

# HSC

# BIOLOGY

**MODULES 1-4**





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## Cover Photograph

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The pied heron (*Egretta picata*) is a bird found in coastal and subcoastal areas of monsoonal northern Australia as well as some parts of New Guinea. It is a small, adaptable heron using a variety of feeding situations and a diversity of feeding techniques to catch small prey, mostly insects gleaned from aquatic plants and also fish caught in very shallow water. [https://en.wikipedia.org/wiki/Pied\\_heron](https://en.wikipedia.org/wiki/Pied_heron)

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# HSC | BIOLOGY MODULES 1-4



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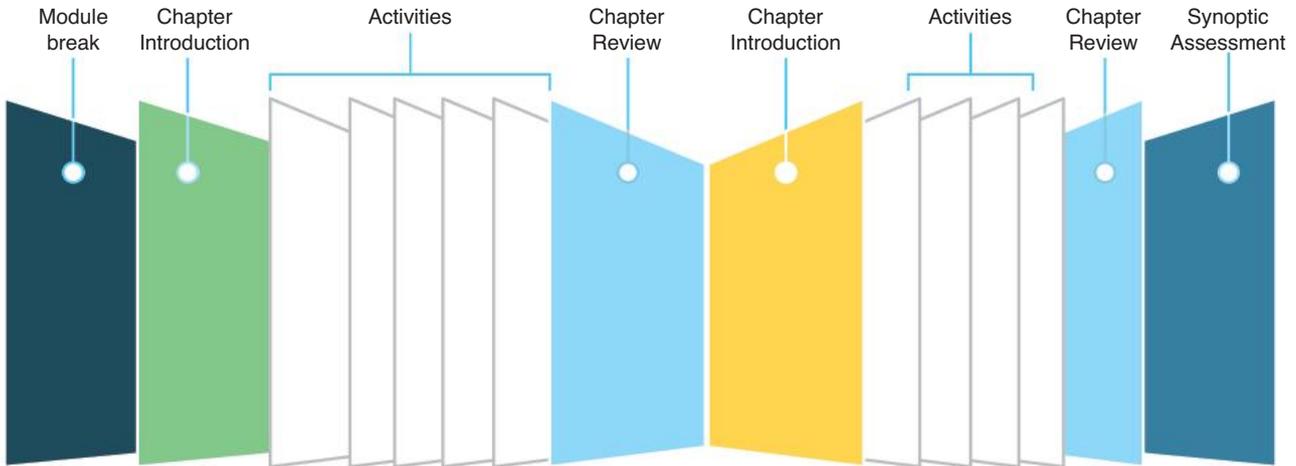
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# Using This Worktext

HSC Biology: Modules 1 - 4 has been specifically written to meet the content and skills requirements of the NSW Stage 6 syllabus (Modules 1 - 4). The worktext follows the structure outlined in the Stage 6 syllabus, so it is easy for you to know where you are in the course. Module breaks divide the content into sections (the modules) and summarise the student outcomes for each module. 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 Assessment activities.

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



## Chapter introduction

- Inquiry questions are identified.
- 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 assessment

- Synoptic assessments conclude the module of study covered in the workbook.
- Practise your written exam skills.



The **chapter introduction** identifies the inquiry question for the chapter. Keep this in mind as you work through the content, and try to relate your learning back to it. The chapter introduction also provides you with a summary of the key skills and knowledge requirements for the topic, written as a set of learning outcomes. Use the check boxes to identify and mark off the points as you complete them. A list of key terms for the chapter is provided to help you practise develop your scientific vocabulary.

58 CHAPTER 3 Cell Function

**Key terms**  
acetyl CoA  
activation energy  
active site  
active transport  
ATP  
ATP synthase  
Calvin cycle  
catalyst  
cellular respiration  
chlorophyll  
chloroplast  
cristae  
denaturation  
diffusion  
electron transport chain  
enzyme  
fermentation  
glucose  
glycolysis  
grana  
Krebs cycle  
light dependent phase  
light independent phase  
link reaction  
matrix  
metabolic pathway  
metabolism  
microtubules

**Activity number**

**Inquiry question:** How do cells coordinate activities within their environment?

**The movement of materials into and out of cells**  
Key skills and Knowledge

- 1 Describe how cells exchange substances by diffusion (including facilitated diffusion) and osmosis. Relate the exchange of materials across membranes to the surface area:volume ratio, concentration gradient, and the characteristics of the materials being exchanged. Explain how cells overcome the limitations to cell size. 31-34
- 2 Investigate diffusion across membranes using a model system. 35-39
- 3 Investigate the effect of cell size on the rate and efficiency of diffusion. 37
- 4 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. 39-43

**Cell requirements**  
Key skills and Knowledge

- 1 Understand that cells exchange matter and energy with their environment. Describe the general requirements of cells, including but not limited to: 40-44
- 2 The need for energy, including light and chemical energy in complex molecules. 45-60
- 3 The need for matter, including nutrients, gases, and ions.

**Waste products**  
of waste materials are produced by them?

**Processes in cells**  
including aerobic and anaerobic ATP metabolic processes. 46-47

location of glycolysis, the Krebs cycle and the electron transport chain. 48-51

**Photosynthesis**  
10 Describe photosynthesis, including the main inputs, outputs, and location of the light dependent and light independent reactions, and the events occurring in those phases. 52-56

11 Use a simple system to investigate factors affecting rate of photosynthesis. 55

12 Use simple chromatography to isolate and visualise photosynthetic pigments. 57

13 Describe how enzymes work to control biochemical processes in cells, including removal of cellular products and wastes, such as hydrogen peroxide. 60-64

14 Using temp peroxidase, investigate factors affecting enzyme activity in cells. 65

**Practical Investigation:** A green PRAC tab indicates a practical investigation is included in the activity.

The activities form most of the workbook. The activity number is found at the top of the first page. Each activity has a short introduction with a key idea identifying the main message of the page. Lots of diagrams and photos are used to deliver the information to you.

30 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.

- Plant and algal cells containing chloroplasts and some bacteria use light from the Sun to power chemical reactions that build organic molecules. These can then be used to power other reactions in the cell or build macromolecules.
- Animals and other consumers 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, nitrate provides nitrogen, which is incorporated into amino acid molecules. Animals use these (by eating plants or plant tissues) to obtain building blocks for their proteins.
- Various metal ions are also needed. Some in relatively large amounts, e.g. Na<sup>+</sup> 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 vasodilation to allow heat to be radiated into the environment.

**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, you will need to apply an understanding of prior content to answer the questions.

1. Why must cells be able to remove wastes?

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

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66 Chapter Review: Did You Get It?

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

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

diffusion 110

osmosis

passive transport

2. The diagram shows a cell. Explain the following:

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

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

67 Synoptic Assessment: Module 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 discuss 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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More information about the tabs can be found on page viii

Prepare for tests and exams by using the in-built assessment tasks in the workbook.

**Chapter Review: Did You Get It?** activities at the end of each chapter will test how well you know the content of the chapter, and are a great way to improve scientific understanding and vocabulary.

**Synoptic Assessment** activities at the end of each module are more formal testing moments. These are good activities for preparing for tests and exams, and provide practise in writing longer, exam type answers.

