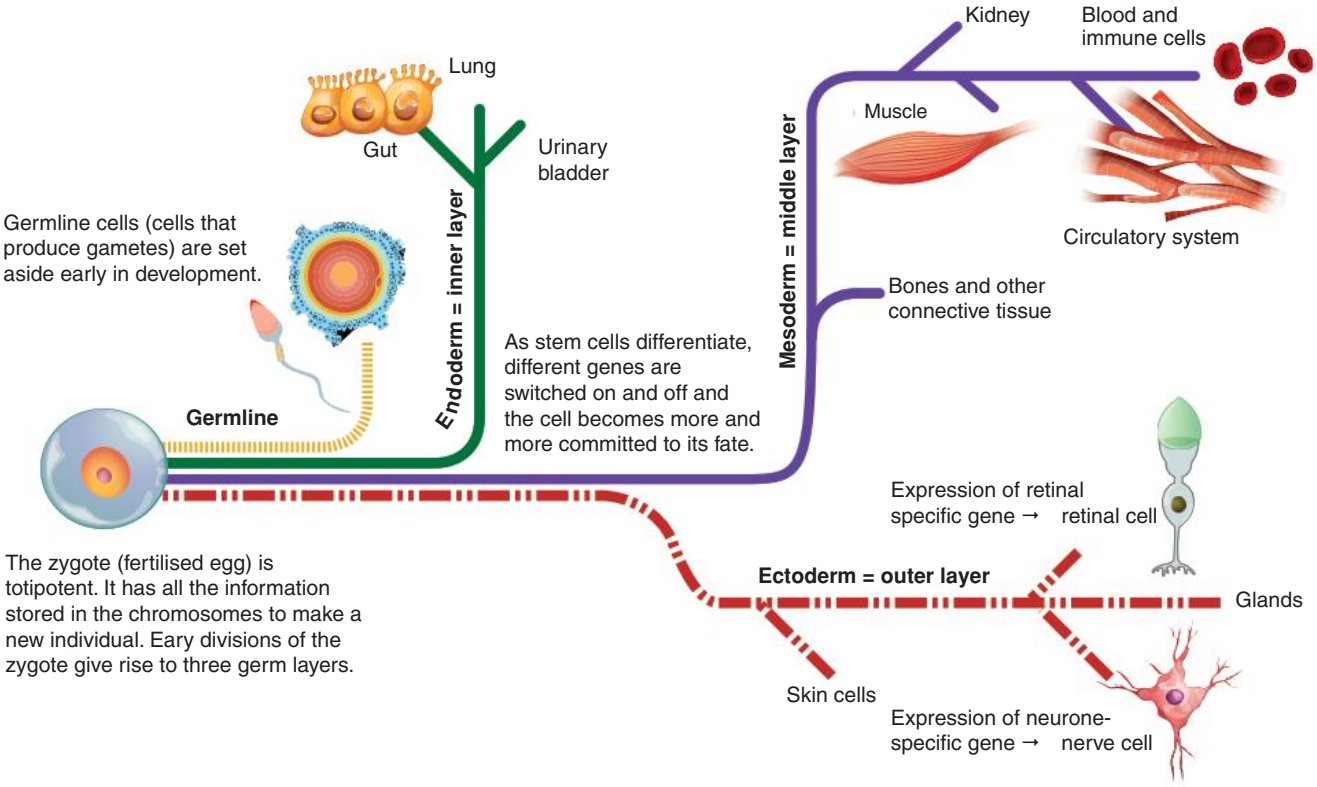
44 Cellular Differentiation

Key Idea: A zygote divides and produces all the cell types in the body by cellular differentiation. Specific patterns of gene switching determine what cell type develops.

Multicellular organisms consist of many different cell types, each specialised to carry out a particular role. A zygote and its first few divisions are totipotent and can differentiate to form any cell type in the body. During development, these cells divide and follow different developmental pathways, giving rise to the three germ layers and the specialised cells that make up the tissues and organs of the body. This process by which more specialised cells develop from more generalised ones is called **cellular differentiation**. It is achieved through switching genes on and off in particular sequences. As a cell proceeds along its developmental pathway, its 'choices' become more limited. Once fully differentiated, it cannot (under normal circumstances) turn into another cell type.



1. Multicellular organisms consist of many different cell types. Explain how it is possible for these all to arise from a single fertilised egg (zygote):

2. The zygote produces cells the differentiate in three cell lineages (germ layers). What types of cells/tissues do each of these lineages produce?

   (a) Endoderm: _____

   (b) Mesoderm: _____

   (c) Ectoderm: _____

3. Why can't a blood cell turn into a nerve cell? _____

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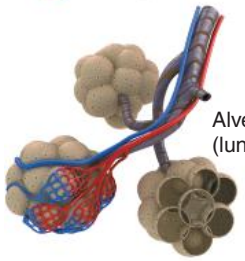
Three distinct cell layers (germ layers) are produced in an early embryonic phase of development called the gastrula. These three cell layers (endoderm, mesoderm, and ectoderm) are the precursors of all adult cells and tissues. At this stage, the cells are now multipotent and considered adult stem cells. Some examples of cells and tissues formed from each layer are described below.

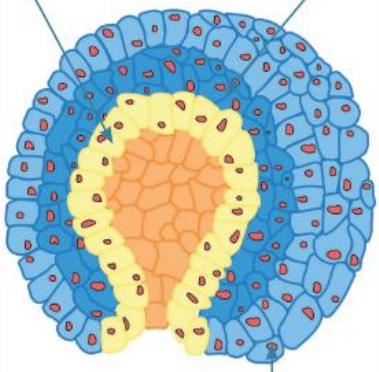
The endoderm

- The endoderm is the innermost germ layer.
- In the early embryo, the endoderm forms the embryonic gut.
- It differentiates to form the digestive system, glands, and part of the respiratory system.

Thyroid



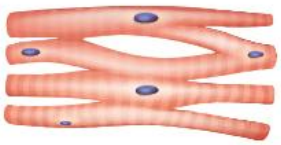
Alveoli (lung)



Gastrula

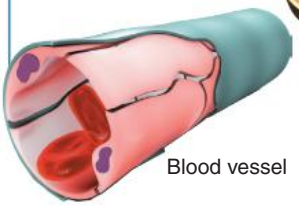
The mesoderm

- The mesoderm is the middle germ layer, between the ectoderm and endoderm.
- The mesoderm differentiates to give rise to the muscles, circulatory system (heart and blood vessels), urinogenital system, dermis (inner skin layer), skeleton, and other supportive and connective tissue.



Muscle fibres

Bone

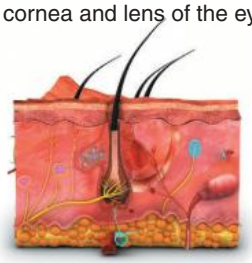


Blood vessel

The ectoderm

- The ectoderm is the outermost germ layer.
- In the fully developed embryo and adult human the ectoderm forms the brain and the nervous system, epidermis of skin (including hair, sweat glands and nails), tooth enamel, some endocrine glands, cornea and lens of the eye.

Nerve cell



Skin

Cornea and lens

4. Identify the three layers of the gastrula and give examples of what each of them give rise to:

(a) _____

_____

_____

(b) _____

_____

_____

(c) _____

_____

_____

5. Explain why the cells of the gastrula are considered to be adult stem cells (multipotent): _____

_____

_____

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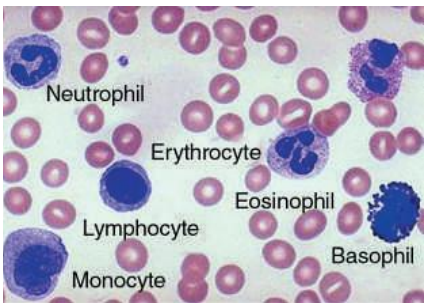
45 Adult Stem Cells Give Rise to Related Cells

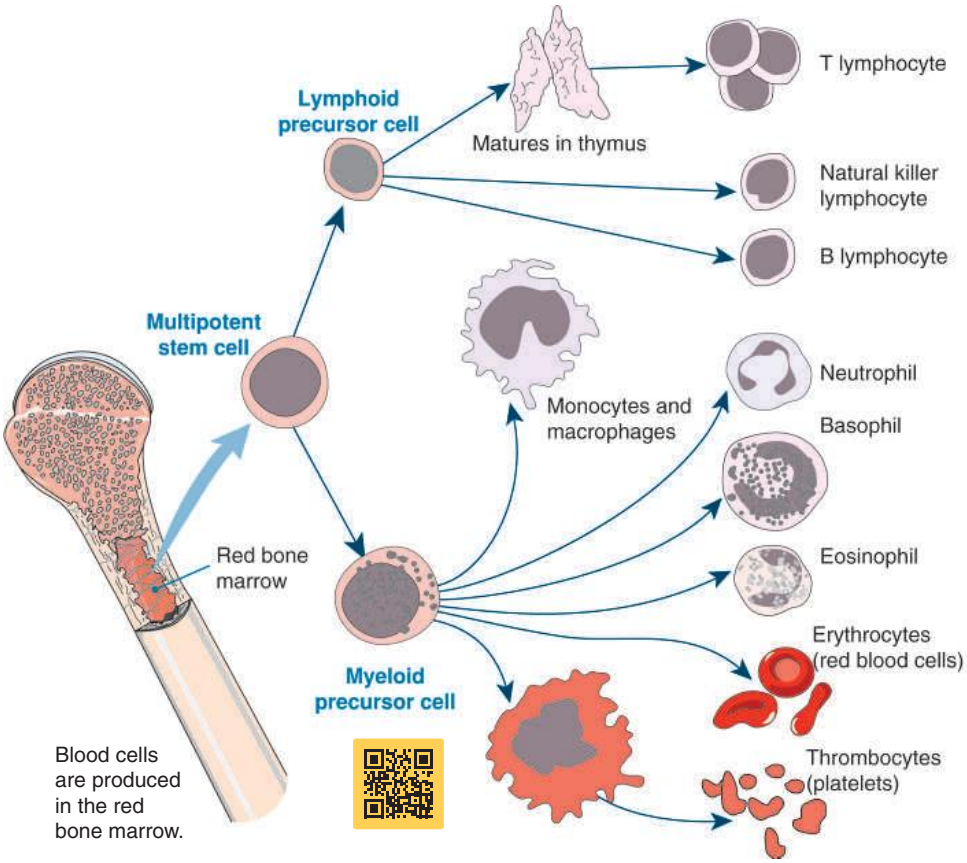
Key Idea: All cells arise from preexisting cells. All cells can be traced back to a particular type of stem cell.

The zygote is the ultimate stem cell and is able to give rise to all other cell types (it is totipotent). As the zygote divides and the cells become more specialised, they lose their ability to differentiate into specific cell types. Adult stem cells are multipotent and are only able to produce a limited range of differentiated cells, related to the tissue of origin.

Stem cells and blood cell production

- After birth, new blood cells are produced in the red bone marrow. All types of blood cells differentiate from a single type of **multipotent stem cell** called a hematopoietic stem cell (haemo- means blood). These cells are capable of mitosis and of differentiation into 'committed' precursors of each of the main types of blood cell.
- Each of the different cell lines is controlled by a specific growth factor. When a stem cell divides, one of its daughters remains a stem cell, while the other becomes a precursor cell, either a **lymphoid cell** or **myeloid cell**. Lymphoid cells and myeloid cells continue to mature into the various specialised cell types (below).





Function

Immunity

White blood cells (leucocytes) are part of the immune system. They defend the body against infectious disease and foreign materials.

Lymphocytes

Specialised white blood cells involved in the specific immune response.

Granulocytes

Neutrophils, eosinophils, and basophils. Specialised white blood cells which destroy foreign material (e.g. bacterial cells) by phagocytosis. They are named for the granular appearance of their cytoplasm.

Gas exchange

Red blood cells are spacialised to transport oxygen around the body.

Blood clotting

Platelets work with factors in the blood to form clots to stop bleeding.

1. Describe the pathway for the production of the following cell types:

   (a) A neutrophil cell: _____

   _____

   (b) A T lymphocyte: _____

   _____

2. How many cell types can a myeloid precursor differentiate into? _____
3. What controls the differentiation of stem cells into specialised cells? _____
4. What happens to the daughter cells when a stem cell divides? _____

   _____
5. Why is the zygote "the ultimate stem cell"? _____

   _____

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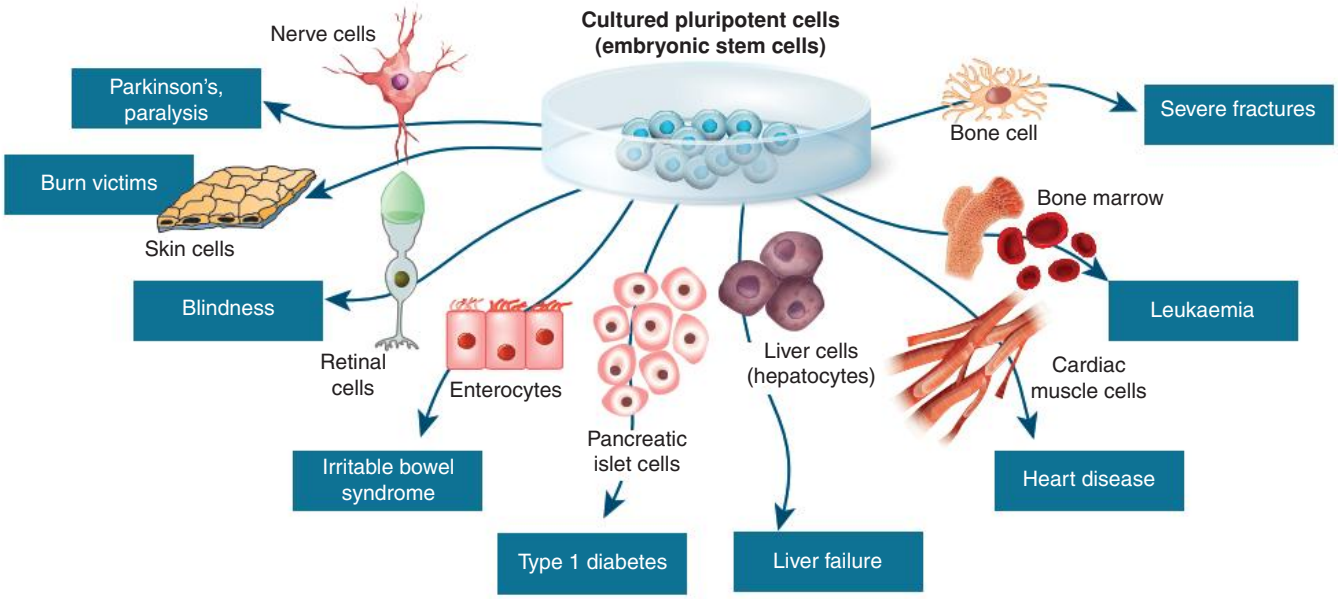
46 Applications of Stem Cells

Key Idea: Stem cells have many potential medical applications, but technical difficulties must be overcome first. Stem cell research is at an early stage and there is much to be learned about the environments that cells require in order to differentiate into specific cell types. The ability of embryonic stem cells (ESC) to differentiate into almost any cell type means that they have potential applications in replacing diseased or damaged cells (below). Adult stem cells, either from a donor or from the patient themselves, also have therapeutic uses. Donor stem cells must be matched for compatibility. Stem cell cells for autologous (self) transplants may require genetic correction before use.

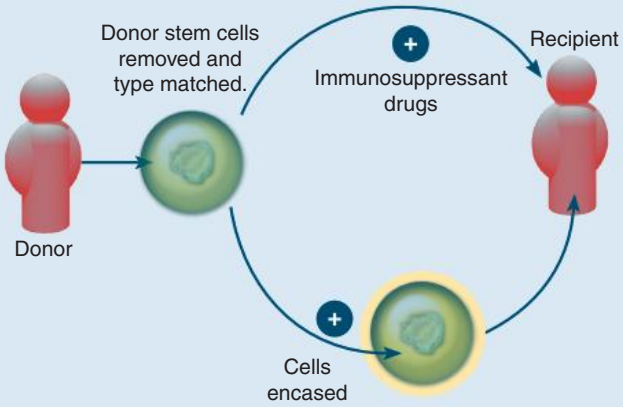


Donor stem cells can be used to repair tissues

Problem: The recipient's immune system will attack the donor's cells.

Solution: Firstly, a donor with a tissue match is selected (the cell surface proteins on donor and recipient cells are the same or very similar). This reduces the risk of the recipient's immune system rejecting the cells. Secondly, the recipient will need to take immunosuppressant drugs to stop their immune system attacking the donated cells.

Another way to prevent immune rejection is to encase donor cells in a protective shell, isolating them from immune detection by the recipient. This is being investigated with respect to pancreatic cells and diabetes.

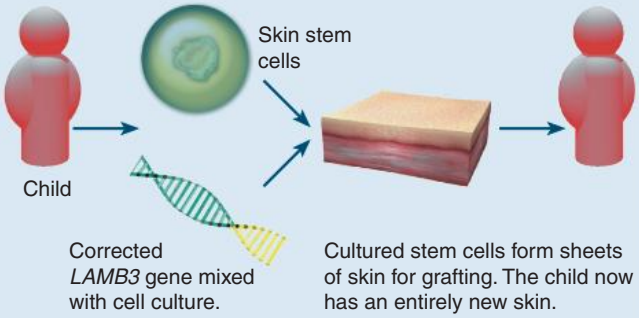


A patient's cells can be corrected before use

Problem: Some diseases are the result of defective genes. Stem cells from the patient will carry these defective genes.

Solution: If the disease is due to a simple genetic fault, then the stem cells can be genetically corrected before use. Stem cells are isolated and cultured in the laboratory in the presence of the corrected gene. Cells with the corrected genes are identified and transplanted back into the patient, without immune rejection (an autologous transplant).

Example: In 2015, a young German child had a mutation in the *LAMB3* gene. His skin cells were not making the protein needed to hold cells together and his skin was falling off. His skin stem cells were genetically corrected and new skin was cultured and grafted back. More than a square metre of skin was grown and grafted onto the child.



1. Identify a problem with using stem cells from a donor to treat a recipient patient: _____

_____

_____

_____

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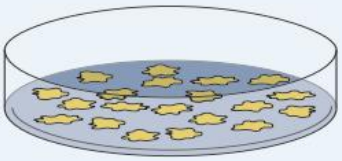
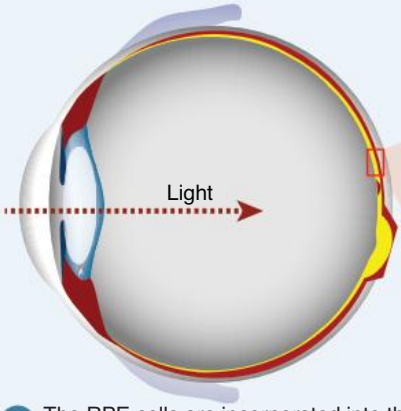
Stem cells for Stargardt's disease

- Stargardt's disease is an inherited form of juvenile macular degeneration (a loss of the central visual field of the eye). The disease is associated with a number of different mutations and results in malfunction of the retinal pigment epithelium (RPE) cells, which normally nourish the retinal photoreceptor cells and protect the retina from excess light.
- Faulty RPE causes deterioration of the photoreceptor cells in the centre of the retina and progressive loss of central vision. This often begins between ages 6 and 12 and continues until a person is legally blind. Trials using stem cells have proved promising as a treatment, with impaired vision being corrected relatively quickly (within weeks).

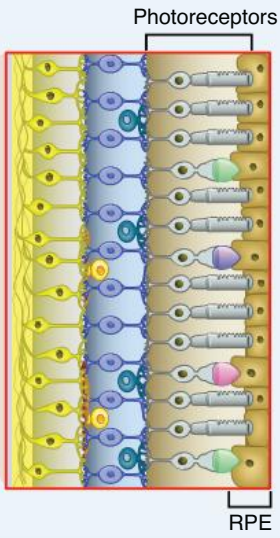
1 Embryonic stem cells are cultured in the lab with specific growth factors (proteins, vitamins) so that they develop into retinal pigment epithelium (RPE) cells.



2 The RPE cells are injected just below the retina of the eye and above the choroid (the layer containing the blood vessels).



3 The RPE cells are incorporated into the retina, replacing the patient's damaged RPE cells and prompting regeneration of the photoreceptor cells.



2. Umbilical cord blood is promoted as a rich source of multipotent stem cells for autologous (self) transplants. Can you see a problem with using a baby's cord blood to treat a disease in that child at a later date?

3. (a) Explain the basis for correcting Stargardt's disease using stem cell technology:

   (b) There have also been stem cell therapy trials using the patient's own cells (e.g. bone marrow) to treat Stargardt's disease. What advantages might there be in using a patient's own cells and what difficulties might be involved?

4. Describe a technical difficulty associated with stem cell therapies when:

   (a) The stem cells come from a donor:

   (b) The stem cells used are ESC:

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47 Bioethical Issues Associated with Stem Cells

Assessment task, Outcome 1: *Response to a bioethical issue*

As we have seen, human stem cells can give rise to many different types of cells. There are many potential uses of these stem cells:

- Treatment of diseases such as Parkinson's, Alzheimer's, leukaemia, stroke, heart disease, diabetes, multiple sclerosis, eye disorders, and rheumatoid arthritis.
- Repair of damaged tissue, e.g. spinal cord injuries, skin conditions, and burns.
- Testing the safety and efficacy of new drugs on cultured cells before testing on humans.

The source of stem cells affects how the technology is applied. For example, the use of ASC from umbilical cord blood or bone marrow can only be used for a limited number of treatments including blood and immune system disorders (e.g. leukaemia). Harvesting ESC opens up more possibilities for therapeutic treatments because they can differentiate into many more cell types and so have the potential to treat more disorders.

Harvesting bone marrow

Stem cell therapy raises the bioethical question "How do the ethical implications of stem cell research and its applications affect society"? Harvesting stem cells from live bone marrow donors or umbilical cord blood is less controversial than harvesting them from early-stage embryos. In Australia, embryonic stem cells are sourced from patients who have undergone fertility treatment and have surplus embryos to donate to medical research. Although these embryos would have otherwise been discarded, many people find this an unacceptable practice and view it as destruction of life.

1. Carry out your own research or use the resources on **BIOZONE's Resource Hub** to research the bioethical issues associated with stem cell therapy. At the end of your research, present your own justified personal response to this bioethical issue. Summarise your findings below or record them on a shared electronic document.

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48 Chapter Review: Did You Get It?

1. Match each term to its definition, as identified by its preceding letter code.

binary fission	**A** A type of cell that possesses the qualities of self renewal and potency (ability to give rise to other types of cell).
cell cycle	**B** Able to differentiate into all the cell types in an organism.
multipotent	**C** Able to give rise to any cells of the body, except extra-embryonic cells.
pluripotent	**D** A type of asexual reproduction in prokaryotes where the genetic material is replicated and the parent cell splits into two identical cells.
potency	**E** The changes that take place in a cell in the period between its formation as a product of cell division and its own subsequent division.
self renewal	**F** Able to give rise a limited number of cell types, related to their tissue of origin.
stem cell	**G** Ability to divide many times while maintaining an undifferentiated state.
totipotent	**H** Ability to differentiate into specialised cell types.

2. Give an example of each of the following stem cell types:

   (a) Multipotent: _____

   (b) Pluripotent: _____

   (c) Totipotent: _____

3. (a) Label the cell cycle right with the following labels: G_1 checkpoint, G_2 checkpoint, metaphase checkpoint.

   (b) Briefly describe what happens in each of the following checkpoints:

   G_1 checkpoint: _____

   _____

   _____

   _____

   G_2 checkpoint: _____

   _____

   _____

   _____

   _____

   M phase checkpoint: _____

   _____

4. Why are cancer cells often called immortal cells? _____

   _____

   _____

   _____

   _____

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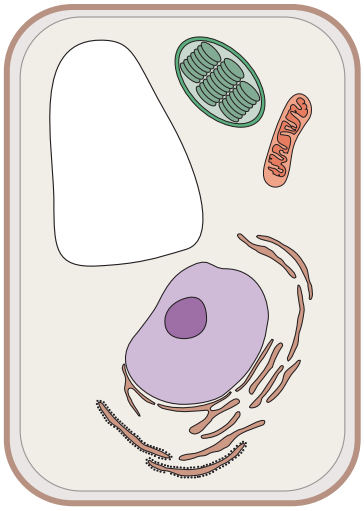
49 Synoptic Question: Unit 1, Area of Study 1

1. (a) Plant cells are eukaryotic cells. Annotate the following diagram to identify the features of a plant cell. In your answer you should briefly state the function of the structures and organelles labelled.



(b) Which organelle shown in the plant cell is not found in an animal cell? _____

2. Describe the characteristics of the plasma membrane and explain how substances are transported across it. Include simple diffusion, facilitated diffusion, osmosis, and active transport. You may use extra paper if required.

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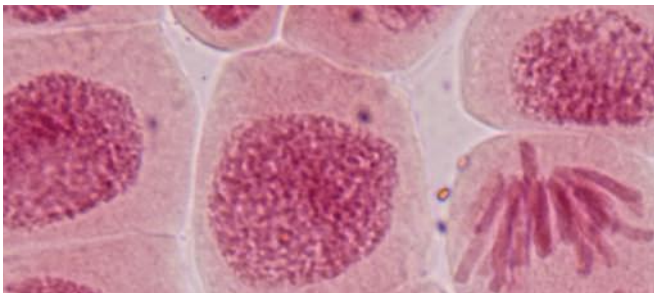
3. Briefly describe the process of binary fission in prokaryotes: _____

4. (a) What type of cells carry out mitosis and what is its purpose? _____

(b) In the photograph right, there is one cell in mitosis:



i) What stage of mitosis is this cell in?

_____

ii) What stage of the cell cycle are the other cells in?

_____

(c) Use the space below to draw a labelled sequence of mitosis, including the important stages:

5. Stem cells have the potential to be an important medical tool for the replacement of damaged or diseased tissue or organs. Explain why stem cells are potentially useful:

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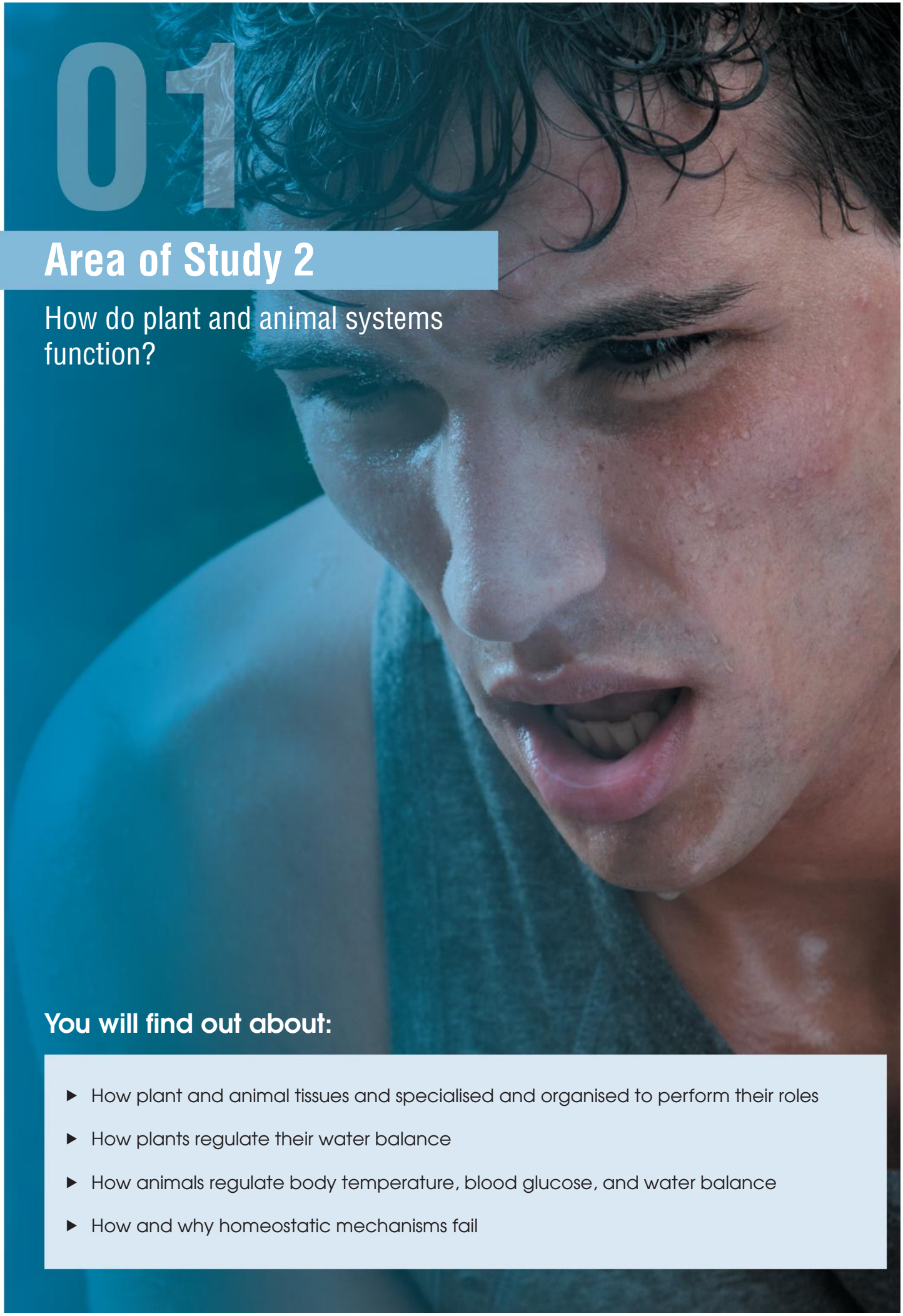


01

Area of Study 2

How do plant and animal systems function?

You will find out about:

- How plant and animal tissues and specialised and organised to perform their roles
- How plants regulate their water balance
- How animals regulate body temperature, blood glucose, and water balance
- How and why homeostatic mechanisms fail

CHAPTER
4

Functioning Systems

Key terms
absorption
cohesion-tension hypothesis
digestion
digestive system
ductless gland
egestion
endocrine system
excretion
excretory system
glomerulus
hormone
intestinal villi
kidney
large intestine
mass flow hypothesis
nephron
organ
organ system
phloem
root
small intestine
specialised cell
stem
stomach
tissue
translocation
transpiration
ultrafiltration
urine
vascular tissue
xylem

Functioning systems in plants

Key skills and knowledge

Activity number

☐ 1 Describe the hierarchy of organisation in a vascular plant, with reference to how its cells are specialised into tissues and tissues into organs for the purposes of water uptake, water transport, and regulation of water loss. **50 - 53**

☐ 2 Identify the cells contributing to xylem in angiosperms and their roles in the tissue. Describe the features of mature xylem and identify xylem tissue in light micrographs. **53**

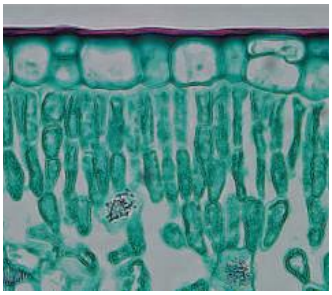
☐ 3 Identify the cells contributing to phloem in angiosperms and their roles in the tissue. Describe the features of phloem and identify phloem tissue in light micrographs. **54**

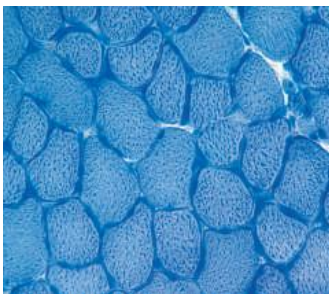
☐ 4 Describe the movement of water through the plant from the roots to the air. Include reference to the pathways for water movement and their relative importance. **55 56**

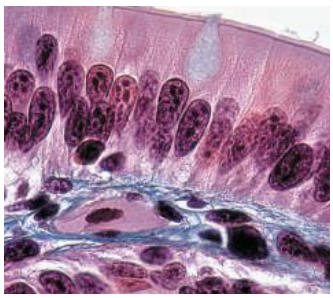
☐ 5 Explain the movement of water through the plant (the transpiration stream) in terms of osmosis, gradients in solute concentration, and the cohesion-tension hypothesis. Identify the benefits and disadvantages of transpiration to the plant. **56**

☐ 6 PRAC Use a potometer to estimate transpiration rates in different plants or different conditions. Interpret data from investigations of transpiration. **57**

☐ 7 Explain the movement of sugar in the phloem by mass flow, including reference to the role of osmosis and active transport at sources and sinks. **58**







Functioning systems in animals

Key skills and knowledge

☐ 8 Describe the hierarchy of organisation in a mammal. Explain how the cells are specialised into tissues and tissues into organs that carry out a specific role, e.g. in digestion, internal transport, gas exchange, hormonal regulation, or excretion. **59 60**

☐ 9 The digestive system **61**
Describe the structure and function of the digestive system, including reference to how food is moved through the gut, how it is broken down by secretions of specialised regions, and how the products of digestion are absorbed.

☐ 10 PRAC Investigate the effect of pH on the activity of the digestive enzyme amylase. How is activity related to the conditions provided by the gut environment? **62**

☐ 11 The endocrine system **63**
Describe the structure and function of the endocrine system, including reference to how hormones bring about changes in distant target organs and tissues. Outline the important role of the pituitary and hypothalamus in many endocrine functions and describe the endocrine role of the adrenal glands, pancreas, and thyroid in particular.

☐ 12 The excretory system **64**
Describe the structure and function of the excretory system, including how blood is filtered by the kidney and how excretory products are disposed of by the body. Include reference to the number and arrangement of nephrons in the kidney, and the role of active and passive transport mechanisms in creating a gradient for the reabsorption of water from the filtrate (urine).

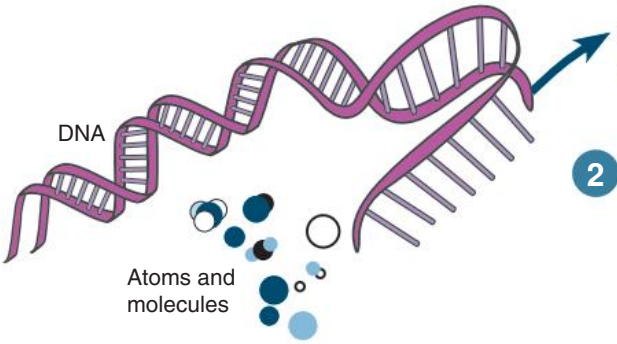
50 The Hierarchy of Life: Plants

Key Idea: The structural organisation of plants, like all multicellular organisms, is hierarchical. Components at each level of organisation are part of the next level.

Plants, like all multicellular organisms, are organised in a hierarchy of structural levels, where each level builds on the one below it. Higher levels of organisation are more complex than lower levels and often exhibit new (emergent) properties. Hierarchical organisation enables specialisation so that individual components perform a specific function or set of related functions. This specialisation enables the organism to function more efficiently. The diagram below explains this hierarchical organisation for a plant.

1 The chemical level

All the chemicals essential for maintaining life, e.g. water, ions, fats, carbohydrates, amino acids, proteins, and nucleic acids.

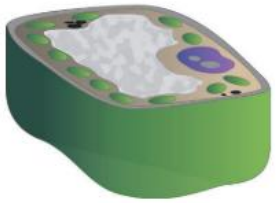


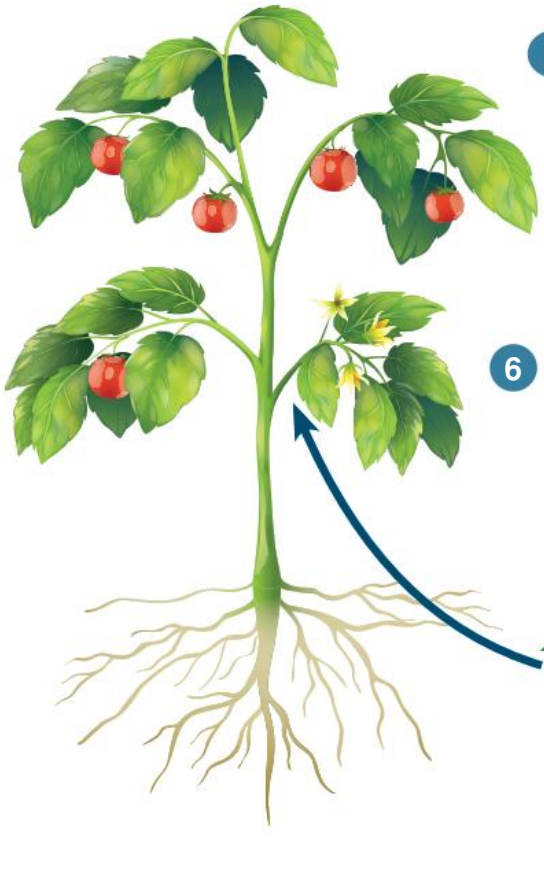
2 The organelle level

Molecules associate together to form the organelles and structural components of cells, e.g. chloroplast (above).

3 The cellular level

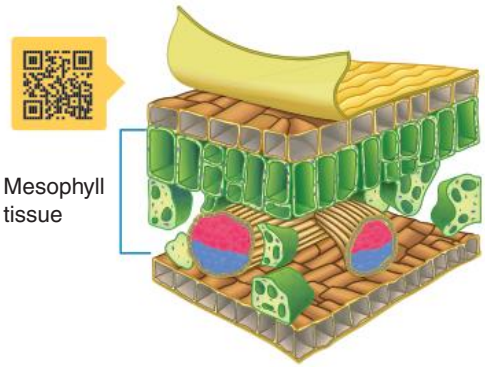
Cells are the basic structural and functional units of an organism. Cells are specialised to carry out specific functions, e.g. mesophyll cell (below).





4 The tissue level

Groups of cells with related functions form tissues, e.g. mesophyll tissue (above). The cells of tissue often have a similar origin.



5 The organ level

An organ is made up of two or more types of tissues to carry out a particular function. Organs have a definite form and structure, e.g. leaf (left).

6 The organ system level

Groups of organs with a common function form an organ system, e.g. the shoot system in plants (the above-ground parts of the plant, left).

7 The organism

The cooperating organ systems make up the organism, e.g. a tomato plant.

1. Briefly describe how hierarchical organisation and cell specialisation allow an organism to function more efficiently:

_____

_____

2. Assign each of the following new (emergent) properties to the level at which you think they first appear:

(a) Metabolism: _____ (b) Response: _____ (c) Self replication: _____

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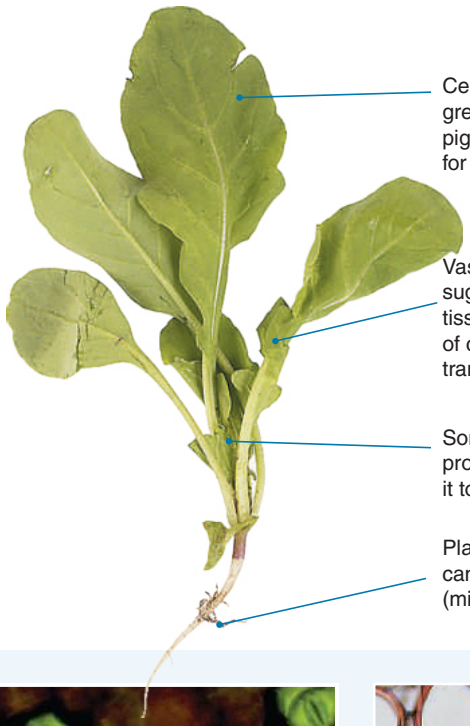
51 Specialisation in Plant Cells

Key Idea: The specialised cells in a plant have specific features associated with their particular roles.

The cell is the functioning unit structure from which living organisms are made. In multicellular organisms (organisms made up of more than one cell) cell differentiation produces specialised cells with specific functions. The differentiation of cells gives rise to specialised cell types that fulfil specific roles in the plant, e.g. support, transport, or photosynthesis.

- A specialised cell is a cell with the specific features needed to perform a particular function in the organism.
- Cell specialisation occurs during development when specific genes (a specific section of DNA that codes for protein) are switched on or off.
- Multicellular organisms have many types of specialised cells. These work together to carry out the essential functions of life.
- The size and shape of a cell allows it to perform its function. The number and type of organelles in a cell is also related to the cell's role in the organism.
- Specialised cells come together to form tissues with a specific functional role, e.g. water transport. In plants, simple tissues contain only one cell type, for which they are named, e.g. parenchyma. Complex tissues, such as xylem and phloem, contain more than one cell type.

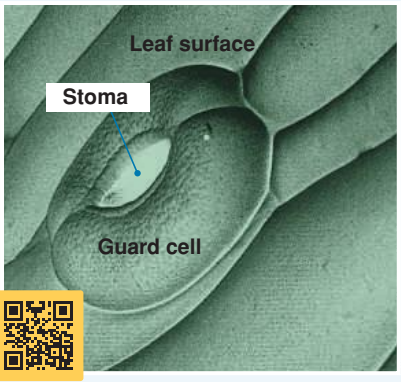


Cells in the leaves of plants are often green because their cells contain the pigment chlorophyll, which is needed for photosynthesis.

Vascular tissue transports water and sugar (sap) around the plant. Vascular tissue (the plant veins) is made up of collections of cells specialised to transport different substances.

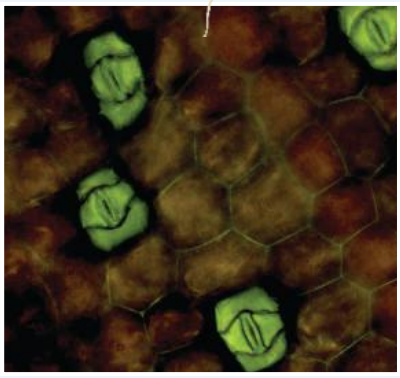
Some cells are strengthened to provide support for the plant, allowing it to keep its form and structure.

Plants have root-hair cells so they can obtain water and nutrients (mineral ions) from the soil.



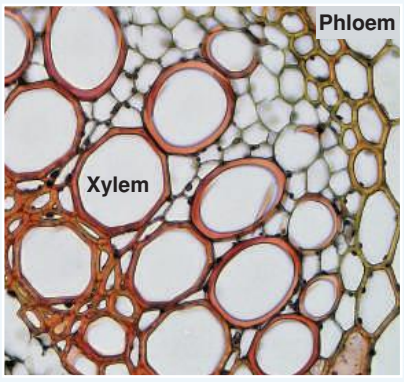
Eli

Specialised guard cells surround the pores (stomata) on plant leaves. The guard cells flanking the pore control the opening and closing of stomata and prevent too much water being lost from the plant.



Alotheistorm PD

The semi-rigid cell wall gives many plant cells a regular shape. This *Tradescantia* epidermis has polyhedral epidermal cells with stomata flanked by guard cells and four more irregular epidermal cells.



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The vascular tissues of plants (xylem and phloem) are complex tissues that transport materials through the plants. The main components of the tissues are supported by packing and strengthening cells.

1. (a) What is a specialised cell? _____

_____

(b) How does cell specialisation occur? _____

_____

2. (a) Name the specialised cell that helps to prevent water loss in plants: _____

(b) How does this cell prevent water from being lost in plants? _____

_____

3. How do specialised root hairs help plants to absorb more water and minerals from the soil? _____

_____

_____

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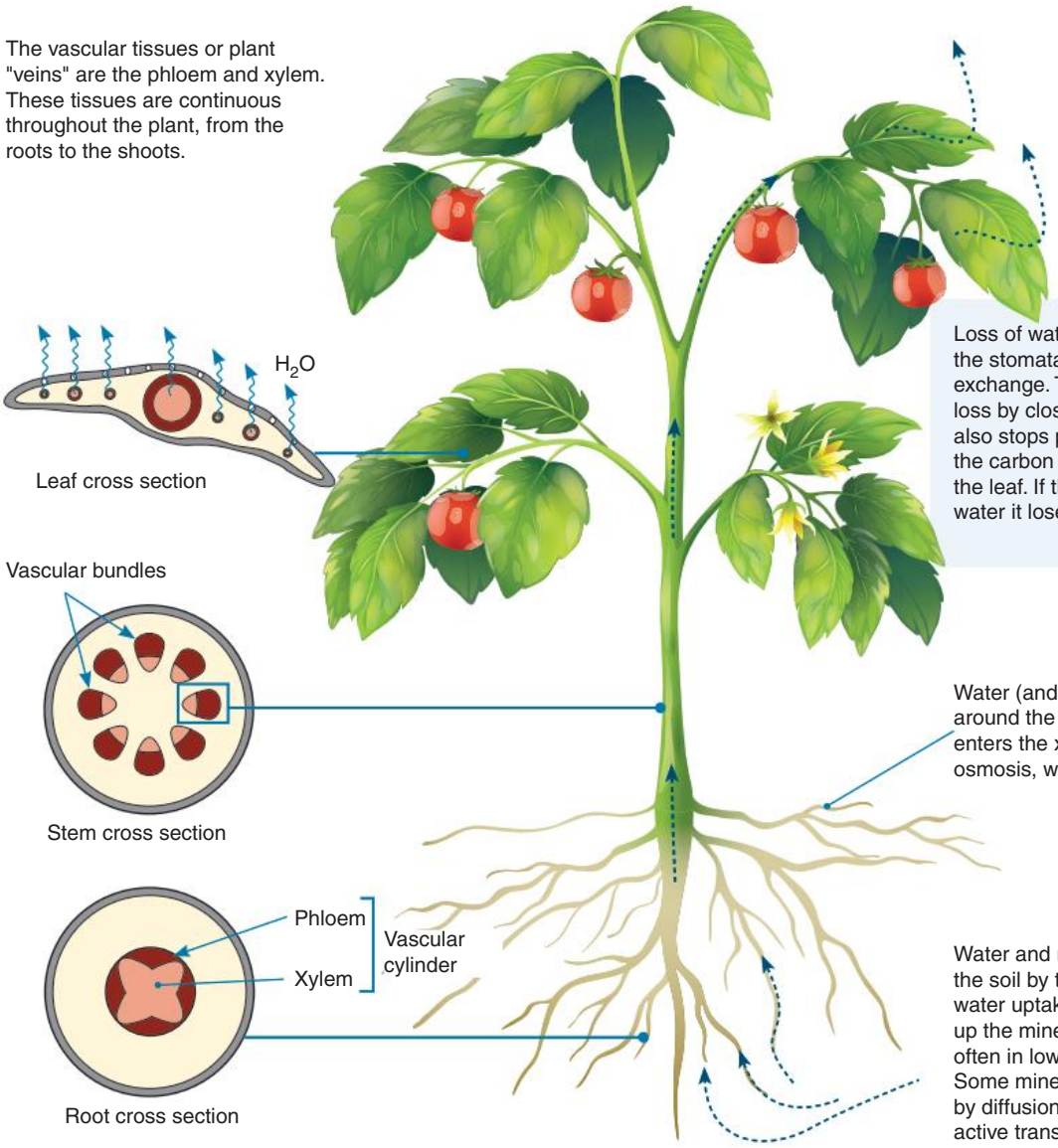
52 The Plant Transport System

Key Idea: The xylem and phloem form the vascular tissue that moves fluids and nutrients about the plant.

The transport system of plants moves water and nutrients around the plant in order to meet the plant's needs for metabolic processes such as photosynthesis and growth. Two types of vascular tissue make up the plant transport system: **xylem**, which transports water and minerals, and **phloem**, which transports sugars. Xylem is highly specialised for its role and its transporting tissues are dead when mature. The transport of water is passive process and does not require energy, so the organelles usually found in cells to support metabolic activity are absent in xylem. Phloem is specialised to transport sugar, which is an active process, so phloem is alive when mature.

The vascular tissues or plant "veins" are the phloem and xylem. These tissues are continuous throughout the plant, from the roots to the shoots.



Loss of water vapour (H_2O) through the stomata is a consequence of gas exchange. The plant can reduce water loss by closing the stomata but this also stops photosynthesis because the carbon dioxide (CO_2) cannot enter the leaf. If the plant cannot replace the water it loses it will wilt and die.

Water (and minerals) are transported around the plant in the xylem. Water enters the xylem at the roots by osmosis, which requires no energy.

Water and minerals are absorbed from the soil by the root system. A large water uptake enables the plant to take up the minerals it needs, as these are often in low concentration in the soil. Some minerals enter the root passively by diffusion and some are taken up by active transport.

1. Name the two vascular tissues in plants: _____

2. Briefly describe why plants need a transport system: _____

_____

_____

3. (a) What is the function of xylem? _____

_____

(b) How does water enter the xylem? _____

(c) Why is water loss a consequence of gas exchange? _____

_____

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53 Xylem

Key Idea: The xylem is involved in water and mineral transport in vascular plants.

Xylem is the principal water conducting tissue in vascular plants. It is also involved in conducting dissolved minerals and in supporting the plant body. As in animals, tissues in plants are groupings of different cell types that work together for a common function. In flowering plants, xylem tissue is composed of five cell types: tracheids, vessels, xylem parenchyma, sclereids (short sclerenchyma cells), and fibres. The tracheids and vessel elements form the bulk of the tissue. They are heavily strengthened and are the conducting cells of the xylem. Parenchyma cells are involved in storage, while fibres and sclereids provide support. When mature, xylem is dead.

1. (a) What cells conduct the water in xylem?

   (b) What other cells are present in xylem tissue and what are their roles?

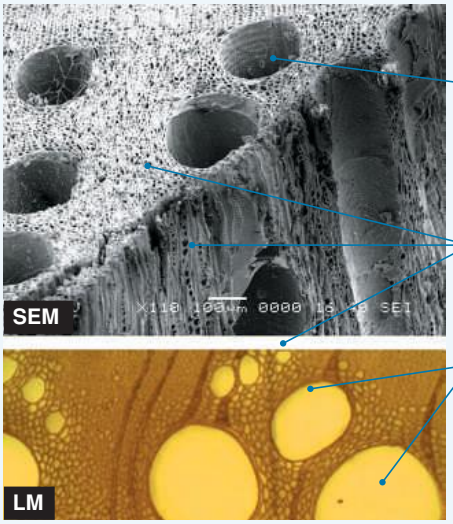
2. (a) How does water pass between vessels?

   (b) How does water pass between tracheids:

   (c) Which cell type do you think provides the most rapid transport of water and why?

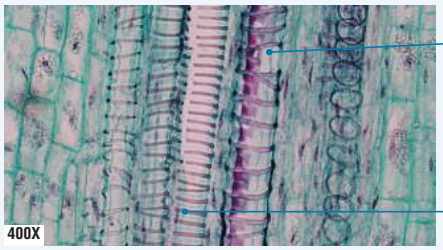
   (d) Why do you think the tracheids and vessel elements have/need secondary thickening?

3. How can xylem vessels and tracheids be dead when mature and functional?



Photos: McKDandy cc 2.5

As shown in these SEM and light micrographs of xylem, the **tracheids** and **vessel elements** form the bulk of the xylem tissue. They are heavily strengthened and are involved in moving water through the plant. The transporting elements are supported by parenchyma (packing and storage cells) and sclerenchyma cells (fibres and sclereids), which provide mechanical support to the xylem.



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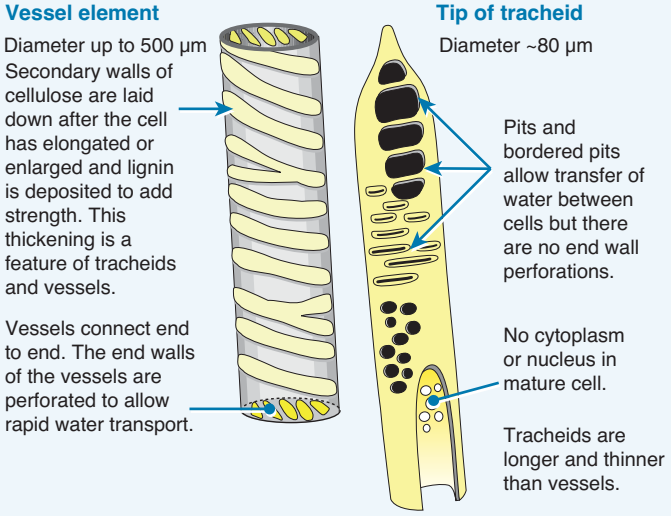

Vessel elements and tracheids are the two water conducting cell types in the xylem of flowering plants. Tracheids are long, tapering hollow cells. Water passes from one tracheid to another through thin regions in the wall called pits. Vessel elements are much larger cells with secondary thickening in different patterns (e.g. spirals). Vessel end walls are perforated to allow efficient conduction of water.

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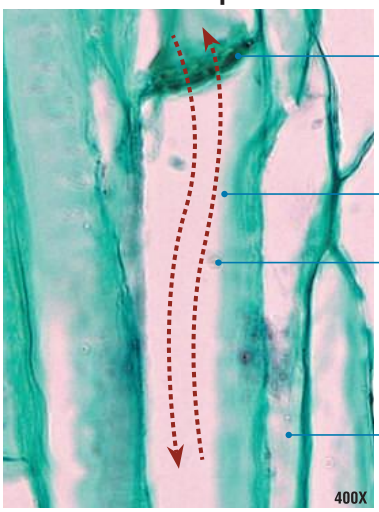
54 Phloem

Key Idea: Phloem is the principal food (sugar) conducting tissue in vascular plants, transporting dissolved sugars around the plant.

Like xylem, **phloem** is also a complex tissue, made up of a variable number of cell types. The bulk of phloem tissue is made up of the **sieve tubes** (sieve tube elements and sieve cells) and their companion cells. The sieve tubes are the main conducting cells in phloem and are closely associated with the **companion cells** which support them. Parenchyma cells, concerned with storage, occur in phloem, and strengthening fibres and sclereids (short sclerenchyma cells) may also be present. Unlike xylem, functional, mature phloem is alive.

LS through a sieve tube end plate



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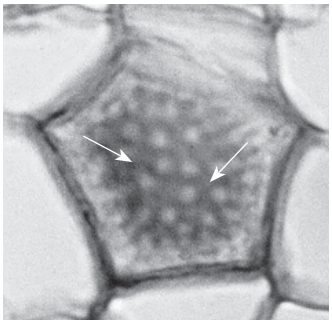
Sieve tube end plate
Tiny holes (arrowed in the photograph below) perforate the sieve tube elements allowing the sugar solution to pass through.

Sugar solution flows in both directions

The sieve tube elements (also called sieve tube members) lose most of their organelles but are still alive when mature.

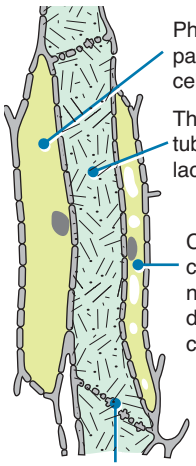
Companion cell
A cell next to the sieve tube member, responsible for keeping it alive.

TS through a sieve tube end plate



RCN

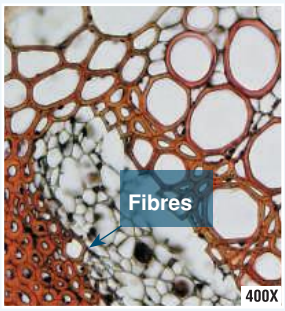
Adjacent sieve tube elements are connected through **sieve plates** through which phloem sap flows.



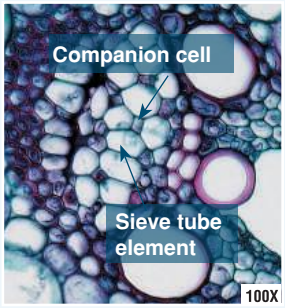
The structure of phloem tissue

Phloem is alive at maturity and functions in the transport of sugars and minerals around the plant. Like xylem, it forms part of the structural vascular tissue of plants.

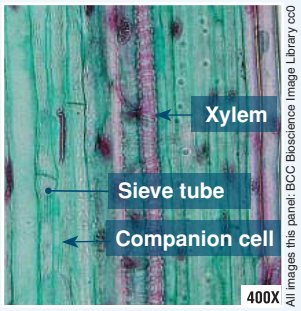
Fibres are associated with phloem as they are in xylem. Here they are seen in cross section where you can see the extremely thick cell walls and the way the fibres are clustered in groups.



In this cross section through the vascular bundle of a corn stem, the smaller companion cells can be seen lying alongside the sieve tube members. It is the sieve tube elements that, end on end, produce the **sieve tubes**. They are the conducting tissue of phloem.



In this longitudinal section of a corn stem, each sieve tube element has a thin **companion cell** associated with it. Companion cells retain their nucleus and control the metabolism of the sieve tube member next to them. They also have a role in the loading and unloading of sugar into the phloem.



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1. (a) What is the conducting cell type in phloem? _____

   (b) What other cell type is associated with these conducting cells? _____

   (c) Describe two roles of these associated cells: _____

   _____

2. Mature phloem is a live tissue, whereas xylem (the water transporting tissue) is dead when mature. Why is it necessary for phloem to be alive to be functional, whereas xylem can function as a dead tissue?

   _____

3. What is the role of fibres and sclereids in phloem? _____

   _____

4. What are the large open cells next to the phloem in the centre photo above right? _____

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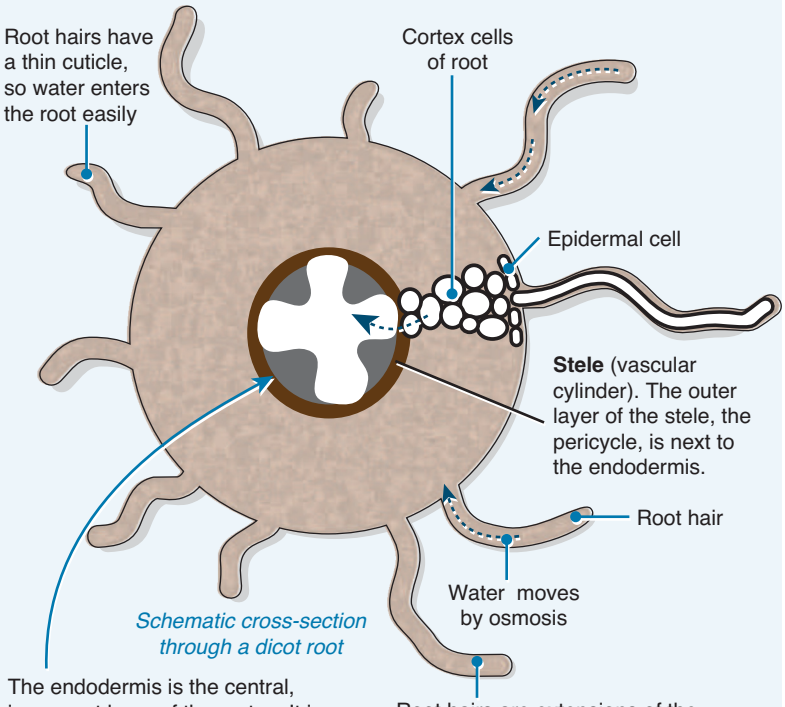
55 Uptake at the Root

Key Idea: Water uptake by the root is a passive process. Mineral uptake can be passive or active.

Plants need to take up water and minerals constantly. They must compensate for the continuous loss of water from the leaves and provide the materials the plant needs to make food. The uptake of water and minerals is mostly restricted to the younger, most recently formed cells of the roots and the root hairs. Water uptake occurs by osmosis, whereas mineral ions enter the root by diffusion and active transport. Pathways for water movements through the plant are outlined below.

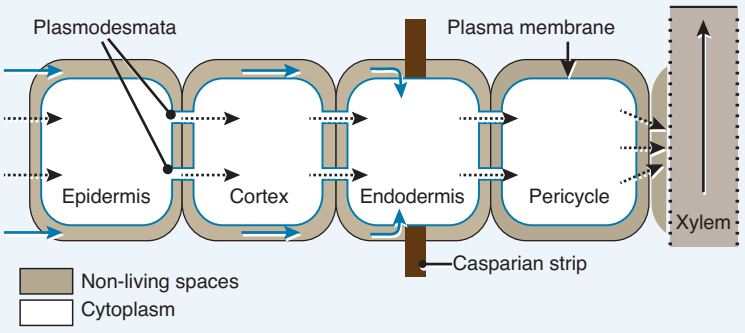
Water and mineral uptake by roots



The endodermis is the central, innermost layer of the cortex. It is a single layer of cells with a waterproof band of suberin, called the **Casparian strip**, which encircles each cell.

Root hairs are extensions of the root epidermal cells and provide a large surface area for absorbing water and nutrients.

Paths for water movement through the plant



Zone of lower solute concentration [higher free water]
May be due to turgid cells, higher wall pressure or lower concentration of dissolved substances

Zone of higher solute concentration [lower free water]
May be due to less turgid cells, lower wall pressure or higher concentration of dissolved substances

The uptake of water through the roots occurs by osmosis, i.e. the diffusion of water from a lower solute concentration to a higher solute concentration. Most water travels through the non-living spaces within the cellulose cell walls, the water-filled spaces of dead cells, and the hollow tubes of xylem. Smaller amounts move through the cytoplasm of cells and the plant vacuoles.

Some dissolved mineral ions enter the root passively with water. Minerals that are in very low concentration in the soil are taken up by active transport. At the waterproof Casparian strip, water and dissolved minerals must pass into the cytoplasm, so the flow of materials into the stele can be regulated.

1. (a) What two mechanisms do plants use to absorb nutrients?

   (b) Describe the two main pathways by which water moves through a plant:

2. Plants take up water constantly to compensate for losses due to transpiration. Describe a benefit of a large water uptake:

3. (a) How does the Casparian strip affect the route water takes into the stele?

   (b) Why might this feature be an advantage in terms of selective mineral uptake?

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56 Transpiration

Key Idea: Water moves through the xylem primarily as a result of evaporation from the leaves and the cohesive and adhesive properties of water molecules.

Plants lose water all the time. Approximately 99% of the water a plant absorbs from the soil is lost by evaporation from the leaves and stem. This loss, mostly through stomata, is called **transpiration** and the flow of water through the plant is called the **transpiration stream**. Plants rely on an increasing gradient in solute concentration from the roots to the air to move water through their cells. Water flows passively from soil to air along this gradient of increasing solute concentration. The gradient is the driving force for the movement of water up a plant. Transpiration has benefits to the plant because evaporative water loss cools the plant and the transpiration stream helps the plant to take up minerals. Factors contributing to water movement are described below.

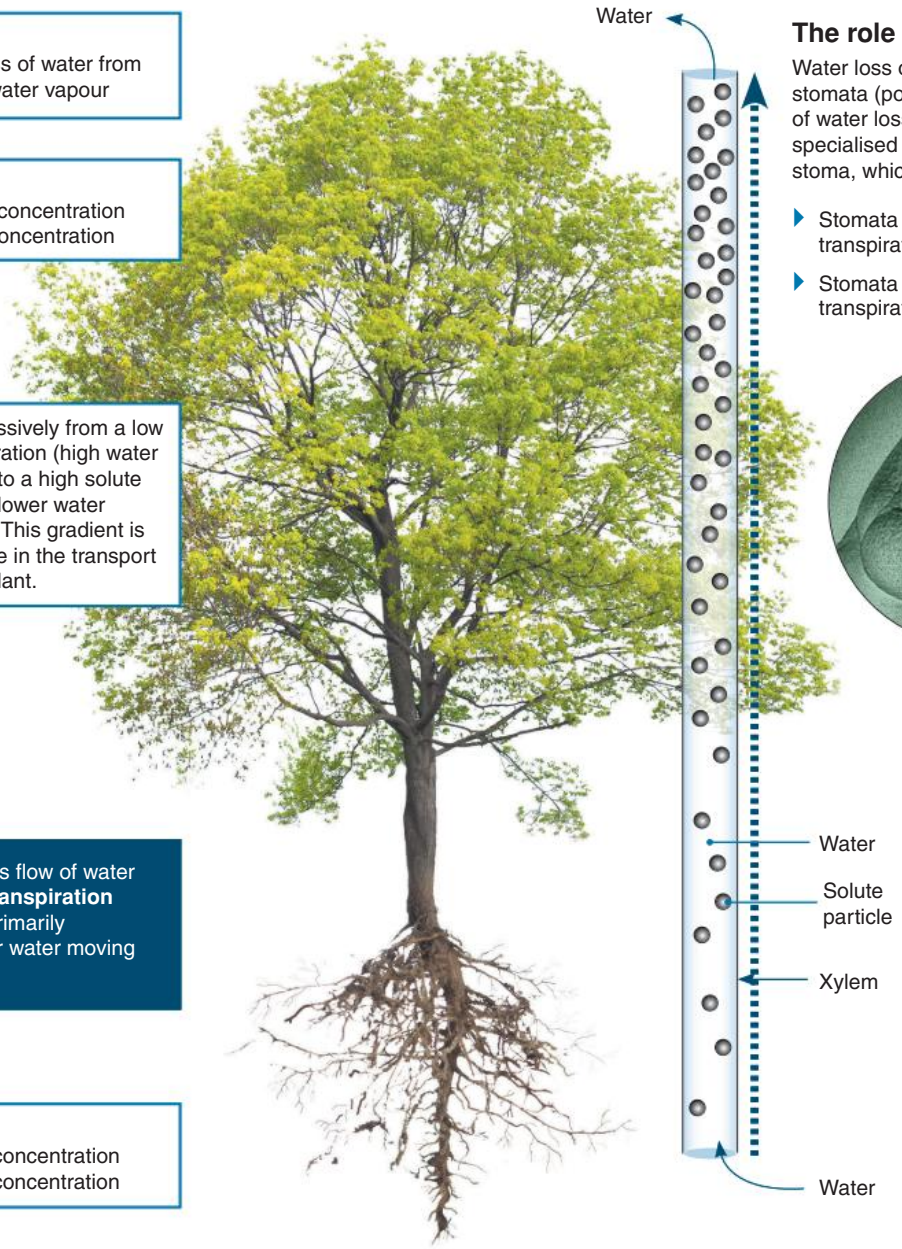
Air
Evaporative loss of water from the leaves as water vapour

Leaves
Highest solute concentration
Lowest water concentration

Water flows passively from a low solute concentration (high water concentration) to a high solute concentration (lower water concentration). This gradient is the driving force in the transport of water up a plant.

The continuous flow of water is called the **transpiration stream**. It is primarily responsible for water moving up the plant.

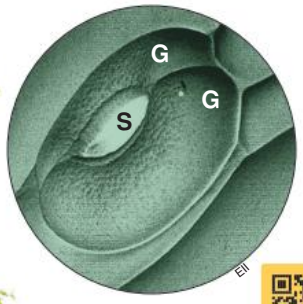
Soil
Highest water concentration
Lowest solute concentration



The role of stomata

Water loss occurs mainly through stomata (pores in the leaf). The rate of water loss can be regulated by specialised guard cells each side of the stoma, which open or close the pore.

- Stomata open: gas exchange and transpiration rate increase.
- Stomata closed: gas exchange and transpiration rates decrease.



1. (a) What is transpiration? _____

_____

(b) Describe one benefit of the transpiration stream for a plant: _____

_____

_____

_____

2. How does the plant regulate the amount of water lost from the leaves? _____

_____

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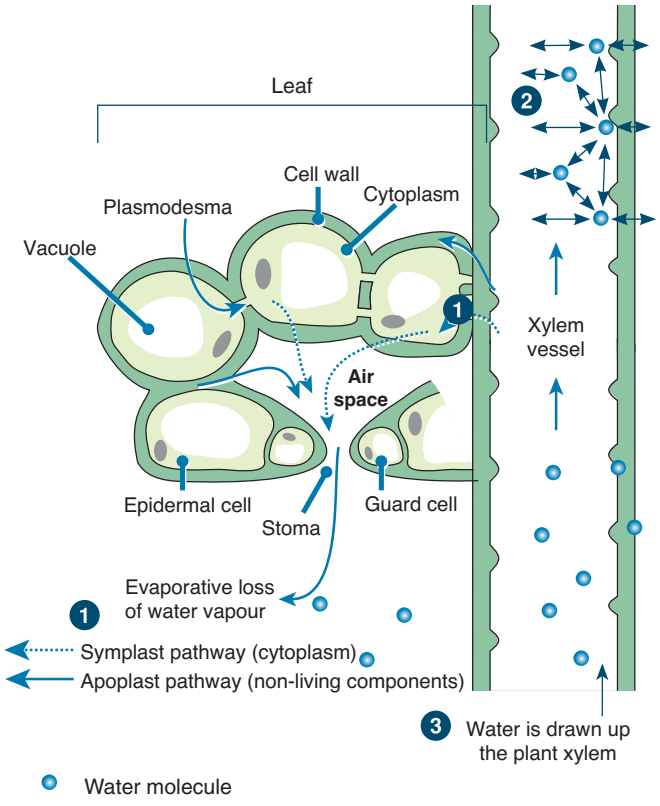
Processes involved in moving water through the xylem

1 Transpiration pull
Water is lost from the air spaces by evaporation through stomata and is replaced by water from the mesophyll cells. The constant loss of water to the air (and production of sugars) creates a solute concentration in the leaves that is higher than elsewhere in the plant. Water is pulled through the plant along a **gradient of increasing solute concentration**.

2 Cohesion-tension
The transpiration pull is assisted by the special **cohesive** properties of water. Water molecules cling together as they are pulled through the plant. They also **adhere** to the walls of the xylem (**adhesion**). This creates one **unbroken column of water** through the plant. The upward pull on the cohesive sap creates a tension (a negative pressure). This helps water uptake and movement up the plant.

3 Root pressure
Water entering the stele from the soil creates a **root pressure**; a weak 'push' effect for the water's upward movement through the plant. Root pressure can force water droplets from some small plants under certain conditions (**guttation**), but generally it plays a minor part in the ascent of water.



3. (a) What would happen if too much water was lost from the leaves? _____

_____

(b) When might this happen? _____

4. Describe the three processes that assist the transport of water from the roots of the plant upward:

(a) _____

_____

_____

_____

(b) _____

_____

_____

(c) _____

_____

_____

5. The maximum height water can move up the xylem by cohesion-tension alone is about 10 m. How then does water move up the height of a 40 m tall tree?

_____

_____

_____

_____

ISBN: 978-1-98-856636-8

57 Investigating Plant Transpiration

Key Idea: The relationship between the rate of transpiration and the environment can be investigated using a potometer.

In this activity, you will investigate the effect of different environmental conditions on transpiration rate using a potometer. You will use the results to predict the kinds of conditions that cause the greatest water losses.

The potometer

A potometer is a simple instrument for investigating transpiration rate (water loss per unit time). The equipment is simple to use and easy to obtain. A basic potometer, such as the one shown right, can easily be moved around so that transpiration rate can be measured under different environmental conditions.

Some physical conditions investigated are:

- Humidity or vapour pressure (high or low)
- Temperature (high or low)
- Air movement (still or windy)
- Light level (high or low)
- Water supply

It is also possible to compare the transpiration rates of plants with different adaptations e.g. comparing transpiration rates in plants with rolled leaves vs rates in plants with broad leaves. If possible, experiments like these should be conducted simultaneously using replicate equipment. If conducted sequentially, care should be taken to keep the environmental conditions the same for all plants used.

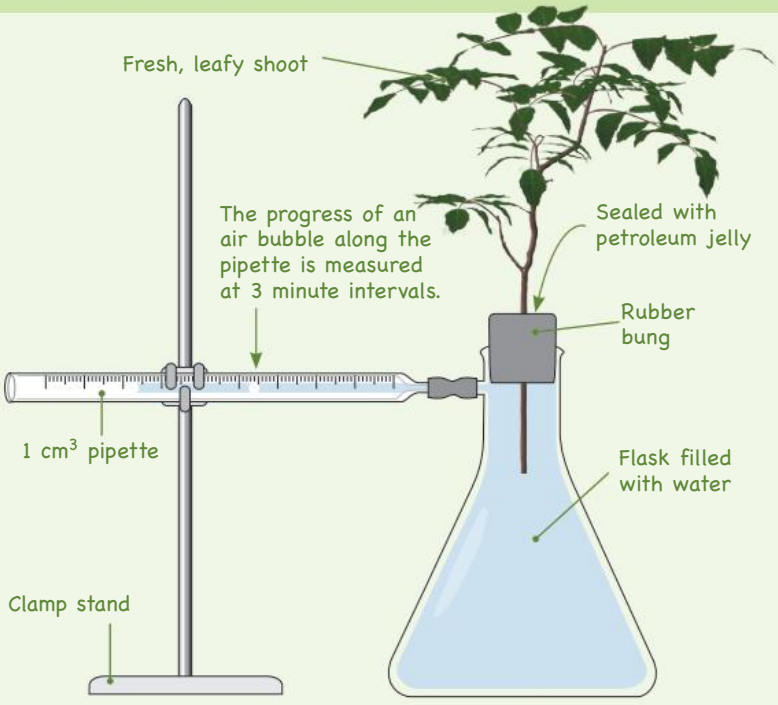
A potometer attached to a data logger

Pasco

Investigation 4.1 Investigating plant transpiration

See appendix for equipment list.

1. Four different conditions that influence transpiration will be tested: room conditions (ambient), wind, bright light, and high humidity.
2. Before starting, your teacher will decide if your group is to test one of these conditions (and which one) and pool class data for all four.
3. Set up the potometer and plant as in the diagram. It is best if the plant leaves used are large and few (4–6 leaves) rather than small and many. Alternatively the plant can before placed in a 250 mL conical flask with 200 mL of water and a thin layer of cooking oil floated on top. This is weighed before the experiment and then every 3 minutes (or as the experiment requires). The difference in mass in grams is equal to the volume of water transpired in mL.



4. After setting up the potometer, let the apparatus equilibrate for 10 minutes, and then record the position of the air bubble in the pipette (or the mass of the equipment for the alternative method). This is time 0 and position 0.
5. The plant can now be exposed to one of the four conditions. Record results in Table 1.
6. For the ambient environment the equipment can be placed on the bench away from bright light or wind. Record the net movement of the bubble every 3 minutes for 30 minutes.
7. For the high wind environment the equipment can be placed on the bench in front of a fan set on a moderate speed (away from bright light). Record the net movement of the bubble every 3 minutes for 30 minutes.

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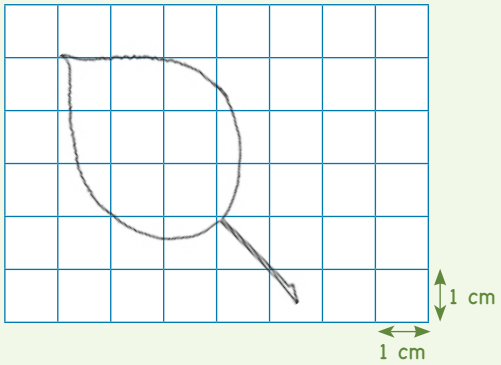
8. For the bright light environment, the equipment can be placed on the bench in front of a bright light (about 40 cm away). Record the **net** movement of the bubble every 3 minutes for 30 minutes.
9. For the high humidity environment the equipment can be placed on a bench away from bright light, in a sealed plastic bag with 2–3 sprays of water from a spray bottle. Record the net movement of the bubble every 3 minutes for 30 minutes.
10. It is important that for fair comparison of transpiration the area of leaf used in each environment (or by different groups) should be calculated and the volume of water lost per square centimetre compared (mL/cm^2).



11. Leaf area can be measured by tracing the leaves onto graph paper and counting the squares, or by tracing or photocopying the leaves onto a paper of a known mass per area, then cutting out the shapes and weighing them. For both methods, multiply by 2 for both leaf surfaces.
12. Once the area of the leaf is calculated the transpiration (water lost) in mL/cm2 can be calculate for each time recording and record in Table 2.

Table 1. Potometer readings (in mL water loss)

Time (min) / Treatment	0	3	6	9	12	15	18	21	24	27	30
Ambient											
Wind											
High humidity											
Bright light											

Table 2. Potometer readings in mL per cm^2

Time (min) / Treatment	0	3	6	9	12	15	18	21	24	27	30
Ambient											
Wind											
High humidity											
Bright light											

1. Measure the area of the leaves you used: _____
2. Why is comparing water loss per square cm over time more important than just comparing the water loss over time?

_____

_____

_____

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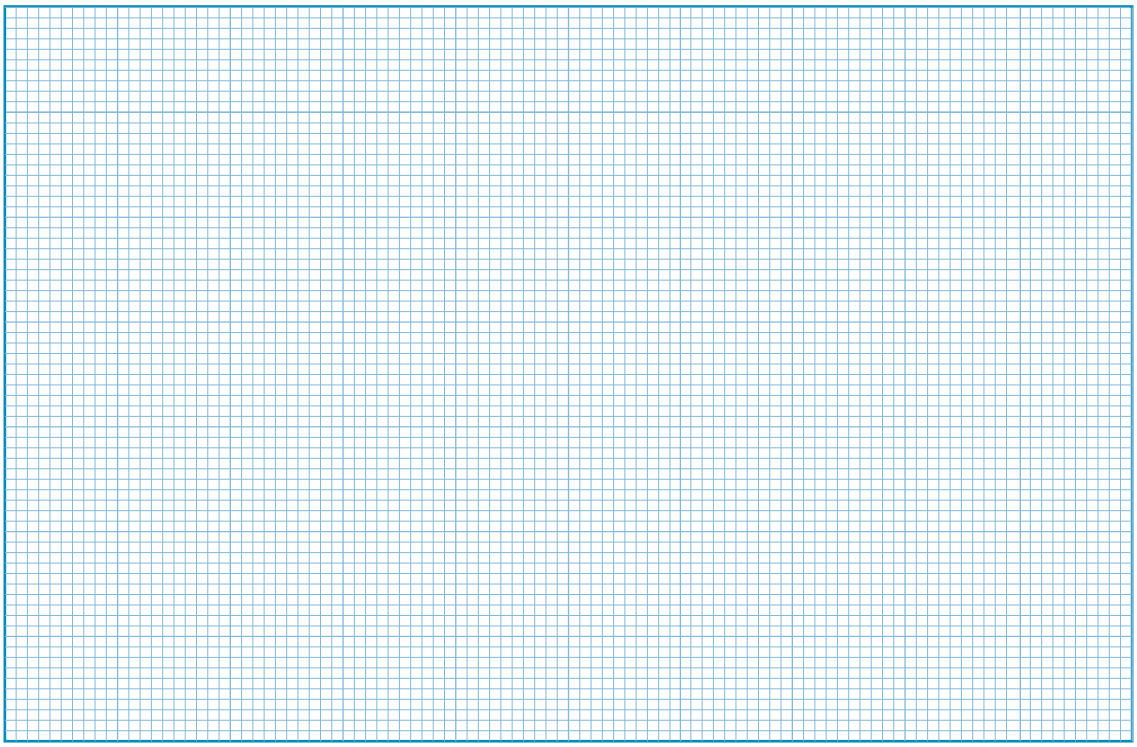
3. Plot the data in Table 2 on the grid provided:



4. Identify the independent variable: _____

5. (a) Identify the control: _____

   (b) Explain the purpose of including an experimental control in an experiment:

   _____

   _____

   _____

6. (a) Which factors increased water loss? _____

   (b) How does each environmental factor influence water loss? _____

   _____

   _____

   _____

   _____

   _____

7. From your results predict how each of the following conditions might influence transpiration:

   (a) Low humidity (e.g. dry desert): _____

   (b) Low light levels (e.g. overcast day): _____

   (c) Hot dry winds: _____

8. How might different types of plants affect the results? _____

   _____

   _____

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58 Translocation

Key Idea: Phloem transports the organic products of photosynthesis (sugars) through the plant by translocation.

In vascular plants, the products of photosynthesis move as phloem sap. Apart from water, phloem sap contains mainly sucrose (up to 30%). It may also contain minerals, hormones, and amino acids in transit around the plant. Movement of sap in the phloem is from a **source** (an organ where sugar is made or mobilised) to a **sink** (an organ where sugar is stored or used). The sap moves through the phloem sieve-tube members, which are arranged end-to-end and perforated with sieve plates. Loading sucrose into the phloem at a source (leaf) involves energy expenditure. We know this because it is slowed or stopped by high temperatures or respiratory inhibitors. In some plants, unloading the sucrose at the sinks also requires energy, although in others unloading into the cells of the sink organ (e.g. root) occurs by diffusion alone.

Phloem transport

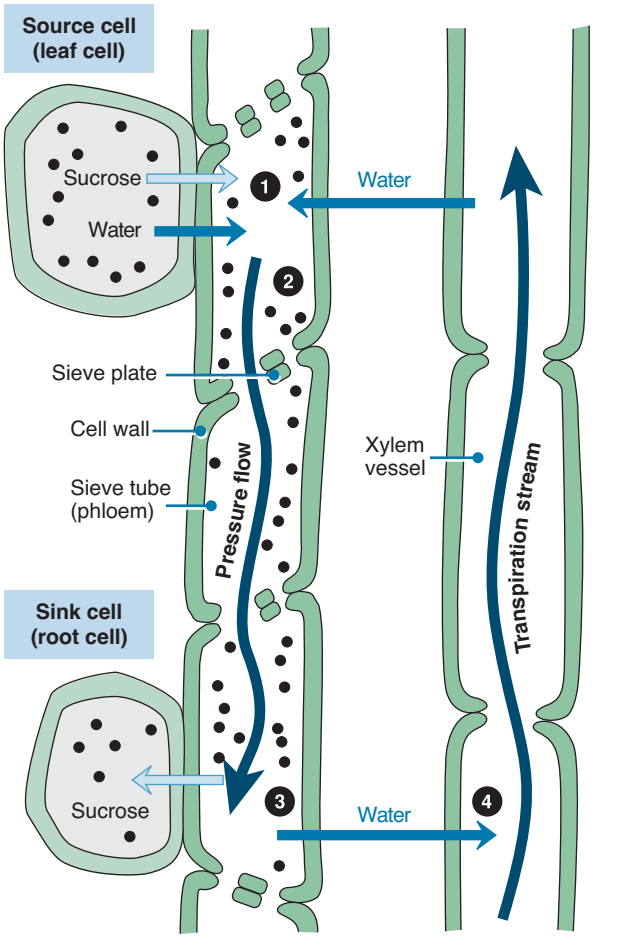
Phloem sap moves from source to sink at rates as great as 100 m/h, which is too fast to be accounted for by cytoplasmic streaming. The most acceptable model for phloem movement is the **mass flow hypothesis** (also know as the pressure flow hypothesis). Phloem sap moves by bulk flow, which creates a pressure (hence the term "pressure-flow"). The key elements in this model are outlined below and right. For simplicity, the cells that lie between the source (and sink) cells and the phloem sieve-tube have been omitted.

1. Loading sugar into the phloem increases the solute concentration inside the sieve-tube cells. This causes the sieve-tubes to take up water by osmosis.
2. The water uptake creates a hydrostatic pressure that forces the sap to move along the tube, just as pressure pushes water through a hose.
3. The pressure gradient in the sieve tube is reinforced by the active unloading of sugar and consequent loss of water by osmosis at the sink (e.g. root cell).
4. Xylem recycles the water from sink to source.

USDA

Measuring phloem flow

Aphids can act as natural phloem probes to measure phloem flow. The sucking mouthparts (stylet) of the insect penetrates the phloem sieve-tube cell. While the aphid feeds, it can be severed from its stylet, which remains in place and continues to exude sap. Using different aphids, the rate of flow of this sap can be measured at different locations on the plant.



Source: Modified after Campbell *Biology* 1993

1. (a) From what you know about osmosis, explain why water follows the sugar as it moves through the phloem:

_____

_____

_____

_____

(b) What is meant by '**source to sink**' flow in phloem transport? _____

_____

_____

2. Why does a plant need to move food around, particularly from the leaves to other regions? _____

_____

_____

_____

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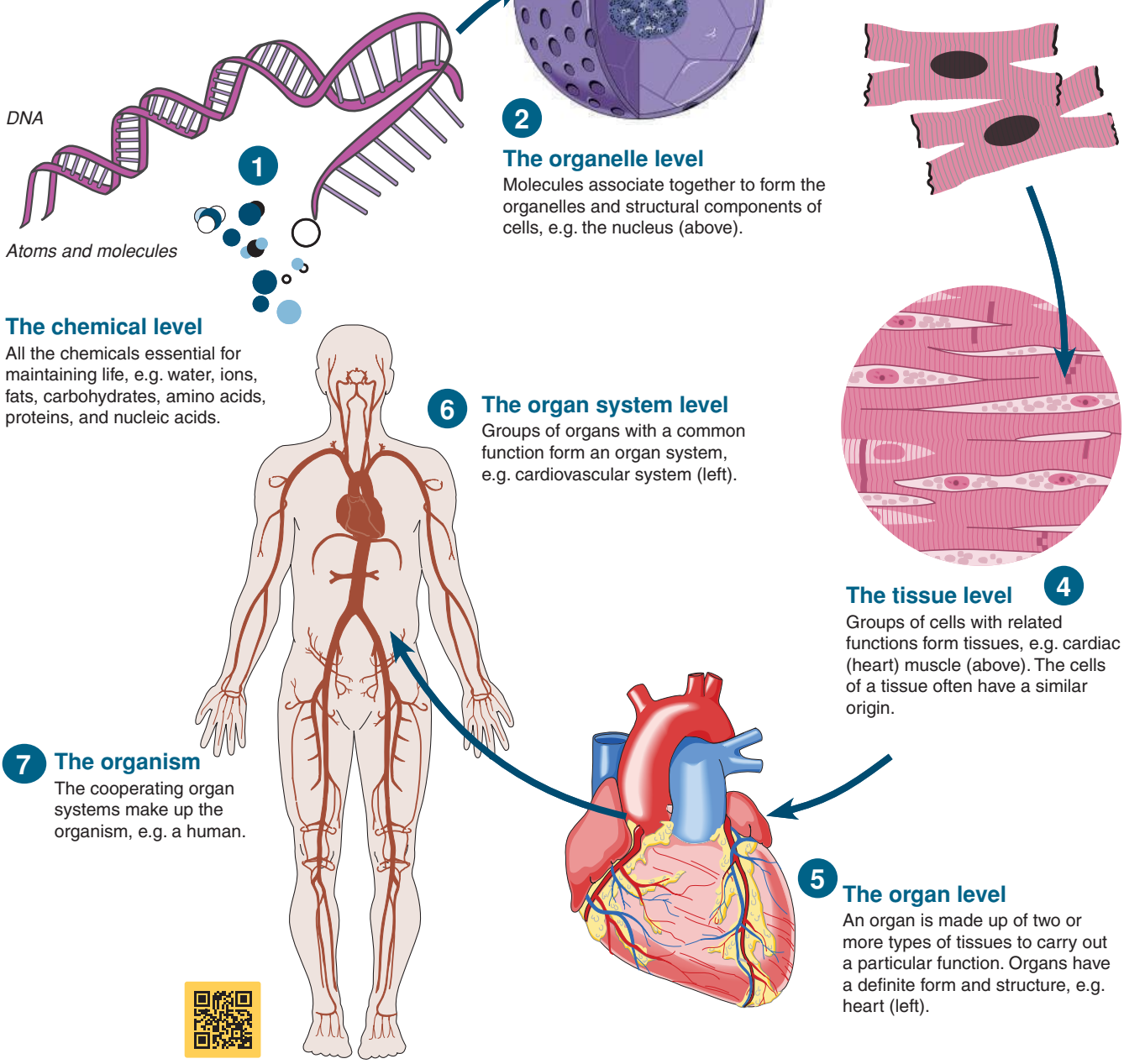
59 The Hierarchy of Life: Mammals

Key Idea: Structural organisation in animals, as in all multicellular organisms, is hierarchical.

Organisation and the emergence of novel properties in complex systems are two of the defining features of living organisms. As we saw for plants, multicellular organisms are organised according to a hierarchy of structural levels. At each level, new properties arise that were absent at the simpler level. Hierarchical organisation allows specialised cells to group together into tissues and organs to perform a specific function. This improves efficiency in the organism.

The diagram below explains this hierarchical organisation for a mammalian example - a human.



1 The chemical level
All the chemicals essential for maintaining life, e.g. water, ions, fats, carbohydrates, amino acids, proteins, and nucleic acids.

2 The organelle level
Molecules associate together to form the organelles and structural components of cells, e.g. the nucleus (above).

3 The cellular level
Cells are the basic structural and functional units of an organism. Cells are specialised to carry out specific functions, e.g. cardiac (heart) muscle cells (below).

4 The tissue level
Groups of cells with related functions form tissues, e.g. cardiac (heart) muscle (above). The cells of a tissue often have a similar origin.

5 The organ level
An organ is made up of two or more types of tissues to carry out a particular function. Organs have a definite form and structure, e.g. heart (left).

6 The organ system level
Groups of organs with a common function form an organ system, e.g. cardiovascular system (left).

7 The organism
The cooperating organ systems make up the organism, e.g. a human.

1. Assign each of the following emergent properties to the level at which it first appears:

   (a) Metabolism: _____

   (b) Behaviour: _____

   (c) Replication: _____

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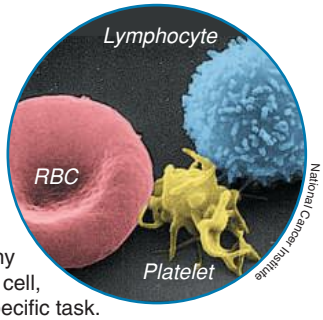
60 Specialisation in Animal Cells

Key Idea: There are many different types of animal cells, each with a specific role in the body. Animal cells are often highly modified for their specific role.

There are over 200 different types of cells in the human body. Animal cells lack a cell wall, so they can take on many different shapes. Some, e.g. white blood cells, are even mobile. The shape, size, and even the internal structure of a specialised cell reflects its functional role in the body.

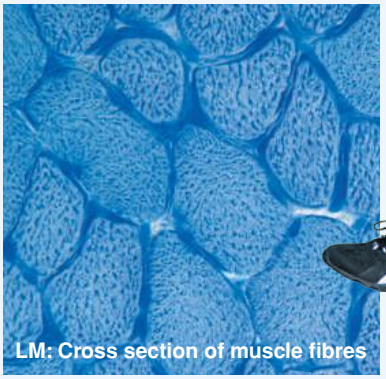
- Specialised cells often have modifications or exaggerations to normal features to help them do their job. For example, nerve cells have long, thin extensions to carry nerve impulses over long distances in the body.
- Specialisation improves efficiency because each cell type performs a specific task or narrow range of tasks. They may have more (or fewer) of a particular organelle in order to perform their role most efficiently.



There are many types of blood cell, each with a specific task. *Image: False colour SEM.*

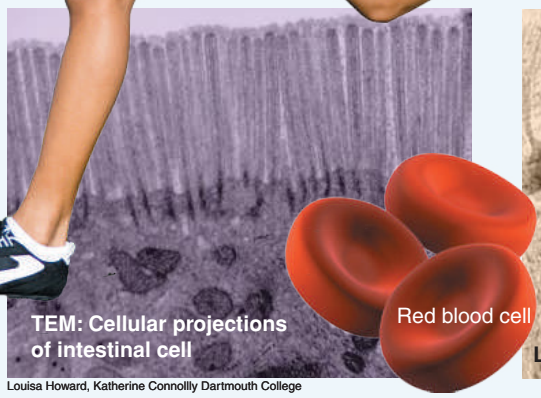
Thin, flat epithelial cells line the walls of blood vessels (arrow). Large fat cells store lipid.

Some nerve cells are over 1 m long.



LM: Cross section of muscle fibres

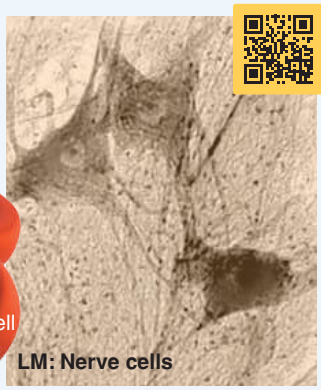
Some animal cells can move or change shape. Muscle cells, called fibres, are able to contract (shorten) as protein fibres within the cell ratchet past each other. This action causes the movement of limbs, and of organs, such as the heart and intestine.



TEM: Cellular projections of intestinal cell

Louisa Howard, Katherine Connollly Dartmouth College

Cells lining the intestine have extended cell membranes. This increases their surface area so that nutrients can be absorbed efficiently. Red blood cells have no nucleus so they can be packed full of oxygen-carrying haemoglobin. A biconcave shape allows them to squeeze through the smallest blood vessels.



LM: Nerve cells

Nerve cells conduct impulses in the form of changes in membrane potential. Impulses are carried from receptors (e.g. eye) to effectors (e.g. muscles and glands) allowing the organism to respond to the environment.