# Using the Tab System

The tab system helps you identify important parts of the HSC Biology course (general capabilities, cross-curriculum priorities, and other curriculum learning areas). The tabs also allow you to see at a glance if online support is provided on BIOZONE's [Resource Hub](#), and if there are content links with other activities. A summary of the icon tabs is provided below.

General capabilities	
	<b>Critical &amp; creative thinking:</b> Develop critical and creative thinking skills through asking questions, making predictions, engaging in practical and secondary-sourced investigations, and analysing and evaluating evidence.
	<b>Ethical understanding:</b> Apply ethical values and principles to your studies and investigations. Understand the implications of these to others and the environment. Understand reasoning can assist making ethical judgements.
	<b>Information &amp; communication technology capability:</b> Use ICT to access information, collect, analyse, and represent data, model and interpret concepts and relationships, process information, and communicate ideas.
	<b>Intercultural understanding:</b> Appreciate and respect diverse cultures (yours and others) and understand how cultural perspectives have impacted the developments, breadth and diversity of scientific knowledge and applications.
	<b>Literacy:</b> Literacy is the ability to identify, understand, interpret, create and communicate effectively using written, visual, oral, and digital formats. Apply these skills to communicate scientific concepts and findings.
	<b>Numeracy:</b> Numeracy involves recognising and understanding the role of mathematics in the world. Develop numeracy skills through measuring, recording, representing, and analysing data.
	<b>Personal &amp; social capability:</b> Establish positive relationships, make responsible decisions, work effectively (alone and with others) and constructively handle challenging situations during your scientific endeavours.
Cross-curriculum priorities	
	<b>Aboriginal &amp; Torres Strait Islander histories &amp; cultures:</b> The traditional knowledge and cultural practices of Aboriginal & Torres Strait Islander peoples provide insight into how the environment and natural world work. Traditional knowledge and Western scientific knowledge can be used together in a complementary way.
	<b>Asia &amp; Australia's engagement with Asia:</b> The diverse environments of Australia and Asia provide opportunities to study interactions within and between the two environments, including how human activity influences the region, and the significance of these to the rest of the world.
	<b>Sustainability:</b> Sustainability is concerned with the ongoing capacity of the Earth to maintain all life. It provides contexts for exploring, investigating, and understanding the interrelatedness and sustainability of Earth's systems, including both natural and human-made environments.
Other learning across curriculum areas	
	<b>Civics &amp; citizenship:</b> Understand how civics, the understanding of Australian society, and citizenship can be applied to scientific ideas and technological advances.
	<b>Difference &amp; diversity:</b> Australian society is diverse in terms of gender, race, and socio-economic circumstances. Working collaboratively provides opportunities to develop an appreciation of the values and ideas of others.
	<b>Work &amp; enterprise:</b> Develop and use safe working practices. Identify risks and carry out hazard assessments when working in the laboratory or field.
Other tabs	
	Grey hub tabs indicate the activity is supported by content on BIOZONE's Resource Hub. See page ix for details about BIOZONE's Resource Hub.
	Green tabs show connections to related activities and content elsewhere in the book.
	Appendix 1: Glossary of key terms and their definitions
	Appendix 2: Equipment list for the practical investigations

# Using BIOZONE's Resource Hub

- ▶ **BIOZONE's Resource Hub** provides links to online content supporting the activities in the book. From this page, you can also check for any errata or clarifications to the book since printing.
- ▶ Many of these external websites are narrowly focused animations and video clips directly relevant to that part of the activity identified by the hub icon. There is also material for data exploration, source material for activities, and some fact sheets, as well as 3D models and spreadsheet models. The hub provides great support for your studies.



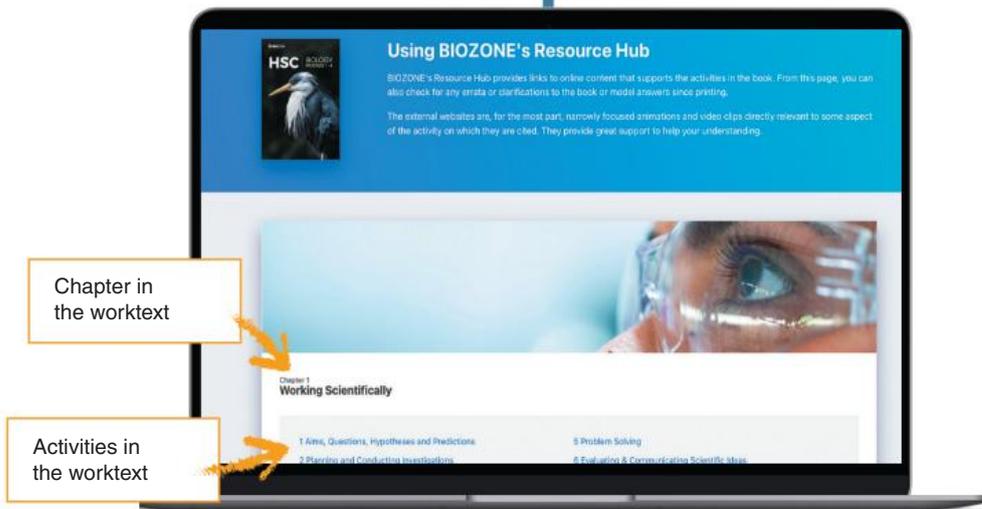
[www.BIOZONEhub.com](http://www.BIOZONEhub.com)

Then enter the code in the text field

**HSC11-1-6542**



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.

200

**Logistic growth**  
 $dN/dt = rN(K-N)$

The population tends to stabilize around carrying capacity ( $K$ ). Any fluctuations (like dashed lines) are caused by variations in the birth rate and death rate as a result of the population density slightly exceeding or falling below carrying capacity.

Carrying capacity ( $K$ )

Environmental resistance increases as the population approaches carrying capacity.

Early on, growth is exponential.

Lag phase

Time ( $t$ )

**Logistic growth**

Logistic growth is characterized by a brief, early phase of exponential growth, followed by a slowing in growth as the population reaches carrying capacity. Logistic growth produces a S-shaped (sigmoidal) growth curve. Populations may fluctuate around  $K$ , but these fluctuations tend to become less pronounced over time.

Logistic growth is expressed mathematically as:  $dN/dt = rN(K-N)$

**Logistic (S) curve**  
As  $N$  approaches  $K$ , the population encounters environmental resistance to growth. The population reaches equilibrium around  $K$ . This is the population size that can be supported by the environment.

Populations of large mammals (above) show logistic growth, and their populations exist at or near carrying capacity, which is usually determined by primary production (the amount of biomass produced by plants).

2. A population started with a total number of 100 individuals. Over the following year, population data were collected. Calculate birth rates, death rates, net migration rate, and rate of population change for the data below (as percentages):

(a) Births = 14: Birth rate = \_\_\_\_\_ (b) Net migration = +2: Net migration rate = \_\_\_\_\_

(c) Deaths = 20: Death rate = \_\_\_\_\_ (d) Rate of population change = \_\_\_\_\_

(e) State whether the population is increasing or declining: \_\_\_\_\_

3. (a) What are the features of exponential growth?  
\_\_\_\_\_

(b) Why don't populations continue to increase exponentially in an environment?  
\_\_\_\_\_

4. (a) Describe the features of logistic growth: \_\_\_\_\_

(b) What is environmental resistance and what role does it have in limiting population growth?  
\_\_\_\_\_

(c) Explain why a population might overshoot carrying capacity before stabilizing around carrying capacity:  
\_\_\_\_\_

5. What happens to population growth rate as  $K-N$  approaches 0?  
\_\_\_\_\_

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# Support for Depth Studies

During your HSC Biology course you will carry out depth studies. A depth study is when you choose an area of the syllabus you have enjoyed or found interesting, and explore it in more depth (you deepen your understanding of the topic).