1. What is the advantage of cell specialisation in a multicellular organism? _____

_____

_____

_____

2. For each of the following specialised animal cells, name a feature that helps it carry out its function:

   (a) Muscle fibre: _____

   (b) Intestinal cell: _____

   (c) Nerve cell: _____

   (d) Red blood cell: _____

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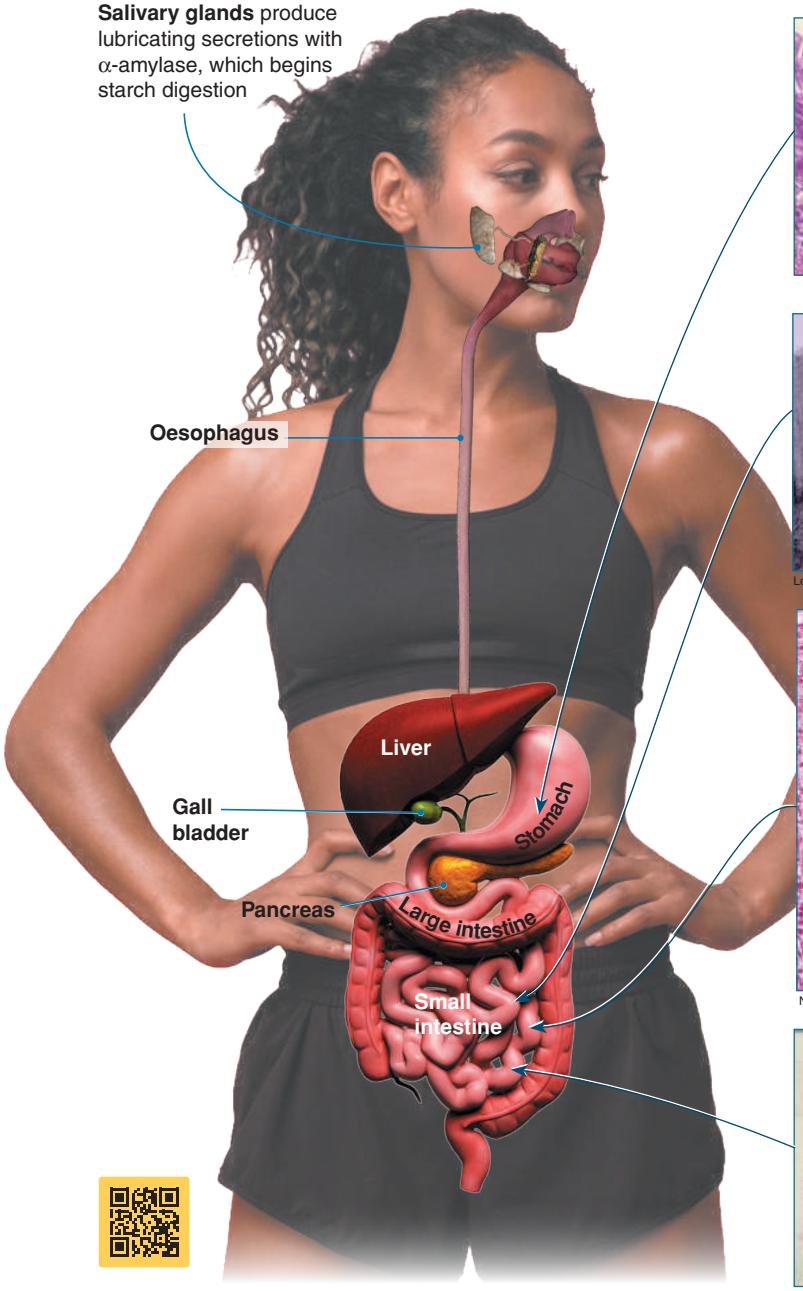
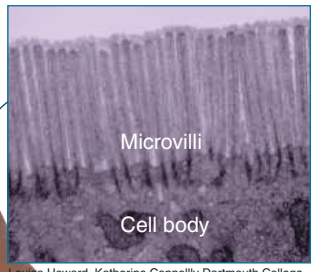
61 The Digestive System

Key Idea: The digestive tract is specialised to maximise the digestion of food, absorption of nutrients, and elimination of undigested material.

The human digestive system (gut) is a tubular tract, which is regionally specialised into a complex series of organs and glands. These work in sequence to maximise the efficiency with which food is processed. Collectively, the organs of the digestive tract carry out the physical and chemical breakdown (digestion) of food, absorption of nutrients, and elimination of undigested material. The gut is a hollow, open-ended, muscular tube, and the food within it is essentially outside the body, having contact only with the cells lining the tract. Several accessory organs and glands lie external to the digestive tract. These secrete enzyme-rich fluids to the food to aid digestion.

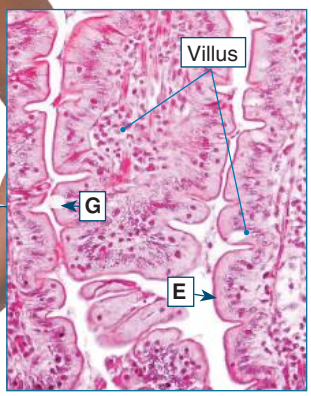


In the stomach, gastric glands contain parietal cells, which produce hydrochloric acid, and chief cells, which produce a protein-digesting enzyme. Scattered endocrine cells secrete a hormone to regulate gastric activity.



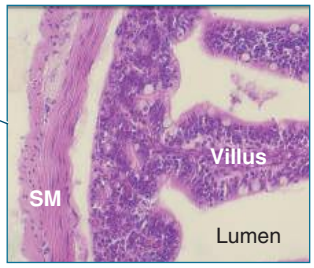
Louisa Howard, Katherine Connollly Dartmouth College

Cells lining the walls on the small intestine (the intestinal epithelium) have microscopic extensions of the plasma membrane called microvilli. These form a brush border that increases the surface area for absorption of food molecules. Under lower power microscopy, it appears as a fuzzy edge.



Nephron

In the small intestine, the intestinal epithelial cells (E) and mucus-producing goblet cells (G) make up the epithelium lining the gut wall. The wall is folded into finger like projections called villi (*sing*. villus). These further increase the surface area of the intestine.



EII

The entire gastrointestinal tract is supported by underlying connective tissue. Two layers of smooth muscle (SM), one running lengthwise and one running around the gut, encircle the tube, contracting in waves to move food through the gut. This process is called **peristalsis**.

1. (a) How are villi formed? _____

   _____

   (b) What is the purpose of microvilli? _____

   _____

2. What is the purpose of the smooth muscle surrounding the intestine? _____

   _____

   _____

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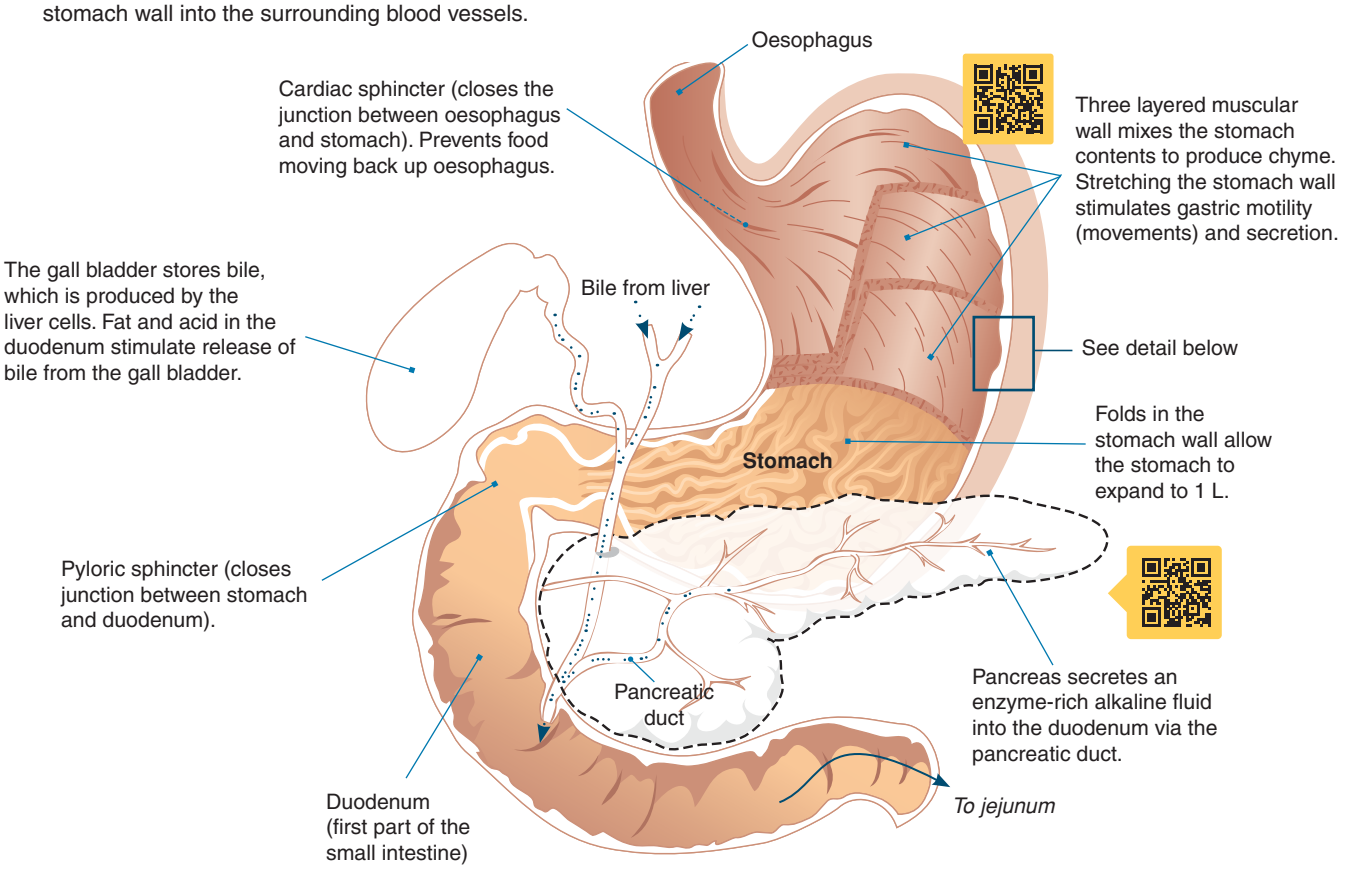
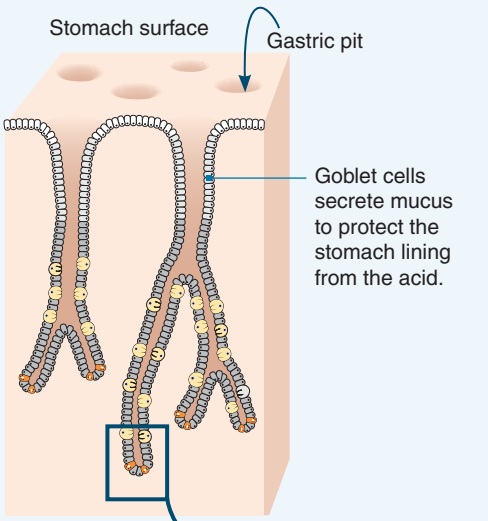
The stomach

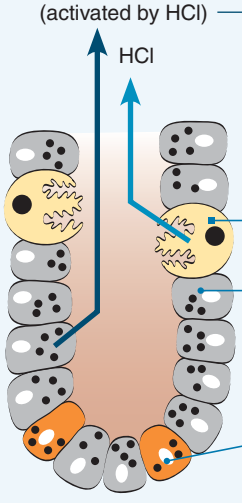
- The stomach is a hollow, muscular organ between the oesophagus and small intestine. In the stomach, food is mixed in an acidic environment to produce a semi-fluid mixture called chyme.
- The low pH of the stomach destroys microbes, denatures proteins, and activates a protein-digesting enzyme precursor.
- There is very little absorption in the stomach, although small molecules (glucose, alcohol) are absorbed across the stomach wall into the surrounding blood vessels.



Detail of a gastric gland (stomach wall)



Right: High powered light micrograph of the stomach epithelium showing the gastric glands



In the stomach, gastric glands contain parietal cells (produce hydrochloric acid), chief cells (produce protein-digesting enzyme precursor), and endocrine cells (produce a hormone to regulate secretions).

Stomach secretions

Gastric juice
Acid (HCl) secretion
Pepsin (optimal pH 1.5-2.0) Acts on proteins and breaks them down into peptides (short chains of amino acids).

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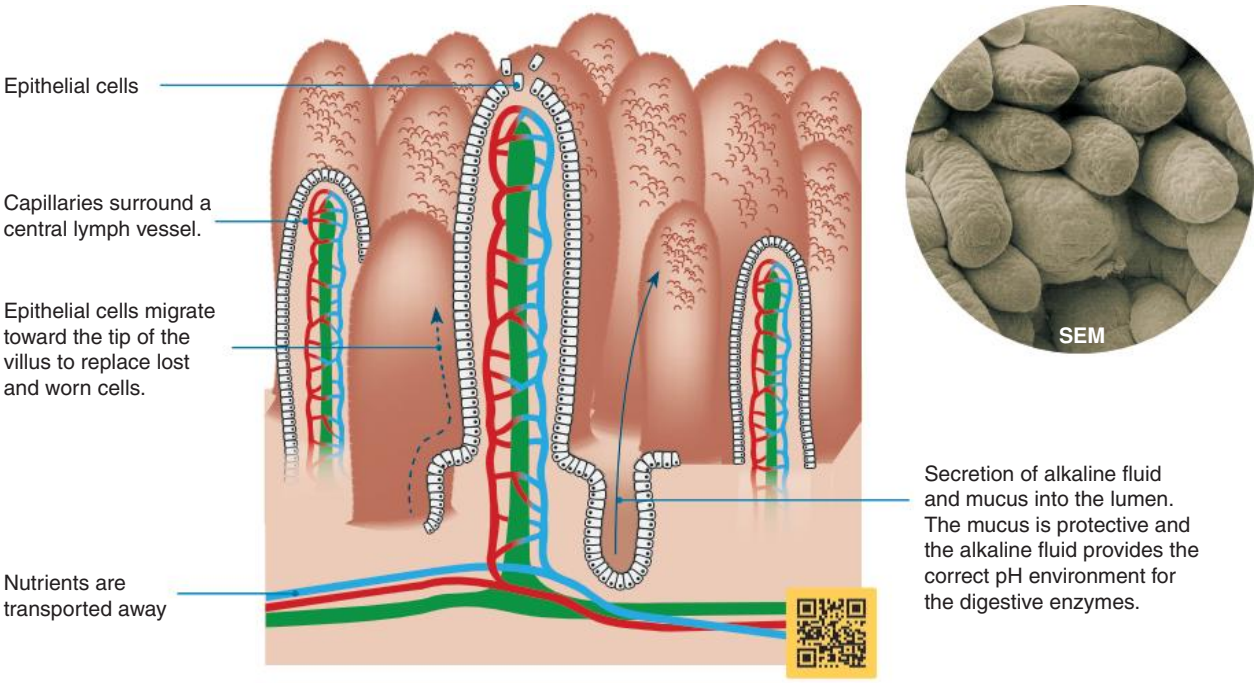
The small intestine

- The small intestine receives the chyme directly from the stomach. Most of the **chemical digestion** and **absorption** of nutrients occurs in the small intestine, which is divided into three sequential regions, distinguished by the cells present. The **duodenum** (nearest the stomach) is where most chemical digestion occurs. The **jejunum** and **ileum** is where most absorption occurs.
- The intestinal lining is folded into many **intestinal villi**, which project into the gut lumen (the space enclosed by the gut). The villi increase the surface area for nutrient absorption. The **epithelial cells** that make up the lining of each villus in turn have a **brush-border** of many **microvilli**, which are primarily responsible for nutrient absorption. The membrane of the microvilli is packed with enzymes that break down food molecules for absorption.
- Enzymes bound to the microvilli of the epithelial cells, and in the pancreatic and intestinal juices, break down fats, peptides, and carbohydrates (see tables below). The small molecules produced by this digestion are then absorbed into the underlying blood and lymph vessels. Tubular exocrine glands and goblet cells secrete alkaline fluid and mucus into the lumen, neutralising the acidity of the chyme entering the small intestine from the stomach and protecting the lining of the intestine from damage.



Photographs below: The intestinal villi are shown projecting into the gut lumen in a scanning electron micrograph (inset above) and in light microscope cross sectional images at different scales (below left and centre). The microvilli forming the brush border of a single intestinal epithelial cell are shown very highly magnified in the transmission electron micrograph (below right).

Louisa Howard, Katherine Connolly Dartmouth College

Enzymes in the small intestine break down food into small molecules that can be absorbed through the gut wall. Enzymes are present in the pancreatic juice added to the duodenum, in intestinal juice, and bound to the surfaces of the intestinal epithelial cells.

Enzymes in pancreatic juice	
Enzymes in duodenum (optimal pH)	
1. Pancreatic amylase (6.7-7.0)	1. Starch → maltose
2. Trypsin* (7.8-8.7)	2. Protein → peptides
3. Chymotrypsin* (7.8)	3. Protein → peptides
4. Pancreatic lipase (8.0)	4. Fats → fatty acids & glycerol
* secreted in an inactive form	

Enzymes in intestinal juice (IJ) and epithelium (E)	
Enzymes in small intestine (location, optimal pH)	
1. Maltase (E, 6.0-6.5)	1. Maltose → glucose
2. Peptidases (proteases) (IJ, E, ~ 8.0)	2. Polypeptides → amino acids
3. Sucrase (E, ~6.0)	3. Sucrose → fructose & glucose
4. Enteropeptidase (IJ 8.0)	4. Activates trypsin*
*Once activated, trypsin activates chymotrypsin	

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3. Summarise the structure and role of each of the following regions of the human digestive tract:

   (a) Stomach: _____

   (b) Small intestine: _____

4. (a) What is the purpose of the hydrochloric acid produced by the parietal cells of the stomach? _____

   (b) Explain why protein-digesting enzymes (e.g. pepsin) are secreted in an inactive form and then activated after release:

5. Identify an endocrine cell in the stomach epithelium and state its purpose: _____

6. How does the stomach achieve the mixing of acid and enzymes with food? _____

7. (a) What is the purpose of the intestinal villi? _____

   (b) What is the purpose of the microvilli (brush border) on intestinal epithelial cells? _____

8. (a) Identify the two sites that produce digestive enzymes active in the small intestine: _____

   (b) Identify the four enzymes in pancreatic juice and what they do:

   i _____

   ii _____

   iii _____

   iv _____

   (c) In general, do the enzymes act in acidic or alkaline conditions? _____

   (d) How is this pH environment generated? _____

9. Suggest why the small intestine is so long: _____

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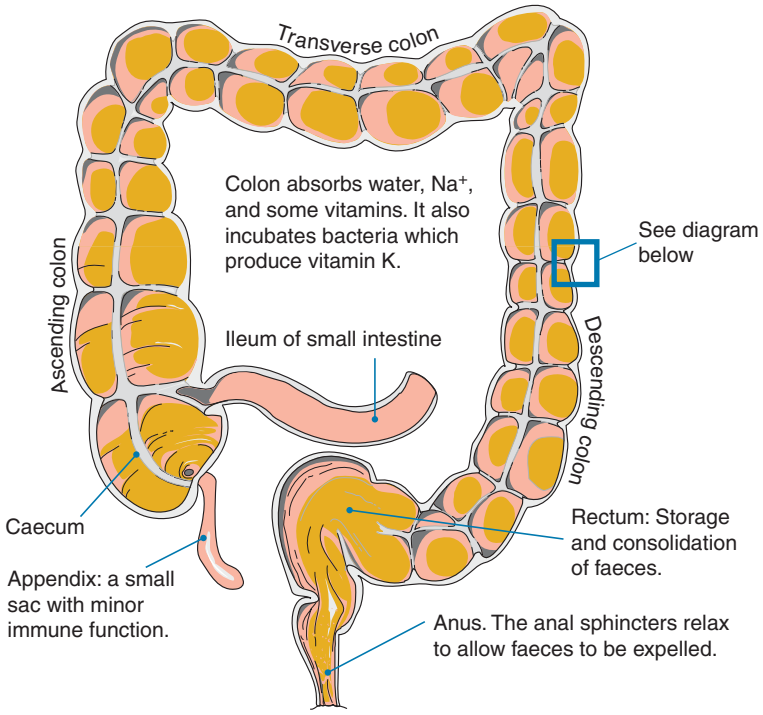
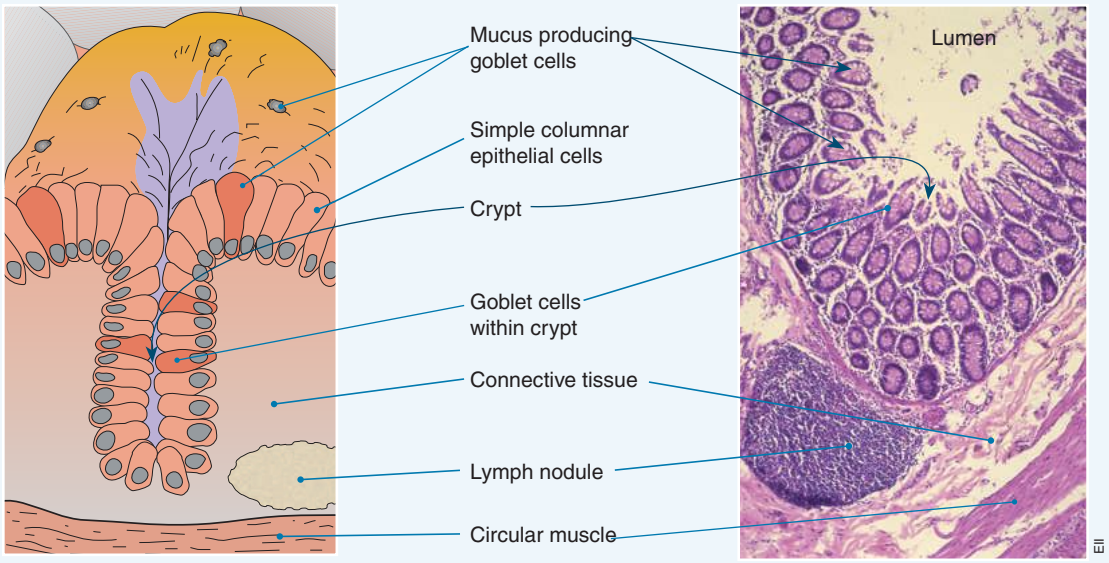
The large intestine

- The large intestine consists of the appendix, caecum, colon, and rectum.
- In humans and other omnivores, the large intestine's main role is to reabsorb water and electrolytes and consolidate the undigested material for egestion (elimination) from the anus.
- After most of the nutrients have been absorbed in the small intestine, the remaining semi-fluid contents pass into the large intestine (appendix, cecum, and colon). This mixture includes undigested or indigestible food, (such as **cellulose**), bacteria, dead cells, mucus, bile, ions, and water.
- The rectum stores the waste faecal material before it is discharged out the anus. Fullness in the rectum produces the urge to defaecate. If too little water is absorbed, the faeces will be watery (diarrhoea). Diarrhoea is not trivial and can be fatal if severe. If too much water is absorbed, the faeces will become compacted and very difficult to expel (a condition called constipation).
- Defaecation is controlled by the anal sphincters, whose usual state is to be contracted (closing the orifice). Defaecation is under nervous control.



Lining of the large intestine

The lining of the large intestine has a simple epithelium containing tubular glands (crypts) with mucus-secreting cells. The mucus lubricates the colon wall and helps to form and move the faeces. In the photo, some crypts are in XS and some are in LS.



Note the abundance of pale goblet cells.

10. What are the two main roles of the large intestine and which region is involved in each?

(a) _____

(b) _____

11. (a) What are the effects of absorbing too much water in the large intestine? _____

_____

(b) What are the effects of absorbing too little water in the large intestine and why is this dangerous? _____

_____

_____

ISBN: 978-1-98-856636-8

62 Investigating Amylase Activity

Key Idea: Salivary amylase works optimally at the pH and temperature conditions of the human body. Enzyme activity outside these conditions decreases.

Amylase is a digestive enzyme that hydrolyses (breaks down) starch into the sugars maltose (a disaccharide) and glucose (a monosaccharide). In mammals, amylase is secreted by the salivary glands into the saliva and by the pancreas into the small intestine. Like all enzymes, amylase works best under certain conditions. In this activity, you will investigate the effect of pH and temperature on amylase activity.

Investigation 4.2 Investigating amylase activity

See appendix for equipment list.

Spotting plate: each well contains a single drop of 0.1 M iodine solution (iodine dissolved in a solution of potassium iodide). Multiple spotting plates will accommodate the number of tests required.

1. Obtain solutions of 0.1 mol/L iodine solution (I2/KI), 1% amylase, and 1% starch and buffer solutions to cover pH 4, 5, 6, 7, and 8. Iodine solution is a yellow/orange colour, but in the presence of starch, it turns a blue/black colour.
2. Use a clean syringe to place a drop of iodine solution in each well of a two 3 x 4 spotting plates.
3. Add 1 mL of pH 4 buffer to a labelled test tube (TT4) and add 2 mL of amylase solution.
4. Add 2 mL of the starch solution to TT4 and start a timer.
5. Wait 10 seconds then use a clean syringe to add one drop of TT4 solution to the second well of the spotter plate (leave one well untouched as time 0). Return the solution in the syringe to TT4.
6. Every 10 seconds add another one drop of solution from TT4 to another well on the spotting plate.
7. Repeat until the iodine solution in the wells no longer changes colour. When this happens record the time as the time taken for the amylase solution to break down the starch.
8. Repeat steps 2 to 7 with the rest of the buffer solutions (TT5, TT6, TT7, TT8).
9. Record the results in the first two empty columns of the table below.

1. Why was it important to add the buffer and enzyme together before adding the starch?

_____

_____

2. Complete your results table (left) by calculating the reaction rate for each pH (1 ÷ seconds):

3. (a) Graph the reaction rate vs pH on the grid.

   (b) Identify the pH where amylase activity was the highest:

   _____

   (c) Is this what you had expected? Explain:

   _____

   _____

   _____

4. Some students repeated the experiment at pH 1. Each sample turned blue/black when added to the iodine even after five minutes of sampling. Explain what has happened here:

_____

_____

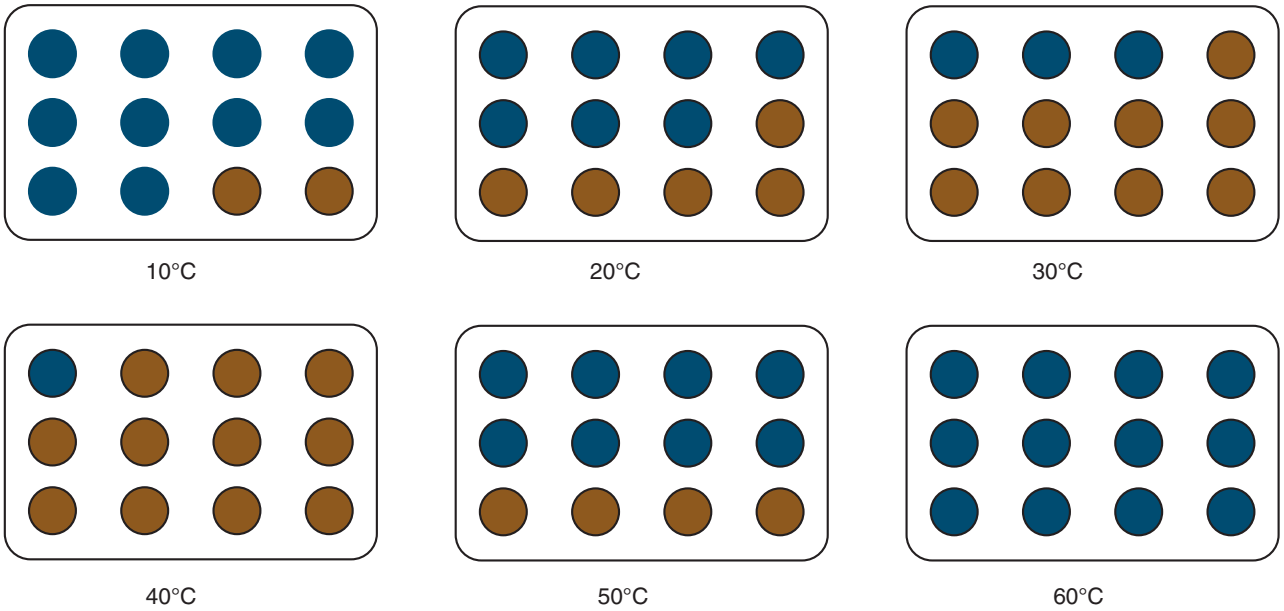
_____

Results

pH	Number of drops until no colour change occurred	Number of seconds until no colour change occurred	Rate of starch reduction (per second)
4			
5			
6			
7			
8			

ISBN: 978-1-98-856636-8

In an experiment, six students wanted to determine the temperature optimum for salivary amylase. Six spotting plates were set up by adding a single drop of 0.1 M iodine solution to each well. 2 cm^3 of 1% amylase solution and 1 cm^3 of a buffered pH 7 solution was added to each of 6 test-tubes. The test tubes were placed in water baths at the test temperatures (10, 20, 30, 40, 50, and 60°C) and left for 5 minutes to equilibrate. Each student was responsible for investigating one temperature. Once the experimental temperature had been reached, 2 cm^3 of a 1% starch solution was added to the test-tube and a timer was started. After one minute, a plastic pipette was used to remove a small amount of solution. A single drop was added to the spotting plate and the colour change observed. Samples were repeated at one minute intervals until no colour change was seen. The results are shown below.



10°C 20°C 30°C

40°C 50°C 60°C

5. The students did not use any controls when they investigated the effect of pH on salivary amylase activity. What would a suitable control have been?

_____

6. Why was the temperature investigation experiment carried out at pH 7? _____

_____

7. Identify the temperature at which amylase shows no activity (the enzyme is denatured):

_____

8. On the grid, plot the time taken for all the starch to be digested against temperature (do not plot 60°C):

9. Identify the optimum temperature for amylase:

_____

10. Describe how temperature affects the activity of amylase:

_____

_____

_____

_____

11. Predict amylase activity below 10°C and give a reason for your prediction:

_____

_____

_____

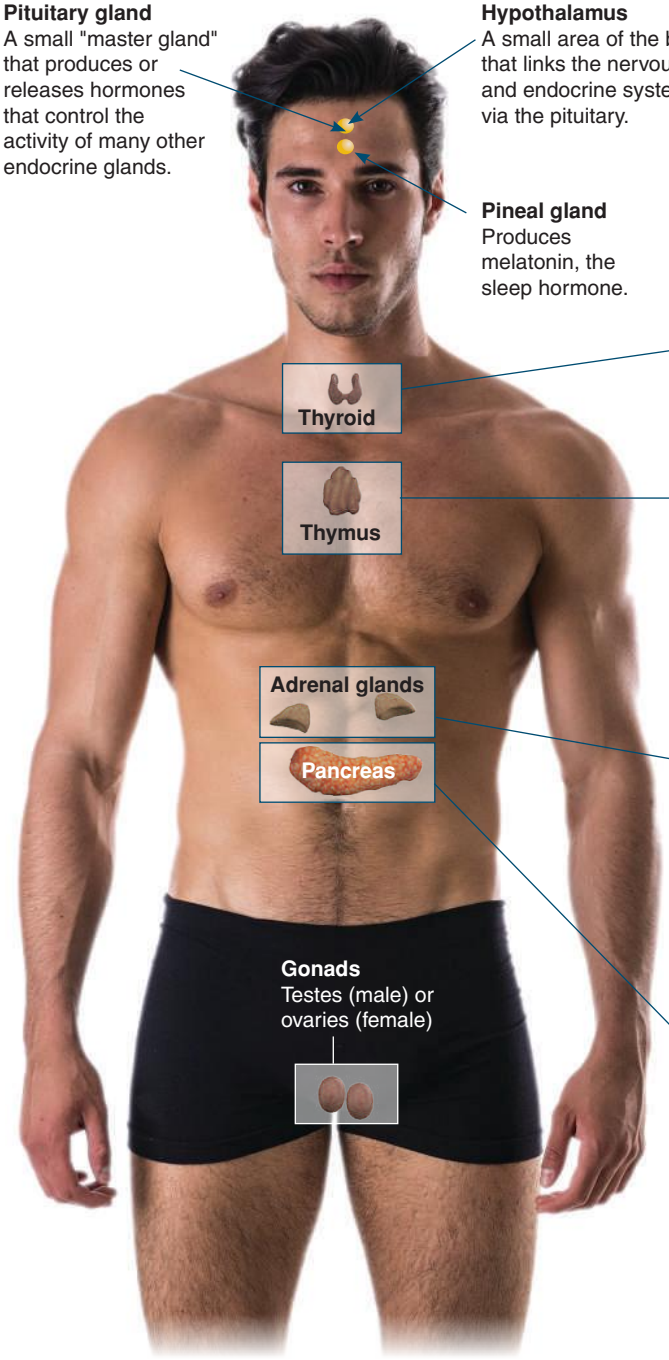
_____

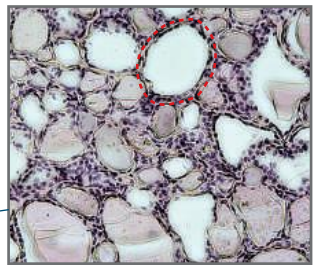
_____

ISBN: 978-1-98-856636-8

63 The Endocrine System

Key Idea: The endocrine system is made up of ductless glands, which secrete hormones into the blood. These participate in feedback loops and regulate internal functions. **Endocrine glands** are scattered widely throughout the body and their positioning does not necessarily reflect the location of their influence. Unlike exocrine glands (e.g. salivary glands), endocrine glands lack ducts and secrete hormones directly into the blood. **Hormones** are chemical messengers that are produced at one endocrine site and carried in the blood to influence target cells that may be quite distant.





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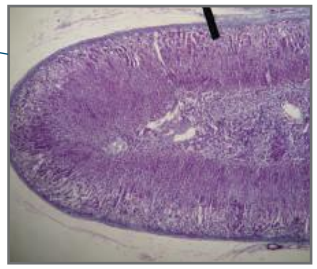
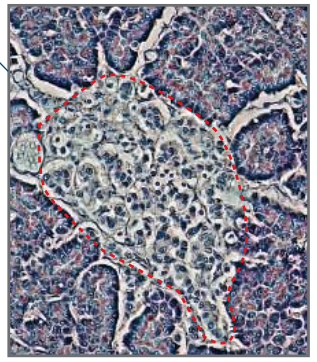
The functional unit of the thyroid is the spherical thyroid follicle (circled left, circular in cross section). These are lined with follicular cells. The thyroid secretes three hormones that influence metabolic rate and protein synthesis.

Tourbulence CC3.0

The thymus plays an important role in immunity. It influences the development of T-lymphocytes via the production of the hormone thymosin. After puberty the thymus slowly shrinks and is replaced by fatty tissue. Many of its exact functions are still not well understood.



The adrenal glands are pyramid-shaped glands found on top of the kidneys. They secrete many hormones including adrenaline (epinephrine), which plays a role in the fight or flight response.



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The pancreas has both endocrine and digestive exocrine functions. The endocrine portion secretes the hormones insulin and glucagon, which regulate blood sugar levels, somatostatin, an inhibitory hormone, and pancreatic polypeptide (PP), which regulates pancreatic exocrine secretions. The pancreatic islets (the islets of Langerhans, circled left) are the functional endocrine unit.

1. (a) What is the function of a hormone? _____

   _____

   (b) How do endocrine glands affect the various cells of the body? _____

   _____

2. How are endocrine glands different to exocrine glands? _____

   _____

   _____

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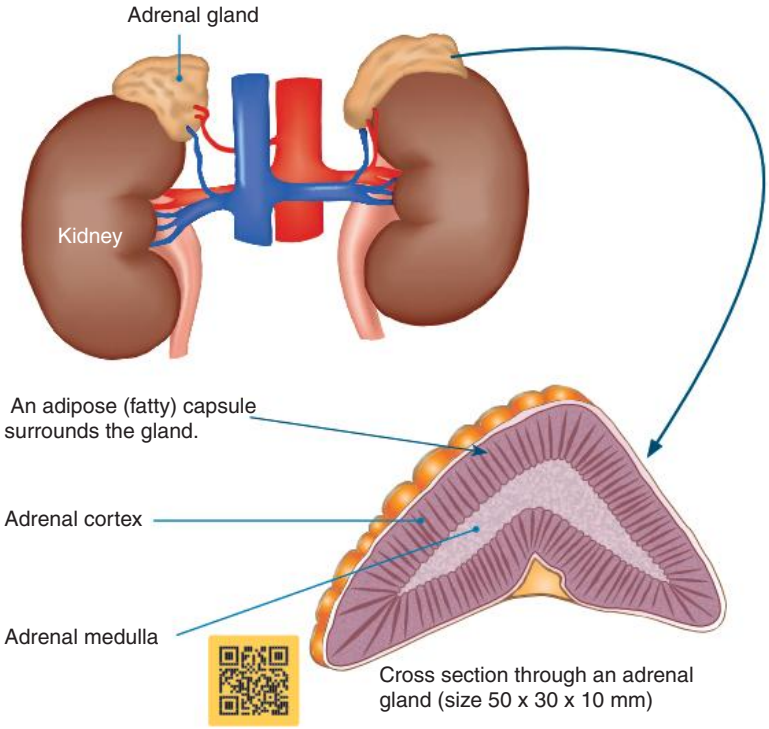
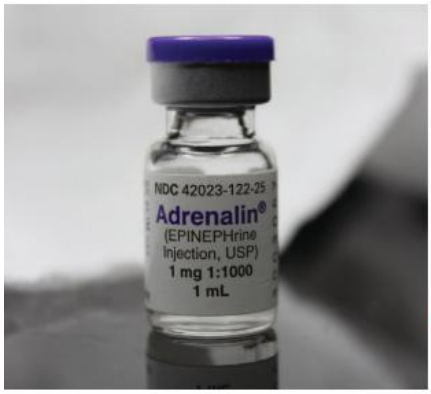
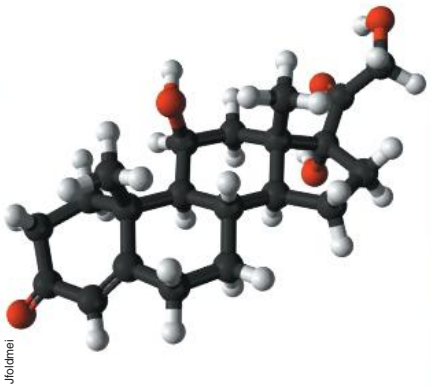
The adrenal glands

- The adrenal glands are endocrine glands that produce a variety of hormones with roles in carbohydrate metabolism, ion regulation, and response to stress.
- One adrenal sits above each kidney. They are surrounded by a fatty capsule and have two functionally and structurally distinct regions: an outer cortex and an inner medulla (below).
- The **inner adrenal medulla** produces the catecholamine hormones **adrenaline** and **noradrenaline**. These are responsible for the 'fight or flight' response, which includes increased breathing and heart rates, and paling of skin.
- The **outer adrenal cortex** produces a number of corticosteroid hormones.
  - **Glucocorticoids** (e.g. cortisol) have effects on carbohydrate metabolism, and are also secreted in response to long term stress.
  - **Mineralocorticoids**, (principally aldosterone) are involved in blood pressure and ion (particularly sodium) regulation.
  - The release of hormones from the adrenal cortex is controlled by the hormone ACTH from the anterior pituitary gland.





Adrenaline (epinephrine) is a stress related hormone involved in the fight or flight response. Medically, it is used as a treatment for heart attacks and anaphylaxis (severe allergic reaction).



Jfoldmei

Cortisol is released by the adrenal cortex in response to stress and low blood glucose. It activates the formation of glucose from glycogen in the liver, and suppresses the inflammatory response.

Aldosterone is involved in regulating blood pressure and ion balance. It acts on the distal convoluted tubule and collecting duct of the kidneys to stimulate reabsorption of sodium and secretion of potassium.

3. (a) Describe the structure of the adrenal glands: _____

_____

(b) What is the role of each distinct region of the adrenal glands: _____

_____

_____

4. (a) What is the effect of adrenaline on the body? _____

_____

(b) What is a medical use of adrenaline? _____

_____

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The pancreas

- The **pancreas** is a diffuse organ, located alongside the stomach. It is both an exocrine gland, producing digestive secretions, and an endocrine gland, producing hormones from ductless cell clusters within the pancreatic tissue.
- This endocrine tissue is called the pancreatic islets (or **islets of Langerhans**, after its discoverer) and the two of the hormones produced, insulin and glucagon, regulate blood glucose levels.

The structure of the pancreas

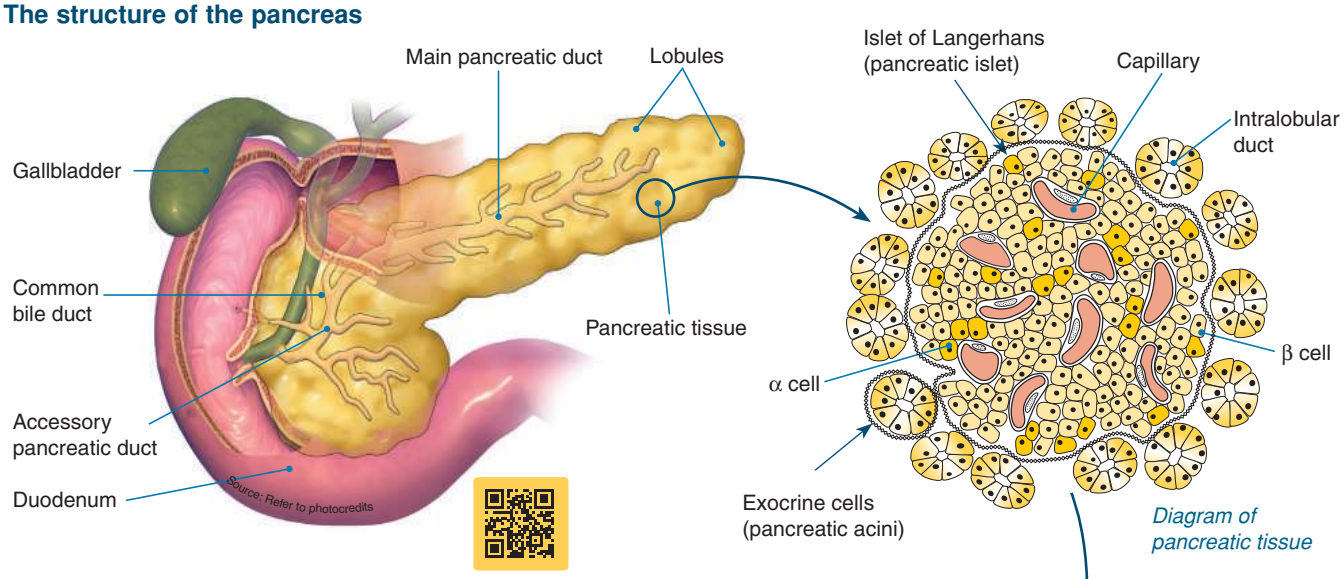
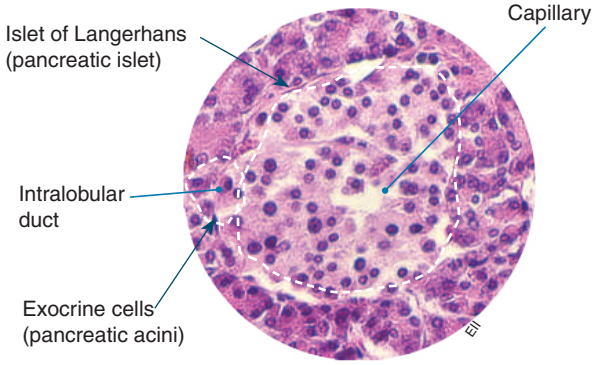


Diagram of pancreatic tissue

- The islets of Langerhans are distinctive areas containing the endocrine cells of the pancreas. They make up 1-2% of the total mass of the pancreas. There are five types of endocrine cells. The alpha (α) cells and beta (β) cells make up the majority of the islet cell mass (15% and 65% of the total respectively). The main homeostatic role of the pancreas is to regulate blood sugar levels.
  - The α cells secrete **glucagon**, which elevates blood glucose levels if they become too low.
  - The β cells secrete **insulin**, which lowers blood glucose by promoting its cellular uptake. The two hormones work together to maintain blood glucose at a constant level.
- The remaining endocrine cells have the following roles:
  - Delta (δ) cells: produce the hormone **somatostatin** which inhibits the secretion of other hormones and affects neurotransmission and cell proliferation.
  - PP-cells: control self regulation of pancreatic secretions.
  - Epsilion (ε) cells: produce ghrelin, an appetite stimulant.



LM of pancreatic tissue

5. (a) Which part of the pancreas has an endocrine function? _____

   (b) What is the endocrine function of the pancreas? _____

   _____

   _____

6. (a) What is the function of α cells? _____

   _____

   (b) What is the function of β cells? _____

   _____

7. (a) Which cells of the pancreas have an exocrine function? _____

   (b) How do these cells connect to the digestive system? _____

   _____

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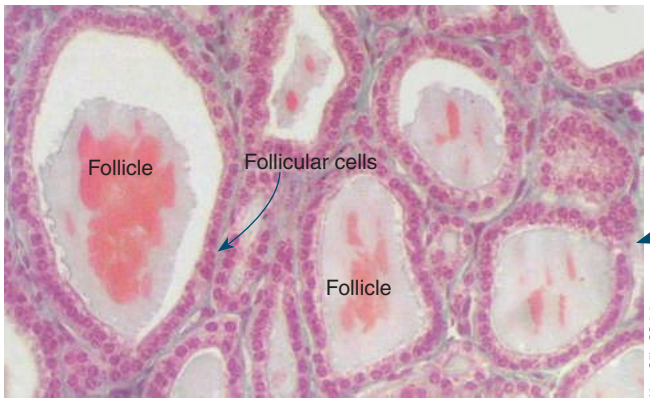
The thyroid

The thyroid is a butterfly-shaped gland located just below and in front of the larynx. The functional unit of the thyroid is the spherical thyroid follicle, which is lined with follicular cells. The thyroid secretes three hormones, the thyroid hormones T_3 and T_4 (thyroxine), and calcitonin. The thyroid hormones influence metabolic rate and protein synthesis. Calcitonin plays a role in calcium homeostasis.

- The thyroid hormones increase metabolic rate and affect a range of functions including appetite, absorption of substances, and gut motility.
- Follicular cells extract iodine and the amino acid tyrosine from the blood and bind them to form the protein thyroglobin. This protein is stored in the follicle.
- Under the influence of the pituitary hormone TSH (thyroid stimulating hormone), thyroglobin reenters the follicular cells. The T_3 and T_4 hormones are cleaved from thyroglobin and released into the blood.



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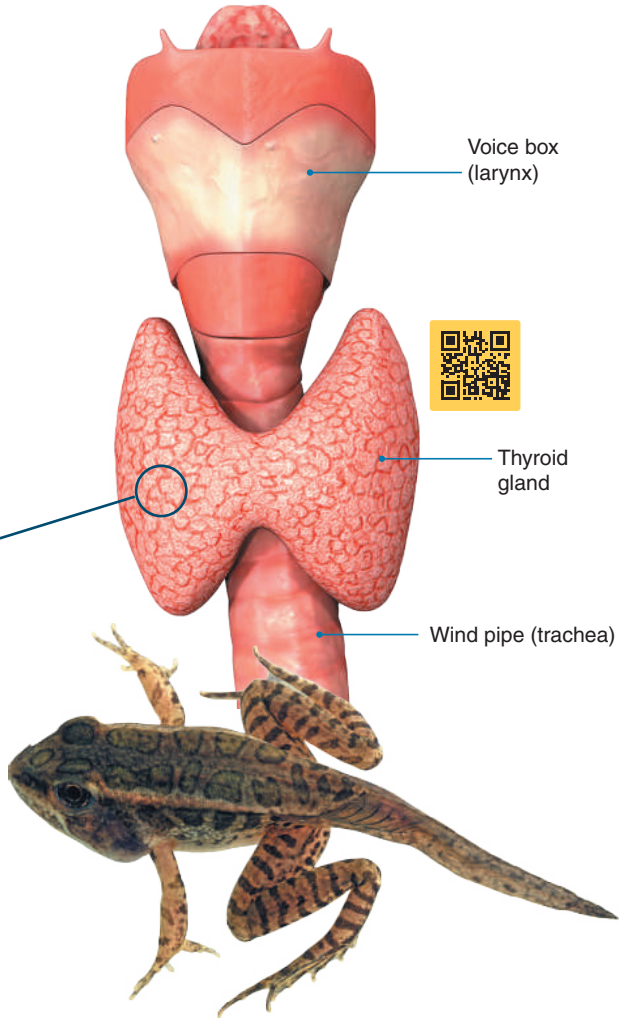

All vertebrates have thyroid glands but in most the role of this gland is not well understood. In amphibians the thyroid plays a role in moulting and metamorphosis from the larval to the adult stage. Giving tadpoles (larval frogs) extra doses of T_4 can induce early metamorphosis and high thyroxine levels are needed for final tail resorption (right).

8. (a) Where is the thyroid located? _____

   (b) What is the functional unit of the thyroid? _____

   (c) What is the general shape of this unit? _____

9. (a) What hormones does the thyroid produce? _____

   (b) Which of these have a role in regulating metabolic rate? _____

10. How are the thyroid hormones produced? _____

    _____

    _____

    _____

11. (a) What hormone influences the thyroid? _____

    (b) Where is it produced? _____

12. What important element do follicular cells extract from the blood? _____

13. What role does the thyroid have in amphibians? _____

    _____

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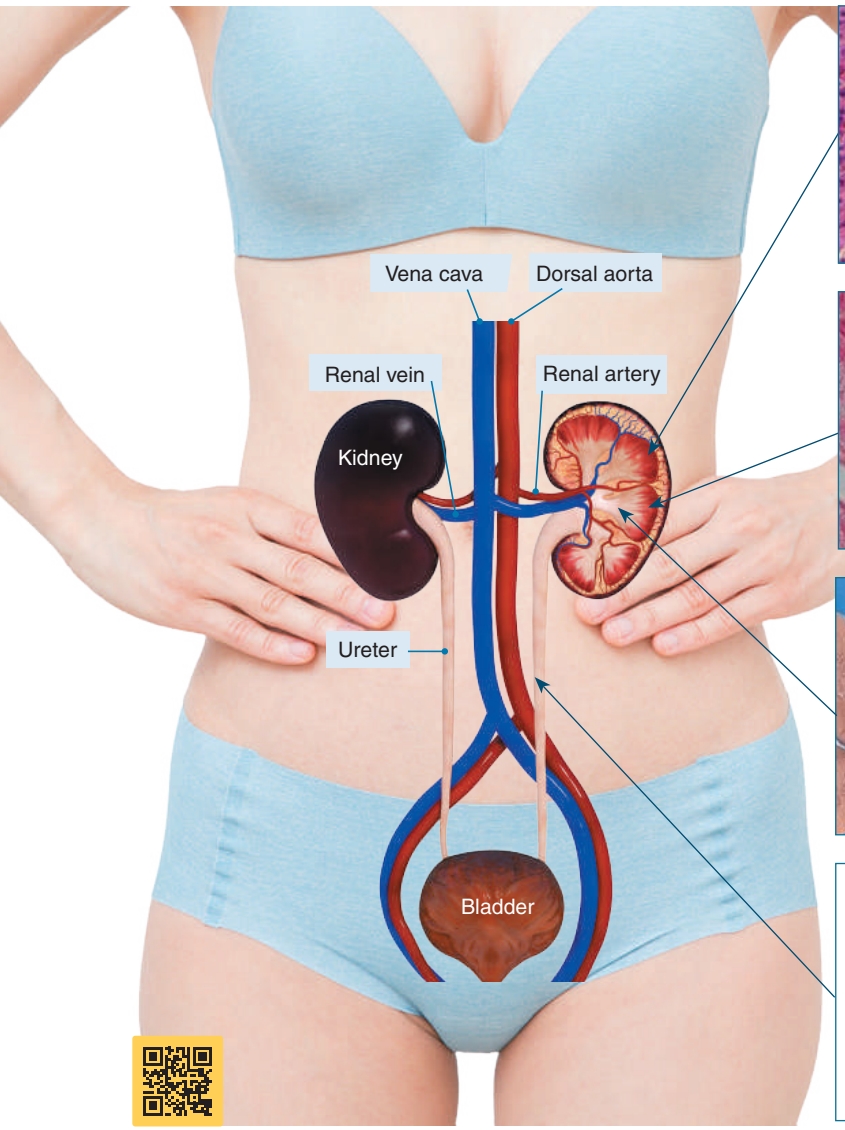
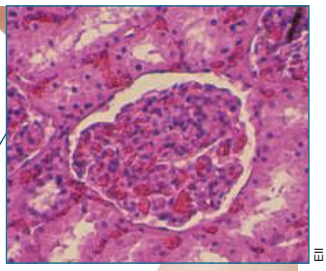
64 The Excretory System

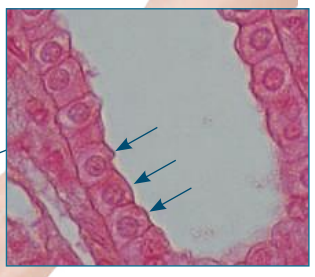
Key Idea: The excretory system is responsible for removing metabolic wastes from the body by filtering the blood.

The mammalian urinary system consists of the kidneys and bladder, and their associated blood vessels and ducts. The kidneys have a plentiful blood supply from the renal artery. The blood plasma is filtered by the kidneys to form urine. Urine is produced continuously, passing along the ureters to the bladder. Mammalian kidneys are very efficient, producing a urine that is concentrated to varying degrees depending on fluid requirements at the time.

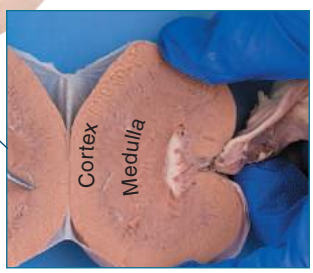




Blood is filtered in the kidneys by the **glomerulus**, a dense knot of capillaries. Blood pressure forces fluid through the capillary walls, a process called ultrafiltration. The filtrate is collected in the **Bowman's capsule** surrounding the glomerulus.



The filtrate moves from Bowman's capsule to the **convoluted tubules**. In the proximal tubule, the cuboidal epithelial cells (arrowed) have microvilli which increase the reabsorption of substances from the substrate. Most reabsorption occurs in the proximal tubule.



The glomerulus, capsule, and tubules form the nephron (the functional unit of the kidney). The thousands of nephrons are aligned and organised in an orderly way. The glomeruli and convoluted tubules are found in the outer cortex, while the "loop of Henle" is found in the inner medulla region.

The filtrate passes to the renal ducts and then to the **ureter** and finally to the bladder. The kidney itself is bean shaped and is around 10 cm long in humans.

1. What is the purpose of the microvilli in the epithelial cells of the convoluted tubules? _____

2. (a) How is filtrate formed? _____

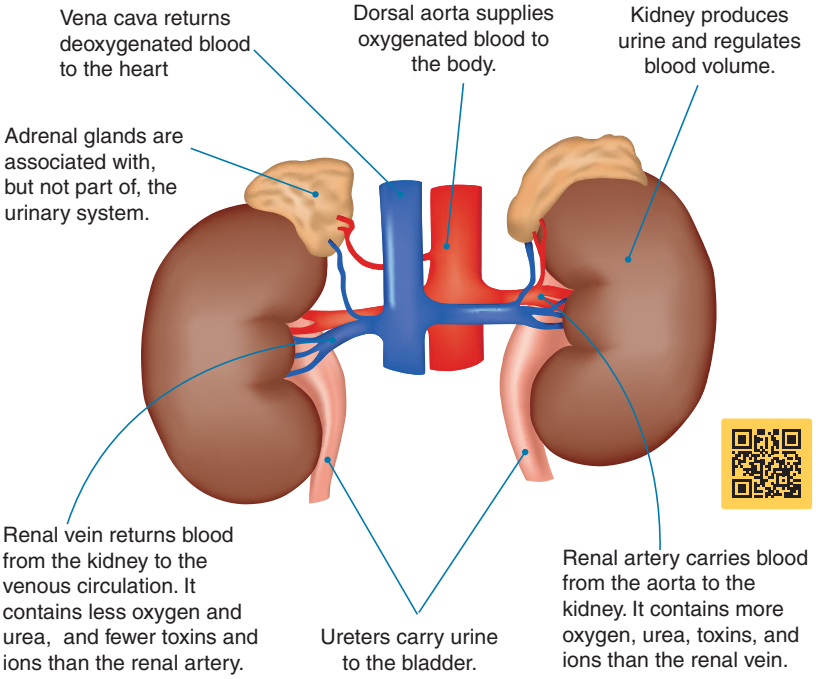
   (b) How is the filtrate modified? _____

3. The circulation rate of blood through the renal artery is about 1.2 L/min, about one quarter of the heart's total output. Why does so much blood need to pass through the kidneys every minute?

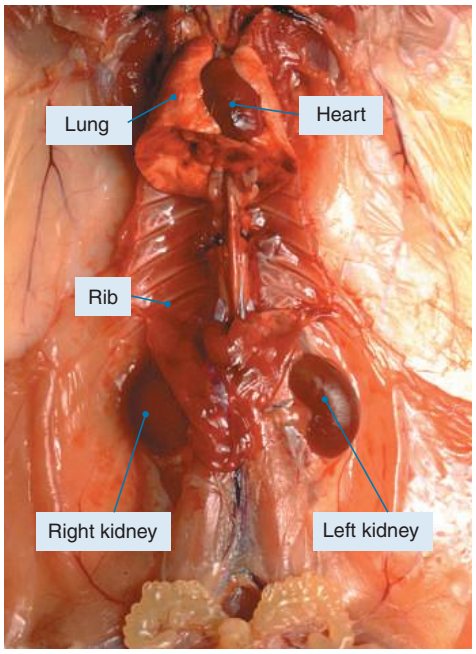
ISBN: 978-1-98-856636-8

The important roles of the kidneys

- The central organs of the excretory system in humans and other mammals are the **kidneys**. These are bean shaped organs that lie at the back of the abdominal cavity to either side of the spine (below right).
- The kidneys act as a selective filter of the blood, removing nitrogenous wastes (**urea**) and toxins and regulating blood composition and pH, while retaining useful substances, such as valuable ions and glucose. The kidneys receive blood under relatively high pressure via the arterioles from the renal artery. This relatively high pressure forces blood plasma out of the capillaries, forming a fluid called filtrate, which is then modified as it passes through the kidney to form the urine.
- Human kidneys (below) are ~100-120 mm long and 25 mm thick. Each day they filter about 180 L of plasma. Most of this is reabsorbed, leaving a daily urine output of about 1 L.
- The kidneys help to maintain the body's internal chemical balance by adjusting the composition of the fluid excreted.



Kidneys *in-situ* (rat)



4. What are the important functions of the kidney? _____

5. Calculate the percentage of the plasma reabsorbed by the kidneys: _____

6. The kidney's are located near the lower part of the ribcage. What do you think is the significance of this location?

7. A person can live more of less normally with just one kidney. What does this tell you about the kidneys?

8. The functional unit of the kidney is a filter element called a nephron. There are at least 1 million nephrons in each kidney. If a person filters 180 L of plasma a day, approximately what volume of plasma does each nephron filter?

9. Describe the general passage of the blood through the kidney and any changes to its composition: _____

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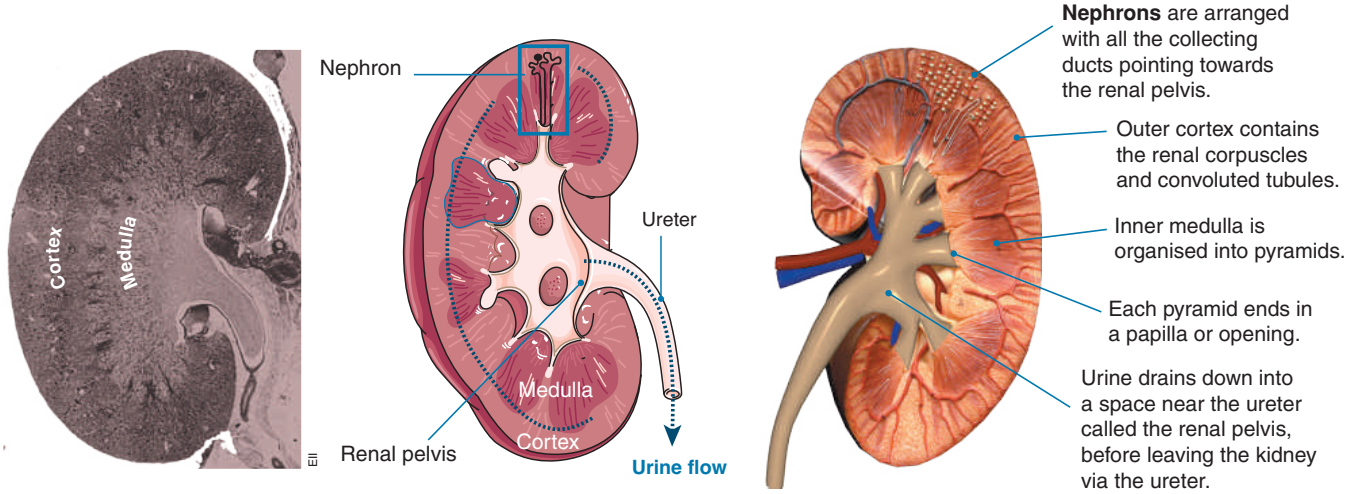
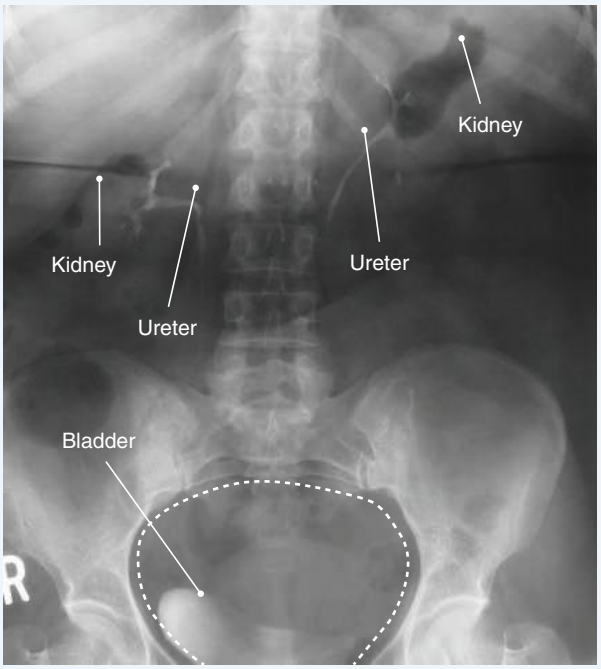
Internal structure of the human kidney



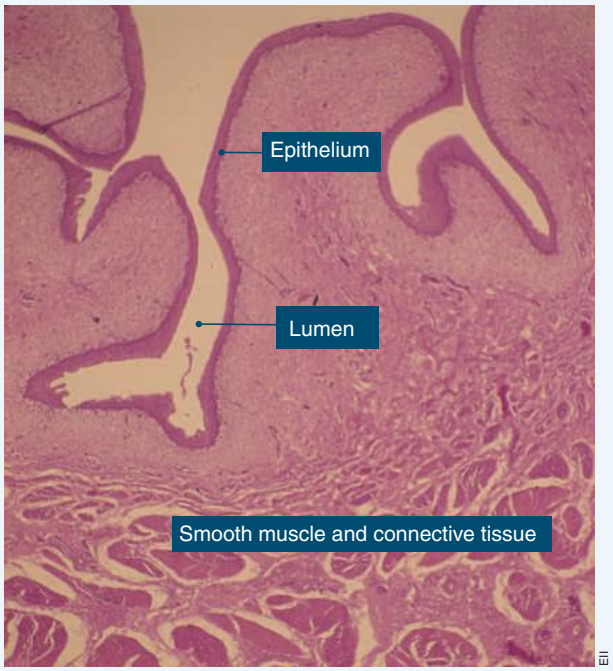
The outer cortex and inner medulla can be seen in a low power LM of the kidney. The ureter is seen extending into the fat and connective tissue surrounding and protecting the kidney.

The functional units of the kidney are selective filter elements called **nephrons**. Each kidney contains more than 1 million nephrons and they are precisely aligned so that urine is concentrated as it flows towards the ureter (model and diagram above). The alignment of the nephrons makes the kidney tissue appear striated (striped) and also makes it possible to fit in all the filtering units needed.

The bladder



The bladder is a hollow stretchable organ, which stores the urine before it leaves the body via the urethra. In this X-ray, it is empty and resembles a deflated balloon. The dotted line shows where it would sit if full.



The bladder is lined with **transitional epithelium**. This type of epithelium is layered, or **stratified**, so it can be stretched without the outer cells breaking apart from each other. This image shows the bladder in a deflated state.

10. Describe the location and orientation of the nephrons in a kidney: _____

_____

_____

_____

11. Describe the structure and function of the bladder: _____

_____

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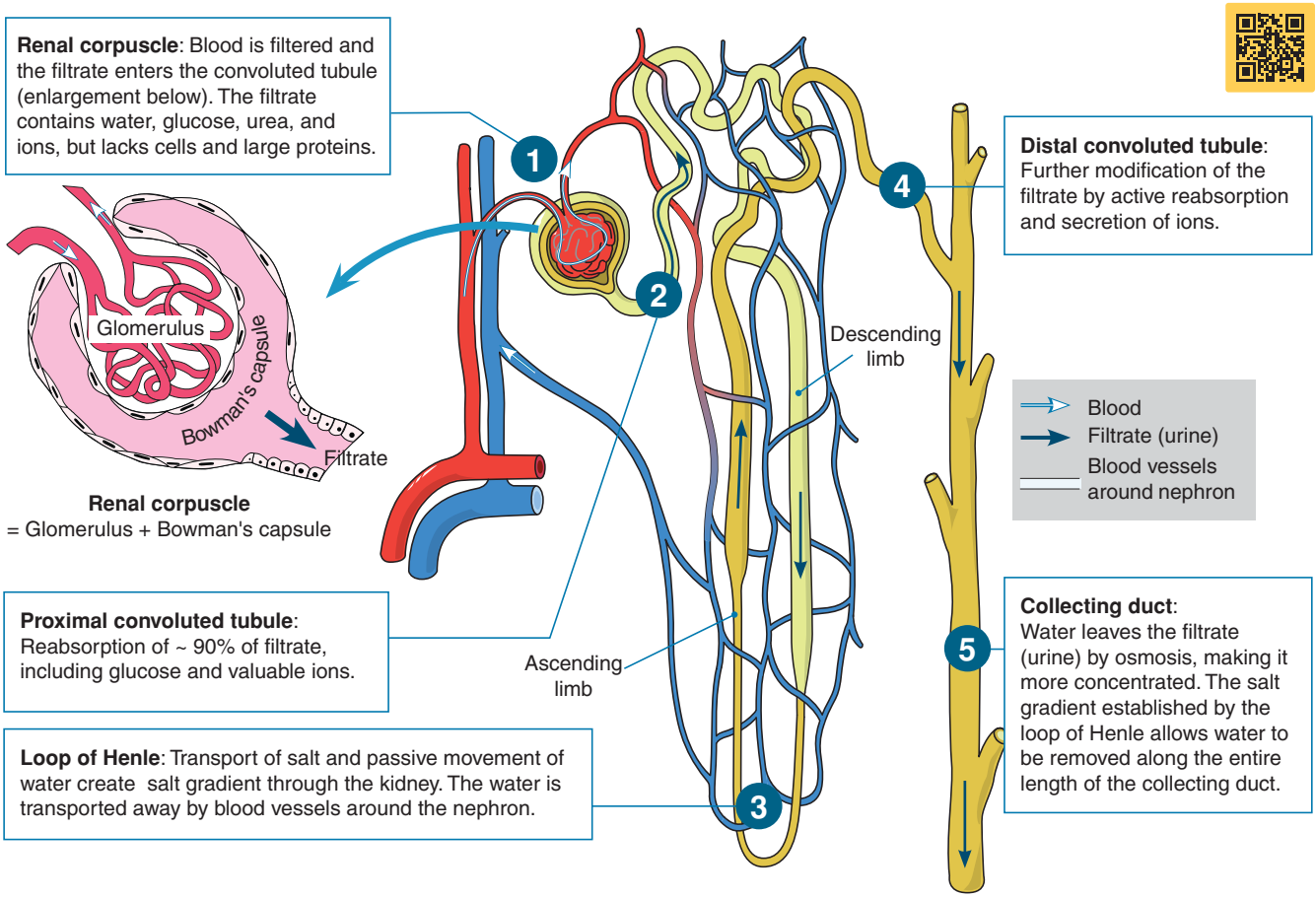
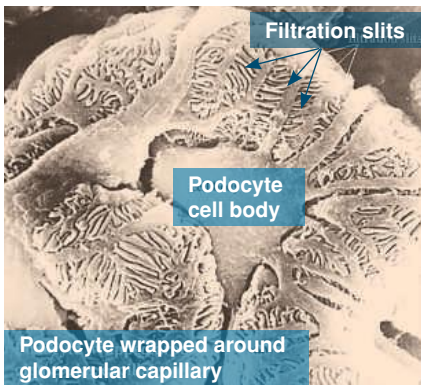
Nephron structure

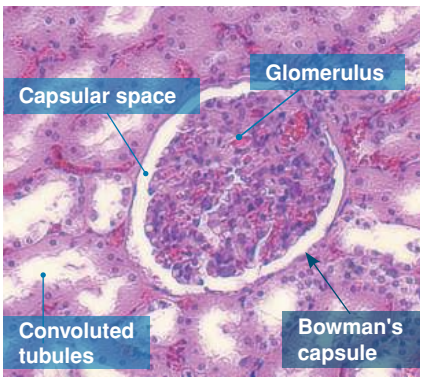
- Ultrafiltration, i.e. forcing fluid and dissolved substances through a membrane by pressure, occurs in the first part of the nephron, across the membranes of the capillaries and the glomerular capsule.
- The formation of the glomerular filtrate depends on the pressure of the blood entering the nephron (below). If it increases, filtration rate increases. When it falls, glomerular filtration rate also falls. This process is precisely regulated so that glomerular filtration rate per day stays constant.
- The initial filtrate, now called urine, is modified through secretion and tubular reabsorption according to body's needs at the time.





Dr D. Cooper: University of California San Francisco

The epithelium of Bowman's capsule is made up of specialized cells called **podocytes**. The finger-like cellular processes of the podocytes wrap around the capillaries of the glomerulus, and the plasma filtrate passes through the filtration slits between them.



EII

Bowman's capsule is a double walled cup, lying in the cortex of the kidney. It encloses a dense capillary network called the **glomerulus**. The capsule and its enclosed glomerulus form a **renal corpuscle**. In this section, the convoluted tubules can be seen surrounding the renal corpuscle.

Dipstick urinalysis is commonly used to detect metabolic errors. Less than 0.1% of glucose filtered by the glomerulus normally appears in urine. The presence of glucose in the urine is usually due to untreated diabetes mellitus, which is characterized by high blood glucose levels.

12. What is the purpose of the nephron? _____

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13. Summarise the main activities in each of the five regions of the nephron:

    (a) Renal corpuscle: _____

    (b) Proximal (near) convoluted tubule: _____

    (c) Loop of Henle: _____

    (d) Distal (far) convoluted tubule: _____

    (e) Collecting duct: _____

14. A kidney contains 1.5 million nephrons (filtering units). A person only needs 300,000 working nephrons to survive.

    (a) What percentage of nephrons actually need to be working for a person to survive? _____

    (b) Why is this important to someone with a damaged kidney? _____

    _____

    _____

15. How is the filtrate formed and modified? _____

    _____

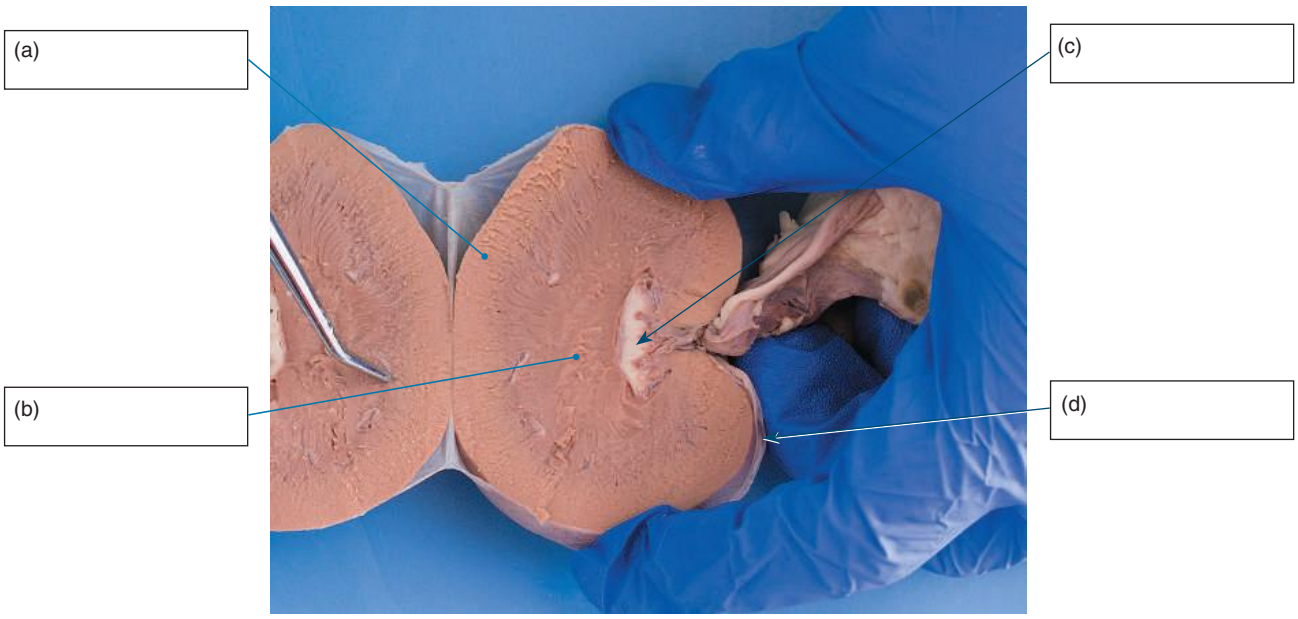
    _____

    _____

16. What does the presence of glucose in the urine possibly indicate? _____

    _____

17. In the kidney photo below, identify and label the following, *renal pelvis, ureter, medulla, cortex, renal capsule*



18. Why is it important that the blood entering the nephron is at a high pressure relative to the blood leaving the nephron?

    _____

    _____

    _____

19. What is the purpose of dipstick urinalysis? _____

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65 Chapter Review: Did You Get It?

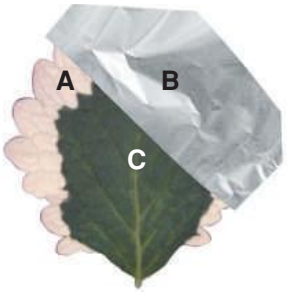
1. (a) What is the name given to the loss of water vapour from plant leaves and stems? _____

   (b) What plant tissue is involved in this process? _____

   (c) Is this tissue alive or dead? _____

   (d) Does this process require energy? _____

2. (a) The leaf right was left in light for 24 hours then tested for starch. In which regions(s) would you expect to find starch (A, B, or C)?



   _____

   (b) Explain your answer:_____

   _____

   _____

   _____

3. (a) What structures from the small intestine of a mammal are shown right?

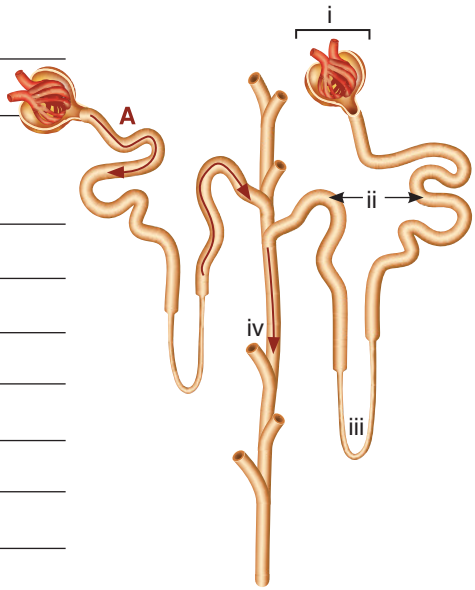
   _____

   (b) What is their function? _____

   _____

   _____

4. (a) The drawing right depicts nephrons from what organ?



   _____

   (b) How many nephrons are shown? _____

   (c) Identify the structures labelled (i)-(iv)

   i) _____ iii) _____

   ii)_____ iv)_____

   (d) What do the arrows on the diagram indicate?_____

   _____

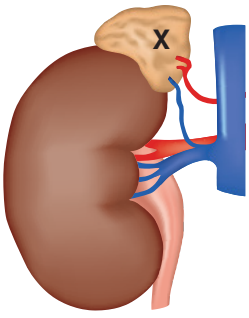
   (e) What important molecule is reabsorbed at point **A**? _____

   _____

   (f) What significant feature is missing from this diagram?_____

   _____

5. (a) Identify the endocrine gland labelled X in the diagram on the right:



   _____

   (b) Name the hormones from this gland involved in the fight of flight response:

   _____

6. (a) Name the endocrine tissue in the pancreas: _____

   (b) What are the two important hormones released by this tissue associated with blood glucose levels and what do they do:

   _____

   _____

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CHAPTER 5

Regulation of Systems

Key terms

antidiuretic hormone (ADH)
diabetes mellitus
effector
glucagon
guard cells
homeostasis
hyperthermia
hyperthyroidism
hypoglycaemia
hypothalamus
hypothermia
insulin
negative feedback
physiological adaptation
positive feedback
receptor
response
stimulus
stomata
thermoregulation

Regulating gas exchange in plants

Key skills and knowledge

Activity number

☐ 1 Explain why water loss in plants is an inevitable consequence of the gas exchanges necessary for photosynthesis. Describe the diffusion of gases into and out of the leaf and relate this to how water is lost from the plant by transpiration. **66**

☐ 2 Explain how plants regulate the rate of water loss from their leaf surfaces. Include reference to how stomatal opening and closing is regulated by ion fluxes into and out of the guard cells. **66**

☐ 3 **TEST** Analyse data on the stomatal densities of plants with different leaf types. **67**

Regulation and homeostasis

Key skills and knowledge

☐ 4 Explain what is meant by homeostasis. Explain why organisms need to regulate their exchanges with the changing environment in order to maintain homeostasis and describe examples. **68**

☐ 5 Use the stimulus-response model to explain how organisms monitor and respond to their environment. Explain the role of feedback loops in homeostatic regulation. Explain how negative feedback stabilises systems against excessive change and how positive feedback has the opposite effect. **68 69**

☐ 6 Interpret feedback control diagrams, recognising stimulus, receptor, control centre, effector, and communication pathways. Examples could include thermoregulation, blood glucose regulation, or regulation of thyroid hormones. **70-72**

☐ 7 Thermoregulation **70**
Explain what is meant by thermoregulation. Describe and explain physiological mechanisms for thermoregulation including:
- autonomic (vasomotor) control of blood flow (vasoconstriction and vasodilation),
- evaporative heat loss from body surfaces,
- thermogenesis (heat production from metabolism).

☐ 8 Explain the role of thyroid hormones in regulating the metabolic generation of heat. Explain the negative feedback regulation of the thyroid hormone thyroxine (T_4). **70 71**

☐ 9 Blood glucose regulation **72**
Explain the role of blood glucose regulation in homeostasis. Explain how blood glucose is regulated, with reference to the role of the hormones insulin and glucagon. Describe the role of the liver in carbohydrate metabolism and blood glucose regulation.

☐ 10 Regulation of fluid balance **74**
Explain why regulating fluid levels (including blood volume) and electrolytes is so important. Describe the role of the kidney in regulating the body's levels of fluid (water) and electrolytes. Explain how urine volume, blood volume, and levels of electrolytes are regulated in response to the demands of normal activity with reference to the role of hypothalamic osmoreceptors and antidiuretic hormone (ADH).

Malfunctions in homeostatic mechanisms

Key skills and knowledge

☐ 11 With reference to hyperthyroidism, describe how disorders of thyroid function affect homeostasis, including thermoregulatory responses. **71**

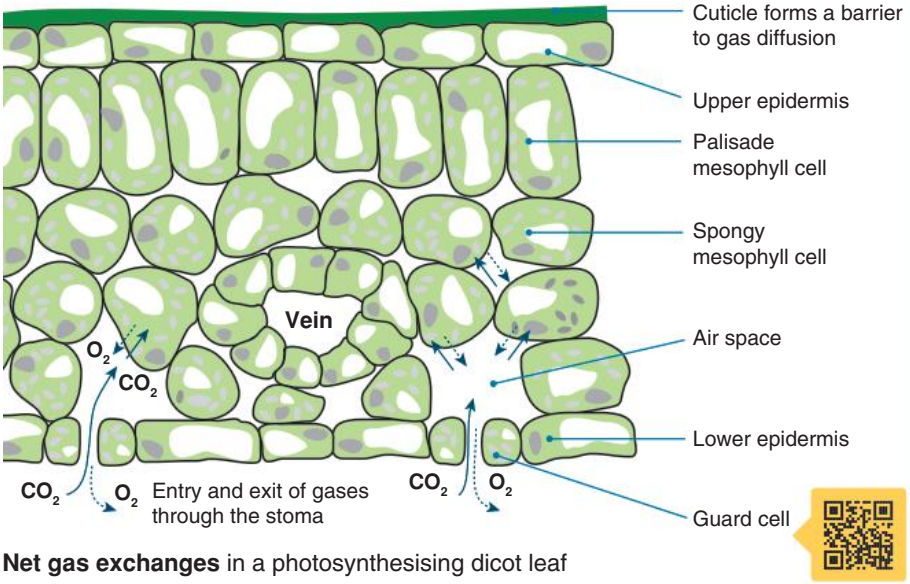
☐ 12 Describe disorders of blood glucose regulation, including hypoglycaemia. Describe and explain the causes, symptoms, and effects of type 1 diabetes. **73**

66 Gas Exchange and Stomata

Key Idea: Gas exchange through stomata is associated with water losses. Guard cells help regulate these water losses.

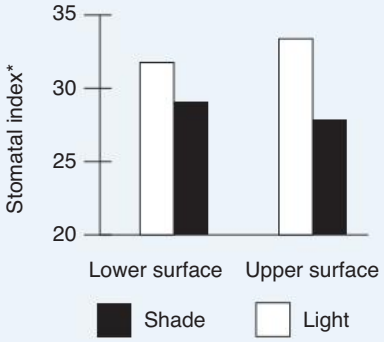
The leaf epidermis of higher plants is covered with tiny pores, called **stomata**. Although stomata permit gas exchange between the air and the loosely packed photosynthetic cells inside the leaf, they are also the major routes for water loss through transpiration. Regulating this water loss, while still permitting the entry of CO_2, is an important part of maintaining **homeostasis** (a steady state) in plants. Each stoma is bounded by two guard cells, which together regulate the entry and exit of gases (including water vapour). They allow the plant to prevent excessive water loss from its leaves.

Gas exchanges and the function of stomata



Net gas exchanges in a photosynthesising dicot leaf

The number of stomata is influenced by the environment



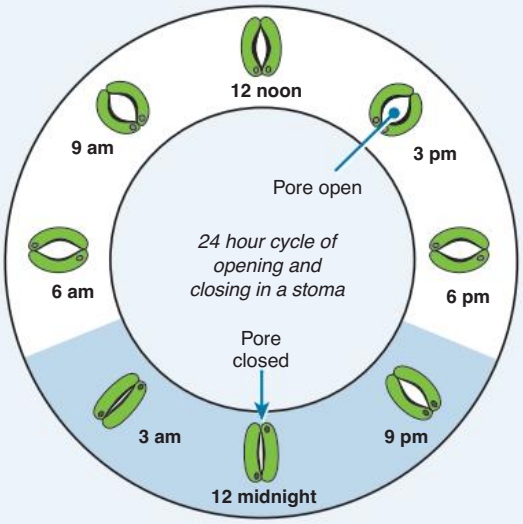
*Stomatal index is the percentage number of stomata compared to all the epidermal cells in a unit area of leaf.

An increase in light intensity on mature leaves increases the number of stomata developing on young leaves.

- Gases enter and leave the leaf through stomata. Inside the leaf (as illustrated for a dicot, above), the large air spaces and loose arrangement of the spongy mesophyll facilitate the diffusion of gases and provide a large surface area for gas exchanges.
- Respiring plant cells use oxygen (O_2) and produce carbon dioxide (CO_2). These gases move in and out of the plant and through the air spaces by diffusion.
- When the plant is photosynthesising, the situation is more complex. Overall there is net consumption of CO_2 and net production of oxygen. Fixation of CO_2 in the carbohydrate products of photosynthesis maintains a gradient in CO_2 concentration between the atmosphere (high CO_2) and the leaf tissue (low CO_2). Oxygen is produced in excess of respiratory needs and diffuses out of the leaf. These **net** exchanges are indicated by the arrows on the diagram.

The cycle of opening and closing of stomata

The opening and closing of stomata shows a daily cycle that is largely determined by the hours of light and dark.



The image left shows a scanning electron micrograph (SEM) of a single stoma from the leaf epidermis of a dicot. Note the guard cells (G), which are swollen tight and open the pore (S) to allow gas exchange between the leaf tissue and the external environment.

Factors influencing stomatal opening

Stomata	Guard cells	Daylight	CO_2	Soil water
Open	Turgid	Light	Low	High
Closed	Flaccid	Dark	High	Low

The opening and closing of stomata depends on environmental factors, the most important being light, CO_2 concentration in the leaf tissue, and water supply. Stomata tend to open during daylight in response to light, and close at night (left and above). Low CO_2 levels also promote stomatal opening. Conditions that induce water stress cause the stomata to close, regardless of light or CO_2 level.

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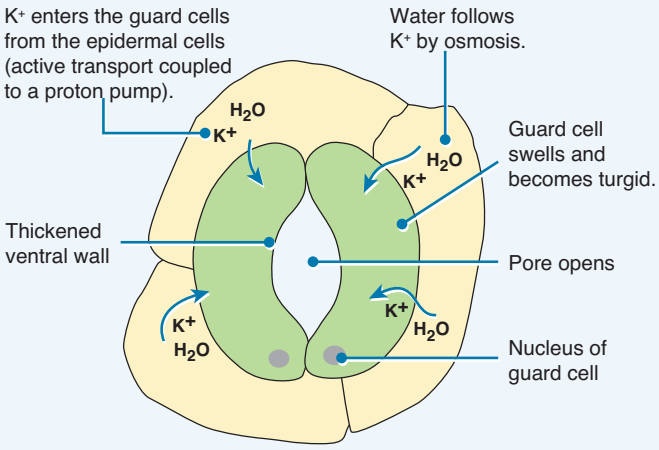
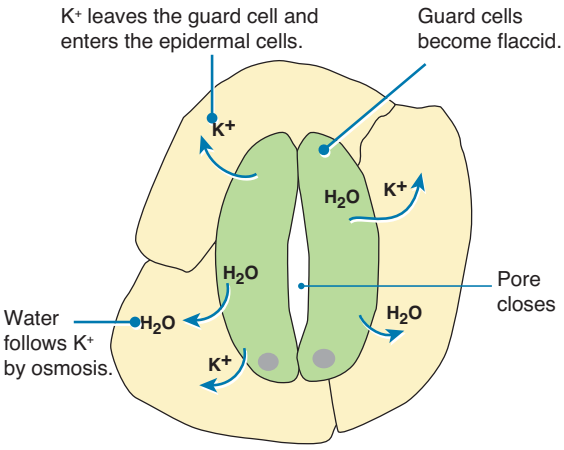
The guard cells on each side of a stoma control the diameter of the pore by changing shape. When the guard cells take up water by osmosis they swell and become turgid, opening the pore. When the guard cells lose water, they become flaccid and the pore closes. By this mechanism a plant can control the amount of gas entering, or water leaving, the plant. The changes in turgor pressure that open and close the pore result mainly from the reversible uptake and loss of potassium ions (and thus water) by the guard cells.

Stomatal pore open



Potassium and water enter the guard cells
Stomata open when the guard cells actively take up K^+ from the neighbouring epidermal cells. As a consequence, water enters the cell by osmosis and they swell and become turgid. The walls of the guard cells are thickened more on the inside surface (the ventral wall) than the outside wall, so that when the cells swell they buckle outward, opening the pore.

Stomatal pore closed



Potassium and water leave the guard cells:
Stomata close when K^+ leaves the guard cells. As a consequence of K^+ outflow from the guard cells, water is lost by osmosis and the cells sag together and close the pore. This process is stimulated by the hormone ABA (abscisic acid), which is synthesised in response to water stress. This response helps to reduce water loss.

1. Name the cells that regulate the opening and closing of the stomata: _____

2. What is the effect of increasing light intensity on the number of stomata? _____

   _____

3. For a terrestrial flowering plant, with no special adaptations for water conservation:

   (a) Describe the **net** gas exchanges between the air and the cells of the mesophyll in the dark (no photosynthesis):

   _____

   (b) Explain how this situation changes when a plant is photosynthesising: _____

   _____

4. Describe two ways in which the continuous air spaces through the plant facilitate gas exchange:

   (a) _____

   (b) _____

5. Outline the role of stomata in gas exchange in a flowering plant: _____

   _____

6. (a) Explain how the guard cells open the stomata: _____

   _____

   _____

   _____

   (b) Explain how the guard cells close the stomata: _____

   _____

   _____

   _____

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67 Analysis of Stomatal Density in Different Plants

Assessment task, Outcome 2: *A data analysis of generated primary and/or collated data*

Different plant species have different leaf shapes and structures and these can be correlated with their environment. Some of these leaf adaptations are associated with regulating water loss. These include the position, arrangement, and density of stomata.

Plant species show different leaf shapes and structures associated with their environments

Aloe (agave)
A succulent

Tropical species with thick, fleshy leaves. Physiology allows it to fix CO_2 during the night and keep stomata closed during the day.

Pine
A conifer

Temperate species with thin, needle like leaves and a thick waxy leaf cuticle. Stomata are sunken into pits.

Eucalyptus
An Australian gum tree

Sub-tropical drought tolerant species with a deep root systems and waxy leaves that hang downwards.

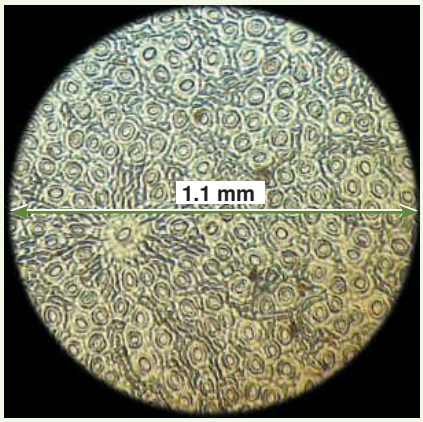
Sunflower
A perennial dicot with large leaves

Widespread cultivated North American dicot with a showy flower head and very large soft leaves.

Investigation 5.1 Comparing stomatal density

See appendix for equipment list.

1. Your teacher will have up to four leaf types from four dicot plants adapted to different environments, or your may need to obtain samples of your own.
2. The number of stomata per mm^2 on the surface of a leaf can be determined by counting the stomata visible under a microscope. Use the clear nail varnish to paint over the lower surface of a leaf. Leave it to dry. This creates a layer with impressions of the leaf surface.
3. Carefully peel off the nail varnish layer and place on a clean microscope slide.
4. Calculate the diameter of the area viewable under a microscope using the field of view divided by the magnification of the eyepiece multiplied by the magnification of the objective lens (for example if the eyepiece magnification is 10, the objective lens magnification 40, and the field of view 18, then 18/(10 x 40) = 0.045 mm diameter. The area viewable is then πr^2.
5. You could also use a micrometer to measure the diameter of the field of view or use a thin clear ruler.
6. Place the slide with the nail varnish layer on it under the microscope and count the number of stomata you see. If there are too many stomata then count one quarter of the field of view and multiply by four. Do this in several places. Enter your results in the table and calculate a mean.
7. You should also take note of where the stomata are on the leaf (are they scattered randomly or in specific places?)
8. Repeat on the upper surface of the leaf.
9. Repeat for the other leaf types.



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	Number of stomata per mm^2 lower surface					Number of stomata per mm^2 upper surface				
	Count number					Count number				
Plant name/type	1	2	3	4	Mean	1	2	3	4	Mean

1. (a) Write an aim for the investigation: _____

   _____

   (b) Write an hypothesis for the investigation: _____

   _____

2. Complete the table above:
3. (a) Which plant has the highest stomatal density? _____

   (b) Which plant has the lowest stomatal density? _____
4. (a) Is there a relationship between the number of stomata per mm^2 and the type of leaf or plant?

   _____

   (b) Explain your answer: _____

   _____

   _____

   _____

   _____
5. (a) Where are the majority of stomata located In a typical dicot leaf? _____

   (b) Suggest why this might be the case: _____

   _____

   _____
6. Explain your results in terms of the environment the plants are adapted for and the need to regulate water loss:

   _____

   _____

   _____

   _____

   _____

   _____

   _____

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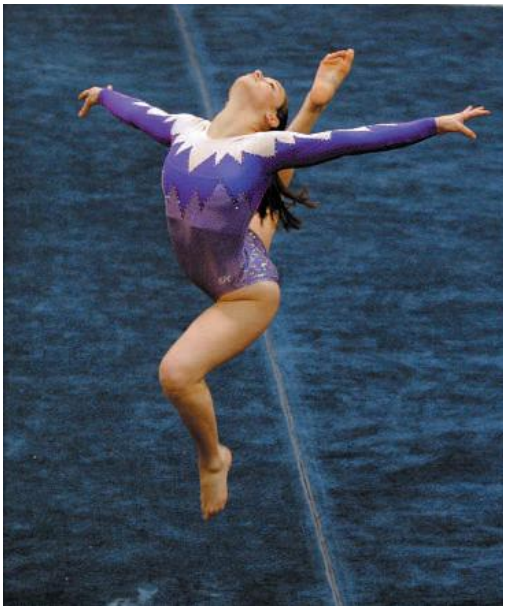
68 Homeostasis

Key Idea: Homeostasis refers to the (relatively) constant physiological state of the body despite fluctuations in the external environment.

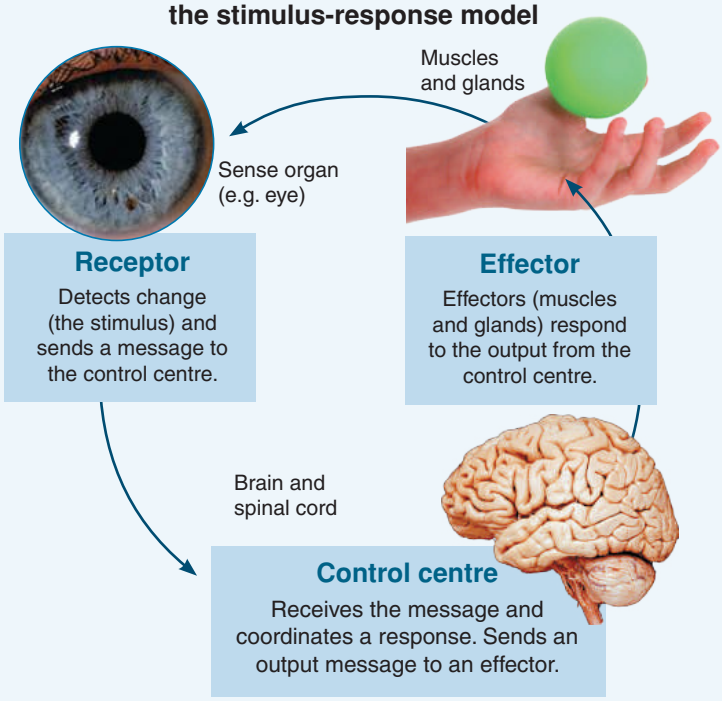


Organisms maintain a relatively constant physiological state, called **homeostasis**, despite changes in their environment. Any change in the environment to which an organism responds is called a **stimulus**. Environmental stimuli are constantly changing, so organisms must also adjust their behaviour and physiology constantly to maintain homeostasis. This requires the coordinated activity of the body's organ systems. Homeostatic mechanisms prevent deviations from the steady state and keep the body's internal conditions within strict limits. Deviations from these limits can be harmful.

An example of homeostasis occurs when you exercise (right). Your body must keep your body temperature constant at about 37.0°C despite the increased heat generated by activity. Similarly, you must regulate blood sugar levels and blood pH, water and electrolyte balance, and blood pressure. Your body's organ systems carry out these tasks.

To maintain homeostasis, the body must detect stimuli through receptors, process this sensory information, and respond to it appropriately via effectors. The responses provide new feedback to the receptor. These three components are illustrated below.

How homeostasis is maintained: the stimulus-response model



Receptor
Detects change (the stimulus) and sends a message to the control centre.

Effector
Effectors (muscles and glands) respond to the output from the control centre.

Control centre
Receives the message and coordinates a response. Sends an output message to an effector.

The analogy of a thermostat on a heater is a good way to understand how homeostasis is maintained. A heater has sensors (a receptor) to monitor room temperature. It also has a control centre to receive and process the data from the sensors. Depending on the data it receives, the control centre activates the effector (heating unit), switching it on or off. When the room is too cold, the heater switches on. When it is too hot, the heater switches off. This maintains a constant temperature.

1. What is homeostasis? _____

_____

2. What is the role of the following components in maintaining homeostasis:

(a) Receptor: _____

_____

(b) Control centre: _____

_____

(c) Effector: _____

_____

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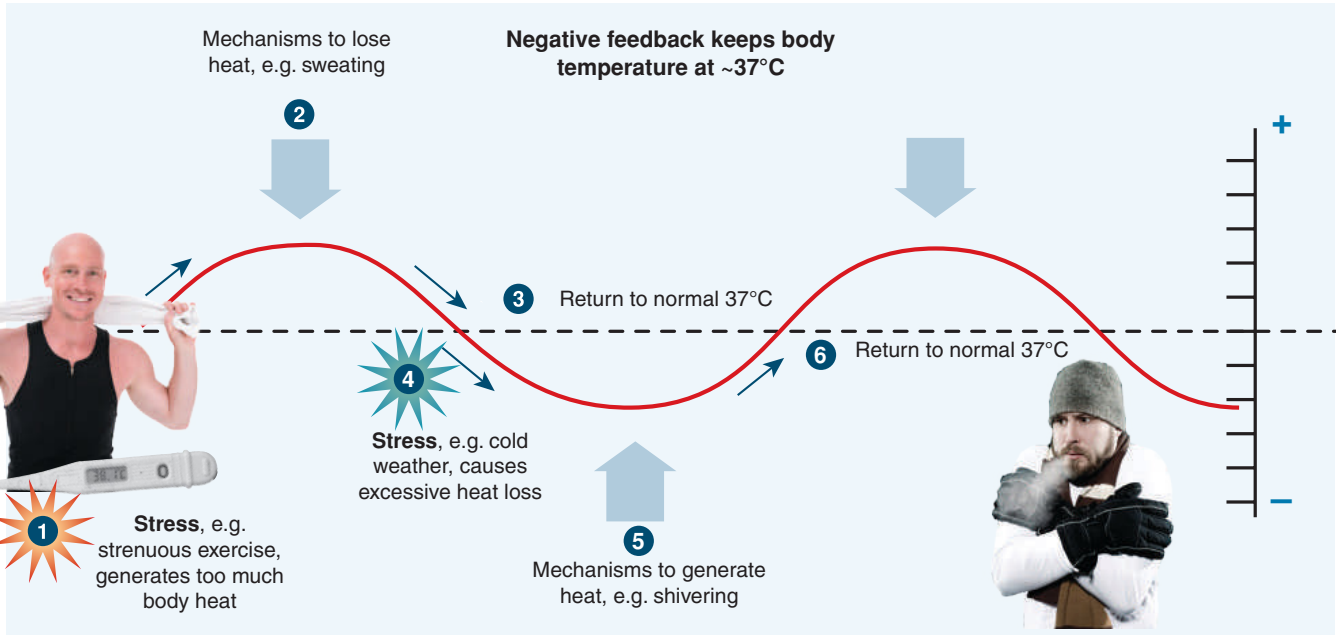
69 Feedback Mechanisms

Key Idea: Feedback mechanisms can stabilise biological systems or exaggerate deviations from the median condition. There are two types of feedback mechanisms used in the body, each producing specific outcomes. Negative feedback maintains a stable internal environment, as occurs in the regulation of body temperature. Positive feedback exaggerates any changes in the internal environment, usually to achieve a specific outcome quickly, e.g. blood clotting.

Negative (counterbalancing) feedback

- Negative (or counterbalancing) feedback is a control system that maintains the body's internal environment at a relatively steady state. Negative refers to the sign used in mathematical models of feedback.
- Negative feedback has a stabilising effect by discouraging variations from a set point. When variations are detected by the body's receptors, negative feedback returns internal conditions back to a steady state (below).
- Most physiological (and environmental) systems achieve homeostasis through negative feedback.



We know when we are too cold but we are unaware of most of the negative feedback operating in our bodies. Yet it keeps our body systems stable.

Food in the stomach activates stretch receptors, stimulating gastric secretion and motility. As the stomach empties, the stimulus for gastric activity declines.

Negative feedback controls almost all the body's functioning processes including heart rate, blood glucose, blood pressure, and pituitary secretions.

Maintaining a stable blood glucose is an important homeostatic function regulated by negative feedback involving two antagonistic hormones.

1. How does the behavior of a negative feedback system maintain homeostasis? _____

_____

_____

_____

_____

2. Why do you think it is important that the regulation of the body's critical functions depends on negative feedback?

_____

_____

_____

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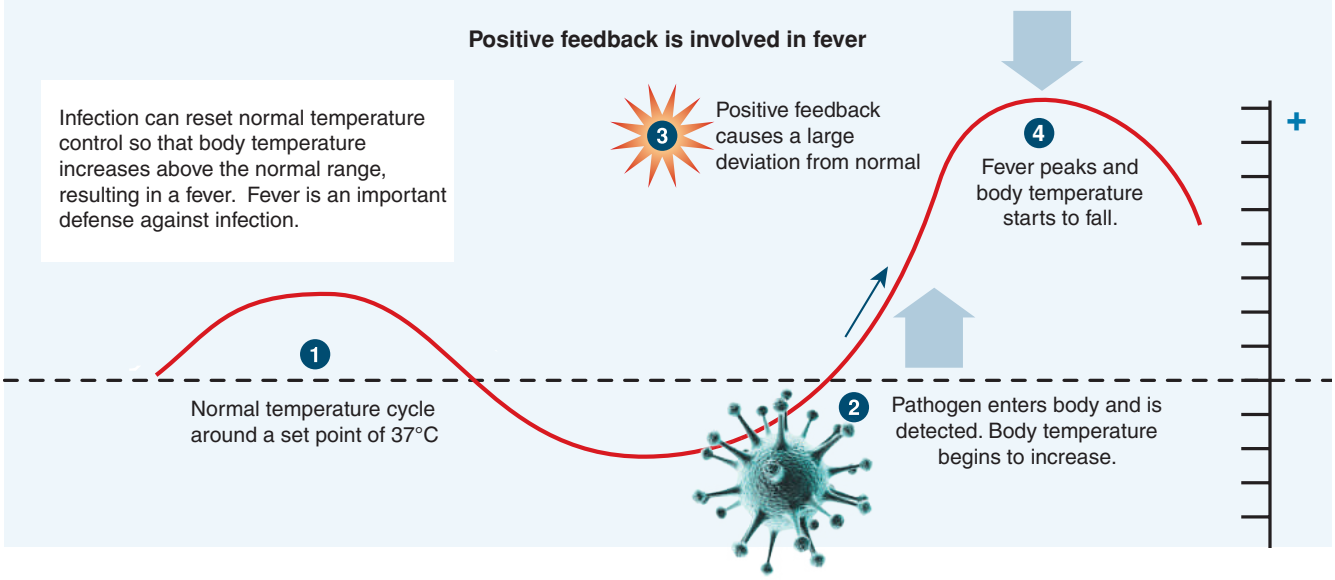
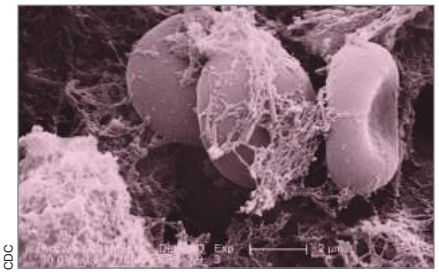
Positive feedback

- Positive feedback mechanisms amplify (increase) a response in order to achieve a particular result. Examples of positive feedback include fruit ripening, fever, blood clotting, childbirth (labour) and lactation (production of milk).
- A positive feedback mechanism stops when the end result is achieved (e.g. the baby is born, a pathogen is destroyed by a fever, or ripe fruit falls off a tree). Positive feedback is less common than negative feedback in biological systems because the escalation in response is unstable. Unresolved positive feedback responses (e.g. high fevers) can be fatal.





CDC

Positive feedback is involved in blood clotting. A wound releases chemicals to activate platelets in the blood. Activated platelets release chemicals to activate more platelets, so a blood clot is formed.

Ragesoss

Ethylene is a gaseous plant hormone involved in fruit ripening. It accelerates ripening in nearby fruits, so these also ripen, releasing more ethylene. Too much ethylene causes over-ripening.

Childbirth involves positive feedback. Pressure of the baby's head causes release of a hormone that increases contractions even more. The feedback loop ends when the baby is born.

3. (a) Why is positive feedback much less common than negative feedback in body systems? _____

_____

(b) How can positive feedback lead to a runaway response in the body? _____

_____

_____

(c) Why can positive feedback be dangerous if it continues on for too long? _____

_____

_____

(d) How is a positive feedback loop normally stopped? _____

_____

(e) Predict what could happen if a person's temperature continued increasing during a fever (did not peak and fall)?

_____

_____

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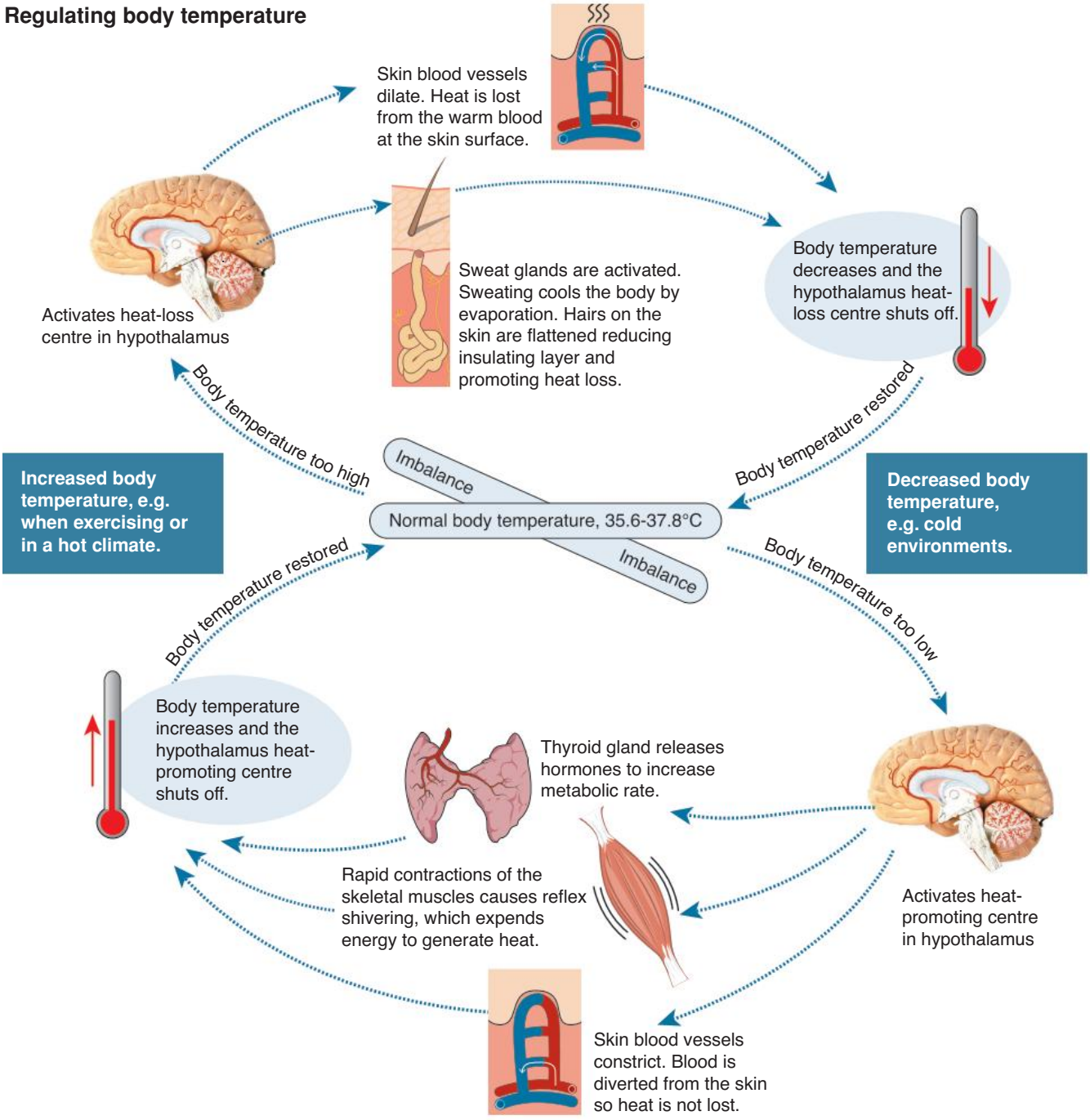
70 How is Body Temperature Regulated?

Key Idea: Temperature regulation is a negative feedback process controlled by the hypothalamus.

In humans, the temperature regulation centre is a region of the brain called the **hypothalamus**. It has thermoreceptors that monitor core body temperature and has a 'set-point' temperature of 36.7°C. The hypothalamus acts like a thermostat. It registers changes in the core body temperature and also receives information about temperature changes from thermoreceptors in the skin. It then coordinates nervous and hormonal responses to counteract the changes and restore normal body temperature. When normal temperature is restored, the corrective mechanisms are switched off.

Regulating body temperature



1. In the diagram above showing the regulation of body temperature:

   (a) Identify the stimulus: _____

   (b) Identify the control centre: _____

   (c) Identify the effectors: _____

2. How do the effectors restore body temperature when it increases above the set point? _____

_____

_____

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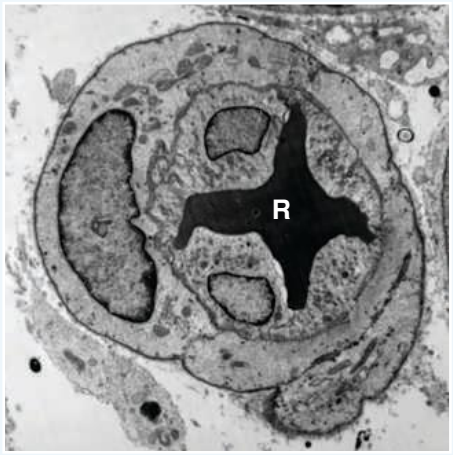
Regulating blood flow to the skin



RM Hunt CC 3.0

Constriction of a small blood vessel. A red blood cell (R) is in the centre of the vessel (TEM).

To regulate heat loss or gain from the skin, the blood vessels beneath the surface constrict (become narrower) to reduce blood flow or dilate (expand) to increase blood flow. When blood vessels are fully constricted there may be as much as a 10°C temperature gradient from the outer to inner layers of the skin. Extremities such the hands and feet have additional vascular controls, which can reduce blood flow to them in times of severe cooling.

Thermoreceptors

Thermoreceptors are simple sensory receptors that are located in the skin and respond to changes in temperature. When they detect a temperature change they send that information (as nerve impulses) to the hypothalamus. Hot thermoreceptors detect an increase in skin temperature above 37.5°C and cold thermoreceptors detect a fall below 35.8°C.

Ildar Sagdejev CC 3.0

The hair erector muscles, sweat glands, and blood vessels are the effectors for mediating a response to information from thermoreceptors.

Temperature regulation by the skin involves **negative feedback** because the output is fed back to the skin receptors and becomes part of a new stimulus-response cycle.

- **Photo above left**: Vasodilation and sweating in response to high temperature or exertion.
- **Photo above right**: Vasoconstriction and "goosebumps" in response to low temperature or inactivity.

3. Describe the role of each of the following in regulating body temperature:

   (a) Shivering: _____

   _____

   (b) The skin: _____

   _____

   (c) Nervous input to effectors: _____

   _____

   (d) Hormones: _____

   _____

4. What is the purpose of sweating and how does it achieve its effect? _____

   _____

   _____

5. Explain how negative feedback is involved in the regulation of body temperature: _____

   _____

   _____

   _____

   _____

6. How do the blood vessels help to regulate the amount of heat lost from the skin and body? _____

   _____

   _____

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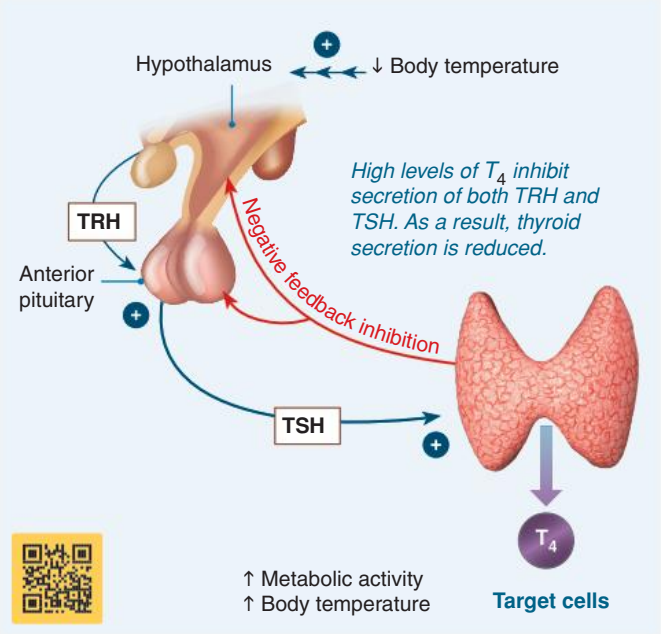
71 The Thyroid and Thermoregulation

Key Idea: Hormones regulate many aspects of metabolism. Over- or under production of hormones can affect metabolic aspects of thermoregulation, as can a lack of cellular response to those hormones.

The hypothalamus has a central role in thermoregulation. It registers changes in core body temperature and coordinates nervous and hormonal responses to restore normal body temperature. Thyroxine (T_4), produced by the thyroid gland, is an important hormone in thermoregulation. Insulin also has a thermoregulatory role but this is less well understood.

Thyroxine (T_4) and temperature regulation

- One of the effects of T_4 is to speed up metabolic activity in cells. The increase in metabolic activity also results in the production of heat. Under normal conditions, this is one of the mechanisms by which body temperature is increased.
- T_4 production is controlled by **negative feedback** (right). This mechanism involves two parts of the brain, the **hypothalamus** and the **pituitary gland**.
- Low body temperature stimulates the hypothalamus to secrete thyrotropin releasing hormone (TRH), which in turn stimulates cells in the anterior pituitary to secrete thyroid stimulating hormone (TSH).
- TSH acts on the thyroid gland, causing it to produce thyroid hormones, including T_4. T_4 binds to target cells, increasing their metabolic activity and producing heat.
- High levels of T_4 inhibit secretion of both TRH and TSH. As a result, thyroid secretion is reduced. When the level of thyroid hormones drops below a certain threshold, TRH and TSH production begins again.



Disorders of T_4 secretion in humans

- The negative feedback regulation of T_4 production can be disrupted by hyperthyroidism, a condition where the thyroid makes too much T_4. This can disrupt temperature regulation causing heat sensitivity and excessive perspiration.
- The most common cause of hyperthyroidism is Graves' disease. An enlarged thyroid (goiter) and bulging eyes (right).
- In Graves' disease, the negative feedback loop is bypassed because a protein called thyroid stimulating immunoglobulin (TSI) binds directly to the thyroid and stimulates T_4 production. Because T_4 production is uncoupled from TSH production, the usual regulatory mechanisms are ineffective.

1. How is T_4 involved in temperature regulation? _____

2. Explain how T_4 production is regulated by negative feedback: _____

3. Why do high levels of thyroxine not inhibit its production from the thyroid gland in a person with Graves' disease?

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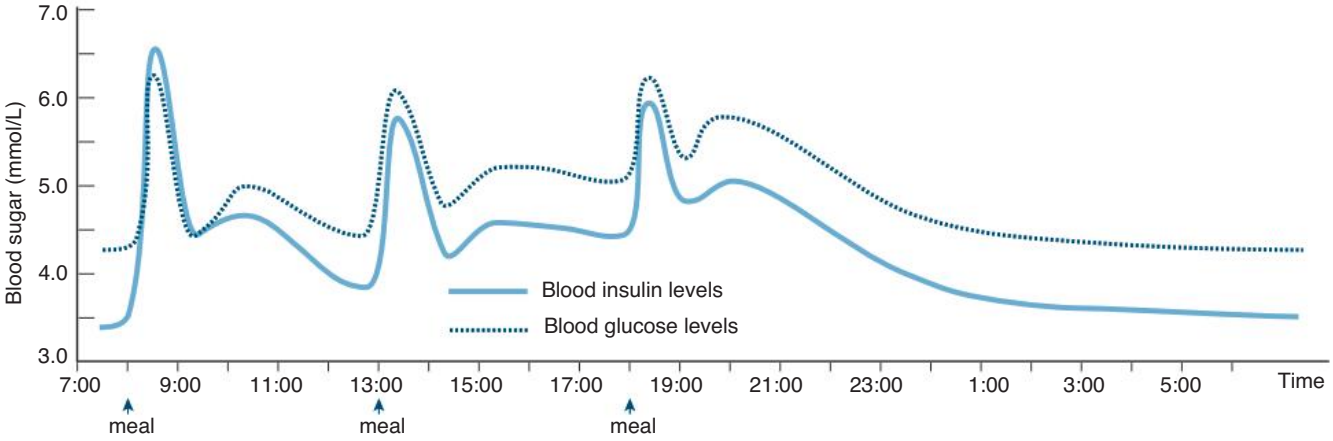
72 Control of Blood Glucose

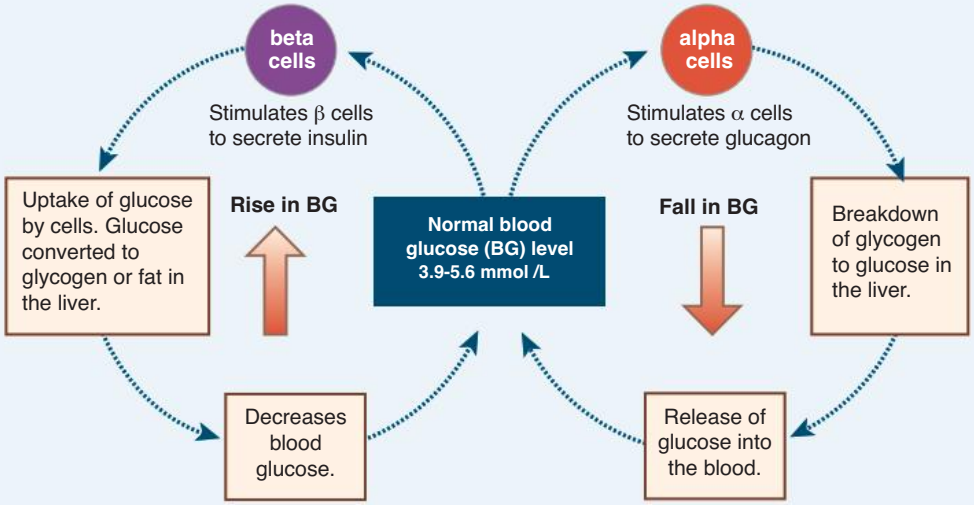
Key Idea: The endocrine portion of the pancreas produces two hormones, insulin and glucagon, which maintain blood glucose at a steady state through negative feedback.

Blood glucose levels are controlled by negative feedback involving two hormones, insulin and glucagon. These hormones are produced by the islet cells of the pancreas, and act in opposition to control blood glucose levels. **Insulin** lowers blood glucose by promoting the uptake of glucose by the body's cells and the conversion of glucose into the storage molecule glycogen in the liver. **Glucagon** increases blood glucose by stimulating the breakdown of stored glycogen and the synthesis of glucose from amino acids. Negative feedback stops hormone secretion when normal blood glucose levels are restored. Blood glucose homeostasis allows energy to be available to cells as required. The liver has a central role in these carbohydrate conversions.



Negative feedback in blood glucose regulation

Blood glucose can be tested using a finger prick test. The glucose in the blood reacts with an enzyme electrode, generating an electric charge proportional to the glucose concentration. This is displayed as a digital readout.



1. (a) Identify the stimulus for the release of insulin: _____

   (b) Identify the stimulus for the release of glucagon: _____

   (c) How does glucagon increase blood glucose level? _____

   _____

   (d) How does insulin decrease blood glucose level? _____

   _____

2. Explain the pattern of fluctuations in blood glucose and blood insulin levels in the graph above:

   _____

   _____

   _____

   _____

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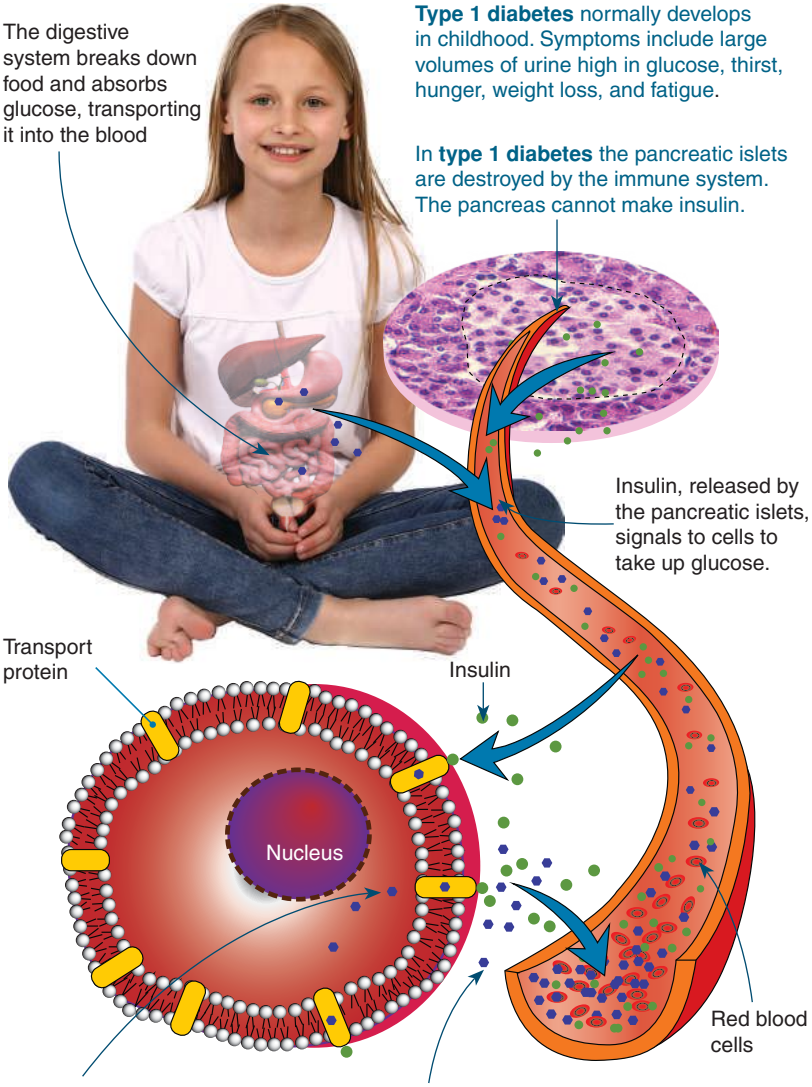
73 Type 1 Diabetes Mellitus

Key Idea: Diabetes mellitus is a condition in which blood glucose levels are too high and glucose appears in the urine. In type 1 diabetes, the insulin-producing cells of the pancreas are destroyed and insulin is not produced.

Diabetes mellitus (often called diabetes) is a condition in which blood glucose is too high because the body's cells cannot take up glucose in the normal way. Diabetes mellitus is characterised by large volumes (diabetes) of sweet (mellitus) urine and extreme thirst. In **type 1 diabetes**, the insulin producing beta cells of the pancreas are destroyed and no insulin is produced. Patients must have regular insulin injections to stabilise blood glucose levels.



Short term effects

Low blood sugar *(hypoglycaemia)*: Blood glucose levels below normal (<4 mmol/L) can result in clumsiness, confusion, and seizures. It can result from too much insulin, usually after injection if glucose levels are already low.

High blood sugar*(hyperglycaemia)*: High blood glucose levels (> 6 mmol/L) occur when glucose fails to enter the cells. Effects include frequent urination, fatigue, thirst, and blurred vision

Ketoacidosis: A lack of insulin can result in a build up of molecules called ketones caused by metabolism of fats for fuel. Ketones are acidic and can lead to metabolic acidosis (fall in tissue pH), which can quite quickly be fatal.

Long term effects

General circulation: Over time, high blood glucose damages the lining of small blood vessels, making them prone to developing plaques and becoming narrow and clogged. The result of this is increased blood pressure.

Heart disease: Nearly 3 in 4 people with type 1 diabetes will suffer some form of heart disease. Causes may be from autoimmune responses and high blood glucose and blood pressure.

Kidney disease: Damage to the small blood vessels of the kidney causes kidney function to decline and produces many associated health problems. Glucose in the urine can also result in fungal infections in the bladder.

Eye problems: Damage to the blood vessels in the eyes leads to cataracts and retinal damage.

Nerve damage: High blood glucose levels cause nerve damage indirectly through blood vessel damage. Symptoms include tingling and weakness in the limbs. Numbness can lead to unnoticed and hard to treat infections and ulcers.

1. (a) What is type 1 diabetes? _____

   (b) Explain how the usual mechanisms for blood glucose homeostasis are disrupted in a person with type 1 diabetes. How does this disruption result in the symptoms observed?

   _____

   _____

   _____

   _____

2. How do regular insulin injections help a person with type 1 diabetes to maintain their blood glucose homeostasis?

   _____

   _____

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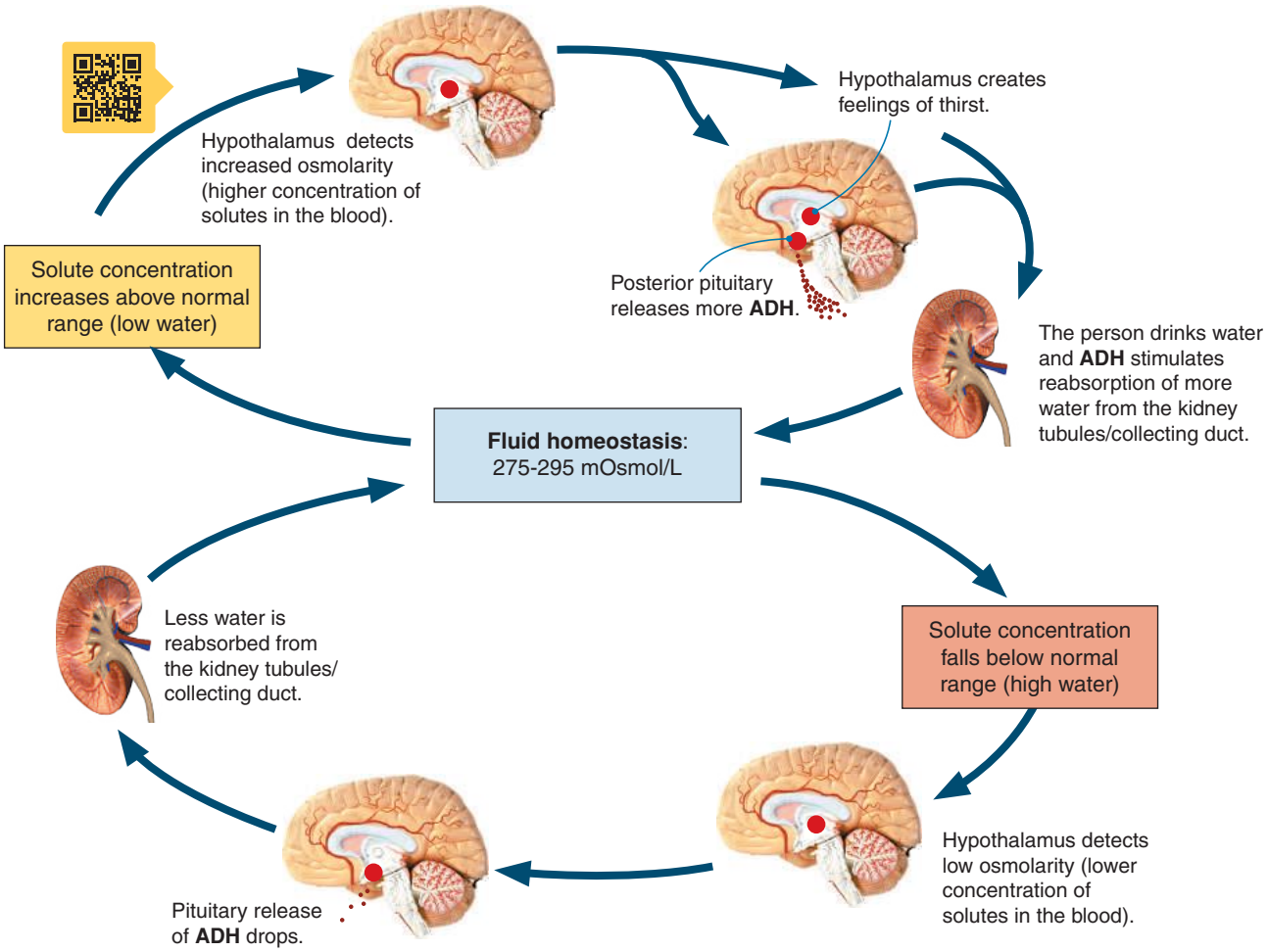
74 ADH and Water Balance

Key Idea: Antidiuretic hormone (ADH) helps maintain water balance by regulating water absorption by the kidneys.

The body regulates fluid balance in response to how much water is gained or lost. One mechanism by which fluid balance is maintained is by varying the volume of water reabsorbed by the kidneys and so also the volume and concentration of urine. This involves a hormone called **antidiuretic hormone** (ADH). Osmoreceptors in the hypothalamus monitor blood osmolarity (solute concentration) and send messages to the pituitary gland, which regulates the amount of ADH released. ADH promotes the reabsorption of water from the kidney tubules and collecting ducts, regulating urine volume.



1. What effect does ADH have on the kidneys? _____

_____

2. (a) What effect would the reabsorption of less water into the nephron tubules would have? _____

_____

(b) What effect would this have on urine concentration? _____

3. Predict whether a high fluid intake would increase or decrease ADH production: _____

4. A high blood osmolarity would be associated with high blood volume / low blood volume (delete incorrect answer)

5. (a) Diabetes insipidus is a type of diabetes caused by the a lack of ADH. Based on what you know about the role of ADH in kidney function, describe the symptoms of this disease:

_____

_____

(b) How would diabetes insipidus be treated? _____

_____

_____

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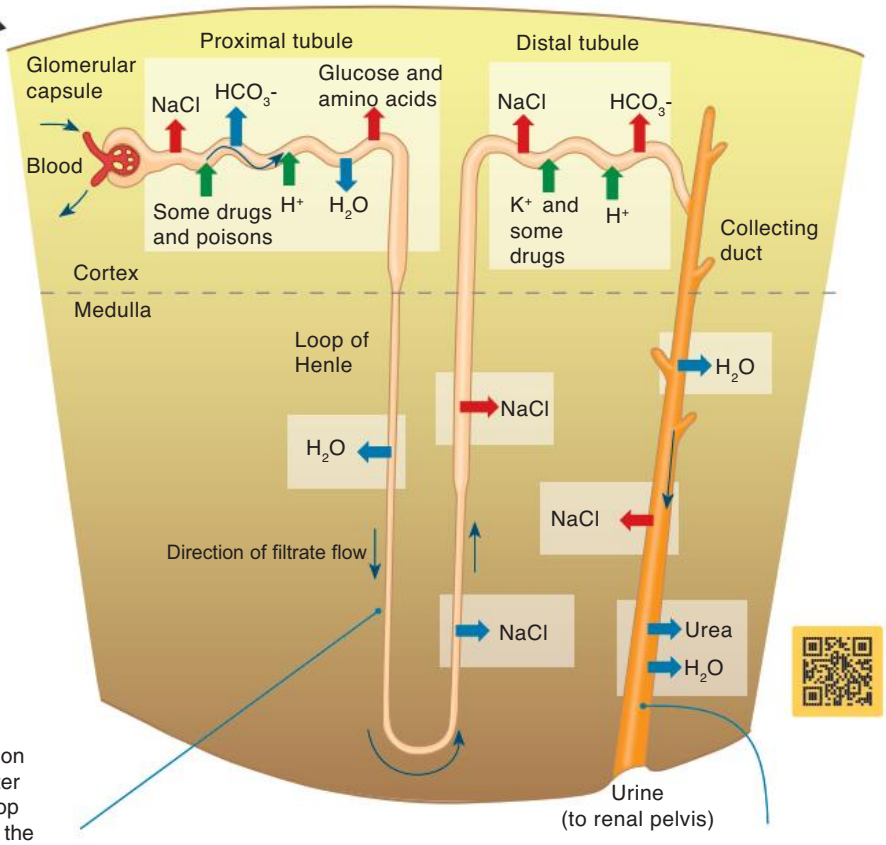
Water and solute reabsorption in the kidney nephron

Urine formation begins by ultrafiltration of the blood, as fluid is forced through the capillaries of the glomerulus, forming a filtrate similar to blood but lacking cells and proteins. The filtrate is then modified by secretion and reabsorption to add or remove substances (e.g. ions). The processes involved in urine formation are summarized below for each region of the nephron (glomerulus, proximal convoluted tubule, loop of Henle, and distal convoluted tubule), and the collecting duct. The loop of Henle acts as a **countercurrent multiplier**, establishing and increasing the salt gradient through the medullary region. This is possible because the descending loop is freely permeable to water but the ascending loop is not.

Filtrate
- H_2O
- Salts (NaCl, etc.)
- HCO_3- (bicarbonate)
- H^+
- Urea
- Glucose; amino acids
- Some drugs

Reabsorption
- Active transport
- Passive transport

Secretion
(active transport)



The thick ascending limb of the loop of Henle pumps out sodium and chloride ions from the filtrate. This produces a high solute concentration in the interstitial space. This in turns draws water by osmosis from the descending limb of the loop Henle into the interstitial space. The water and the ions are transported away by the capillaries. The countercurrent flow within the descending and ascending limbs multiplies the osmotic gradient between the tubular fluid and the interstitial space.

Reabsorption of a small amount of urea from the urine helps to maintain the osmotic gradient for the removal of water.

6. (a) What is the purpose of the salt gradient in the kidney? _____

_____

_____

(b) How is this salt gradient produced? _____

_____

_____

_____

7. (a) The kidneys of desert mammals are adapted to conserve water. One of these adaptations is in the length of the loop of Henle. Would a desert mammal have a longer or shorter loop of Henle that a non-desert adapted mammal?

_____

(b) Explain why: _____

_____

_____

8. Where in the nephron is water reabsorbed? _____

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75 Chapter Review: Did You Get It?

1. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

ADH .....

homeostasis .....

insulin .....

negative feedback .....

positive feedback .....

thermoregulation .....

A A destabilising mechanism in which the output of the system causes an escalation in the initial response.

B A hormone involved in regulating the amount water absorbed by the kidneys and the concentration of the urine produced (acronym).

C The regulation of body temperature.

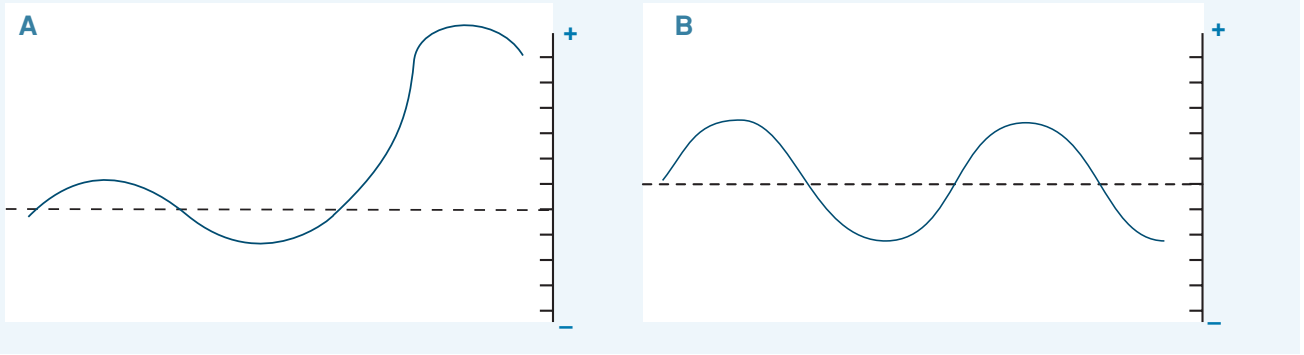
D The hormone that lowers blood glucose by promoting the uptake of glucose by the body's cells.

E Regulation of the internal environment to maintain a stable, constant condition.

F A mechanism in which the output of a system acts to oppose changes to the input of the system. The net effect is to stabilise the system and dampen fluctuations.

2. Using the words *receptor*, *effector*, and *control centre* explain how the body maintains homeostasis:

3. Test your knowledge about feedback mechanisms by studying the two graphs below, and answering the questions about them. In your answers, use biological terms appropriately to show your understanding.



A

(a) Type of feedback mechanism: _____

(b) Mode of action: _____

(c) Biological examples of this mechanism:

B

(d) Type of feedback mechanism: _____

(e) Mode of action: _____

(f) Biological examples of this mechanism:

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76 Synoptic Question: Unit 1, Area of Study 2

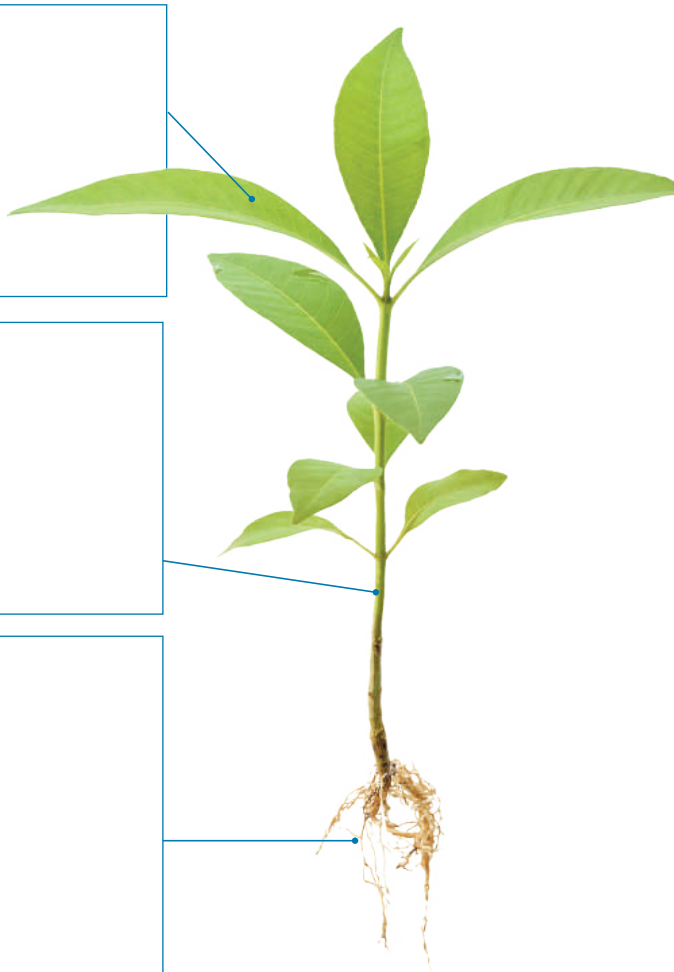
1. Describe the structure of the digestive system with reference to its cells, tissues, and organs. Comment on how negative feedback regulates stomach (gastric) activity.

2. In each of the regions shown below use the spaces to describe how the cells of a plant are specialised for the uptake, transport and loss of water. Drawings may help your description.

Leaves

Stems

Roots



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3. Homeostasis refers to the (relatively) constant physiological state of the body despite fluctuations in the external environment. Using the control of blood glucose as an example, discuss why it is important that animals maintain a constant internal environment. You may draw diagrams and use extra paper if needed. Your answer should include:
    - The components of the control system involved
    - The role of hormones and negative feedback in maintaining blood glucose levels
    - How disease can disrupt blood glucose homeostasis

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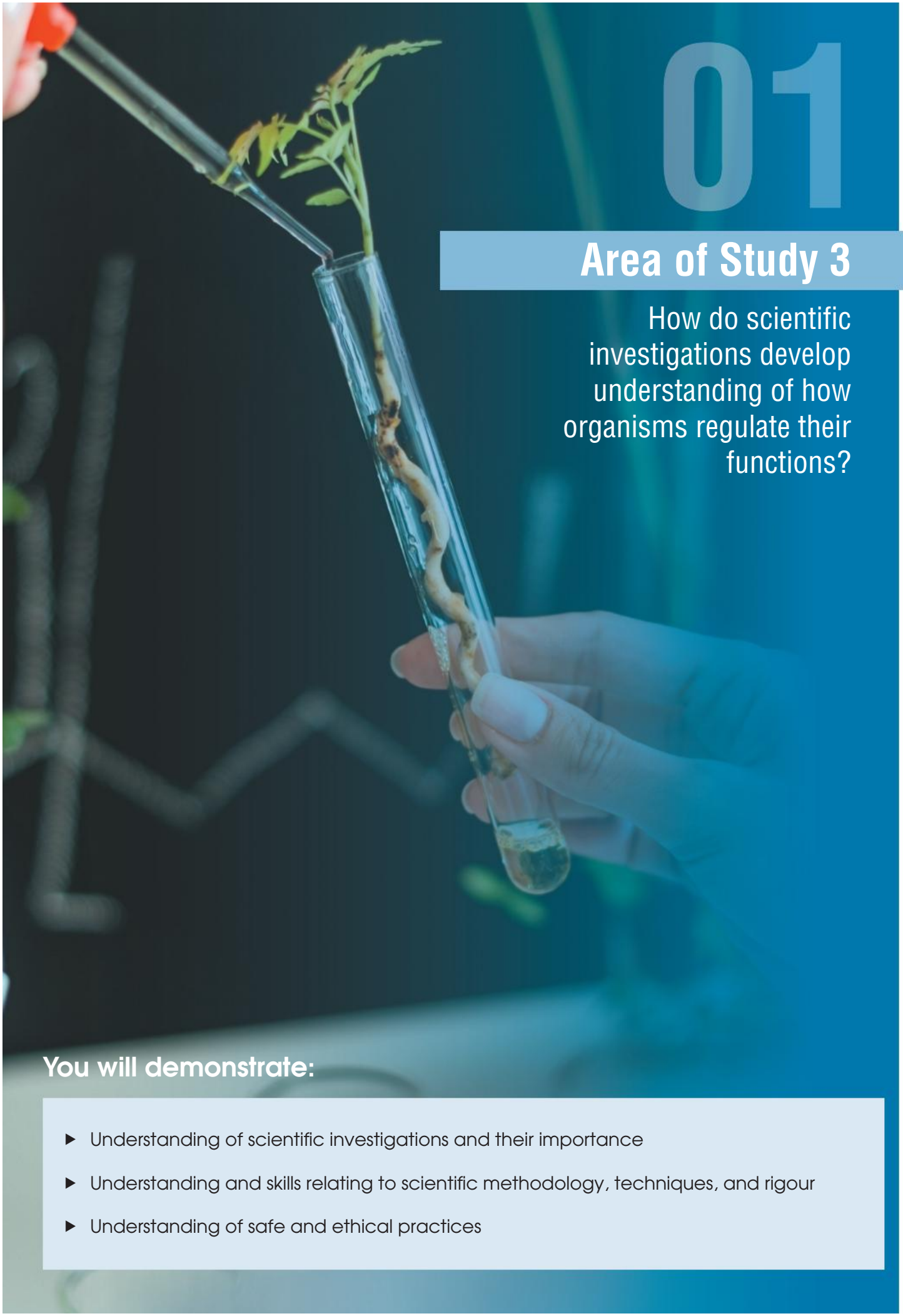


01

Area of Study 3

How do scientific investigations develop understanding of how organisms regulate their functions?

You will demonstrate:

- Understanding of scientific investigations and their importance
- Understanding and skills relating to scientific methodology, techniques, and rigour
- Understanding of safe and ethical practices

CHAPTER 6

Investigating Organism Function

Key terms
accuracy
aim
citation
controlled experiment
correlational study
hypothesis
model
precision
prediction
qualitative data
quantitative data
repeatability
reproducibility
simulation
theory
validity

Background to Area of Study 3

This Area of Study requires you to adapt or design and then conduct a scientific investigation related to the function and/or regulation of cells or systems in living organisms. You must use the data you have generated to draw conclusions related to your research question, and then communicate your findings in a scientific way. The activities in this chapter provide you with support for the skills you will need. A concluding activity provides a template for your investigation, which you may find useful.

Investigation design

Key skills and knowledge

Activity number

- ☐ 1 Identify your research question and describe the biological science concepts specific to it, including any important terms. Describe the type of investigation you plan to do, e.g. controlled experiment, classification and identification, correlational study, field study, simulation, or model. Will the primary data be qualitative or quantitative? **77**
- ☐ 2 Describe the scientific methods relevant to your investigation, including the techniques you will use to generate primary data and its relevance to the investigation. **77**
- ☐ 3 Critically evaluate the validity of your investigation (did it measure what it set out to measure). Validity incorporates the accuracy and precision of your measurements, as well as the reproducibility if there is more than one investigator or set of equipment or if the measurements took place in different locations and/or at different times. **77**
- ☐ 4 Acknowledge and adhere to any health, safety, and ethical guidelines relevant to your investigation, whether it is in the laboratory or in the field. **77**



Scientific evidence

Key skills and knowledge

- ☐ 5 Understand the difference between an aim, a hypothesis, a model, a theory, and a law. You will collect data with an experimental aim in mind to test the predictions or a hypothesis. You may choose to base your investigation on existing models. **78**
- ☐ 6 Recall the characteristics of primary data and demonstrate skills in organising, analysing, and evaluating primary data to identify patterns and relationships. You should be aware of (and acknowledge) any sources of error. **78**
- ☐ 7 Use a logbook to collect your data, including all ideas, notes, schematics, and changes to methodology that may help you in analysing and evaluating your data. **78**
- ☐ 8 Acknowledge the limitations of your investigation, including those relevant to the type of investigation and the methods used to collect and analyse the data. Time and resources are common limitations. Comment on how these made a difference to your investigation and how they affected the possible conclusions you were able to make. **78**

Science communication

Key skills and knowledge

- ☐ 9 Use standard conventions of report writing to communicate the findings of your investigation. Whatever format you choose for your report (e.g. scientific poster, article, practical report, oral presentation, or slideshow) you should use correct scientific terminology and representations, and standard abbreviations and units of measurement. **79**
- ☐ 10 Select ways to present your key findings that are appropriate to the design of the investigation and the type of data. Comment on the strengths of your work, as well as how you avoided or resolved problems. Your teacher will also expect you to have considered any potential ethical issues associated with your research. Discuss the implications of your findings. Be tentative about your claims. At this level, it is likely that your investigation can only support (or not) an existing theory or model. **79 80**

77 Investigation Design

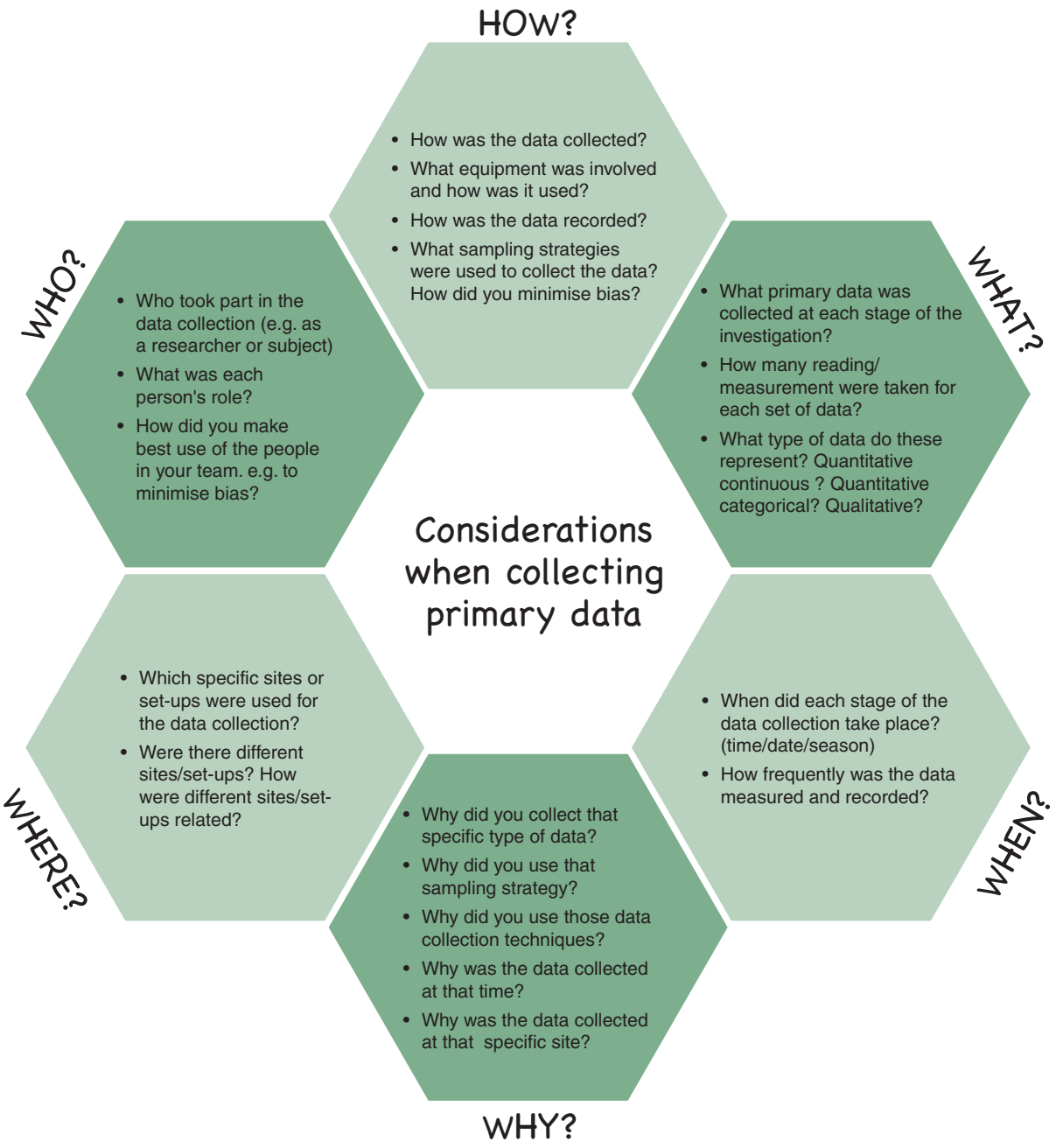
Key Idea: A sound design that minimises bias and systematic error is necessary to produce a valid investigation.

During the VCE course you will investigate how organisms are able to regulate their functions to enhance their survival. To achieve this, you will need to adapt (change) or design an appropriate investigation to generate primary data, then draw conclusions from the data it generates. Designing a good scientific investigation requires careful planning before you begin. A failure to plan can mean that your investigation does not provide data that is accurate and reliable enough to draw valid conclusions. The diagram below provides some points to think about when collecting your data, but check back to the first chapter on key science skills to help you plan and carry out your investigation too.

Laboratory experiments

Field work

Surveys and questionnaires



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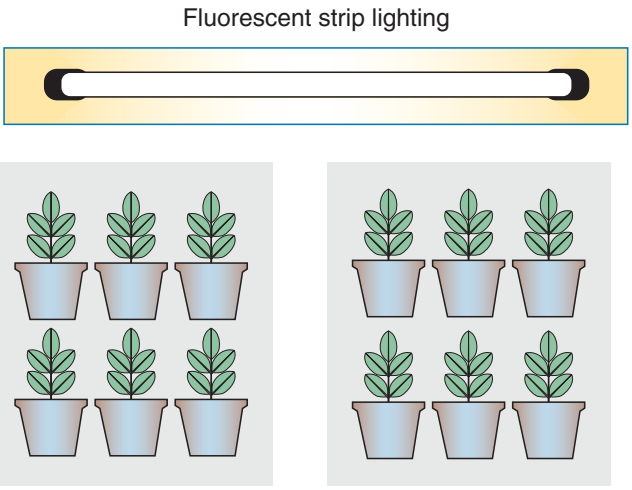
- When designing investigations, there are many factors you need to consider. The sort of data you collect (qualitative or quantitative) will influence your design, methodology, and analysis. You need to consider the investigation variables (dependent, independent, and controlled), and include any assumptions you are making.
- This page outlines a basic design to investigate the effect of pH on the growth of a plant species adapted to living in a bog. It is not a full methodology, but gives you some points to consider when designing your own investigation.

*Some students designed a controlled experiment to test the effect of pH on plant growth. They used a **schematic diagram** (below) to show the setup of their investigation. Schematic diagrams are a useful way of communicating information clearly and concisely, especially when a written explanation could be confusing. Consider using a schematic diagram to show your experimental set up, or to show how your apparatus is set up.*



Notes on preparation and data collection

- 60 seeds were germinated on damp blotting paper. Of these, 24 in a similar stage of germination (10 mm shoot) were chosen for the experiment.
- Each seedling was weighed to the nearest 0.1 g before planting into each of the 24 test pots.
- All treatments were arranged on a lab bench in the centre of an internal lab (no windows).
- Growth rate per day was estimated from the total wet weight of each plant at the end of 20 days.

Two students noticed that plant species A grew in large numbers in a boggy area of land near their school. They tested the soil pH in the area and found it to be quite low (around pH 5). Garden soil was about pH 6.5-7.0.

Experiment

The students designed an experiment to test the prediction that the plants would grow best at pH 5. The basic design is described but it is not intended to be a full methodology.

Control of variables

Fixed (controlled) variables: These are controlled and the same across all treatments.

- Lighting regime (*quantity and quality*)
- Age and history of plants
- Type and volume of soil
- Pot size and type (*dimensions, material*)
- Watering regime (*volume per day, frequency*)

Dependent variable: This is the biological response.

- Plant growth rate (g /day) calculated from wet weight of entire plants (washed and blotted) after 20 days

Independent variable: This is the factor that is being manipulated in the experiment

- pH of the water provided to the plants

Control: In this experiment, one treatment with the assumed ideal pH for plant growth (pH 7) serves as the control. For other experimental designs, the control is the treatment that lacks the variable of interest.

Other variables: Factors that cannot be controlled.

- Genetic variation between plants (uncontrollable but assessed by having six plants per treatment)
- Temperature (all plants received the same room temperature regime but this was not controlled)

Assumptions

Features of the experiment assumed to be true but were not (or could not be) tested.

- A pH of 7 is a good indicator of the ideal growth pH for most non-acid adapted plants.
- All plants are essentially no different to each other in their growth response at different pH levels.
- The soil mix, light quality and quantity, and temperature are adequate for healthy continued growth.
- Watering volume is adequate. This could be tested with a trial experiment beforehand.

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Sample size

Sample size is the number of individual samples measured or observations made in a survey or experiment. Statistically it is represented by the letter *n*. In general, the larger the sample size, the more likely it is that your data will provide an accurate reflection of what you are trying to measure or test. An easy way to increase the validity of your data is to increase sample size. Sample size is not the same as replication, which refers to running complete duplicates of your investigation at the same time.

Deciding on the sample size depends on several factors:

- How much time is available? Is your data collection restricted to a certain time period or season?
- Do you have the resources available to carry out the measurements? This includes both equipment and people.
- How are you collecting the data? Data can be collected continually using a data logger, but if it is collected manually, your design must accommodate taking fewer measurements.
- How much will your sampling cost? Your budget may limit how many samples you can take. You may only be able to take one field trip, or buy reagents to analyse 10 samples.

Yohan euan o4

The experiment above is investigating the effects of nutrient level on plant growth. The sample size is 5 (n = 5), there are three treatments (three nutrient levels) and four replicates (12 pots in all; not all are visible). The plot is randomised. Sample size should be large enough to provide reliable data but will be limited by the time and resources available.

Qualitative and quantitative data: What's the difference?

The site had still, black murky water with some boggy hummocks. Secchi depth was 0.3 m, water pH = 5.0, water depth 0.5-1.2 m, current velocity 0.2 cm/s. Plant species A made up 75% of the vegetation present. The site area was 40% vegetation and 60% open water.

QUALITATIVE DATA	QUANTITATIVE DATA
• Deals with descriptions • Details can be observed but not measured • Examples include; colour (e.g. eye colour), smell (pleasant/unpleasant), taste (sweet, sour, bitter), texture (rough or smooth), or sex (male, female).	• Deals with numbers (numerical values) • Data can be measured • Examples include; length, weight, speed, time, temperature, sound level, cost, etc.
Ways to collect qualitative data: • Observations where the data collected is non-numerical (e.g. recording behaviour) • Surveys and questionnaires with open ended questions • Interviews • Focus groups	Ways to collect quantitative data: • Experiments and investigations • Observations where the data collected is numerical (e.g. the number of cars driving past a school in 10 minutes) • Surveys and questionnaires with closed end questions

1. The description of the sampling site in this investigation contains qualitative and quantitative information. In the space below categorise the information into qualitative and quantitative data:

2. Refer back to the experimental set up on the opposite page. In the experiment, the pots were arranged on a bench in the lab. In the space below, show how you might organise the pots to maximise the collection of unbiased data:

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Types of investigations

Scientific investigations take many forms. Selecting an appropriate investigation type and devising a solid methodology is critical to answering the question or hypothesis you have posed. Some common investigation types are described below.

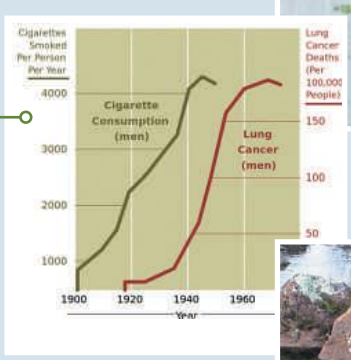
You may find it useful to make a glossary or reference vocabulary to define specific terms you will be using in your investigation. This helps focus your research terms. You can use the glossary at the back of this book to help you with general terms, but you will probably need to add words specific to your investigation too.

Classification & identification: Identifying and counting the organisms present in an ecosystem can be used to identify new species or new distributions, find out about ecosystem composition, monitor ecosystems for change, and monitor the health of the environment, e.g. how does the presence of a gold mine affect ecosystem diversity?

Stephen Moore

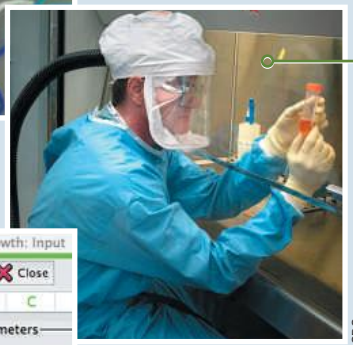
Controlled experiment: In a controlled experiment, only one variable in the experiment is altered so its effect on another variable can be measured (a fair test). For example, the effect of temperature on plant growth can be measured by having the plants at different temperatures but leaving all other conditions the same (e.g. light levels and watering frequency).

Correlational study: Correlation studies determine if there is a relationship between two variables. Correlation studies often do not involve carrying out an experiment. A relationship may be studied by analysing data instead, e.g. does cigarette smoking increase the chances of developing lung cancer?



Fieldwork: Fieldwork allows you to carry out an investigation within a particular environment (often not controlled). For example, a study to analyse the effect of water pH on the composition of the invertebrate community in a stream. Data is usually collected from both the living organisms and their physical environment as a way to evaluate uncontrolled variables.

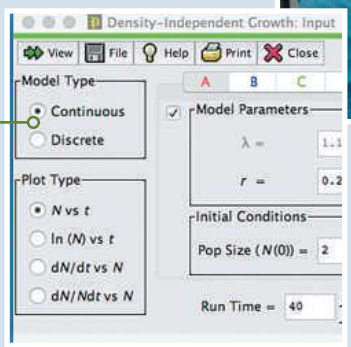
Modelling: Models can be used to visualise processes or structures, or to understand how complex systems work. Models range in complexity from very simple models (e.g. using pipe-cleaners to model how amino acid composition influences protein folding) to very sophisticated mathematical models (e.g. using climate models to predict changes in global temperatures).



CDC

Product, process, or system development: Design processes can be used to develop new processes, systems, or products, e.g. a new vaccine for Covid-19. Design processes can also be used to refine existing products and systems to make them better, e.g. improved electric vehicle technology to make electric cars more efficient and less expensive.

Simulation: Simulations mimic a process, environment, or situation you cannot study easily in real life. For example, you cannot investigate the effect of rainfall on a real population of kangaroos in the classroom. However, you can manipulate the variables in a computer simulation to see how a population would respond hypothetically.



ISBN: 978-1-98-856636-8

78 Scientific Evidence

Key Idea: Data you collect yourself during your scientific investigation is called primary data.

The quality of your analysis will depend on the quality of the data you collect. When setting up your investigation you will be collecting primary data, i.e. first-hand data you have collected yourself. During your investigation you may use (and collate or organise) secondary data (data that other people have collected) to provide background to your investigation. Some features of primary and secondary data are provided below.

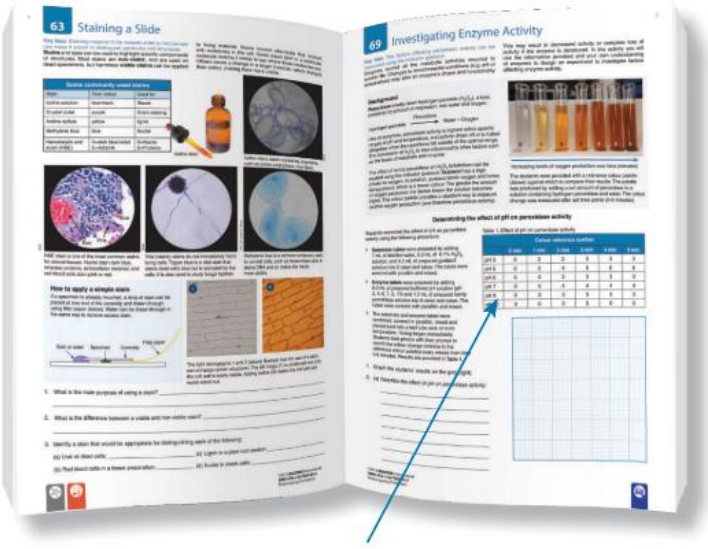
Primary data

Primary data is any data collected directly by researchers. For example, measuring the pH of water samples or recording how many students took the bus to school on a certain day. Primary data can be gathered through questionnaires and surveys, observations, interviews, and experiments. It is important to consider what data you will collect and how you will collect it when you plan your investigation so your analysis can be meaningful. For the purposes of easy analysis, it is best to collect quantitative data where possible.

This student is using a pH meter to collect primary data by measuring the pH of a soil solution. The data will be recorded in a logbook before analysis. Tables and graphs are an excellent way to present primary data, because trends and patterns in the data can be seen more easily. Choosing the correct graph will depend on the type of data collected. For continuous data, histograms, line graphs and scatter plots may all be appropriate. For categorical data, pie charts, kite graphs, or bar or column charts are appropriate. Histograms and bar charts are compared below.

Secondary data

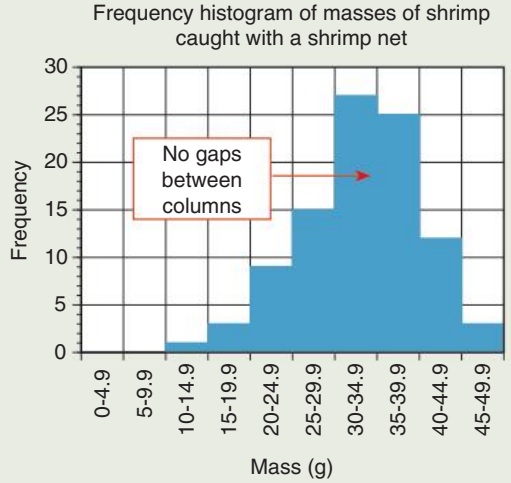
Sometimes you might be asked to analyse secondary data. This is when you are provided with data which has been gathered from studies, surveys, or experiments carried out by other people. You might find secondary data useful for providing background information to your own investigation (*what have other researchers done already?*). You can also use it to compare your findings with another person's (*are my results the similar to or different from the results of other researchers?*).



In this book, the student is being asked to analyse second-hand data (the data is provided) to see how pH affects enzyme activity.

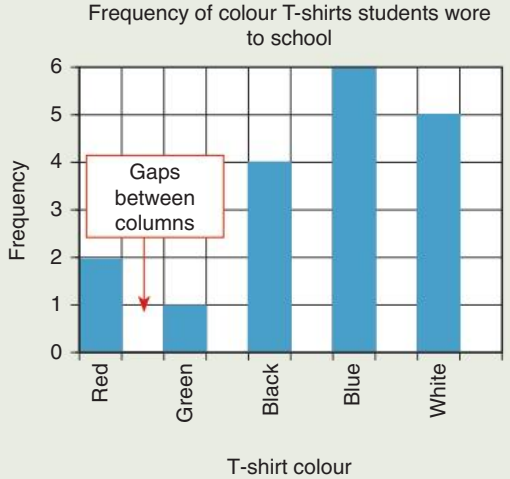
Histograms

A histogram plots counts (frequency) against a continuous variable (a measure). The columns of a histogram touch because the data is continuous and can have part values, so runs from one category to the next. Examples of data you would plot as a histogram include mass, height, or length.



Bar and column graphs

The bars of a bar or column chart do not touch. This is to show that your data is not continuous (it is discrete) and the data has limited values (no part values). Bar graphs are used when your data is recorded as counts. For example, number of puppies in a litter of different dog breeds, number of males and females in a class, and numbers of six insect species found at a sampling site.



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79 Scientific Communication

Key Idea: The findings of your investigation must be communicated in a clear and ordered way, and follow certain rules for scientific communication.

Communicating the findings of your investigation is as important as the research you carried out. Poorly presented information cannot be easily understood, and key findings may not be communicated to your audience. No matter which presentation format you use, it is important to remember all of your ideas must be clearly identified and relevant to your investigation. There are certain rules you must follow for scientific writing. These are explained on the scientific poster below, but they apply to all scientific writing.

THE GOAL: Communicate the findings of your investigation in a clear, concise, and accurate way

YOUR RESPONSIBILITY

To represent the science and the findings of your investigation accurately.

WHAT TO AVOID

- Jargon
- Over-explaining
- Misleading headings
- Misrepresenting the findings

WHAT TO INCLUDE

- Appropriate scientific terms
- Clear, descriptive language
- Factual statements
- Unbiased analysis

General considerations in communication

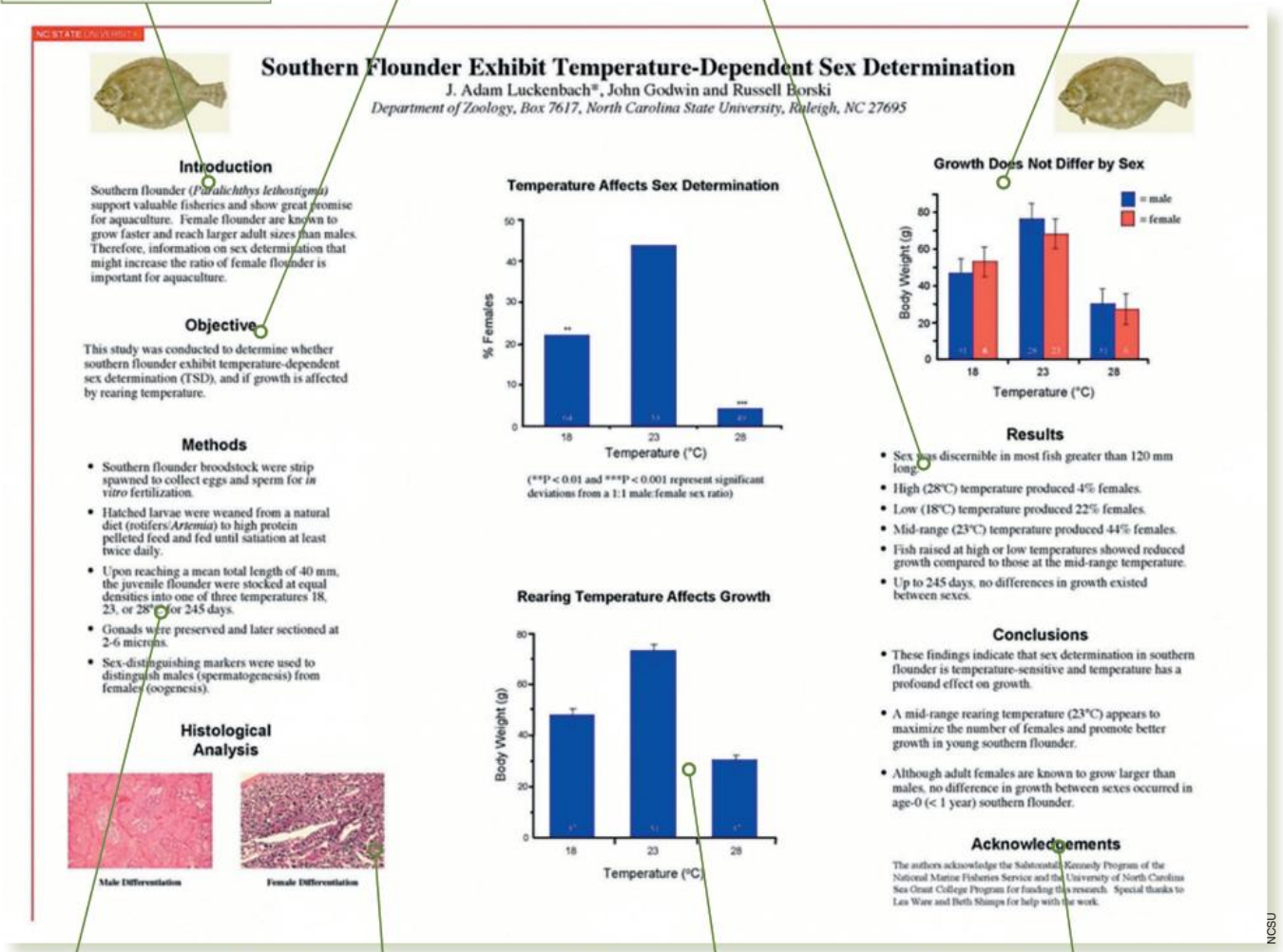
The poster below illustrates some of the basic features of a good piece of scientific communication. Formats can vary considerably, often depending on the ideas or work being reported (literature review, personal response, formal lab report, or field report).

Use the correct scientific terminology but avoid too much jargon as it may confuse your audience!

What is the report's main focus (what idea or concept are you trying to explain)?

Check your spelling and grammar. Is your argument presented logically? Is the flow information easily followed?

Clear presentations let the data tell the story without a lot of text.



Southern Flounder Exhibit Temperature-Dependent Sex Determination

J. Adam Luckenbach*, John Godwin and Russell Borski

Department of Zoology, Box 7617, North Carolina State University, Raleigh, NC 27695

Introduction

Southern flounder (*Paralichthys lethostigma*) support valuable fisheries and show great promise for aquaculture. Female flounder are known to grow faster and reach larger adult sizes than males. Therefore, information on sex determination that might increase the ratio of female flounder is important for aquaculture.

Objective

This study was conducted to determine whether southern flounder exhibit temperature-dependent sex determination (TSD), and if growth is affected by rearing temperature.

Methods

- Southern flounder broodstock were strip spawned to collect eggs and sperm for *in vitro* fertilization.
- Hatched larvae were weaned from a natural diet (rotifers/*Artemia*) to high protein pelleted feed and fed until satiation at least twice daily.
- Upon reaching a mean total length of 40 mm, the juvenile flounder were stocked at equal densities into one of three temperatures 18, 23, or 28°C for 245 days.
- Gonads were preserved and later sectioned at 2-6 microns.
- Sex-distinguishing markers were used to distinguish males (spermatogenesis) from females (oogenesis).

Histological Analysis

Male Differentiation

Female Differentiation

Temperature Affects Sex Determination

% Females

Temperature (°C)

(**P < 0.01 and ***P < 0.001 represent significant deviations from a 1:1 male:female sex ratio)

Rearing Temperature Affects Growth

Body Weight (g)

Temperature (°C)

Growth Does Not Differ by Sex

Body Weight (g)

= male

= female

Temperature (°C)

Results

- Sex was discernible in most fish greater than 120 mm long.
- High (28°C) temperature produced 4% females.
- Low (18°C) temperature produced 22% females.
- Mid-range (23°C) temperature produced 44% females.
- Fish raised at high or low temperatures showed reduced growth compared to those at the mid-range temperature.
- Up to 245 days, no differences in growth existed between sexes.

Conclusions

- These findings indicate that sex determination in southern flounder is temperature-sensitive and temperature has a profound effect on growth.
- A mid-range rearing temperature (23°C) appears to maximize the number of females and promote better growth in young southern flounder.
- Although adult females are known to grow larger than males, no difference in growth between sexes occurred in age-0 (< 1 year) southern flounder.

Acknowledgements

The authors acknowledge the Substantial Kennedy Program of the National Marine Fisheries Service and the University of North Carolina Sea Grant College Program for funding this research. Special thanks to Lea Ware and Beth Shimps for help with the work.

NCSU

Use correct standard abbreviations and units of measure.

Photographs inform without too much text and also add visual interest.

Present findings concisely but accurately. Tables and graphs provide a space-efficient summary.

Acknowledging and referencing all sources is important.

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Why is referencing important?

Referencing (listing your information sources) is an important part of communicating your findings. It lets your audience distinguish your ideas and research from those of someone else. It also shows you have carried out background research and assessed and evaluated it in relation to your own investigation. When used properly, it shows you have understanding of your topic.

You must acknowledge the source of any information to avoid plagiarism (taking someone's work or ideas and passing them off as your own). Penalties are often put in place if someone has been found to be using another's work without acknowledging it. You may lose marks or your work may not be accepted at all.

There are many information sources you can use to investigate a topic. These include books, journal articles, newspapers, websites, and talking directly to someone who has expertise in the area you are investigating (expert opinion). Regardless of how you get the information, the sources must be properly acknowledged.

Referencing protocols

Scientific reporting requires correct acknowledgement of the work of others, so you must provide a list of material you have used during your investigation. This can be done through a reference list or through a bibliography.

The two are compared in the table right. For scientific reporting, a reference list is generally preferred. Different information sources need to be referenced in a slightly different way, but in general they all provide information about the author, when the information was published, the name of the publication, and a URL if applicable. Examples are shown below. There is further information on referencing online resources in Chapter 12.

BIBLIOGRAPHY	REFERENCE LIST
Includes all sources of information you used, even those you may not have mentioned in your text.	A detailed list of the sources of information that you have cited (made reference to) in the report.
Provides background information or suggestions for further reading.	Each reference in the reference list must be used and correctly cited in the text.
Alphabetical listing at the end of the communication.	Numerical or alphabetical listing at the end of the communication.

The APA style is often preferred for formatting references. Check with your teacher on the recommended format for reference lists. Always be consistent in your formatting!

Citing and referencing correctly

Sources of information should be cited directly after the sourced information occurs in the text. Unlike a bibliography, a reference list offers the flexibility to order the reference list alphabetically or numerically, in order of appearance. Numeric citations are given by a superscript numbers ([1]) after each new reference, and the numbers appear in order in the reference list. Citations for an alphabetical reference list state the author(s) and year in brackets after each reference. The methods are compared below for the same sources.

ALPHABETICAL ORGANISATION

Citation *(how it appears in the text)*

The sugar and squirrel glider are remarkably similar in appearance (Smith 1973; Alexander 1981) and have interbred in captivity (Fleay 1947)... The sugar glider is smaller than the squirrel glider (95-160 g and 200-260 g respectively; Suckling 1995)...

When citing sources with more than three authors within your text, use the first author's name followed by et al. instead of writing all their names.

Reference list *(how it appears at the end of the communication)*

Alexander, J. S. A. 1981. The status of the squirrel glider, *Petaurus norfolcensis* (Marsupialia: Petauridae) in Victoria. Hons thesis. La Trobe University, Vic.

Fleay, D. 1947. The squirrel glider. Victorian Naturalist 70: 208-210.

Smith, M.J. 1973. *Petaurus breviceps*. Mammalian species 30: 1-5.

Suckling, G. C. 1995. Squirrel Glider. Page 140 in The Mammals of Australia, edited by R. Strahan. Angus and Robertson Publishers, Sydney, NSW.

NUMERIC ORGANISATION

Citation *(how it appears in the text)*

The sugar and squirrel glider are remarkably similar in appearance [1,2] and have interbred in captivity[3]... The sugar glider is smaller than the squirrel glider (95-160 g and 200-260 g respectively [4])...

Reference list *(how it appears at the end of the communication)*

1. Smith, M.J. 1973. *Petaurus breviceps*. Mammalian species 30: 1-5.
2. Alexander, J. S. A. 1981. The status of the squirrel glider, *Petaurus norfolcensis* (Marsupialia: Petauridae) in Victoria. Hons thesis. La Trobe University, Vic.
3. Fleay, D. 1947. The squirrel glider. Victorian Naturalist 70: 208-210.
4. Suckling, G. C. 1995. Squirrel Glider. Page 140 in The Mammals of Australia, edited by R. Strahan. Angus and Robertson Publishers, Sydney, NSW.

Source text, please see *Photocredits and Acknowledgements*, page 284

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80 A Template for your Investigation

Assessment task, Outcome 3: *Scientific investigation of how organisms regulate their functions*

Use the spaces provided below to create a bullet-point list of important features in each phase of your investigation.

Aim:

What do you want to investigate?
Talk to your teacher about your investigation.
Do you have the equipment and time to do this topic?

Background research:

Prepare well so that you have a good knowledge of the topic before you begin.
Consult the web, journals, textbooks and people with expertise in your topic.

Research hypothesis:

This is a proposed explanation for your observations that is usually stated along with a testable prediction, e.g. if plants need light to photosynthesise, they will grow more vigorously in the light than in the dark.

Design of the investigation and method:

Outline the basic design of your investigation.
Write the method out as a procedure that someone else could follow to get the same results. If your investigation is an experiment, think about sample size and controls. If it is field based, consider sample size and size of your sampling unit (e.g. quadrat size). What type of data will you collect?

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Data collection:

Record your data in a table, logbook, or spreadsheet as you collect it.

Does the data make sense (does it help answer the question you have asked)?

Note any problems with the method, or any changes you made as you worked through the investigation.

Results (data analysis and presentation):

Decide how to present and summarise your results (e.g. table or graph).

Are there any outliers? If so, should you include these in the analysis? Why or why not?

Include measures of variability to help you evaluate the reliability of your data. Will you use a statistical test?

Discussion:

Discuss your findings.

Use key facts from the background information to explain your results (including unexpected ones).

How could your method have been improved?

Conclusion:

Your conclusions summarise how your results support or contradict your hypothesis.

References & acknowledgements:

Include all of your sources of information as a reference list or bibliography. Your teacher will tell you what format to use.

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UNIT

02

How does inheritance affect diversity?

Area of Study 1

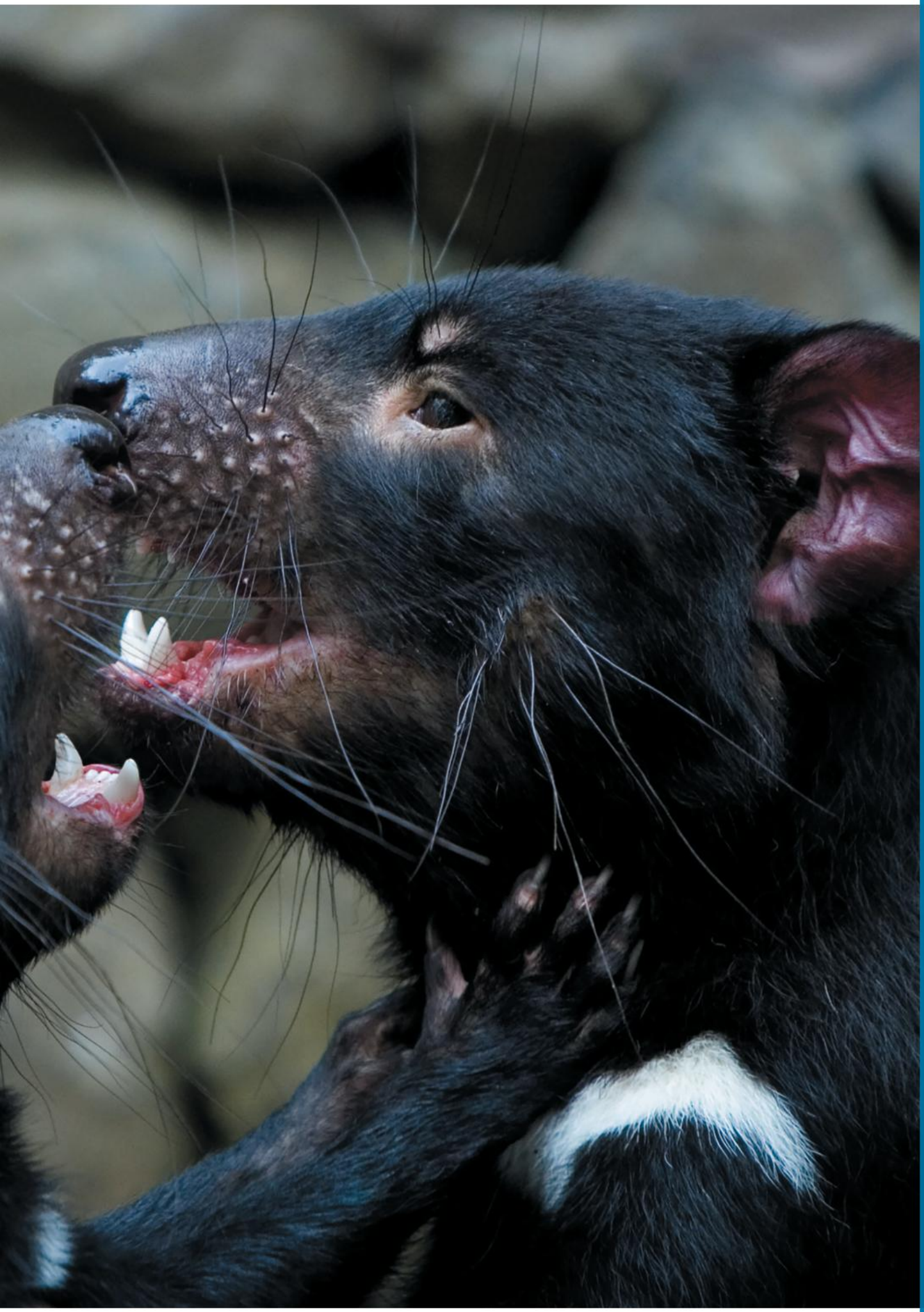
How is inheritance explained?

Area of Study 2

How do inherited adaptations affect diversity?

Area of Study 3

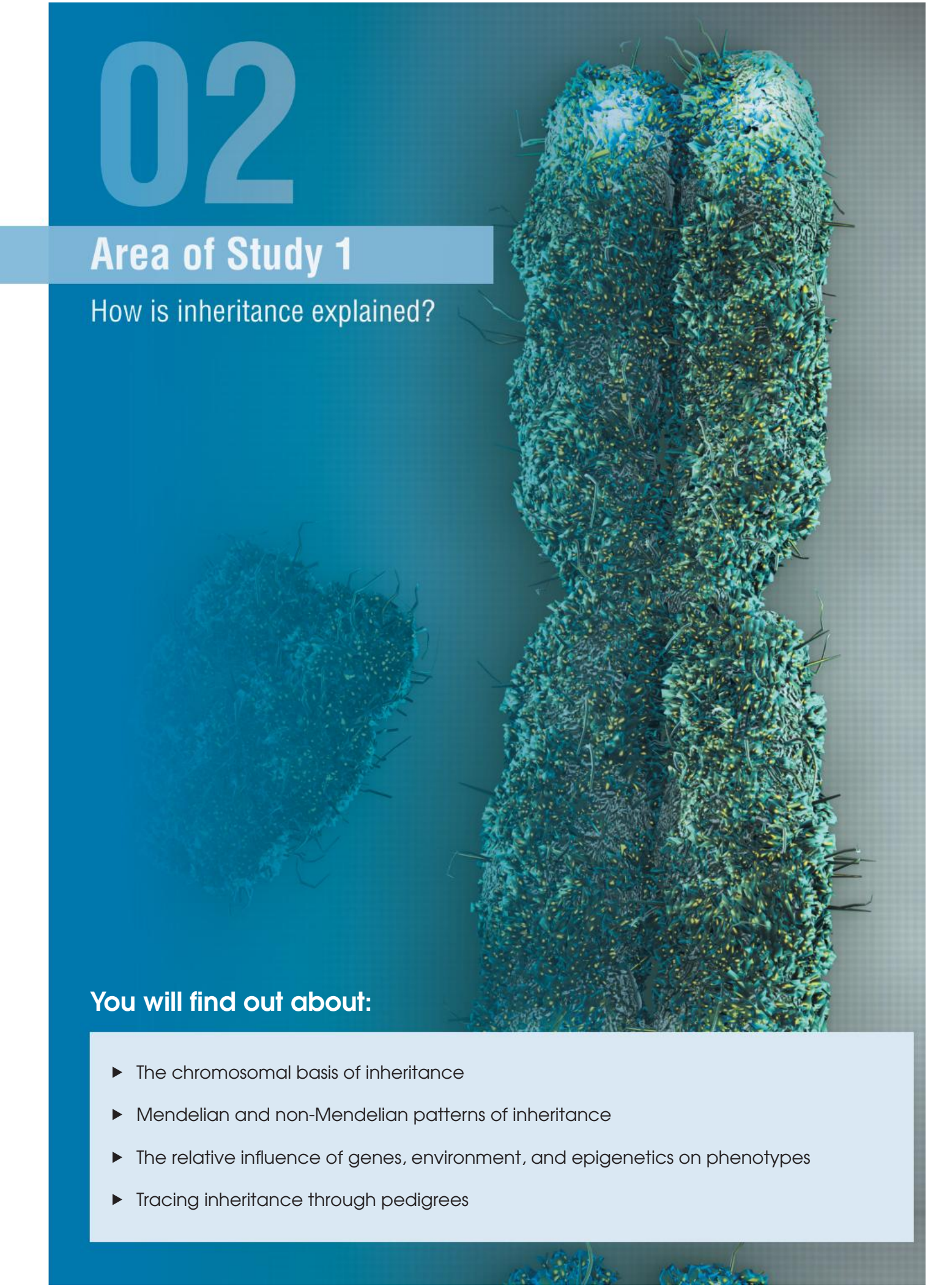
How do humans use science to explore and communicate contemporary bioethical issues?



02

Area of Study 1

How is inheritance explained?