There are lots of options for a depth study:

- Do you want to work alone or in a group?
- Do you want to carry out your own investigation (collect primary data) or analyse second hand data (someone else's research)?
- Do you want to do a research project, create a model, or carry out a practical investigation in the laboratory or field?



There are too many options for us to cover in this worktext, but we have provided some helpful information to help you make your depth study a success! Chapter 14 of this worktext provides you with information for choosing what type of depth study you want to do, it provides guidance on planning and carrying out the study, and also some tips on how to share your findings with others. Refer to these pages often as you plan and work on your depth study. Your teacher will also help you with your choice, and they will provide more information about what you need to do to meet the syllabus requirements for the depth study.

## Chapter 14 provides support to help you plan and carrying out your depth study

### Choosing your depth study

- What types of studies, projects, or investigations can be used for a depth study?
- What type of study is most appropriate for the topic I want to study?
- What are the differences between a primary practical investigation and a secondary-sourced investigation?



### Tips for planning your depth study

- What does the planning process look like?
- What do I need to think about when planning my depth study?
- What do I want to find out from my study?
- What type of data should I collect and how will I analyse it?
- What equipment will I need?
- How long will it take?

### Sharing your findings

- What communication style is best for my study?
- What style of communication do I prefer or feel confident with?
- How should I structure the way I deliver my findings?
- How do I acknowledge the work of others?

## Key terms

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

## Working scientifically skills

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

Activity  
number

### Questioning and predicting

- 1 Identify, develop, and construct questions and hypotheses for scientific investigation. Modify hypotheses based on new data and evidence. 1

### Planning investigations

- 2 Assess safety, risks, and ethical issues. Apply relevant occupational health and safety guidelines during practical work. Select appropriate methods and technologies for carrying out the investigation. 2 3
- 3 Identify experimental controls and variables and justify their use. Develop appropriate methodology to ensure a valid procedure. Adapt methodologies as required and record and justify these modifications. 2

### Conducting investigations

- 4 Demonstrate safe laboratory practices and risk management during an investigation. 3
- 5 Select and use appropriate equipment and technologies. Systematically generate and record primary data, and collate secondary data. Acknowledge secondary sources using accepted referencing. 2 208

### Processing data and information

- 6 Select and record qualitative and quantitative data. Represent data in a range of appropriate formats, and present them using appropriate digital technologies and/or media. 4
- 7 Apply appropriate quantitative processes to data. Evaluate the quality of collected data and improve where necessary. 4



### Analysing data and information

- 8 Identify trends and patterns in data. Recognise and assess errors and limitations of the data. 4
- 9 Assess the relevance, accuracy, validity, and reliability of both primary and secondary data. Suggest ways to improve or extend investigations. 4

### Problem solving

- 10 Model primary and secondary data to explain phenomena, make predictions and solve problems. Use scientific evidence and critical thinking to provide solutions and solve problems. 5

### Communicating

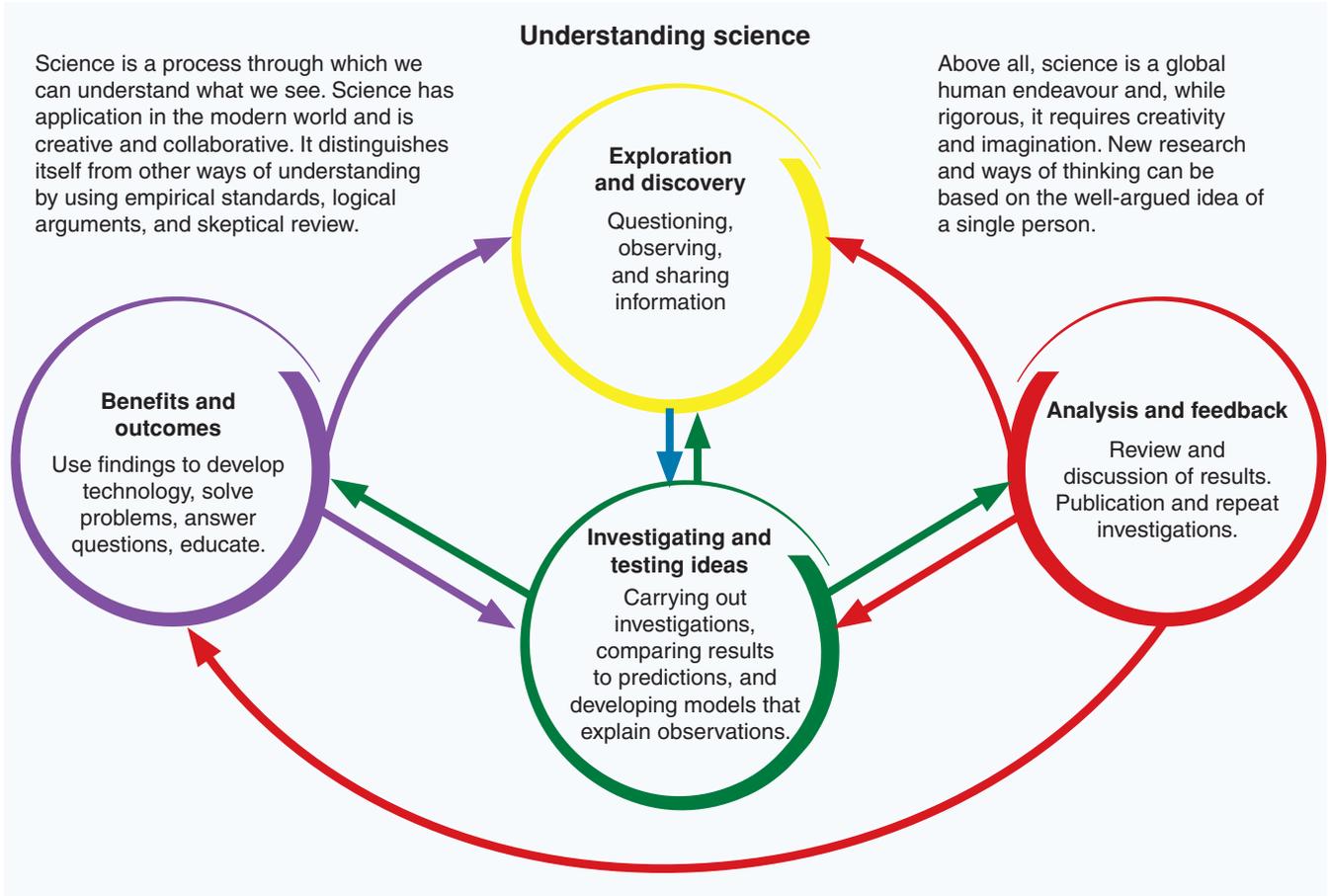
- 11 Select and use appropriate forms of communication including, digital, written, oral, and visual formats. 6 208
- 12 Use appropriate scientific notation and terminology when communicating scientific ideas. Construct evidence based arguments. Evaluate arguments and conclusions based on feedback. 6 208

# 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 refutable 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 disproved/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.