You will find out about:

- The chromosomal basis of inheritance
- Mendelian and non-Mendelian patterns of inheritance
- The relative influence of genes, environment, and epigenetics on phenotypes
- Tracing inheritance through pedigrees

CHAPTER 7

From Chromosomes to Genomes

Key terms

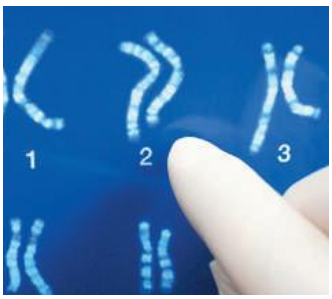
allele
aneuploidy
chomatid
chromatin
chromosome
crossing over
diploid
fertilisation
gamete
gene
genome
haploid
histone
homologous chromosomes
independent assortment
interphase
karyogram
karyotype
locus (pl. loci)
maternal chromosome
meiosis
non-disjunction
paternal chromosome
sexual reproduction
syndrome

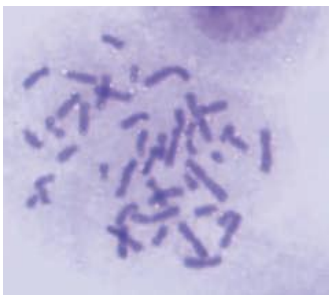
Genes, genomes, and alleles

Key skills and knowledge

Activity number

- ☐ 1 Distinguish between a genome, gene, and allele. State how the genome is measured and describe the variation in genome size between different organisms — 81
- ☐ 2 Describe the basic structure of a replicated chromosome as seen in metaphase of mitosis. Identify the chromatids and the role of the centromere. Explain the role of histone proteins in packaging the DNA in an orderly, highly organised way. — 82
- ☐ 3 Distinguish between autosomes and sex chromosomes. Explain what is meant by a homologous pair of chromosomes. Appreciate that the sex chromosomes are not homologous and explain why. — 82
- ☐ 4 Describe how the number and size of chromosomes and the number of genes they carry varies between different organisms. Recognise that there is no clear relationship between number of chromosomes, number of genes, and organism complexity. — 83





Karyotyping and karyograms

Key skills and knowledge

- ☐ 5 Define the term karyotype. Describe how an individual's complete set of chromosomes can be prepared and displayed in an organised way to produce a karyogram. — 84
- ☐ 6 Explain how aneuploidies can arise when chromosomes fail to separate during meiosis (non-disjunction). Show in a diagram how non-disjunction in meiosis can produce abnormal gametes and lead to an individual having too few or too many chromosomes. — 85
- ☐ 7 Explain how a karyogram can be used to identify chromosomal abnormalities, particularly aneuploidies, e.g. Down syndrome (autosomal trisomy), and Turner and Klinefelter syndromes (sex chromosome aneuploidies). — 84 85
- ☐ 8 TEST Create a karyogram to determine phenotype by matching the size and banding pattern of individual chromosomes. — 86

Meiosis

Key skills and knowledge

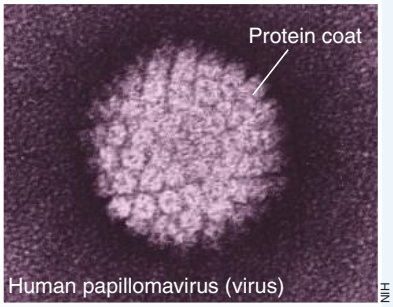
- ☐ 10 Summarise the roles of mitosis and meiosis in the life cycle of sexually reproducing organisms, recognising the role of mitosis in growth and repair and meiosis and fertilisation in producing genetically variable offspring. — 87
- ☐ 11 Explain the significance of the following events in meiosis: — 88 89
  - Crossing over between homologous chromosomes in prophase I of meiosis.
  - Recombination of alleles as a result of crossing over.
  - Independent assortment of homologous pairs in metaphase I.
  - The non-dividing centromere in metaphase I.
- ☐ 12 Explain how the events in meiosis lead to production of haploid gametes (or haploid spores in plants) from diploid cells. — 88 89
- ☐ 13 PRAC Investigate the key events in meiosis using a simple physical model. — 90

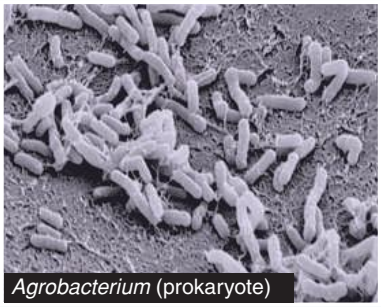
81 Genomes, Genes, and Alleles

Key Idea: A genome is the entire haploid amount of genetic material, including all the genes, of a cell or organism. Eukaryotes can have different versions of a gene (alleles) because they have two copies of each gene.

The **genome** refers to all the genetic material in one haploid set of chromosomes. The genome contains all of the information the organism needs to function and reproduce. Every cell in an individual has a complete copy of the genome. Within the genome are sections of DNA, called **genes**, which code for proteins. Collectively, genes determine what an organism looks like (its traits). Eukaryotes have two copies of each gene (one inherited from each parent), so it is possible for one individual to have two different versions of a gene. These different versions are called **alleles**.

The location and size of the genome varies between organisms





Genome size — Small → Large

Number of genes — Few → Many

The viral genome is contained within the virus's outer protein coat. Viral genomes are typically small and highly variable. They can consist of single stranded or double stranded DNA or RNA and contain only a small number of genes.

The human papillomavirus (HPV) genome is a double stranded circular DNA molecule ~8000 bp long.

In prokaryotes, most of the DNA is located within a single circular chromosome, which makes them haploid (i.e. one allele) for most genes. Many bacteria also have small accessory chromosomes called plasmids, which carry genes for special functions such as antibiotic resistance and substrate metabolism.

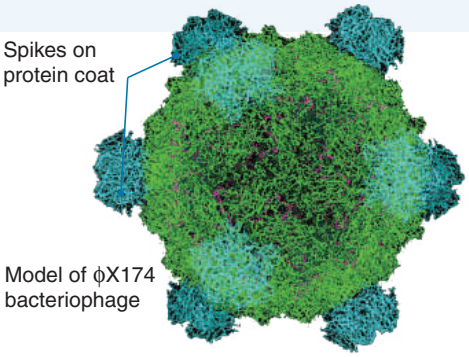
The *Agrobacterium* genome (5.7 Mb long) is unusual. It consists of a circular chromosome, a linear chromosome, and two plasmids. Linear chromosomes are very rare in bacteria.

In eukaryotes, most of the DNA is located inside the cell's nucleus. A small amount resides in the chloroplasts (in plants) and in mitochondria. The DNA is arranged into linear chromosomes and most eukaryotes are diploid, with two sets of chromosomes, one from each parent.

The koala genome is ~3.37 Mb long in 8 chromosomes (the diploid number is 16). This genome size is similar to humans.

Measuring genomes

- Genome size is often expressed as the number of base pairs (bp). The unit most often used to show the size of a genome is the megabase (Mb). Note: 1 megabase = 1 million base pairs.
- The image right shows the ϕX174 bacteriophage, a virus that infects bacterial cells. Its entire genome is only 5375 bp long (0.005375 Mb) and it contains only nine genes, coding for nine different proteins. At least 2000 times this amount of DNA would be found in a single bacterial cell. 500,000 times that quantity would be found in the genome of a single human cell.



1. Define the following terms:

   (a) Genome: _____

   (b) Gene: _____

   (c) Allele: _____

2. Describe the general trend for genome size and gene number for viruses, bacteria, and eukaryotic organisms:

   _____

3. Explain why an individual eukaryote can have different versions of a gene (allele) but viruses and bacteria do not:

   _____

   _____

   _____

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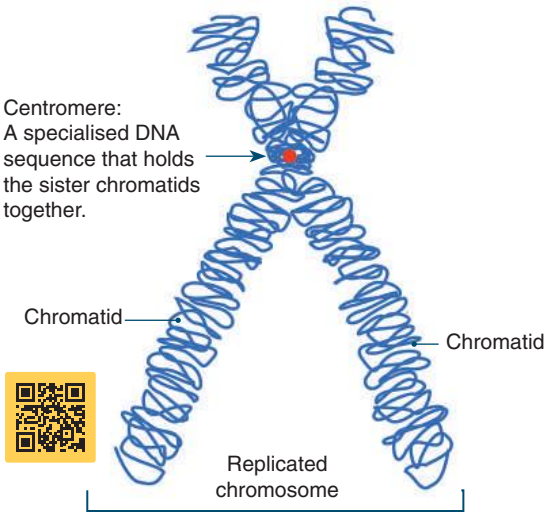
82 The Nature of Chromosomes

Key Idea: Eukaryotes generally have paired chromosomes. Each chromosome contains many genes and each gene may have several versions (alleles) in the population.

Most genetic material (DNA) in eukaryotes is present as chromosomes. In eukaryotes, the chromosomes are located within the cell's nucleus. Sexually reproducing organisms usually have two sets of chromosomes (they are diploid). One set is inherited from each parent at the time of fertilisation. The corresponding chromosomes from each parent form a pair called a **homologous pair** (**homologous chromosomes**). Chromosomes can be classified either as sex chromosomes or autosomes (see below).

Eukaryotic chromosomes

- When the cell is in interphase (between cell divisions) DNA exists as a complex of DNA and histone proteins, called chromatin.
- The DNA is wound around the histones in an organised way (think of beads on a string) so that it fits inside the cell's nucleus.
- During mitosis and meiosis, the chromosomes are remodelled into highly condensed (compact) chromosomes (representation below). These become visible in prophase and remain condensed until the cell divides.
- Humans have 23 pairs of chromosomes.



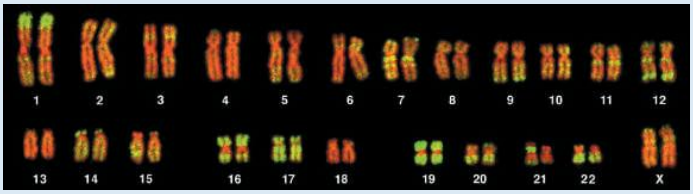
Sex chromosomes and autosomes

Sex chromosomes

- **Sex chromosomes** determine the sex of organisms and the genes they carry are called sex linked.
- Humans have two sex chromosomes (X and Y). Egg cells contain 22 autosomes and an X chromosome. Sperm cells contain 22 autosomes and either an X or Y chromosome. Humans have one pair of sex chromosomes: XX = females. XY = males.
- Sex chromosomes are not homologous. They differ in height, banding pattern, and centromere position. The X chromosome is much larger than the Y chromosome and contains more genes (above right). Genes on the X chromosome that are not present on the Y chromosome will always be expressed in males.

Autosomes

- Most chromosomes are **autosomes** (non-sex chromosomes). Their genes determine most phenotypic characteristics (but not sex).
- Human cells have 22 pairs of autosomes (1-22 below). The pairs are homologous so the chromosomes in each pair have similar heights, banding patterns, and centromere positions. They also carry the same genes, in the same location.



Bolzer et al PLOS (2005) cc 4.0

Karyogram (chromosome picture) of human female 22 - XX

1. Identify what is being described in each of the descriptions below:

   (a) A complex of DNA and protein: _____

   (b) One half of a replicated chromosome: _____

   (c) Chromosomes with the same genes and very similar characteristics: _____

2. Summarise the differences between sex chromosomes and autosomes under the headings below:

   (a) Function:

   i) Autosome: _____

   ii) Sex chromosome: _____

   (b) Are the chromosomes homologous (Yes/No):

   i) Autosomes: _____ ii) Sex chromosomes: _____

   (c) Number/pairs of chromosomes in humans:

   i) Autosome: _____ ii) Sex chromosome: _____

   (d) Are the genes sex linked (Yes/No):

   i) Autosome: _____ ii) Sex chromosome: _____

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What are homologous chromosomes?

The equivalent chromosomes that form a pair are called **homologous chromosomes** (or homologous pair). Homologous chromosomes have the same structural features (e.g. size and banding pattern) and have the same genes at the same position. However, they may have different versions of a gene. The different versions of a gene are called **alleles**. A diploid organism can only carry two alleles for a gene but in the population as a whole there may be more than two alleles for any one gene. This provides more phenotypic variation in the population.

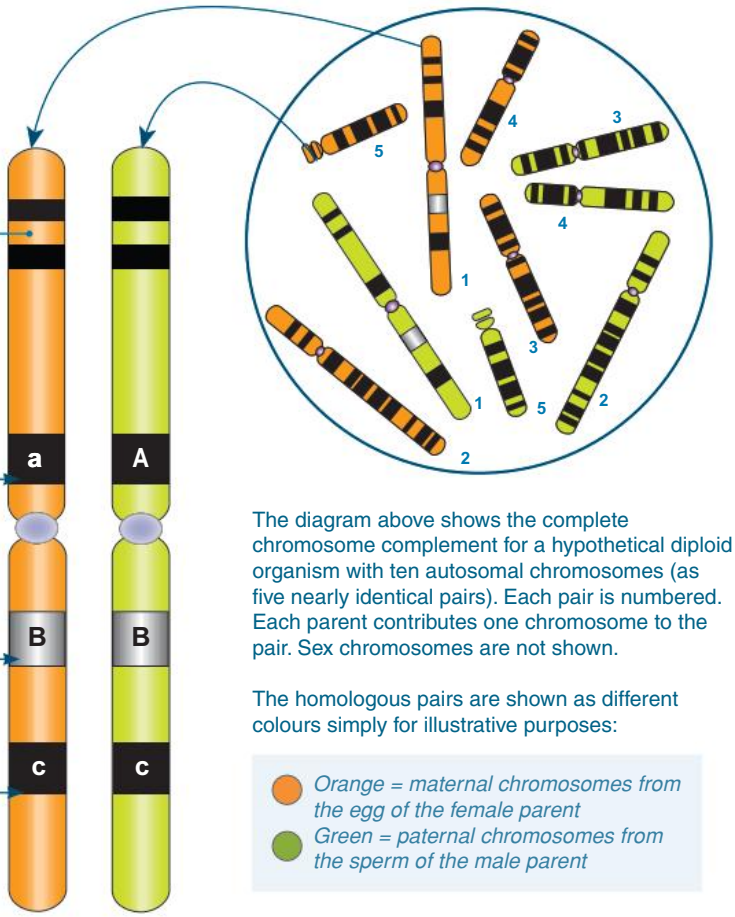
The diagram below shows the position of three different genes on the same chromosome that control three different phenotypic characteristics (A, B and C).

A gene is the unit of heredity. The position of a gene on a particular chromosome is called the **locus** (plural = loci). Genes occupying the same locus on a chromosome code for the same phenotypic character (e.g. hair colour).

Having two different versions (**alleles**) of a gene is called the **heterozygous** condition. Alleles differ by only a few bases. New alleles arise through mutation, usually as a result of copying errors during DNA replication. In this example, there is a dominant allele (A) and a recessive allele (a), although alleles can also be codominant or show incomplete dominance (as you will find out later).

When both chromosomes have identical copies of the dominant allele for a gene, the organism is **homozygous dominant** for that gene.

When both chromosomes have identical copies of the recessive allele for a gene the organism is **homozygous recessive** for that gene.



The diagram above shows the complete chromosome complement for a hypothetical diploid organism with ten autosomal chromosomes (as five nearly identical pairs). Each pair is numbered. Each parent contributes one chromosome to the pair. Sex chromosomes are not shown.

The homologous pairs are shown as different colours simply for illustrative purposes:

- *Orange = maternal chromosomes from the egg of the female parent*
- *Green = paternal chromosomes from the sperm of the male parent*

3. (a) Explain where each chromosome in a homologous pair of chromosomes comes from: _____

_____

_____

(b) Why are the autosomes called homologous? _____

_____

_____

4. Explain how alleles provide phenotypic variation in a population: _____

_____

_____

5. Define the following terms and provide an example from the diagram above to illustrate each definition:

(a) Heterozygous: _____

_____

(b) Homozygous dominant: _____

_____

(c) Homozygous recessive: _____

_____

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83 Species Have Different Chromosome Numbers

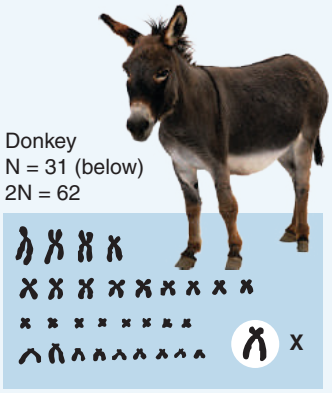
Key Idea: The number and size of chromosomes is highly variable between species. The number of chromosomes does not reflect the "genetic complexity" of an organism.

Every eukaryotic species has at least two chromosomes. The number of chromosomes is generally fixed for a given species (but a few have variable numbers). The number of chromosomes does not reflect how genetically "complex" a species is. For example, the largest number of chromosomes known in a eukaryote is found in a primitive plant called the adder's tongue fern, which has 631 pairs. Compare this with a gorilla (a complex organism), which has far fewer chromosomes (24 pairs of chromosomes).

Chromosome numbers for different species

The number of chromosomes between species is extremely variable. Even closely related species can have large differences in the number of chromosomes. For example, horses, donkeys, and zebras (genus *Equus*) have 64, 62, and 44 chromosomes respectively.

Organism	Chromosome number (2N)
Vertebrates	
cat	38
rat	42
rabbit	44
human	46
chimpanzee	48
gorilla	48
cattle	60
dog	78
turkey	82
goldfish	94
Invertebrates	
horse roundworm	2
fruit fly *Drosophila*	8
housefly	12
honey bee	32 or 16
Hydra	32
Plants	
broad bean	12
cabbage	18
garden pea	14
rice	24
Ponderosa pine	24
orange	18, 27, or 36
potato	48



Donkey
N = 31 (below)
2N = 62

Zebra
N = 22 (below)
2N = 44

Useful definitions

Haploid (N)
A cell (or organism) containing a single set of chromosomes. For example, human sperm and egg cells are haploid.
Hint: the prefix haplo- means single or simple.

Diploid (2N)
A cell (or organism) containing two complete sets of chromosomes. One set is inherited from each parent
Hint: the prefix di- means two.

Heterogametic sex
The sex of a species that has two different sex chromosomes. For example, in humans and *Drosophila*, males have XY sex chromosomes, so are the heterogametic sex. In some species, the female is the heterogametic sex (e.g. birds and reptiles).
Hint: the prefix hetero- means different.

Homogametic sex
The sex of a species that has two of the same sex chromosome. For example, in humans and *Drosophila*, females have two X sex chromosomes, so are the homogametic sex.
Hint: the prefix homo- means the same.

1. (a) What is the difference in the diploid chromosome number between humans and chimpanzees? _____

   (b) Which animal has the minimum number of chromosomes possible? _____

   (c) Which plant has the same number of chromosomes as a gorilla? _____

2. Why is the number of chromosomes in an organism not a reflection of their genetic complexity?

   _____

   _____

   _____

   _____

3. The image on the right shows the sex chromosomes from a human individual. Is this individual heterogametic or homogametic? Explain your answer:

   _____

   _____

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84 Karyotyping

Key Idea: The karyotype is the number and appearance of chromosomes in the nucleus of a eukaryotic cell. The karyotype can be pictured in a standard format, called a karyogram, in which the chromosomes are ordered by size.

Karyotyping begins with 'freezing' the nuclei of cultured white blood cells in the metaphase stage of mitosis. A photograph of the chromosomes is then cut up and the chromosomes are organised on a grid, with homologous pairs together, to produce a karyogram. In humans, the male karyotype has 44 autosomes (non-sex chromosomes), and an X and a Y chromosome (44 + XY). The female karyotype has 44 autosomes and two X chromosomes (44 + XX).

Preparing a karyotype

1 A sample of cells is taken from the person of interest. This may be from the amniotic fluid surrounding a fetus or from a blood sample from an adult or child.

2 The sample is centrifuged and the lymphocytes (a type of white blood cell) are removed and induced to divide (mitosis).

They are grown for several days in culture and then treated to halt the cycle at the metaphase stage.

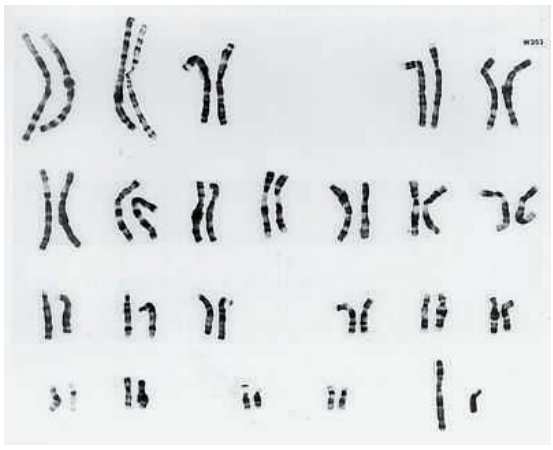
3 A drop of the cell suspension in preservative is spread on a microscope slide, dried and stained with a dye that causes a banding pattern to appear on each chromosome.

Microscope slides with stained smears

4 The stained white blood cells are viewed under a microscope and a clearly arranged spread of chromosomes is photographed.

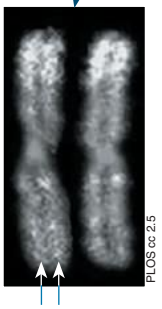
Newer techniques use fluorescent probes to colour-code chromosomes and provide a spectral karyogram (left and below).

5 The photograph is cut up (manually or electronically with the use of a computer) so that each chromosome is separate from the others. The chromosomes are then arranged into homologous pairs according to size, shape, and banding pattern (or colour).



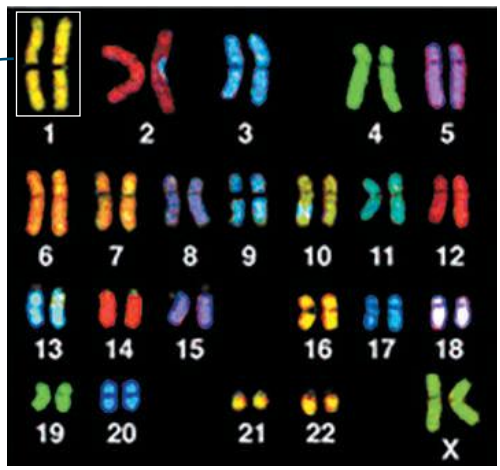
Karyotypes: Cytogenetics Dept, Waikato Hospital

Conventional karyogram (male): 44 + XY



PLOS cc 2.5

Close up reveals two chromatids



Spectral karyogram (female): 44 + XX

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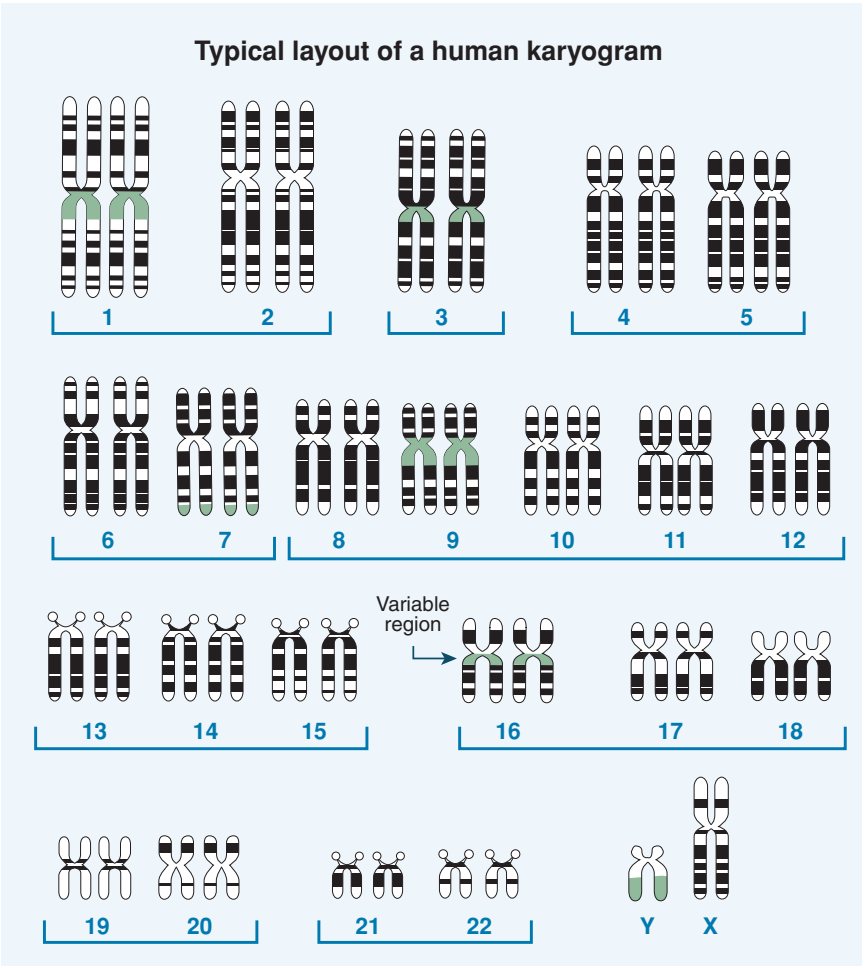
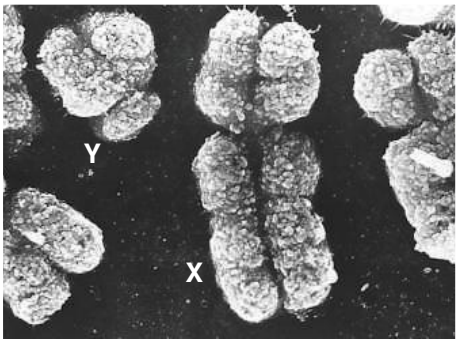
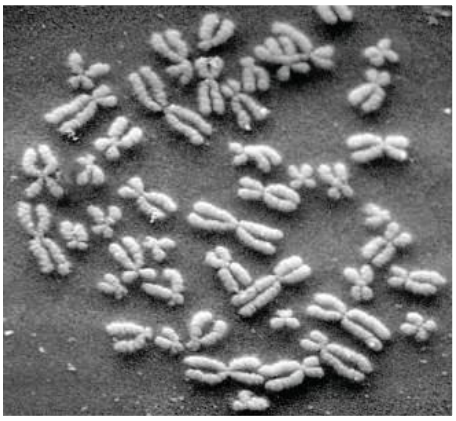




SEM showing human X and Y chromosomes. Although these two are the sex chromosomes, they are not homologous.



A scanning electron micrograph (SEM) of human chromosomes clearly showing their double chromatids.

1. (a) What is a karyogram? _____

_____

_____

(b) What information can it provide? _____

_____

2. On the male karyogram on the previous page, number each homologous pair of chromosomes. Use the karyogram above as a guide.
3. Circle the sex chromosomes on female and the male karyograms on the previous page.
4. Write down the number of autosomes and the arrangement of sex chromosomes for each sex:

(a) Female: No. of autosomes: _____ Sex chromosomes: _____

(b) Male: No. of autosomes: _____ Sex chromosomes: _____

5. State how many chromosomes are found in a:

(a) Normal human (somatic) body cell: _____ (b) Normal human sperm or egg cell: _____

6. What features of the chromosomes allow them to be paired up for a karyogram? _____

_____

_____

_____

7. Why are the X and Y chromosomes not homologous? _____

_____

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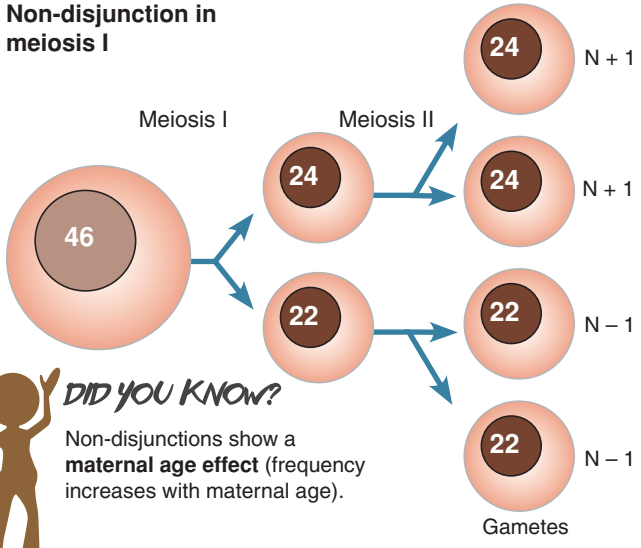
85 Abnormal Chromosome Numbers

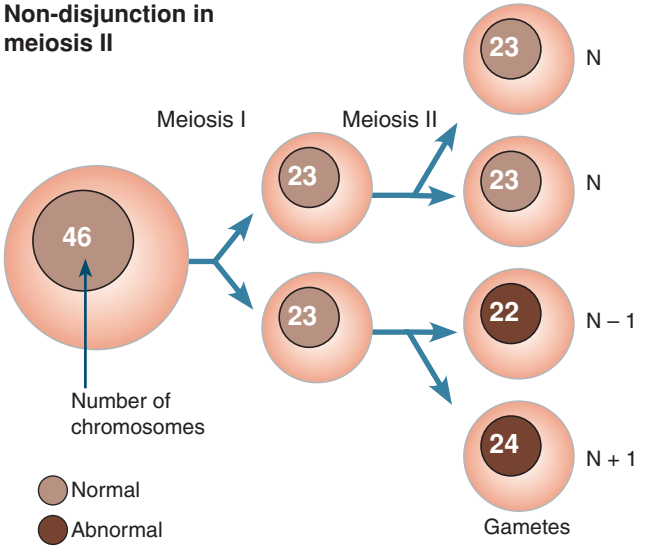
Key Idea: Non-disjunction during meiosis results in incorrect apportioning of chromosomes to the gametes.

In meiosis, chromosomes are usually distributed to daughter cells without error. Occasionally, homologous chromosomes fail to separate properly in meiosis I, or sister chromatids fail to separate in meiosis II. In these cases, one gamete receives two of the same type of chromosome and the other gamete receives no copy. This error is known as **non-disjunction** and it results in abnormal numbers of chromosomes in the gametes. The union of an aberrant and a normal gamete at fertilisation produces offspring with an abnormal chromosome number. This condition is known as **aneuploidy**.

Non-disjunction in meiosis I



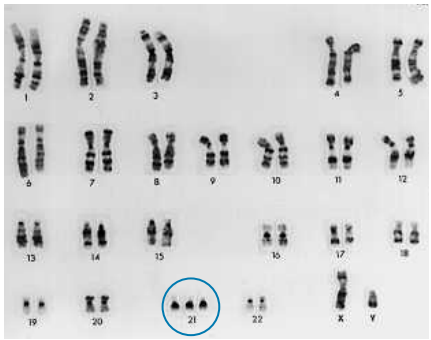
Non-disjunction in meiosis II



DID YOU KNOW?

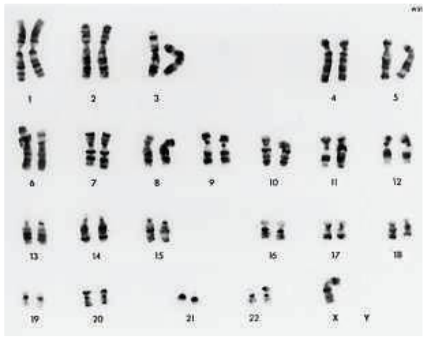
Non-disjunctions show a **maternal age effect** (frequency increases with maternal age).

Down syndrome (trisomy 21)



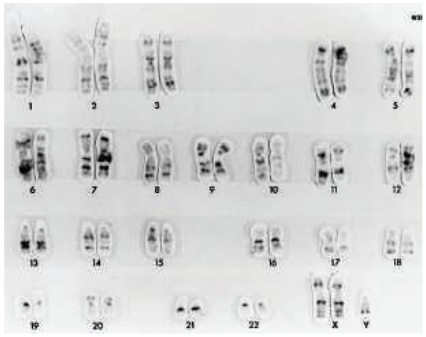
Down syndrome is the most common of the human aneuploidies. The incidence rate in humans is about 1 in 800 births for women aged 30 to 31 years, but the rate increases with maternal age (a phenomenon known as the **maternal age effect**). The most common form of this condition arises when meiosis fails to separate the pair of chromosome number 21s in the eggs that are forming in the woman's ovaries.

Turner syndrome (XO)



Turner syndrome (2N – 1, female). This syndrome results from the non-disjunction of the sex chromosomes during meiosis. The individual has only **one sex chromosome** (**X**). The karyotype (above) has a total of 45 chromosomes. The incidence rate is 1 in 5000 live female births. In most cases, the X chromosome comes from the mother, and faulty sperm production causes the lack of a second sex chromosome.

Klinefelter syndrome (XXY)



PHOTOS: Cytogenetics Department, Waikato Hospital

Klinefelter syndrome (2N + 1, male). This syndrome results from the non-disjunction of the sex chromosomes during meiosis. The individual has an extra sex chromosome (**X**), to produce a **XXY** genotype. This karyotype of a Klinefelter syndrome individual shows a total complement of **47** including **XXY** sex chromosomes. The incidence rate is an average of 1 in 1000 live male births, with a maternal age effect.

1. Describe the consequences of non-disjunction during meiosis: _____

_____

_____

2. Explain why non-disjunction in meiosis I results in a higher proportion of faulty gametes than non-disjunction in meiosis II:

_____

_____

3. How does non-disjunction lead to aneuploidy? _____

_____

_____

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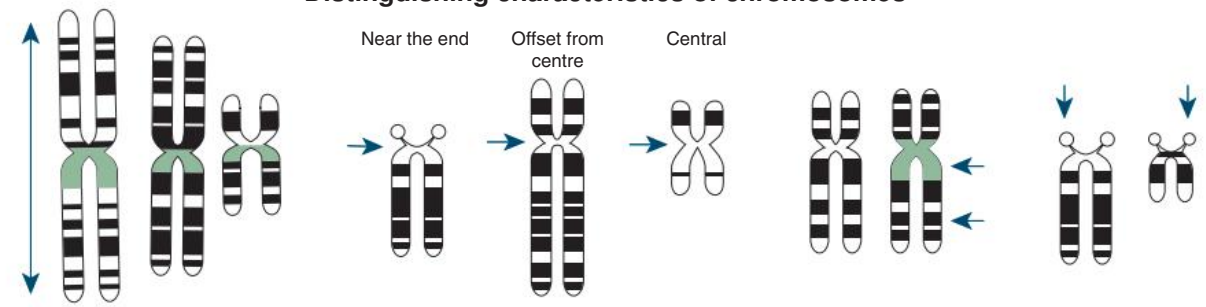
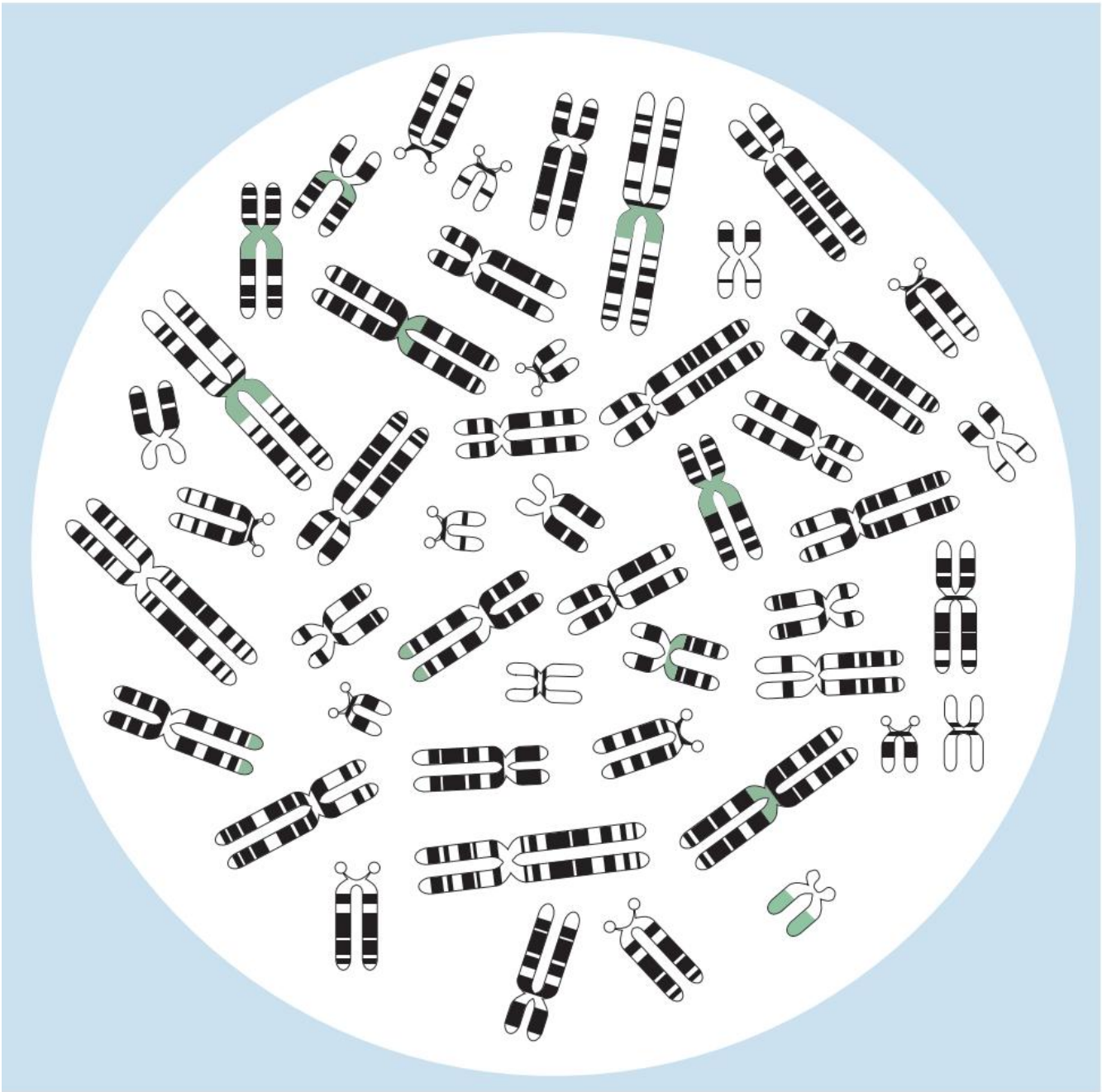
86 Making a Karyogram

Assessment Task, Outcome 1: *Problem solving involving biological concepts or skills*

Each chromosome has specific distinguishing features. Chromosomes are stained in a special technique that gives them a banded appearance in which the banding pattern represents regions containing up to many hundreds of genes. Cut out the chromosomes below and arrange them on the record sheet in order to determine the sex and chromosome condition of the individual whose karyotype is shown. The karyograms presented on the previous pages and the hints on how to recognise chromosome pairs can be used to help you complete this activity.

Distinguishing characteristics of chromosomes





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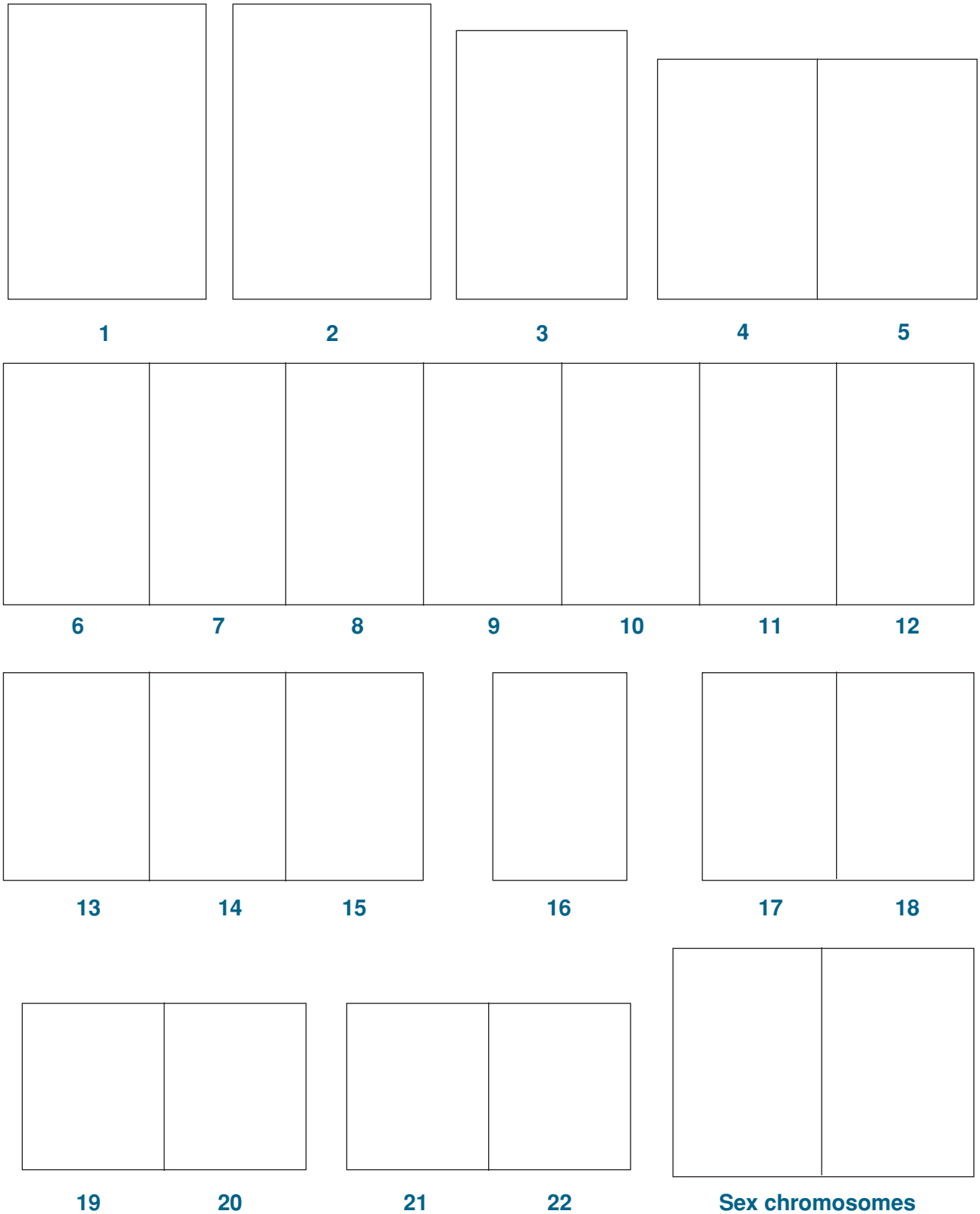
1. Cut out the chromosomes on page 159 and arrange them in homologus pairs on the record sheet below:
2. (a) Is the sex of this individual male or female? _____

   (b) Ia the individual's chromosome arrangement normal or abnormal? _____

   (c) If the arrangement is abnormal, state in what way and name the syndrome displayed: _____

   _____



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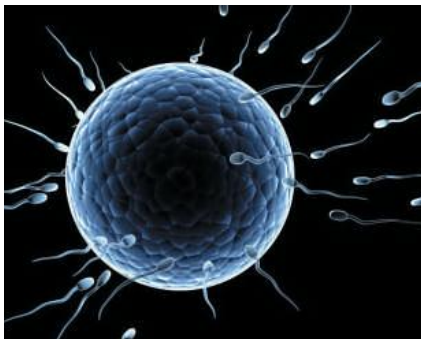
87 Cell Division

Key Idea: There are two types of cell division in eukaryotes, mitosis and meiosis. Barring mutation, only meiosis produces cells that are genetically different to the parent cell.

New cells are formed when existing cells divide. There are two forms of cell division in eukaryotes, mitosis and meiosis. **Mitosis** produces two identical daughter cells from a parent cell. **Meiosis** is a special type of cell division, it produces sex cells (gametes or spores) for sexual reproduction. In sexual reproduction, sex cells from two parents combine to form a new individual that is genetically different to its parents.

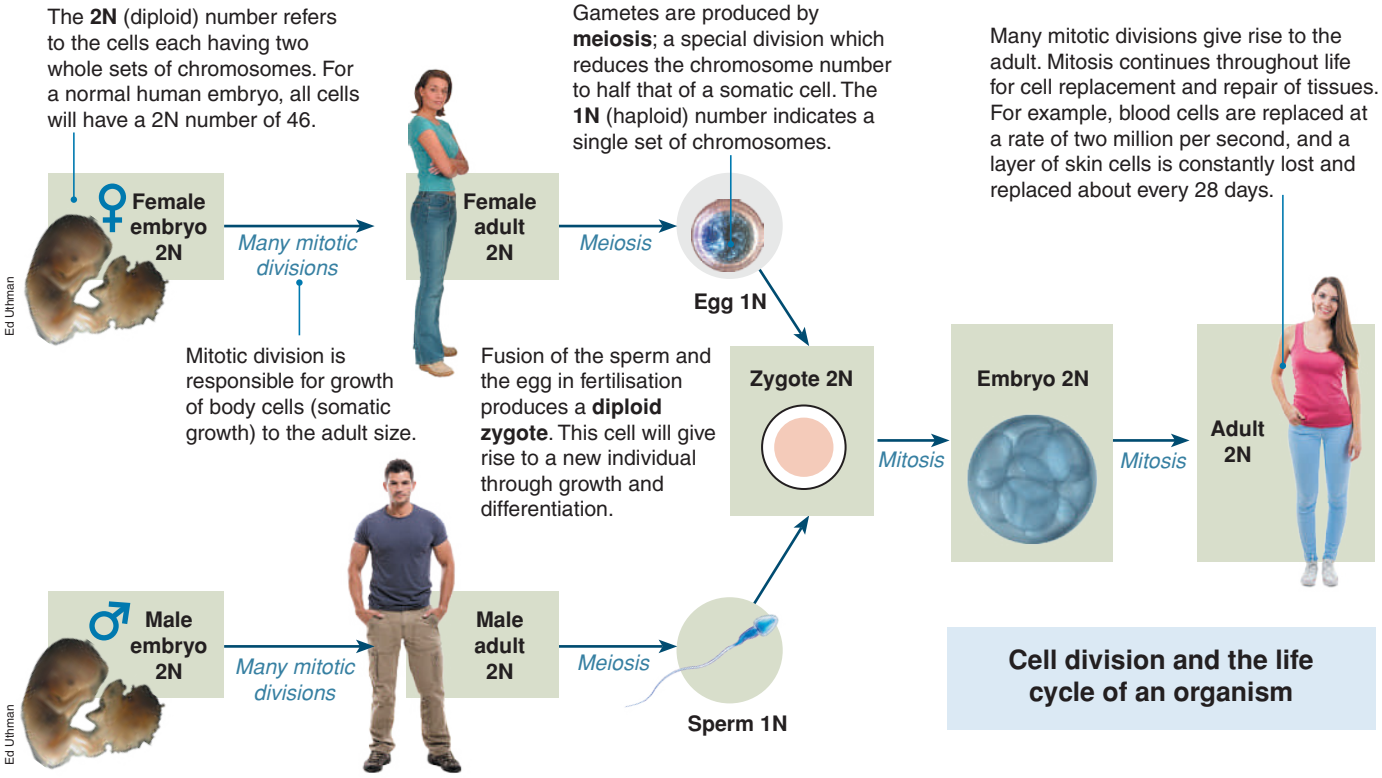


The sex cells (eggs and sperm) in humans are produced by meiosis. Events occurring during meiosis creates gametes with unique combinations of gene variants and this creates genetic variability.

Sexual reproduction rearranges and reshuffles the genetic material into new combinations. This is why family members may look similar, but they'll never be identical (except for identical twins).

Jpbarrass

Mitosis produces genetically identical cells. This characteristic allows the body to produce cells to heal itself when it is damaged, and is also responsible for the production of the cells required for growth.



1. (a) Where does mitosis take place in animals? _____

   (b) Describe the roles of mitosis in the human body: _____

   _____

   (c) In mitosis, the daughter cells are genetically different to the parent cell. True or False (delete one)

2. (a) Where does meiosis take place in animals? _____

   (b) What is the purpose of meiosis? _____

   _____

   (c) In meiosis, the sex cells are genetically different to the parent cell. True or False (delete incorrect answer)

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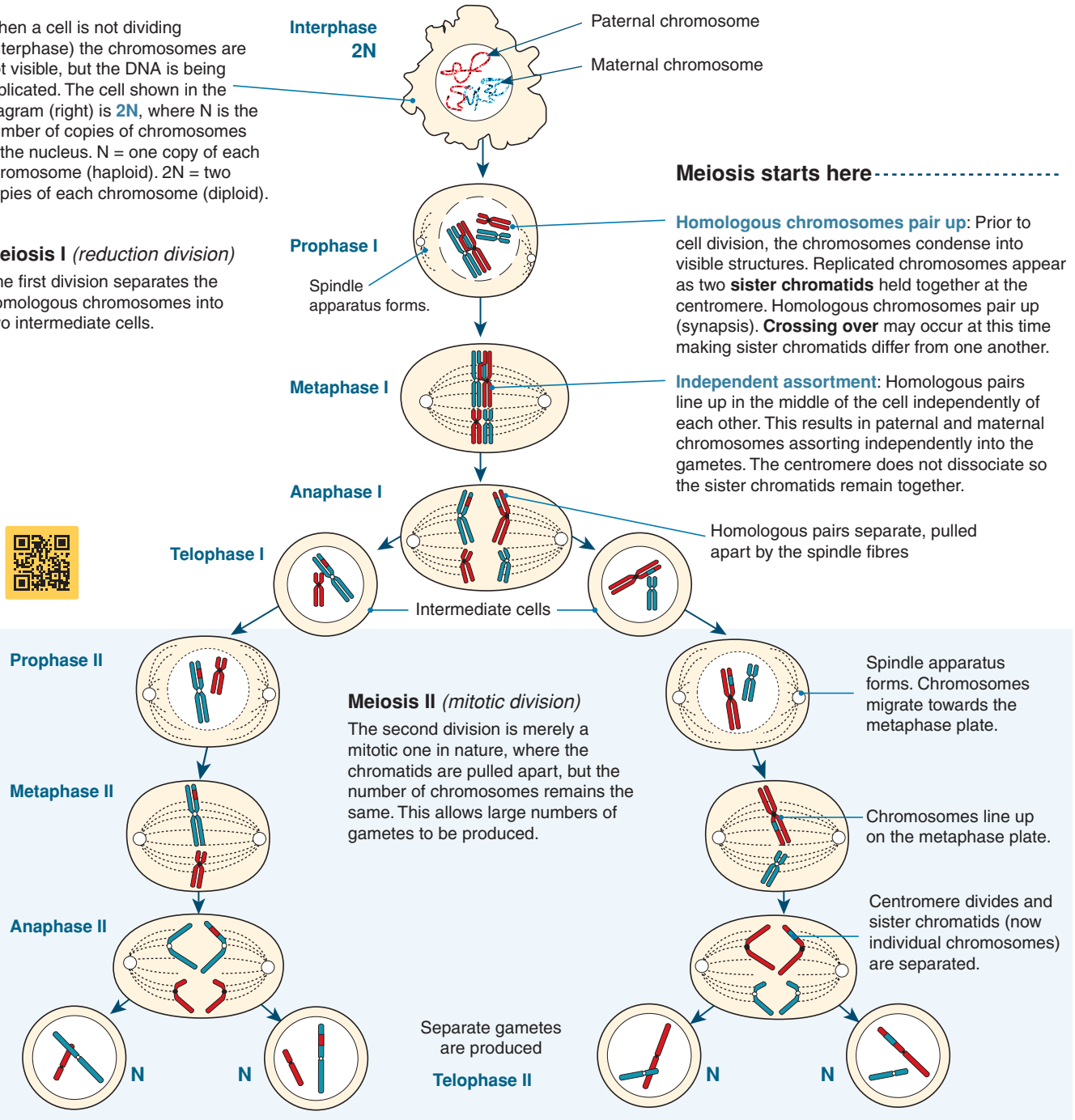
88 Meiosis

Key Idea: Meiosis is a special type of cell division. It produces sex cells (gametes) for the purpose of sexual reproduction. Meiosis involves a single chromosomal duplication followed by two successive nuclear divisions, and results in a halving of the diploid chromosome number. Meiosis occurs in the sex organs of animals and the sporangia of plants. If genetic mistakes (gene and chromosome mutations) occur here, they will be passed on to the offspring (they will be inherited).

When a cell is not dividing (interphase) the chromosomes are not visible, but the DNA is being replicated. The cell shown in the diagram (right) is **2N**, where N is the number of copies of chromosomes in the nucleus. N = one copy of each chromosome (haploid). 2N = two copies of each chromosome (diploid).

Meiosis I *(reduction division)*

The first division separates the homologous chromosomes into two intermediate cells.



1. Describe the behaviour of the chromosomes in the first division of meiosis: _____

_____

_____

_____

2. Describe the behaviour of the chromosomes in the second division of meiosis: _____

_____

_____

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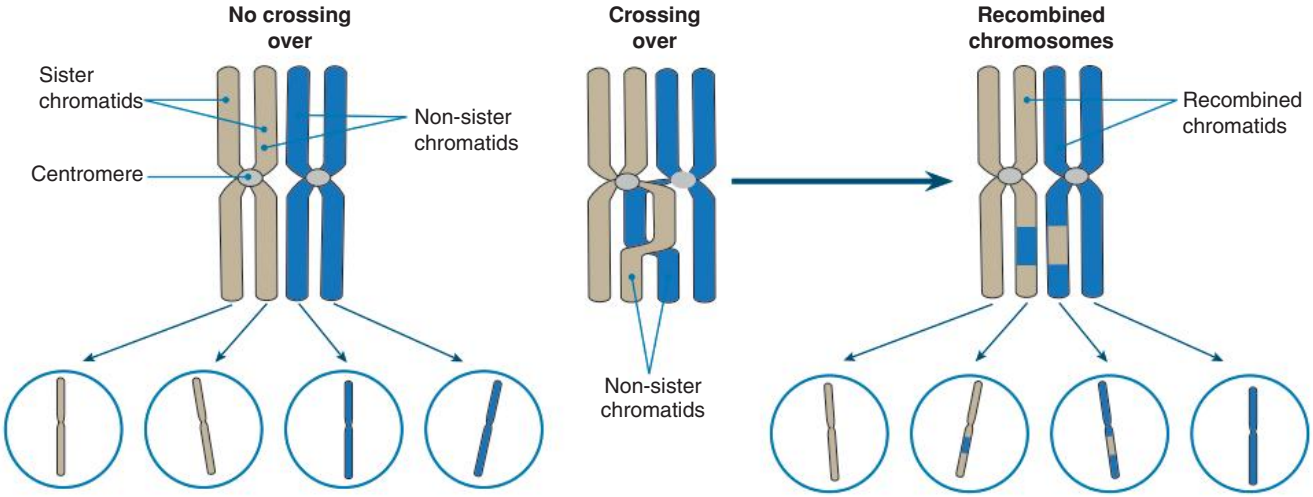
89 Meiosis and Variation

Key Idea: Meiosis produces genetic variation via the processes of crossing over and independent assortment.
Meiosis creates genetic variation in the sex cells through crossing over and independent assortment. Crossing over refers to the mutual exchange of pieces of chromosome (and their genes) between homologous chromosomes. In independent assortment, homologous chromosomes are randomly distributed to the gametes.

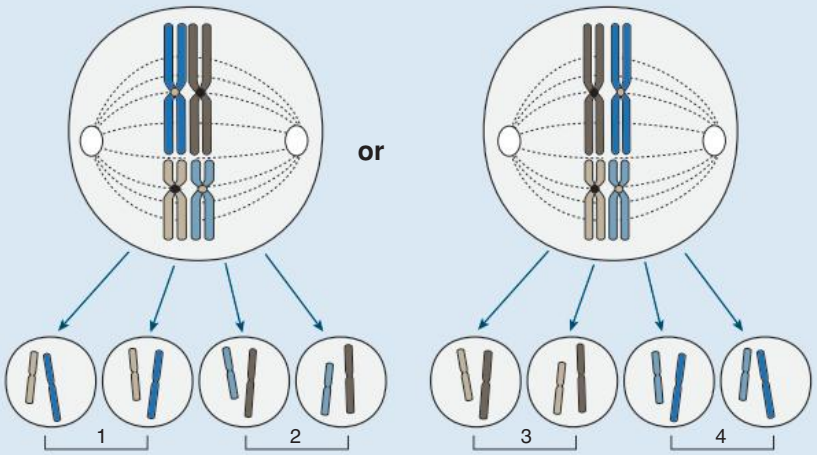
Crossing over and recombination

Chromosomes replicate during interphase, before meiosis, to produce replicated chromosomes with sister chromatids held together at the centromere (see below). When the replicated chromosomes are paired during the first stage of meiosis, non-sister chromatids may become entangled and segments may be exchanged in a process called **crossing over**. Crossing over results in the **recombination** of alleles (variations of the same gene) producing greater variation in the offspring than would otherwise occur.



Independent assortment

Independent assortment is the random alignment and distribution of chromosomes during meiosis. Independent assortment is an important mechanism for producing variation in gametes. During the first stage of meiosis, replicated homologous chromosomes pair up along the middle of the cell. The way the chromosomes pair up is random. For the homologous chromosomes right, there are two possible ways in which they can line up resulting in four different combinations in the gametes. The intermediate steps of meiosis have been left out for simplicity.



1. How does independent assortment increase the variation in gametes? _____

2. (a) What is crossing over? _____

   (b) How does crossing over increase the variation in the gametes (and hence the offspring)? _____

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90 Modelling Meiosis

Key Idea: We can simulate crossing over, gamete production, and the inheritance of alleles during meiosis using ice-block sticks to represent chromosomes.

This practical activity simulates the production of gametes (sperm and eggs) by meiosis and shows you how crossing over increases genetic variability. This is demonstrated by studying how two of your own alleles are inherited by the "child" produced at the completion of the activity. Completing this activity will help you to visualise and understand some of important aspects of the events in meiosis.

Investigation 7.1 Modelling meiosis using popsicle sticks

See appendix for equipment list.

To study the effect of crossing over on genetic variation, you will work in pairs to simulate the inheritance of two of your own traits: ability to tongue roll and handedness. This activity will take 25–45 minutes.

1. Record your phenotype and genotype for each trait in the table (right). If you have a dominant trait, you will not know if you are heterozygous or homozygous for that trait, so you can choose either genotype.
2. Before you start the simulation, partner up with a classmate. Your gametes will combine with theirs (fertilisation) at the end of the activity to produce a 'child'. Decide who will be female, and who will be male. You will need to work with this person again at step 7.
3. Collect four popsicle sticks. These represent four chromosomes. Colour two sticks blue or mark them with a P. These are the paternal chromosomes. The plain sticks are the maternal chromosomes. Write your initials on each of the four sticks. Label each chromosome with its number. Label four sticky dots with the alleles to describe your phenotype and stick each onto the appropriate chromosome. In the example shown, the person is heterozygous for tongue rolling so sticky dots with alleles T and t are placed on chromosome 10. The person is also left handed, so alleles r and r are placed on chromosome 2 (right).
4. Randomly drop the chromosomes onto a table. This represents a cell in either the testes or ovaries.

   Duplicate your chromosomes by adding four more identical popsicle sticks to the table (right).
   What are you simulating with this action?

   _____

5. Simulate the first stage of meiosis by lining the duplicated chromosome pair with their homologous pair (below). For each chromosome number, you will have four sticks touching side-by-side (A, below).

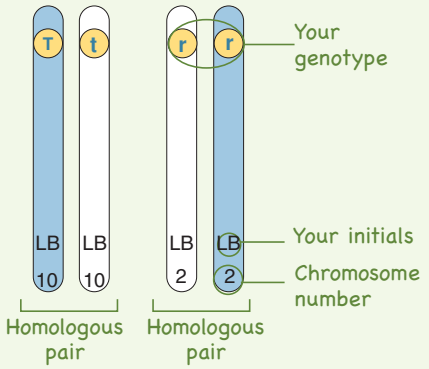
   At this stage crossing over occurs. Simulate this by swapping sticky dots from adjoining homologues (B, below).

Chromosome number	Phenotype	Genotype
10	Tongue roller	TT, Tt
10	Non-tongue roller	tt
2	Right handed	RR, Rr
2	Left handed	rr

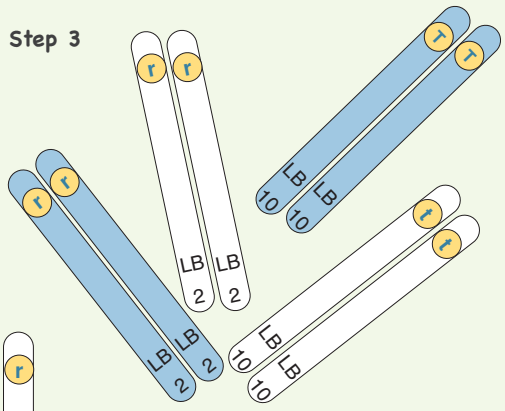
Step 1

Trait	Phenotype	Genotype
Handedness		
Tongue rolling		

Step 2

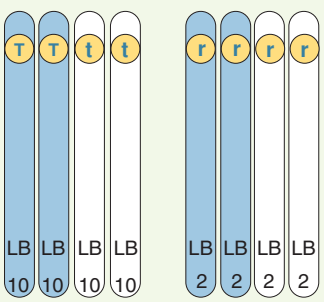


Step 3

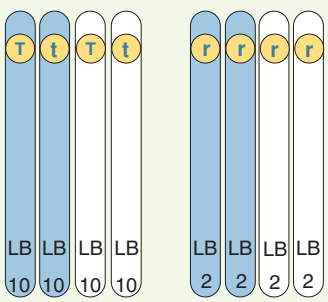


Step 4

(A)



(B)



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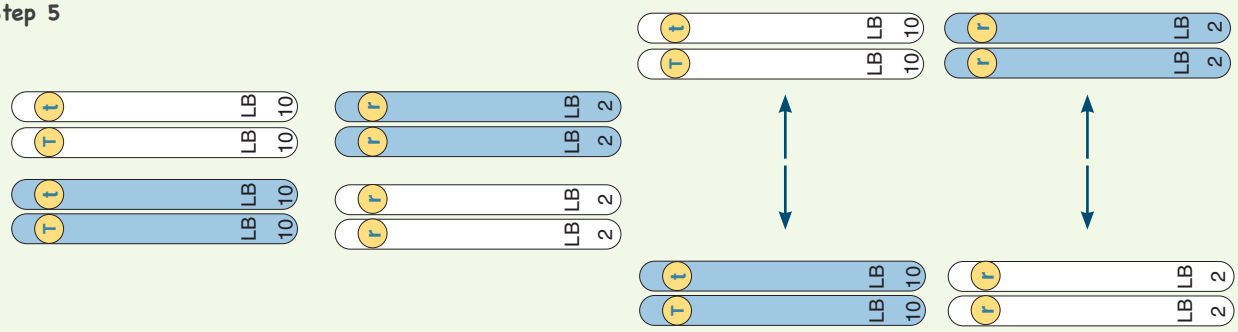
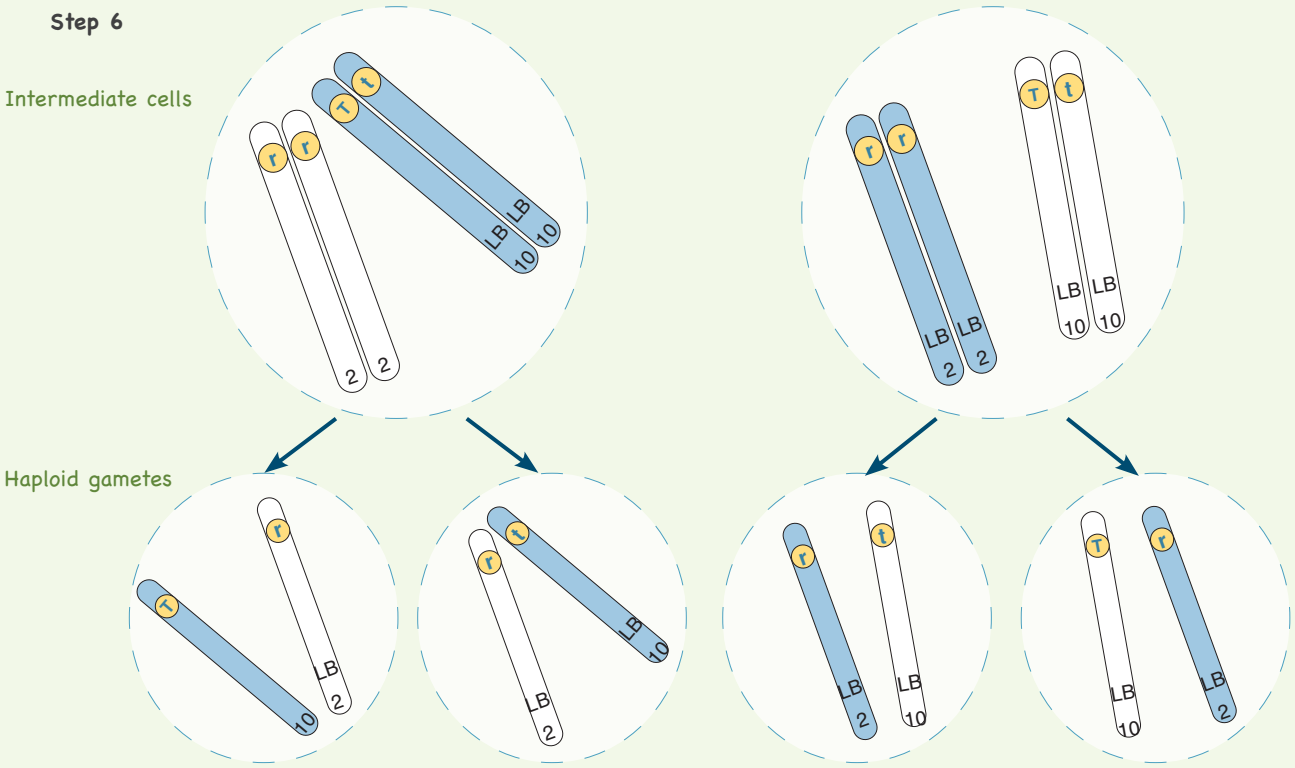
6. Randomly align the homologous chromosome pairs to simulate alignment across the cell's centre (equator) (as occurs in the next phase of meiosis). Simulate the separation of the chromosome pairs.
For each group of four sticks, two are pulled to each pole (end) of the cell.

Step 5



7. Two intermediate cells are formed. If you have completed step 5 correctly, each intermediate cell will be haploid (half the diploid chromosome number shown in step 3) with a mixture of maternal and paternal chromosomes. This is the end of the first division of meiosis. Your cells now need to divide for a second time. Repeat steps 4 and 5 but this time there is no crossing over and you are now separating replicated chromosomes, not homologues. At the end of this process each intermediate cell will have produced two haploid gametes. Each will have a maternal chromosome (white) and a paternal chromosome (blue) (below).

Step 6



8. Pair up with the partner you chose at the beginning of the exercise to carry out fertilisation. Randomly select one sperm and one egg cell. The unsuccessful gametes can be removed from the table. Combine the chromosomes of the successful gametes. You have created a child! Fill in the following chart to describe your child's genotype and phenotype for tongue rolling and handedness.

Trait	Phenotype	Genotype
Handedness		
Tongue rolling		

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91 Chapter Review: Did You Get It?

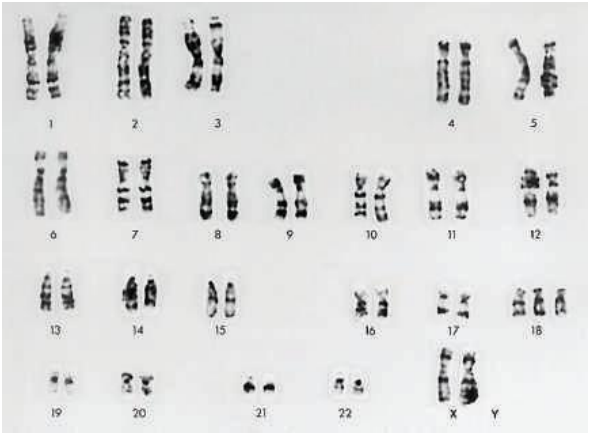
1. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

autosome	A	Single piece of DNA that contains many genes and associated regulatory elements and proteins.
chromatid	B	One of two identical DNA strands forming a replicated chromosome and held together by the centromere.
chromosome	C	The number and appearance of chromosomes in the nucleus of a eukaryotic cell.
karyogram	D	A non-sex chromosome.
karyotype	E	An error during meiosis in which homologous chromosomes or sister chromatids do not separate correctly.
non-disjunction	F	The chromosome that carries the gene for determination of sex in individual organisms.
sex chromosome	G	The rearrangement of a micrograph of chromosomes into a standard image and format.

2. For each of the karyograms shown below:

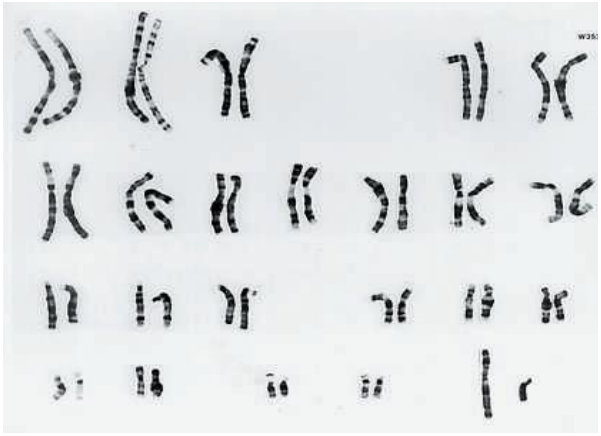
   (a) Determine the sex of the individual:

   (b) Determine if the karyotype shown is normal/abnormal:



i) Sex: _____

Normal / abnormal



ii) Sex: _____

Normal / abnormal

3. Circle the correct answer for the following question:

   Meiosis results in:

   A. 2 haploid daughter cells

   B. 4 haploid daughter cells

   C. 2 diploid daughter cells

   D. 4 diploid daughter cells

4. Circle the correct answer for the following question:

   Which of the following cells undergo mitosis:

   A. Egg cells

   B. Kidney cells

   C. Bacterial cells

   D. All of the above

5. Explain the difference between mitosis and meiosis: _____

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CHAPTER 8

Genotypes and Phenotypes

Key terms

allele
codominance
continuous variation
DNA methylation
dominant allele/trait
epigenetics
genetic cross
genotype
heterozygous
homozygous
incomplete dominance
locus
multiple alleles
mutation
phenotype
polygenes (=multiple genes)
recessive allele/trait
trait

Describing genotypes

Key skills and knowledge

Activity number

- ☐ 1 Recall the difference between genes and alleles. Demonstrate understanding of the terms used in studying inheritance: allele, locus, trait, heterozygous, homozygous, genotype, phenotype, cross. — 92
- ☐ 2 Use symbols to represent genotypes for the alleles present at a particular gene locus and distinguish between alleles in genetic crosses. — 92 93
- ☐ 3 Giving examples, distinguish between the expression of recessive and dominant phenotypes, including codominance and incomplete dominance. — 93



Influences on phenotype

Key skills and knowledge

- ☐ 4 Describe how genetic make-up (genotype), environmental factors, and epigenetic factors contribute to produce the phenotype of an organism. — 94
- ☐ 5 Recall how sexual reproduction contributes to genotypic and phenotypic variation in the offspring of sexually reproducing organisms. Describe other contributors to variation, including the role of mutation in creating new alleles, and single nucleotide polymorphisms (SNPs) in contributing to phenotypic variation in populations. — 95
- ☐ 6 Recognise epigenetic factors as modifications to DNA that do not affect the DNA sequence itself. Explain how these modifications can make genes more or less likely to be expressed. Describe examples of how epigenetic changes can affect phenotype. How are epigenetic influences measured and tested? — 96
- ☐ 7 Describing examples in both plants and animals, explain how the environment of an organism during or after development can alter the expression of the genotype and produce variable phenotypes. Is the response different for plants and animals? If so, can you suggest why? Recognise that the influence of environment on phenotype is typically mediated through epigenetic modifications. — 97

Polygenic inheritance and continuous variation

Key skills and knowledge

- ☐ 8 Using examples, describe polygenic inheritance and explain how it contributes to continuous variation in a population. Describe the contribution of environment to the continuous variation observed for phenotypes determined by the inheritance of multiple genes (polygenes). — 98
- ☐ 9 PRAC Investigate continuous variation in a population sample for a characteristic determined by multiple genes, e.g. height, hand span, foot length. — 98

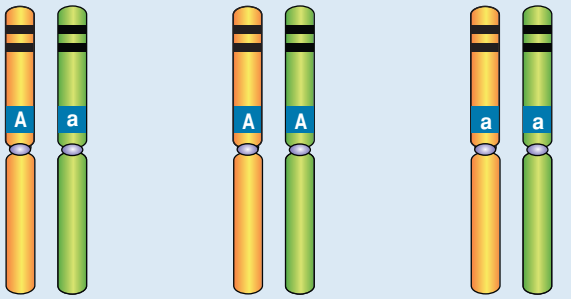
92 Expressing Genotypes

Key Idea: In genetics, symbols are used to describe dominant or recessive alleles, or to describe the genotype of an organism for a particular trait.

When describing alleles, it is common to talk about if they are dominant or recessive. The trait coded for by a dominant allele will always be expressed over a recessive allele. The dominant allele must be absent for a recessive allele to be expressed. Symbols and letters are used as a short hand way to describe the alleles at a particular gene location (locus). A capital letter (often the first letter of a dominant trait) is used to show the allele is dominant. A lower case letter is used to represent the recessive allele. For example, in pea plants, the allele for round seeds (R) is dominant over the allele for wrinkled seeds (r).

How do we write genotypes?

- Recall that we inherit half of our chromosomes from our mother and half from our father. Therefore, it is possible for an individual to have a number of allele combinations for each gene.
- The diagram below shows all the possible allele combinations for gene A.
- The dominant allele is "A" (given in uppercase) and the recessive allele is "a" (given in lowercase).
- Individuals that are homozygous for a particular allele or alleles will be true-breeding for that trait/those traits.



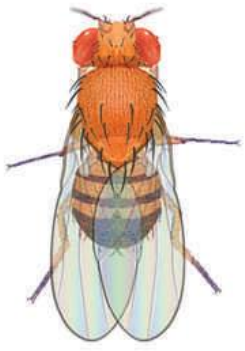
Heterozygous Aa | Homozygous dominant AA | Homozygous recessive aa

Fruit fly genotypes

Fruit flies (*Drosophila melanogaster*) are model organisms for studying inheritance and mutations. They have short life cycles, share many genes in common with humans, and are easy and inexpensive to study. Commonly studied characteristics include eye colour, body colour, and wing shape. Notation in *Drosophila* genetics differs from the usual dominant-recessive notation shown left because there are so many mutant phenotypes.

Individuals with a typical (normal) appearance are said to be **wild-types**. Wild-type alleles can be indicated with a "+" superscript or given an uppercase symbol of the mutant phenotype. For example, red eyes (w^+) is the wildtype eye colour, and is dominant over white eyes (w).

In genetic crosses, *Drosophila* are most often named using an uppercase of the mutant phenotype. A recessive mutation, e.g. ebony body (*eb*) and curled wings (cu), is given in lowercase, and the wild-type is given an uppercase symbol of the mutant phenotype, e.g. grey body (*Eb*) and straight wings (*Cu*).



This individual has the wild-type red eye colour.

1. In your own words define:

   (a) Dominant allele: _____

   _____

   _____

   (b) Recessive allele: _____

   _____

   _____

2. Imagine allele "S" is dominant and stands for smooth hair and the allele "s" is recessive and stands for rough hair. What phenotype (appearance) would an individual with the following genotypes have?

   (a) SS: _____ (b) Ss: _____ (c) ss: _____

3. Imagine a genetic cross in true-breeding *Drosophila* between a female with an ebony body and curled wings and a male that is wild-type for those genes. Write the genotypes of the parents and the outcome of the cross (the offspring):

   _____

4. Describe the main difference when writing allele combinations in humans compared to *Drosophila*: _____

   _____

   _____

   _____

   _____

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93 Inheritance of Traits

Key Idea: A phenotype refers to the observable characteristics of an organism. A variant of a phenotypic characteristic is a trait. Traits may result from dominant or recessive alleles.

Traits are particular variants of phenotypic (observed physical) characters. For example, a phenotypic character is eye colour, a trait is blue eye colour. Traits may be controlled by one gene or many genes and can show discontinuous variation (e.g. flower colour in pea plants) or continuous variation (e.g. height in humans). What trait appears depends on the alleles present. Dominant alleles will produce a dominant trait. Recessive alleles will only produce a recessive trait if both alleles present are recessive.

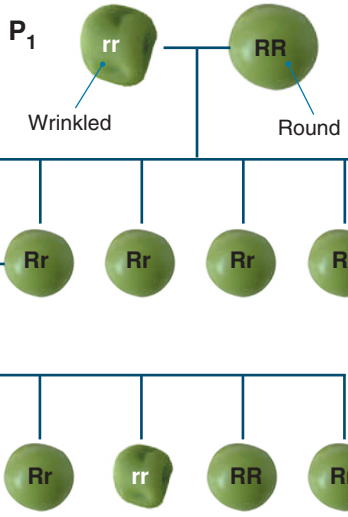
Some of the best known experiments in phenotypes are the experiments carried out by Gregor Mendel (right) on pea plants. During one of the experiments (shown below) he noticed how traits expressed in one generation disappeared in the second generation, but reappeared in the third generation. In his experiments Mendel used true breeding plants. When self-crossed, true breeding organisms produce offspring with the same phenotypes as the parents (because they are homozygous for the alleles concerned).

Mendel's experiments

Mendel studied seven phenotypic characters of the pea plant:

- Flower colour (violet or white)
- Pod colour (green or yellow)
- Height (tall or short)
- Position of the flowers on the stem (axial or terminal)
- Pod shape (inflated or constricted)
- Seed shape (round of wrinkled)
- Seed colour (yellow or green)

In this diagram R (round) is dominant to r (wrinkled).



One of the experiments crossed true breeding round seed plants with true breeding wrinkled seed plants.

Out of the thousands of seeds produced, all were round, none were wrinkled.

Mendel then crossed the F_1 offspring together. The wrinkled seed reappeared in the second generation. He saw similar results with all the other phenotypic characters he studied.

How can this be explained?

Mendel was able to explain his observations in the following way:

- Traits are determined by a unit, which passes unchanged from parent to offspring (we now know these units are genes).
- Each individual inherits one unit (gene) for each trait from each parent (each individual has two units).
- Traits may not physically appear in an individual, but the units (genes) for them can still be passed to its offspring.

1. What is the difference between a trait and a phenotypic characteristic? _____

2. Why do you think true breeding parents could be useful when performing genetic crosses? _____

3. (a) What was the ratio of smooth seeds to wrinkled seeds in the F_2 generation? _____

   (b) Why did the wrinkled seed trait not appear in the F_1 generation? _____

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The pea seed example on the previous page is an example of complete dominance, where the presence of a dominant allele completely masks the expression of the recessive allele. However, there are inheritance patterns where this pattern does not occur. Two common examples are **incomplete dominance** and **codominance**.

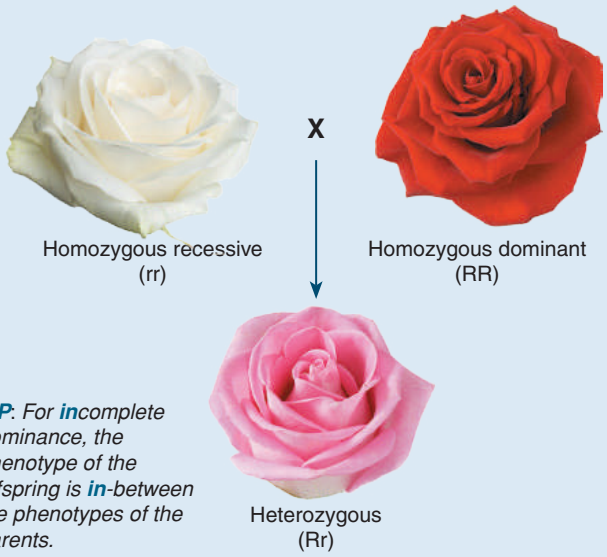
Incomplete dominance

Definition:
The dominant allele does not completely mask the effects of a recessive allele creating an intermediate phenotype.

Physical appearance:
In heterozygous offspring, their phenotype (physical appearance) is a blend of the dominant and recessive alleles.

Examples:
In roses, the allele for red flowers (R) is dominant over white flowers (r). If a homozygous white flower is crossed with a homozygous red flower all the offspring will be heterozygous and have pink flowers (an intermediate of red and white).

In humans, when one parent has straight hair and the other has curly hair, their offspring will have wavy hair due to the expression of both alleles.



***TIP**: For **in**complete dominance, the phenotype of the offspring is **in**-between the phenotypes of the parents.*

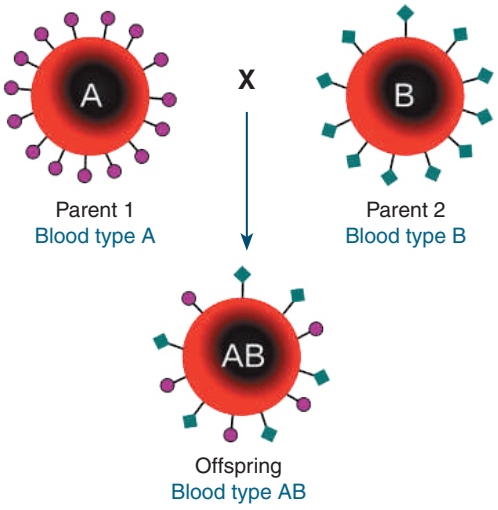
Codominance

Definition:
There is no recessive allele, both alleles are equally and independently expressed within an organism.

Physical appearance:
The phenotype may not be uniform because each allele may be expressed in different cells or different parts of the organism giving an uneven appearance of phenotype.

Examples:
Holstein cows have white spots and black spots. This occurs because the white allele and black allele are each fully expressed in different parts of the organism.

In humans, three alleles (A, B, and O) are involved in the ABO blood group system. It is an example of codominance in a **multiple allele system**. The letters indicate the presence of one, both, or neither of the A and B proteins on the red blood cells. Someone inheriting an A allele from one parent and a B allele from the other will express both proteins on their red blood cells. Their blood type will be AB.



4. Summarise the main difference between incomplete dominance and codominance: _____

_____

_____

_____

5. Decide whether the following examples show complete dominance, incomplete dominance, or codominance:

   (a) A red bull and a white cow were mated together and produced a calf with a roan coat (it has red and white hairs):

   _____

   (b) A pea plant with yellow seeds is crossed with a pea plant with green seeds. All the offspring have yellow seeds:

   _____

   (c) Crossing a long-furred Angora rabbit and a short-furred Rex rabbit produces offspring with intermediate length fur:

   _____

   (d) A dog with many spots is crossed with a dog with no spots. Their puppies have some spots:

   _____

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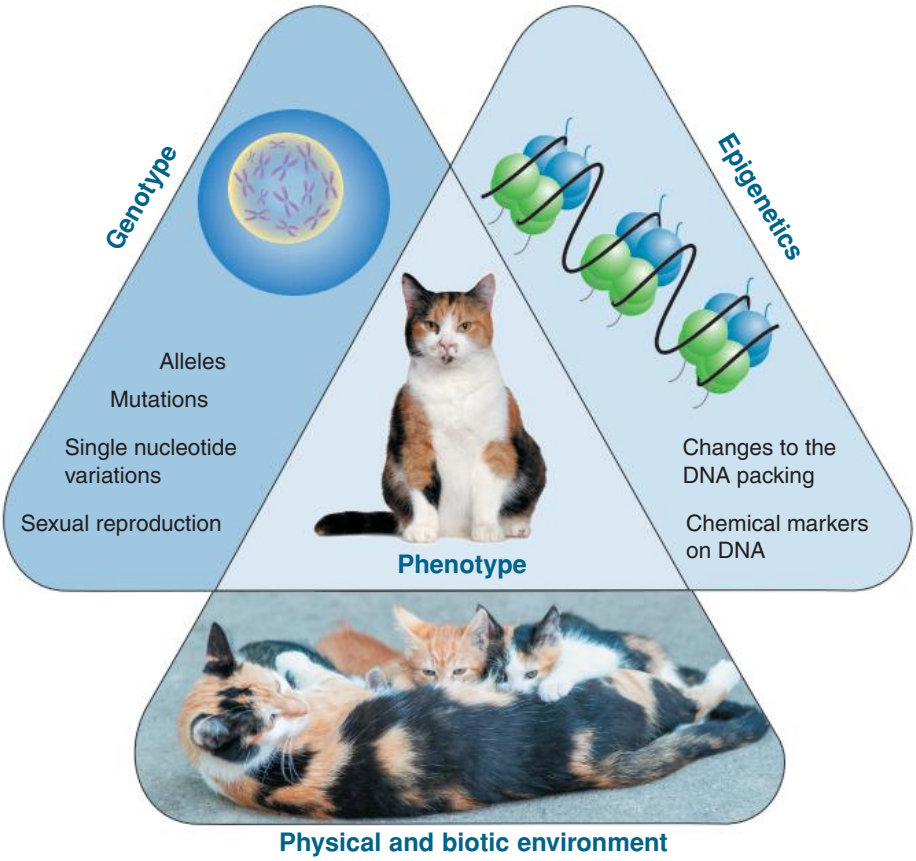
94 Influences on Phenotype

Key Idea: An organism's phenotype is influenced by the effects of the environment during and after development, even though the genotype remains unaffected.

The phenotype encoded by genes is a product not only of the genes themselves, but of their internal and external environment and the variations in the way those genes are controlled (epigenetics). Even identical twins have minor differences in their appearance due to epigenetic and environmental factors such as diet and what the environment was like in the uterus during development. Genes, together with epigenetic and environmental factors, determine the unique phenotype that is produced.



Polyphenism: same genotype, different phenotype

Butterfly images: © 2010 Jee & Rani Nature Photography cc BY-SA 4.0

Noor et al PLOS cc BY-SA 4.0

See text left for explanation

- The phenotype is the product of the many complex interactions between the genotype, the environment, and the chemical tags and markers that regulate gene expression of the genes (epigenetic factors).
- **Polyphenism** is the expression of different phenotypes in organisms with the same genotype as a result of environmental or epigenetic influences. Examples include temperature dependent sex determination in reptiles, seasonal fur colour changes in Arctic foxes, seasonal changes in wing patterns in peacock pansy butterflies (photo panel A and B), and changes in body colour in response to food resources in peppered moth caterpillars (photo panel C).
- The amount of change in a phenotype due to environmental influences is called its phenotypic plasticity. Plants often have high phenotypic plasticity because they are unable to move and so must adjust to environmental changes throughout their lives.

1. (a) What are some sources of genetically induced variation? _____

_____

_____

(b) What are some sources of environmentally induced variation? _____

_____

2. Explain why genetically identical twins are not always phenotypically identical: _____

_____

_____

_____

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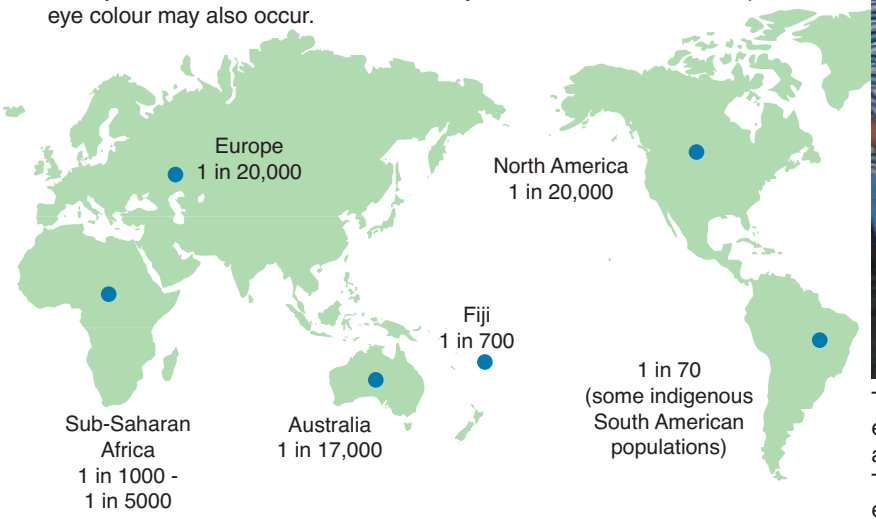
95 Genotype Influences Phenotype

Key Idea: Sexual reproduction, mutations, and variable regions of DNA (SNPs) each contribute to phenotype.

An individual's genotype is a result of a combination of a number of different factors. These include the combination of alleles they receive through sexual reproduction, changes in the DNA through mutation, and variability in DNA due to single nucleotide polymorphisms (SNPs). Each of these variations in genotype influence the phenotype of the individual.

Changes in phenotype: albinism

The photo (right) shows a family group of where one of the children has an appearance quite different ot the others. The child is an albino. Albinism is an inherited genetic disease resulting in the absence of pigmentation or colouration. There are several types of albinism, the most common, OCA, affects the skin, hair, and eyes. Albinos with OCA have white or extremely pale skin and hair, so must take care in the Sun not to damage their skin and eyes. In humans with albinism, blue eyes are common, but red or pink eye colour may also occur.

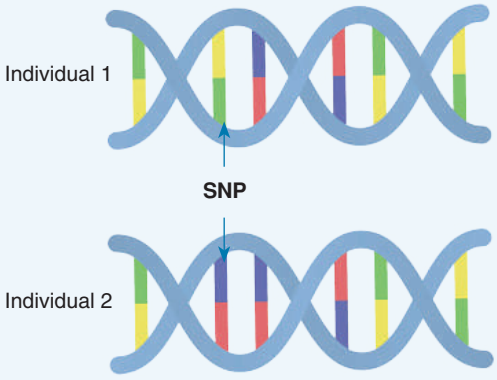


The rate of OCA varies between countries. Some ethnic groups, and some populations in isolated areas show higher levels of albinism than others. This may be due to the presence of certain ethnic specific genetic factors called SNPs (gene variations in different parts of the world).

Factors contributing to genetic variation

How is it that some individuals have normal colouration and some are albinos? One factor contributing to the condition is genotype variation. This may arise through:

- **Sexual reproduction**: The processes of crossing over and independent assortment during meiosis increases genetic variability in the gametes (egg and sperm). Random fertilisation between egg and sperm further enhances genetic variation in the resulting zygote.
- **Alleles**: Alleles are different versions of a gene. Different alleles arise through changes in the DNA sequence. This increases genetic variation between individuals.
- **Mutation**: Mutations are changes to a DNA sequence and are a source of new alleles. Mutations arise through errors in DNA copying or can be caused by external factors called mutagens (e.g. UV radiation). Mutations may change only a single base pair in the DNA, or large parts of chromosomes.
- **Single nucleotide polymorphism (SNPS)**: SNPs (pronounced snips) are a single change in a nucleotide base between individuals (diagram, top right). SNPs are the most common form of variation in the human genome it is estimated the human genome contains 3–10 million SNPs. Some SNPs are associated with different variants of albinism.



DID YOU KNOW?

What's the difference between a mutation and SNP?

SNPs and single nucleotide substitution mutations are very similar. To be classified as a SNP, the substitution must occur in more than 1% of the population.

1. What health problem might people with albinism suffer from because of low pigmentation levels? _____

_____

_____

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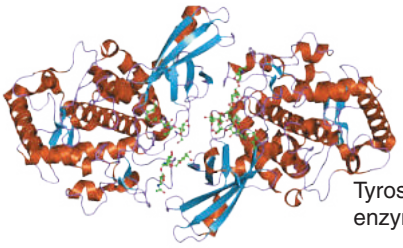
The genome and albinism

Allele combination

We can represent the alleles for albinism as **P** (normal pigmentation) and **p** (albino pigmentation) The abnormal allele (**p**) for OCA is inherited in a homozygous recessive pattern. An individual must have two copies of the abnormal gene to be albino. Individuals with one copy are carriers, they show no characteristics of being albino, but they can pass the gene for albinism on to their offspring.

SNPs

Most SNPs do not occur in regions coding for genes, but when they do they can be associated with disease. Sometimes SNPs can occur more often in certain populations (see previous page) so can be useful for tracking disease genes. Albino kangaroos and wallabies are fairly uncommon and SNP analysis is limited. Only one albino is born for every 50,000-100,000 births. The rate of albinism is much higher in humans (on average one in every 17,000 - 20,000 births).


Tyrosinase enzyme

Sexual reproduction

The law of independent assortment (sorting chromosomes during meiosis) means there is no way to predict which gametes will receive an albino allele. However, the probability of producing albino offspring can be predicted by studying the inheritance pattern for the disease. You will study inheritance patterns in the next chapter.

Mutation

Several gene mutations are known to result in albinism. The most common form of OCA is caused by a mutation to the TYR gene. The TYR gene produces an enzyme called tyrosinase, which is needed to make the pigment melanin. Melanin gives the skin, hair, and eyes their colour. Without tyrosinase there is no melanin, which is why albinos have a pale or white appearance.

2. Explain the difference between a single nucleotide mutation and a SNP: _____

3. Using the alleles P (normal pigmentation) and p (albino pigmentation), write the allele combination for someone who:

   (a) Has albinism: _____

   (b) Is a carrier of albinism: _____

   (c) Does not have albinism and is not a carrier: _____

4. Why do carriers for albinism not show symptoms of albinism? _____

5. Explain how the TYR gene mutation is involved in producing the classic OCA phenotype: _____

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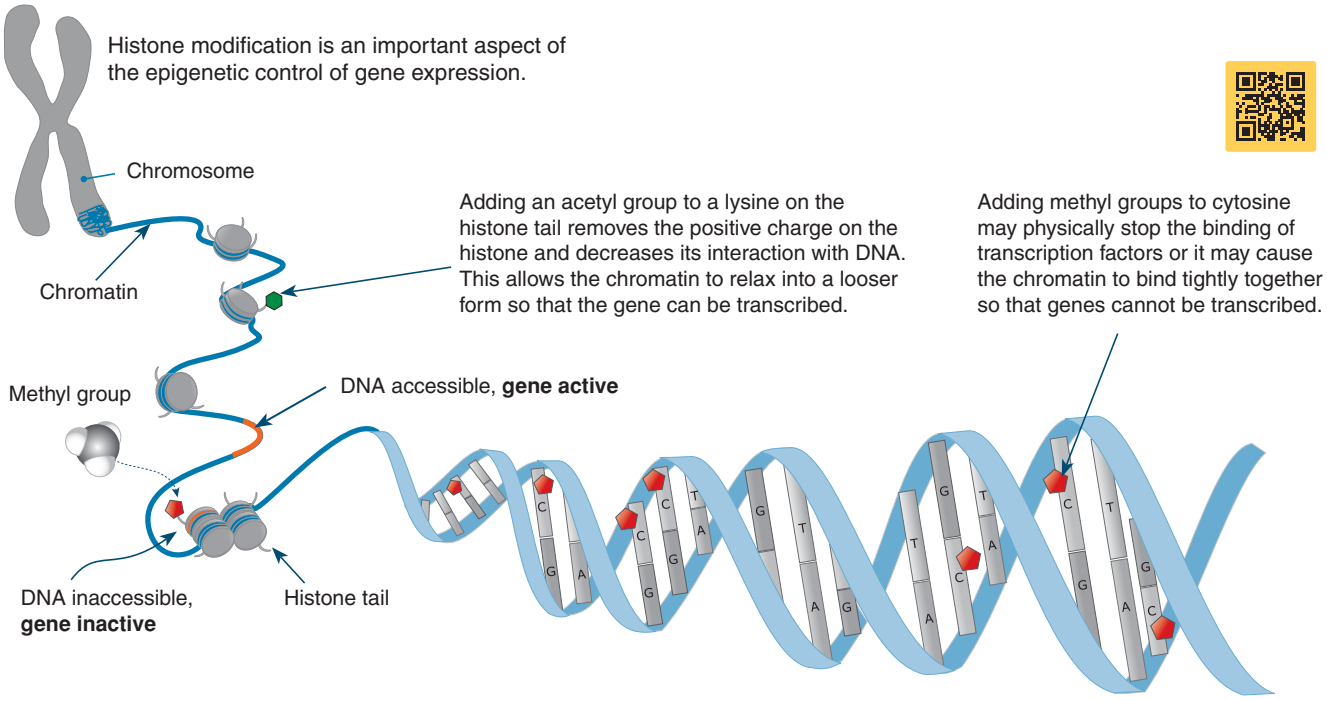
96 Epigenetic Regulation of Gene Expression

Key Idea: The mechanisms by which the environment modifies the expression of genes are often epigenetic.

As you saw earlier, gene expression can be influenced in part by the environment. But how is the influence of environment moderated? Sometimes (as with colour pointing) the environment directly influences a protein's function. Most often though, the regulation is epigenetic. Epi- means 'on top of' or 'extra to'. Thus epigenetic factors are those external to the gene itself (e.g. chemical tags) that influence how that gene is expressed. Epigenetic regulation is achieved by modifying the way the DNA is packaged and its availability to be transcribed. The DNA sequence is unchanged.

The regulation of gene expression in eukaryotes is a complex process beginning before the DNA is even transcribed. The packaging of DNA regulates gene expression either by making the nucleosomes in the chromatin pack together tightly (**heterochromatin**) or more loosely (**euchromatin**). This affects whether or not RNA polymerase can attach to the DNA and transcribe the DNA.



1. What is epigenetics? _____

_____

_____

2. (a) Describe the effect of histone modification and adding methyl groups on DNA packaging: _____

_____

_____

(b) How do these processes affect transcription of the DNA? _____

_____

_____

3. The graphs (right) show the relative amount of genomic methylation and the effect of this on the frequency of gene expression. Describe the relationship between methylation and gene expression:

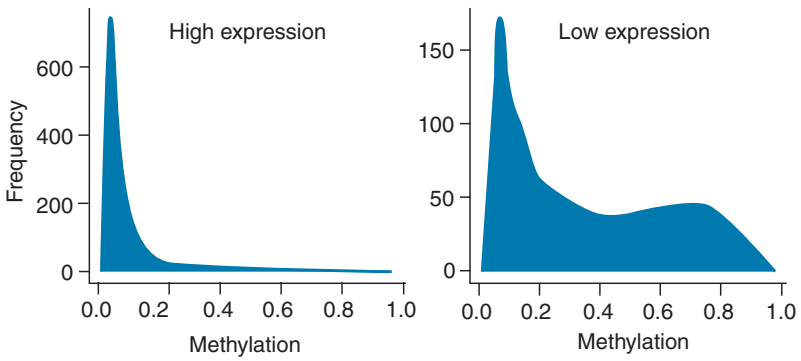
_____

_____

_____

_____

_____



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Epigenetics affects development

- One of the biggest debates in the study of development is the idea of nature versus nurture. To what extent do genes or the environment affect development and phenotype?
- A 2004 study of the grooming of rat pups by their mothers helps provide some insight. In this study, the quality of care by a pup's mother affected how the pup behaved when it reached adulthood.
- Rat pups that were groomed more often by their mother were better at coping with stress than pups that received less grooming. What's more, it was shown that the effect was caused by changes in the expression of the glucocorticoid receptor, which plays a role in the response to stress.
- DNA analysis found differences in the way the DNA was chemically tagged. Rats that received a lot of grooming had DNA that allowed for greater transcription and so had higher expression of the glucocorticoid receptor. The opposite was true for rats that received little grooming.

Twins in space

- Twin studies can provide a lot of information about how the environment affects gene expression. The studies are often done when identical twins have been separated at birth (usually because one or both of them are adopted out). Their similarities and differences can then be studied to assess how much the environment influenced their development.
- In 2015, NASA astronaut Scott Kelly blasted into space for a year long stay on the International Space Station. His identical twin brother Mark remained on Earth. This gave NASA a chance to study the real effects of space travel on the human body. Importantly, the gene expression of the men could be measured before and after Scott went to space.
- It was found that six months after Scott's return, 7% of his genes had not returned to their normal level of gene expression. Also, although there was no decrease in Scott's cognitive abilities, there was a decrease in his speed and accuracy until his readjustment to Earth gravity. The space environment had altered Scott Kelly's gene expression compared to his identical twin Mark Kelly.

NASA

4. (a) Describe how grooming by mother rats on their pups affected the pups in the long term: _____

_____

(b) How could this have been achieved by epigenetics? _____

_____

_____

5. How might twin studies help the study of gene-environment responses? _____

_____

_____

_____

6. What evidence is there that epigenetics can have long term to permanent effects on gene expression? _____

_____

_____

_____

_____

7. When a zygote forms at fertilisation, most of the epigenetic tags are erased so that cells return to a genetic 'blank slate' ready for development to begin. However some epigenetic tags are retained and inherited. Why do you think it might be advantageous to inherit some epigenetic tags from a parent?

_____

_____

_____

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97 Environment and Phenotype

Key Idea: The environment can play a big part in an organism's eventual phenotype.

Environmental factors, including physical factors such as temperature and biotic factors such as presence of predators, can influence how genes are expressed. Factors such as heat or chemicals can turn genes on (genes are expressed) or off. When and for how long the genes are expressed can have large effects on an organism's eventual phenotype.

The effect of temperature

Crocodiles hatching

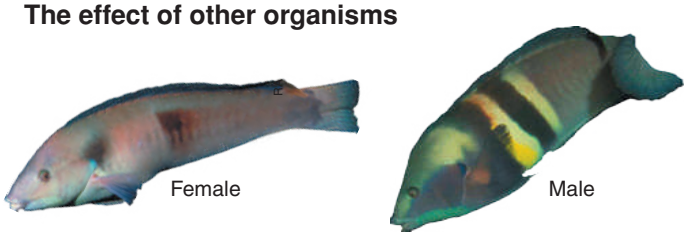
The sex of turtles, crocodiles, and the American alligator is determined by the incubation temperature during embryonic development. In some species, high incubation temperatures produce males and low temperatures produce females. In other species, the opposite is true. Temperature regulated sex determination may provide an advantage by preventing inbreeding.

Colour pointing

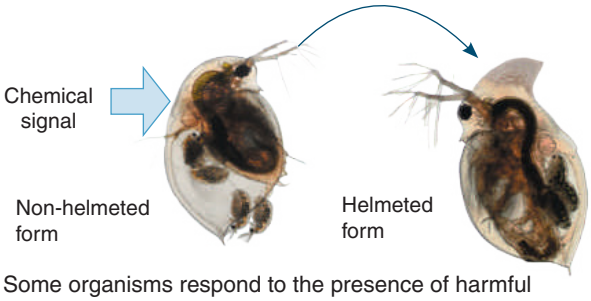
Cindy McCravey cc2.0

Siamese kittens are born fully white, but develop dark patches after birth. The dark colour is caused by the pigment melanin. In Siamese, the tyrosinase enzyme involved in melanin production is mutated and is inactivated at normal body temperature. Tyrosinase can only function to produce melanin in the cooler areas of the body (ears, feet, tail), in the rest of the body where body temperature is higher, no melanin is produced.

The effect of other organisms



For some fish species, including some in the wrasse family (e.g. *Coris sandageri*, right), the presence of other individuals of the same species may control sex determination. The fish live in groups consisting of a single male with attendant females and juveniles. In the presence of a male, all juveniles become females. When the male dies, the dominant female will undergo changes in physiology and appearance to become a male.



Some organisms respond to the presence of harmful organisms by changing their morphology or body shape. When the water flea *Daphnia* is exposed to predatory phantom midge larvae it develops a helmet and/or tail spine which make it more difficult to attack. They also produce young with the same defensive structures. These responses are mediated through chemicals produced by the predator.

1. Why are the darker patches of fur in Siamese cats only present on the face, paws and tail? _____

2. (a) How is helmet and spine development in *Daphnia* a response to environment? _____

   (b) How does the phenotypic response help the animal survive? _____

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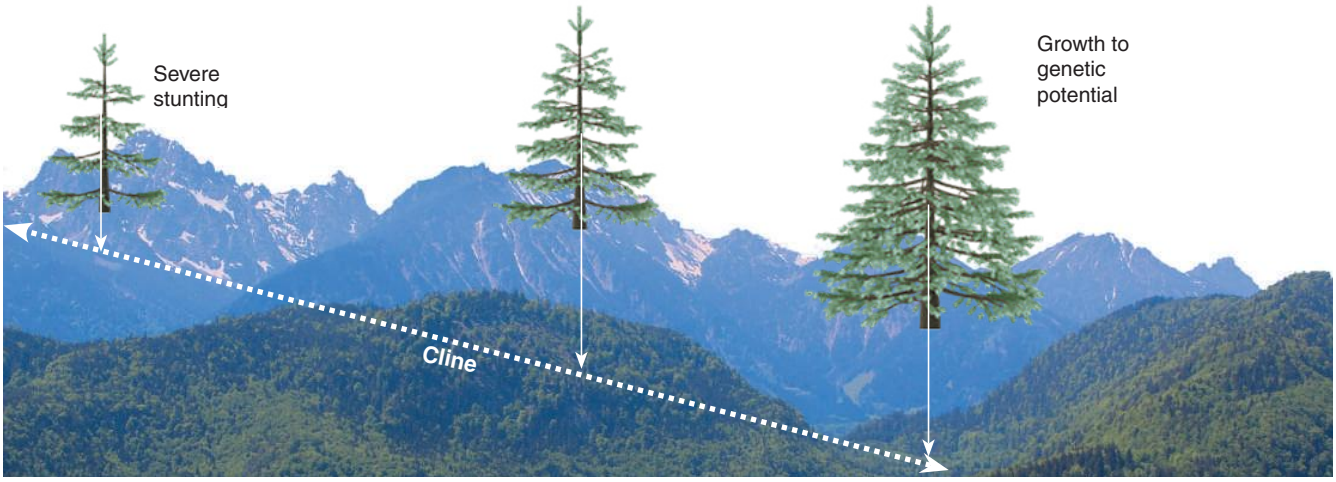
Environment can determine whether or not an organism reaches its genetic potential

Increasing altitude can stunt the phenotype of plants with the same genotype. In many tree species, such as spruce (below) and mountain beech, plants at low altitude grow to their full genetic potential, but growth becomes more and more stunted as elevation increases and the abiotic factors (e.g. temperature) change. Growth is gnarled and plants are shorter at the highest sites. Gradual change in phenotype over an environmental gradient is called a cline.



How do chemicals affect hydrangea flowers?

- Changes in the chemical environment influence flower colour in hydrangeas (right). They have blue flowers when they are grown in acidic soil (pH <7.0) and pink flowers when grown in neutral to basic soils (≥ 7.0).
- The colour change is a result of the mobility and availability of aluminum ions (Al^{3+}) at different pH.
- At low pH Al^{3+} is highly mobile. It binds with other ions and is taken up into the plant, reacting with the usually red/pink pigment in the flowers to form a blue colour.
- In soil pH at or above 7.0, the aluminum ions combine with hydroxide ions to form insoluble and immobile aluminum hydroxide ($Al(OH)_3$). The plant doesn't take up the aluminum and remains red/pink.
- Other conditions (e.g. high phosphorus levels) can also affect aluminum mobility and availability.

Soil pH <7.0: blue flowers

Soil pH > 7.0: pink flowers

3. Describe an example to illustrate how genotype and environment contribute to phenotype: _____

4. (a) What is a cline? _____

(b) Describe how the phenotype of the spruce changes with an increase in altitude: _____

(c) Physical (abiotic) factors change with altitude. Suggest what physical factors may influence the tree's phenotype:

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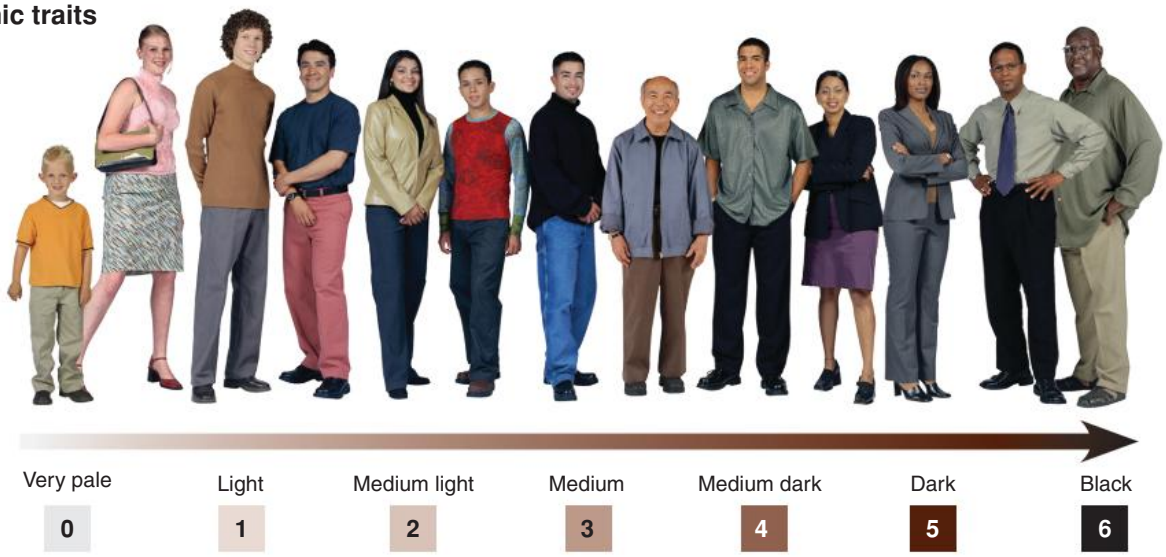
98 Genes, Environment, and Continuous Variation

Key Idea: Many phenotypes are affected by multiple genes.
Many phenotypes are controlled by more than one gene. This is called polygeny or polygenic inheritance. As there are many genes and therefore many alleles controlling the phenotype, there are a large range of possible phenotypes. Combined with environmental effects, this produces **continuous variation** within the population. Two examples in humans are skin colour and height.

Polygenic traits



Polygenic traits are usually identified by

- Traits are usually quantified by measuring rather than counting.
- Two or more genes contribute to the phenotype.
- Phenotypic expression is over a wide range (often in a bell shaped curve).
- Polygenic phenotypes include skin colour, height, eye colour, and weight.

RECALL...

*Multiple genes (many **genes** contributing to a phenotype) are quite different to multiple alleles (many **alleles** present in the population for one phenotypic characteristic).*

It is estimated that skin colour is controlled by at least eight genes (probably more). There are various ways to compare skin colour. One is shown right, in which there are seven shades ranging from very pale to very dark. Most individuals are somewhat intermediate in skin colour.

The table (right) shows a cross between three genes involved in skin colour, A, B, and C, each with two alleles (AaBbCc x AaBbCc). This is sufficient to give the seven shades of skin colour shown above. The shaded boxes indicate their effect on skin colour when combined. No dominant allele results in a lack of dark pigment (aabbcc). Full pigmentation (black) requires six dominant alleles (AABBCC). Note that for three genes with two alleles each there are 23 x 23 = 8 x 8 = 64 possible genotypes.

Gametes	ABC	ABc	AbC	Abc	aBC	aBc	abC	abc
ABC	AABB CC	AABB Cc	AABb CC	AABb Cc	AaBB CC	AaBB Cc	AaBb CC	AaBb Cc
ABc	AABB Cc	AABB cc	AABb Cc	AABb cc	AaBB Cc	AaBB cc	AaBb Cc	AaBb cc
AbC	AABb CC	AABb Cc	AAbb CC	AAbb Cc	AaBb CC	AaBb Cc	Aabb Cc	Aabb Cc
Abc	AABb Cc	AABb cc	AAbb Cc	AAbb cc	AaBb Cc	AaBb cc	Aabb Cc	Aabb cc
aBC	AaBB CC	AaBB Cc	AaBb CC	AaBb Cc	aaBB CC	aaBB Cc	aaBb CC	aaBb Cc
aBc	AaBB Cc	AaBB cc	AaBb Cc	AaBb cc	aaBB Cc	aaBB cc	aaBb Cc	aaBb cc
abC	AaBb CC	AaBb Cc	Aabb CC	Aabb Cc	aaBb CC	aaBb Cc	aabb CC	aabb Cc
abc	AaBb Cc	AaBb cc	Aabb Cc	Aabb cc	aaBb Cc	aaBb cc	aabb Cc	aabb cc

1. (a) What is polygeny? _____

_____

(b) How does polygeny contribute to continuous variation? _____

_____

_____

2. Study the cross between the A, B, and C genes above. Write down the frequencies of the seven phenotypes (0-6):

_____

_____

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Investigation 8.1 Measuring continuous variation

See appendix for equipment list.

1. Choose one variable which occurs as a result of continuous variation (e.g. height, weight, hand span, or foot length) and write the variable you will be investigating here:

   _____

2. Select 30–50 classmates to be your sample. Measure the variable of interest (to one decimal place) and record the results in the space for raw data below.
3. Decide on appropriate frequency for the data, then record it as a tally chart in the space below.

Raw data

Tally chart

4. Summarise the features of your data in the table right. You can enter your data on a spreadsheet to make it easier to calculate if you want.
5. Plot the tally chart data as a histogram on the grid (next page).

Number of entries	
Sum	
Mean	
Standard deviation	

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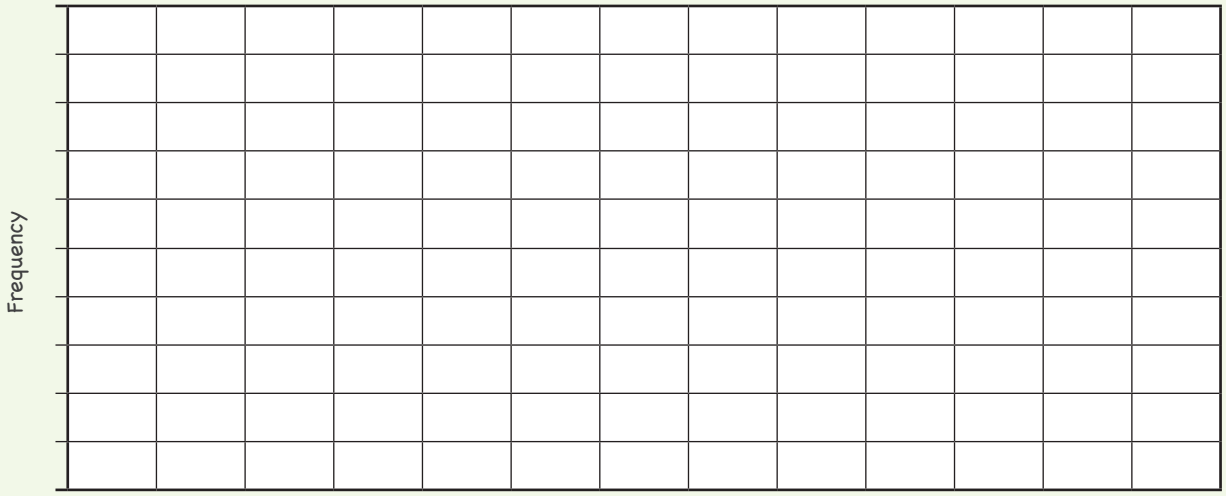
Variable: .....



3. (a) Describe the pattern of the distribution shown in your graph: _____

(b) What is the genetic basis of this distribution? Give a brief explanation of what this means: _____

(c) What is the importance of a large sample size when gathering data relating to a continuous variable?_____

4. Explain the differences between continuous and discontinuous variation, giving examples to illustrate your answer:

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99 Chapter Review: Did You Get It?

1. A breeder has two guinea pigs, one with black fur and the other with white. The two are bred together and all the offspring are black. Two of the offspring are then crossed. Four offspring are born one is white the rest are black.

   (a) What phenotype is being investigated here? _____

   (b) Which phenotypic trait is dominant? _____

2. Explain how a mutation might cause a new phenotype: _____

3. The photographs right show Arctic foxes in their summer (left) and winter (right) colouration:

   

   

   Jonathen Pie cc0

   (a) What feature is illustrated by these photographs?

   _____

   _____

   (b) Explain the likely mechanisms by which these changes in phenotype are regulated.

   _____

   _____

4. A student decides to investigate the width of a flower for a school project. She measures the diameter of forty of her chosen flower type from the local botanical gardens. The raw data are shown below:

Flower diameter (mm)
65, 40, 40, 66, 64, 42, 39, 67, 68, 38, 43, 60, 67, 38, 37, 37, 43, 60, 63, 67, 68, 67, 30, 34, 43, 44, 38, 71, 72, 70, 67, 69, 69, 31, 37, 39, 40, 44, 43, 73

   (a) Tally the data into a frequency table:

Tally chart of flower diameter (mm)

   (b) Graph the data on the grid (right):

   (c) Describe the shape of the graph and suggest one possible reason for the shape:

   _____

   _____

   _____

   _____

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CHAPTER 9

Patterns of Inheritance

Key terms

allele
autosomal dominant trait
autosomal recessive trait
codominance
dihybrid cross
genetic cross
genotype
heterozygous
homozygous
incomplete dominance
linked genes
locus
Mendelian inheritance
monohybrid cross
multiple alleles
multiple genes (=polygenes)
pedigree
phenotype
probability
Punnett square
recombination
sex linkage
trait
X-linkage

Pedigree charts and patterns of inheritance

Key skills and knowledge

Activity number

- ☐ 1 Analyse pedigree charts to trace the inheritance patterns of particular traits, including autosomal dominant, autosomal recessive, X-linked, and Y-linked traits. — 100 102
- ☐ 2 Develop your own set of guidelines for interpreting pedigree charts based on a range of examples. — 100

Genetic crosses

Key skills and knowledge

- ☐ 3 Understand the rules for calculating probability and apply them to predictions of the genotype and phenotype ratios of genetic crosses. — 101
- ☐ 4 Use Punnett squares to predict the frequencies of genotypes and phenotypes in monohybrid crosses and monohybrid test crosses. — 103 104
- ☐ 5 Use Punnett squares to predict the frequencies of genotypes and phenotypes in crosses involving incomplete dominance. Recall the features of this type of inheritance. — 105
- ☐ 6 Use Punnett squares to predict the frequencies of genotypes and phenotypes in crosses involving codominance. Recall the features of this type of inheritance. — 106
- ☐ 7 Using an example, explain how multiple allele systems allow for many possible dominance relationships. Use Punnett squares to predict the frequencies of genotypes and phenotypes in crosses involving codominance of multiple alleles. — 106
- ☐ 8 Explain what is meant by a sex-linked gene. What are the characteristics of inheritance of X-linked dominant traits? Of X-linked recessive traits? — 107 108
- ☐ 9 Use Punnett squares to determine genotypes and predict the outcomes of genetic crosses involving autosomal and sex linked monohybrid inheritance. — 107-109

Dihybrid inheritance and linked genes

Key skills and knowledge

- ☐ 10 Use Punnett squares to solve problems involving dihybrid inheritance of unlinked (independent), autosomal genes for two characteristics. — 110 113
- ☐ 11 Explain what is meant by genetic linkage (linked genes) and explain its biological consequences. Describe the dihybrid inheritance of linked genes. — 111-113
- ☐ 12 Explain how recombination of alleles can occur as a result of crossing over between linked genes. Explain how recombination is identified in the offspring of genetic crosses involving the inheritance of two characteristics. Know that a recombinant frequency of 50% generally means that the genes are not linked (they are on separate chromosomes and assorting independently). — 112
- ☐ 13 Use the chi-squared test to test the outcome of genetic crosses against predicted outcomes. Use the chi-squared test to provide evidence for genotype and linkage. — 113

100 Pedigree Charts

Key Idea: Pedigree charts are a way to graphically illustrate inheritance patterns over a number of generations. They are used to study the inheritance of genetic disorders and make it possible to follow the genetic history of an individual.

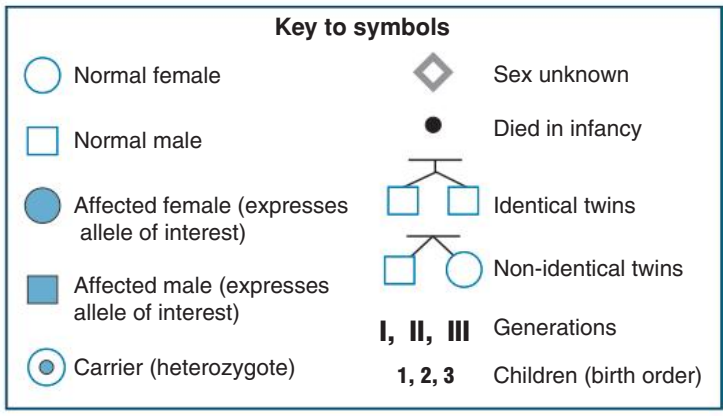
Pedigree charts

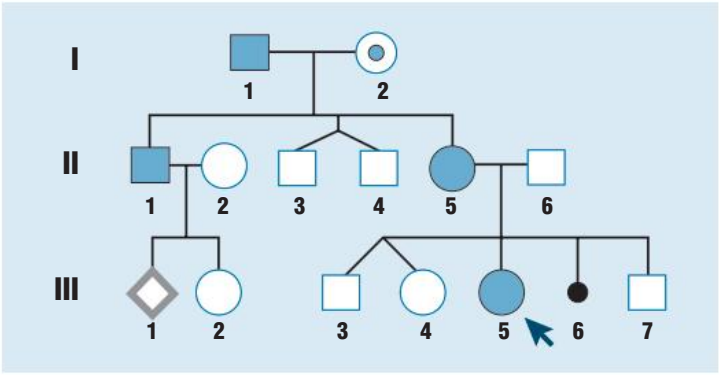
A pedigree chart is a diagram that shows the occurrence and appearance of a particular gene or trait from one generation to the next. In humans, pedigree charts are often used to analyse the inheritance of heritable conditions. In domestic animals, pedigree charts are often used to trace the inheritance of characteristics in selective breeding programmes for horses and dogs.

Pedigree charts use symbols to indicate an individual's particular traits. The key (right) explains the meaning of the symbols. Particular individuals are identified by their generation number and their order number in that generation. For example, **II-6** is the sixth person in the second row. The arrow indicates the person through whom the pedigree was discovered (i.e. who reported the condition).

If the chart on the right were illustrating a human family tree, it would represent three generations: grandparents (I-1 and I-2) with three sons and one daughter. Two of the sons (II-3 and II-4) are identical twins, but did not marry or have any children. The other son (II-1) married and had a daughter and another child (sex unknown). The daughter (II-5) married and had two sons and two daughters (plus a child that died in infancy).

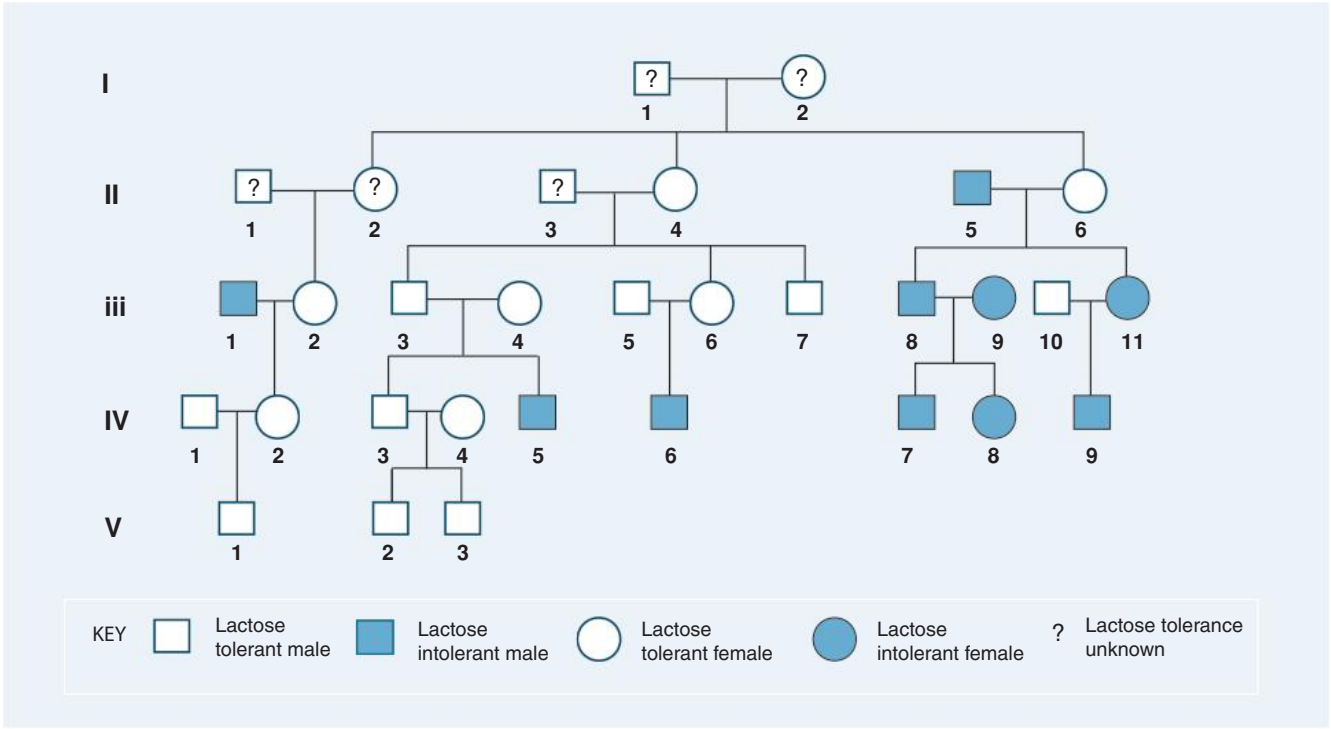
For the particular trait being studied, the grandfather was expressing the phenotype (showing the trait) and the grandmother was a carrier. One of their sons and one of their daughters also show the trait, together with one of their granddaughters (arrow).





The pedigree of lactose intolerance

Lactose intolerance is the inability to digest the milk sugar lactose. It occurs because some people do not produce lactase, the enzyme needed to break down lactose. The pedigree chart below was one of the original studies to determine the inheritance pattern of lactose intolerance. Researchers concluded that because two lactose tolerant parents can produce a lactose intolerant child, lactose intolerance must be a recessively inherited condition (it needs two copies of the gene for lactose intolerance to show up).



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1. **Autosomal recessive traits**

Albinos lack pigment in the hair, skin and eyes. This is an autosomal recessive trait.

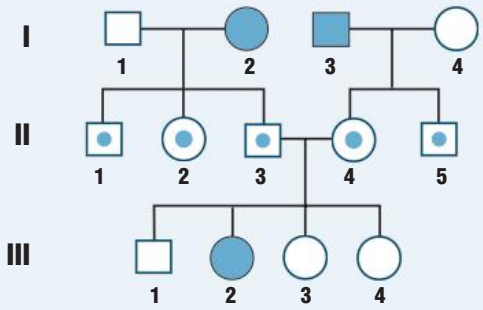
(a) Write the genotype for each of the individuals on the chart using the following letter codes: **PP** normal skin colour; **P-** normal, but unknown if homozygous; **Pp** carrier; **pp** albino.

(b) Why must the parents (II-3) and (II-4) be carriers of a recessive allele:

_____

_____

Albinism in humans



2. **Sex linked recessive traits**

Haemophilia is a disease where blood clotting is affected. A person can die from a simple bruise (which is internal bleeding). The clotting factor gene is carried on the X chromosome.

(a) Write the genotype for each of the individuals on the chart using the codes: **XY** normal male; **X_hY** affected male; **XX** normal female; **X_hX** female carrier; **X_hX_h** affected female:

(b) Why can males never be carriers? _____

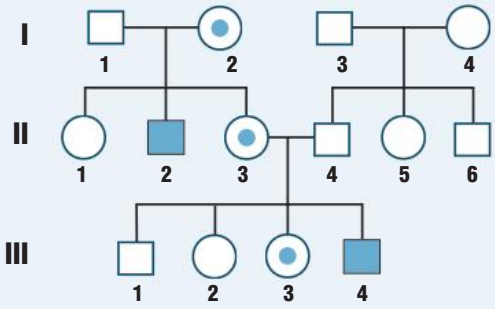
_____

_____

_____

_____

Haemophilia in humans



3. **Autosomal dominant traits**

An unusual trait found in some humans is woolly hair (not to be confused with curly hair). Each affected individual will have at least one affected parent.

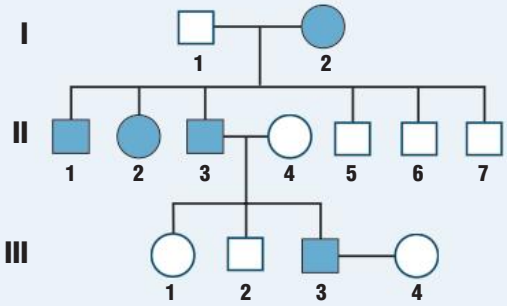
(a) Write the genotype for each of the individuals on the chart using the following letter codes:
WW woolly hair; **Ww** woolly hair (heterozygous); **W-** woolly hair, but unknown if homozygous; **ww** normal hair

(b) Describe a feature of this inheritance pattern that suggests the trait is the result of a **dominant** allele:

_____

_____

Woolly hair in humans



4. **Sex linked dominant traits**

A rare form of rickets is inherited on the X chromosome. All daughters of affected males will be affected. More females than males will show the trait.

(a) Write the genotype for each of the individuals on the chart using the following letter codes:
XY normal male; **X_RY** affected male; **XX** normal female; **X_{R-}** female (unknown if homozygous); **X_RX_R** affected female.

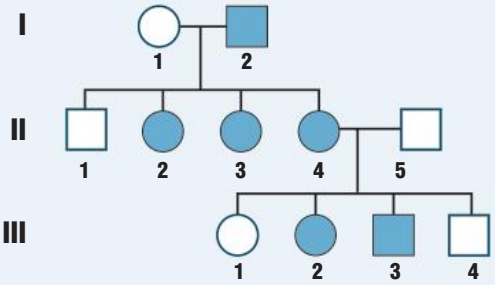
(b) Why will more females than males be affected?

_____

_____

_____

A rare form of rickets in humans



5. Using the examples on these two pages, make up your own set of guidelines for interpreting pedigree charts. How do you distinguish an autosomal inheritance pattern from an X-linked one? What are the features of autosomal recessive inheritance? Of autosomal dominant? Of X-linked dominant traits and X-linked recessive traits. Attach your summary to this page.

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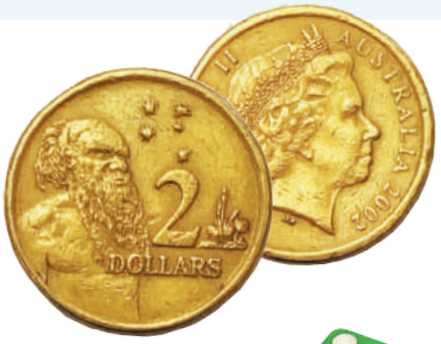
101 Probability in Genetics

Key Idea: Probability can be used to determine how likely it is an event will occur, or to quantify the statistical difference between means.

We cannot always predict events with absolute certainty, but we can use **probability** to calculate the likelihood of an event occurring. The probability of an event ranges from 0 to 1. The sum of all probabilities equals 1. In biology, probability is used to determine the statistical significance of an outcome or the probability of an event occurring, e.g. getting an offspring with a certain genotype and phenotype in a genetic cross.

Probability of an event happening =

$$\frac{\text{Number of ways it can happen}}{\text{Total number of outcomes}}$$



- Tossing a coin and predicting whether it will land heads (H) up or tails (T) up is a good example to illustrate probability.
- There are two possible outcomes; the coin will either land heads up or tails up, and only one outcome can occur at a time. Therefore the probability of a coin landing heads up is 1/2. The likelihood of a coin landing tails up is also 1/2.
- Remember probability is just an indication of how likely something will happen. Even though we predict that heads and tails will come up 50 times each if we toss a coin 100 times, it might not be exactly that.

1. Calculate the probability that a 6 will occur when you roll a single dice (die):

The rules for calculating probability

- Probability rules are used when we want to predict the likelihood of two events occurring together or when we want to determine the chances of one outcome over another.
- The rules are useful when we want to determine the probably of certain outcomes in genetic crosses, especially when large numbers of alleles are involved.
- The probability rule used depends on the situation.

PRODUCT RULE for independent events

For independent events, A & B, the probability (P) of them both occurring (A&B) = P(A) X P(B)

Example: If you roll two dice at the same time, what is the probability of rolling two sixes?
Solution: The probability of getting six on two dice at once is 1/6 x 1/6 = 1/36.

SUM RULE for mutually exclusive events

For mutually exclusive events, A & B, the probability (P) that one will occur (A or B) = P(A) + P(B)

Example: A single die is rolled. What are the chances of rolling a 2 **or** a 6?
Solution: P(A or B) = P(A) + P(B). 1/6 + 1/6 = 2/6 (1/3). There is a 1/3 chance that a 2 or 6 will be rolled.

2. In a cross Aa x Aa, use the sum rule to determine the probability of the offspring having a dominant phenotype:

3. Use the product rule to determine the probability of a first and second child born to the same parents both being boys:

4. In a cross of rabbits both heterozygous for genes for coat colour and length (BbLl x BbLl), determine the probability of the offspring being BbLl.
HINT: Calculate probabilities for Bb and Ll separately and then use the product rule. Test your calculation using the Punnett square (right).

5. In a cross of two individuals with various alleles of four unlinked genes: AaBbCCdd x AabbCcDd, explain how you would calculate the probability of getting offspring with the dominant phenotype for all four traits:

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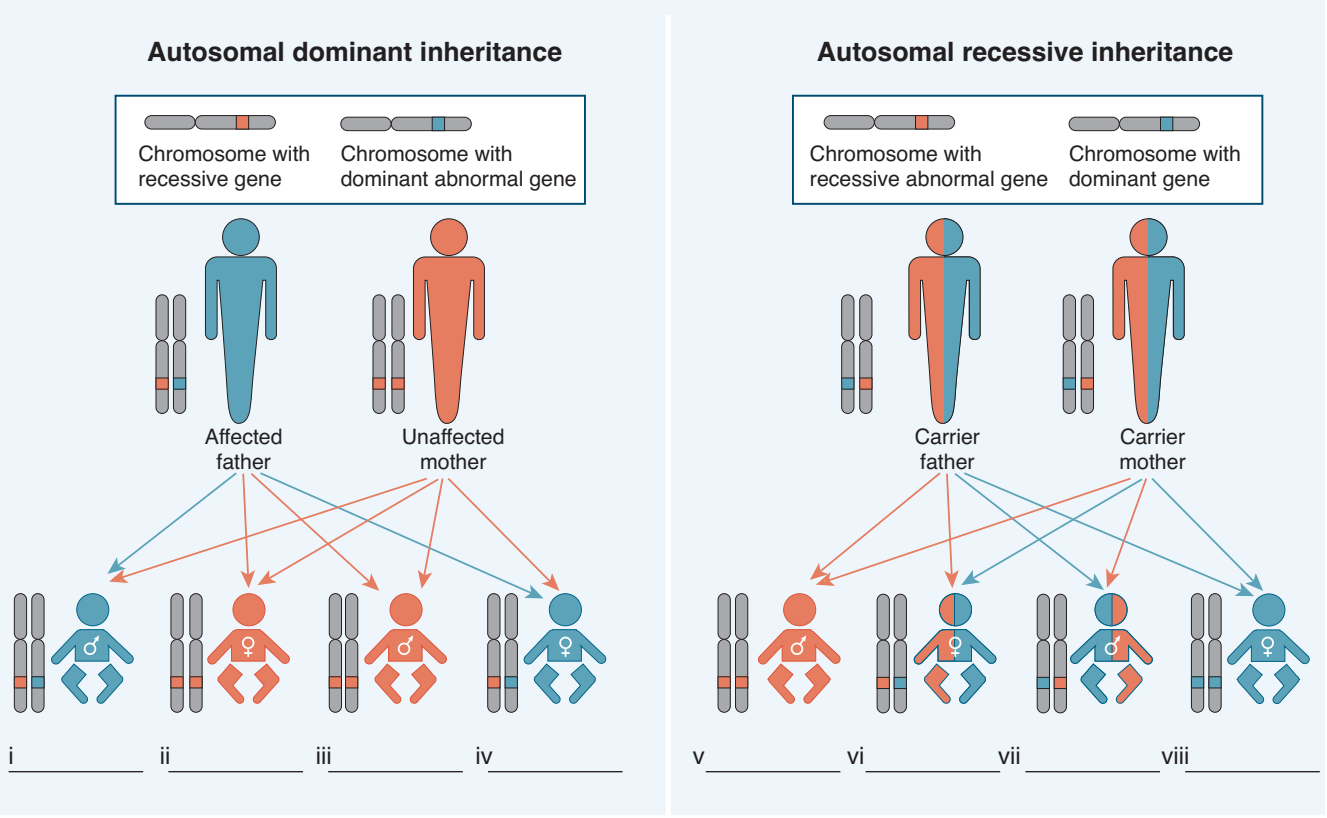
102 Autosomal Dominant and Recessive Inheritance

Key Idea: Autosomal dominant traits are always expressed regardless of whether there is one or two copies of the allele.

An autosomal gene refers to a gene that is carried on an autosome (not a sex chromosome). A dominant allele will always be expressed in the phenotype regardless of whether the individual has one copy (heterozygous) or two copies (homozygous) of the dominant allele. For alleles that cause a recognisable disease, an autosomal dominant condition is easily recognised because people with only one copy of the allele will be affected and show symptoms. In autosomal recessive inheritance, two copies of the gene must be present for the disease to occur. Individuals with only one copy of a gene are carriers, they do not have the disease but they can pass the gene on to their offspring.



1. Explain the inheritance pattern of an autosomal dominant allele: _____

2. Fill in the spaces (i-viii) in the diagram above to identify the children as **affected**, **carrier**, or **unaffected**. A carrier carries the mutated allele but does not show any symptoms of the disease.

3. The diagram above left shows inheritance when the father is heterozygous for the affected allele. Describe what the phenotype of the offspring would be if the father had been homozygous for the affected allele:

4. Contrast the pattern of inheritance for an autosomal dominant and an autosomal recessive condition:

5. Some diseases caused autosomal dominant alleles, such as Huntington's disease, do not become apparent until well into adulthood. Suggest how this might explain why such diseases persist in the population:

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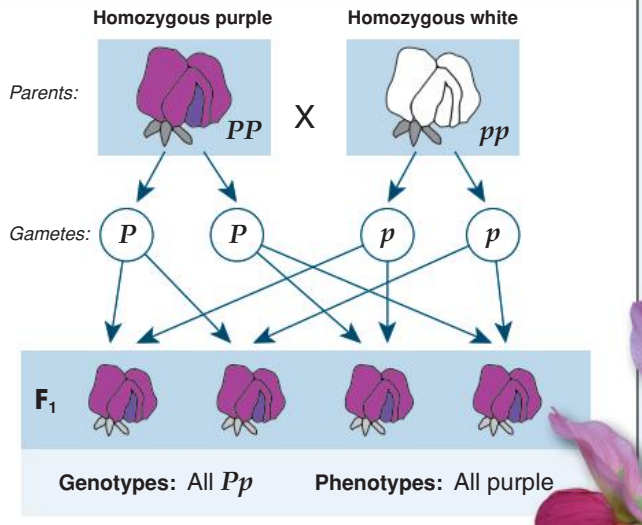
103 The Monohybrid Cross

Key Idea: The outcome of a cross depends on the parental genotypes. A true breeding parent is homozygous for the gene involved.

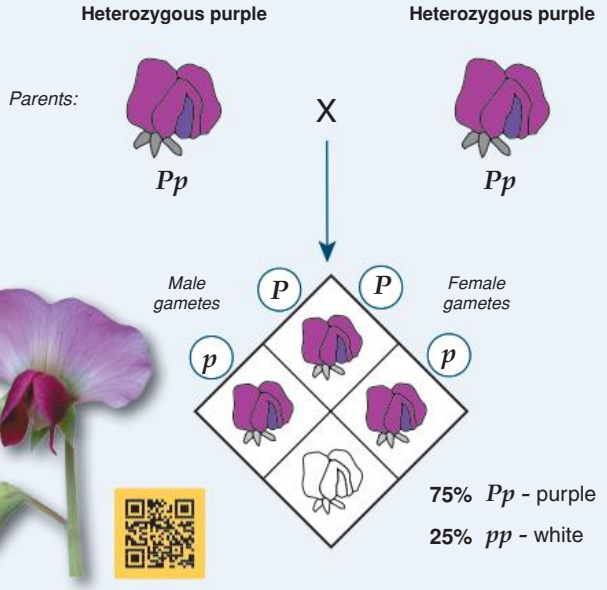
Examine the diagrams depicting monohybrid (single gene) inheritance. The F_1 generation by definition describes the offspring of a cross between distinctly different, **true-breeding** (homozygous) parents. A **back cross** refers to any cross between an offspring and one of its parents. If the back cross is to a homozygous recessive, it is diagnostic, and is therefore called a test cross.

Monohybrid cross F_1



A true-breeding organism is homozygous for the gene involved. The F_1 offspring of a cross between two **true breeding** parent plants are all purple (*Pp*).

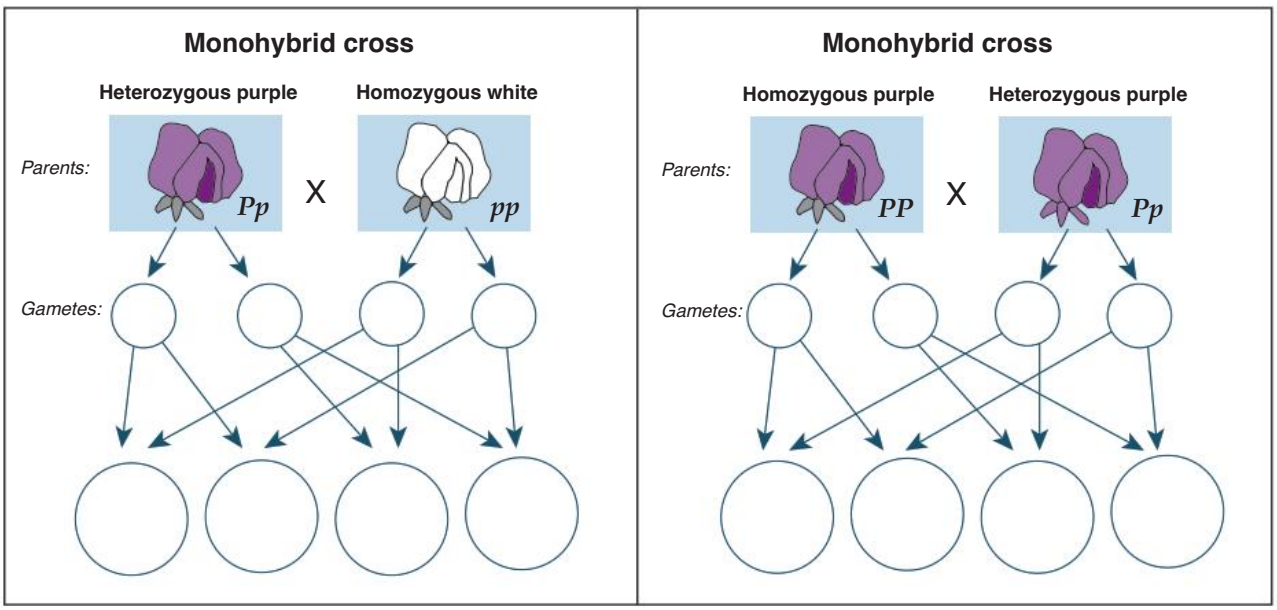
Monohybrid cross F_2



A cross between the F_1 offspring (*Pp x Pp*) would yield a 3:1 ratio in the F_2 of purple (*PP, Pp, Pp*) to white (*pp*).

1. Study the diagrams above and explain why white flower colour does not appear in the F_1 generation but reappears in the F_2 generation:

2. Complete the crosses below:



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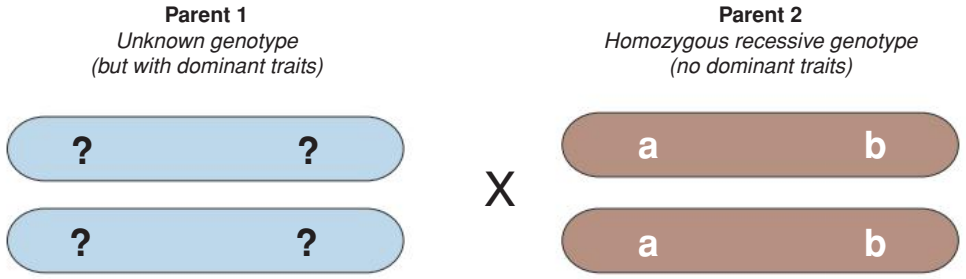
104 The Test Cross

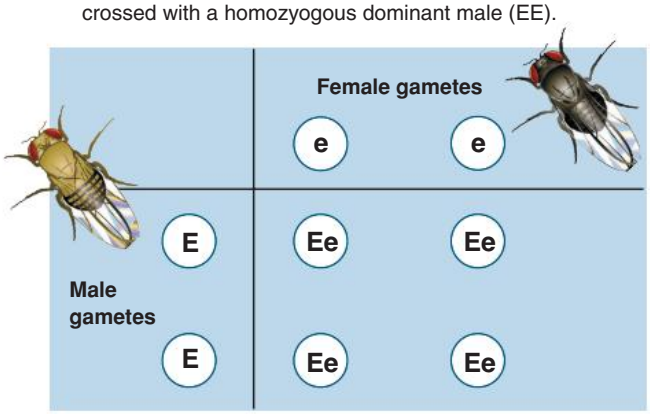
Key Idea: If an individual's genotype is unknown it can be determined using a test cross.

It is not always possible to determine an organism's genotype by its appearance because gene expression is complicated by patterns of dominance and by gene interactions. The test cross was developed by Mendel as a way to establish the genotype of an organism with the dominant phenotype for a particular trait. The principle is simple. The individual with the unknown genotype is bred with a homozygous recessive individual for the trait(s) of interest. The homozygous recessive can produce only one type of allele (recessive), so the offspring phenotypes will reveal the genotype of the unknown parent (below). A test cross can be used to determine the genotype of single or multiple genes in an individual.



The common fruit fly (*Drosophila melanogaster*) is often used to illustrate basic principles of inheritance because it has several genetic markers whose phenotypes are easily identified. Once such phenotype is body colour. Wild type (normal) Drosophila have yellow-brown bodies. The allele for yellow-brown body colour (E) is dominant. The allele for an ebony coloured body (e) is recessive. The test crosses below show the possible outcomes for an individual with homozygous and heterozygous alleles for ebony body colour.

A. A homozygous recessive female (ee) with an ebony body is crossed with a homozyogous dominant male (EE).

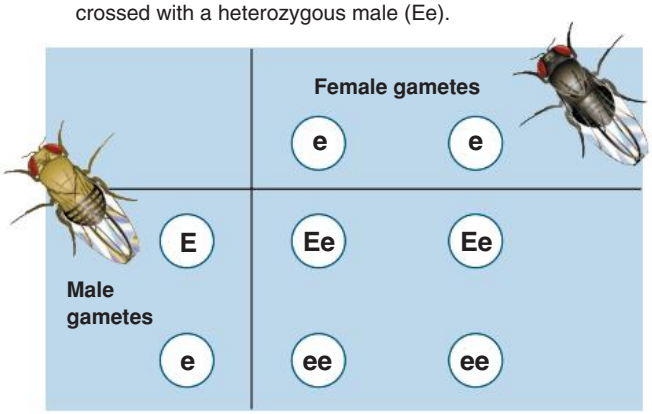


Cross A:

(a) Genotype frequency: 100% Ee

(b) Phenotype frequency: 100% yellow-brown

B. A homozygous recessive female (ee) with an ebony body is crossed with a heterozygous male (Ee).



Cross B:

(a) Genotype frequency: 50% Ee, 50% ee

(b) Phenotype frequency: 50% yellow-brown, 50% ebony

1. In *Drosophila*, the allele for brown eyes (b) is recessive, while the red eye allele (B) is dominant. How would you set up a **two gene test cross** to determine the genotype of a male who has a normal body colour and red eyes?

2. List all of the possible genotypes for the male *Drosophila*: _____

3. 50% of the resulting progeny are yellow-brown bodies with red eyes, and 50% have ebony bodies with red eyes.

   (a) What is the genotype of the male *Drosophila*? _____

   (b) Explain your answer: _____

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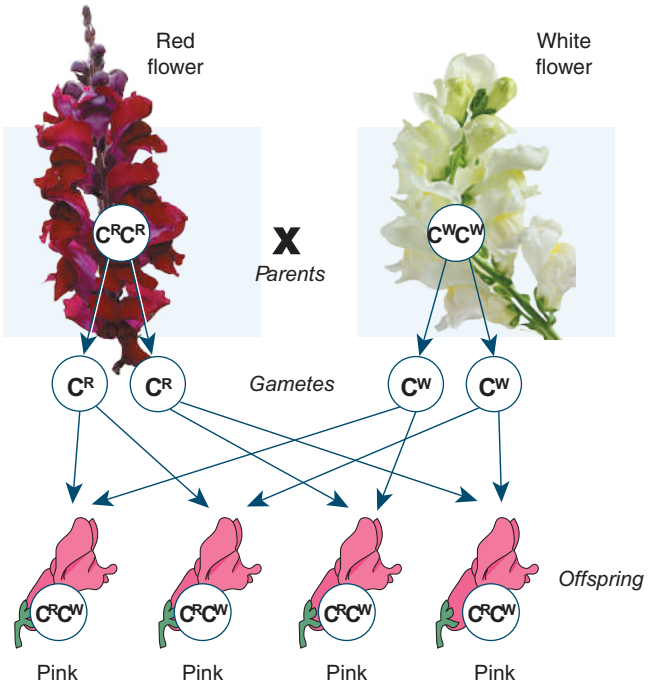
105 Crosses Involving Incomplete Dominance

Key Idea: Incomplete dominance describes the situation where the action of one allele does not completely mask the action of the other and neither allele shows dominance in determining the trait.

In incomplete dominance the heterozygous offspring are intermediate in phenotype between the contrasting homozygous parental phenotypes. In crosses involving incomplete dominance, the phenotype and genotype ratios are identical. The phenotype of heterozygous offspring results from the partial influence of both alleles. Examples of incomplete dominance includes flower colour in snapdragons (*Antirrhinum*) and four o'clocks (*Mirabilis*) (below).



Pure breeding snapdragons produce red or white flowers (left). When red and white-flowered parent plants are crossed a pink-flowered offspring is produced. If the offspring (F_1 generation) are then crossed together, all three phenotypes (red, pink, and white) are produced in the F_2 generation.

Four o'clocks (above) are also known to have flower colours controlled by alleles that show incomplete dominance. Pure breeding four o'clocks produce crimson, yellow or white flowers. Crimson flowers (above) crossed with yellow flowers produced reddish-orange flowers, while crimson flowers crossed with white flowers produce magenta (reddish-pink) flowers.

1. Explain how incomplete dominance of alleles differs from complete dominance: _____

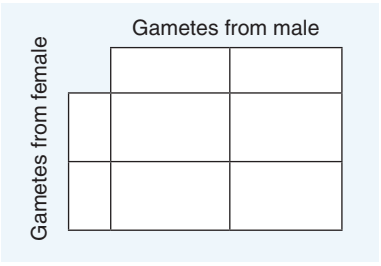
_____

_____

_____

_____

2. A plant breeder wanted to produce snapdragons for sale that were only pink or white (i.e. no red). Determine the phenotypes of the two parents necessary to produce these desired offspring. Use the Punnett square (right) to help you:



_____

_____

3. Another plant breeder crossed two four o'clocks, known to have its flower colour controlled by alleles that show incomplete dominance. Pollen from a magenta flowered plant was placed on the stigma of a crimson flowered plant.

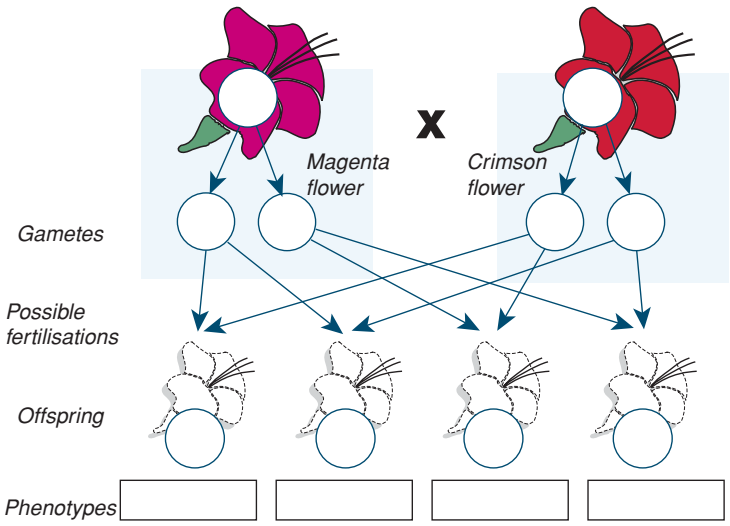
   (a) Fill in the spaces on the diagram on the right to show the genotype and phenotype for parents and offspring.

   (b) State the phenotype ratio:

   _____

   _____

   _____

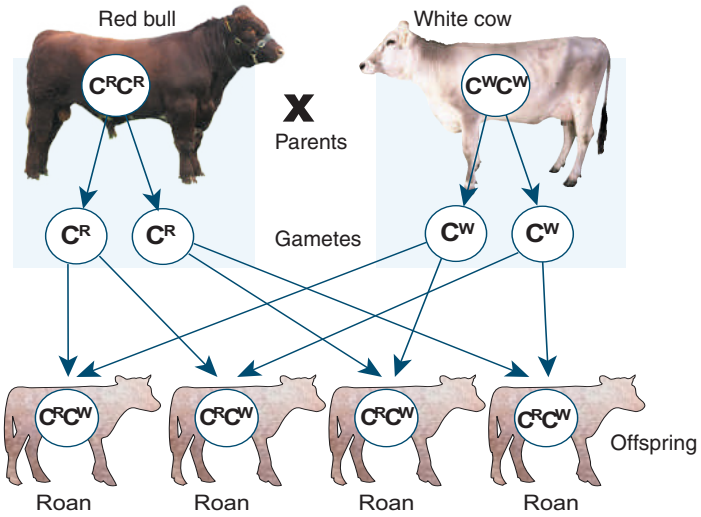


ISBN: 978-1-98-856636-8

106 Crosses Involving Codominance

Key Idea: In the inheritance of codominant alleles, neither allele is recessive. Both alleles are equally and independently expressed in the heterozygote.

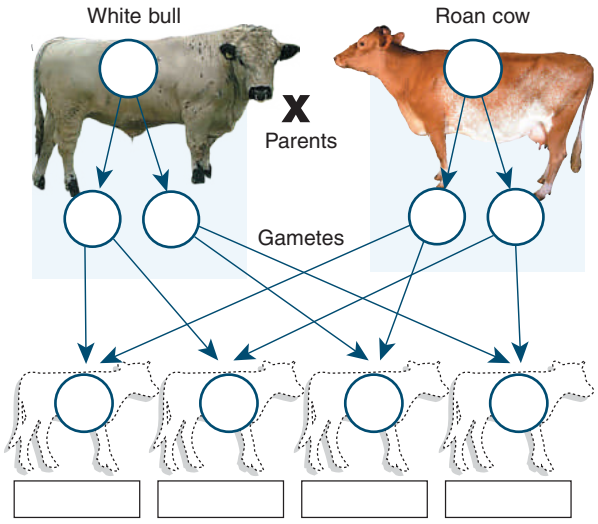
Codominance is an inheritance pattern in which both alleles in a heterozygote contribute to the phenotype and both alleles are independently and equally expressed. Examples include the human blood group AB and certain coat colours in horses and cattle. Reddish coat colour is equally dominant with white. Animals that have both alleles have coats that are roan (both red and white hairs are present).



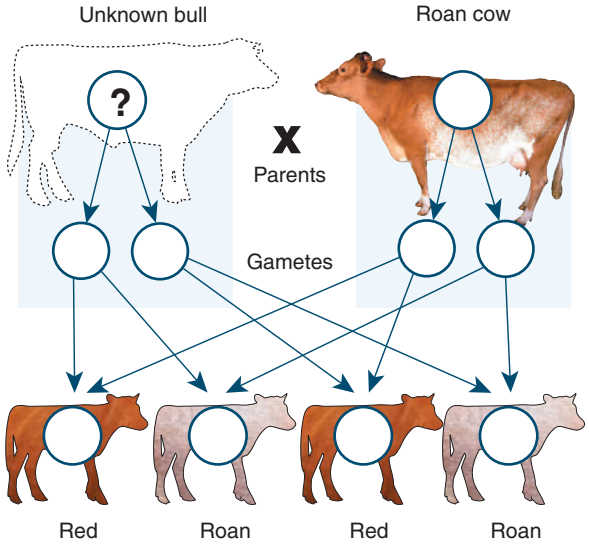
In the shorthorn cattle breed, coat colour is inherited. White shorthorn parents always produce calves with white coats. Red parents always produce red calves. When a red parent mates with a white one, the calves have a coat colour that is different from either parent; a mixture of red and white hairs, called roan. Use the example (left) to help you to solve the problems below.

1. Explain how codominance of alleles can result in offspring with a phenotype that is different from either parent:

2. A white bull is mated with a roan cow (right):
   (a) Fill in the spaces to show the genotypes and phenotypes for parents and calves:
   (b) What is the phenotype ratio for this cross?
   (c) How could a cattle farmer control the breeding so that the herd ultimately consisted of only red cattle:



3. A farmer has only roan cattle on his farm. He suspects that one of the neighbours' bulls may have jumped the fence to mate with his cows earlier in the year because half the calves born were red and half were roan. One neighbour has a red bull, the other has a roan.
   (a) Fill in the spaces (right) to show the genotype and phenotype for parents and calves.
   (b) Which bull serviced the cows? red or roan (delete one)



4. Describe the classical phenotypic ratio for a codominant gene resulting from the cross of two heterozygous parents (e.g. a cross between two roan cattle):

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- The human ABO blood group system also shows codominance. The four common blood groups of the human 'ABO blood group system' are determined by three alleles: A, B, and O. The ABO antigens consist of sugars attached to the surface of red blood cells. The alleles code for enzymes (proteins) that join these sugars together.
- The allele O is recessive. It produces a non-functioning enzyme that cannot make any changes to the basic sugar molecule.
- The other two alleles (A, B) are codominant and are expressed equally. They each produce a different functional enzyme that adds a different, specific sugar to the basic sugar molecule.
- The blood group A and B antigens are able to react with antibodies present in the blood of other people so blood must always be matched for transfusion.

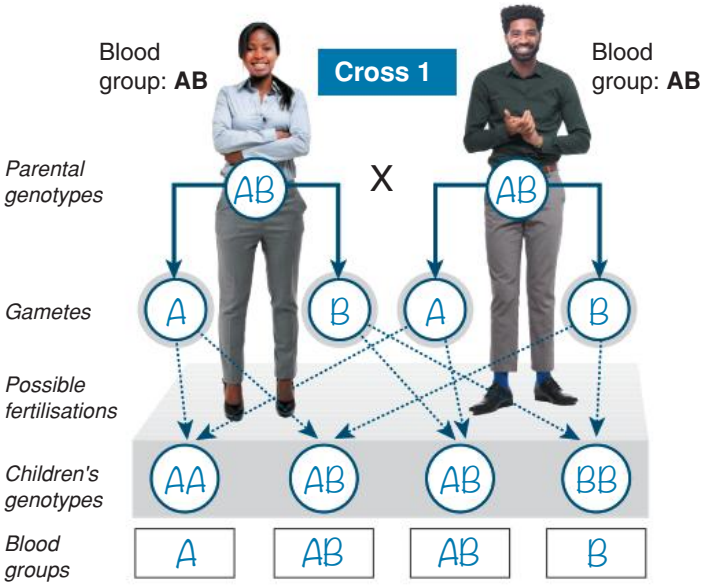
Recessive allele: ***O*** produces a non-functioning protein
Dominant allele: ***A*** produces an enzyme which forms **A antigen**
Dominant allele: ***B*** produces an enzyme which forms **B antigen**

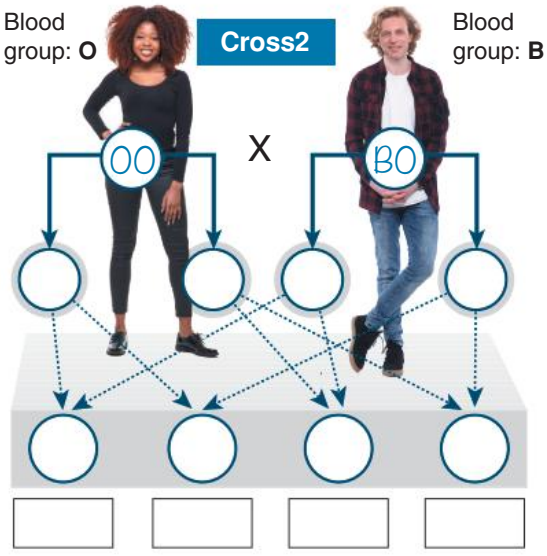
If a person has the **AO** allele combination then their blood group will be group **A**. The presence of the recessive allele has no effect on the blood group in the presence of a dominant allele. Another possible allele combination that can create the same blood group is **AA**.

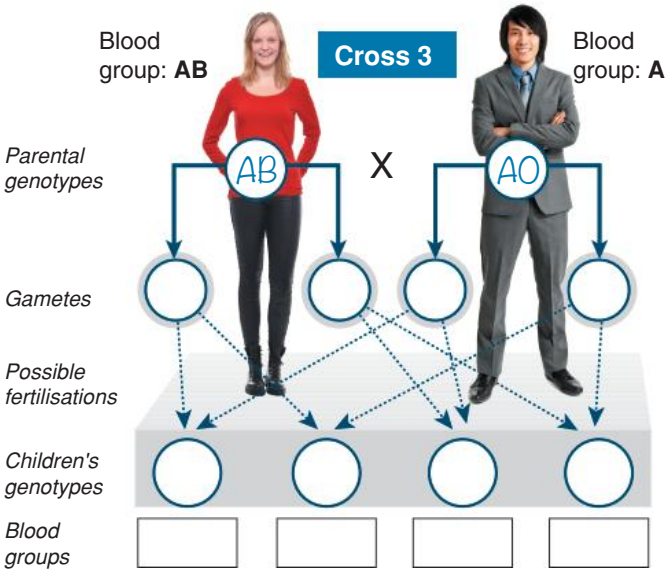
Blood group (phenotype)	Possible genotypes	Frequency in Australia
O	*OO*	49%
A	*AA AO*	38%
B		10%
AB		3%

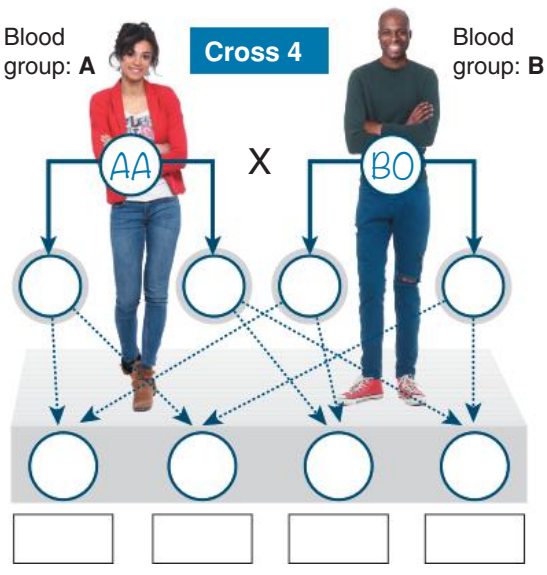
5. Use the information above to complete the table for the possible genotypes for blood group B and group AB.

6. Below are four crosses possible between couples of various blood group types. The first example has been completed for you. Complete the genotype and phenotype for the other three crosses below:









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107 Sex Linkage

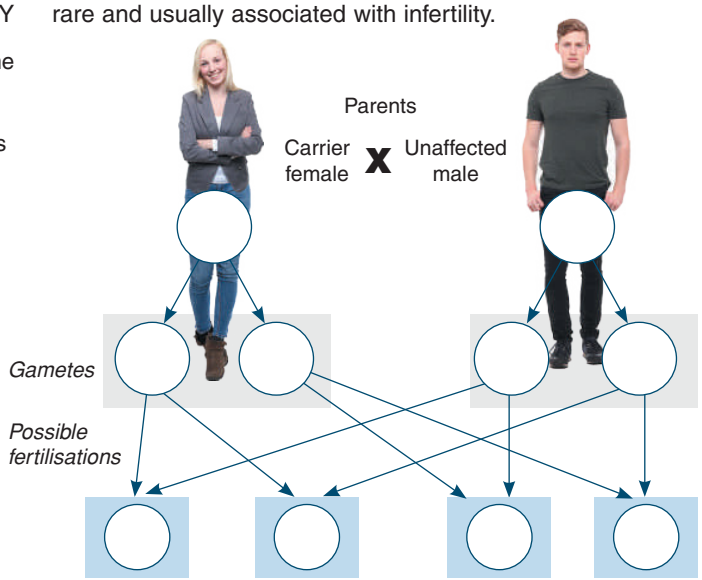
Key Idea: Many genes on the X chromosome do not have a match on the Y chromosome. In males, which are XY, a recessive allele on the X chromosome will be expressed.

Sex linkage refers to the way genes on the sex chromosomes are inherited and expressed. In humans, the sex chromosomes are X and Y, but sex linkage usually involves genes on the X chromosome, which has many more genes than the Y chromosome. X-linked recessive traits are usually seen only in males (XY) and occur rarely in the females (XX) because females may be heterozygous (carriers). X-linked dominant traits do not necessarily affect males more than females. In humans, recessive sex linked genes are responsible for a number of heritable disorders in males. Y-linked disorders are rare and usually associated with infertility.

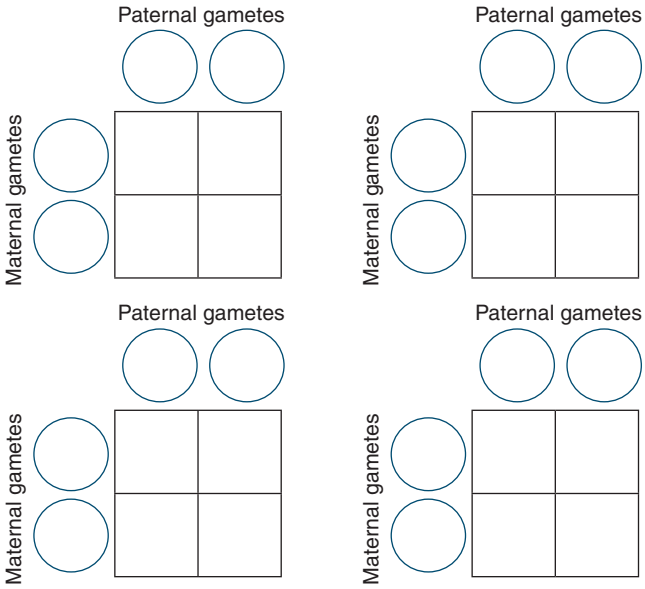
Haemophilia is a recessive disorder linked to the X-chromosome that results in ineffective blood clotting when a blood vessel is damaged. The most common type, haemophilia A, occurs in 1 in 5000 male births. Any male who carries the gene will express the phenotype. Haemophilia is extremely rare in women.

1. A couple wish to have children. The woman knows she is a carrier for haemophilia. The man is not a haemophiliac. Use the notation X^h for haemophilia and X^H for the dominant allele to complete the diagram on the right including the parent genotypes, gametes and possible fertilisations. Write the genotypes and phenotypes in the table below.

	Genotypes	Phenotypes
Male children		
Female children		



2. (a) A second couple also wish to have children. The woman knows her maternal grandfather was a haemophiliac, but neither her mother or father were. Determine the probability she is a carrier (X^HX^h) Use the Punnett squares, right, to help you:



(b) The man is not a haemophiliac. Determine the probability that their first male child will have haemophilia. Use the Punnett squares to help you:

3. The gene for red-green colour vision is carried on the X chromosome. If the gene is faulty, colour blindness (X^b) will occur in males. Red-green colour blindness occurs in about 8% of males but in fewer than 1% of females.

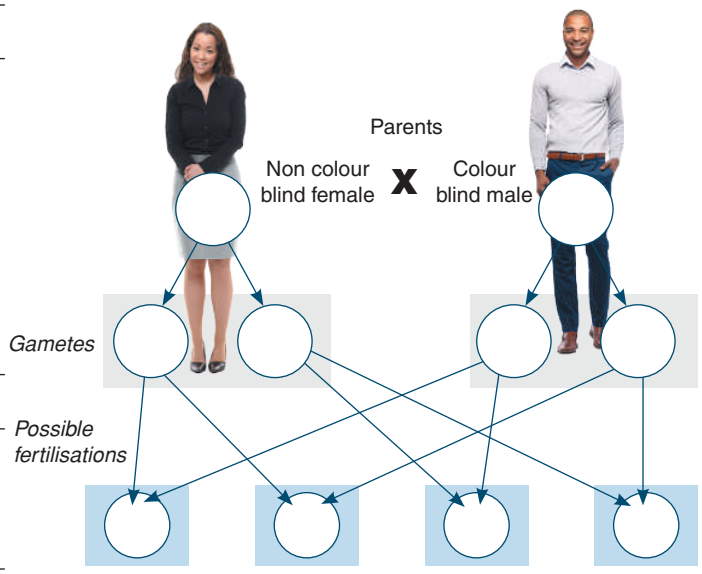
A colour blind man has children with a woman who is not colour blind. The couple have four children: 1 non colour blind son, 1 colour blind son, 2 non colour blind daughters. Describe the mother's:

(a) Genotype: _____

(b) Phenotype: _____

(c) Identify the genotype not possessed by any of the children:

_____



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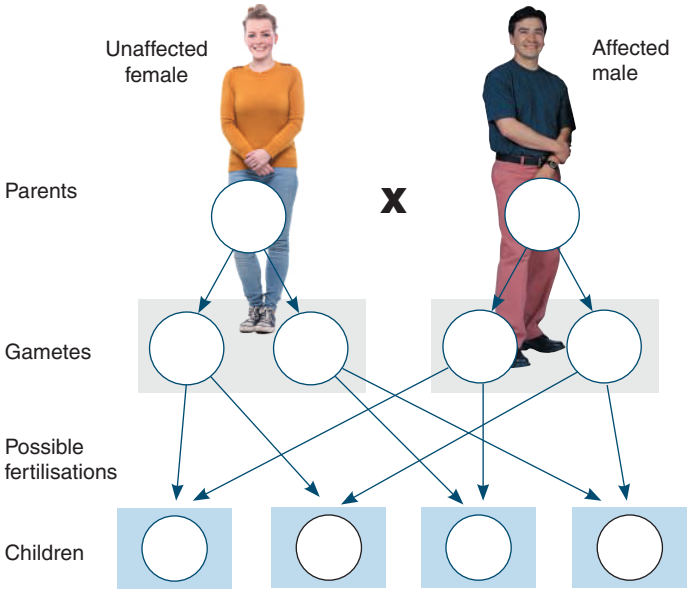
Dominant allele in humans

A rare form of rickets in humans is determined by a dominant allele of a gene on the X chromosome (it is not found on the Y chromosome). This condition is not successfully treated with vitamin D therapy. The allele types, genotypes, and phenotypes are as follows:

Allele types		Genotypes		Phenotypes
X^R	= affected by rickets	X^RX^R, X^RX	=	Affected female
X	= unaffected	X^RY	=	Affected male
		XX, XY	=	Unaffected female, unaffected male

As a genetic counsellor you are presented with a couple where one of them has a family history of this disease. The male is affected by this disease and the female is unaffected. The couple, who are thinking of starting a family, would like to know what their chances are of having a child born with this condition. They would also like to know what the probabilities are of having an affected boy or affected girl. Use the symbols above to complete the diagram right and determine the probabilities stated below (expressed as a proportion or percentage).



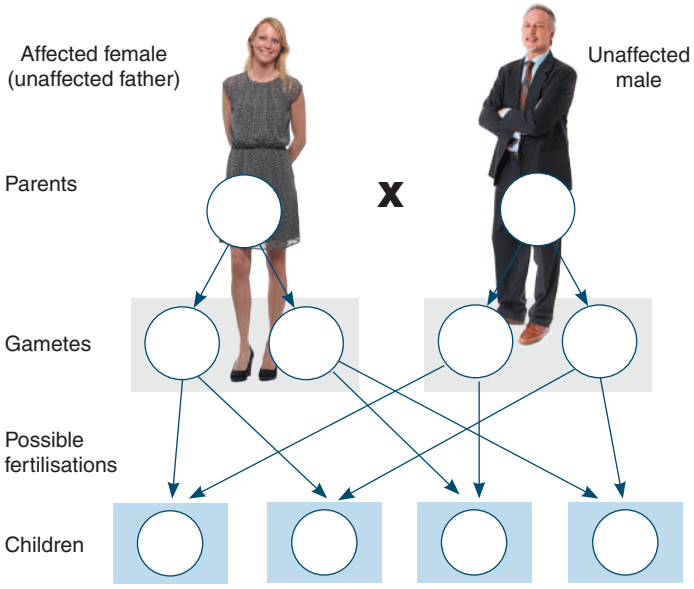
4. Determine the probability of having:

   (a) Affected children: _____

   (b) An affected girl: _____

   (c) An affected boy: _____

Another couple with a family history of the same disease also come in to see you to obtain genetic counselling. In this case, the male is unaffected and the female is affected. The female's father was not affected by this disease. Determine what their chances are of having a child born with this condition. They would also like to know what the probabilities are of having an affected boy or affected girl. Use the symbols above to complete the diagram right and determine the probabilities stated below (expressed as a proportion or percentage).



5. Determine the probability of having:

   (a) Affected children: _____

   (b) An affected girl: _____

   (c) An affected boy: _____

6. Why are males much more likely to inherit X-linked recessive disorders than females?

_____

_____

_____

7. From what you know about sex linkage, what two features could you use to detect a Y-linked disorder in a pedigree?

   (a) _____

   (b) _____

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108 Inheritance Patterns

Key Idea: Sex-linked traits and autosomal traits have different inheritance patterns.

Complete the following monohybrid crosses for different types of inheritance patterns in humans: autosomal recessive, autosomal dominant, sex linked recessive, and sex linked dominant inheritance.

1. Inheritance of autosomal recessive traits

Example: *Albinism*

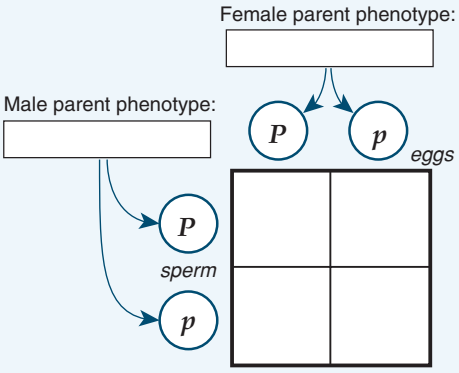
Albinism (lack of pigment in hair, eyes and skin) is inherited as an autosomal recessive allele (not sex-linked).

Using the codes: **PP** (not albino) **Pp** (carrier)
pp (albino)

(a) Enter the parent phenotypes and complete the Punnett square for a cross between two carrier genotypes.
(b) Give the ratios for the phenotypes from this cross.

Phenotype ratios: _____

_____



2. Inheritance of autosomal dominant traits

Example: *Woolly hair*

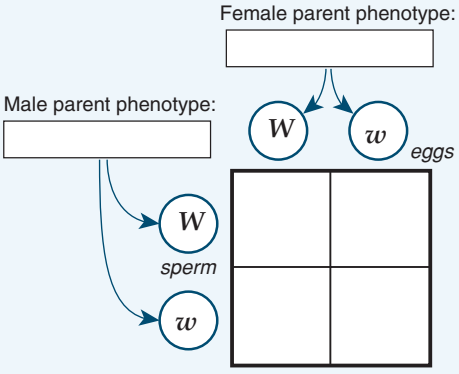
Woolly hair is inherited as an autosomal dominant allele. Each affected individual will have at least one affected parent.

Using the codes: **WW** (woolly hair)
Ww (woolly hair, heterozygous)
ww (hair not woolly)

(a) Enter the parent phenotypes and complete the Punnett square for a cross between two heterozygous individuals.
(b) Give the ratios for the phenotypes from this cross.

Phenotype ratios: _____

_____



3. Inheritance of sex linked recessive traits

Example: *Haemophilia*

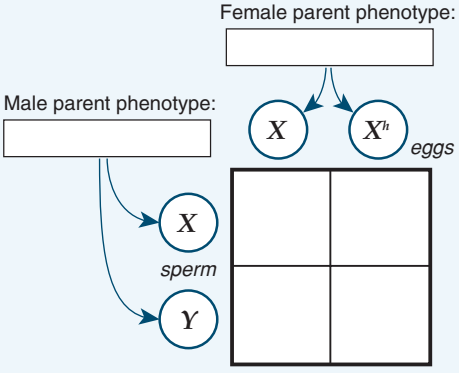
Inheritance of haemophilia is sex linked. Males with the recessive (haemophilia) allele, are affected. Females can be carriers.

Using the codes: **XX** (unaffected female)
X^hX (carrier female)
X^hX^h (haemophiliac female)
XY (unaffected male)
X^hY (haemophiliac male)

(a) Enter the parent phenotypes and complete the Punnett square for a cross between an unaffected male and a carrier female.
(b) Give the ratios for the phenotypes from this cross.

Phenotype ratios: _____

_____



4. Inheritance of sex linked dominant traits

Example: *Sex linked form of rickets*

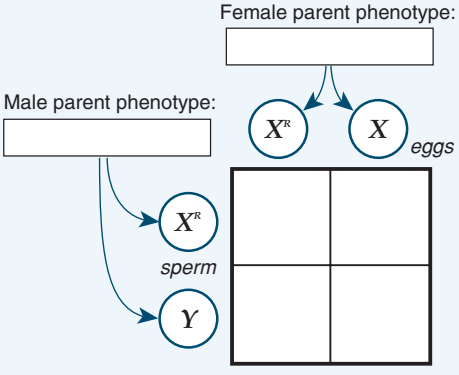
A rare form of rickets is inherited on the X chromosome.

Using the codes: **XX** (unaffected female); XY (unaffected male)
X^RX (affected heterozygote female)
X^RX^R (affected female)
X^RY (affected male)

(a) Enter the parent phenotypes and complete the Punnett square for a cross between an affected male and heterozygous female.
(b) Give the ratios for the phenotypes from this cross.

Phenotype ratios: _____

_____



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109 Problems Involving Monohybrid Crosses

Key Idea: For monohybrid crosses involving autosomal unlinked genes, the offspring appear in predictable ratios.

Test your understanding of monohybrid crosses by solving these problems involving the inheritance of a single gene.

1. A dominant gene (**W**) produces wire-haired texture in dogs; its recessive allele () produces smooth hair. A group of heterozygous wire-haired individuals are crossed and their progeny are then test-crossed. Determine the expected genotypic and phenotypic ratios among the test cross progeny:

2. In sheep, black wool is due to a recessive allele (**b**) and white wool to its dominant allele (**B**). A white ram is crossed to a white ewe. Both animals carry the black allele (**b**). They produce a white ram lamb, which is then back crossed to the female parent. Determine the probability of the **back cross** offspring being black:

3. A recessive allele, **a**, is responsible for albinism, an inability to produce or deposit melanin in tissues. Humans and a variety of other animals can exhibit this phenotype. In each of the following cases, determine the possible genotypes of the mother and father, and of their children:

   (a) Both parents have normal phenotypes; some of their children are albino and others are unaffected: _____

   (b) Both parents are albino and have only albino children: _____

   (c) The woman is unaffected, the man is albino, and they have one albino child and three unaffected children:

4. Two mothers give birth to sons at a busy hospital. The son of the first couple has haemophilia, a recessive, X-linked disease. Neither parent from couple #1 has the disease. The second couple has an unaffected son, despite the fact that the father has haemophilia. The two couples challenge the hospital in court, claiming their babies must have been swapped at birth. You must advise as to whether or not the sons could have been swapped. What would you say?

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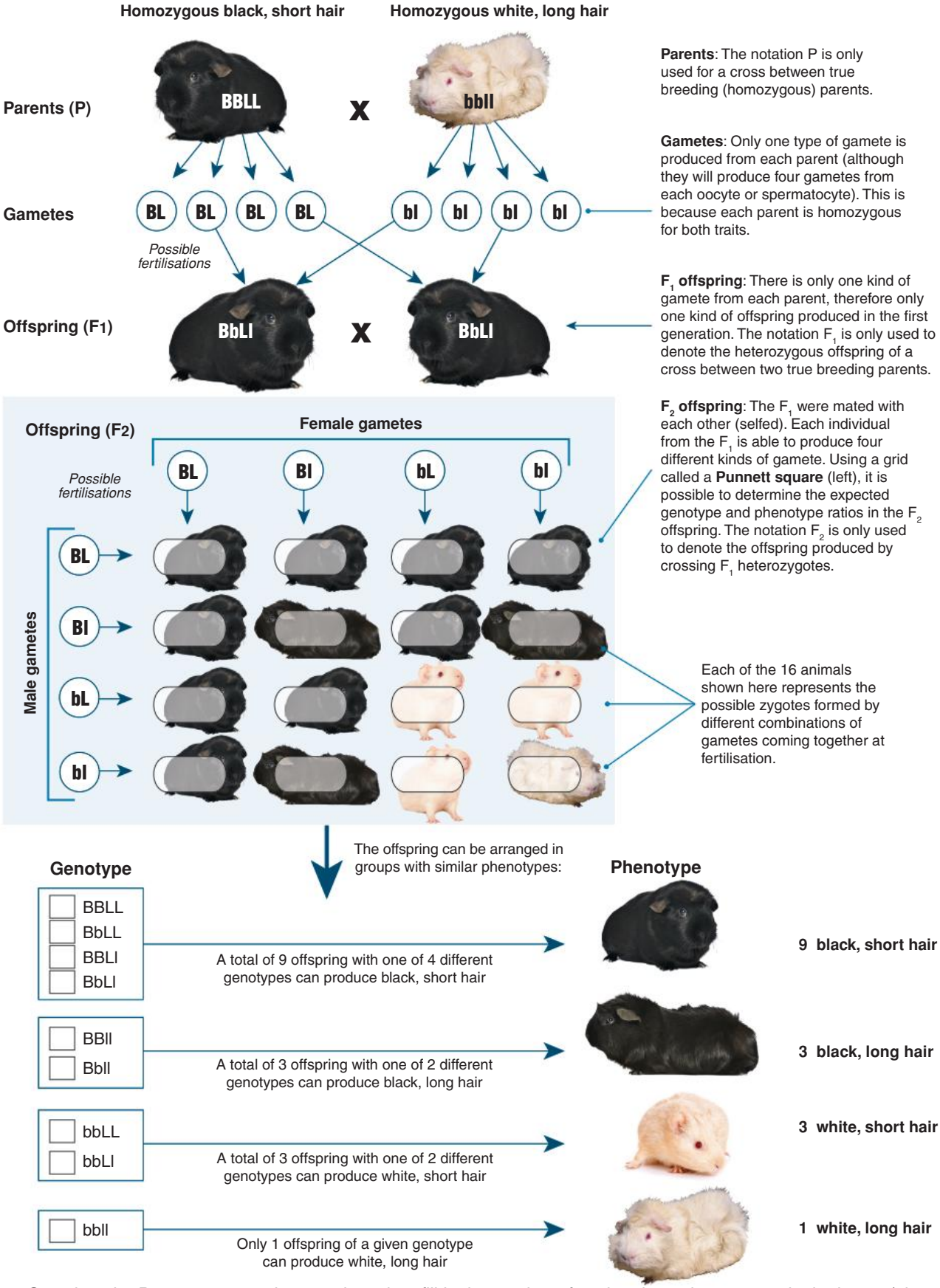
110 Dihybrid Inheritance

Key Idea: A dihybrid cross studies the inheritance pattern of two genes. In crosses involving unlinked autosomal genes, the offspring occur in predictable ratios.

There are four types of gamete produced in a cross involving two genes, where the genes are on separate chromosomes and assort independently. The two genes in the example of guinea pigs below are on separate chromosomes and control two unrelated characteristics, **coat colour** and **length**. Black (**B**) and short (**L**) are dominant to white and long. S is not used to denote short, because it is used for the spotting gene.



Parents: The notation P is only used for a cross between true breeding (homozygous) parents.

Gametes: Only one type of gamete is produced from each parent (although they will produce four gametes from each oocyte or spermatocyte). This is because each parent is homozygous for both traits.

F_1 offspring: There is only one kind of gamete from each parent, therefore only one kind of offspring produced in the first generation. The notation F_1 is only used to denote the heterozygous offspring of a cross between two true breeding parents.

F_2 offspring: The F_1 were mated with each other (selfed). Each individual from the F_1 is able to produce four different kinds of gamete. Using a grid called a **Punnett square** (left), it is possible to determine the expected genotype and phenotype ratios in the F_2 offspring. The notation F_2 is only used to denote the offspring produced by crossing F_1 heterozygotes.

Each of the 16 animals shown here represents the possible zygotes formed by different combinations of gametes coming together at fertilisation.

1. Complete the Punnett square above and use it to fill in the number of each guinea pig genotype in the boxes (above left).

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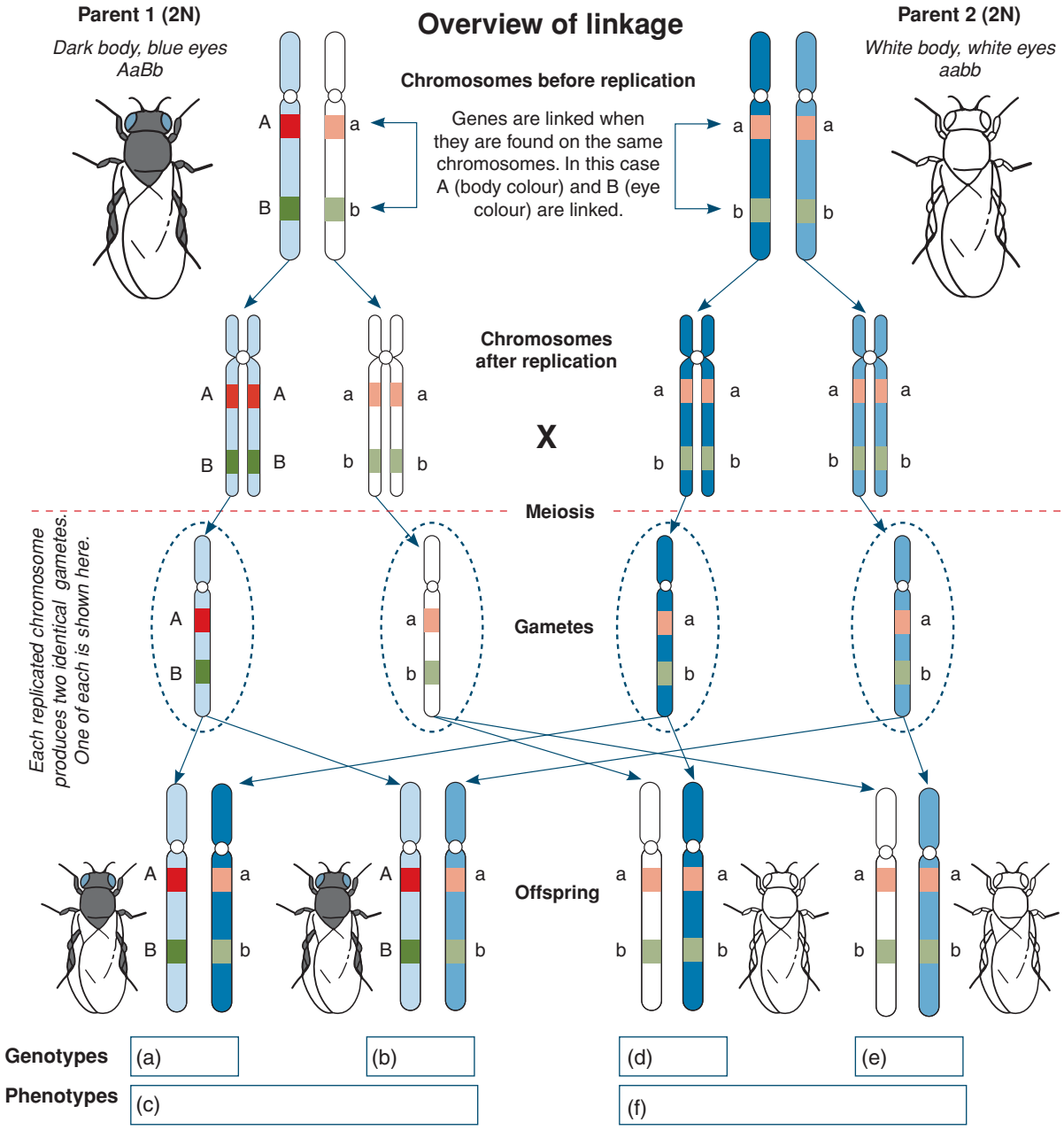
111 Inheritance of Linked Genes

Key Idea: Linked genes tend to be inherited together. Linkage reduces the genetic variation in the offspring.

Genes are said to be linked when they are on the same chromosome. Linked genes tend to be inherited together. The likelihood of crossing over between linked genes decreases when genes are closer together. In genetic crosses, linkage is indicated when a greater proportion of the offspring are of the parental type (than would be expected if the alleles were on separate chromosomes and assorting independently). Linkage reduces the genetic variation in the offspring.



Possible offspring

Only two kinds of genotype combinations are possible. They are they same as the parent genotype.