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.



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: \_\_\_\_\_  
 \_\_\_\_\_

## 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

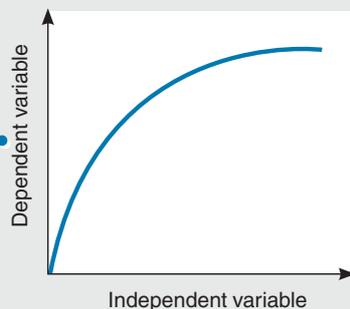
Analyse the data. Tables can summarise data. Graphs present the data to show patterns and trends. Statistical tests can determine the significance of results. Present your findings, e.g. as a poster, a digital presentation, or an oral report.

### 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 standard; any growth above that seen on the control plate is attributed to the nutrient.

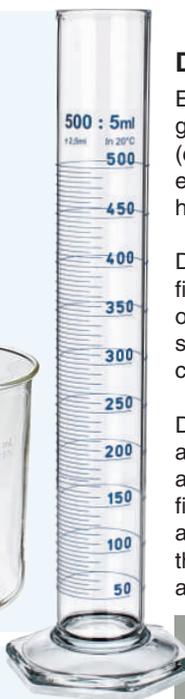


## Selecting the correct equipment

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.



## 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 positioned 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.

## 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:

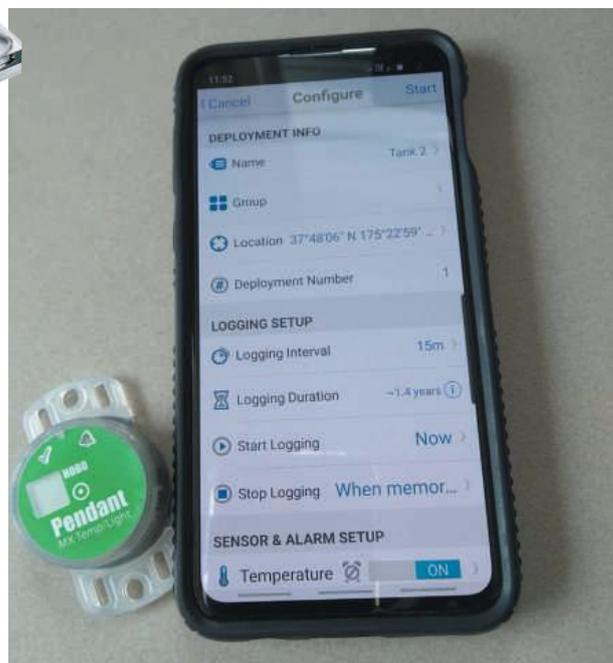
$$\frac{\text{experimental value} - \text{ideal value}}{\text{ideal value}} \times 100$$

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.

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

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



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. A researcher wanted to investigate the number of steps the students in a classroom did during their day at school. What piece of equipment would be useful for this investigation and how might the investigation be carried out?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

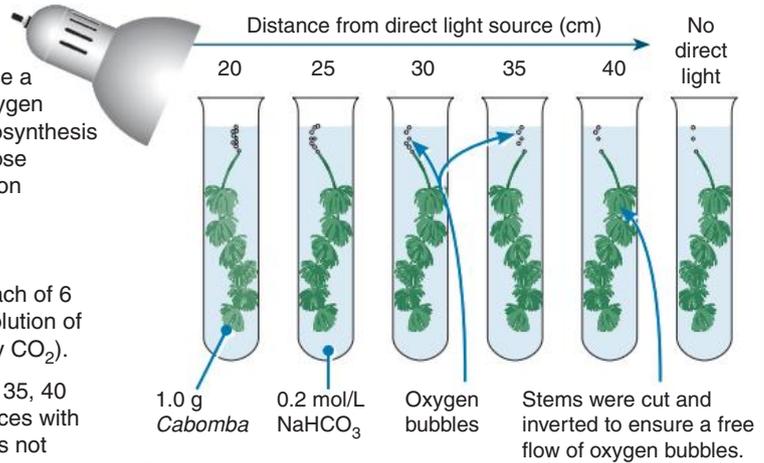
## Investigation: Effect of light on rate of photosynthesis

### 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.

### 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.



4. Write a suitable aim for this experiment: \_\_\_\_\_
5. Write a possible hypothesis for this experiment: \_\_\_\_\_
6. (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: \_\_\_\_\_
7. Some common lab equipment is shown in the table below. Which of the equipment would be best used in this investigation to measure the independent variable? Why?

### Common lab instruments and equipment in biology and their use

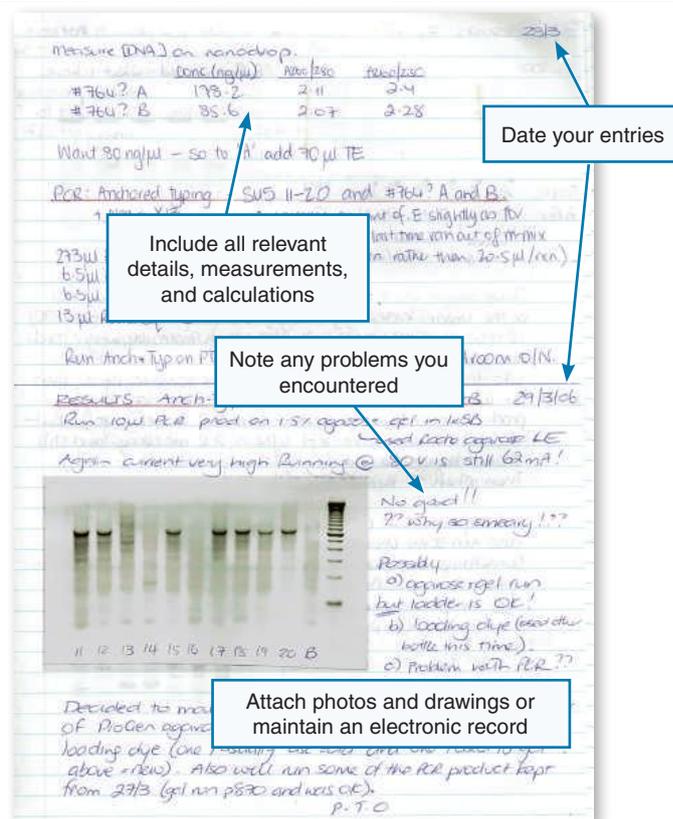
<b>Anemometer:</b> used to measure wind speed.	<b>Lux meter:</b> Measures the amount of light falling on a specified area.
<b>Balance</b> (triple beam or electronic): used to measure mass.	<b>pH meter:</b> used to measure acidity/alkalinity
<b>Clinometer:</b> Used to measure the angle of a slope.	<b>Thermometer:</b> used to measure temperature
<b>Colorimeters and spectrophotometers:</b> used to measure absorbance or determine concentration of a substance.	<b>Water baths:</b> maintain set temperature

8. (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? \_\_\_\_\_

## 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 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.



Date your entries

Include all relevant details, measurements, and calculations

Note any problems you encountered

Attach photos and drawings or maintain an electronic record

9. Which tube is the control for the experiment? \_\_\_\_\_

10. Identify two assumptions being made about the experiment on the previous page:

(a) \_\_\_\_\_

(b) \_\_\_\_\_

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

\_\_\_\_\_

12. How might you test the gas being produced is oxygen: \_\_\_\_\_

\_\_\_\_\_

13. Why is it important to keep a detailed logbook during a scientific investigation? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 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.