1. Complete the diagram above by writing the genotypes and phenotypes in the boxes provided:

2. What is the effect of linkage on the inheritance of genes? _____

_____

3. Explain how linkage decreases the amount of genetic variation in the offspring: _____

_____

_____

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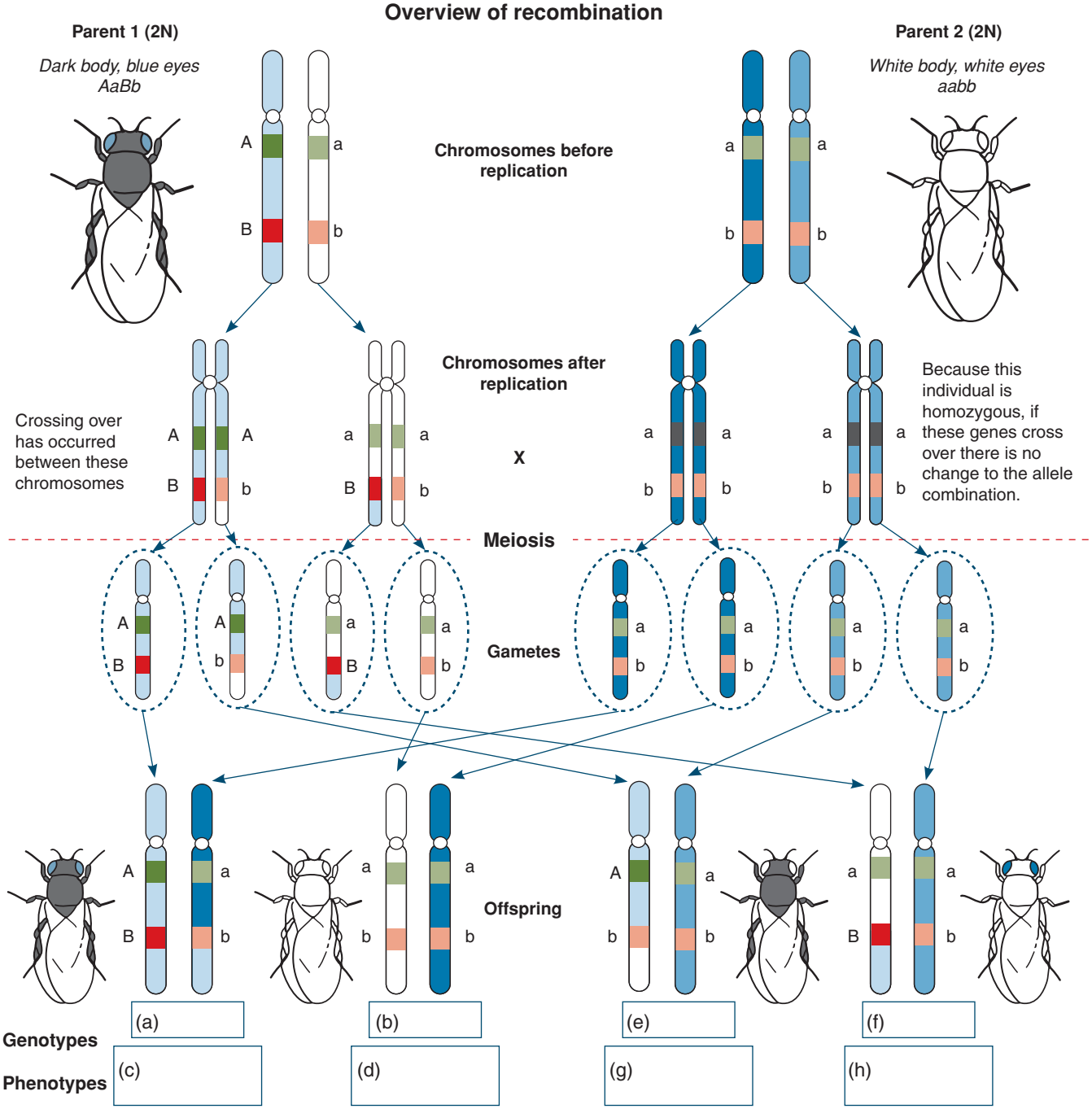
112 Recombination and Dihybrid Inheritance

Key Idea: Recombination is the exchange of alleles between homologous chromosomes as a result of crossing over. Recombination increases the genetic variation in the offspring. The alleles of parental linkage groups can separate in crossing over so that new associations of alleles are formed in the gametes (alleles are reshuffled). Offspring formed from these gametes show combinations of characteristics not seen in the parents and are called **recombinants**. In contrast to linkage, recombination increases genetic variation in the offspring. Recombination between the alleles of parental linkage groups is indicated by the appearance of non-parental types in the offspring

Overview of recombination



Non-recombinant offspring
These two offspring show allele combinations that are expected as a result of independent assortment during meiosis. Also called parental types.

Recombinant offspring
These two offspring show unexpected allele combinations. They can only arise if one of the parent's chromosomes has undergone crossing over.

1. Complete the diagram above by writing the genotypes and phenotypes in the boxes provided:

2. Describe the effect of recombination on the inheritance of genes: _____

_____

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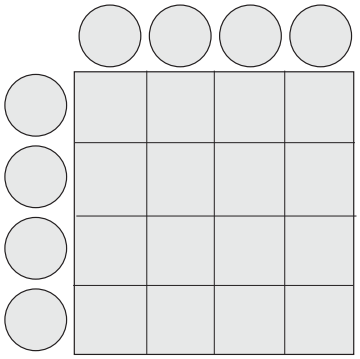
113 Problems Involving Dihybrid Crosses

Key Idea: For dihybrid crosses involving autosomal unlinked genes, the offspring appear in predictable ratios.

Test your understanding of dihybrid inheritance by solving problems involving the inheritance of two genes.

1. In rabbits, spotted coat **S** is dominant to solid colour **s**, while for coat colour, black **B** is dominant to brown **b**. A brown spotted rabbit is mated with a solid black one and all the offspring are black spotted (the genes are not linked).



   (a) State the genotypes:

   Parent 1: _____

   Parent 2: _____

   Offspring: _____

   (b) Use the Punnett square to show the outcome of a cross between the F_1 (the F_2):

   (c) Using ratios, state the phenotypes of the F_2 generation: _____

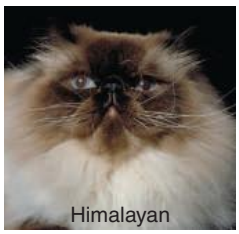
   _____

   _____

2. The Himalayan colour-pointed, long-haired cat is a breed developed by crossing a pedigree (true-breeding), uniform-coloured, long-haired Persian with a pedigree colour-pointed (darker face, ears, paws, and tail) short-haired Siamese.


Persian


Siamese

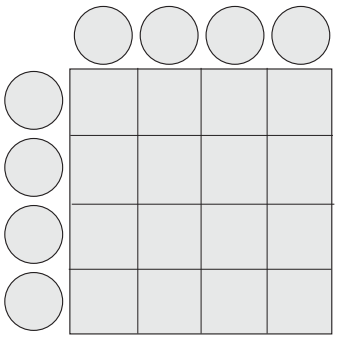

Himalayan

   The genes controlling hair colouring and length are on separate chromosomes: uniform colour **U**, colour pointed **u**, short hair **S**, long hair **s**.

   (a) Using the symbols above, indicate the genotype of each breed below its photograph (above, right). _____ _____ _____

   (b) State the genotype of the F_1 (Siamese X Persian): _____

   (c) State the phenotype of the F_1: _____



   (d) Use the Punnett square to show the outcome of a cross between the F_1 (the F_2):

   (e) State the ratio of the F_2 that would be Himalayan: _____

   (f) State whether the Himalayan would be true breeding: _____

   (g) State the ratio of the F_2 that would be colour-point, short-haired cats: _____

3. A *Drosophila* male with genotype **CucuEbeb** (straight wing, grey body) is crossed with a female with genotype **cucuebeb** (curled wing, ebony body). The phenotypes of the F_1 were recorded and the percentage of each type calculated. The percentages were: Straight wings, grey body 45%, curled wings, ebony body 43%, straight wings, ebony body 6%, and curled wings grey body 6%.

   (a) Is there evidence of crossing over in the offspring? _____

   (b) Explain your answer: _____

   _____

   _____

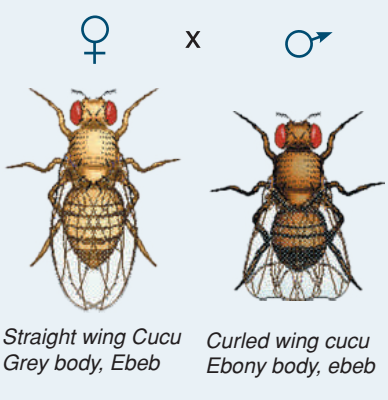
   _____

   _____

   (c) Determine the genotypes of the offspring: _____

   _____

   _____



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Testing the outcome of genetic crosses against predicted ratios

The chi-squared test for goodness of fit (χ^2) can be used for testing the outcome of dihybrid crosses against an expected (predicted) Mendelian ratio.

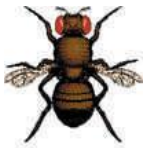
Using χ^2 in Mendelian genetics

- In genetic crosses, certain ratios of offspring can be predicted based on the known genotypes of the parents The chi-squared test is a statistical test to determine how well observed offspring numbers match (or fit) expected numbers. Raw counts should be used and a large sample size is required for the test to be valid.
- In a chi-squared test, the null hypothesis predicts the ratio of offspring of different phenotypes is the same as the expected Mendelian ratio for the cross, assuming independent assortment of alleles (no linkage, i.e. the genes involved are on different chromosomes).
- Significant departures from the predicted Mendelian ratio indicate linkage (the genes are on the same chromosome) of the alleles in question.
- In a *Drosophila* genetics experiment, two individuals were crossed (the details of the cross are not relevant here). The predicted Mendelian ratios for the offspring of this cross were 1:1:1:1 for each of the four following phenotypes: grey body-long wing, grey body-vestigial wing, ebony body-long wing, ebony body-vestigial wing.
- The observed results of the cross were not exactly as predicted. The following numbers for each phenotype were observed in the offspring of the cross:

Grey body, vestigial wing
88

Grey body, long wing
98

Ebony body, long wing
102



Ebony body, vestigial wing
112

Table 1: Critical values of χ^2 at different levels of probability. By convention, the critical probability for rejecting the null hypothesis (H_0) is 5%. If the test statistic is less than the tabulated critical value for $P = 0.05$ we cannot reject H_0 and the result is not significant. If the statistic is greater than the tabulated value for $P = 0.05$ we reject (H_0) in favour of the alternative hypothesis.

Degrees of freedom	Level of probability (P)					
	0.50	0.20	0.10	0.05	0.02	0.01
1	0.455	1.64	2.71	3.84	5.41	6.64
2	1.386	3.22	4.61	5.99	7.82	9.21
3	2.366	4.64	6.25	7.82	9.84	11.35
4	3.357	5.99	7.78	9.49	11.67	13.28
5	4.351	7.29	9.24	11.07	13.39	15.09
	Do not reject H_0 ←				Reject H_0 →	

Steps in performing a χ^2 test

1 Enter the observed value (O).

Enter the values of the offspring into the table (below) in the appropriate category (column 1).

2 Calculate the expected value (E).

In this case the expected ratio is 1:1:1:1. Therefore the number of offspring in each category should be the same (i.e. total offspring/ no. categories). 400 / 4 = 100 (column 2).

3 Calculate O – E and $(O-E)^2$

The difference between the observed and expected values is calculated as a measure of the deviation from a predicted result. Since some deviations are negative, they are all squared to give positive values (columns 3 and 4).

4 Calculate χ^2

For each category, calculate $(O - E)^2 / E$. Then sum these values to produce the χ^2 value (column 5).

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

5 Calculate degrees of freedom

The probability that any particular χ^2 value could be exceeded by chance depends on the number of degrees of freedom. This is simply one less than the total number of categories (this is the number that could vary independently without affecting the last value) In this case 4 – 1 = 3.

6 Use χ^2 table

On the χ^2 table with 3 degrees of freedom, the calculated χ^2 value corresponds to a probability between 0.2 and 0.5. By chance alone a χ^2 value of **2.96** will happen 20% to 50% of the time. The probability of 0.0 to 0.5 is higher than 0.05 (i.e 5% of the time) and therefore the null hypothesis cannot be rejected. We have no reason to believe the observed values differ significantly from the expected values.

	1	2	3	4	5
Category	O	E	O–E	$(O-E)^2$	$(O-E)^2/E$
GB, LW	98	100	-2	4	0.04
GB, VW	88	100	-12	144	1.44
EB, LW	102	100	2	4	0.04
EB, VW	112	100	12	144	1.44
				χ^2 →	2.96

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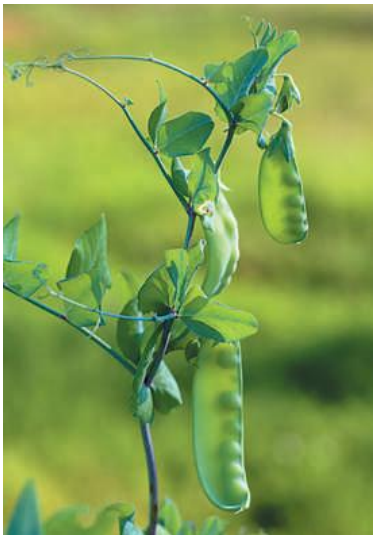
4. Students carried out a pea plant breeding experiment in which they crossed two plants heterozygous for seed shape and colour. The predicted Mendelian ratios for the offspring were **9:3:3:1** for each of the four following phenotypes: round-yellow seed, round-green seed, wrinkled-yellow seed, wrinkled-green seed.



The observed results of the cross were not exactly as predicted. The numbers of offspring with each phenotype are provided below:

Observed results of the pea plant cross

Round-yellow seed	**441**	Wrinkled-yellow seed	**143**
Round-green seed	**159**	Wrinkled-green seed	**57**

(a) State your null hypothesis for this investigation (H_0): _____

_____

_____

(b) State the alternative hypothesis (H_A): _____

_____

Use the chi-squared test to determine if the differences between the observed and expected phenotypic ratios are significant. Use the table of critical values for χ^2 at different *P* values on the previous page.

(c) Enter the observed and expected values (number of individuals) and complete the table to calculate the χ^2 value.

Category	O	E	O – E	$(O - E)^2$	$\frac{(O - E)^2}{E}$
Round-yellow seed					
Round-green seed					
Wrinkled-yellow seed					
Wrinkled-green seed					
					Σ

(d) Calculate the χ^2 value using the equation $\chi^2 = \sum \frac{(O - E)^2}{E}$ (right hand column of the table):

(e) Calculate the degrees of freedom: _____

(f) Using the χ^2 table, state the P value corresponding to your calculated χ^2 value: _____

(g) State your decision (circle one): reject H_0 / do not reject H_0

5. In another experiment, a group of students bred two corn plants together. One corn plant was known to have grown from a kernel that was colourless (c) and did not have a waxy endosperm (w). The other corn plant was grown from a seed that was coloured (C) but with a waxy endosperm (W). When the corn ear was mature the students removed it and counted the different phenotypes in the corn kernels.

Observed results of corn kernels

Coloured - waxy	**201**	Colourless - waxy	**86**
Coloured - not waxy	**85**	Colourless - not waxy	**210**

From the observed results the students argued two points:

(1) The plant with the dominant phenotype must have been heterozygous for both traits.
(2) The genes for kernel colour and endosperm waxiness must be linked (on the same chromosome).

(a) Defend the students' first argument: _____

_____

(b) On a separate sheet, use a chi-squared test to provide evidence for or against the students' second argument:

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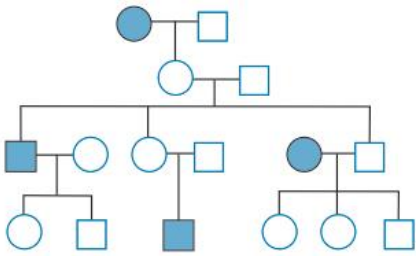
114 Chapter Review: Did You Get It?

1. Study the pedigree chart on the right.



(a) What type of inheritance pattern is shown? _____

(b) Give a reason for your answer: _____

_____

_____

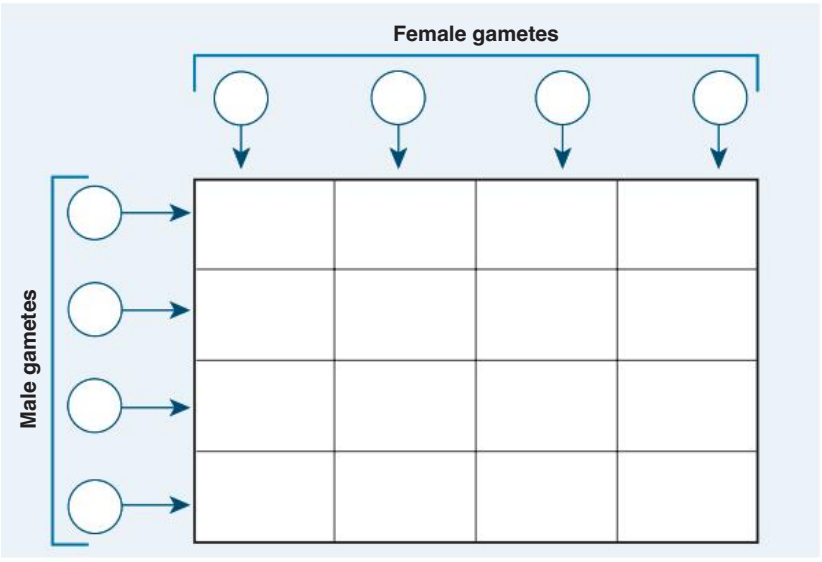
_____

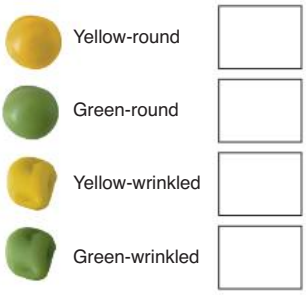
2. The following dihybrid cross shows the inheritance of colour and shape in pea seeds. Yellow (**Y**) is dominant over green (**y**) and a round shape (**R**) is dominant over the wrinkled (**r**) form.

(a) Describe the appearance (phenotype) of pea seeds with the genotype YyRr: _____

_____

(b) Complete the Punnett square below when two seeds with the YyRr genotype are crossed. Indicate the number of each phenotype in the boxes on the right.





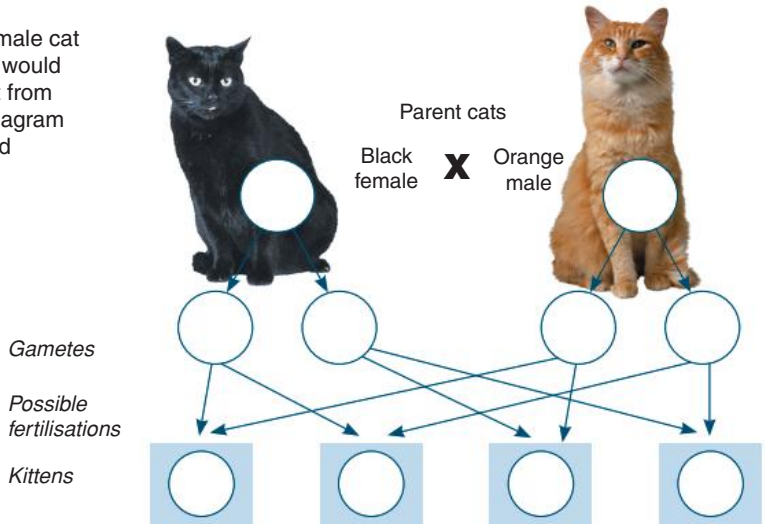
3. One of the gene loci controlling coat colour in cats is sex-linked. The two alleles, red and non-red (or black), are found only on the X-chromosome. Use the alleles listed to answer the following questions:

Allele types		Genotypes		Phenotypes
X_o =	Non-red (=black)	X_oX_o, X_oY	=	Black coated female, male
X_O =	Red	X_OX_O, X_OY	=	Orange coated female, male
		X_OX_o	=	Tortoiseshell, i.e. mix of black and orange in fur (female cats only)

An owner of a cat is thinking of mating her black female cat with an orange male cat. Before she does this, she would like to know what possible coat colours could result from such a cross. Use the symbols above to fill in the diagram on the right. Summarise the possible genotypes and phenotypes of the kittens in the tables below.

	Genotypes	Phenotypes
Male kittens		

Female kittens		



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115 Synoptic Question: Unit 2, Area of Study 1

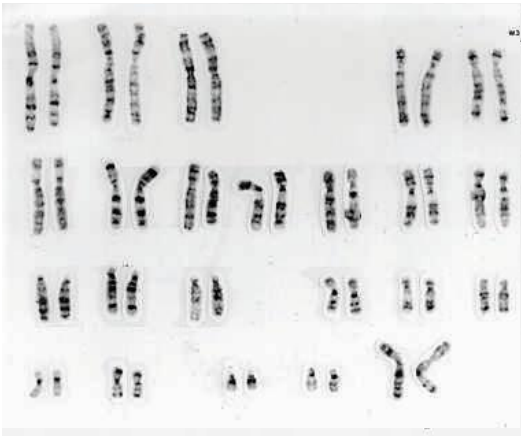
1. The preparation of a karyogram involves arranging the chromosomes of an individual into homologous pairs in order.
   (a) Name some applications of this process: _____

   (b) Study the karyogram on the right. Circle the sex chromosomes:

   (c) State the sex of this individual: _____

   (d) Determine if the karyotype shown is normal/abnormal:

   (e) Explain the reason for the answer you have given in (d):



Cytogenetics Dept, Waikato Hospital

2. (a) What would you expect to see in the karyogram of an individual with Down syndrome?

   (b) What type of disorder is Down syndrome? _____

   (c) Explain the cause of Down syndrome: _____

3. The picture shows an albino western grey kangaroo with her grey offspring. Explain the genetics of this relationship, i.e. genotypes of parents and joey:

4. Using examples, discuss how phenotype can be affected by:

   (a) Genotype: _____

   (b) Environment: _____

   (c) Epigenetic factors: _____

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5. Explain how the number of genes associated with a phenotypic trait affects its appearance: _____

6. In guinea pigs, black hair (B) is dominant over white hair (b) and short hair (L) is dominant over long hair (l). In order to produce consistent and reliable coat colour in guinea pigs, breeders use true breeding parents. A breeder has a male guinea she knows to be BBLL and a female she knows to be bbll. She wants to use them to begin a breeding programme to produce a pure breeding white, short haired guinea pig.

   Explain how the desired pure breeding animal can be produced and how its ability to breed true can be proved. Support your answer with Punnett squares and the correct use of the allele letters given (you may use extra paper if required):

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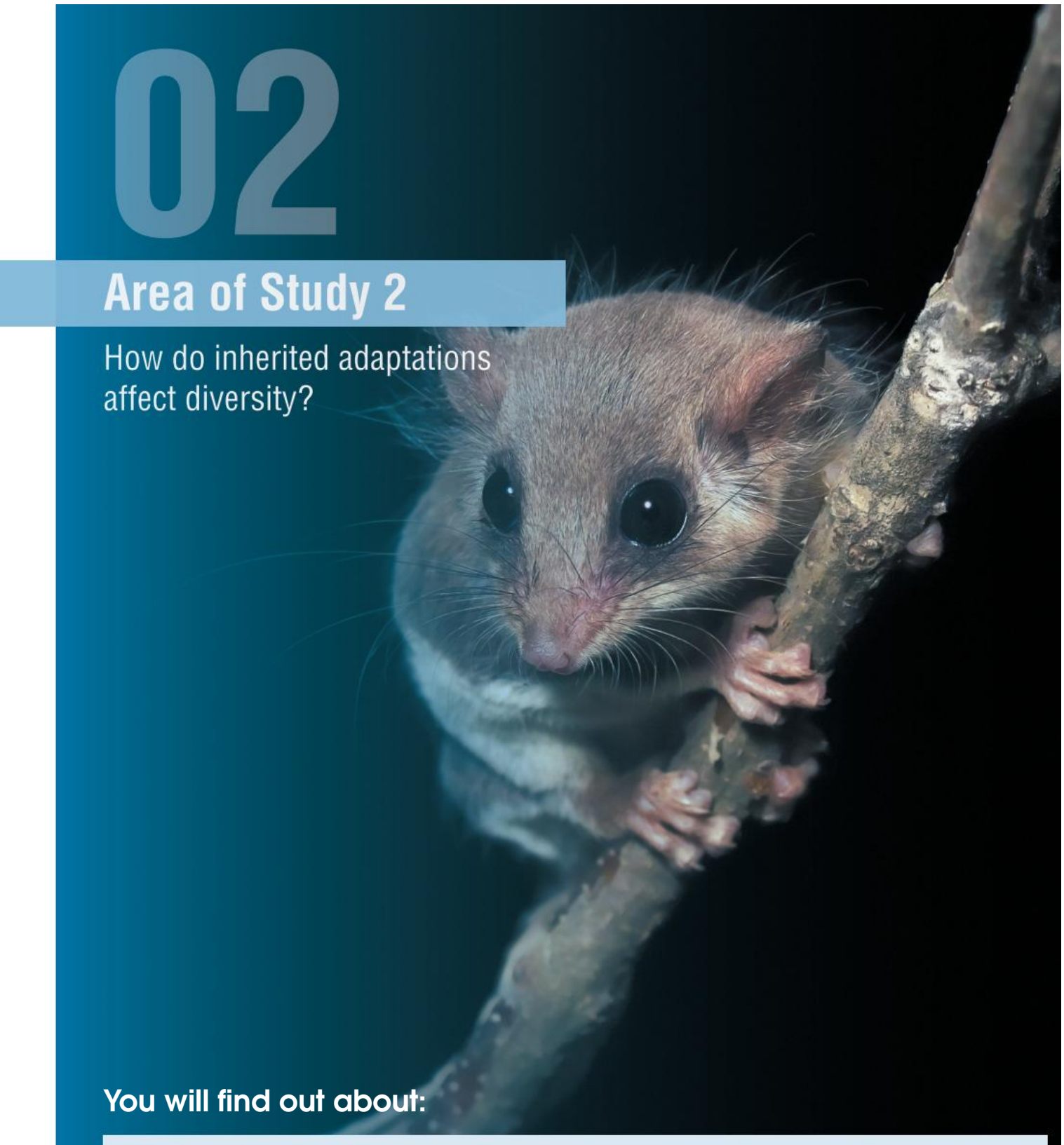
02

Area of Study 2

How do inherited adaptations affect diversity?



You will find out about:

- The features of sexual and asexual reproduction
- Reproductive cloning technologies
- The biological importance of genetic diversity
- The adaptations and interdependencies of species in natural ecosystems
- Indigenous perspectives on ecological relationships

CHAPTER 10

Reproductive Strategies

Key terms

asexual reproduction
budding
bulb
callus
clone
cutting
diploid
explant
fission
fragmentation
graft
haploid
micropropagation
plant tissue culture
rhizome
root stock
scion
sexual reproduction
somatic cell nuclear transfer
spore
tuber
vegetative propagation

Asexual reproduction

Key skills and knowledge

Activity number

- ☐ 1 Using examples, describe the types of asexual reproduction in unicellular and multicellular eukaryotes to include fission, budding, and fragmentation. **116**
- ☐ 2 Discuss the biological advantages of asexual reproduction, including rapid population increase and saturation of the environment, low risk, and low energy investment. Use Australian examples to explore the reasons for the high frequency of asexual reproduction in desert-dwelling vertebrates. **116**
- ☐ 3 Discuss the biological disadvantages of asexual reproduction, including low genetic diversity and lack of adaptability, and greater susceptibility to disease. Suggest why some organisms might periodically interrupt cycles of asexual reproduction with a short phase of sexual reproduction. **116**
- ☐ 4 Describe the biological advantages of spore formation in prokaryotes. Why would bacteria produce spores when they already produce so rapidly by binary fission? **116**
- ☐ 5 Describe mechanisms for asexual reproduction by vegetative propagation in plants. Include reference to natural vegetative structures such as bulbs, rhizomes, and tubers, and methods used by growers to produce plant clones, such as cuttings and grafting. **118**

Sexual reproduction

Key skills and knowledge

- ☐ 6 Recall the role of sexual reproduction in producing genetically variable offspring. **89 117**
- ☐ 7 Using examples, describe and explain the advantages of sexual reproduction in which all the offspring are genetically unique. How does this compare with the benefits afforded to organisms of rapid population growth by asexual reproduction? **117**
- ☐ 8 Interpret a schematic diagram illustrating how sexual reproduction and mutation in sexually reproducing populations generates and propagates variation. **117**

Reproductive cloning technologies

Key skills and knowledge

- ☐ 9 Explain what is meant by a clone and explain why clones are genetically identical. Explain the principles behind the production of plant clones by micropropagation. **119**
- ☐ 10 Describe the applications of micropropagation in agriculture and horticulture. Describe the biological implications of this technology, recognising that while it has benefits in the rapid propagation of successful varieties, there are disadvantages associated with loss of genetic diversity. **120**
- ☐ 11 Describe how animals are cloned by embryo splitting. Describe the applications of this technology and its biological implications (advantages and disadvantages). **121**
- ☐ 12 Describe the production of cloned embryos in animals by somatic cell nuclear transfer (SCNT). Explain the current and potential uses of the technology as well as its biological implications. Explain why the technology is unlikely to be widely used in agriculture. **121**

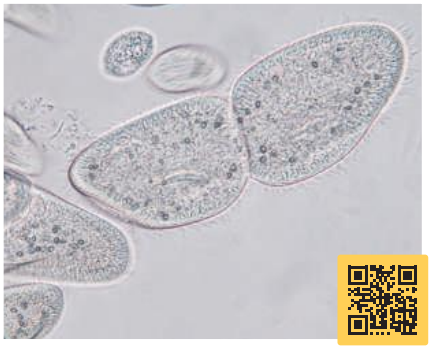
116 Features of Asexual Reproduction

Key Idea: Asexual reproduction produces offspring that are identical to the parent (the offspring are clones).

In most forms of asexual reproduction, the parent splits, fragments, or buds to produce offspring identical to itself. Parthenogenesis is a special type of asexual reproduction in which unfertilised eggs give rise to clones. Asexual organisms do not need to find a mate, and this saves them energy. Although asexual reproduction is rapid and highly efficient, all the offspring are genetically identical. If environmental conditions change, there is little ability to adapt.

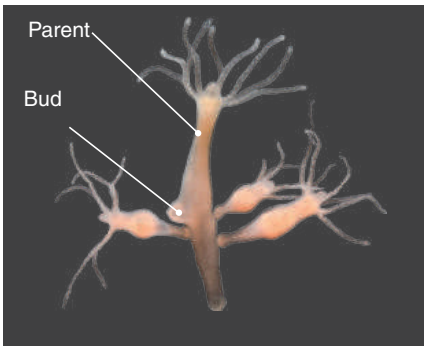
Types of asexual reproduction

- As its name suggests, asexual reproduction requires no sex. That is no exchange or mixing of genetic material from different individuals in order to produce a new individual. The offspring are therefore genetically identical to the parent.
- There are numerous ways of asexual reproduction. In general, the larger and more complex an organism is the less likely it will carry out asexual reproduction. For example, many single cell eukaryotes almost exclusively reproduce by asexual reproduction. In smaller, less complex multicellular organism, asexual reproduction can be carried out under certain conditions. It never happens in mammals, but there have been a few accounts of asexual reproduction in reptiles birds (via parthenogenesis) but the offspring are usually not viable. However many plants are able to carry out asexual reproduction.
- While many organisms reproduce asexually, they often overcome any disadvantages, such as susceptibility to disease, by interspersing asexual and sexual phases. Usually sexual reproduction in a usually asexual population is induced by environmental factors such as lack of resources or change in temperature, and it is often associated with a dispersal phase.



Unicellular eukaryotes can reproduce asexually by splitting in two (fission). This process involves mitosis and cytokinesis, and is not to be confused with the binary fission of bacteria which does not involve mitosis and cytokinesis. In the image above, a *Paramecium* splits to form two new cells.

Some cnidarians, sponges and flatworms can reproduce by fragmentation. In this process, the organism spontaneously divides into fragments. Each fragment develops into a mature, fully grown individual identical to the original organism. Planarians (above) can regenerate from very small fragments (1/279th of the original size).



Sponges and most cnidarians (e.g. *Hydra* above) can reproduce by budding. Cell division at one particular site on the parent body produces a new individual, which is smaller than the parent. This new individual may remain attached as part of the colony, or the bud may be released as an independent organism.

Many plants reproduce asexually through vegetative structures. Runners (as in strawberry, above) arise from stems, whereas suckers (as in mulgas) arise from rootstock. Other plants produce tubers (e.g. potatoes), bulbs (e.g. garlic), corms (e.g. crocus), or rhizomes (e.g. ginger).

Parthenogenesis occurs in a variety of egg laying species ranging from aphids (above) to some species of reptiles (including the Komodo dragon). The New Mexico whiptail lizard reproduces only by parthenogenesis and the species is entirely female. In birds, parthenogenetic offspring are all male.

Kalyan Varma cc 3.0

Many organisms, although not animals, produce spores as a means of dispersal. A spore is a unicellular, usually haploid, reproductive unit. Asexual reproduction by spores is common in fungi and some, including bread mould, rarely have a sexual phase in the life cycle at all.

1. What are the genetic consequences of asexual methods of reproduction? _____

2. What is parthenogenesis? _____

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Advantages of asexual reproduction

Rapid population growth

Investment is small relative to gain

Asexual reproduction allows a population to grow very rapidly. For example, if an aphid lands on an unoccupied plant, the population can quickly increase by parthenogenesis, taking advantage of plentiful resources before predators or competitors arrive. Saturating the environment quickly provides a buffer against the arrival or predators and competitors and promotes dispersal.

The investment in asexual reproduction is small relative to the large gains. In most cases, asexual reproduction produces many offspring quickly. The energy needed to do this is often proportionally much less than the energy required to reproduce the same offspring by sexual reproduction.

No need for a mate

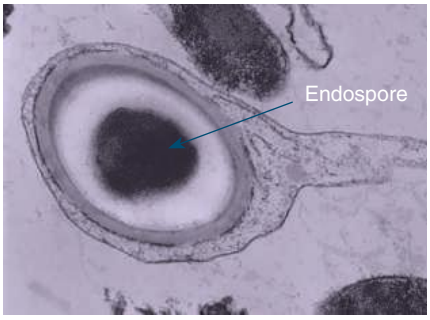
Mating can be dangerous. It requires allowing another individual into your personal space. In many predatory invertebrate species (e.g. spiders and mantids) the male must be very careful not to be attacked and eaten by the female before mating has even occurred.

No need to move

Mark Marathon cc 3.0

In some environments, such as deep oceans and arid deserts, individuals may be few and widely dispersed. Finding a mate may involve risky, long distance travel. For isolated plants, such as mulga (above) opportunities for cross pollination are limited and suckering provides a low risk strategy.

Survival



Martin Wu

Asexual reproduction can provide a way to survive extreme conditions. Endospores are small resistant spores produced by some bacteria during conditions unfavourable for growth. A small daughter cell is drawn into the original cell and forms a very thick wall. Endospores can remain viable for many years.

3. (a) What is the difference between a spore and an endospore? _____

(b) How do endospores provide bacteria with a survival advantage? _____

4. Discuss the advantages of asexual reproduction over sexual reproduction: _____

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Disadvantages of asexual reproduction

Reduces genetic diversity

- Because there is no exchange or recombining of genetic material there is often little genetic diversity in the population, although there are exceptions (right). Individuals are genetically identical to their parent. Any deleterious alleles (including harmful mutations) in the parent will be present in all offspring.

Inability to adapt

- The lack of genetic diversity usually reduces the phenotypic (physical) variability in an asexually reproducing population relative to a sexually reproducing one. This reduced phenotypic variation means that an asexually reproducing population is not able to adapt to environmental changes as easily or as quickly as a sexually reproducing population. In any sexually reproducing population, there is always spread of phenotypic variation that usually approximates a bell shaped curve. This means that there are likely to be some phenotypes with greater fitness (better survival and reproductive success) when the environment changes. In an asexually reproducing population, individuals tend to be clustered around a few variations. Environmental changes can easily shift conditions to be beyond the tolerance range of these few variants.

Increased susceptibility to disease

- Part of phenotypic variability is variability in the immune system. Reduced immune variability in clones reduces the ability of the population to resist new challenges from new pathogens (disease-causing organisms).

Why is sex rarer in the desert?

When compared to closely related organisms that reproduce sexually, the distribution of asexually reproducing organisms is biased towards higher latitudes, higher altitudes, and arid, disturbed, or marginal environments. When does an asexual reproductive strategy become advantageous and why? Two examples from Australia's lizards offer some insight into this.

Common dwarf skink (*Menetia greyii*)

Bynoe's (or prickly) gecko (*Heteronotia binoei*)

The common dwarf skink and Bynoe's gecko are widespread in Australia's arid zones and both reproduce by parthenogenesis. In these species, parthenogenetic forms are triploid, have a high heterozygosity compared with sexual forms (i.e. greater genetic diversity), and high clonal diversity. These asexual forms likely arose by hybridisation between two sexual lineages. In desert environments, where long droughts can lead to low population numbers, the absence of males increases reproductive efficiency. It is likely that the origin of parthenogenetic lineages through hybridisation captures the genetic diversity of sexual lineages, fixing well adapted, novel phenotypes.

5. (a) Explain why susceptibility to disease is greater in populations that reproduce asexually (rather than sexually):

_____

_____

_____

_____

(b) Explain how some populations, which typically reproduce asexually most of the time, overcome this disadvantage:

_____

(c) When might they do this?_____

_____

_____

6. Using examples, explain the advantages of asexual reproduction in desert environments such as Australia's interior:

_____

_____

_____

_____

_____

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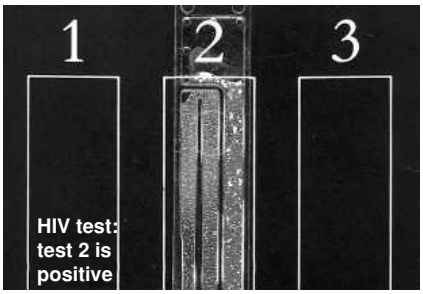
117 The Advantages of Sexual Reproduction

Key Idea: Sexual reproduction produces genetic variation in the offspring. Variation allows a population to adapt to a changing environment.

Sexual reproduction produces genetic variation (diversity of genotypes) and therefore contributes to variation in the phenotype (appearance) of organisms. In a genetically variable population, some individuals have better survival and produce more offspring than others. If the environment changes, different phenotypes may be favoured. In contrast, populations of asexually reproducing organisms are clones. The lack of variation in the population makes every individual equally susceptible to unfavourable environmental change.

Variation and disease resistance

Sexual reproduction produces variability in the offspring and so provides a greater chance that any one of the offspring will survive an environmental challenge, such as a disease outbreak. Individuals with better survival and reproduction (higher fitness) will predominate. Those with less favourable phenotypes will become less common.



Resistance to the pathogen HIV varies within the human population. A genetic mutation (change in the DNA) confers resistance to HIV. People who inherit two copies of the mutation (one from each parent) are often immune to the HIV virus and survive infection. In this way, favourable mutations can spread quickly through a population.

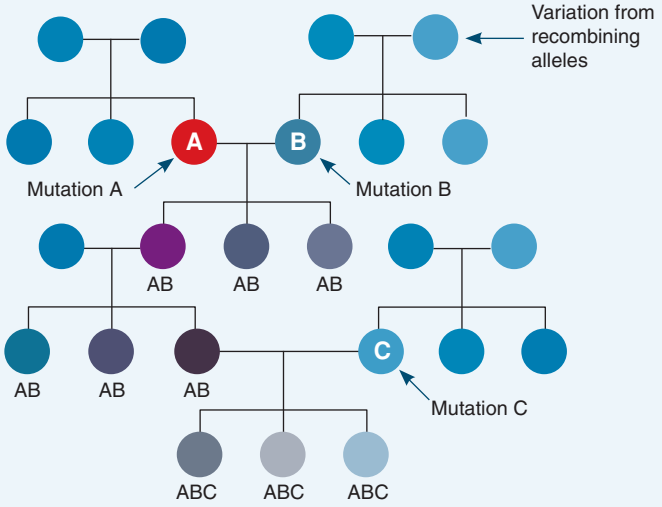
Wild tomatoes (*Lycopersicon*) show a large amount of natural variation in the Pto gene for resistance to the bacterial pathogen *Pseudomonas*. There are many forms of the gene (alleles) in the tomato population, so the resistance to the pathogen is maintained even when the pathogen gains favourable mutations.

Variation is greater when organisms reproduce by sexual reproduction

During meiosis, alleles are recombined in new combinations. Some combinations of alleles may be better suited to a particular environment than others. This variability is produced without the need for mutation, however beneficial mutations in separate lineages can be quickly combined through sexual reproduction.

The environment is always 'testing' new combinations of alleles. Sexual reproduction is always producing new variations for testing in a changing environment.

Remember, when interpreting this diagram, you are following the mutation, not the genotype.



1. How does sexual reproduction contribute to variation? _____

2. Why is variation important in populations? _____

3. How can sexual reproduction contribute to disease resistance in a population as a whole? _____

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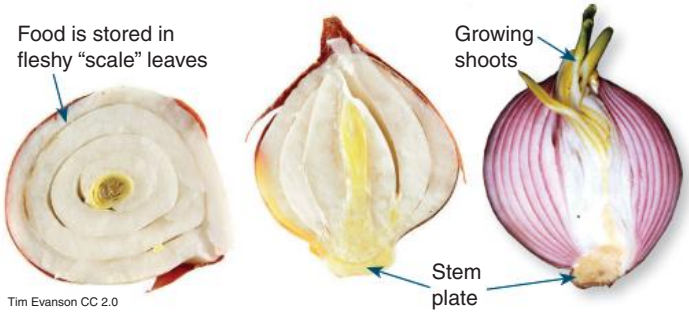
118 Plant Propagation

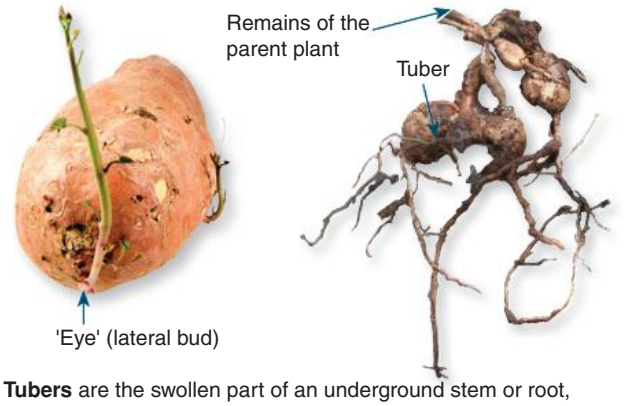
Key Idea: Plant propagation can produce large numbers of genetically identical individuals quickly.

Many flowering plants reproduce asexually by **vegetative propagation**, the process by which new plants arise from vegetative tissues of the parent plant. This ability is the result of the totipotency exhibited by plant cells. Vegetative propagation allows plants to spread rapidly in favourable conditions, avoiding the high energy cost of producing flowers, pollen, seeds, or fruits. Humans exploit the vegetative abilities of plants widely, so that many crop strains today are hardly ever grown from seed. Vegetative propagation enables successful varieties to be propagated indefinitely.

Natural vegetative structures in plants



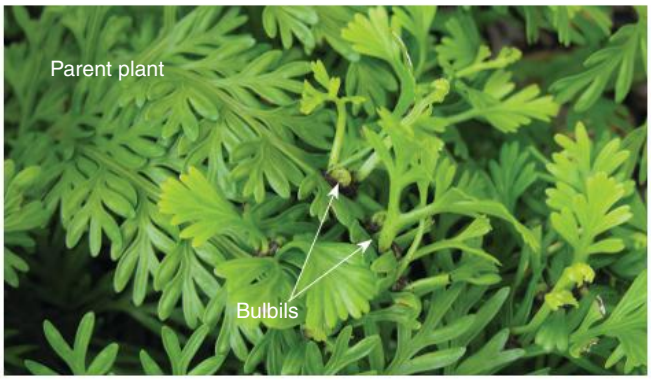
A **bulb** is really just a typical shoot compressed into a shortened form. Fleshy storage leaves are attached to a stem plate and form concentric circles around the growing tip. New roots form from the lower part of the stem.



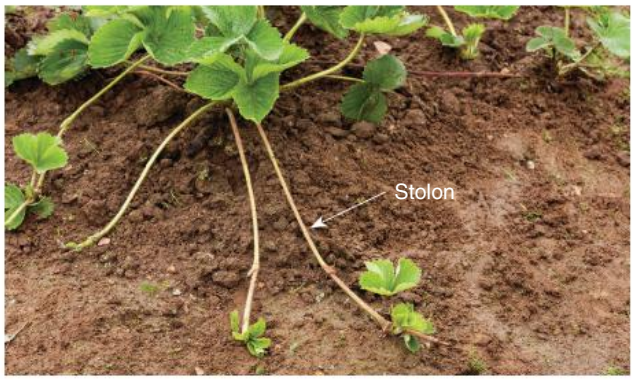
Tubers are the swollen part of an underground stem or root, usually modified for storing food. The potato (above, left) is a stem tuber, as indicated by the presence of terminal and lateral buds. The dahlia (above, right) is a root tuber.

In **rhizomes**, food is stored in the horizontal, underground stem. Rhizomes tend to be thick, fleshy or woody, and bear nodes with scale or foliage leaves and buds. Growth occurs at the buds on the ends of the rhizome or nearby nodes. Ginger, turmeric, irises and lily-of-the-valley are rhizomes.

In a **corm**, food is stored in stem tissue. Corms look like bulbs, but if you cut a corm in half you see a mass of homogenous tissue rather than concentric rings of fleshy leaves as in a bulb. Cyclamen, gladiolus, taro (left), and crocus (right) are corms.



Some plants produce copies of themselves (tiny plantlets called bulbils) from axillary buds. These in time fall off as independent plants. Examples include the hen and chickens fern (A*splenium bulbiferum*) (above) and kalanchoes (*Bryophyllum).*



Stolons (runners) are horizontal stems that grow above the ground. At certain points along the stolon where it touches the ground roots may form and a small plantlet appear. If the stolon breaks the new plant becomes independent.

1. (a) What is meant by vegetative propagation? _____

_____

_____

(b) What feature of plant cells underlies this ability? _____

_____

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Taking advantage of vegetative structures for propagation

Many plants grown by humans are propagated from natural vegetative structures. Often specific strains are grown from seed until vegetative structures are produced. These are then distributed to growers to produce the main crop.

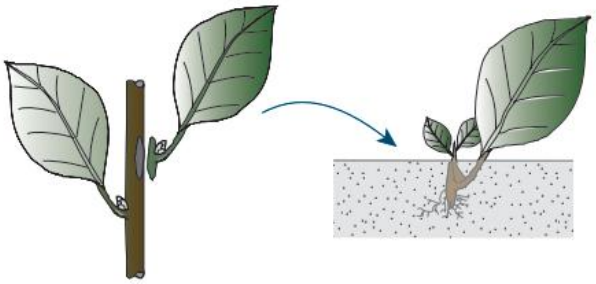
New potato hybrids are grown from seed. These produce tubers and the tubers are sold to farmers as seed potatoes. The seed potatoes produce a new plant and many more tubers, which are harvested for food.

Whole garlic bulbs are actually groups of individual garlic bulbs, called cloves. Each clove can be separated from the bulb, planted and grown to produce more whole garlic bulbs.

Sweet potato (*Ipomoea batatas*) are the root tubers of a vine that grows close to the ground (related to the morning glory). Like potatoes, the tubers are planted and produce more tubers that are then harvested.

Propagating plants from cuttings

Cuttings are sections of a parent plant, which are removed and grown as new individuals. These individuals will be **clones** (genetically identical copies) of the parent plant. The plant hormone auxin accumulates at the base of the stem triggering the formation of roots. Adding synthetic auxins to the end of the cutting promotes greater root development.



1. A leaf and accompanying axial bud are cut from the parent stock.
2. The cutting is placed in a growth medium containing rooting hormones and a new plant grows.

Melburnian

The spiny daisy (*Acanthocladium dockeri)* is a critically endangered daisy found in South Australia. It was first collected in 1860 in New South Wales, but by 1990, it was thought to be extinct. In 1999, five plants were found on a farm in South Australia. Cuttings were taken and the resulting plants have been successfully established around Banrock Station (SA).

2 (a) Describe some of the natural means of vegetative propagation in plants? _____

_____

_____

_____

(b) Can you think of one major advantage of having a reproductive structure filled with stored food (as in a tuber):

_____

_____

3. Describe how plants benefit generally by reproducing vegetatively: _____

_____

_____

_____

4. Describe how humans have benefited from the vegetative propagation of plants: _____

_____

_____

_____

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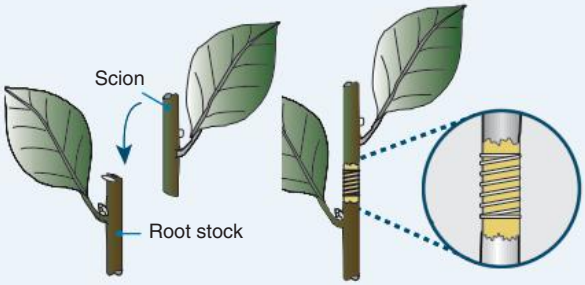
Propagating plants using grafting

Grafting involves joining structures from two or more plants, usually varieties of the same species. Typically a twig section (**scion**) from one plant is joined to the shoot of another (**root stock**). Grafting is a very common technique in the production of fruit and landscape trees.



1. A scion is prepared by taking a cutting. The scion is then grafted to another plant (root stock).
2. The graft is covered in wax to prevent infection and held together with twine or raffia.

Multiple graftings

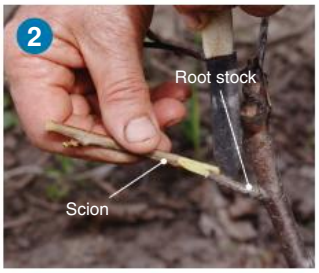
Multiple grafts can be made on to a single root stock. A large tree can have virtually every branch grafted. Many people like to grow fruit trees but do not have the room to grow more than one or two. It is now possible to buy fruit trees with two, three, four, or more fruit types grafted onto the one plant. Grafting more than one plant variety together can also help pollination because many plants are not self fertile and need a pollinating plant nearby.

Bob Embleton cc 2.0

This apple tree has been grafted to produce two varieties. On the left is a red skinned variety, whereas the right branches produce a green skinned variety.

Grafting process

A scion is removed from the parent plant prior to grafting.



Scion being grafted onto the stem of the root stock.

The graft is sealed and covered to prevent water loss and infection.

The graft is then labelled for future reference and monitoring.

5. Many rare plants around the world, including the spiny daisy (*Acanthocladium dockeri*) in South Australia, have been brought back from the brink of extinction using various propagation techniques.

   (a) Explain how vegetative propagation of plant material can be used as a strategy in species conservation:

   (b) Suggest why stocks of rare plants could be reproduced this way, rather than using seed:

   (c) Describe a potential disadvantage of vegetative propagation of plants that are endangered by disease:

6. Explain why grafting plants with dual qualities is advantageous:

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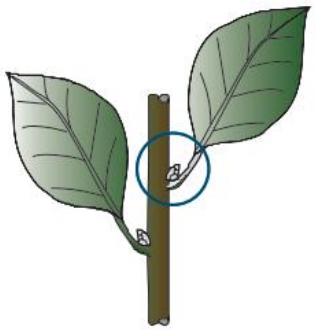
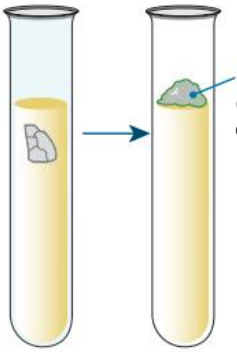
119 Micropropagation

Key Idea: Micropropagation is the propagation of multiple clones from one piece of plant tissue.

Micropropagation (plant tissue culture) is a method used for cloning plants. It is widely used for the rapid multiplication of commercially important plant varieties with superior genotypes, as well as in the recovery programmes for endangered plant species. Micropropagation is possible because differentiated plant cells have the potential to give rise to all the cells of an adult plant (they are totipotent). Micropopagation has many advantages over traditional methods of plant propagation but it is very labour intensive. Its success is affected by factors such as the composition of the culture media, selection of the original parent material, hormone levels, lighting, and temperature.

The process of micropropagation

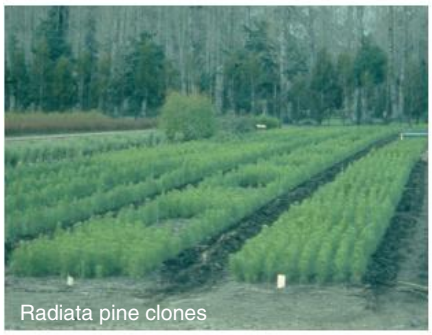




1 An **explant** (in this case it is an axial bud) is removed from a disease-free stock plant. Explants are commonly taken from cotyledons, axial buds, or roots.

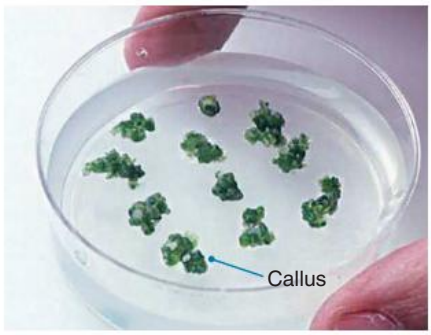
2 Explant tissue is cultured in a sterile nutrient medium until a callus forms. The callus is transferred to another test tube containing growth hormones, and shoots are encouraged to grow.

3 Shoots develop from the callus and begin to photosynthesise. The new shoots are removed from the callus and placed in individual culture media. The process is repeated every few weeks so that one explant will give rise to many plants.



Scion

Micropropagation is widely used in the forestry industry to produce uniform trees for timber. Disease-free explants can be easily exchanged internationally.



Micropropagation is useful for quickly propagating genetically engineered plants using material taken from a callus containing genetically engineered material.

Joydeep cc 3.0

Banana plants, which are sterile, are produced by micropropagation, as they cannot be grown from seed.

1. What is the general purpose of micropropagation? _____

2. (a) Explain what a callus is: _____

   (b) How can a callus be stimulated to initiate root and shoot formation? _____

3. Describe some advantages of micropropagation: _____

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120 Case Study: Cloning in Horticulture

Key Idea: The use of cloning in horticulture has produced limited genetic diversity in some common fruit varieties.

Cloning has been used in horticulture for many hundreds of years. Many of the most commonly eaten fruits including apples, oranges, grapes, and bananas are clones, produced by the propagation of one or two varieties for hundreds, or even thousands, of years. The cloning of fruit varieties has been extraordinarily successful in the mass production and distribution of plants and fruits. However it has also created some problems. Many ancient varieties of fruit have been lost in the move to mass produce a small number of cultivars. Also, as many millions of plants are clones, they all have the same vulnerabilities, e.g. to disease. This makes it extremely important to preserve older plant varieties and maintain the genetic diversity necessary to produce vigorous, disease resistant varieties in the future.

Cloning and horticulture:

- Imagine you were walking through an orchard and found a fruit tree seedling that had been missed by the orchardist's mowing and spraying machines. You dig it up and plant it at home. When it fruits, you find it produces the best tasting, longest lasting fruit of its type ever.
- Wanting to capitalise on your discovery, you plant the seeds from one of the fruits, but they do not germinate. Closer inspection of seeds from other fruit on the tree finds the seeds never fully form. The tree cannot be regrown from seed; it is a one-off chance event and sterile.
- However, there is another way to produce more of this unique fruit tree - cloning it using cuttings and grafting. Some cuttings are grown directly into trees, others are grafted on to the root stock of another variety of the fruit. Soon, thousands of new trees are produced and distributed to orchards. Within a few years, your new fruit variety is the dominant one grown worldwide. Within decades it is virtually the only fruit of that type grown.
- Then disaster strikes. The fruit is susceptible to a soil fungus found in a country different to the variety's origin. Unknowingly, the fungus has been spread worldwide in orchard equipment. Within a year of discovering the fungus, half of the trees are failing. Within two years, three quarters of the fruit trees worldwide are dead. Another year and it is no longer economical to even plant the variety as the plants never reach maturity. Meanwhile, as a result of to the fruit's dominance, nothing is left to replace it. For years there is a massive shortage of the fruit, until older varieties can be re-established.
- Sound fictional? It has happened at least once and may not be far from happening again.

Zwilfree cc 4.0

The Gros Michel (Big Mike) banana, now commercially extinct. Its physical properties (thick skin and dense bunches) made it ideal for export and it has a high concentration of the ester used for the "banana" food flavouring. Vast areas of banana plantations succumbed to a fungus and exports stopped in the 1960s.

1. Why are crops like bananas and navel oranges not able to be planted from seed? _____

2. Why are Granny Smith apples not produced from seed? _____

3. How do bananas illustrate the vulnerability of these crops? _____

4. Bananas are cultivated using micropropagation. What are some disadvantages of micropropagation for a vulnerable food plant like the banana?

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Cavendish banana

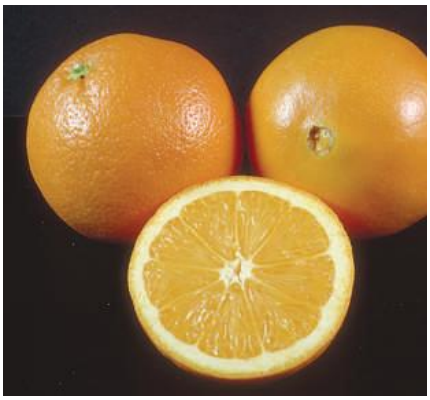
Young Cavendish clones under cultivation

There are many varieties of banana. All commercial bananas are descendents of the two banana species *Musa acuminata* and *M. balbisiana*. The most common banana, the Cavendish, is a triploid (three sets of chromosomes) variant of the banana species *Musa acuminata*. This makes it sterile. All the Cavendish plants worldwide are clones. The Cavendish replaced the Gros Michel, which was devastated by Panama disease, around the 1950s. The Cavendish is now being badly affected by a new strain of the disease and scientists are trying to find or develop a variety to replace the Cavendish should the need arise.

Granny Smith variety

Granny Smith graft

The Granny Smith apple originated in Eastwood, New South Wales, around 1870. It is named after its discoverer Maria Ann Smith, who also originally propagated it. How exactly she found the original tree is unclear but it may have come from a variety of crab apple. The Granny Smith became extremely popular during WWII due to its long shelf life, making it easy to export. It is not grown commercially from seed as the fruit produced varies and is usually very tart in taste. As a result, all the trees are clones directly related to the original tree in Eastwood. It is still in the top twenty most popular apples in the USA.



The popular seedless navel orange

Navel orange tree grafted on to rootstock

In 1820, a mutation was found in an orange tree in Bahia, Brazil. The mutant tree produced a sweet, seedless fruit with an undeveloped fruit near the base, giving the characteristic "navel". Cuttings were grafted on to citrus root stock and new plants were grown. The new plants were taken to the United States and grown in California. The fruit was received well by orchardists and is now the single most popular orange variety in the world. However, because it is seedless, all the plants are clones grown by grafting onto root stock. Since its discovery, there have been a few new mutations that have produced new varieties of navel orange. Other new fruit varieties arising as a result of chance mutation are nectarines (from peaches) and red Anjou pears.

5. Occasionally banana plants under cultivation will produce a "sport". This is a branch arising from a chance mutation that has different characteristics to the parent (e.g. in leaves or fruit).

   (a) Explain how this sport could be propagated to produce a new variety of banana:

   _____

   _____

   _____

   (b) How could this help towards ensuring the continued availability of bananas? _____

   _____

   _____

   _____

   (c) In what other crop plants has mutation helped to produce new varieties? _____

   _____

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121 Reproductive Cloning in Animals

Key Idea: The cloning of animals using nuclear transfer or embryo splitting techniques provides a way to retain useful traits in a population and conserve species close to extinction.

In agriculture, especially dairy and beef farming, a few males with the most desirable traits produce the semen that will be used to impregnate many of the breeding females. This produces offspring with a mix of traits from the father and mother, hopefully most of which will be desirable in the animal. Cloning provides a way to make sure the most desirable traits are always present in the offspring. There are two main techniques for animal cloning, somatic cell nuclear transfer (SCNT) and embryo splitting. SCNT produces clones of the donor of the cell nucleus (an individual more or less genetically identical to the nuclear donor). Embryo splitting produces essentially identical twins, which are genetically identical to each other, but not to any other animal. Both techniques offer ways to conserve highly endangered species by retaining genetic information.

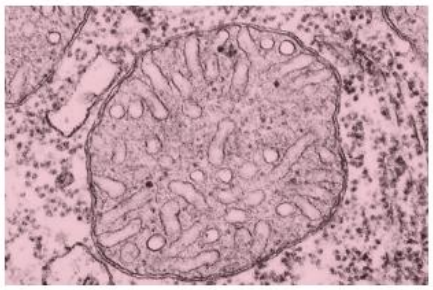
Somatic cell nuclear transfer

- SCNT was first successfully carried out on a mammal in 1996 with the birth of Dolly the sheep, a clone of a Finn Dorset ewe. Since then, many mammalian and other species have been cloned using the technique, including dogs, cats, deer, and horses.
- Although the principle behind the technique (shown below) is relatively simple, the success rate for viable births is very low. It is still not currently a viable technique for mass production of clones and is limited to specific uses such as in cloning high value livestock, in endangered species recovery, and in medical research.
- Although the clone and the donor have identical nuclear DNA, the mitochondrial DNA is different. This may lead to incompatibilities and may contribute to the low success rate.

Dolly was euthanised in 2003 after living only half the normal lifespan for the breed. Her taxidermy mount resides at National Museum of Scotland in Edinburgh.

Toni Barros cc BY-SA cc 2.0

Somatic cell nuclear transfer has been used to clone endangered species including the Bucardo (above), the Mouflon, and the Enderby Island cattle in New Zealand.



SCNT does not produce perfect clones. The mitochondrial DNA is from the donor egg cell cytoplasm, and not from the donor of the nuclear DNA. This may introduce some physiological variation in the clones.

Some people have suggested using SCNT to bring back extinct animals e.g. the woolly mammoth. This is highly unlikely for a variety of reasons including being unable to replicate the full DNA sequence.

1. Give a brief description of how SCNT produces a clone: _____

_____

_____

_____

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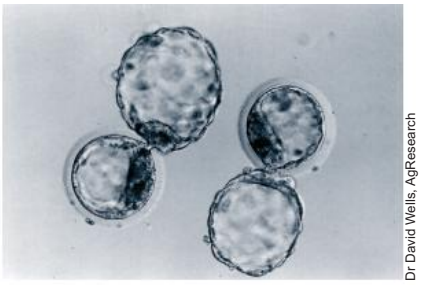
Embryo splitting

Embryo splitting simply replicates the natural twinning process. A fertilised egg is grown into eight cells before being split into four individual embryos, each consisting of just two cells. The four genetically identical embryos are then implanted into surrogate mothers. While this technique produces multiple clones, the clones are derived from an embryo whose physical characteristics are not completely known. This represents a limitation for practical applications where the aim is to produce high value livestock.

Stud merino rams, Australia

Livestock are selected for cloning on the basis of desirable qualities such as wool, meat, or milk productivity.



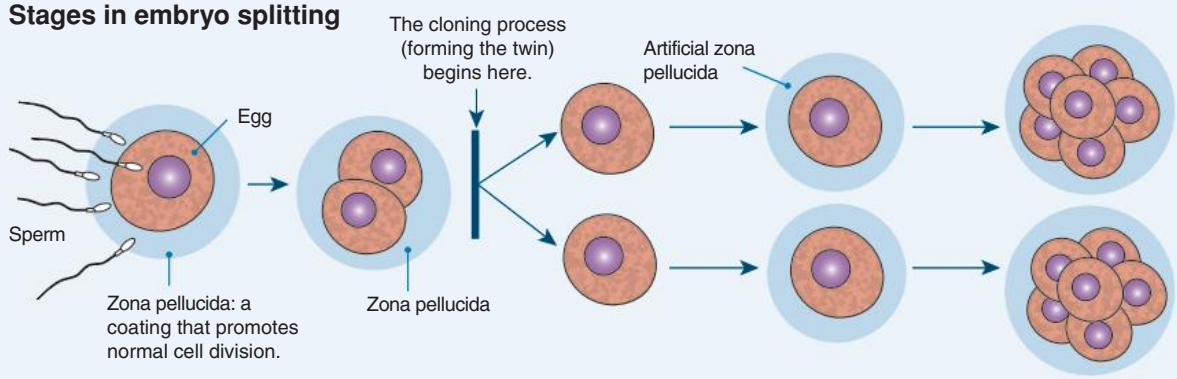
Dr David Wells, AgResearch

Cloned embryos immediately prior to implantation into a surrogate. These are at the blastocyst stage.

Twins, Pag Is. sheep, Croatia

The individuals produced by embryo splitting are identical to each but differ from the parents in the same way that twins do.

Stages in embryo splitting



Egg cells are removed from an animal and fertilised in a petri dish.

At the first stage of development, one of these fertilised eggs divides in two.

The zona pellucida is removed with an enzyme and the two cells are separated.

An artificial zona is added, allowing development to proceed.

The cells continue to divide, forming genetically identical embryos. These are implanted into surrogates.

2. How would cloning be useful for the conservation of animal species? _____

3. Why does embryo splitting not produce clones of the parents? _____

4. Why would it be undesirable to produce all livestock using cloning techniques? _____

5. Why is SCNT not currently a viable technique for the mass production of clones? _____

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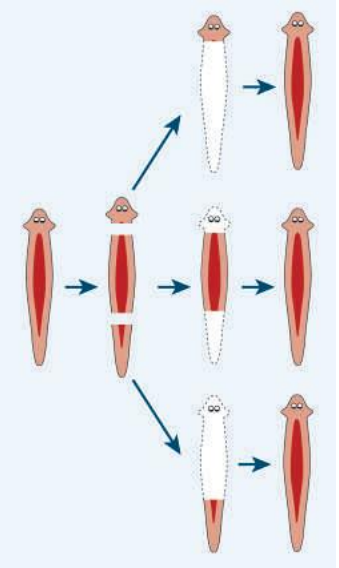
122 Chapter Review: Did You Get It?

1. (a) What method of asexual reproduction is depicted in the diagram (right) and what does it involve?



(b) How is this process different to fission in eukaryotic organisms? _____

(c) How is it different to budding? _____

2. Distinguish between grafting and producing cuttings in plants: _____

3. Explain why the grafting of multiple plant types can be useful: _____

4. Explain how micropropagation is used in the production of new plants and its advantages and disadvantages:

5. (a) What is a spore? _____

(b) What is the role of spores in the asexual reproduction of fungi? _____

6. Briefly describe the possible benefits to be gained from cloning the following:

(a) Stem cells for medical use: _____

(b) High milk yielding cows: _____

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CHAPTER 11

Adaptations and Diversity

Key terms

abundance
autotroph
behavioural adaptation
biodiversity
competition
consumer
density
distribution
distribution
ecosystem
fitness
food chain
food web
genetic diversity
habitat diversity
hydrophyte
keystone species
mark and recapture
mutualism
omnivore
parasitism
physiological adaptation
population
population size
predation
producer
quadrat
sample
species diversity
structural adaptation
symbiosis
traditional ecological knowledge
transect
xerophyte

The biological importance of genetic diversity

Key skills and knowledge

Activity number

Incandescent cc 2.0

Robert Kerton, CSIRO cc3.0

Mike Lehmann cc 3.0

Adaptation

Key skills and knowledge

Species interdependencies

Key skills and knowledge

123 Genetic Diversity

Key Idea: Genetic diversity is important in maintaining healthy species populations.

The vast majority of the genetic material in two unrelated individuals in a species is identical. It must be or else they would likely not be the same species. However a small fraction of the genetic material (about 0.1% in humans) varies between individuals (compared to about 1% difference between humans and chimpanzees). This tiny variation results in the differences between individuals of the same species (e.g. eye colour, predispositions in height, body shape, or behaviour). These variations allow a species to adapt to changes in the environment, such as changes in food availability or the ability of the immune system to react to a disease. As a result, maintaining genetic diversity is extremely important for the long term survival of a species. Many endangered species have low genetic diversity.

What is diversity?

Biological diversity consists of three main parts:

Genetic diversity is the total number of genetic characteristics in a species. Genetic diversity is an important consideration in studies of biodiversity because species with high genetic diversity are less susceptible to disease and inbreeding depression (reduced breeding success as a result of inbreeding).
Example: Eastern grey kangaroos have a high level of genetic diversity due to their abundance, wide distribution, and connected gene flow (movement between populations).

Species diversity is the number of different species (species richness) that are represented in a given community and their relative abundance (species evenness). High species diversity is associated with stable ecosystems and a large number of biotic interactions.
Example: The Raja Ampat Islands in Indonesia are considered the center of marine biodiversity. The region is home to 75% of all known species of hard corals.

Habitat diversity describes the number of different habitats provided by a particular region. Habitat diversity is often described as heterogeneity and is associated with species diversity. More heterogeneous environments can support a larger number of species with different habitat needs.
Example: The tropical climate of the Raja Ampat Islands provides an enormous range of marine and terrestrial habitats. It is also relatively undisturbed by humans.

Genetic diversity affects ecosystems

- Genetic diversity is important in determining how well an ecosystem functions. Important components include:
  - Fitness (survival and reproductive success) of individuals
  - Long term viability and adaptability of populations
  - Evolution of new species or traits
  - Community structure and stability
- Genetic diversity affects how members of the same species behave (e.g. some may be more aggressive or less curious). This in turn affects how they interact with other organisms and so with the ecosystem as a whole.
- The millions of interactions from genetically diverse organisms ultimately affect how stable and resilient the ecosystem is.

1. What percentage of DNA is variable between any two humans? _____

2. What is genetic diversity? _____

3. Why is it advantageous for a population to have high genetic diversity? _____

4. Why would the functioning of an ecosystem be affected by genetic diversity? _____

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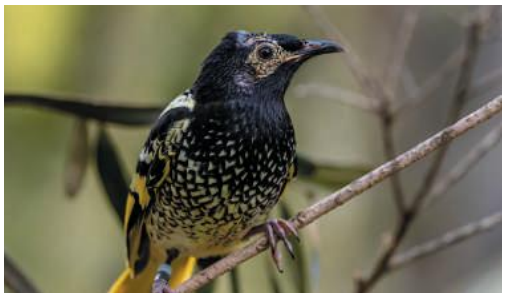
Measuring diversity

There are various ways to measure the genetic diversity of populations and individuals. The most common way is to measure the diversity of single nucleotide polymorphisms. (SNPs). Recall that SNPs are variations in single DNA bases.

- SNPs behave just like alleles, i.e. individuals can be heterozygous or homozygous for an SNP. The proportion of heterozygous SNPs in individuals can therefore give a measure of the genetic variation in the population.
- A second measure is the heterozygous SNP rate. This is the number of heterozygous SNPs divided by the size of the genome. A high heterozygous SNP rate indicates a high degree of variation.



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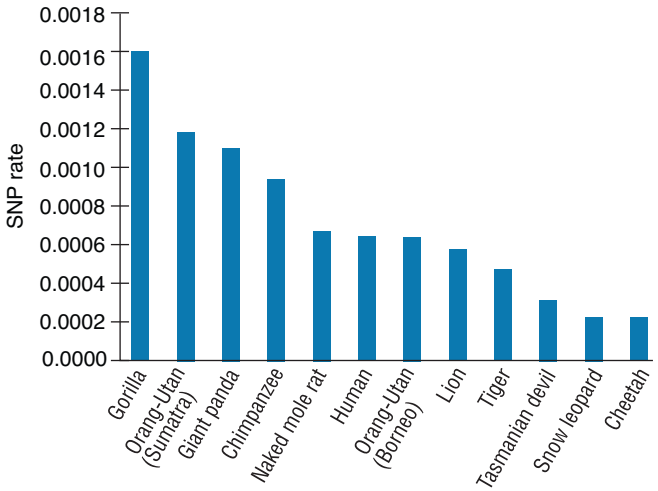
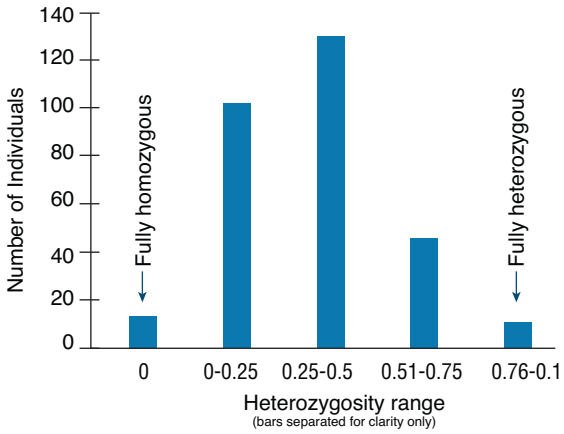
The regent honeyeater has high genetic diversity despite being critically endangered. The populations are highly mobile and this maintains gene flow.

Mammalian genetic diversity



Source: The tiger genome and comparative analysis with lion and snow leopard genomes. Yun Sung Cho et al www.nature.com/naturecommunications

Tasmanian devil SNP heterozygosity



Development of a SNP-based assay for measuring genetic diversity in the Tasmanian devil insurance population. Wright et al. BMC Genomics (2015) 16:791

Degree of diversity

Different species have different amounts genetic variation. These differences are the result of the species' biology and their evolutionary histories. Genetic diversity declines when populations suffer a near extinction, and species with small populations (e.g. Tasmanian devils) often do have lower genetic diversity than those with large populations. However, this is not always the case. In fact, there is no clear correlation between population size and genetic diversity. Western lowland gorillas, for example, have a much higher genetic diversity than humans.

Diversity in Tasmanian devils

Tasmanian devils have a particularly low genetic diversity. This is particularly so in the MHC (Major Histocompatibility Complex) genes. This group of genes codes for the cell surface proteins responsible for immune recognition of self and non-self. Low allelic diversity means that tissue from one devil is recognised by another individual's immune system as "self" and is not attacked. This has led to an infectious cancer spreading among devils because cancerous tissue transferred among individuals in fights is not recognised by the recipient's immune system as foreign.

5. (a) What might cause some species to have lower genetic diversity than others:_____

(b) How might gene flow (individuals moving between populations and sub-populations) account for higher than expected genetic diversity in some endangered species (e.g. regent honeyeater)?

6. (a) What is one negative effect of low genetic diversity in Tasmanian devils? _____

(b) Describe the heterozygosity range in Tasmanian devils: _____

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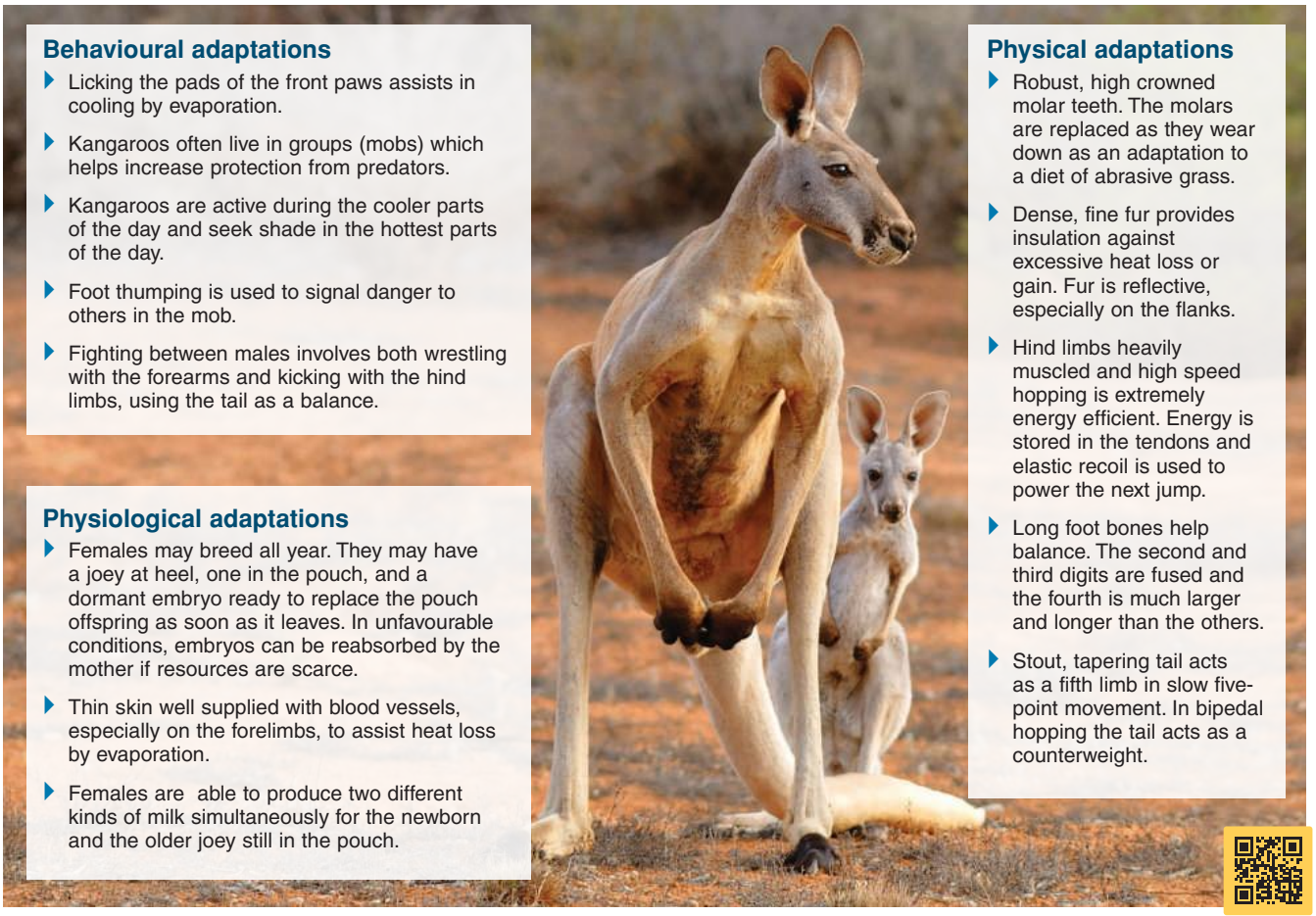
124 Types of Adaptations

Key Idea: An adaptation is any heritable trait that equips an organism for its functional role in the environment (its niche). An adaptation is any heritable characteristic (trait) that equips an organism for its niche, enhancing its exploitation of the environment and contributing to its survival and successful reproduction (fitness). Adaptations may be structural (morphological), physiological, or behavioural. The adaptations of species are the result of their evolution in particular environments. Traits that are not helpful to survival and reproduction will not be favoured and will be lost.

Kangaroo adaptations

The **red kangaroo** (below) is the largest living marsupial. It is powerfully built and adapted for high speed, hopping locomotion, and survival in dry habitats. They are active mainly at night, roaming in small groups over a home range of 8 km^2 (or larger when resources are scarce). Dominant males establish exclusive mating rights by boxing.



Behavioural adaptations

- Licking the pads of the front paws assists in cooling by evaporation.
- Kangaroos often live in groups (mobs) which helps increase protection from predators.
- Kangaroos are active during the cooler parts of the day and seek shade in the hottest parts of the day.
- Foot thumping is used to signal danger to others in the mob.
- Fighting between males involves both wrestling with the forearms and kicking with the hind limbs, using the tail as a balance.

Physiological adaptations

- Females may breed all year. They may have a joey at heel, one in the pouch, and a dormant embryo ready to replace the pouch offspring as soon as it leaves. In unfavourable conditions, embryos can be reabsorbed by the mother if resources are scarce.
- Thin skin well supplied with blood vessels, especially on the forelimbs, to assist heat loss by evaporation.
- Females are able to produce two different kinds of milk simultaneously for the newborn and the older joey still in the pouch.

Physical adaptations

- Robust, high crowned molar teeth. The molars are replaced as they wear down as an adaptation to a diet of abrasive grass.
- Dense, fine fur provides insulation against excessive heat loss or gain. Fur is reflective, especially on the flanks.
- Hind limbs heavily muscled and high speed hopping is extremely energy efficient. Energy is stored in the tendons and elastic recoil is used to power the next jump.
- Long foot bones help balance. The second and third digits are fused and the fourth is much larger and longer than the others.
- Stout, tapering tail acts as a fifth limb in slow five-point movement. In bipedal hopping the tail acts as a counterweight.

1. (a) What is an adaptation? _____

   _____

   (b) How do adaptations contribute to an organism's fitness? _____

   _____

   _____

2. Describe two behavioural adaptations for protection against predators in red kangaroos:

   _____

   _____

   _____

3. Describe two physical adaptations for locomotion in red kangaroos: _____

   _____

   _____

   _____

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125 Adaptations of Xerophytes

Key Idea: Xerophytes are plants with adaptations that allow them to conserve water and survive in dry environments.

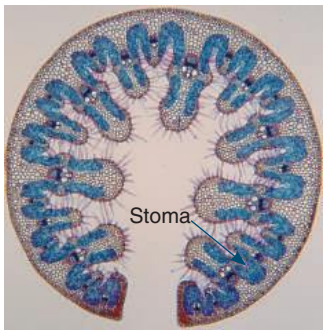
Plants adapted to dry conditions are called **xerophytes**. Xerophytes are found in a number of environments, but all show adaptations to conserve water. These adaptations include small, hard leaves, an epidermis with a thick cuticle, sunken stomata, succulence, and permanent or temporary absence of leaves.

- Most xerophytes are found in deserts, but they may be found in humid environments, provided that their roots are in dry micro-environments (e.g. the roots of epiphytic plants that grow on tree trunks or branches).
- Many xerophytes have a succulent morphology. Their stems are often thickened and retain a large amount of water in the tissues, e.g. *Aloe*.
- Many xerophytes have a low surface area to volume ratio, reducing the amount of water lost through transpiration.
- Salt tolerant plants and many alpine species may show xeromorphic features in response to the lack of free water and high transpirational losses in these often windy, exposed environments.

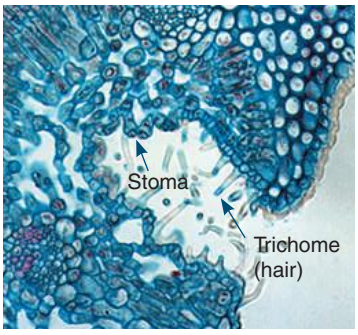
Acacia trees have deep root systems, allowing them to draw water from sources deep underground.

An outer surface coated in fine hairs traps air close to the surface and reduces the transpiration rate.

Desert xerophytes in Arizona have a succulent photosynthetic stem



Grasses on coastal sand dunes (e.g. marram grass, above) curl their leaves. Stomata are sunken in pits, creating a moist microclimate around the pore, which reduces transpiration rate.



Oleander has a thick multi-layered epidermis and the stomata are sunken in trichome-filled pits on the leaf underside which restrict water loss. Trichomes (leaf "hairs) maintain a layer of still air at the leaf surface.

1. What is a xeromorphic adaptation? _____

_____

2. Describe three xeromorphic adaptations of plants that reduce water loss:

   (a) _____

   (b) _____

   (c) _____

3. (a) How does creating a moist microclimate around the areas of water loss reduce the transpiration rate? _____

   _____

   _____

   (b) How do trichomes contribute to reducing the transpiration rate? _____

   _____

4. How does a low surface area to volume ratio in a plant such as a cactus reduce water loss? _____

   _____

5. How does a cactus photosythesise given it has no leaves? _____

   _____

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Adaptations in cacti

- Desert plants, such as cacti (below), must cope with low or sporadic rainfall and high transpiration rates.

Leaves modified into spines or hairs to reduce water loss. Light coloured spines reflect solar radiation.

Rounded shape reduces surface area.

Stem becomes the major photosynthetic organ, plus a reservoir for water storage.

The surface tissues of many cacti are tolerant of temperatures over 50°C.

Cacti have a shallow, but extensive fibrous root system. When in the ground the roots are spread out around the plant.

DID YOU KNOW?

Australia has no native cacti although many have become naturalised. However, two endemic species, the Wongan cactus (*Daviesia euphorbioides*) and the Dunna Dunna (*Lawrencia helmsii*) resemble cacti and are often mistaken for them (an example of convergence, opposite).

Convergent adaptation in unrelated xerophytes

- The North American cactus and African *Euphorbia* species shown above are both xerophytes. They have evolved similar structural adaptations to conserve water and survive in a hot, dry, desert environment. Although they have a similar appearance, they are not related. They provide an excellent illustration of how unrelated organisms living in the same environment have independently evolved the same adaptations to survive.
- Their appearance is so similar at first glance that the *Euphorbia* is often mistaken for a cactus. Both have thick stems to store water and both have lost the presence of obvious leaves. Instead, they have spines or thorns to conserve water (a leafy plant would quickly exhaust its water reserves because of losses via transpiration). In cacti, spines are highly modified leaves. In *Euphorbia*, the thorns are modified stalks. It is not until the two flower that their differences are obvious.

6. (a) Explain why the North American cactus and African *Euphorbia* species have evolved such similar adaptations:

_____

_____

(b) Identify two ways in which a cactus and a euphorbia can be distinguished: _____

_____

_____

7. Why would a shallow fibrous root system be an advantage to a cactus? _____

_____

_____

_____

8. Identify the features of the xerophyte shown that help it conserve water:

_____

_____

_____

_____

_____

_____

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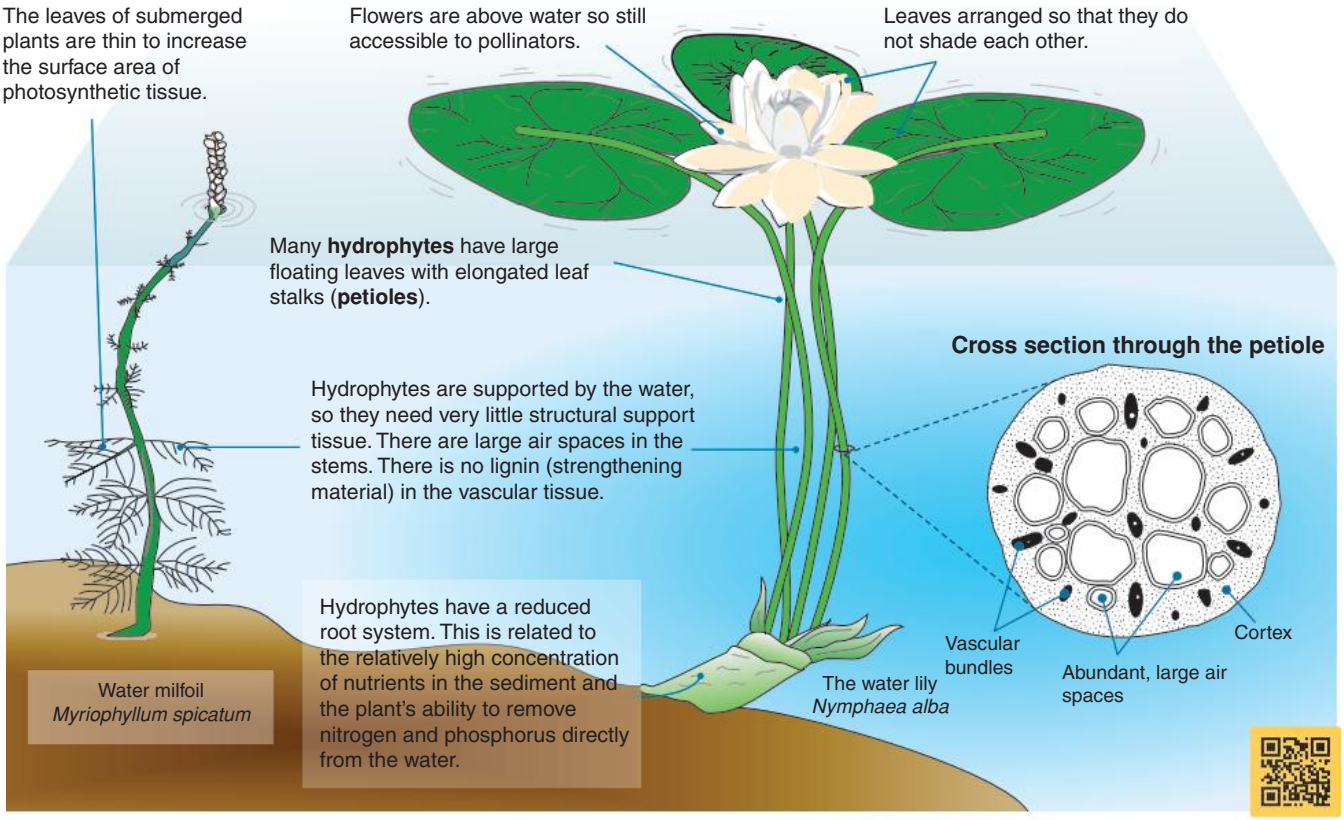
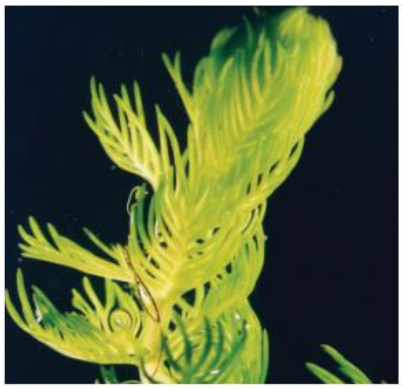
126 Adaptations of Hydrophytes

Key Idea: Hydrophytes are adapted to living in water. They require little structural support tissue because they are supported by the denser medium of water and have few adaptations to reduce water loss.

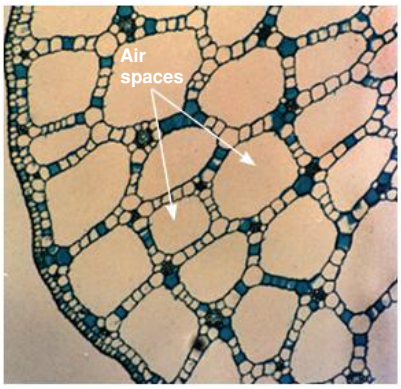




Stephen Moore

Myriophyllum's submerged leaves are well spaced and taper to the surface to help with gas exchange and distribution of sunlight.

The floating leaves of water lilies (*Nymphaea*) have a high density of stomata on the upper leaf surface so they are not blocked by water.



WBS

Cross section through *Potamogeton*, showing large air spaces which assist with flotation and gas exchange.

1. Explain how the following adaptations assist hydrophytes to survive in an aquatic environment:

   (a) Large air spaces within the plant's tissues: _____

   _____

   (b) Thin cuticle: _____

   _____

   (c) High stomatal densities on the upper leaf surface: _____

   _____

2. Why do hydrophytic plants retain an aerial (above water) flowering system? _____

   _____

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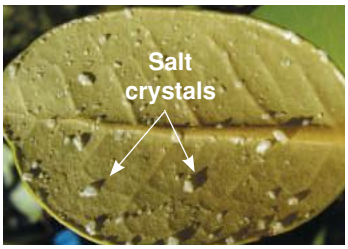
127 Mangrove Adaptations

Key Idea: Mangroves are salt tolerant (halophytes) and specifically adapted to the high salt, water-logged environments of estuaries, tidal flats, and salt marshes.

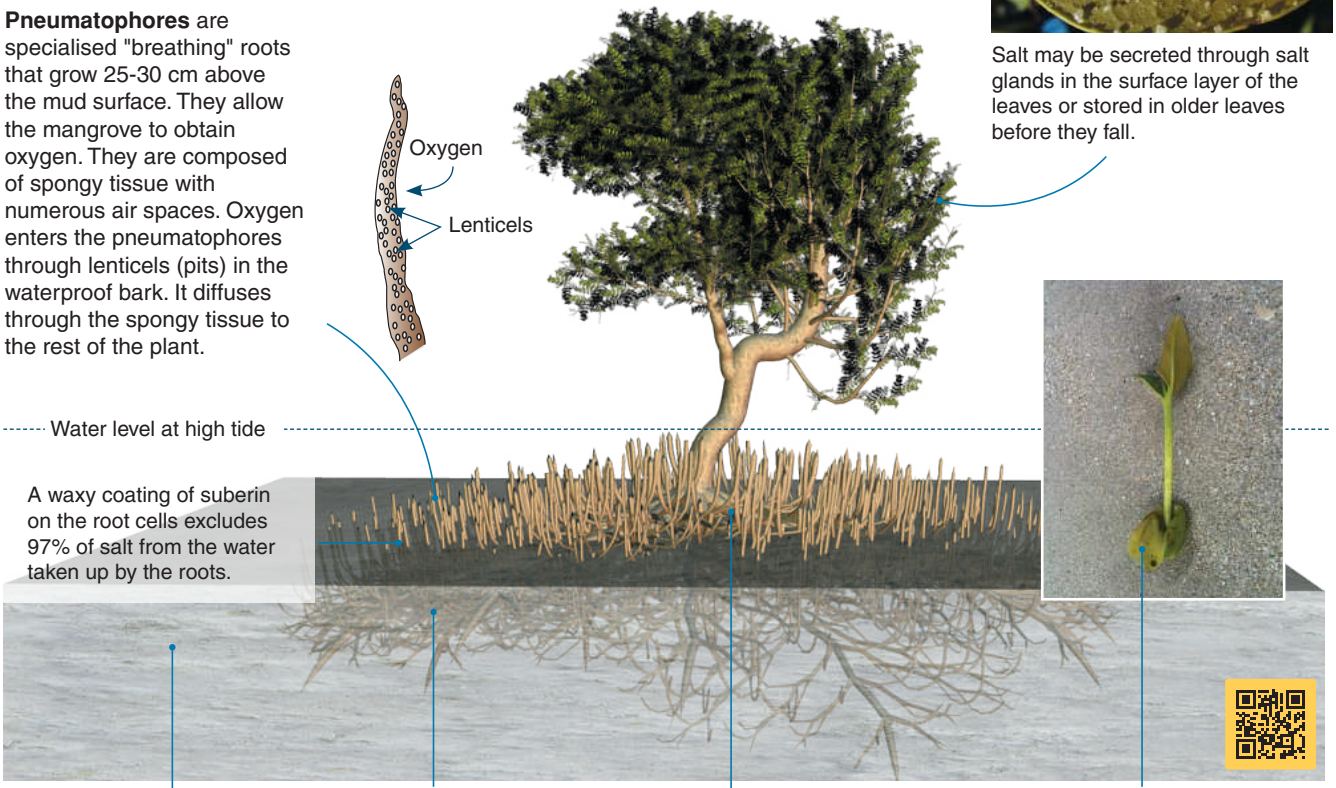
Mangroves are **halophytes**, a group of plants with adaptations for growth in seawater or salty, water-logged soil. They grow in the upper part of the intertidal zone, but also extend further inland to form salt marshes and other coastal wetland communities. Australia has 36 species of mangroves.