## Health 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.

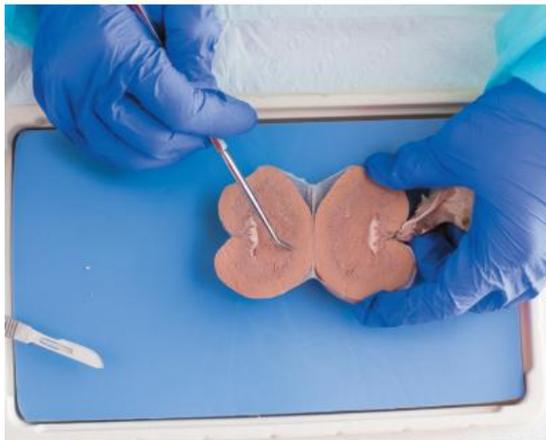
- ▶ **Chemical:** Chemicals could be ingested, absorbed through the skin, or inhaled. Examples include cleaning agents, disinfectants, and reagents (powdered and liquid). Some chemicals can cause fires or explosions if not handled correctly.
- ▶ **Biological:** All biological material should be treated 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.
- ▶ Keep workspaces and floors clean 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):

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---

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

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---



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 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 or 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 copy directly from sources. Representing the work of others as your own is plagiarism.



Take care to maintain 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: \_\_\_\_\_

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

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(c) Guessing or making up values in a set of experimental measurements because you missed a day of recordings: \_\_\_\_\_

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

(a) \_\_\_\_\_

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(b) \_\_\_\_\_

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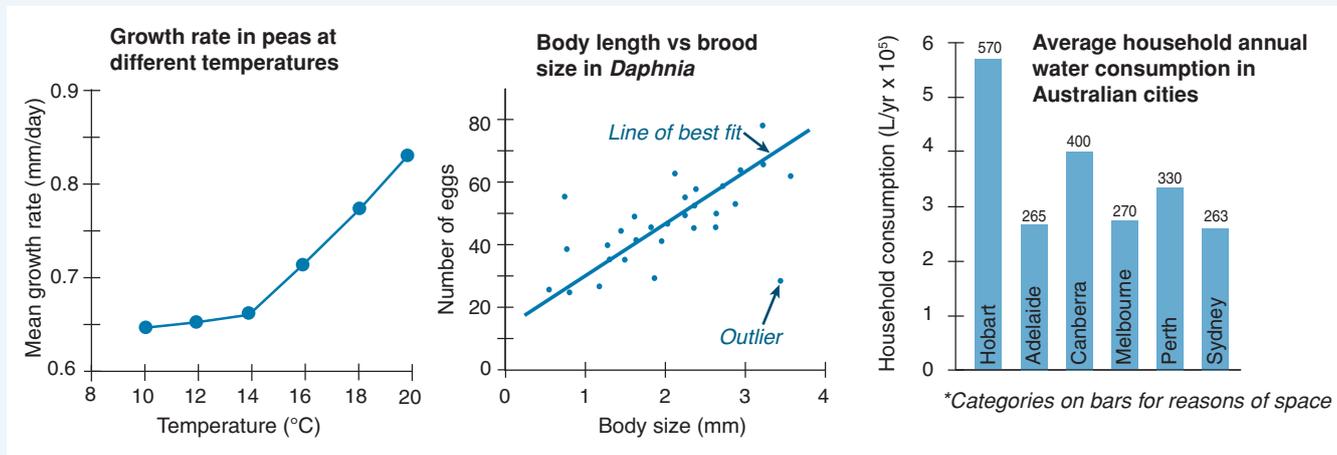


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### Presenting data in graphs

- ▶ 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 included 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 line 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 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.

4. 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.

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

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

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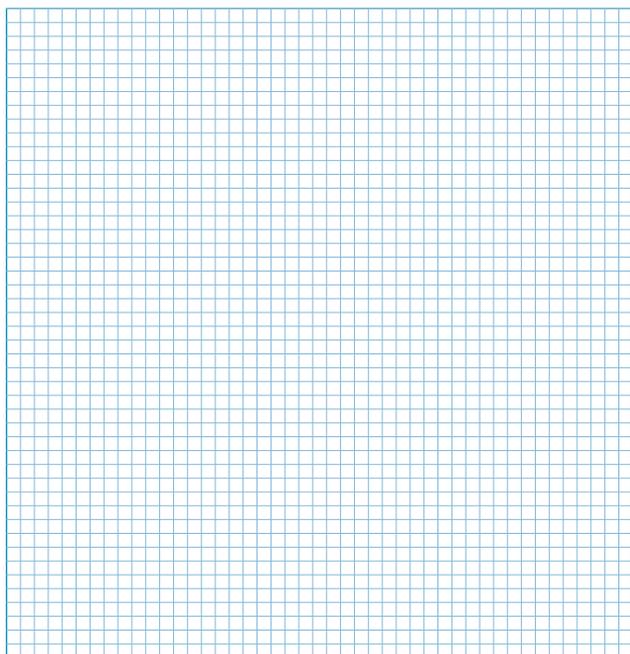
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(b) The total mass calculated for fertiliser concentration 0.24 g/L excludes sample #1 and the mean is calculated from 4 values. Explain why:

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## Analysing data

The analysis 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<sup>3</sup> are equivalent, as are L and dm<sup>3</sup>.

7. Convert 5.6 cm<sup>3</sup> to mm<sup>3</sup> (1 cm<sup>3</sup> = 1000 mm<sup>3</sup>):

---

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<sup>3</sup>, dm<sup>3</sup>, 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<sup>3</sup>g<sup>-1</sup>s<sup>-1</sup> using inverse notation or cm<sup>3</sup>/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:

8. 43.2 x 1044: \_\_\_\_\_

9. 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 <sup>3</sup> )	Rate of reaction (cm <sup>3</sup> /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<sup>3</sup> - 34 cm<sup>3</sup> = 8 cm<sup>3</sup>

Rate of reaction between 2-4 min: 8 ÷ 2 min = 4 cm<sup>3</sup>/min

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

Time (min)	Pipette reading (cm <sup>3</sup> )	Water loss (cm <sup>3</sup> /min)
0	9.0	—
5	8.0	0.2
10	7.2	
15	6.2	
20	4.9	

### Fractions

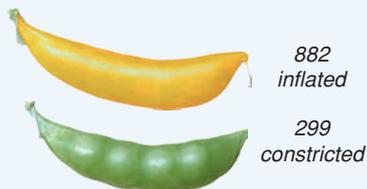
Fractions express how many parts of a whole are present. They are expressed as two numbers separated by a solidus (/) (e.g. 1/2). The top number is the numerator. The bottom number is the denominator, which cannot be zero. Fractions are written in their simplest form, while still being whole numbers.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

**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  $2/5 = 0.4 \times 100 = 40\%$
- ▶ 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 <sup>3</sup> )	Volume of water (cm <sup>3</sup> )	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?

$$160 - 116 \div 116 = 0.275$$

$$0.275 \times 100 = 27.5\% \text{ increase.}$$



11. (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):

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

(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.

12. Simplify the following fractions:

- (a) 3/9: \_\_\_\_\_ (b) 84/90: \_\_\_\_\_ (c) 11/121: \_\_\_\_\_

13. (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:

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

(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?

\_\_\_\_\_

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



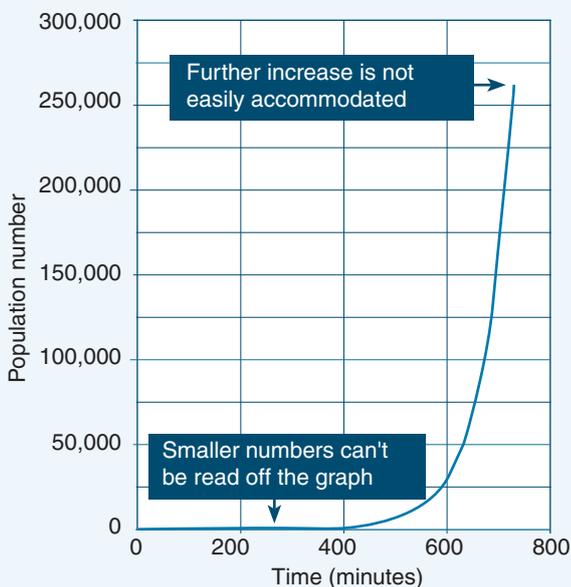
Clover plant type	Frost free area		Frost prone area		Totals
	Number	%	Number	%	
Cyanogenic	124	78	26		
Acyanogenic	35		115		
Total	159				

**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**

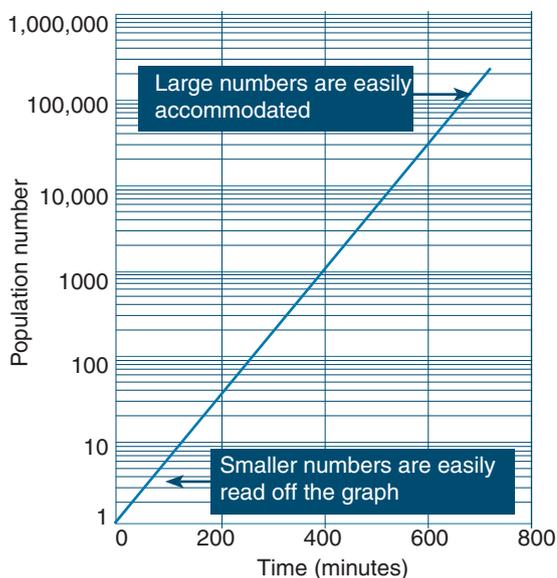
- ▶ Exponential growth occurs at an increasingly rapid rate in proportion to the growing total number or size.
- ▶ In an exponential function, the base number is fixed (constant) and the exponent is variable.
- ▶ The equation for an exponential function is  $y = c^x$ .
- ▶ Exponential growth and decay (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.



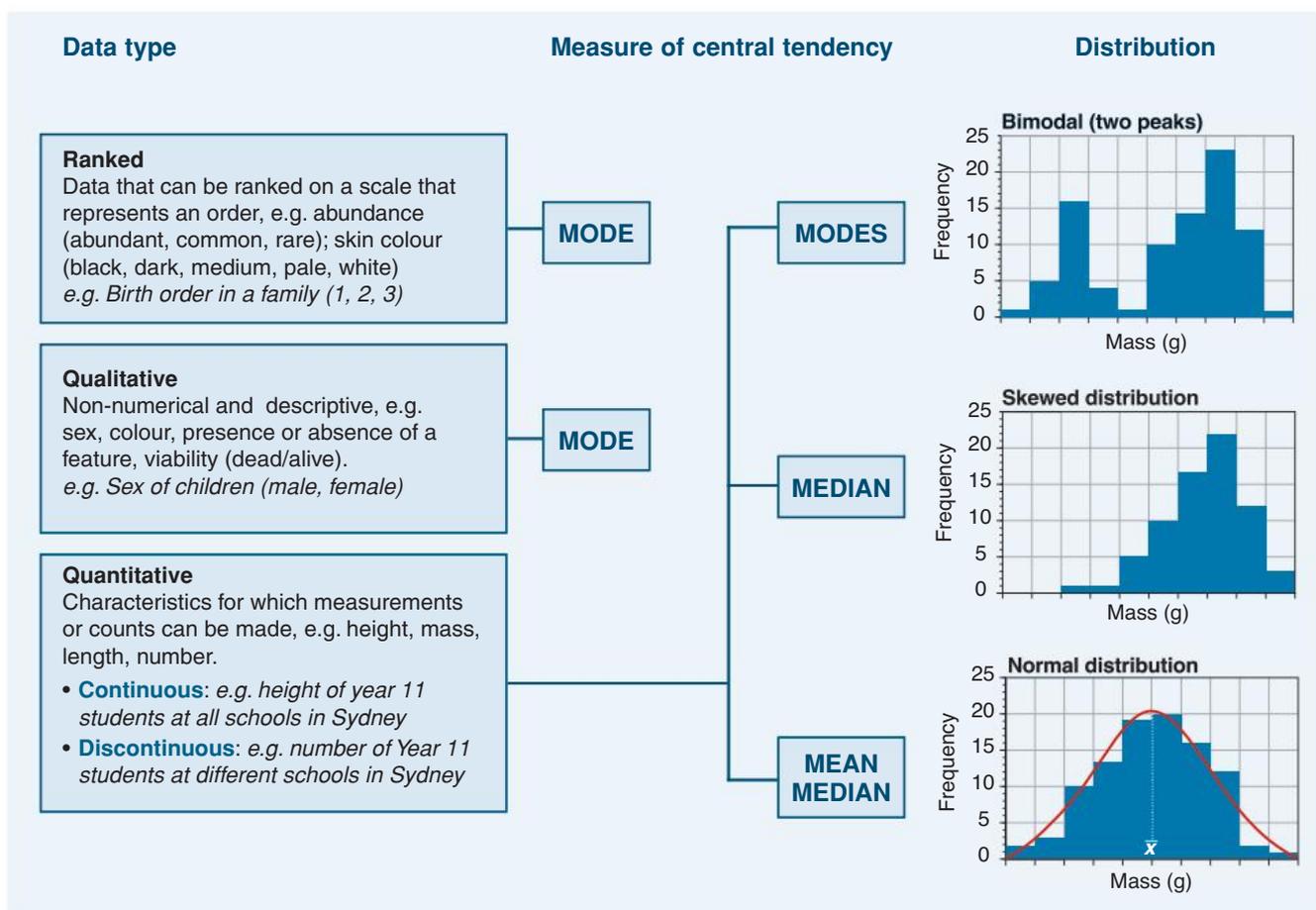
**Example:** The same yeast cell growth plotted on a log-linear scale. The y axis present 6 exponential cycles

15. Why is it useful to plot exponential growth using semi-log paper? \_\_\_\_\_

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

### 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 NSW, or from a sample, e.g. mean condition score of koalas in the Clarence Valley. 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).