Mangroves grow from the upper part of the intertidal zone to the high water mark, forming some of the most complex and productive ecosystems on Earth. The high salt environment would kill most other kinds of plants as high salt levels cause water to flow out of the cells. Mangroves overcome this by storing salt in their cell vacuoles and maintaining a high concentration of solutes in the cytoplasm of their cells. This reverses the osmotic gradient and maintains the transpiration stream.



Salt may be secreted through salt glands in the surface layer of the leaves or stored in older leaves before they fall.

Pneumatophores are specialised "breathing" roots that grow 25-30 cm above the mud surface. They allow the mangrove to obtain oxygen. They are composed of spongy tissue with numerous air spaces. Oxygen enters the pneumatophores through lenticels (pits) in the waterproof bark. It diffuses through the spongy tissue to the rest of the plant.



Only the top few centimetres of the mud contains oxygen. Beneath, the mud is anaerobic (lacking oxygen), black, and foul-smelling. A deep root system is of no use here.

Cable roots radiate from the trunk, about 20-30 cm below the surface. Growing off these radial roots are fine **feeding-roots** (not shown), which create a stable platform.

Prop roots that descend from the trunk act like buttresses, providing additional support for the tree in the soft mud and supplement the oxygen uptake from the pneumatophores.

The mangrove **propagule** is a partially developed seedling adapted for dispersal in water. It is able to quickly take root once it reaches a suitable site.

1. What two physical adaptations of mangroves provide support for the plant in the soft mud?

   (a) _____

   (b) _____

2. What is the purpose pneumatophores? _____

   _____

3. Describe a physiological problem associated with living in a high-salt substrate: _____

   _____

4. Describe three methods by which various mangrove species solve the problem of a high salt environment:

   (a) _____

   (b) _____

   (c) _____

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128 Plant Adaptations to Fire

Key Idea: Some Australian plants have adaptations that allow them to survive and even benefit from episodes of fire.

Some Australian plants have adaptations associated with surviving and even benefiting from fires. Species living in ecosystems prone to fire must be able to survive the fire, or leave offspring that will germinate after the fire. In general, plants cope with fire in two ways. Some re-sprout from protected buds after above-ground parts have been burned away. Other plants may die completely, relying on the germination of fire resistant seeds to recolonise.

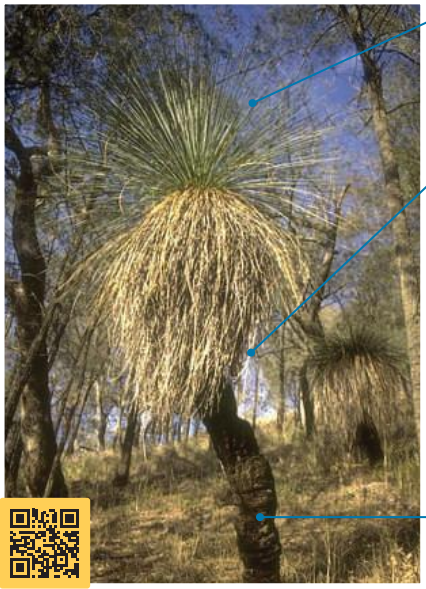
Robert Kerton, CSIRO cc3.0

Some Australian eucalypt trees have **epicormic buds**. These are dormant buds protected from fire because they lie deep beneath the thick bark. They sprout after the fire, allowing the vegetative regeneration of branches from their trunks.

Genet cc3.0

A **lignotuber** is a woody swelling of the root crown. It protects the plant stem from being destroyed by fire. It is safe from fire and can store water and food to support regrowth. The same lignotuber can survive many fires.

The seeds of eucalypts are often held in an insulated capsule, which opens only in response to heat of the fire. The smoke from the fire stimulates the seeds of annual plants, which may have been dormant for many years, to germinate.



New growth: After a fire, new growth emerges from the top of the stem.

Dead leaves: Dead leaves form a skirt at the base of the crown. These burn rapidly and fiercely but do not damage the growing tip in the crown.

Fire-blackened stem: Although it looks damaged, the fibrous stem provides special protection from the fire and the important vascular tissue survives well. The plant sheds its leaves each year, but the bases remain attached to the stem and produce a thick gum that glues the whole lot together into a very effective fire guard.

Fire tolerant grasses, (such as the one below) are burnt in bush fires, but quickly regenerate so long as they are not heavily grazed. After the fire, new growth emerges from the stubble. The growing tips are protected during a fire by soil or the clumped nature of the grass.

Burnt stubble: Old, dry leaves are burnt off easily during the fire, but the intensity of the flame is not great and does not damage the growing tissue.

1. How do lignotubers and epicormic buds aid survival of fire-tolerant species? _____

2. Bush fires are natural events, but humans have increased the frequency of fire occurrence when clearing land. This has meant that species that would usually mature and set seed before the next fire do not have the chance to do so. What would happen to these seed-producing species if fire frequency in an area increased markedly?

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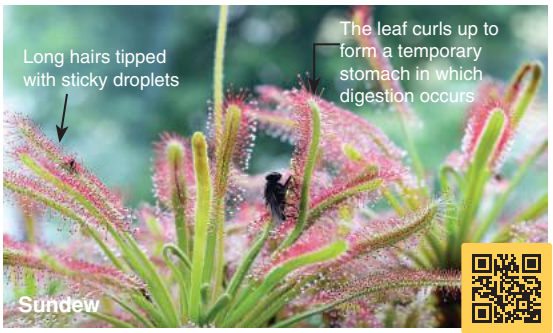
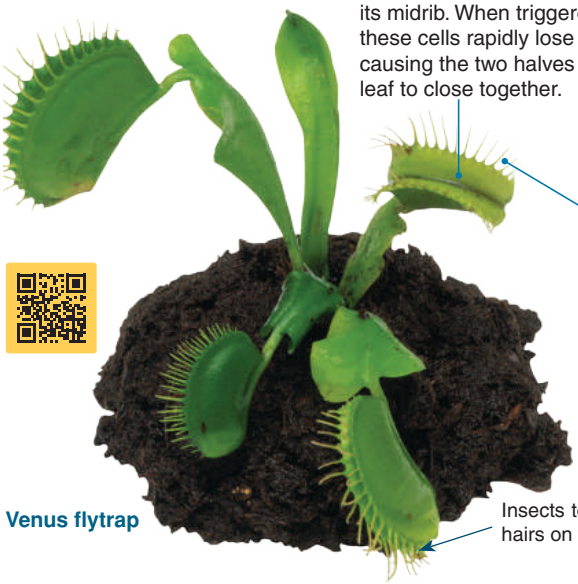
129 Adaptations of Insectivorous Plants

Key Idea: Insectivorous plants capture and digest small invertebrates to meet their nitrogen requirements.

Plants that live in acid bogs or in nutrient-poor soils often obtain extra nutrients (particularly nitrogen) by capturing and digesting small invertebrates. These plants are called **insectivorous** (or sometimes carnivorous). They photosynthesise to make their own sugars, but obtain some of their nitrogen and minerals from animal tissues. The traps are leaf modifications and usually contain special glands that secrete digestive enzymes. Insectivorous plants are usually small because their nutrient-poor environment does not support the growth of large plants.



Sundew (left): Sundews (*Drosera*) capture their prey in the sticky secretions on their leaf hairs. These make a trap like flypaper. The hairs bend over the prey and restrain it and the entire leaf cups around to enclose the prey. Sundews are found throughout most of Australia, apart from the arid centre.



Venus fly trap: The Venus fly trap consists of two, lobed modified leaves that can rapidly close together to trap prey (usually small insects). The trigger for closing is a touch on the sensory hairs of the leaves.

Pitcher plant: This plant is a passive trap. Prey fall into the water collected at the base of the pitcher and then drown. The digestive enzymes produced by the plant slowly digest the prey's tissues. Pitcher plants grow in the tropical rainforests of Cape York peninsula.

1. (a) What does an insectivorous plant gain from digesting insects? _____

   (b) How this is an advantage to the plant in its habitat? _____

   _____

   _____

2. (a) Describe one cost (disadvantage) to the plant of producing insect-trapping modified leaves: _____

   _____

   (b) Why are insectivorous plants not usually found growing in nutrient rich soils where ordinary plants are present?

   _____

   _____

3. Describe the modifications to the leaf structure of the Venus fly trap that enable it to capture insects:

   _____

   _____

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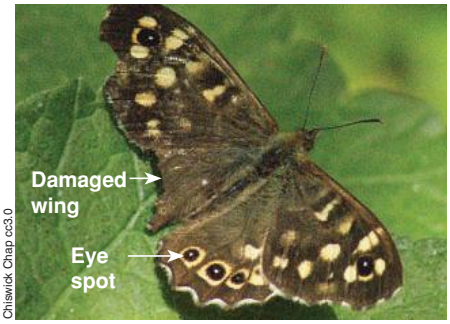
130 Adaptations in Animals

Key Idea: Structural, physiological, and behavioural adaptations contribute to increased fitness.

The adaptations of animals (like all organisms) are the product of evolution and contribute to their fitness (survival and successful reproduction). Animals must find food, avoid being eaten, and survive environmental extremes (e.g. cold, wet, dry). The adaptations of two very different taxa, butterflies and lace monitors (goannas), illustrate the range and diversity of animal adaptations, both to physical environment and to niche. Butterflies are a globally successful group of insects adapted to a wide range of conditions. Goannas are highly successful top predators, often in harsh environments.

Butterfly adaptations

Basking: Butterflies must bask in the sun to raise their body temperature so that they can fly. Heat capture is maximised by holding their wings outstretched and angled towards the sun to increase energy capture. Their wings are often dark coloured because dark colours absorb more of the sun's energy than light colours.



Fright and distraction: Eye spots on the wings of some butterflies can trick predators into thinking it is a much larger animal, and deter an attack. Eye spots are often located at the posterior of the animal, so if the butterfly is attacked, the head is not targeted. Damage to the wings is unlikely to kill the animal, but an attack to the head is likely to be fatal.

Surviving winter: Butterfly species have a number of strategies to survive low winter temperatures. Strategies include dormancy in adult butterflies to save energy, or laying eggs in late summer or autumn so that eggs hatch in spring when food is plentiful. Some species overwinter as caterpillars or a chrysalis insulated within vegetation or underground.

Camouflage: Some butterfly species use camouflage to blend into their surroundings. Colours and patterns on the wings make it difficult for their predators to see them, allowing the butterfly to avoid being eaten while at rest or feeding.

Mimicry: Some species do not try to hide and are very brightly coloured. This colouration is a warning to predators that they are poisonous (e.g. monarch butterfly) and should not be eaten. Other species take advantage of this and mimic the warning colours. For example, the viceroy butterfly is not poisonous, but survives by mimicking the Monarch's colouration. Predators treat it as poisonous and leave it alone. Some species mimic other animals such as wasps and snakes.

1. Some butterflies use camouflage as a passive defence against being eaten, while others, such as the monarch butterfly are very brightly coloured. Briefly describe how these two very different adaptations aid survival.

2. Butterflies must use the Sun's energy to raise their body temperature so that they can fly.

   (a) What is a disadvantage of this? _____

   (b) What adaptations do butterflies have to overcome this disadvantage? _____

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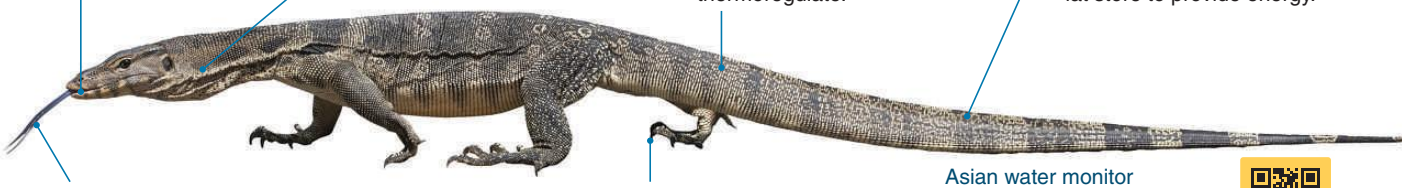
Adaptations of goannas or monitor lizards (*Varanus* spp.)

Upper jaw can move independently of the rest of the skull to help swallow prey whole. Sharp, recurved teeth help hold and handle prey.

Strong neck and jaw muscles aid holding, shaking, and subduing prey. They are strict carnivores eating a range of available animal species, including carrion.

The skin of species in arid regions is highly reflective to reflect heat and help thermoregulate.

Strong muscular tail used in defence. The base of the tail may become thickened as a fat store to provide energy.



Asian water monitor

Forked tongue collects scent particles, which are delivered to the Jacobson's chemosensory organ on the roof of the mouth.

Long, sharp claws are used for tearing at prey

Monitors are active during the day in all seasons, maintaining high body temperatures (up to 38°C) through basking. Gular pumping helps ventilate the lungs during periods of high activity. Hissing and an upright threat posture (right) deter attackers.

A water monitor shows basking behaviour

Gould's monitor in raised stance

Goannas are found in a wide variety of habitats, from aquatic to arid semi-desert. In hot environments, gaping and panting, accompanied by pumping movements of the throat region (gular pumping) when the mouth is open, aid evaporative cooling by increasing convective heat loss.

Nile monitor gaping with gular ventilation.

3. Describe a structural, physiological, and behavioural adaptation of goannas. For each, explain how the adaptation assists survival in the environment and contributes to fitness:

   (a) Structural adaptation: _____

   _____

   _____

   (b) Physiological adaptation: _____

   _____

   (c) Behavioural adaptation: _____

   _____

   _____

   _____

4. The desert-dwelling greater bilby (*Macrotis lagotis*) is a species endemic to Australia. The species is well adapted for life in arid environments although habitat losses now threaten it. Research some of the adaptations of the bilby to its desert lifestyle and list them below.

   _____

   _____

   _____

   _____

   _____

   _____

   _____

ISBN: 978-1-98-856636-8

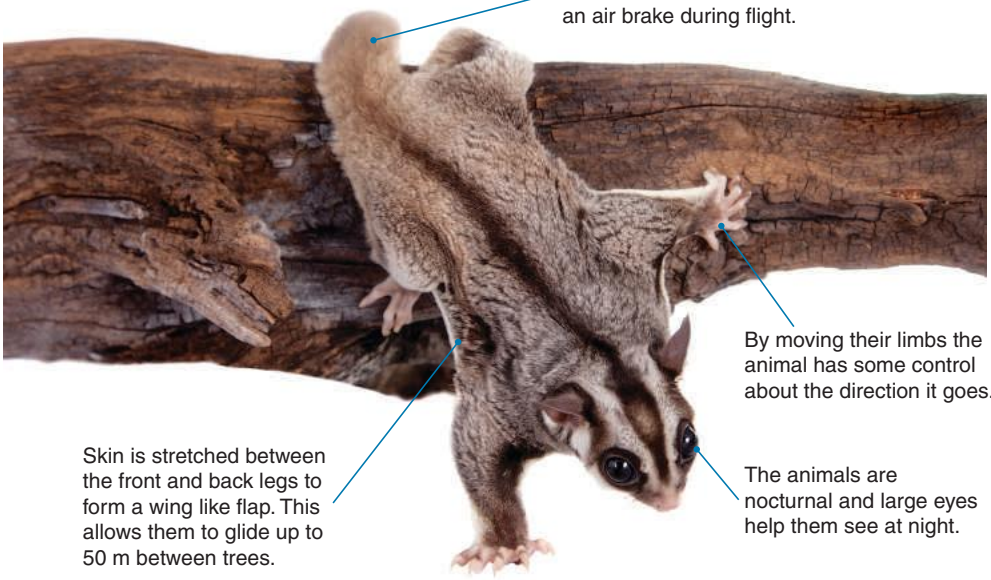
Similar adaptations in unrelated animals

The ability for mammals to glide between trees has evolved independently in unrelated animals. The characteristics listed below for the sugar glider are typically found in the gliding mammals shown here.


Colugo (related to lemurs)


Flying squirrel (rodent)

Sugar glider (marsupial)



5. Suggest why gliding between trees (rather than walking) is an advantage to the gliding mammals described above:

6. The echidnas and hedgehogs are an example of unrelated organisms that have both evolved spines. Explain the advantage of this adaptation to both these animals and why might it have evolved?

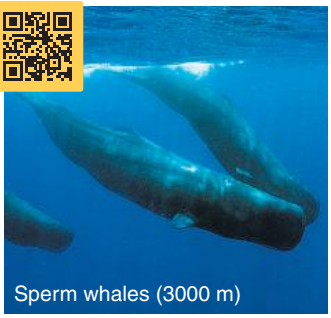
7. Identify two other unrelated organisms adapted to similar environments and describe an adaptation that they both share:

ISBN: 978-1-98-856636-8

131 Adaptations for Diving

Key Idea: Diving animals have adaptations that allow them to stay active while submerged for extended periods of time.

All air breathing animals that dive must maintain an oxygen supply to the tissues while submerged. This is a problem for mammals and birds in particular because their metabolic rates and oxygen demands are high. In addition, resurfacing from dives of 20 m or more carries a risk of decompression sickness, where dissolved gases in the blood produce bubbles as pressure reduces. Primates (including humans) are one of the few orders of mammals without diving representatives.


Sperm whales (3000 m)


Weddell seals (1000 m)

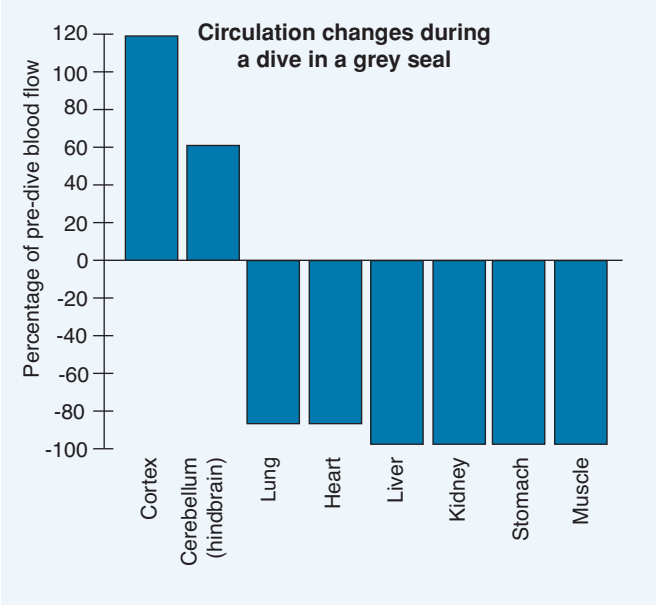

Pantropical spotted dolphins (300 m)

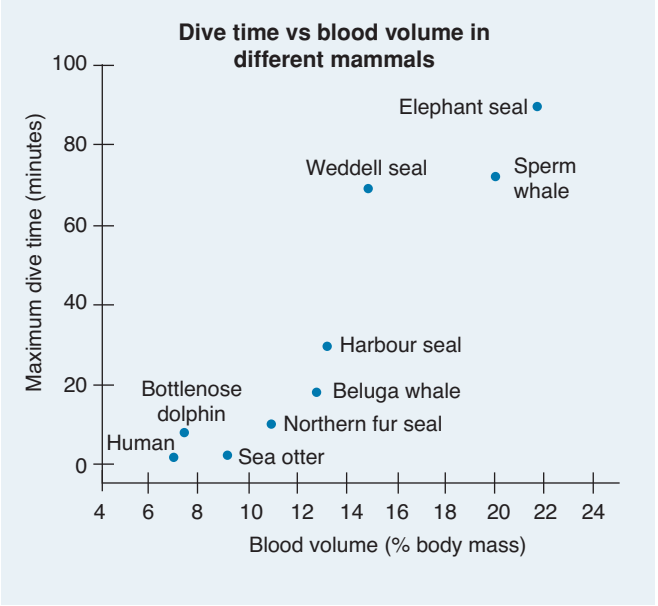

Dugong (10 m)

Diving mammals have physiological adaptations that enable them to stay underwater

Dolphins, whales, seals, and to a lesser extent dugongs (Australia) and manatees (Northern Hemisphere), are among the most well adapted diving animals. They exhale before diving, expelling most of the air from their lungs. In deep divers, the flexible rib cage allows the lungs to be compressed at depth so that only the trachea contains air. This stops nitrogen entering the blood and prevents decompression sickness ("the bends") when surfacing. During dives, heart rate slows and blood flow is redistributed to critical organs (plot, below left). Most diving mammals have high levels of myoglobin, an oxygen-binding protein found in skeletal muscle (plot, opposite page). Sperm whales are the deepest divers (3000 m) and Weddell seals dive to 1000 m for 40 minutes or more (plot below, right). During these dives, heart rate drops to 4 or 5 beats per minute (4% of the rate at the surface).

Dugongs and manatees, which graze on the ocean floor, are also well adapted for diving, but their dives are generally shallow feeding dives (~3 m) and their muscles do not contain the high concentrations of myoglobin typical of deep divers.





Diving birds
Penguins show many of the adaptations typical of diving birds. During dives, their heart rate slows, and blood is diverted to the head, heart, and eyes.

Diving reptiles
Sea turtles such as the green sea turtle have low metabolic rates, and tolerate low oxygen. They use the lining of the mouth and the cloaca for gas exchange and can overwinter at 10-15 m depth for several months.

Bony fish
Fish don't dive like air breathing animals. However bony fish do experience the effects of pressure. They use an air filled swim bladder to adjust their buoyancy. If they surface too quickly, the swim bladder can expand like balloon.

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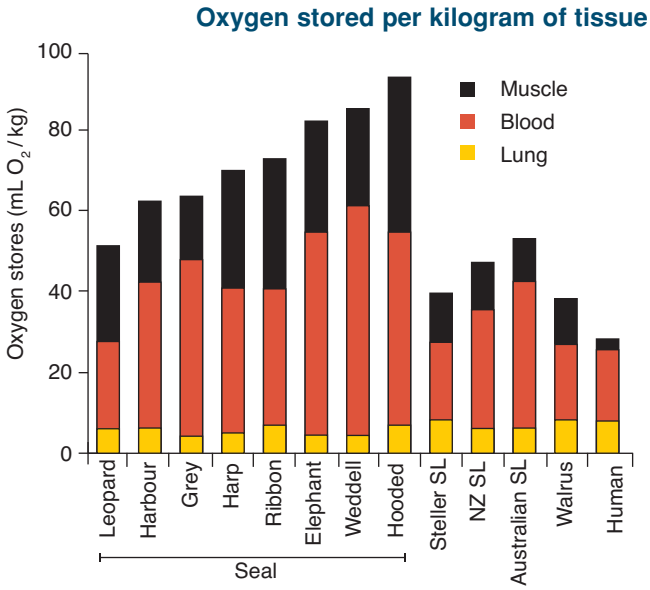
1. Unlike humans, mammals that have evolved adaptations for diving exhale before they dive (humans inhale). How might this be an advantage to diving mammals?

2. What is the relationship between blood volume as a percentage of body mass and the maximum dive time in mammals with adaptations for diving?

3. Describe the blood flow in a seal during a dive: _____

4. The ability to remain submerged for long periods of time depends on the ability to maintain the oxygen supply to the tissues. This depends on oxygen stores. The graph below compares the amount of oxygen in different regions of the body during a dive in various seal and sea lion (SL) species and a human (not on scuba).



(a) Describe how seals store oxygen in their body: _____

(b) How does this compare to a human? _____

(c) The seals are more specialised for a life in water than the eared sea lions. Does the evidence above support this?

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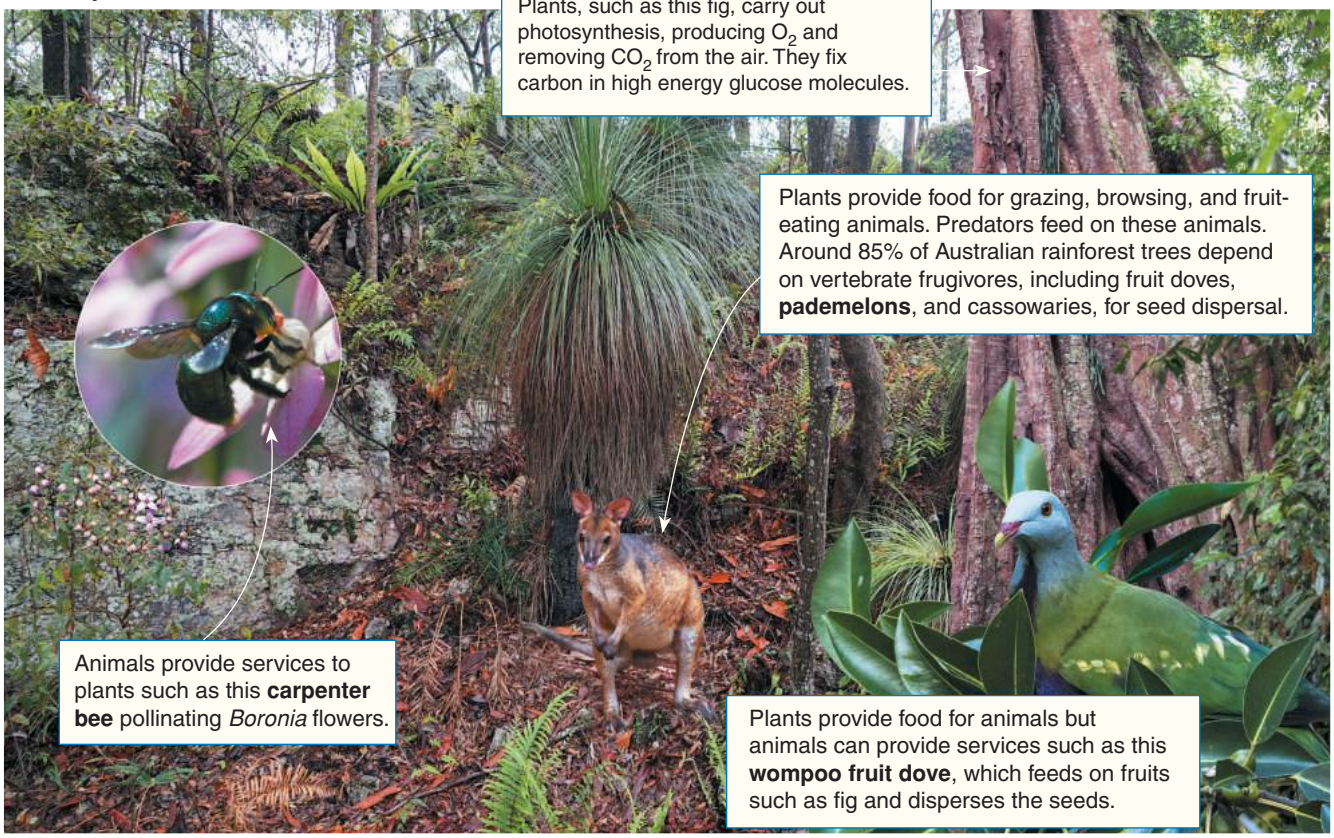
132 Interdependencies in Ecosystems

Key Idea: All organisms in an ecosystem are interdependent.

Ecosystem are composed of many interacting species. These interactions create interdependencies as species come to rely on each other for food and services such as pollination and seed dispersal. The organisms involved in these interdependent relationships are not acting altruistically. They are simply functioning in their niches in a way that maximises their own fitness (survival and production). A pademelon feeding on fallen fruits and then dispersing seeds is ensuring its own survival. The services it provides to the tree is one consequence of its activity. In the rainforests of Australia, these interdependencies are crucial to forest survival.

Interdependencies in a forest



1. Use the examples described above to illustrate interdependencies in ecosystems:

2. Some plant and animal species have very specific relationships. In some, e.g. the Moreton Bay fig and the fig wasp, one plant species is pollinated by only one species of insect. What would be the effect on either species is one was lost?

3. Ecosystems are made up of thousands of interactions between species. Human activities are having increasing effects on ecosystems, one of which is the removal of species by hunting or habitat destruction. How would the interactions and interdependencies be affected over time as more and more species are lost from an ecosystem?

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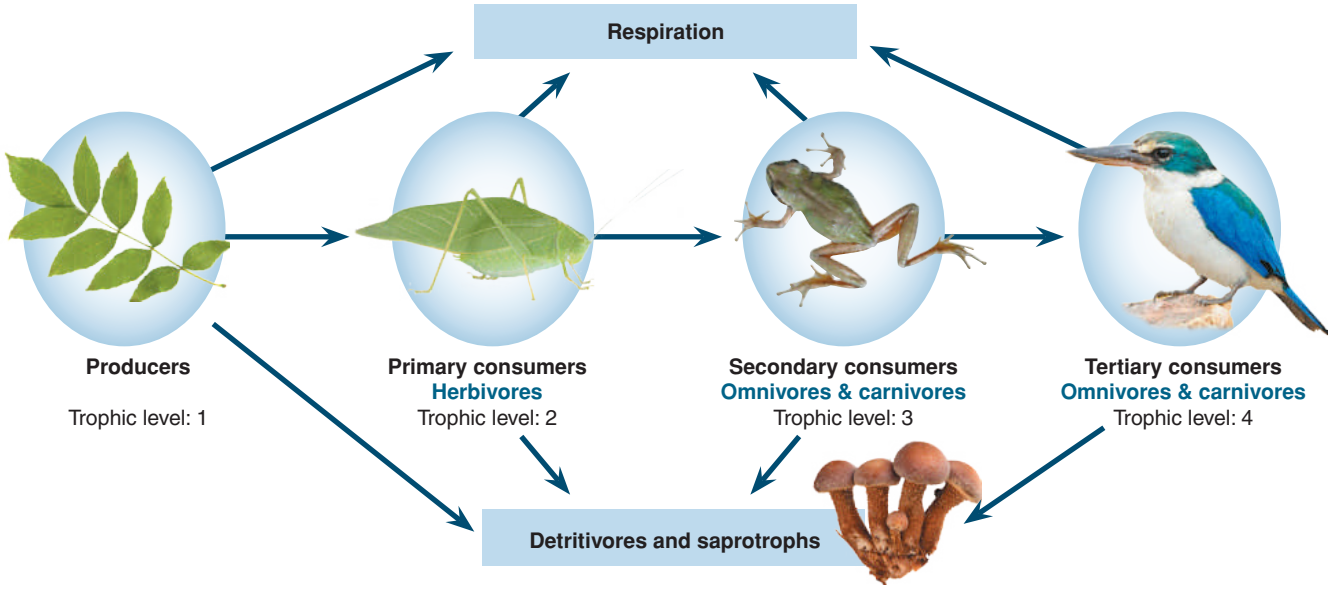
Interdependencies in food chains

Some of the most critical interdependencies in ecosystems occur in food chains and food webs.

- A food chain is one of the simplest sequences of interactions. One species is eaten by another, which is eaten by another, and so on until the chain ends in a top (apex) predator. This apex predator is dependent on all the previous feeding interactions that concentrate food energy in its prey. The interconnections among many food chains produces a food web.



Symbiosis and interdependence

Symbiosis is a term that means "living together". It encompasses a range of interactions involving a close relationship between two (or sometimes more) species. In a mutualism, the relationship is beneficial to both parties, with each providing resources or services to the other. In parasitism, only one species (the parasite) benefits by obtaining resources, while the other (the host) is harmed.

Mutualism involves a close association between two species that offers both an advantage. Lichens (above) are the result of a mutualism between a fungus and an alga or a cyanobacterium

Termites have a mutualistic relationship with the cellulose digesting microbes (primarily protozoa) in their guts. A similar mutualistic relationship exists between ruminants and their gut microflora of bacteria and ciliates.

Parasites exploit a host's resources for their own benefit. The host is harmed, but rarely killed and some individuals in the population tend to carry most of the parasite burden. Parasites may live inside or on their host.

4. Which organism in the food chain above do all the *consumers* depend on? _____

5. Suggest what may happen over time to the populations of primary and secondary consumers if the top predator was removed from the food chain:

_____

_____

_____

6. In what way are termites and the protozoa in their gut dependent on each other?_____

_____

_____

_____

7. Why do you think parasitic relationships are able persist in ecosystems when the host is harmed by the relationship:

_____

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Competition is an important interaction

Competition is a key interaction within and between species in ecosystems. It occurs when organisms attempt to access the same limited resource.

- Interspecific competition (i.e. competition between members of different species) may force organisms to occupy a more restricted niche than would be available to them in the absence of competition.
- To avoid direct competition, naturally coexisting species have evolved slightly different niche requirements, even if many of their resource needs are much the same. For example, they may exploit the same resources but at different times or in slightly different types of habitat. Alternatively, they may exploit slightly different sizes of the same type of resource, e.g. seeds.


Young squirrel glider


Sugar glider

Gliders in Australia

Gliders are small, nocturnal possum-like marsupials that live most of their life in tree canopies. Seven species of glider are found in Australia, and six of these are found in Queensland. In Australia, gliders of the genus *Petaurus* occupy very similar niches. All are nocturnal, require tree hollows for nesting, and feed on insects, nectar, pollen, honeydew, and plant sap.

Squirrel glider: The squirrel glider (top right) is distributed from Victoria to northern Queensland, but is not found on the Cape York Peninsula. Squirrel gliders have a limited habitat range, and are restricted to dry eucalypt forests and woodlands. Squirrel gliders live in family groups of 2-10 individuals and weigh 200-260 g.

Sugar glider: The distribution of the sugar glider (right) is broader than the squirrel glider. It inhabits the eastern and northern coasts of Australia, New Guinea, and the surrounding islands. The sugar glider is found in a wide range of habitats including drier coastal eucalypt forests and woodlands to wetter rainforest habitats. Sugar gliders live in family groups of 2-10 individuals and weigh 95-160 g.

Investigating niche overlap and coexistence in gliders

In large areas of eastern Australia, the distribution of sugar gliders and squirrel gliders overlap. Researchers looked at historical and recent data (below) to see how the two species were ecologically separated where their distribution overlapped.

Table 1. Occurrence of glider species in rainforest and other forest.

	Forest type	
	Rainforest	Other
Historical data		
Sugar glider	77%	23%
Squirrel glider	17%	83%
Recent data		
Sugar glider	64%	36%
Squirrel glider	7%	93%

Table 2. Frequency of glider species at different elevations.

	Records in elevation class			% of records that were rainforest at:	
	< 80 m	80-300 m	> 300 m	< 80 m	> 80 m
Historical data					
Sugar glider	77%	0%	23%	70%	100%
Squirrel glider	85%	12%	3%	14%	33%
Recent data					
Sugar glider	71%	0%	29%	50%	75%
Squirrel glider	85%	13%	2%	6%	13%

Data: Rowston, C & Catterall, C.P. (2004) Habitat segregation, competition and selective deforestation: effects on the conservation status of two similar *Petaurus* gliders. Conservation of Australia's forest fauna http://hdl.handle.net/10072/416

8. Study table 1. What do you notice about the type of forest each species is found in? _____

9. The majority of both species are found below 80 m (Table 2). How do you think they avoid competition with each other?

10. Suggest why the niche of the sugar glider is more restricted when both species inhabit the same area: _____

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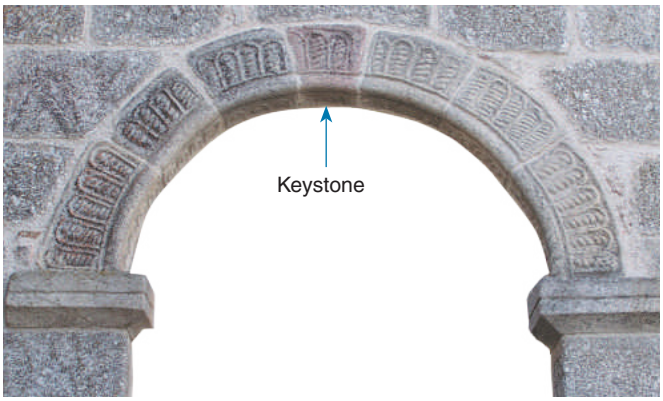
133 Interdependencies: Animal Keystone Species

Key Idea: All organisms within an ecosystem contribute to its structure and functioning, but keystone species have a disproportionate effect on ecosystem processes.

Although every species has a role in ecosystem function, some have a disproportionate effect on ecosystem processes and stability (how unchanging the ecosystem is over time). These species are called **keystone species** and they are important because they play a pivotal role in the way the ecosystem works, e.g. as top predators or by recycling nutrients. The loss of a keystone species can have a large and rapid impact on the structure and function of an ecosystem, changing the balance of relationships and leading to instability. This has important implications for ecosystem management because many keystone species are endangered.

Why are keystone species important?

A keystone species is one that plays a unique and crucial role in the way an ecosystem functions. Often, but not always, keystone species are top predators. The role of the keystone species varies from ecosystem to ecosystem, but the loss of a keystone species from any ecosystem has a domino effect, and a large number of species can be affected. This can lead to can rapid ecosystem change or the collapse of the ecosystem completely.



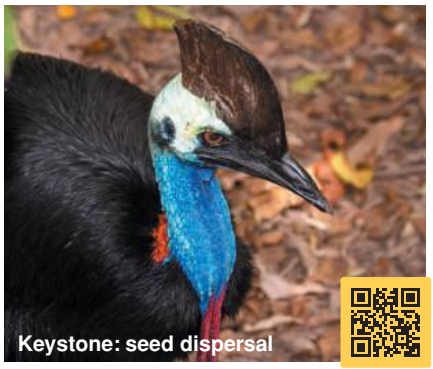
The term keystone species comes from the analogy of the keystone in a true arch (above). An archway is supported by a series of stones, the central one being the **keystone**. If the keystone is removed the arch collapses.

Ochre starfish: Paine removed these in his study to see what the effect would have on the rocky shore community.

Keystone species in action

The idea of the keystone species was first hypothesised in 1969 by Robert Paine. He studied an area of rocky seashore, noting that diversity seemed to be correlated with the number of predators (ochre starfish) present (i.e. diversity declined as the number of predators declined).

To test this he removed the starfish from an 8 m by 2 m area of seashore. Initially, the barnacle population increased rapidly before collapsing and being replaced by mussels and gooseneck barnacles. Eventually the mussels crowded out the gooseneck barnacles and the algae that covered the rocks. Limpets that fed on the algae were lost and the number of species present in the study area dropped from 15 to 8.



The endangered southern cassowary is a keystone species in Australia's wet tropics. They are obligate fruit eaters, and their gut passes seeds, unharmed, into a pile of manure. More than 200 plant species depend on the cassowary to disperse their seeds, yet their populations are all declining. Their loss would also mean the loss of an ecological role.

Taro Taylor cc 2.0

The humphead wrasse is a protected reef fish. It is large, long lived and slow breeding species and an opportunistic predator of a wide range of invertebrates. It is a keystone species because it preys on crown-of-thorns starfish and keeps the populations of this coral predator in check. It is also considered an **umbrella species** because its protection benefits a large number of other species.

Top predators, such as Australia's dingo, are often keystone species. Many conservationists regard dingoes as a functional replacement for native predators that are now extinct, such as the Tasmanian tiger. Dingoes have a varied diet and are a major constraint on introduced species, such as a foxes and pigs, thereby helping to maintain native mammal diversity.

1. Why are keystone species so important to ecosystem function? _____

_____

_____

_____

_____

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Albert kok cc3.0

Andrew Mercer cc 4.0

Many sharks are top predators and are keystone species in the waters around Australia. One shark species inhabiting Shark Bay (WA) is the tiger shark. It doesn't even have to kill its prey to exert an effect on ecosystem structure. The presence of the tiger shark causes marine herbivores such as green turtles and dugongs to avoid the area or to spend less time grazing because they are looking out for the sharks. As a result, the seagrass meadows thrive and support many more species than would be possible if they were grazed intensively by herbivores. As a result, biodiversity in Shark Bay is high. Fishing is the main threat to tiger sharks as they hunted for their flesh, fins, and skin. Finning is banned in Australian waters, but still continues illegally because of the difficulty in policing.

The grey-headed flying fox (*Pteropus poliocephalus*) is found in a variety of habitats along the east coast of Australia, including Victoria. The grey-headed flying fox feeds on the fruit and nectar of over 180 species of trees, including Australian natives *Eucalyptus*, *Banksia*, palms, and myrtles. It will fly up to 50 km each night looking for food and this allows it to fulfill an important ecological role by dispersing the pollen and seeds of a wide range of plants. Its role is especially important in the subtropical rainforests as it is the only mammalian species to consume nectar and fruit in these regions. The species is under threat from the loss of foraging and roosting habitat and control measures by horticulturists to prevent crop losses.

2. For each species below, summarise the features of its ecology that contribute to its position as a keystone species:

   (a) Southern cassowary: _____

   _____

   _____

   (b) Humphead wrasse: _____

   _____

   _____

   (c) Dingo: _____

   _____

   _____

   (d) Tiger shark: _____

   _____

   _____

   (e) Grey-headed flying fox: _____

   _____

   _____

3. The arrival of the dingo in Australia probably resulted in the loss or reduction of many top marsupial predators. It now plays a role as a keystone species in modern Australia. How might this have occurred?

   _____

   _____

   _____

   _____

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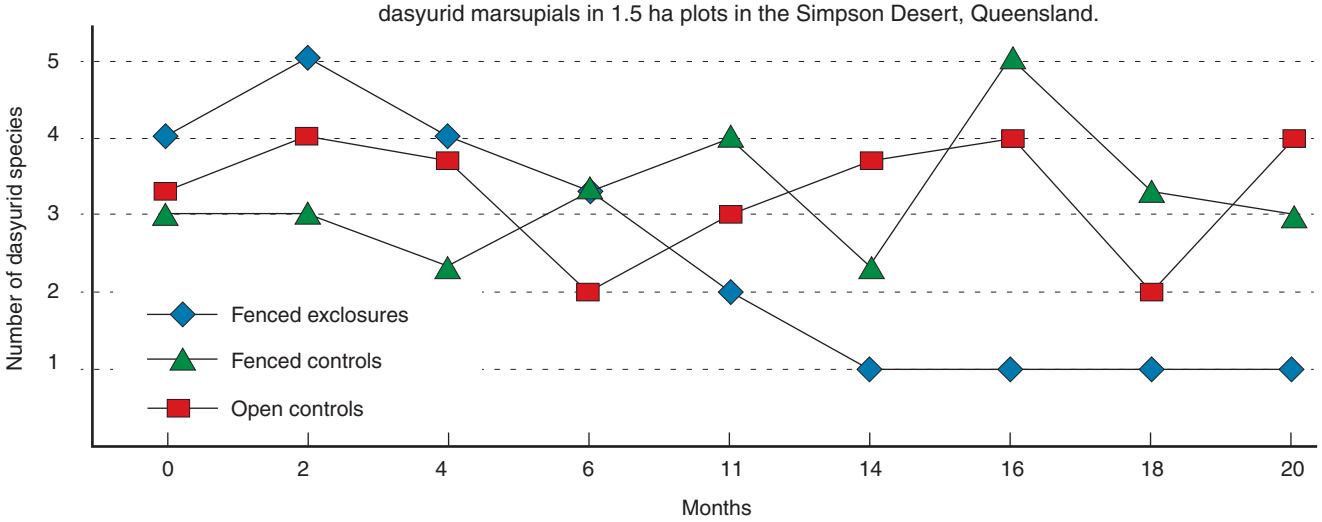
Case study: crest-tailed mulgara as a keystone species

- Two species of mulgara (*Dasycercus* genus) are found in Australia, the brush-tailed mulgara and the crest-tailed mulgara. Mulgara are nocturnal marsupials belonging to the family Dasyuridae, which includes the Tasmanian devil and the quolls. Both mulgara species are small (30 cm long from head to tail) and weigh up to 190 g.
- Mulgaras live in arid central Australia, and burrow 50 cm under the surface to avoid the heat. While the brush-tailed mulgara has an extensive range through the middle of Australia, the crest-tailed mulgara is found only in a small part of the Simpson Desert within Queensland's borders.
- The effect of the crest-tailed mulgara (*Dasycercus cristicauda*) as a keystone species was tested by excluding them from a 1.5 ha plot of land. Fenced exclosures were established 10 months after sampling began. All dasyurid species (except mulgara) could access the site. Fenced controls and open controls were established at the same time. All dasyurid species (including mulgara) could access these plots. The results are shown in the graph below.

Bobby Tamayo CC 4.0

Effects of crest-tailed mulgara (*Dasycercus cristicauda*) on the number of smaller dasyurid marsupials in 1.5 ha plots in the Simpson Desert, Queensland.



Data source: Dickman in Attiwill, P. and Wilson. B (2003) Ecology: An Australian Perspective.

4. Describe what happens to species numbers after the fences were established (at 10 months) for each of the following:

   (a) Fenced exclosures: _____

   (b) Fenced controls: _____

   (c) Open controls: _____

5. Describe the difference in species numbers between the fenced exclosure and the:

   (a) Fenced control: _____

   (b) Open control: _____

6. (a) Based on the data presented above, do you think the crest-tailed mulgara acts as a keystone species? _____

   (b) Explain your answer: _____

   _____

   _____

   _____

7. Why do you think the researchers included a fenced control and open control? _____

   _____

8. Why let other dasyurid species into the exclosures? _____

   _____

   _____

ISBN: 978-1-98-856636-8

134 Interdependencies: Plant Keystone Species

Key Idea: Plants are common keystone species and, as important food providers, influence a range of other species.

Plants and other producers are at the base of food chains, so their role in ecosystems is always going to be important. However, some plants have a much greater influence than just providing food as leaves, roots, seeds, or fruit. They may provide crucial habitat, stabilise soil, or provide nutrients to the soil though the leaf litter that accumulates around them.

Keystone plants

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Gnangarra cc 2.5

Wendy Cutler CC 2.0

Cockatoo grass (*Alloteropsis semialata*) is found through tropical savannas in northern and north eastern Australia. Cockatoo grass is an early developer in the wet season, providing a food source to many animal species before other plant species are available. Cockatoo grass is considered to be a keystone species because at certain times of the year it is the only food source available for two endangered species, the golden-shouldered parrot and the Northern bettong, a small marsupial. Young cockatoo grass is a preferred food source cattle and pigs, so it is easily overgrazed, leaving little for the wild species that rely on it. Conservation efforts are made to protect stands of cockatoo grass in some areas.

All species of banksias produce large amounts of nectar, and are a vital component of food chains in the Australian bush.

In the Avon Wheatbelt region of Western Australia, the acorn banksia is the sole source of nectar for honeyeaters at certain times of the year. The loss of this plant species would also result in the loss of honeyeaters from the region.

Fig trees of the genus *Ficus* act as keystone species in many parts of Australia. The rusty fig (*F. rubiginosa*) in eastern Australia grows to 30 m tall and is used as a shade tree in parks, spreading to 30 m wide. It provides food for both frugivorous (fruit-eating) and insectivorous (insect-eating) birds. Insectivorous birds eat the pollinating wasps before the fruits ripen. Frugivorous birds eat the ripened fruits. Studies have shown that over 80 species of both frugivorous and insectivorous birds feed on the fig tree. The wasp *Pleistodontes imperialis* is an obligate pollinator, although another 14 species of wasp and 2 species of nematode feed on the leaves and fruit. Both the grey headed and spectacled flying fox feed on the fruit.

1. For each species below, summarise the features of its ecology that contribute to its position as a keystone species:

   (a) Cockatoo grass: _____

   _____

   _____

   (b) Banksia: _____

   _____

   _____

   (c) Rusty fig: _____

   _____

   _____

2. Both plants and animals can act as keystone species. Compare and contrast their roles as keystone species. Do plants exert their influences through the same mechanisms as animals?

   _____

   _____

   _____

   _____

   _____

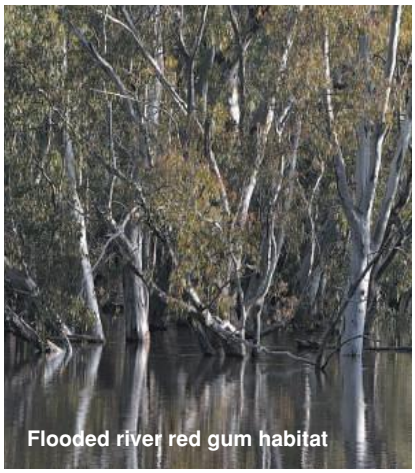
   _____

ISBN: 978-1-98-856636-8

Case study: Importance of the river red gum

The river red gum is a keystone species in the Murray Darling Basin (MDB). A reduction in its numbers due to reduced flooding events and increased harvesting has altered the ecology of the Murray Darling Basin.

Increasing demand on water resources in the MDB has resulted in wide-spread dieback of floodplain forests. This has been observed in the river red gum (*Eucalyptus camaldulensis*). The river red gum is the dominant floodplain tree in the southern MDB and is a keystone species. Their loss alters biodiversity in the region.

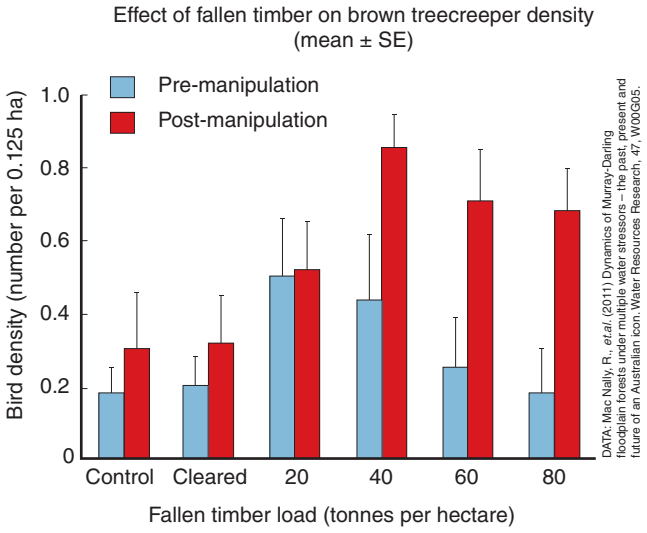


Flooded river red gum habitat

- River red gum is commonly found along Australian waterways and has the widest natural distribution of Australian eucalyptus species. In its natural habitat, the species is subject to regular flooding. Regular flood events recharge the soil with water.
- River red gums provide habitat for many species. For example:
  - Fallen trees produce "snags" in the water course. These provide breeding sites for blackfish during the flooding season. Aquatic birds feed off fish in the snags.
  - Hollows in trees create habitat for many species including the superb parrot, a threatened species. Birds, bats, and carpet pythons are also found in hollows.
  - The gum's dense foliage provides species with shade and shelter from the sun.
- River red gums contribute nutrients and energy to the ecosystem through leaf and insect fall. This is especially important in areas with low nutrient levels.
- The trees have an important role in flood mitigation and slow silt runoff.
- Unlike species that are chosen as flagship species, river red gums are not cute or charismatic. However, their conservation has many benefits because of the large number of species that depend on them either directly or indirectly.

Changes to the woodlands

Over the last century higher water demands (extraction and damming) have changed the flow characteristics along the MDB. Tree dieback has occurred as a result, and large changes to the vegetation structure and composition have been observed. Dieback is likely to continue with predicted climate changes (reduced precipitation and increased temperatures). Human management of the river red gum forests has also contributed to community change. Typically, the natural forest structure consists of large spreading trees with mixed aged trees between. Harvesting has resulted in mostly even-aged tree stands with "straight poles", and few stands of spreading trees. A higher percentage of fallen trees occur in natural forests compared to managed forests, and this likely affects forest fauna. Small mammals and birds prefer the spreading canopy and higher loads of fallen trees because they provide increased cover, shelter from predators, and more invertebrate food sources. Natural forests also contain more hollows than managed forest. The graph (right) shows how manipulating the load of fallen timber affects the density of brown treecreepers, a near threatened species. A near threatened species is one that may be threatened with extinction in the near future.



3. Study the post manipulation data (above). Explain the effect of fallen timber load on brown treecreeper density:

4. Explain what continued loss of river red gum could mean for the survival of the brown treecreeper:

5. Flagship species are chosen to raise public support for biodiversity conservation in a region. They are usually charismatic animals but they are not always keystone species. Why might the conservation of a keystone species such as river red gum be more effective as a conservation strategy than use of flagship species?

ISBN: 978-1-98-856636-8

135 Predators and Their Ecological Roles

Key Idea: The role a predator plays in a ecosystem depends in part on its position in the food chain and whether or not it is native or has been introduced.

A predator is an organism that kills and eats another. Commonly the term predator is applied to animal that eats the flesh or body fluids of another, although is can apply to all consumers. Predators play important ecological roles by influencing the age structure, size, growth rate, and distribution of prey populations. In naturally occurring communities, predators rarely eliminate prey species, which have their own defences against natural predators and often survive in habitat refugia. However, introduced predators can completely eliminate naive prey species, which have not evolved defences against new threats. Similarly, habitat loss or fragmentation can reduce suitable refugia so that prey species are unable to find places to hide from predators.

The variety of predators

Predators are diverse in their shapes, size, and strategies for prey capture. Each has evolved its own suite of adaptations to secure and consume prey. These adaptations reflect the evolutionary history of the species and its habitat.

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Ambush predators capture prey by stealth or strategy, rather than using speed or strength. They sit and wait for prey, camouflaged or from a concealed position, and the strike when the prey is close enough.

Christin Khan, NOAA cc0

Many species filter the water to extract food. Baleen whales, manta rays, and flamingoes are all filter feeders. It is a relatively passive feeding method although some whales will actively concentrate prey before feeding.

Grey wolves running down a bull elk

Pursuit predators actively chase their prey, running them down. This may be done individually (e.g. cheetahs, dragonflies) or as coordinated packs (e.g. grey wolves, above, and African wild dogs).

Some animals, particularly primates and crows, are gifted tool users. Chimps and New Caledonian crows (above) use specially stripped prepared twigs to extract insects from their nests. In both species, existing tools are modified and the information is communicated to others in the cultural group.

Many predators use lures to attract prey. Glow worms, some turtles, and anglerfish all use lures to attract prey within striking range. In anglerfish, the lure is modified from a fin ray.

Spiders have developed a unique method of trapping their prey by spinning webs. Webs are often placed across open spaces where flying insects will blunder into them.

1. Ambush is a very common predatory strategy. Identify three ambush predators above:

2. Suggest why predators rarely eliminate their prey in natural communities. How would this situation change when a new predatory species is introduced to an ecosystem:

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The role of top predators

Almost for as long as humans have been farming livestock or gathering animal resources, they have competed with the natural apex predator. Recall that apex predators occupy the top trophic level. They control prey density, regulate disease by taking old and sick individuals, and limit the numbers of smaller predators. Orca, saltwater crocodiles, and great skuas are all apex predators.

- In many regions of the world, the apex predators have been removed or severely reduced in numbers. This is often intentional, to protect people and livestock, or simply for trophy hunting. In other cases, habitat loss has made apex predators more vulnerable.
- The loss of key apex predators has resulted in many ecosystems being skewed towards herbivores. This in turn has resulted in over-grazing and ecosystem damage. The effects of apex predators on lower trophic levels are called **trophic cascades**.

Robert Pitman cc0

Orca (killer whales) are the apex predator in the oceans. Orca hunt in packs and are capable of preying on any other marine species. Overfishing can alter normal trophic balances and cause Orca to switch prey.

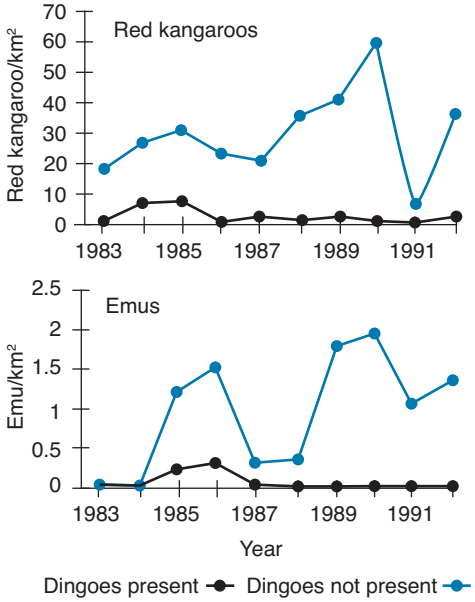
Grey wolves hunt in packs by running down their prey. Their reintroduction to Yellowstone Park in the USA resulted in large beneficial changes the park ecosystem, with a restoration of its former biodiversity.

Trophic cascades can be dramatic. When Arctic foxes were introduced to the Aleutian Islands, they preyed on seabirds. This reduced sea to land nutrient transport and grassland plants were replaced with tundra species.

The effect of dingoes on the Australian ecosystem

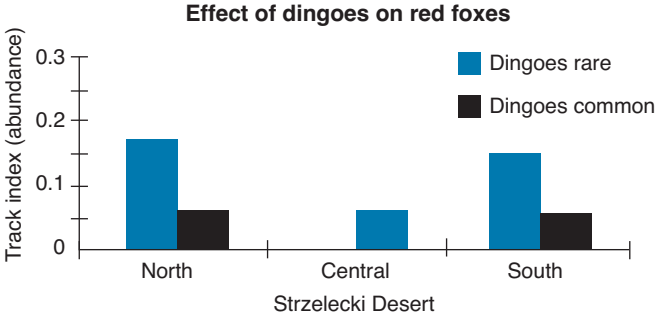
- The dingo has a controversial history in Australia. The earliest dingo fossils date to about 3500 years ago. Genetic evidence suggests the dingoes split from their ancestors in Southeast Asia about 8000 years ago. It is therefore believed the dingo was introduced to Australia between those two dates. The genetic evidence also suggests the dingo has never had significant domestication. Its arrival coincides with the reduction then loss of the last large Australian mainland marsupial predators. This does not mean it caused these losses. However its arrival at this time means it was able to take the place of these predators and fill the role as the apex predator on the continent.
- The dingo fence spans 5600 km from Yalata in the south to north of Brisbane. It has provided ecologists with the opportunity to study ecosystems in the presence and absence of a top predator.

Effect of dingoes on populations

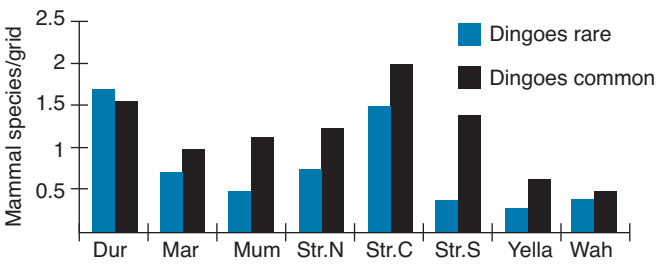


Long term studies of kangaroos and emus in areas with and without dingoes shows how dingoes help regulate prey populations. In the absence of dingoes, kangaroo and emu populations tend to fluctuate with the climate, rising after rainfall (vegetation growth) and falling in dry periods (low vegetation).

Effect of dingoes on red foxes



Effect of dingoes on small mammals



Further studies show the effect of dingoes on middle order predators (e.g. red foxes, top) and small mammals vulnerable to predation by middle order (rather than top) mammalian predators (bottom). Location codes: Dur = Durham, Mar = Maree, Mum = Mumpie, Str. (N,C,S) = Strzelecki (North, Central, South), Yella = Yellabinna, Wah = Wahgunyah

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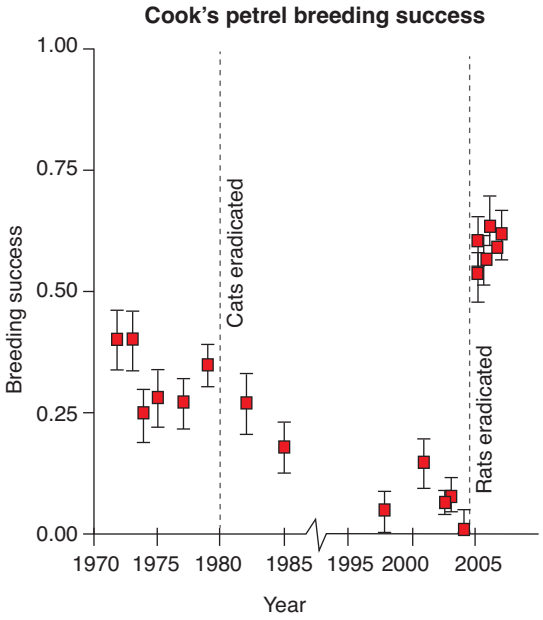
Invasive predators and their effects

The influence of apex predators is well illustrated by the response of prey populations when predators are introduced and then removed. In New Zealand, cats and Pacific rats (kiore) were introduced to Little Barrier Island during human colonisations. The island is a breeding ground for Cook's petrel (titi), which lives and feeds at sea except when breeding and has no natural mammalian predators on land. The rats prey on the birds, and the cats prey on both the birds and the rats. Cats were eradicated in 1980 and rats were eradicated in 2004. Breeding success over 35 years is plotted right.



3. (a) What is the effect of dingoes on kangaroo and emu populations?

(b) For kangaroo and emu population regulation, which appears to have a greater effect, the presence of dingoes or the amount of food present? Explain your answer.

4. (a) What is the effect of the presence of dingoes on small mammal species? _____

(b) Explain this effect: _____

5. What was the effect of removing the top predator (cats) from Little Barrier Island? Why? _____

6. Many conservation efforts now focus on reintroducing (e.g. grey wolves) or conserving (e.g. great white sharks) top predators. Why is this?

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136 Why Do We Sample?

Key Idea: Sampling an ecosystem provides information about its composition and structure, its health, and the likelihood it will be able to resist change.

Take a look outside. Could you count every individual organism in the ecosystem you see? Could you reliably plot their location? Most likely not, because there are too many individuals and not enough time or resources to count them all. To get around these problems researchers **sample** the ecosystem. Sampling involves choosing a smaller area that represents the ecosystem and counting the organisms in that area. The information gathered from the sample is used to draw conclusions about that ecosystem. But how well does the sample represent the community? You will see in the next few activities that there are ways to design sampling to make it as representative of the ecosystem as possible.

What can sampling tell us?

Stephen Moore

Community composition
Sampling reveals which species are present in an ecosystem and helps to build a picture of community structure or identify species of particular interest. For example, are there endangered species, or introduced or pest species present?

Marc Tarlock cc 2.0

Species interactions
Sample data can be used to construct models of species interactions (e.g. food webs or ecological pyramids). The information can be used to predict the effect of a change in community structure (e.g. decrease in one species).

Species distribution
How is a particular species distributed in the ecosystem and does this change over time (e.g. seasonally). Sample data can tell us about the geographical range of the species and how might this be affected by environmental change.

Species abundance
Sampling reveals information about species abundance, i.e. how many of a particular species are present at the location. Species abundance is one measure for estimating biodiversity as well as ecosystem health and stability. The presence or absence of certain species can be used to indicate ecosystem health.

Ecosystem stability
Data can be used to predict how likely it is that an ecosystem will remain unchanged in its characteristics. We know that low diversity systems are more likely to be negatively affected by disturbance than high diversity systems. The presence or absence of key indicator species are also used to monitor ecosystem changes.

Incandescent cc 2.0

Conservation management
Sampling provides a way to evaluate the success of conservation management strategies. For example, are the numbers of a threatened or endangered species increasing or decreasing? How are the numbers of an invasive species changing? If no progress is made towards conservation goals, the plan can be altered.

1. Why do you think it is important to select a sampling area that is a true representation of the area you are sampling?

2. Why must scientists sample an ecosystem or population instead of studying it in its entirety? _____

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137 How Do We Sample Ecosystems?

Key Idea: Sampling should provide data that is unbiased and accurate. Choice of sampling method and design should be based on suitability to the populations being sampled, the environment, and the time and resources available.

Most practical exercises in ecology involve collecting data about the distribution and abundance of one or more species in a community. Most studies also measure the physical factors in the environment, as these may help to explain the patterns of distribution and abundance observed. There are many sampling options (below), each appropriate to different environments or organisms and with advantages and drawbacks. You must take several factors into account when sampling to make sure the data you collect accurately and impartially represents the ecosystem being investigated.

Sampling considerations

- **Random sampling** methods should be used to avoid bias in the data. In random sampling, every possible sample of a given size has the same chance of selection.
- The methods used to sample communities and their populations must be appropriate to the ecosystem being investigated. Communities in which the populations are at low density and have a random or clumped distribution will require a different sampling strategy to those where the populations are uniformly distributed and at higher density.
- The sample size (e.g. the number of quadrats) must be large enough to provide data to enable us to make inferences about aspects of the whole population.

1. Name a sampling technique that would be appropriate for determining:

   (a) Percentage cover of a plant species in pasture:

   _____

   _____

   (b) Change in community composition from low to high altitude on a mountain:

   _____

   _____

   (c) Association of plant species with particular soil types in a nature reserve:

   _____

   _____

   (d) Determining the population size of a fish in a lake:

   _____

   _____

2. What are the benefits of collecting information about the physical environment when sampling populations?

   _____

   _____

   _____

   _____

   _____

   _____

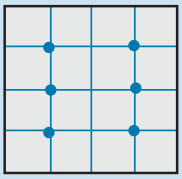
   _____

Sampling designs and techniques

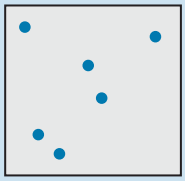
Point sampling

Individual points are chosen using a grid reference or random numbers applied to a map grid. The organisms at each point are recorded. Point sampling is often used to collect data about vegetation distribution.

Pros: Point sampling is efficient if time is limited. It is a good method for determining species abundance and community composition.
Cons: May miss organisms in low abundance.



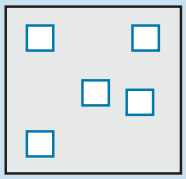
Systematic (grid)



Random

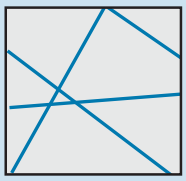
Area sampling using quadrats

A quadrat provides a known unit area of sample (e.g. 1 m^2). Quadrats are placed randomly or in a grid pattern on the sample area. The presence and abundance of organisms in each square is noted. Quadrat sampling is appropriate for plants and slow moving animals and can be used to evaluate community composition.

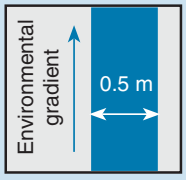


Line and belt transects

In a **line transect**, a tape or rope marks the line. The species occurring on the line are recorded (all along the line or at regular points). Lines can be chosen randomly (right) or may follow an environmental gradient. **Pros**: Low environmental impact and good for assessing the presence/absence of plant species. **Cons**: Rare species may be missed.

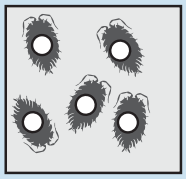


In a **belt transect**, quadrats are used to sample the plants and/or animals at regular intervals along a measured strip.
Pros: Provide a lot of information on abundance and distribution as well as presence/absence. **Cons**: Can be time consuming to carry out properly.



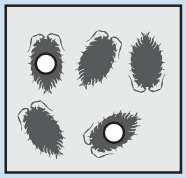
Mark and recapture sampling

1. Animals are captured, marked, and then released back into the population (right).



1: All marked.

2. After a suitable time to allow the marked animals to remix with the population, the population is resampled. The number of marked animals recaptured in a second sample is recorded as a proportion of the total. **Pros**: Useful for highly mobile species which are otherwise difficult to record. **Cons**: Time consuming to do well.



2: Proportion recaptured

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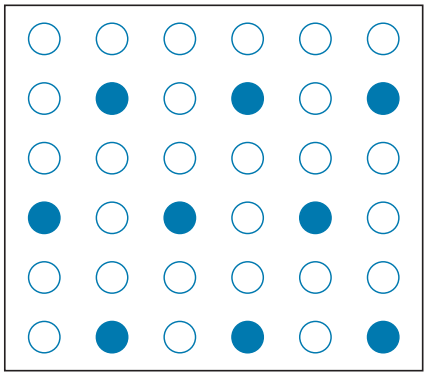
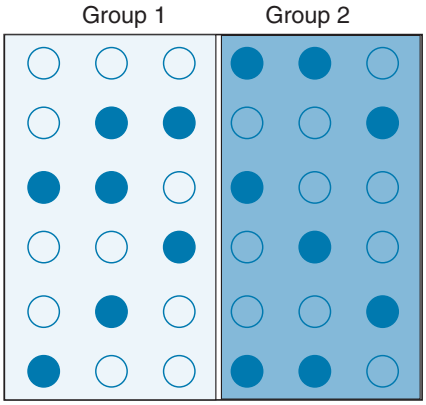
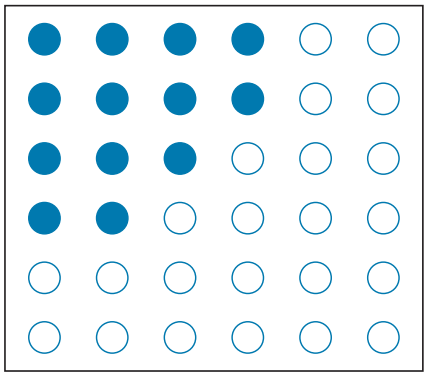
Sampling strategies

In most ecological studies, it is not possible to measure or count all the members of a population. Instead, information is obtained through sampling in a manner that provides a fair (unbiased) representation of the organisms present and their distribution. This is usually achieved through **random sampling**. Sometimes researchers collect information by **non-random sampling**, a process that does not give all the individuals in the population an equal chance of being selected. While faster and cheaper to carry out than random sampling, non-random sampling may not give a true representation of the population.







Systematic sampling

Samples from a larger population are selected according to a random starting point and a fixed, periodic sampling interval. For the example above, the sampling period is every fourth individual. Systematic sampling is a random sampling method, provided the periodic interval is determined beforehand and the starting point is random.

Example: Selecting individuals from a patient list.

Stratified sampling

In stratified sampling the population is divided into subgroups (strata) before sampling. Samples are then taken from a stratum in proportion to its representation in the total population. The strata should be mutually exclusive, and individuals must be assigned to only one stratum. Random or systematic sampling is then applied within each stratum.

Example: Dividing the population into males and females.

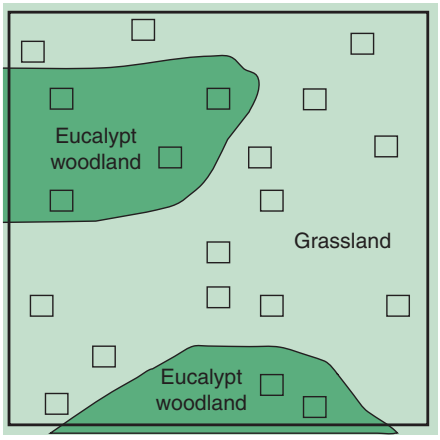
Opportunistic sampling

A non-random sampling technique in which subjects are selected because of they are easily accessible to the researcher. Opportunistic sampling excludes a large proportion of the population and is usually not representative of the population. It is sometimes used in pilot studies to gather data quickly and with little cost.

Example: Selecting 13 people at a cafe where you are having lunch.

Stratified sampling in ecology

- Many study areas are not uniform. Instead, they include a variety of distinct habitats, especially if the study site is large. In stratified sampling, the various habitats are sampled separately in proportion to their representation in the total area. This ensures that the sampling fairly represents the entire habitat.
- The sample area is usually divided into groups (strata) based on biophysical features (e.g. landform, soil type, elevation etc) and then by vegetative structure (e.g. forest, woodland, grassland etc).
- Proportional sampling is an essential feature of stratified sampling. For example, the ecosystem on the right contained 30% eucalypt woodland and 70% grass. The researcher decided to place 20 random quadrat samples in total. To ensure proportional sampling, they placed six quadrats in the eucalypt woodland and 14 in the grass.



3. A student wants to investigate the incidence of asthma in their school. Describe how they might select samples from the school population using:

   (a) Systematic sampling: _____

   _____

   (b) Stratified sampling: _____

   _____

   (c) Opportunistic sampling: _____

   _____

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Reducing sampling bias

Bias refers to the selection for or against one particular group. It has the potential to dramatically influence the findings of an investigation and is often a result of non-random sampling, so that certain individuals are under- or over-represented relative to others in the population. Bias can also occur when counts and identification are not accurate, e.g. when only larger (adult) invertebrates from a sample are correctly identified and recorded. Sampling bias can be reduced by:

- **Large sample size**: The sample size (number of samples) should be large enough to accurately reflect the population as a whole. However, the number of samples taken is often determined by the resources and time available.
- **Random sampling**: This ensures that all organisms have an equal chance of being selected. Some sample sites may be very difficult and expensive to access. It can be tempting to not sample them, and sample the easily accessible sites, but their exclusion can bias results.
- **Appropriate collection methods and apparatus**. Failure to select the right sampling technique could mean that some organisms are not recorded at all, so the results are not a true reflection of the population. This type of bias tends to be systematic, e.g. when the wrong net size is chosen to sample a lake community.

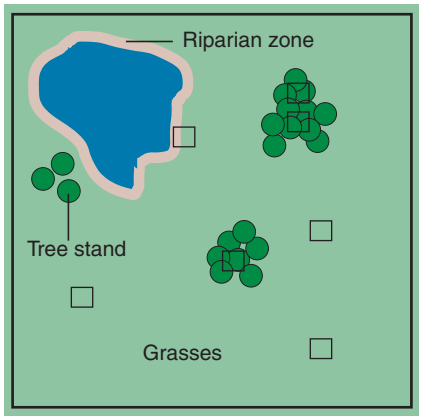
Pooter being used to collect insects from a collection net.

Fritz Geller-Grimm CC3.0

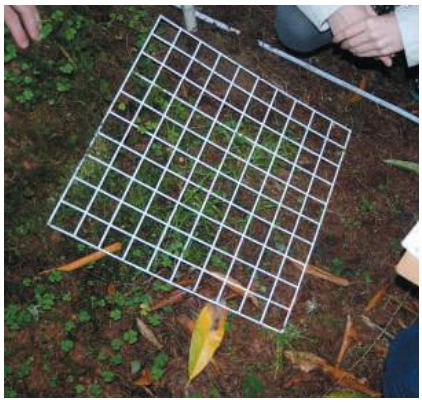
Quadrats are excellent for collecting data on plants but it is not so useful for highly mobile species. Researchers use a variety of collection methods, including pooters (aspirators) to collect insects and other mobile species.

4. Explain when stratified sampling would be used in ecological sampling: _____

5. Study the diagram on the right, it shows three strata. Identify two errors the researcher has made with their sampling design:



6. Mike, Georgia, and Sam were sent out to randomly sample near a stand of trees along the school fence line. Their instructions were to record the number of plant and animals species present using quadrat sampling (right). The area that they were sampling was quite uniform except for around one tree near a slowly leaking tap, which was quite damp and looked to have different plant species present. During their sampling they found a range of different plants, some slow moving animals, and some fast moving animals (e.g. centipedes).



   (a) Do you think the students should have included the damp area in their sampling? Why or why not?

   (b) The students noticed that some animals moved very quickly and were difficult to count. Describe the limitations of a quadrat for fast moving animals, and explain how it could bias the results:

   (c) Suggest a technique they could use to collect information on mobile species: _____

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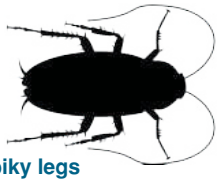
138 Investigating Distribution and Abundance

Key Idea: Leaf litter communities can be used to assess biodiversity. Many different species are found in leaf litter, but some are more common than others.

Many different species are found in the leaf litter and in surface soil under trees. Decomposers such as bacteria and fungi have essential roles in breaking down organic matter, recycling nutrients, and making minerals available to plants. Larger organisms, through activities such as burrowing and digging, also contribute to decomposition and improved soil structure. The biodiversity of invertebrate communities can provide valuable reference information to monitor ecosystem change and the effect of management practices.

Common invertebrates found in leaf litter

Leaf litter provides habitat to a wide range of invertebrates. While many are too small to be observed with the naked eye, it is possible to identify and count many of the larger species (> 1 mm). These invertebrates generally fall into two categories: the mesofauna (100 µm -10 mm), and the macrofauna (10 mm - 10 cm). The table below will help you identify some of the common invertebrates you may find during your own investigations.

With wings	May have wings	Usually wingless	Appears wingless but wings are hidden	Winged or wingless. Broad flat body
 **Hard wing covers** BEETLES Over 30,000 different species in Australia. Some are specific to eucalyptus stands. Depending on species they eat other insects, plant material, fungi, or dead animal matter.	 **Membranous wings** BUGS A very diverse group found in a wide range of different habitats and with varied diets. Their defining feature is a 'beak' with modified mouthparts forming a piercing stylet.	 **Narrow waist** ANTS Large number of species and found in most terrestrial ecosystems. Diverse feeding habits (will eat earwigs). Prey to a number of other invertebrates (e.g. pseudoscorpion).	 **Tail nippers** EARWIGS Flat, flexible body, short, rarely used wings. Common under bark and plant debris. Omnivorous and mostly nocturnal. Prey to frogs, lizards, spiders, mantids, ants, and birds.	 **Spiky legs** COCKROACHES Native cockroaches are found in leaf litter, bark, or rotting wood. Most eat pollen, bark and leaf material. Prey for lizards, birds and some invertebrates.
Seems to have more than 6 legs	Six legs, very small (1 mm long or less)	Six slender legs, small (1-10 mm long)	Six legs but not insects wingless, <6 mm long	Eight legs. Body divided into two parts
 **4-10 false legs** CATERPILLARS The larvae of butterflies and moths. Many species overwinter in the soil surface or leaf litter as larvae or pupae. Eat leaf material. Eaten by predatory beetles birds, and wasps.	 **Very small and slender** THRIPS Many species transition from pupa to adult in soil and leaf litter. Common food sources for leaf-litter dwelling species are fungi found in leaf litter or on dead branches, supplemented by pollen.	 **Often long wings** BOOKLICE (BARKFLY) Mainly found on plants, but sometimes found in leaf litter. Booklice feed on lichens, algae, plant spores, and dead plant and insect material. Prefer moist environments.	 **Have a folded tail-like furcula for jumping** SPRINGTAILS Important detritivores. Abundant in soil and leaf litter, especially after rain (prefer moist conditions). Omnivorous, mainly eating bacteria and fungi, and dead organic matter.	 **Obvious fangs** SPIDERS Arachnids. A number of different species may occupy leaf litter. Most species are predatory, feeding on invertebrates, including other spiders. Some are web builders, others run down prey.
Eight legs. 'Head" is actually just mouthparts	Eight legs, 2-8 mm, and long pincers	14 legs, flattened body, antennae	Many legs, one pair of legs per body segment	Many legs, two pairs of legs per body segment
 **Small size, simple unsegmented body** MITES Common arachnids throughout Australia. Often large numbers in soil and leaf litter where they are important detritivores, feeding on dead organic matter. Food for predatory invertebrates.	 **Flat pear-shaped body** PSEUDOSCORPIONS Also called false scorpions. Long pincers may be different colour to the body. Found in many habitats, mainly under leaf litter, bark and rocks. They are predators and feed on small invertebrates (e.g. ants, mites beetles, booklice).	 **Body segmented** WOODLICE (SLATERS) Crustaceans restricted to moist conditions (they easily dry out and die in dry conditions). Mainly active at night when dehydration risk is low. Often grouped together in the day. Feed on dead plant matter. Preyed on by woodlouse spiders.	 **Body flattened** CENTIPEDES Size ranges from a few mm to more than 10 cm. Fast moving nocturnal carnivores, with poison pincers. They prey mainly on invertebrates, including spiders. Found in a variety of habitats, mostly under rocks, logs, leaf litter and tree bark.	 **Body rounded** MILLIPEDES More common in milder climates. They prefer moist conditions, being generally absent from dry habitats. Their absence is used as an indicator of environmental water stress. Slow moving detritivores eating dead plant material.

Insect hexapods | Non-insect hexapods | Arachnids | Crustaceans | Myriapods

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The soil and leaf litter under trees in a *Eucalyptus pilularis* forest in NSW was sampled for invertebrates. Abundance of the mesofauna and macrofauna found is provided in the table below.

Organism	Abundance (number per m^2)
Mites (Mi)	130
Spiders (Sp)	6
Pseudoscorpions (Ps)	9
Centipedes (Ce)	18
Beetles (Be)	18
Springtails (St)	48
Earwigs (Ew)	1
Cockroaches (Co)	1
Millipedes (Ml)	2
Ants (An)	3
Bugs (Bu)	24
Woodlice (Wo)	13
Caterpillars (Ca)	8
Booklice (Bo)	1
Thrips (Th)	24
TOTAL	**296**

Data: Hurditch, W.J. (1981). From Recher, H.E ed) *et al.* (1992) A Natural Legacy Ecology in Australia.

1. Graph the species abundance on the grid above. Use the letter codes provided in the table to identify each organism:

2. (a) Identify the most abundant species found: _____

   (b) What percentage of the total organisms does it make up? _____

   (c) Describe their importance in this habitat: _____

   _____

   _____

3. One measure of environmental stress is lack of soil moisture. What litter invertebrates would be useful indicators of environmental stress and why?

   _____

   _____

   _____

4. (a) Identify an organism that you might not find easily if you sample during day time: _____

   (b) Could this affect your biodiversity assessment? Explain? _____

   _____

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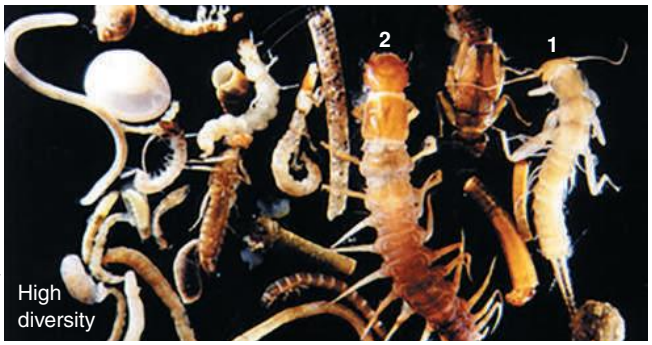
Biodiversity in a community

Distribution and abundance tells how many there are and where the organisms in an ecosystem live. Diversity combines those two measurements into a single number.

- A diversity index, e.g. Simpson's index of diversity, is a mathematical measure of species diversity in a community, taking into account the number of species present as well as their relative abundance.
- Diversity indices can also be used to assess the health of an ecosystem. A change in species composition can indicate changes in an ecosystem's status (e.g. in response to pollution or climate change). Certain 'sensitive' species are associated only with specific conditions (e.g. clean, cold water). The presence (or absence) of these indicator species tells us about the health of an ecosystem.



Photos: Stephen Moore

Using diversity indices and the role of indicator species

To be properly interpreted, indices are often evaluated with reference to earlier measurement or a standard ecosystem measure. The images above show samples from two streams, a high diversity community with a large number of invertebrate species (left) and a low diversity community (right) with fewer species in large numbers. These images also show typical stream indicator species. The left photograph shows a stonefly (1) and an alderfly larva (2). These species (and mayfly larvae) are typical of high water quality. The right photograph shows a dominance of snails (3) which are tolerant of a wide range of conditions, included degraded environments.

Simpson's index of diversity

Simpson's Index of Diversity (below) produces values ranging between 0 and almost 1. There are other variants of this index, but the more limited range of values provided by this calculation makes it more easily interpreted. No single index offers the "best" measure of diversity; each is chosen on the basis of suitability to different situations.

Simpson's Index of Diversity (D) is easily calculated using the simple formula below. Communities with a wide range of species produce a higher score than communities dominated by larger numbers of only a few species.

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

D = Simpson's diversity index
N = Total number of individuals (of all species) in the sample
n = Number of individuals of each species in the sample

Example of species diversity in a stream

The example below describes the results from a survey of stream invertebrates. It is not necessary to know the species to calculate a diversity index as long as the different species can be distinguished. For the example below, Simpson's Index of Diversity using $D = 1 - (\sum n(n-1) \div N(N-1))$ is:

	Species	n	n(n–1)
A	Backswimmer	12	132
B	Stonefly larva	7	42
C	Silver water beetle	2	2
D	Caddisfly larva	6	30
E	Water spider	5	20
F	Mayfly larva	8	56
	N(N–1) = 1560	$\sum n$ = 40	$\sum n(n-1)$ = 282
	$\sum n(n-1) \div N(N-1)$ =	282 ÷ 1560 =	0.18
	D =	1 – 0.18 =	**0.82**

5. (a) Use the data from the *Eucalyptus* forest on the previous page to calculate Simpson's diversity index for the forest's invertebrate community. Follow the example above and carry out your calculations on a separate sheet and staple them to this page. Write your answer below:

_____

_____

(b) Comment on the invertebrate community's diversity: _____

_____

6. Comment on the forest invertebrate community structure in terms of predators and prey: _____

_____

_____

_____

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139 Aboriginal and Torres Strait Islander Perspectives

Key Idea: Recognising traditional ecological knowledge can lead to a better understanding of interdependencies in ecological systems.

Increasingly, the scientific community is recognising that the inclusion of indigenous perspectives and knowledge is critical to developing a broader appreciation and a deeper understanding of the interactions within Australia's diverse ecosystems. Integrating Western science with indigenous or traditional ecological knowledge (TEK) is more likely to result in long term sustainable management practices.

Indigenous knowledge and ecosystems interactions

There are numerous examples of how indigenous knowledge of the interactions in ecosystems has been used to community advantage. It took considerable time for some of these to be acknowledged by Western authorities, but they have since been recognised as important in advancing knowledge of ecosystems and their management.

Ecosystems and bushfire prevention

Large parts of Australia experience extremely high temperatures in the dry season. Combined with a dry and flammable landscape, this leads to often large and dangerous bush fires. For many decades, conservation of bushland based on Western ideals has focussed on preventing fires. Only recently has it been acknowledged that this practice has contributed to some of the largest wildfires in decades, because it allowed the build up of dry undergrowth and debris that would ordinarily be removed by fire every few years.

In Australia, Aboriginal knowledge of fire use for bush management is beginning to be employed, including the use of back burning and controlled burns. Traditional Aboriginal knowledge of cool fires, soils, and flowering and fruiting of trees can all be used to decide when and where controlled burns can be used to manage the bush, reduce wildfires, and encourage plant growth and animal diversity.

Fire control Northern Queensland

Arsonists in the skies

Fires are known to jump across fire breaks. But in some cases fires were beginning up to a kilometre from the fire break. Stories among indigenous people of North Australia held that birds were actually starting the fires. This was taken into account by Aboriginal rangers but was often met with official skepticism. In 2017, this behaviour was finally observed and documented by researchers, some 53 years after indigenous doctor Phillip W. Roberts wrote of it in his 1964 autobiography.

Researchers observed at least three bird of prey species picking up smouldering twigs and flying up to a kilometre before dropping them in dry grassland. Groups of birds would then wait at the fire front, feeding on prey species fleeing the fire.

Birds of prey exploit fire front, Queensland

Fisheries management

The Torres Strait between northern Queensland and Papua New Guinea has some 580 coral reefs and some of the most extensive seagrass beds in the world. These are grazed by dugongs, a traditional source of food for the Torres Strait Islanders. The dugong is critically endangered. Using TEK, policies are being developed to help conserve the dugong and other traditional seafoods while still allowing access to this traditional food source.

Dugong

Julien Willem CC 3.0

1. Why would integrating traditional knowledge and Western science produce a better understanding of the relationships and interdependencies within ecosystems?

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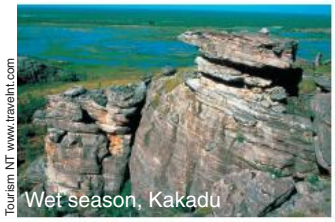
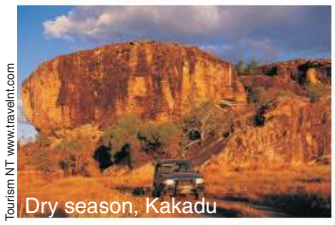
Calendars and ecosystems interactions

The Gregorian calender used by a large part of the world is designed mainly around organising social events, e.g. religious holidays.

- From it we are able to obtain exact dates as to when ecological events will (or should) occur. Seasonal dates worked into the calender are essentially arbitrary (e.g. summer starts on December 1, not on November 30, or December 2).
- Indigenous or seasonal calendars usually operate around ecological events, such as the beginning of the wet season or flowering of certain plant species. These calendars emphasise cyclical processes, acknowledging interactions within ecosystems. For example the return of the a certain bird from migration indicates certain fruits will soon be ripening.
- Seasonal calendars are linked to places so they vary regionally. The calender below is based on the Kakadu National Park (NT).

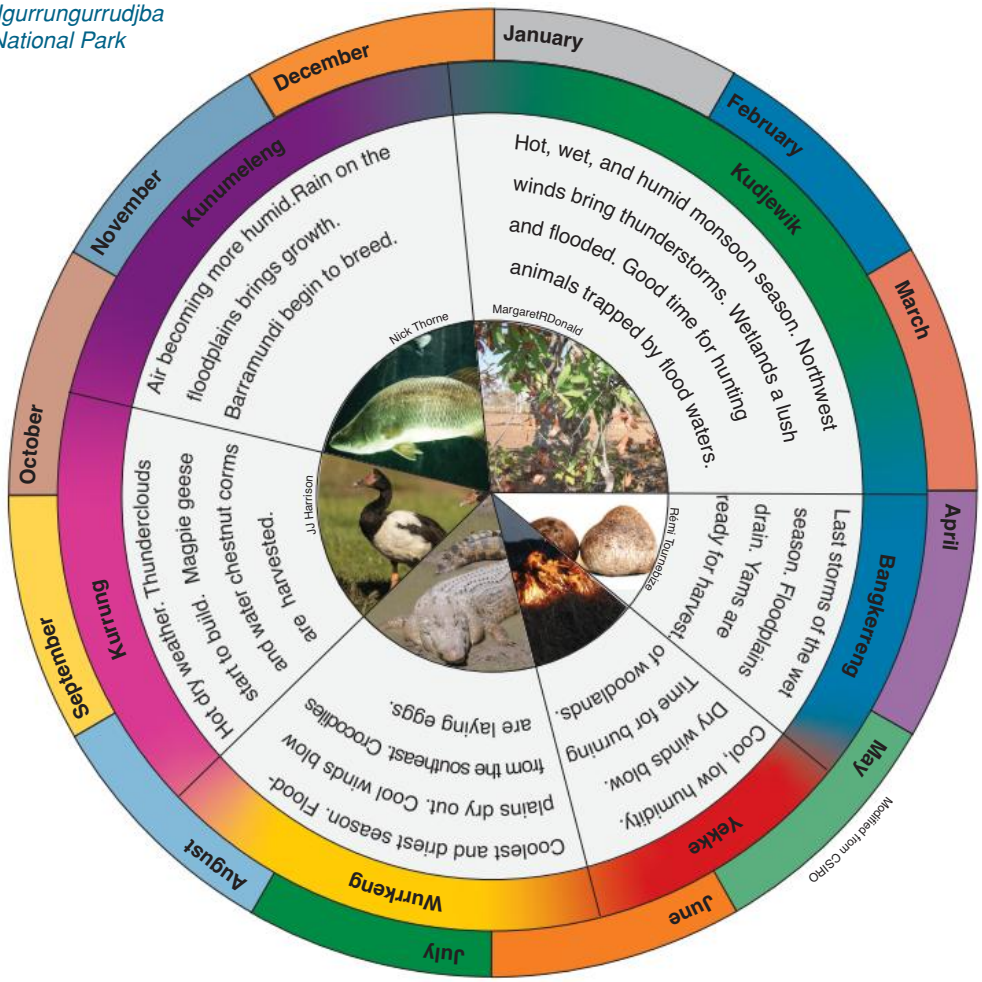
Right: Seasonal calender of the Ngurrungurrudjba (Yellow Water) region in Kakadu National Park


Tourism NT www.travelnt.com
Wet season, Kakadu


Tourism NT www.travelnt.com
Dry season, Kakadu


Indigenous rock art featuring barramundi


Controlled fire Kakadu



2. What is the main difference between the use of the Gregorian calender and a seasonal calender?

3. Describe how the seasonal calender shows relationships within the ecosystem it is linked to?

4. Why is the indigenous seasonal calender more useful in predicting ecosystem events than a Gregorian calender:

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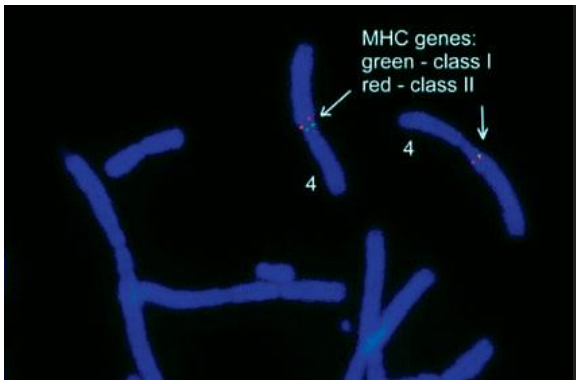
140 Tasmanian Devil: Disease and Populations

Assessment task, Outcome 2: *Case study analysis*

Recall that the genetic diversity of Tasmanian devils is particularly low. This case study explores the relationship between MHC allelic diversity affects and reproductive success in Tasmanian devils. The MHC genes control self recognition in the immune system.

Mike Lehmann cc 3.0

Tasmanian devils are the largest surviving marsupial carnivore. Although now restricted to Tasmania, devils were once found throughout mainland Australia, but became locally extinct about 3000 years ago. Genetic evidence suggests that the devils went through at least two historic population crashes, one about 30,000 years ago and another about 3000 years ago. Coupled with these historic declines are modern declines (1850 to 1950) as a result of trapping and disease



Cheng et al. For full credit, see photocredits, page 284

MHC genes are located on chromosome 4 of the Tasmanian devil genome.

1. **PREAMBLE**
   The data on the right is part of a study on the breeding success of a group of captive Tasmanian devils. The data shows the age of the male and female in the pair, the reproductive success of the pair, and the number (out of 6) of MHC class-I heterozygous loci (location of microsatellite alleles) of each male and female in the pair.

   You will analyse this data to determine the effect of two separate variables on the breeding success of Tasmanian devils and use your analysis to recommend the best course of action to increase reproductive success in devils.

   The variables you will investigate are female age and genetic diversity.

   You may require extra paper to work through and organise the data into meaningful groups. Attach all extra paper to this page. Alternatively the data could be entered into a spreadsheet.