17. 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:

\_\_\_\_\_

\_\_\_\_\_

### 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).
- ▶ **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.

sagrl, 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 demonstrates 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.

pH meter

Calipers

*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.*

18. 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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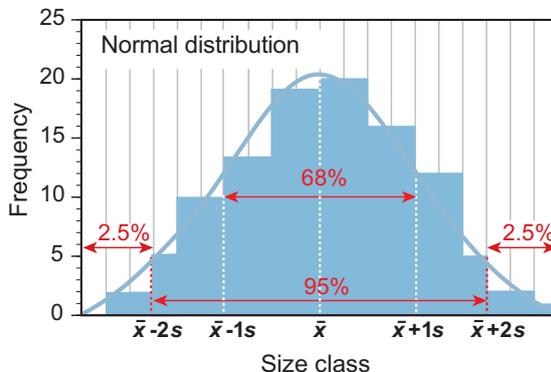
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### Expressing confidence in your data

- ▶ 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

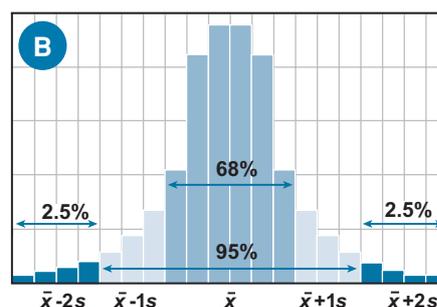
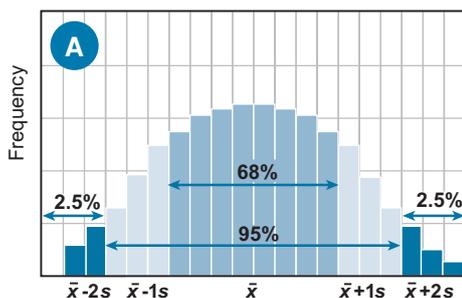
$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

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

$n$  = sample size.

$n - 1$  provides an 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.



19. 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?

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

- Calculate the mean for the data: \_\_\_\_\_
- Use manual calculation, a calculator, or a spreadsheet to calculate the standard deviation ( $s$ ) for the data:  
\_\_\_\_\_
- State the mean  $\pm 1s$ : \_\_\_\_\_
- What percentage of values are within  $1s$  of the mean? \_\_\_\_\_
- 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	



# 5

## Problem Solving

**Key Idea:** Solving problems may require modelling in the form of physical or mathematical models.

Solving problems is an important part of science and biology. These problems may be large and complex, e.g. what is the best way to conserve wildlife within a particular area of habitat? Or they can be simpler, e.g. what is the most efficient and accurate way to measure 50 mL of water? To help solve

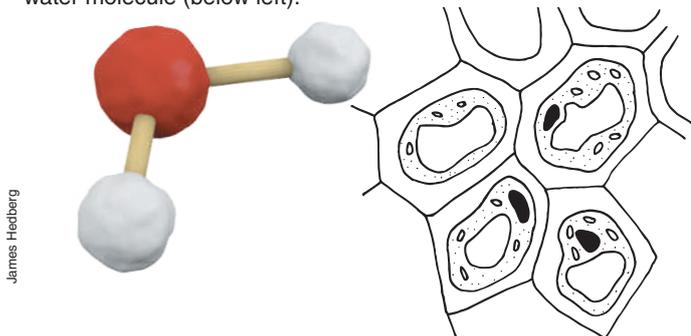
these problems evidence in the form of data might need to be gathered. Modelling the data in some way could provide a better understanding of the problem and so provide the best answer. Models are a representation of a system being studied. They can be simple e.g. a ball and stick model of an oxygen molecule, or they can be complex, e.g. modelling the interactions of organisms in an ecosystem.

### Modelling data

There are many different ways to model data. Often seeing data presented in different ways can help us to understand it better. Some common examples of models are shown here.

### Visual models

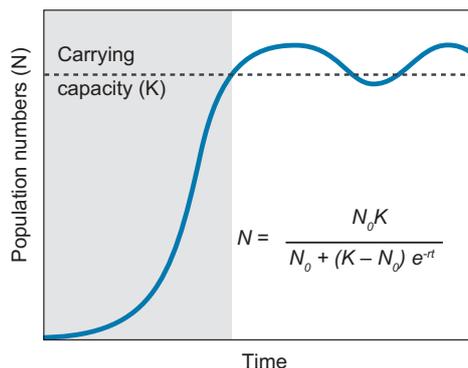
Visual models can include drawings, such as these plant cells (below right) or three dimensional physical or computer generated models. Three dimensional models can be made out of materials such as modelling clay and ice-cream sticks, like the model of a water molecule (below left).



James Hechberg

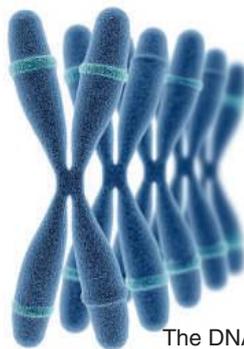
### Mathematical models

Displaying data in a graph or as a mathematical equation, as shown below for logistic growth, often helps us to see relationships between different parts of a system.



### Analogy

An analogy is a comparison between two things. Comparing a biological system to an everyday object can sometimes help us to understand it better. For example, the heart pumps blood in blood vessels in much the same way a fire truck pumps water from a fire hydrant through a hose. Similarly, the DNA in chromosomes is like a library. Extending that analogy further, the steps in baking a cake from a recipe book provide an analogy for how the instructions in DNA (the recipe) are translated into a specific protein (the cake).



The DNA in chromosomes is like ..... a library of books

1. (a) What is a model? \_\_\_\_\_

\_\_\_\_\_

(b) Why do scientists often study one part of a system rather than the whole system? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. Climate change is one of the major problems facing the environment today and in the future. Climate change models developed over the last few decades include many inputs that influence the climate, such as the amount of carbon dioxide produced by industry each year. How do climate change models help us predict future effects of various human activities and therefore help us solve the problem of climate change?

\_\_\_\_\_

\_\_\_\_\_

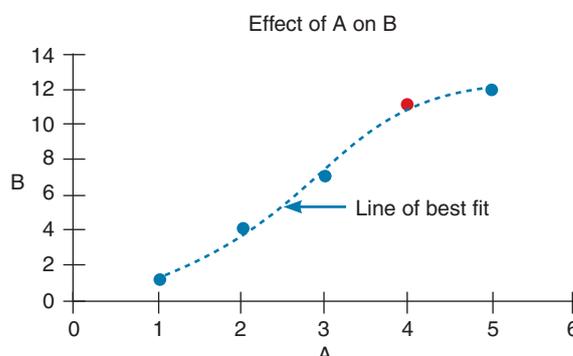
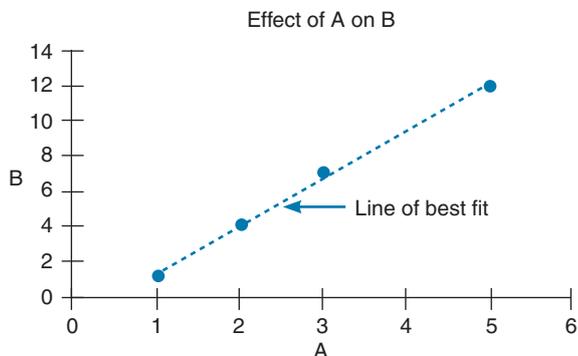
\_\_\_\_\_

\_\_\_\_\_

### Using models to predict outcomes

- ▶ Gathered data and observations of a phenomenon can be used to produce a model of the system. The model is then tested to see if it predicts real world outcomes. If the model is correct its prediction should match observed results in the real world. If not the model will need to be reworked.
- ▶ Consider the data in the table right. It shows the value of the dependent variable B when the independent variable A is set at various levels. One of the data points was missed out.