No. female heterozygous loci	Female age (Yr)	No. male heterozygous loci	Male age (Yr)	Successful/ Unsuccessful	A
4	4	1	4	successful	
4	3	2	3	unsuccessful	
4	3	3	3	unsuccessful	
3	2	2	3	unsuccessful	
4	3	1	5	successful	
4	2	3	3	successful	
6	4	1	5	successful	
6	2	3	3	successful	
3	2	4	2	unsuccessful	
3	2	3	3	unsuccessful	
4	3	2	2	unsuccessful	
1	3	4	3	successful	
4	3	3	2	unsuccessful	
4	3	3	4	unsuccessful	
4	2	1	2	successful	
6	2	2	2	successful	
6	4	3	4	successful	
5	2	1	3	successful	
5	3	2	3	successful	
5	3	2	3	successful	
3	2	4	4	successful	
1	2	4	3	successful	
1	3	3	3	successful	
5	2	2	3	successful	
5	2	1	3	successful	
5	4	1	3	unsuccessful	
5	4	2	3	unsuccessful	
2	2	3	2	successful	
2	4	2	4	unsuccessful	
5	2	0	2	successful	
3	2	4	2	successful	
3	5	2	5	unsuccessful	
1	3	1	5	unsuccessful	
1	2	4	2	successful	
1	3	3	3	unsuccessful	
2	2	4	2	successful	
5	3	4	4	unsuccessful	
5	2	1	2	unsuccessful	
1	2	4	3	successful	
2	3	4	4	unsuccessful	
2	4	2	4	unsuccessful	
3	2	4	3	successful	
5	3	2	2	successful	
5	5	2	5	unsuccessful	
3	3	6	4	unsuccessful	
2	2	2	3	successful	
2	3	2	3	unsuccessful	
5	2	4	3	successful	
5	3	3	4	successful	

MHC diversity and female age underpin reproductive success in an Australian icon; the Tasmanian devil Tracey Russell *et al* www.nature.com, 8 March 2018 CC 4.0

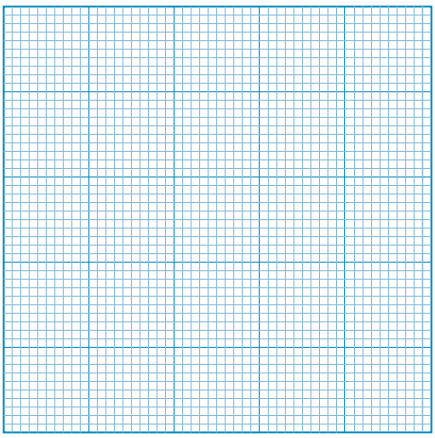
ISBN: 978-1-98-856636-8

2. **Effect of female age**

(a) To analyse the effect of female age you need to organise the data into female age groups (from 2 years to 5 years) then into successful or unsuccessful breeding. A tally chart may be useful:

Age group (female)	2	3	4	5
Successful				
Unsuccessful				
Total				
% Successful				

(b) Produce a scatter plot of the result on the grid below (age on the x axis, % success on the y axis).



3. **Effect of heterozygous loci**

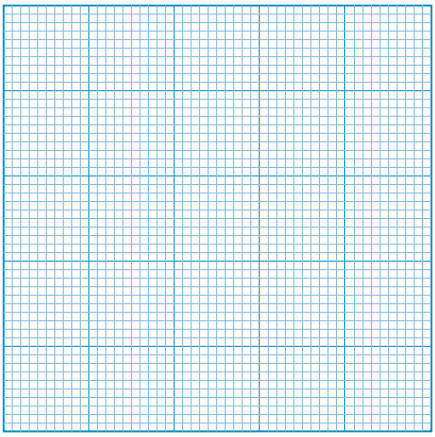
There is a body of evidence to suggest that greater heterozygosity correlates with greater breeding success. Here you will analyse the effect of the absolute difference in heterozygosity of the 6 MHC loci (male and female). For example the male may be heterozygous for 2 loci and the female may be heterozygous for 4 loci. The absolute difference in heterozygosity is therefore 2.

(a) For each pairing, calculate the absolute difference in heterozygous loci. Write this in column A in the table on the previous page.

(b) Now use a tally chart as before to group successful and unsuccessful pairings according to the absolute difference in heterozygosity:

Absolute difference in heterozygosity	0	1	2	3	4	5
Successful						
Unsuccessful						
Total						
% Successful						

(c) Produce a scatter plot the result as on the grid below (absolute difference on the x axis, % success on the y axis).



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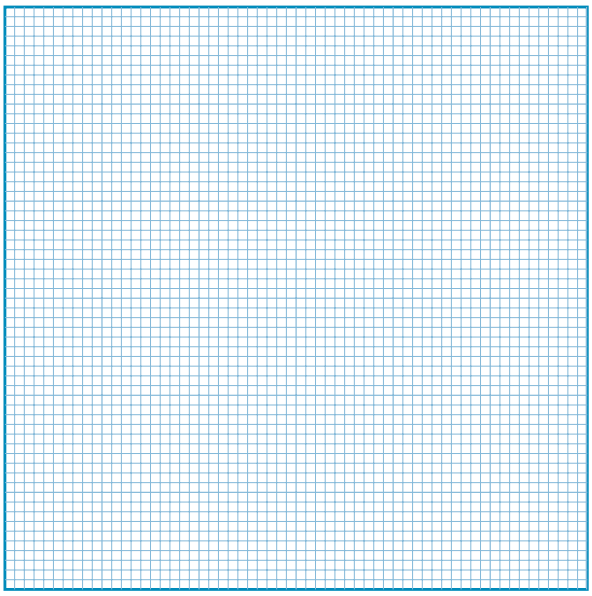
4. **Comparison of male and female heterozygosity**
For the successful breeding pairs plot a graph of the number of female heterozygous loci (x axis) vs the number of male heterozygous loci (y axis)



5. Finally, calculate the mean age of females that bred successfully and unsuccessfully, and the average absolute difference in heterozygosity for successful and unsuccessful pairings.

6. Describe the relationship between female age and breeding success:

7. Describe the relationship between the difference in heterozygosity and breeding success:

8. Describe the relationship between the number heterozygous loci of the male and female in a successful breeding pair:

9. (a) Based on your analysis, what would you recommend to increase the breeding success of captive Tasmanian devils?

(b) Suggest other analysis of the data could be done that may provide insight into breeding success:

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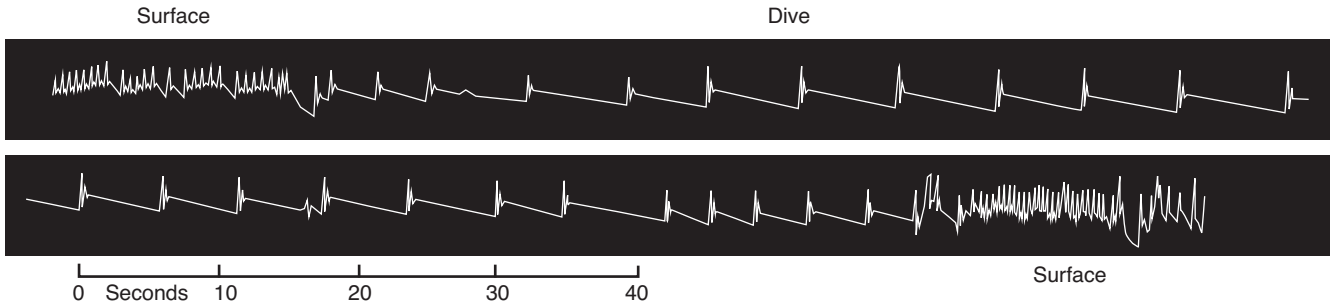
141 Chapter Review: Did You Get it?

1. Identify and describe the three parts of biological diversity: _____

2. The trace below shows pulse of a seal on the surface and as it dives.



(a) What happens to the seal's pulse as it dives? _____

(b) What physiological changes are associated with this? _____

3. Define the following:

(a) Keystone species: _____

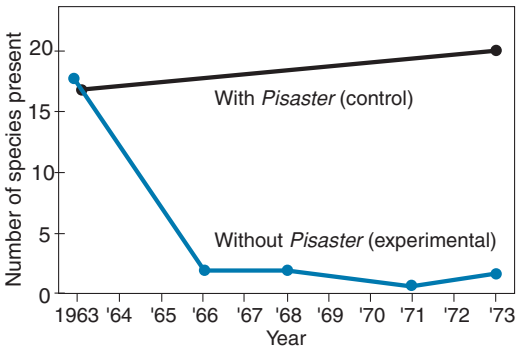
(b) Adaptation: _____

(c) Consumer: _____

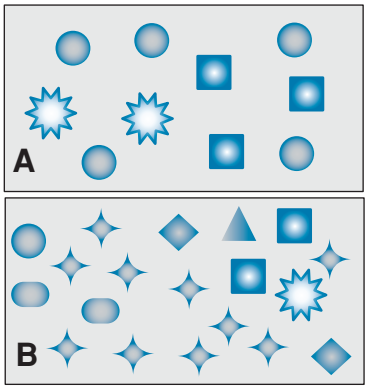
4. The plot right shows the results of the experimental removal of the starfish *Pisaster* from a region of an ecosystem:

(a) What does the graph show? _____

(b) What do the results suggest about *Pisaster*'s role in this ecosystem?



5. The diagrams right show two different communities of organisms. Which appears to have a greater biodiversity and how would you justify your answer?



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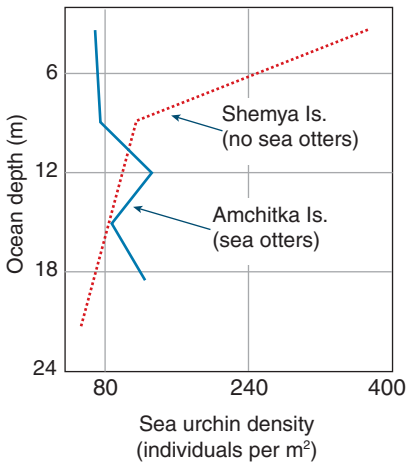
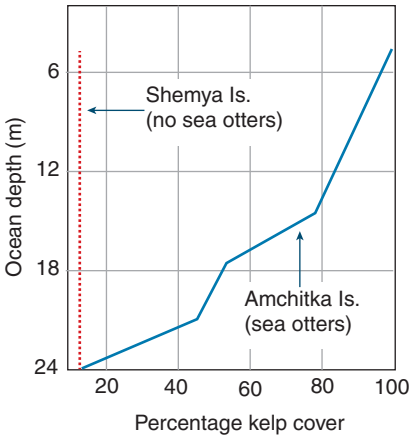
142 Synoptic Question: Unit 2, Area of Study 2

1. The graphs below show the sea urchin density and kelp cover around two North Pacific islands, one with a population of sea otters, the other without.





(a) What effect do sea otters have on sea urchin numbers? _____

_____

(b) What effect do sea urchins have on kelp cover? _____

(c) What evidence is there that the sea otter is a keystone species in these Northern Pacific coastal ecosystems?

_____

_____

_____

(d) The data indicate that sea otters are what type of species in the ecosystem? _____

2. The graph on the right shows the effect of heterozygosity of parental tree frogs on the number of hatched offspring. Describe this effect:

_____

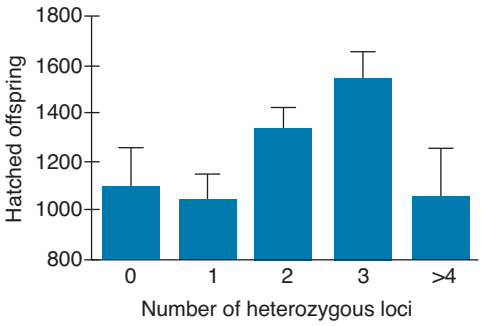
_____

_____

_____

_____

Hatched offspring v parent heterozygosity



3. Using the example of a kangaroo, distinguish between physical, behavioural, and physiological adaptations:

_____

_____

_____

_____

_____

_____

_____

_____

_____

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4. Explain why genetic diversity is an important part of an ecosystem's biodiversity: _____

5. Describe the general circumstances that cause cacti and euphorbias to evolve their very similar adaptations:


Cacti in the desert

6. Some animals and most plants are able to reproduce asexually.

   (a) What is asexual reproduction? _____

   (b) Describe a method of asexual reproduction for a named animal and explain how asexual reproduction is advantageous for the animal:

7. (a) Explain how micropropagation is used to increase productivity in horticulture: _____

   (b) Identify a disadvantage of using micropropagation to produce all the plant stock from one parent plant:

8. Explain why an animal produced by somatic cell nuclear transfer is not an exact clone of the original animal:

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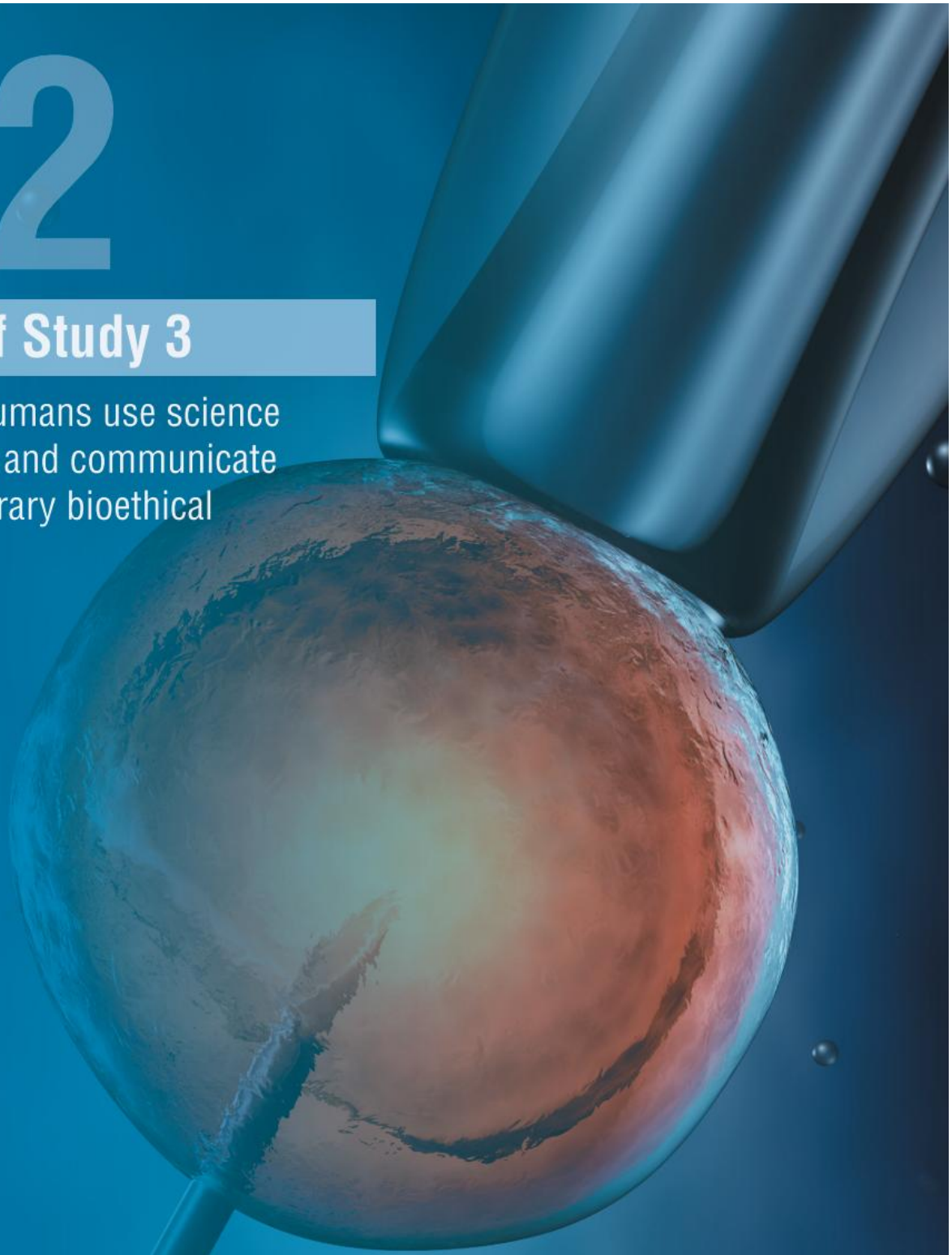
02

Area of Study 3

How do humans use science to explore and communicate contemporary bioethical issues?



You will be able to:

- Identify, analyse, and evaluate a bioethical issue in genetics, reproductive science, or ecology
- Show understanding of scientific evidence and its use
- Communicate scientific information relating to your bioethical issue concisely and coherently

CHAPTER
12

Exploring Bioethical Issues

Key terms
bioethical issue
citation
primary data
scientific evidence
secondary data
validity

Background to Area of Study 3

This Area of Study requires you to identify, analyse, and evaluate a bioethical issue relating to the application of genetic knowledge, reproductive science, inheritance, or adaptations and ecological interdependencies. Examples of topics include, but are not restricted to: genomic and epigenetic research; cloning; assisted reproductive technologies; genetic screening; strategies for maintaining genetic diversity; the use of biomimicry to solve human challenges; or biopiracy of indigenous knowledge. You can draw on the key knowledge and skills outlined below and related science skills in Chapter 1. The activities in this chapter provide you with support for the skills you will need. A concluding activity provides a checklist for your report, which you may find useful.

Scientific evidence

Key skills and knowledge

Activity number

- ☐ 1 Recall the distinction between primary and secondary data. In your research of a bioethical issue, you will be collating secondary data. — **78**
- ☐ 2 Recall the distinction between opinion, anecdote, and evidence and between scientific and non-scientific ideas. During your research, be aware of the quality of the information, including validity and bias. — **6 144**
- ☐ 3 Devise a way to collate your secondary data so that you can analyse and evaluate it more easily. Use a logbook (or spreadsheet) to authenticate collated secondary data. — **4 144**

Blonde d'Aquitaine cc 3.0

Scientific communication

Key skills and knowledge

- ☐ 4 Explain the biological concepts specific to your bioethical issue using appropriate biological terminology, conventions, and representations. — **145**
- ☐ 5 Recall the characteristics of effective scientific communication. Is the biological information you have presented accurate? Have you clearly explained the biological concepts? Have you discussed the implications of your findings? Is your presentation coherent and appropriate for its audience? — **7 79 145**
- ☐ 6 Use data representations, models, and theories to explain the biological concepts involved in your chosen bioethical issue, and their limitations. — **145**
- ☐ 7 In your response, discuss the social, economic, legal, and/or political factors relevant to your selected research question. — **146**
- ☐ 8 Follow conventions for referencing and acknowledging sources of information. — **79 147**

Analysis and evaluation of bioethical issues

Key skills and knowledge

- ☐ 9 Explain how you identify a bioethical issue. — **143**
- ☐ 10 Recognise approaches to analysing and resolving bioethical issues. Which approach will be most appropriate for the analysis of your chosen research question? Apply one or more bioethical concepts as appropriate to the bioethical issue being investigated. — **146**

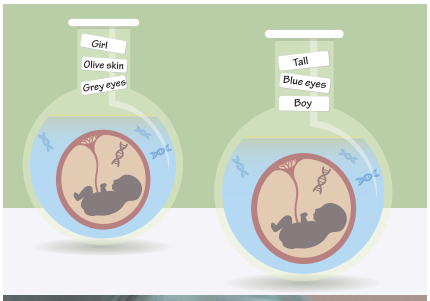
143 Identifying Bioethical Issues

Key Idea: The very nature of applying technology to biology raises ethical issues over just how far the technology should be taken, or how we are interfering with life.

Bioethical issues arise when any living organism is used by humans for any purpose. Bioethical issues are also generated when humans use technology to gain information about the biological nature of another human. An example might be the possibility of using someone's genomic information for a purpose different to its original intent (e.g. using it to disadvantage someone attempting to obtain health insurance). Other bioethical issues arise when genomic analysis indicates a heritable and life threatening disease. Should you be told, and would you or should you have to tell a partner with whom you might have children?

Genetic screening in Australia

- The genetic screening of gametes, embryos, children, and adults for some diseases is now possible. Genetic screening has many applications including in the detection and treatment of diseases.
- Genetic screening has many positive applications, but it raises a number of bioethical issues. This is particularly the case for the screening of embryos and fetuses because it may result in their destruction if they have genetic defects, or even an undesirable genotype (e.g. the wrong sex).



Diagnostic testing: A person may have symptoms typical of a particular genetic disorder. Genetic screening is used to determine if the person has the gene associated with a particular disease or not.

Pharmacogenetics: Genetic screening can be used to help decide what type, or dose, of medicine will be best for an individual. Targeted treatment can increase the chances of the medicine working.

USAF

Newborn screening: Newborns are screened for a range of metabolic disorders (e.g. phenylketonuria). If a disease is detected, treatment can begin immediately and the child's prognosis is improved.

Arguments for genetic screening

- Testing allows potential carriers to be screened for a disease so they can decide whether they have children or not. This is important for diseases that do not show any symptoms until later in life (e.g. Huntington's disease).
- Researchers can study individuals with the gene(s) associated with a disease and this may help them to develop a treatment or cure for that disease.
- Knowing a person's genetic make-up can be used to optimise drug therapies and improve treatment outcomes.
- Knowing the risk of developing a disease allows informed decisions to be made about medical options. For example, breast cancer can be treated, so an individual may decide to increase screening to increase the chance of early detection. They may choose to reduce risk factors (e.g. breast removal if they are at high risk of breast cancer).
- The discovery of a genetic defect in an unborn child provides an opportunity to come to terms with the situation and prepare for the delivery and ongoing care of a special needs child.

Arguments against genetic screening

- Genetic tests can only tell you if you carry a gene for an associated disorder. They cannot yet predict when and if you will develop the disease, or to what extent. Testing therefore carries the risk of causing unnecessary anxiety.
- An individual's privacy may be compromised by testing. The knowledge that you may develop a genetic disorder in the future could be used against you (e.g. medical insurance could be declined or an employer may no longer want to employ you)
- Designer babies could be produced where parents pick certain characteristics they want their child to have. This is already seen in countries where more value is placed on the birth of a boy child than a girl, and unwanted female fetuses are terminated.
- The discovery of a genetic defect in an unborn child may lead to the decision to terminate the pregnancy, an action some people believe is morally wrong because they feel it devalues human life.

1. Describe some of the benefits of genetic screening:_____

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Reproductive technologies

- Reproductive technologies have helped many people who are unable to conceive naturally to have children. However, these technologies also produce many bioethical issues including the ethics of cloning, sex or trait selection, and even issues surrounding conservation and the resurrection of extinct species.

Assisted reproduction

Assisted reproduction includes a wide array of reproductive technologies. It has been used for decades to help couples have children when they are unable to conceive naturally. Technologies include *in-vitro* fertilisation, in which sperm and an egg cell are mixed in the laboratory to produce an embryo. The embryo is then transplanted into the mother (or a surrogate). Issues arise around the selection of the embryos, age of parents, and cost to society.

Cloning

Embryo transferred Charolais calves with their Angus and Hereford recipient mothers.

Plants and animals can both be cloned. Plant cloning is widely used with few bioethical concerns, but animal cloning is less common and more ethically problematic because of welfare issues and the implications for humans. In theory, a cloning technique that successfully clones an animal could also be used on humans. Cloned human cells could produce immunocompatible organs for transplant. But it also raises issues around cloning humans.

Conservation

Spiny daisy (*Acanthocladium dockeri*)

Melburnian

Reproductive technologies are often used in conservation. The Wollemia pine (*Wollemia nobilis*) and spiny daisy (above) are critically endangered species that have been saved from extinction by cloning from cuttings. Cloning and embryo transfer may be the only chance to save some animal species on the brink of extinction (e.g. Northern white rhino). Sometimes reproductive technologies are used to reduce pest populations by sterilisation or contraception.

Ethical issues around reproductive technologies include:

Possible wrongs to the community by the use of IVF

- IVF is a costly procedure.
- Couples who can afford IVF may be putting money and effort into conception instead of the community.
- The community may have to bear the cost of IVF and welfare for financially struggling parents.
- Offspring with health issues due to IVF may be an ongoing burden to the community.

The rights of the pre-embryo (blastocyst)

- Multiple blastocysts are transferred to a woman's uterus to increase the chances of implantation. After implantation, many of these blastocysts are destroyed by selective pregnancy reduction.
- Many different ideas and definitions exist over the start of personhood or individuality. What are the ethics around destroying embryos?

Possible wrongs to those directly involved in an IVF conception

- Multiple blastocysts are transferred to a woman's uterus to increase the chances of successful implantation. This can result in a multiple pregnancy, which can have psychological and health effects on the parents.
- In cases where the IVF requires a gamete donor outside of the couple, what are the rights of that donor?
- The parents may have to carry the cost of IVF, creating financial strain.

Possible wrongs to the offspring by the use of IVF

- There is some evidence to suggest IVF babies have a higher chance of some medical problems, including pre-term birth, low birth weight, spina bifida, and heart defects.
- Parents with genetic defects preventing them from conceiving naturally may pass these defects to the offspring.

2. Describe the ethical and medical issues surrounding reproductive technologies:

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Bioprospecting

- Bioprospecting is the systematic search for and development of new sources of useful products from nature, e.g. chemical compounds or microorganisms. Bioprospecting looks for ways to commercialise biodiversity.
- Bioprospecting is not new. Most of our medical drugs are based on chemicals found in nature. In the late 1700s, English doctor and scientist, William Withering noticed that patients suffering from a serious heart condition became better when given a traditional herbal remedy. He went on to isolate the active compound from the foxglove plant, which he called digitalis (or digitoxin). It is now listed by the WHO as one of the most important heart medications globally.
- Patent laws are designed to protect the investment a person or company puts into creating something new. They stop other people or companies taking someone else's idea and making money from it for a period of time so that the patent holder has time to develop and sell the idea (or product) to recoup the investment they put into it.

White willow bark yields the active ingredient of aspirin, used to treat pain fever, and inflammation.

Digitalin, containing cardiac glycosides derived from foxglove, is used in drugs to treat congestive heart disease.

Biopiracy

- **Biopiracy** is a term used to describe the taking of a traditional resource (e.g. a traditional medicine or plant type), applying a patent to it, and then stopping any traditional use of the resource, or selling it back to the people who traditionally used it in the first place. This can happen relatively easily, especially when resources are acquired from countries that have traditionally thought of those resources as communal, with no stated ownership.

The smokebush plant

- Smokebush plants (*Conospermum*) (right) are found throughout Australia, but most commonly in Western Australia. The plant is traditionally used in medicine by Aboriginal peoples. In the 1960s, several specimens were collected by the US National Cancer Institute and tested for anti-cancer activity. All tests were negative. However, the specimens were tested again in the 1980s, this time to treat HIV infection. The results showed anti-HIV activity.
- The US Government filled out patents for the US in 1993, and Australia in 1994. This gave the US Government exclusive rights to any compounds derived from the plants. Despite Aboriginal knowledge of the medical properties of the plant, no mention of royalties or compensation to them was made in the legal negotiations around the use of compounds derived from the plant. What's more, the Aboriginal people of WA noted that Aboriginal people would be prevented from using any plants that are the subject of the exclusive agreement.

Melburnian CC 3.0

3. (a) What is bioprospecting? _____

(b) What is biopiracy? _____

(c) Explain how the patent system can encourage biopiracy: _____

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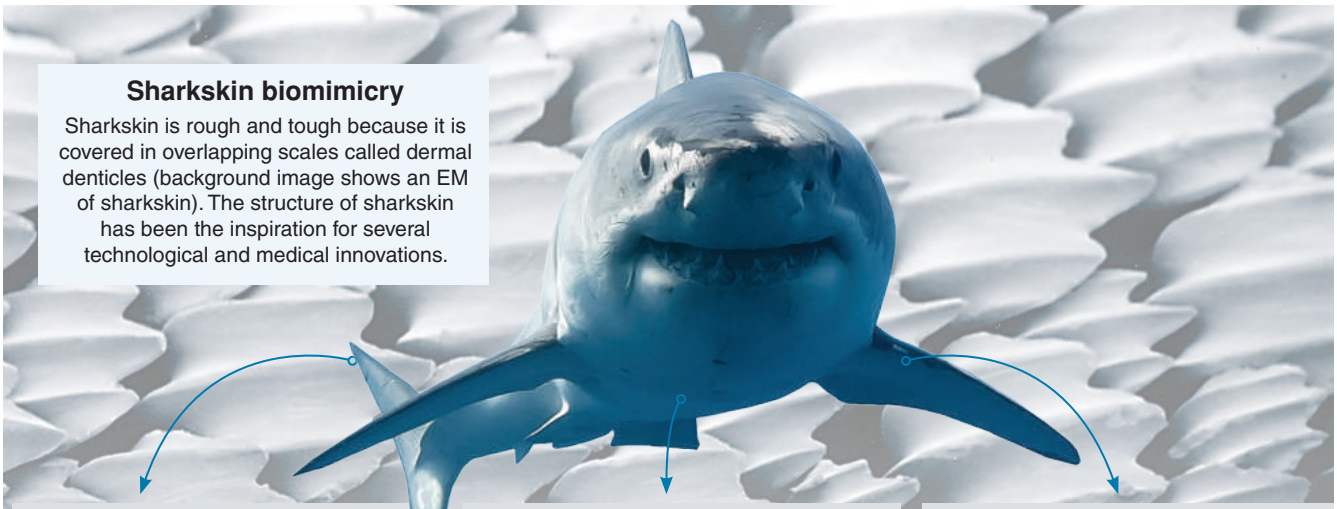
Biomimicry and associated bioethical issues

- The inspiration for many new technologies comes from studying organisms, systems, and structures in nature. This is called **biomimicry**. Studying organisms and natural process provides ideas on how to develop and improve technologies for human use. The applications are varied, ranging from energy production through to medicine.
- Ethical issues arise when technology based on the scientific understanding of a natural process or material is then used in a way that has negative effect on the natural environment. For example, a new saw design based on an animal's tooth shape that was then used to cut down rainforest more efficiently.
- Is the development of technology based on natural designs exploitative? Might aspects of biopiracy be involved?



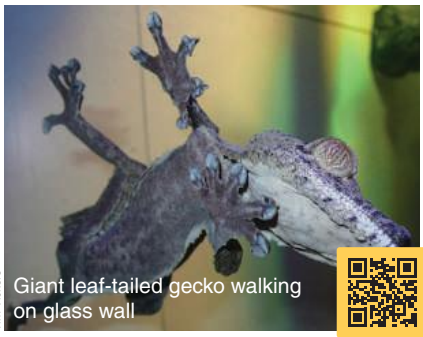
Sharkskin biomimicry

Sharkskin is rough and tough because it is covered in overlapping scales called dermal denticles (background image shows an EM of sharkskin). The structure of sharkskin has been the inspiration for several technological and medical innovations.

Antifouling coatings
In the marine industry, an elastic silicone product mimicking sharkskin is painted on to the hull of boats to improve hydrodynamics, allowing ships to move through the water more efficiently. The product also prevents the growth of marine organisms without the damaging environmental effects of traditional chemical antifouling agents.

Performance swimwear
Grooves running the length of each denticle allow water to slip past the fish, reducing hydrodynamic drag when swimming. This inspired the development of the controversial sharkskin swimsuit, which was used in the 2008 Summer Olympics. It is now banned from competition because of the competitive advantage provided by reduced drag.

Sharklet™ catheter tubing
The structure of sharkskin prevents attachment and growth of microbes. It has inspired improvements in surgical catheters, which are a common source of infections in hospitals. Sharklet™ tubing has a textured surface, which resists bacterial colonisation within the tube, reducing infection rates in patients.



Tim Vickers

Giant leaf-tailed gecko walking on glass wall

Geckos have rows of tiny hairs on their feet allowing them to walk on smooth surfaces. Each hair has 1000 microscopic pads at the tip, each generating a van der Waals force that adheres the gecko to the surface. Although the individual forces are weak, collectively they are very strong, and a gecko can hold its entire weight vertically using only a single toe. This ability has inspired the design of powerful adhesives which have the potential to be used under water, in space, or as a replacement for sutures and staples in hospitals.

Many butterflies have wings that appear to change colour in flight, a property known as iridescence. Butterfly wings are covered in thousands of tiny scales, each with two or three layers of their own. When light hits the different layers, it is reflected back many times producing a bright, intense colour. This arrangement has been mimicked in electronic displays to improve the quality. Thousands of microscopic mirrors beneath the surface of a monitor's glass take the white light and reflect back a colour image. The intensity changes with the level of light.

The initial bite of a mosquito is quite painless. This is because their mouthparts are made up of several moving parts that are able to pierce the skin with minimal pain. Japanese researchers have developed a medical needle based on the mosquito mouthpart. The needle uses pressure to stabilise and pierce the skin painlessly. In the UK, a neuroprobe (used in brain surgery) has been developed using a similar design. It requires less force to manipulate it, so reduces the chances of accidently causing damage during surgery.

4. In groups, list any pieces of technology you can think of that where the design is based on natural materials:

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144 Scientific Evidence

Key Idea: Balanced reporting provides unbiased information where both the positive and negative aspects are presented without a particular emphasis on either.

The reporting of scientific information should always be unbiased and a statement of fact backed by evidence. Unfortunately, a lot of information reported today is highly biased, lacks scientific rigour, or is interpreted incorrectly, resulting in the public being misled about many issues. It is important when you present arguments for or against a particular action that you have thoroughly checked the validity of the evidence you are citing. This may mean finding the original source of the information you have used (e.g. original research) and deciding if it has provided valid, peer-reviewed evidence (such as would appear in a scientific journal).

Gathering evidence

- Gathering evidence to test a hypothesis is central to a scientific investigation. However, unless the methods of gathering the evidence are fair (i.e. without deliberate or unknowing bias) the evidence gathered can produce data that supports hypotheses that are flawed.
- For example, it is very easy to gather data that supports the idea that light objects fall more slowly that heavy objects. Dropping a feather and a hammer from head height in a closed room will undoubtedly result in the hammer hitting the ground first. However, that is not a valid result because of the biased nature of the test.
- It is this kind example that makes it very important to verify the quality of the evidence presented. Was the test fair? Were the assumptions made valid? Is the source of the data known to be authoritative?
- It is also important to distinguish between primary and secondary sources of information. **Primary** sources provide first hand evidence and include transcripts and raw data. **Secondary** sources provide analysis and commentary. They include articles, books and reports. Primary sources are considered more credible than secondary sources.

How good was the investigation's design? Was it a fair test?

The nature of evidence

- It is important to understand the difference between scientific evidence (evidence backed up by valid scientific research), anecdotal evidence (evidence from casual observation), and opinion.
- **Anecdotal evidence** is evidence based on anecdotes, stories or observations from the general public that are not backed by rigorous evidence. Anecdotal evidence is often regarded as weak or of little use, but it can be based on fact. A well known example is the existence of rogue waves at sea. For decades, sudden huge waves were often reported by ships at sea, but with no recorded evidence the reports were generally dismissed as just stories. It wasn't until 1995 that a rogue wave was detected and recorded by science. They are now regarded as fact, and are an area of active research.
- **Expert opinions** are judgements based on known physical and statistical evidence. Opinions may vary between scientists so must be considered carefully and evaluated in light of all evidence.

Stories of rogue waves were only proven true in 1995

Misusing scientific information

- Scientific investigations and experiments are carried out to enhance our understanding of how different systems (biological, physical, geological, or chemical) work. Many of these investigations involve equipment, data, and results that are highly technical and can be easily misunderstood by people outside the field of study.
- Sometimes investigations are made that deliberately intend to collect data to support a particular point of view, i.e. they are biased. This can be done by asking questions or manipulating an investigation in such a way that only biased or skewed results will be obtained. For example, consider the following questions:
  - Do you support the use of dihydrogen monoxide as a solvent for sucrose in carbonated beverages?
  - Do you support water being used to dissolve sugar in soft drink?

  Both these questions ask exactly the same thing, but could get different results if asked in a survey.
- Deliberate misuse of scientific data often involves people or groups using selected parts of a report and matching them to an incomplete knowledge of a particular scientific concept.

Rosalee Yaghara CC 2.0

Scientific data can be misused to support particular views.

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Finding information

- As described in earlier chapters, there are many resources that can be used to obtain information about your issue. Most are available on the internet if your use the appropriate wording in your chosen search engine. For example, typing "genetic screening" into your search engine will find general information on genetic screening. Typing "genetic screening in Australia" will provide information about genetic screening in Australia.
- As outlined in earlier chapters, be aware of the sites from which you obtain information. Whatever your sources of information, think critically when reading and ask questions about how the claims are supported. Does the material show bias or is it impartial in its presentation of ideas?

Collating information

- In order to make a reasoned response to a bioethical issue, you are likely to obtain information from a range of sources, and those sources are likely to present different points of view, and offer different evidence or weight their evidence differently. To make formulating a response easier, you should collate the information in an organised way.
- There are no set rules about how to collate information. You can use summary tables or spreadsheets, schematic diagrams or flow charts, or even mind maps. Collation allows you to locate specific sources again, summarise the important points of each source (including evidence) and sort second-hand data into categories, e.g. (1) for genetic screening, (2) against genetic screening, (3) neutral to genetic screening. Example (in part) below.

Source of information	Type	Group	Evidence
www.abc.net.au/news/health/2017-11-03/genetic-carrier-screening-should-be-recommended/9115880	Blog	1	Risks of CF, spinal muscular atrophy, & fragile X syndrome
www.essentialbaby.com.au/conception/trying-to-conceive/the-pros-and-cons-of-prepregnancy-genetic-screening-20170804-gxpanf	Expert opinion	3	None
https://link.springer.com/article/10.1007/s12687-019-00443-6	Scientific journal	1	Correlational analysis of AR conditions and carrier frequency.

1. Distinguish be scientific evidence, anecdotal evidence, and opinion: _____

2. (a) Compile a list of information sources that could be scientific and authoritative: _____

   (b) Compile a list of information sources that could be non-scientific: _____

3. How do you plan to collate the information you collect from different sources during your research? In the space below, identify the bioethical issue you intend to research and explain how you will organise it:

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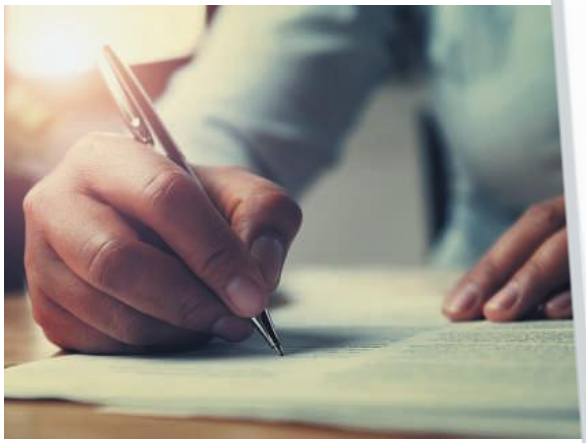
145 Scientific Communication

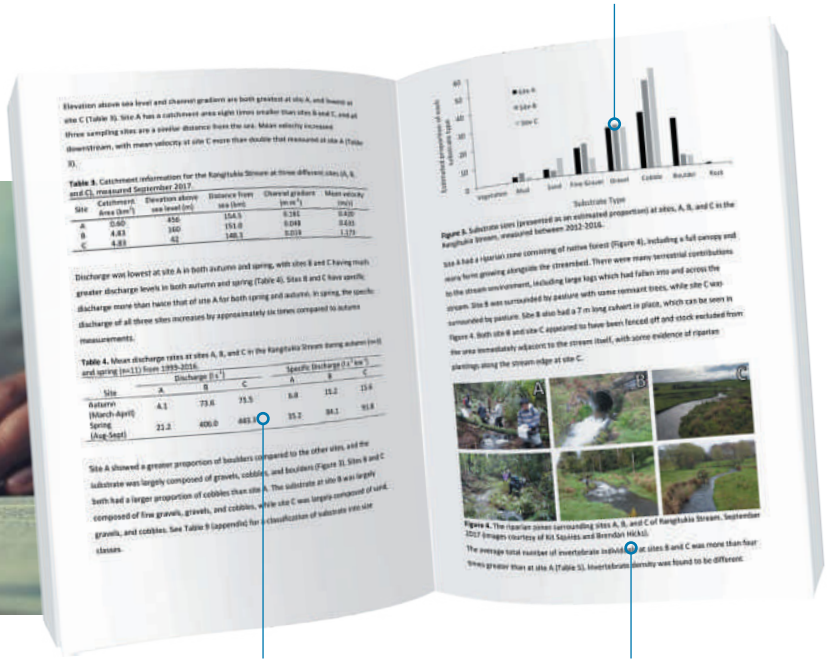
Key Idea: To effectively communicate scientific ideas, data and analysis must be clearly presented.

There are numerous ways to communicate your response to a biological issue. Essays and posters are common, but using presenting software such as MS PowerPoint is also effective. In any case the layout will be very similar. You must introduce your issue, explain why it is an issue, highlight conflicting ideas or opinions, and then provide your own conclusions.

Essay or formal report

***Features**: Formal report with clear sections. It may include appendices for supporting information. Writing should be clear and concise, but includes more detail than would be provided in a poster format. Relevant secondary data may be reproduced with acknowledgement as supporting evidence.*





Figures labelled sequentially through the report. Figure legends usually sit below the figure.

Tables labelled sequentially through the report followed by a summary of results. Table legends usually sit above the table.

Site or set up photographs

Poster

***Features**: More informal and compact presentation, condensing information so that the viewer can quickly see the aims and outcomes of the research, without extra detail. Ideal for presenting a wide range of audiences. Format will vary depending on whether the data is first or second hand.*

START HERE WITH AN ENGAGING, DESCRIPTIVE TITLE
Your name here

WHAT I LEARNED

Here is a place for your message

- What do you want to say about your research? Why is it important?
- State your findings simply and clearly.
- Focus the viewer's attention on what you are trying to communicate.

INTRODUCTION

Introduces the issue and includes background information relevant to the investigation or research.

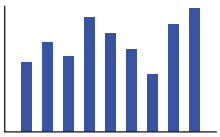
METHODS

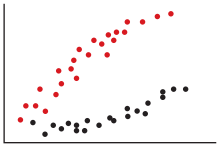
A description of the materials and methodology (e.g. sampling, survey, literature search), and any experimental procedures involved.

Features of the design or sampling protocols should be noted.

Photographs, diagrams, or schematics can be used to illustrate specific features of the research.

RESULTS OR ANALYSIS





A statement or description of the results or supporting evidence. This section should not discuss the results, only present them.

Present processed (tabulated or plotted) data, rather than raw data.

Tables and graphs should be identified sequentially, Fig.1, so they can be clearly identified in the discussion.

CONCLUSIONS

1. Clear points you want the viewer to take away with them.
2. A clear statement describing whether or not the results of the investigation support your hypothesis

REFERENCES

Acknowledge sources of information and help, e.g. field or lab assistance.

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Slideshow presentation

***Features**: An engaging way to present information to many audiences. Minimal information on each slide, with slide progressions allowing the story to unfold.*

Communicating your ideas

- All reports or presentations are based around a similar reporting format even though the information may be presented in different ways. In general, the format for reporting or responding to information you have researched and collated is:

1. **Introduction**: Introduce your issue by defining or explaining the issue your are exploring.
2. **Background information**: This will give the issue a context. Examine any viewpoints relating to your issue.
3. **Analysis**: An explanation of data or viewpoints. Essentially replaces the results and discussion section of a formal report of a scientific investigation (e.g. a lab report).
4. **Conclusions**: State your viewpoint an provide an evidence-based argument to support it.
5. **Acknowledgements/references**: Include a section listing your sources of information. This helps validate your arguments.

TYPE OF PRESENTATION	ADVANTAGES	DISADVANTAGES
Formal report essay	• Can be used to explain technical concepts using both words and diagrams. • Paper format makes it simple for handling and reading (people are often more likely to read printed paper than on screen notes). • Diagrams and graphs can be displayed easily.	• Generally, the least visually appealing format. • An essay format can be difficult to read and process for some audiences. Font type and size must be chosen carefully for readability. • The information may be too technical or difficult for some audiences.
Poster presentation	• Presenter not required. • All information presented on one surface making access to information simpler. • Can be made visually appealing, producing a good first impression for the viewer.	• Limited size means some supporting figures may need to be reduced in size or information may need to be simplified. • Static images and figures might not always convey the correct idea to viewers.
Slideshow presentation	• Can be viewed with or without a presenter. • Presentation can be brief and contain just the most important facts and figures. • Slideshows viewed without a presenter provide as much or as little information as required (there is no physical limit to the file size). • Can be visually appealing to many people and may present information in many ways (e.g. short video clips or animations).	• Presentation software can be tedious to work with and watch, especially if very long or overcrowded. • There can be a tendency to put in too many builds such as words flying in or slides spinning. • Presentations can end up with many slides and become tedious to work through.

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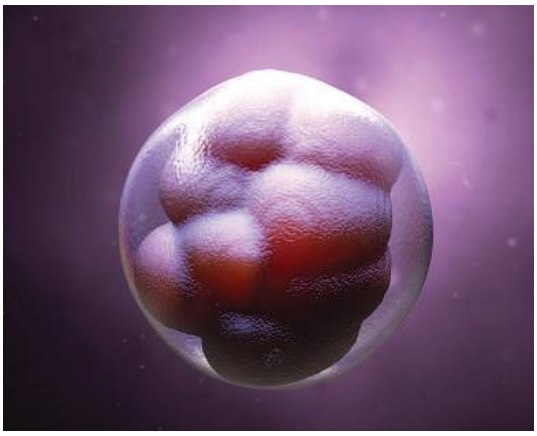
146 Analysis and Evaluation

Key Idea: The evaluation of biological information requires critical analysis of its validity and bias.

Your investigation of an issue requires you to explain biological concepts, identify, analyse, and evaluate bioethical implications, and generate a response to your findings. In order to do this, you must review a range of information related to your issue of choice. Socio-scientific issues can be very difficult to research because there are often two or more very different viewpoints involved. A difficulty with many scientific ideas and actions is that there are both negative and positive outcomes. The intent may be to use a new technology only for good but, because negative outcomes are a possibility, there will always be an argument against developing that technology. For example, genetic engineering may help to solve food shortage problems, but GM plants can also become pests, so many people are against their use.

Scientific ideas often produce ethical issues

- Many scientific concepts and breakthroughs come with both positive and negative effects. Many scientific works seek to explain observations by creating mathematical formulas that will predict outcomes, or producing some model that shows how the concept works. They may also include some positive and negative effects of the concept but do not usually seek to advise on these. That is the realm of ethics.
- An example of this is nuclear power. The process of the nuclear chain reaction is well understood. Even during the initial investigations into nuclear processes it became clear that nuclear energy could provide virtually limitless electricity if captured properly. It was also clear it could be used to destroy entire cities.
- Humans then had to decide what the process was used for. Because of the Second World War, the process was used to a build a bomb before it was used to provide electricity. Politicians and military advisors had to weigh the ethics of continuing to fight a long war conventionally or ending it quickly with nuclear weapons.
- The same principles apply to biological issues. Many of the scientific ideas and technologies we have developed can be used both for good and for bad. It is up for humans to decide how they are applied.
- A major problem is that what is good and what is bad are often subjective. Is it good to be able to select embryos with specific genetic traits? Those traits could help it go on to lead a successful and healthy life. Or it is bad to select those traits? Why is it that only certain people can select embryos? What if an embryo is selected only so it can be use later as a transplant donor?
- Too often people only hear or see evidence for one side of the debate. This is often the side with a most dramatic outcomes. Films of nuclear tests or footage of the aftermath of the nuclear bombs dropped in World War two are highly emotive. Similarly, arguments over designer babies, or genetically modified "frankenfoods" evoke worries about "interfering with nature". Often these emotive arguments can be so compelling that people will simply refuse evidence for the beneficial outcomes of various technologies.



1. Why are bioethical issues often subjective? _____

2. Why is the presentation of information important when dealing with bioethical issues? _____

3. Try thinking of a bioethical issue now, such as "*should chickens be barn raised or free range?"* Carry out a quick yes or no survey of the class. Are the responses clear cut or divided? Why?

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Evaluating and responding to bioethical issues

In order to recognise and validate biological information, you need to identify and explain the purpose of the biological information that is presented to the public. Does the person/ group presenting the information have a particular agenda (issue they want to push) or bias?

- Is there more than one side or view to this issue?
- Are all the views presented?
- Have compromises been made to reach an outcome?
- What information is presented to the public and is it scientifically correct (valid)?
- Is the information balanced or biased?
- Is some information more important than other information? If so, how is importance assigned?
- Discuss the significance of the biological information. What are the consequences to the public if:
  - the information presented is poor science?
  - the information presented is good science?
  - the information presented is anecdotal?
- Don't forget to reference information completely and correctly and use citations where required.

Resolving ethical issues

There are three major approaches to studying bioethical issues. Depending on the bioethical issue you have chosen you could choose to take one or more of the following approaches:

- **Consequences-based**: Concerned with the results of an action, with the aim being to maximise positive and minimise negative outcomes.
- **Duty or rule-based**: Concerned with following ethical "rules" regardless of the consequences.
- **Virtues-based**: Person-based rather than action-based. Consideration is given to the importance of behaving in the right way.

As well as your approach, your response should apply one or more of the **ethical concepts** tabulated below. A mnemonic (Be FAIR) will help you to remember the concepts to consider.

CONCEPT	EXPLANATION
Be Benefits	Maximising benefits and minimising risks associated with a particular action.
F Fair	Fairness or justice means to consider all points of view and ensure benefits are distributed equally.
A Avoid harm	Any harmful effects, if unavoidable, should not be disproportionate to benefits.
I Integrity	A commitment to searching for knowledge and honesty in reporting and communicating results.
R Respect	Considering the intrinsic value of living things and giving regard to beliefs and cultural heritage.

Genetic knowledge through ultrasound

To identify, analyse, and evaluate a bioethical issue, you must be aware of different bioethical approaches and concepts. You will need to decide how you will approach your analysis. Are you concerned with ethical rules, or will your approach be consequences-based (above left). Similarly, not all ethical concepts may apply to your issue of choice. The bioethical issues of genetic screening for example are different to those associated with biopiracy. However, you will find that a number of the concepts in the table left will be relevant to the issue you are investigating.

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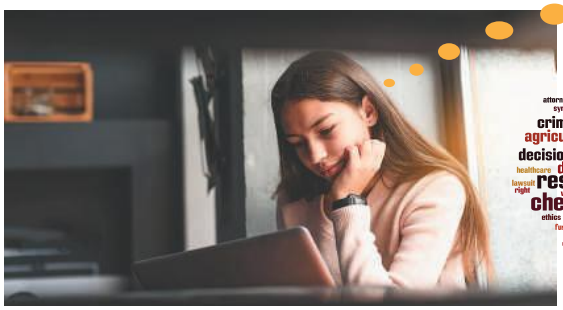
147 Your Research Question and Analysis

Assessment Task, Outcome 3: *Response to an investigation into a bioethical issue*



- Your task in this assessment is to make a considered response to a bioethical issue. You will explore a contemporary bioethical issue relating to one of the following:
  - the application of genetic knowledge
  - reproductive science
  - adaptations beneficial to survival
- To do this, you will first have to identify, analyse, and evaluate the bioethical issue you have selected.
- Your investigation or research should examine the science, including the type and quality of the evidence, the biological concepts involved, and the reasons for identifying your choice as a bioethical issue.
- You will need to collate your information to provide a framework for your report.
- Your communication of the issue should be clear and concise, evidence-based, and expressed using appropriate biological terminology.
- Use a standard convention for acknowledging all sources of information. Proper referencing of information sources is an important aspect of reporting. It shows that you have explored the topic and recognise and respect the work of others. There are two aspects to consider: citing sources within the text (making reference to other work to support a statement or compare results) and compiling a reference list at the end of the report.
- A bibliography lists all sources of information, but these may not necessarily appear as citations in the report. In contrast, a reference list should contain only those texts cited in the report. A reference list can offer more flexibility (ordered numerically or alphabetically) if you have cited references using a umber system.
- The checklist right will help you to organise your findings to produce a clear, well organised, and logical response.

General structure

- ☐ Is there a clear introduction, body, and structure?
- ☐ Do the paragraphs connect together?
- ☐ Are citations and references included?
- ☐ Are arguments presented clearly and in a logical order?

Response

- ☐ Have you introduced your issue clearly?
- ☐ Have you clearly stated viewpoints around the issue?
- ☐ Have you stated your own arguments clearly?

Paragraph structure

- ☐ Does each paragraph have a clear purpose?
- ☐ Is each argument clearly presented?
- ☐ Is evidence included with each argument?

Conclusion

- ☐ Have you summarised your arguments?
- ☐ Have you stated your position?
- ☐ Do your arguments support your position?
- ☐ Have you included a concluding statement?

References

- ☐ Have you correctly cited your sources of information? Could someone else find them?
- ☐ Are your sources reliable and extensive enough?
- ☐ Do enough sources corroborate each other's information?

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A guide to referencing online resources

- Your exploration of a bioethical issue will begin with a literature or resource review. As described earlier, it is useful to collate the information as you work through it so you can organise the material and make it easier to formulate your response. Much of your research is going to be online where a large amount of information from many sources is readily available.
- Where you use information from the internet, you must provide the correct details according to the information source (see below).
- The guide below shows how to reference some of the online resources you will commonly find. In all cases, if no publication date is given, replace the date format with (n.d.) for no date.

Referencing Government sites

Website 1 is a government site with no specific author, so the following format would be used:

Organisation name (year, month day). *Page title*. Site name. URL

When the organisation name and page title are the same (yellow highlight) you can remove the page title from your reference.

Government of Western Australia, Department of Primary Industries and Regional Development (2019, June 18). *Regulation of genetically modified crops in Australia*. Government of Western Australia, Department of Primary Industries and Regional Development. https://www.agric.wa.gov.au/genetic-modification/regulation-genetically-modified-crops-australia

Referencing peer reviewed journals

Website 2 is an online journal article with an author. Use this format:

Last name, Initials. (Year). Article title. Journal Name, Volume (Issue), Page range. DOI or URL.

Maghari, B.M & Ardekani, A.M. (2011). Genetically modified foods and social concerns. Avicenna J Med Biotechnol., 3(3), pp. 109-117. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3558185/

Referencing company websites

Website 3 is a company website with no author. Use this format:

Organisation name (year, month day). *Page title*. Site name. URL

Bayer (n.d) *Safety of GM crops*. Shaping Agriculture. https://www.cropscience.bayer.com/who-we-are/transparency/a/safety-gm-crops

Referencing online articles

Website 4 is an opinion piece by a Greenpeace scientist NGO's website with an author. Use this format:

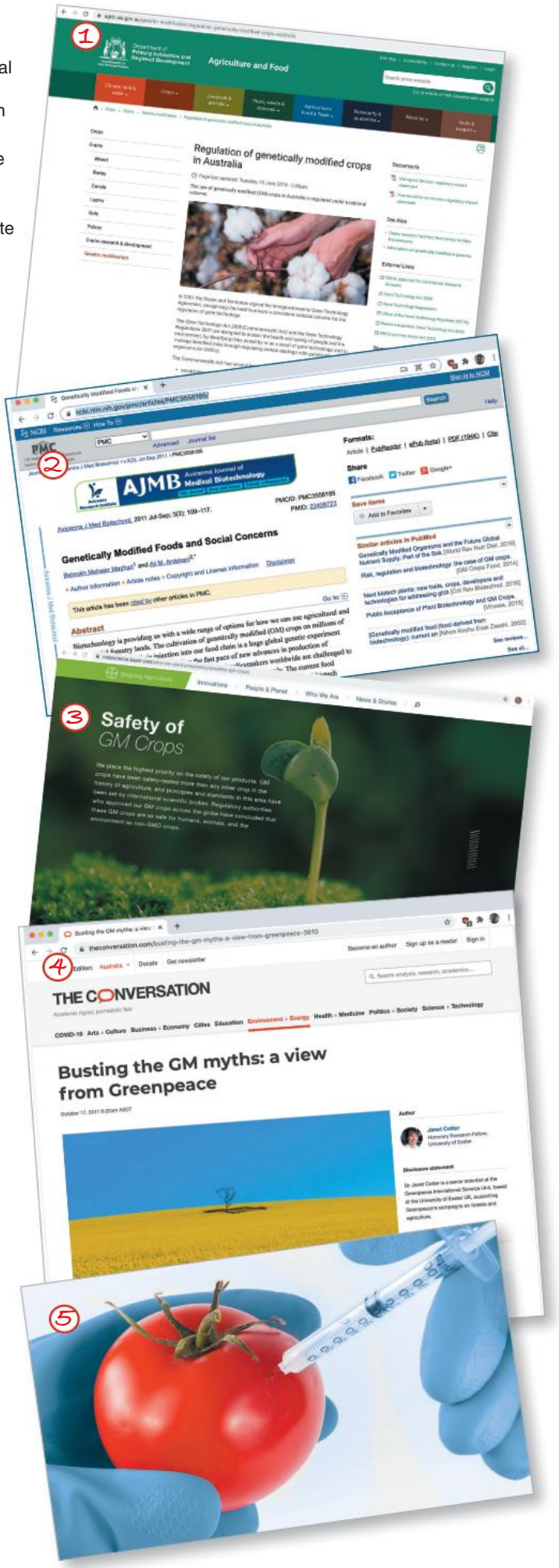
Last name, initials. (year, month day). Article title. *Publication name*. URL

Cotter, J. (2011, October 17). Busting the GM myths: a view from Greenpeace. *The Conversation*. https://theconversation.com/busting-the-gm-myths-a-view-from-greenpeace-3610

Referencing social media

Screen 5 represents social media. When referencing social media use this format:

Last name, initials. (year, month day). *First 20 words of post* [description of multimedia aspects] [type of post]. Site name. URL



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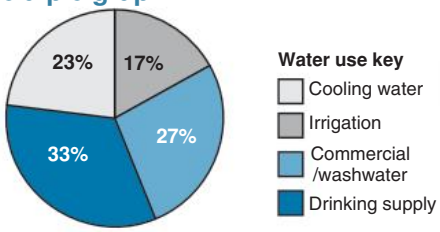
A-1 Appendix 1: Which Graph to Use?

The first chapter in this book gave you some guidelines for plotting data. Before you graph your data, it is important to identify what type of data you have. Choosing the correct type of graph can highlight trends or reveal relationships between variables. Choosing the wrong type of graph can obscure information and make the data difficult to interpret. A flow chart for selecting an appropriate plot for your data is provided below. You can refer to it at any time in your work.

What type of data have you collected?

- One variable is a category
- One variable is a count (or calculated percentage)

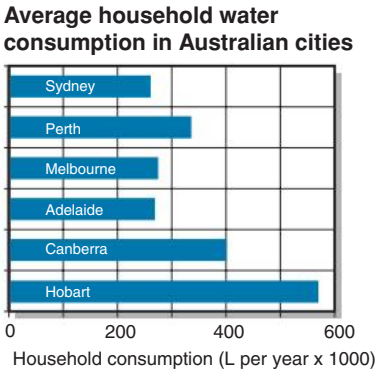
→ **Use a pie graph**



Use to compare proportions in different categories.

- One variable is a category
- One variable is continuous data (measurements)

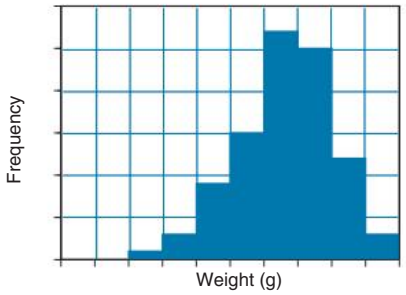
→ **Use a bar or column graph**



Use to compare different categories (or treatments) for a continuous variable.

- One variable is continuous data (measurements)
- One variable is a count

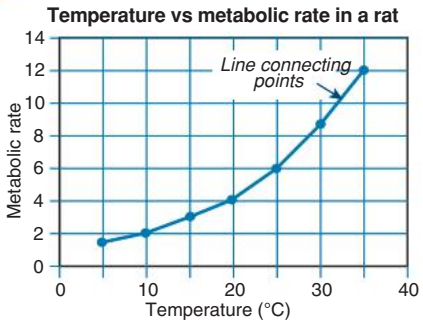
→ **Use a histogram**



Use to show a frequency distribution for a continuous variable.

- Both variables are continuous
- The response variable is dependent on the independent variable
- The points are connected point to point

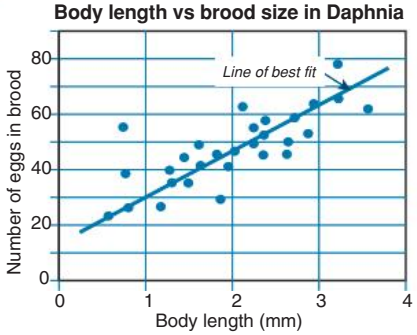
→ **Use a line graph**



Use to illustrate the response to a manipulated variable.

- Both variables are continuous
- The two variables are inter-dependent but there is no manipulated variable
- A line of best fit can be drawn through the points

→ **Use a scatter plot**



Use to illustrate the relationship between two correlated variables.

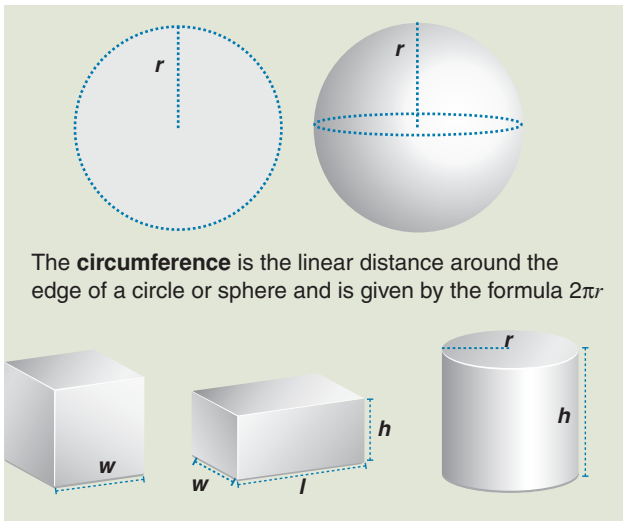
A-2 Appendix 2: Some Basic Mathematical Formulae

The first chapter in this book provided some basic guidance on calculating some commonly used data transformations, including ratios, rates, and percentages. Mathematics is used to analyze, interpret, and compare data. It is important that you are familiar with mathematical notation (the language of mathematics) and can confidently apply some basic mathematical principles and calculations to your data. Data collected in the field or laboratory is called raw data. It often needs to be transformed to reveal trends or patterns. Thid page summarises some of the formulae you might commonly use (such as mean and standard deviation) and some that may be of use in specific circumstances.

Using mathematical routines may include:

- Determining the best method to solve a mathematical problem, e.g. explaining the best way to compare water intake in different plants.
- Applying appropriate mathematical routines or relationships to solve a problem, with working shown, e.g. calculating population growth over time.
- Calculating a numeric answer to a problem, using the appropriate units, e.g. calculating the rate of water loss from a plant over 24 hours.

Calculating surface area and volume for shapes



r = radius ***l*** = length ***w*** = width ***h*** = height $\pi = 3.14$

	Sphere	Cube	Rectangular prism	Cylinder
Biological example	Coccus bacterium	Kidney tubule cell	Intestinal epithelial cell	Axon of neuron
Surface area	$4wr^2$	$6w^2$	$2(lh + lw + hw)$	$(2\pi r^2) + (2\pi rh)$
Volume	$(^4/_3)\pi r^3$	w^3	lwh	$\pi r^2 h$

Units of measure

Name	Unit	Symbol
Mass	gram*	*g*
Length	metre	*m*
Time	second	*s*
Temperature	Celsius Kelvin	°C K
Volume	Litre	*L*

*Gram (g) is the singular unit of mass, but kilogram is the SI unit.

All units can be prefixed with a multiplier:		
milli: 10^{-3}	centi: 10^{-2}	deci: 10^{-1}
hecto: 10^2	kilo: 10^3	mega: 10^4

Basic statistical formulae

	Symbol	Formula
Mean	$\bar{x}$	$\bar{x} = \sum x \div n$
Sample standard deviation	s	$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n-1}}$
Standard error	SE	$SE = \frac{s}{\sqrt{n}}$
95% confidence interval	$95\%\ CI$	$95\%\ CI = SE \times t_{(P=0.05)}$

Worked examples from a data set of fern sori

64, 69, 71, 67, 60, 70, 69, 64, 64, 63, 59, 63, 62, 70, 70, 64, 68, 70, 66, 63, 66, 63, 61, 62, 70

Mean: $\bar{x}$: $\bar{x} = \sum x \div n$:
$\sum x = 1638$. n = 25.
$1638 \div 25 = 65.52 =$ **66**

Sample standard deviation s: $s = \sqrt{\frac{\sum(x - \bar{x})^2}{n-1}}$

$(x - \bar{x})^2$ (for each data point) (the first three are shown):
$(64 - 65.52)^2 = 2.3104$, $(69 - 65.52)^2 = 12.1104$,
$(71 - 65.52)^2 = 30.0304$

$\sum(x - \bar{x})^2 = 2.3104 + 12.1104 + 30.0304 + 2.1904 + 30.4704 + 20.0704 + 12.1104 + 2.3104 + 2.3104 + 6.3504 + 42.5104 + 6.3504 + 12.3904 + 20.0704 + 20.0704 + 2.3104 + 6.1504 + 20.0704 + 0.2304 + 6.3504 + 0.2304 + 6.3504 + 20.4304 + 12.3904 + 20.0704$
$= 316.24 =$ **316**.

n – 1 = 25 – 1 = 24. $316 \div 24 = 13.18$. $\sqrt{13.18} = 3.63 =$ **4**.

Standard error: SE = $\frac{s}{\sqrt{n}}$

$3.63 \div \sqrt{25} = 0.73 =$ **1**

95% Confidence interval: $95\%\ CI = SE \times t_{(P=0.05)}$

0.73 x t (from t tables) = 0.73 x 2.064 = 1.50 = **2**.

Note: *Sori are found under the fronds of ferns. They are spore bearing structures and so there can only be whole numbers of sori. The answers to all formulas must therefore be given in whole numbers even though decimals are used in the working.*

A-3 Appendix 3: Glossary

A

absorption
The process by which nutrients are taken up by the body (from intestine to blood).

abundance
The number of individuals of a species.

accuracy
The correctness of a measurement; how close a measured value is to the true value.

active transport
The movement of molecules or ions across a cell membrane against a concentration gradient, requiring an expenditure of energy.

adult stem cell
An unspecialised cell found in the body after development that can give rise to one or more different types of specialised cells.

aim
A single statement describing the purpose or reason for conducting an experiment.

allele
Any of the alternative versions of a gene that may produce distinguishable phenotypes.

anaphase
A stage in cell division when chromosomes are pulled toward opposite ends of the cell.

aneuploidy
A chromosomal aberration in which one or more chromosomes are present in extra copies or are deficient in number.

anecdote
A personal account or report of a particular incident or event.

antidiuretic hormone (ADH)
A hormone secreted by the pituitary gland that limits urine output and helps control the body's water balance.

argumentation
The scientific process of proposing, supporting, critiquing, and refining ideas.

asexual reproduction
A type of reproduction involving a single parent that results in offspring that are genetically identical to the parent.

assumption
A statement that is assumed to be true but is not (or cannot be) tested.

autosomal dominant trait
A trait or disorder that may be passed from one generation to the next, where only one allele is required to pass on the trait.

autosomal recessive trait
A trait or disorder that may be passed from one generation to the next, where two copies of an abnormal gene must be present in order for the trait to be expressed.

autotroph
An organism that produces its own food using materials from inorganic sources.

B

behavioural adaptation
Actions of an organism that contribute to fitness (survival and reproduction).

binary fission
The process by which one prokaryotic cell divides into two identical daughter cells.

biodiversity
The amount of biological variation present in a region (includes genetic, species, and habitat diversity) .

bioethical issue
Ethical issues emerging from advances in healthcare, medicine, research, biotechnology, and the environment.

budding
A type of asexual reproduction in which a new organism develops from an outgrowth due to cell division at one particular site.

bulb
A modified stem that is the resting stage of certain seed plants.

C

callus
A mass of dividing, undifferentiated cells growing at the site of a wound or in culture.

cancer
The malignant growth of cells due to uncontrolled cell division.

carrier protein
A protein with a function to transport small molecules (or other proteins) through biological membranes.

cell cycle
The cycle of stages that take place in a cell as it grows and divides to produce new daughter cells.

cell division
Any process by which a parent cell divides into two or more daughter cells.

cell wall
The rigid outermost cell layer found in plants and certain algae, bacteria, and fungi but absent from animal cells.

centrioles
A cylindrical cell structure made of microtubules which exists as part of the centrosome, found in most eukaryotic cells.

channel protein
A protein that allows the transport of specific substances across a cell membrane.

chloroplast
An organelle within the cells of plants and green algae that contains chlorophyll and is the site of photosynthesis.

chromatid
One half of a replicated chromosome, held to its other half at the centromere.

chromatin
A complex of DNA and proteins, making up the chromosomes.

chromosome
A cellular structure consisting of one DNA molecule and associated protein molecules.

cilium *(pl. cilia)*
Minute hairlike organelles found on the surfaces of eukaryotic cells, which beat rhythmically to provide locomotion or to move liquids over the cell surface.

citation
A quotation of or explicit reference to a source for substantiation or evidence, as in a scholarly paper.

clone
An individual that is genetically identical to another individual.

codominance
A phenomenon in which two alleles are expressed to an equal degree within an organism.

cohesion-tension hypothesis
The hypothesis that explains how water is transported in plants to extreme heights against the force of gravity.

competition
Interaction within or between species in which individuals attempt to access the same limited resource.

concentration gradient
The difference in the amounts of a dissolved substance on either side of a membrane or in two areas of a biological system.

consumer
An organism that feeds on producers, other consumers, or non-living organic material.

continuous variation
Variation in phenotypic traits in which in which there is a complete spread of forms (phenotypes) across a range.

controlled experiment
An experiment in which all factors are held constant except for one, which is the variable being tested.

correlational study
A scientific study in which a researcher investigates associations between variables and none of the variables are manipulated.

crossing over
The reciprocal exchange of genetic material between non-sister chromatids during prophase 1 of meiosis.

cutting
A plant section originating from the stem, leaf, or root and capable of developing into a new plant.

cytokinesis
The part of the cell division process when the cytoplasm of a single eukaryotic cell divides to produce two daughter cells.

cytoplasm
The watery solution with a cell, including dissolved substances, enzymes, and cell organelles (except for the nucleus).

D

data
A set of values of qualitative or quantitative variables, collected through observation.

density
The number of individuals per unit area or volume.

diabetes mellitus
A severe, chronic form of diabetes caused by insufficient production of insulin, resulting in abnormal metabolism of carbohydrates, fats, and proteins.

differentiation
The normal process by which a less specialised cell undergoes maturation to become a more specialised cell.

diffusion
The net movement of molecules from a region of high concentration to one of lower concentration.

digestion
The process of breaking down large, insoluble molecules of food into smaller, water-soluble molecules, which can then be absorbed by the body.

digestive system
An organ system consisting of the central gastrointestinal tract and associated organs that are responsible for digestion.

dihybrid cross
A cross between two organisms that differ in two observed traits.

diploid
Having paired sets of chromosomes, one from each parent, in a cell or cell nucleus.

distribution
The spatial arrangement of organisms.

DNA methylation
A biological process by which methyl groups are added to the DNA molecule.

DNA replication
The chemical duplication of a DNA molecule, producing two identical copies from one original DNA molecule.

dominant allele
An allele that is expressed (as a trait) even if the individual only has one copy of the allele.

dominant trait
See **dominant allele**.

ductless gland
Glands that secrete their product directly onto a surface rather than through a duct.

E

ecosystem
All the organisms in a given area as well as the abiotic factors with which they interact.

ectoderm
The outermost layer of cells or tissue of an embryo in early development, including the epidermis and nerve tissue.

effector
In a neural circuit, a muscle or gland that brings about a response.

egestion
The act of discharging undigested solid waste material from a cell or organism.

electron micrograph
A photograph or image of a specimen taken using an electron microscope, which produces images using a beam of electrons.

embryonic stem cell
A stem cell derived from the early stages of an embryo, which is capable of differentiating into any type of body cell.

endocrine system
A collection of ductless glands, which produce hormones and secrete them into the circulatory system.

endoderm
The innermost primary germ layer in a very early human embryo.

endoplasmic reticulum
A membranous network found in eukaryotic cells, composed of ribosome-studded (rough) and ribosome-free (smooth) regions.

epigenetics
The study of heritable phenotypic changes that do not involve alterations in the DNA sequence.

eukaryote
Organism whose bodies are made up of eukaryotic cells, such as plants, animals, protists, and fungi.

eukaryotic cell
A cell that contains a membrane-bound nucleus and organelles.

excretion
The process by which organisms expel metabolised waste products and other toxic substances from their body.

excretory system
The organ system that removes metabolic wastes and toxins from the body.

explant
Living tissue transferred from (usually) a plant to an artificial medium for culture.

F

facilitated diffusion
The passive movement of molecules along the concentration gradient.

fertilisation
The union of haploid gametes to produce a diploid zygote, initiating the development of a new organism.

first gap phase (G_1)
The first gap, or growth phase, of the cell cycle, consisting of the portion of interphase before DNA synthesis.

fission
The separation of an organism into two or more individuals of approximately equal size.

fitness
An organism's ability to survive to reproductive age and produce offspring. A mathematical measure of an organism's genetic contribution to the next generation.

flagellum (*pl. flagella*)
A microscopic hair-like structure involved in the locomotion of a cell.

food chain
The pathway along which food energy is transferred from one trophic level to another, beginning with producers.

food web
The interconnected feeding relationships in an ecosystem.

fragmentation
A means of asexual reproduction whereby a single parent breaks into parts that regenerate into whole new individuals.

G

gamete
A mature sexual reproductive cell, as a sperm or egg, that unites with another cell to form a new organism.

gene
A unit of hereditary information consisting of a specific nucleotide sequence in DNA.

genetic cross
The purposeful mating of two individuals resulting in the combination of genetic material in the offspring.

genetic diversity
The variation in genes and genotypes within a species or an ecosystem.

genome
The genetic material of an organism, and all the heritable traits encoded in its DNA.

genotype
The genetic makeup, or set of alleles, of an organism.

germ layer
Any of three main layers of cells formed during embryonic development that will form the various tissues of an animal body.

glomerulus
A ball of capillaries surrounded by Bowman's capsule in the nephron, serving as the site of filtration in vertebrate kidneys.

glucagon
A hormone secreted by the pancreas that raises blood glucose levels and promotes the release of glucose by the liver.

Golgi apparatus
An organelle found in eukaryotic cells that packages and transports molecules from the endoplasmic reticulum to their destination.

graft *(in plant biology)*
A plant formed by joining tissues from two or more sources.

guard cells
The two cells that flank the stomatal pore and regulate the pore's opening and closing.

H

habitat diversity
The variety of habitats present in a region.

haploid
Having a single set of each chromosome in a cell or cell nucleus. In most animals, only the gametes are haploid.

heterozygous
Having two different alleles for any hereditary characteristic.

histone
A small basic protein found in the nucleus of eukaryotic cells that organises DNA strands to form chromatin.

homeostasis
The steady-state physiological condition of the body.

homologous chromosomes
A pair of chromosomes, one inherited from each parent, with the same genes in the same order along their chromosomal arms.

homozygous
Having two identical alleles for any hereditary characteristic.

hormone
Chemical messengers secreted directly into the blood, where they circulate to exert specific effects on target tissues and organs.

hydrophyte
A plant that grows either partly or totally submerged in water.

hyperthermia
A condition in which the body's temperature is elevated above normal (*cf. hypothermia*).

hyperthyroidism
Excess production of thyroid hormones (T_3 and T_4) by the thyroid gland.

hypertonic
A solution with higher osmotic pressure than another solution; a solution that, when surrounding a cell, will cause the cell to lose water (*cf. hypotonic*).

hypoglycaemia
A fall in blood sugar (glucose) to levels below normal; low blood sugar.

hypothalamus
The ventral part of the vertebrate forebrain. It functions in maintaining homeostasis, especially in coordinating the endocrine and nervous systems and controlling the secretion of hormones by the pituitary gland.

hypothermia
A drop in body temperature to dangerously low levels (*cf. hyperthermia*).

hypothesis
A tentative explanation, proposition, or set of propositions capable of being tested by scientific experimentation.

hypotonic
A solution with lower osmotic pressure than another solution; a solution that, when surrounding a cell, will cause the cell to take up water (*cf. hypertonic*).

IJ

incomplete dominance
A gene interaction in which both alleles of a gene at a locus are partially expressed, resulting in an intermediate phenotype.

independent assortment
With reference to inheritance, describing how alleles for separate traits are passed to the gametes independently of one another.

insulin
A hormone secreted by pancreatic β cells that lowers blood glucose levels by promoting cellular uptake of glucose and synthesis and storage of glycogen in the liver.

interphase
The period in the cell cycle when the cell is not dividing, which accounts for about 90% of the cell cycle. During interphase, cellular metabolic activity is high and cell size may increase.

intestinal villi
Tiny, finger-like protrusions lining the mucous membrane of the small intestine, serving as the site of absorption of fluids and nutrients.

ion pump
Membrane proteins that is capable of transporting ions against a concentration gradient using the energy from ATP.

isotonic
Referring to a solution that, when surrounding a cell, causes no net movement of water into or out of the cell.

K

karyogram
A photograph of the chromosomes of a cell, arranged in homologous pairs and in a numbered sequence.

karyotype (*noun*)
The observed characteristics of the chromosomes of an individual or species.

karyotype (*verb*)
To investigate the chromosomal characteristics of an individual or species.

keystone species
A species that occupies an essential role in an ecosystem and on which most or all of the other species in an ecosystem depend on, directly or indirectly.

kidney
In vertebrates, one of a pair of excretory organs where blood filtrate is formed and processed into urine.

L

large intestine
In vertebrates, the last part of the gastrointestinal tract and digestive system, comprising the caecum, colon, and rectum.

light microscope
An optical instrument with lenses that refract visible light to magnify images of specimens.

line of best fit
A straight line through a scatter plot of data points that is the best approximation of the given set of data.

linked genes
Genes located on the same chromosome. Functionally refers to genes located close enough together on a chromosome that they tend to be inherited together.

locus (*pl., loci*)
A specific place along the length of a chromosome where a given gene is located.

logbook
A record of laboratory or field activities, experiments, and conditions.

lysosome
A membrane-enclosed sac of hydrolytic enzymes found in the cytoplasm of animal cells and some protists.

M

M phase
The period in the cell cycle during which cell division takes place.

magnification
The amount or degree of visual enlargement of an observed object.

mark and recapture
In ecology, a repeated sampling technique used to estimate the size of a population of mobile organisms.

mass flow hypothesis
A hypothesis that describes the movement of sap in plant phloem through diffusion gradients and hydrostatic pressure.

maternal chromosome
The chromosomes in the nucleus received from the female gamete during fertilisation.

mean
The sum of the data divided by the number of data entries; a measure of central tendency in a normal distribution.

median
The middle number in an ordered sequence of numbers. For an odd number of values, it is the average of the two middle numbers.

meiosis
The process of double nuclear division in sexually reproducing organisms, which results in cells with half the original number of chromosomes (haploid).

Mendelian inheritance
Patterns of inheritance that are characteristic of organisms that reproduce sexually, such as independent assortment and segregation of chromosomes.

mesoderm
The middle of the three primary germ layers of the embryo that is the source of many of the body's tissues and structures.

metaphase
The third stage of mitosis, in which the spindle is complete and the chromosomes are all aligned at the equator of the cell.

micropropagation
The process of cloning plants through tissue culture or cell culture techniques.

mitochondrion (*pl., mitochondria*)
An organelle in eukaryotic cells that serves as the site of cellular respiration.

mitosis
The phase of the cell cycle resulting in nuclear division.

mode
The value that occurs most often in a data set.

model
A conceptual, mathematical or physical representation of a real-world phenomenon.

monohybrid cross
A cross between two organisms that differ in one observed trait.

multiple alleles
The existence of more than two alleles for a gene in the population.

multiple genes
When many genes contribute to a single phenotype (*synonym, polygenes*).

multipotent
The ability (of stem cells) to develop into more than one cell type related to the tissue of origin; adult stem cells.

mutation
A change in the nucleotide sequence of an organism's DNA (or RNA).

mutualism
Biological interaction between (usually two) species that benefits both parties.

N

negative feedback
In physiology, a primary mechanism of homeostasis where a change in a variable triggers a response that counteracts the initial change.

nephron
The tubular excretory unit of the vertebrate kidney.

nondisjunction
The failure of homologous chromosomes or sister chromatids to separate properly during cell division.

nucleic acid
A polymer (poly-nucleotide) consisting of many nucleotide monomers; serves as a blueprint for proteins and, through the actions of proteins, for all cellular activities. The two types are DNA and RNA.

nucleolus (plural, nucleoli)
A specialised spherical structure in the nucleus, consisting of chromosomal regions containing ribosomal RNA (rRNA); the site of rRNA synthesis and ribosomal assembly.

nucleus
The organelle of a eukaryotic cell that contains the genetic material in the form of chromosomes, made up of chromatin.

O

omnivore
An organism that eats both plant and animal matter.

organ
A a group of tissues in a living organism that work together to perform a specific function.

organ system
A group of organs that work together to perform a vital function, e.g. digestion.

organelle
A subcellular structure with one or more specific jobs to perform in the cell.

osmolarity
The concentration of a solution expressed as the total number of solute particles per litre; number of moles of solute per litre.

osmosis
The diffusion of free water across a selectively permeable membrane.

P

parasitism
Biological interaction in which one organism, the parasite, benefits at the expense of the other, the host.

partially permeable
A membrane that is permeable to the small molecules of water and certain solutes but does not allow the passage of large solute molecules.

passive transport
The diffusion of a substance across a biological membrane with no expenditure of energy.

paternal chromosome
The chromosomes in the nucleus received from the male gamete during fertilisation.

pedigree
A diagram of a family tree with conventional symbols, showing the occurrence of heritable characters in parents and offspring over multiple generations.

phenotype
The observable physical and physiological traits of an organism, which are determined by its genetic makeup, environment and epigenetic factors.

phloem
Living plant vascular tissue that transports sugar and other nutrients.

phospholipid
A lipid composed of glycerol joined to two fatty acids and a phosphate group. Phospholipids form bilayers that function as biological membranes.

physiological adaptation
An internal or cellular process that regulates and maintains homeostasis for an organism, enabling to survive in its environment.

plant tissue culture
The *in-vitro* cultivation of plant cells, tissues, or organs.

plasma membrane
The membrane at the boundary of every cell that acts as a selective barrier, regulating the cell's chemical composition.

plasmolysis
A phenomenon in walled cells in which the cytoplasm shrivels and the plasma membrane pulls away from the cell wall; occurs when the cell loses water to a hypertonic environment.

pluripotent
Ability (of a stem cell) to give rise to all the cells of the adult body, but not extra-embryonic tissues such as the placenta.

polygenes
See **multiple genes**.

population
A group of interbreeding organisms of the same species, found in the same geographical area.

population size
The number of individuals in a population.

positive feedback
In physiology, a control mechanism in which a change in a variable triggers a response that reinforces or amplifies the change.

potency
The ability of a stem cell to differentiate into different cell types.

precision
The consistency of results when measurements or tests are repeated. Precision is independent of accuracy.

predation
Biological interaction in which one organism, the predator, kills and eats another organism, its prey.

prediction
What is expected to happen if the hypothesis of an experiment or scenario is true.

primary data
Data that is collected by a researcher from first-hand sources, e.g. investigation.

probability
The chance or likelihood that a certain event will occur or that a prediction will be correct.

producer
See **autotroph**

prokaryote
A unicellular organism consisting of a single prokaryotic cell. Prokaryotes lack membrane-bound organelles and a nucleus.

prokaryotic cell
A type of cell lacking a membrane-enclosed nucleus or other cell organelles.

prophase
The first stage of mitosis, in which the chromatin condenses into discrete chromosomes, the miotic spindle begins to form, and the nucleolus disappears.

protein
A biologically functional molecule consisting of one or more polypeptides folded into a specific three-dimensional structure.

Punnett square
A diagram used in the study of inheritance to show the predicted genotypic results of random fertilisation in genetic crosses between individuals of known genotype.

Q

quadrat
A frame used to outline a standard unit of area for study.

qualitative data
Non-numerical data that describes qualities or characteristics.

quantitative data
Numerical data expressing a certain quantity, amount, or range.

R

random error
An error in measurement caused by unknown and unpredictable changes in the experiment.

receptor
A protein molecule inside a target cell or on its surface that receives a chemical signal and brings about a response.

recessive allele
An allele that is only expressed if the individual has two copies of the allele (also known as being homozygous).

recessive trait
See **recessive allele**.

recombination
The process by which genes are exchanged between different chromosomes to produce new combinations of alleles.

reliability
The degree of consistency of a measurement (see **precision**).

repeatability
The closeness of the agreement between repeated measures under the same conditions of measurement.

replication
The process of duplicating and entire experimental design, at the same time, as a procedure in scientific experiments.

reproducibility
A major principle of the scientific method; the closeness of agreement between measurements carried out under different conditions of measurement.

resolution
A microscope's ability to distinguish detail.

response
Any behaviour of a living organism that results from an external or internal stimulus.

rhizome
A horizontal underground plant stem that sends out both shoots and roots.

ribosome
A complex of rRNA and protein molecules that function as a site of protein synthesis in the cytoplasm.

root
An organ in vascular plant that anchors the plant and enables it to absorb water and minerals from the soil.

rootstock
A root system of a plant, often with a portion of the stem, from which new growth can be produced in plant propagation.

rough endoplasmic reticulum (rER)
The portion of the endoplasmic reticulum with ribosomes attached.

S

S phase
The synthesis phase of the cell cycle, during which chromosomes are replicated.

sample
A representative part or a single item from a larger whole or group.

sample size
The number of units in a group or population to be studied.

scientific evidence
Empirical evidence gathered from research, which serves to either support or counter a scientific theory or hypothesis.

scion
The portion of a plant that is grafted onto the rootstock when making a graft.

second gap phase (G_2)
The second gap, or growth phase, of the cell cycle; a period of rapid cell growth and protein synthesis during which the cell prepares for mitosis.

secondary data
Pre-existing data that has already been collected from first-hand sources.

self renewal
The process of giving rise to indefinitely more cells of the same cell type.

sex linkage
An association between genes in sex chromosomes that makes some characteristics appear more frequently in one sex.

sexual reproduction
A type of reproduction in which offspring are created by combining genetic information from two individuals of different sexes.

simulation
The re-creation of a real world process in a controlled environment.

small intestine
Part of the gastrointestinal tract where most of the absorption of nutrients occurs.

smooth endoplasmic reticulum (sER)
The portion of the endoplasmic reticulum that lacks ribosomes.

somatic cell nuclear transfer
The process of transplanting nuclei from adult cells into denucleated oocytes to produce pluripotent cells.

specialised cell
A cell that has developed the characteristics needed to perform particular functions.

species diversity
The number and relative abundance of species in a biological community.

spore
A reproductive cell capable of asexual reproduction, adapted for dispersal and for survival in unfavourable conditions

standard deviation
A measure used to used to quantify the amount of variation in a set of data.

stem
An organ in vascular plants that supports the above-ground parts of the plant, transports water and dissolved substances, and produces new living tissue.

stem cell
An undifferentiated cell, characterised by self renewal and potency.

stimulus
In neural or hormonal circuits, a fluctuation in a variable that triggers a response.

stomach
An organ of the digestive system that stores food and begins protein digestion.

stoma (plural, stomata)
A microscopic pore in the epidermis of leaves and stems that allows gas exchange between the plant and the environment.

structural adaptation
A physical (morphological) feature of an organism that contributes to its fitness (survival and reproduction).

surface area : volume ratio
The amount of surface area per unit volume of an object.

symbiosis
A close ecological relationship between organisms of different species.

syndrome
A set of signs and symptoms that appear together and characterise a medical condition.

systematic error
An error in measurement that is predictable and either constant or proportional to the measurement.

T

telophase
The final stage of mitosis in which daughter nuclei are forming.

theory
An explanation of the natural world that has been repeatedly tested and verified using the scientific method.

thermoregulation
The maintenance of internal body temperature within a tolerable range.

tissue
An integrated group of cells with a common structure, function, or both.

totipotent
Ability (of a stem cell) to give rise to all the cells of the adult body and extra-embryonic tissues such as the placenta.

traditional ecological knowledge
Indigenous and other traditional knowledge of local resources and interdependencies.

trait
One of two or more detectable variants in a genetic character.

transect
A line across a habitat or part of a habitat, used for sampling.

translocation
The transport of organic nutrients in the phloem of vascular plants.

transpiration
The evaporative loss of water from a plant.

tuber
Enlarged, specialised plant organ formed by the swelling of an underground stem or root and used to store nutrients.

tumour
An abnormal mass of tissue that results from uncontrolled, excessive cell division.

turgor
Distention or rigidity of plant cells, resulting from fluid pressure against the rigid cell wall.

UVW

ultrafiltration
Filtration of fluid by hydrostatic pressure against a semi permeable membrane (as occurs in the kidney).

urine
A liquid containing metabolic waste products filtered from the blood by the kidneys.

vacuole
A membrane-bounded vesicle whose function varies in different kinds of cells.

validity
The extent to which a measurement, test, or study measures what it sets out to measure.

vascular tissue
Plant tissue consisting of cells joined into tubes that transport water and nutrients.

vegetative propagation
Asexual method of plant reproduction that occurs in its leaves, roots and stem.

XYZ

X-linkage
Sex linkage involving the X chromosome.

xerophyte
A plant adapted to an arid climate.

xylem
Vascular plant tissue consisting of tubular dead cells that conduct water and minerals up the plant from the roots.

zygote
A fertilised egg.

A-4 Appendix 4: Equipment List

The equipment list provides the material and equipment needed per student, pair, or group.

2: Cellular Structure and Function

INVESTIGATION 2.1
Simple diffusion across a membrane

Per student/pair
- 200 mL beaker
- 1 mL pipette
- Glucose dipsticks
- Lugol's indicator
- 4 x test tubes
- Dialysis tubing
- Thread or nylon line
- Distilled water
- 1% starch solution
- 10% glucose solution
- Timer or watch

INVESTIGATION 2.2
The effect of temperature on membrane permeability

Per student/pair
- 15 x 10 mL test tubes
- 200 mL beaker
- Beetroot
- Cork borer (internal diameter 4 mm)
- Five water baths at 0°, 20°, 40°, 60°, 90°C
- Paper towels
- Colorimeter set to 530 nm
- Distilled water
- Marker pen
- Timer or watch

INVESTIGATION 2.3
Estimating osmolarity

Per student/pair
- 6 x 500 mL beakers
- Balance and equipment to weigh sugar
- Table sugar or lab sucrose
- Potato
- Cork borer or scalpel
- Paper towels
- Marker pen

4: Functioning Systems

INVESTIGATION 4.1
Investigating plant transpiration

Per pair/group
- 250 mL conical flask with rubber bung
- Petroleum jelly
- 1 cm^3 pipette
- Clamp stand
- Leafy plant shoot
- Water
- Cooking oil (for optional set up)
- Timer or watch
- Lamp, or plastic bag and water spray bottle, or fan

INVESTIGATION 4.2
Investigating amylase activity

Per class
- Buffer solutions at pH 4, 5, 6, 7, 8
- 0.1 mol/L iodine solution (I2/KI)
- 1% amylase solution
- 1% starch solution

Per pair/group/pH
- Timer
- 1 mL pipette
- 2 mL pipette
- Clean syringe
- Test tube
- Spotting plate

5: Regulation of Systems

INVESTIGATION 5.1
Comparing stomatal density

Per pair/group
- Variety of leaf types
- Clear nail varnish
- Microscope slide
- Light microscope (with eyepiece micrometer if available)

7: From Chromosomes to Genomes

INVESTIGATION 7.1
Modelling meiosis

Per pair
- 16 x ice block (popsicle) sticks
- Sticky dots
- Marker pen

8: Genotypes and Phenotypes

INVESTIGATION 8.1
Investigating continuous variation

Per pair
- Measuring tape or scales
- Graph paper

Image Credits

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SPECIAL REFERENCES

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Index

Long Answers

Chapter 9: Patterns of Inheritance

100. Pedigree Charts (page 184)

5. Suggestions for interpreting a pedigree chart. Students can come up with their own list of guidelines:

   If most of the males in the pedigree are affected, then the disorder is X-linked.

   If it is a 50/50 ratio between men and women the disorder is autosomal.

   If the disorder is dominant, one of the parents must have the disorder.

   If the disorder is recessive, neither parent has to have the disorder because they can be heterozygous (carriers).

   Autosomal recessive
   - Appears in both sexes with equal frequency.
   - Trait tends to skip generations.
   - Affected offspring are usually born to unaffected parents.
   - When both parents are heterozygous, approximately 1/4 of the progeny will be affected.

   Autosomal dominant
   - Appears in both sexes with equal frequency
   - Both sexes transmit the trait to their offspring
   - Does not skip generations
   - Affected offspring must have an affected parent unless they posses a new mutation

   X-linked dominant
   - Both males and females are affected; often more females than males are affected.
   - Affected sons must have an affected mother.
   - Affected daughters must have either an affected mother or an affected father.
   - Affected fathers will pass the trait on to all their daughters.

   X-linked recessive
   - More males than females are affected.
   - Affected sons are usually born to unaffected (carriers) mothers, thus the trait skips generations.

113. Problems Involving Dihybrid Crosses (page 202)

5. Argument 2: "The genes for kernel colour and endosperm waxiness must be linked (on the same chromosome)."

   Enter the observed and expected values (number of individuals) and complete the table to calculate χ^2.

Category	O	E	O – E	$(O - E)^2$	$(O - E)^2 / E$
Colored - waxy	201	145	56	3136	21.63
Colored - not waxy	85	145	-60	3600	24.83
Colorless - waxy	86	145	-59	3481	24.0
Colorless - not waxy	210	145	65	4225	29.14
					Σ 99.60

   H_0: In a cross of CcWw x ccww we would expect a 1:1:1:1 ratio of all four phenotypes if the genes are assorting independently (on separate chromosomes).
   H_A: In a cross of CcWw x ccww we would expect a significant deviation from the expected 1:1:1:1 ratio of all four phenotypes if the genes are linked.

   χ^2 value = 99.60

   d.f. = 3
   $P_{0.05}$ value corresponding to calculated χ^2 = 7.82

   Reject H_0 / do not reject H_0 : **Reject H_0**.
   The students are correct; the genes are linked.