A	B
1	1
2	4
3	7
4	–
5	12



- ▶ The data can be plotted on a graph. The straight line shows the line of best fit. It follows the equation  $B = 2.74A - 1.54$
- ▶ Because the line of best fit passes very close to all four points we could say the relationship between A and B is modelled by the equation  $B = 2.74A - 1.54$ .
- ▶ If the equation is used to predict B when A is 4 the answer is 9 (in whole numbers).
- ▶ A new observation finds that in fact when A is 4, B is 11. This falls an unexpected distance from the line of best fit. A new equation is needed.
- ▶ In this case the data is now more closely modelled by the equation  $B = -0.25A^3 + 2.04A^2 - 1.71A + 1$ .

3. The equation  $6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$  models the overall process of photosynthesis. Photosynthesis is, of course, the process by which plants harness light energy to produce organic molecules which allows them to grow. How to grow more productive crops has been a problem for farmers since farming first began. By modelling photosynthesis as a simple chemical equation it is possible to see solutions to this problem.

(a) Water is usually abundant in a plant and so does not usually affect the rate of photosynthesis. From the model, which two other factors might be important for increasing the rate of photosynthesis in a plant?

---

(b) Growing crops in glasshouses allows farmers to increase supply of the two factors in 3 (a). How might they do this?

---



---



---

4. Modelling the spread of an infectious disease (e.g. Covid-19) helps medical planners to produce methods to actually stop or control a disease's spread if it gets into the community. How infectious a disease is and to how many people it may spread from an infected person is an important part of any model.

(a) If an infectious person infects two other people (and then recovers) how many people will be infected after five cycles of infections?

---

(b) How many people in total (recovered and infected) will have been infected after five cycles of infection?

---

(c) What kind of growth pattern would fit this model of infection? \_\_\_\_\_

(d) In numerical terms, to reduce the spread of an infectious disease what must happen to the number of infections per infectious person per infection cycle?

---



---

## 6 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 the 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.
- ▶ 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.
    - Is the information 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 advisors.



- ▶ 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.



### 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 of one person's blog: \_\_\_\_\_

---

# 7

## 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 cities: \_\_\_\_\_

(e) Mean catalase reaction rate at different temperatures: \_\_\_\_\_

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

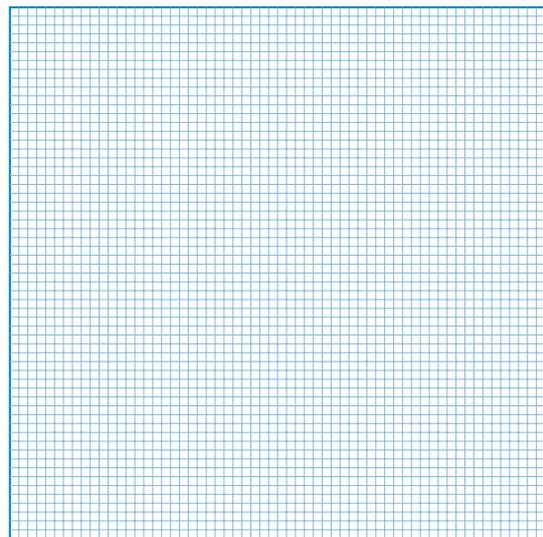
(g) Mean monthly rainfall vs mean monthly temperature: \_\_\_\_\_

3. 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<sup>3</sup>/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 <sup>3</sup> )	Rate of sweat loss (cm <sup>3</sup> /min)
0	0	
10	50	
20	130	
30	220	
60	560	



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

---



---



---



---

4. 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? \_\_\_\_\_

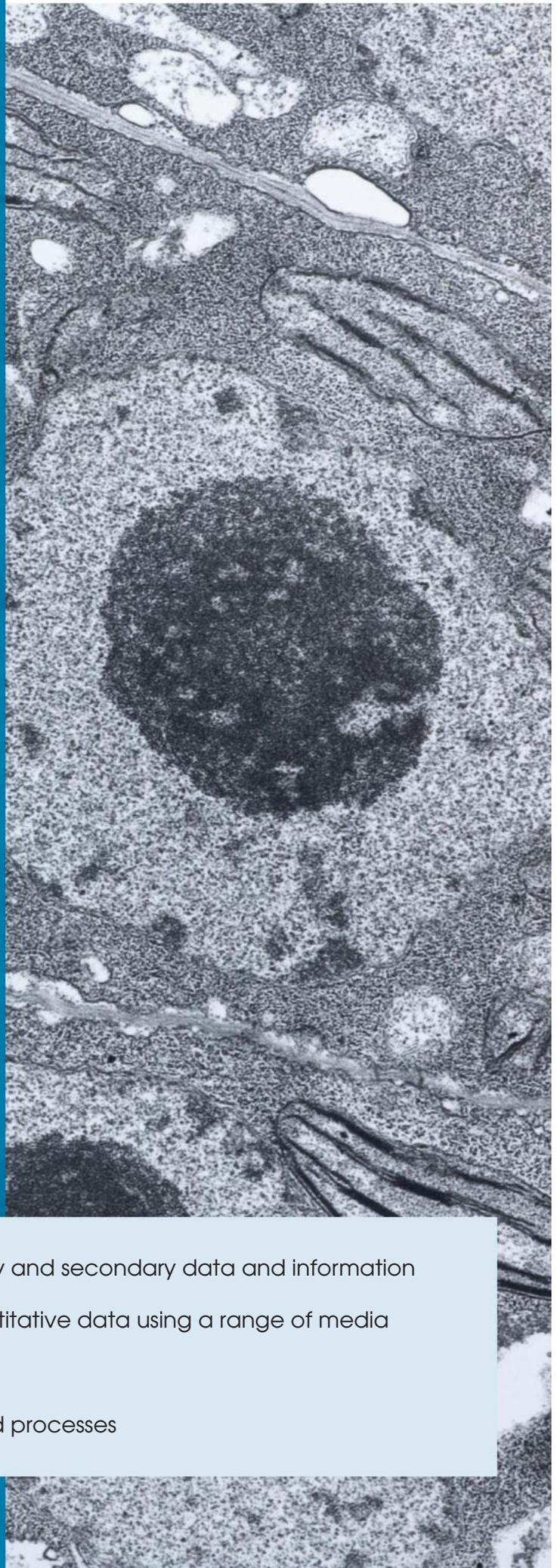
(d) The student had some outlier values in each of their treatments and wanted to repeat the investigation. Briefly describe two ways they could increase the validity of their findings, assuming plentiful resources and time:

---

MODULE

# 01

Cells as the basis of life



## Student outcomes:

- ▶ Carry out investigations to collect primary and secondary data and information
- ▶ Select and process qualitative and quantitative data using a range of media
- ▶ Describe cell structure and function
- ▶ Analyse and explain cellular features and processes

# Cell Structure

Activity  
number

## Key terms

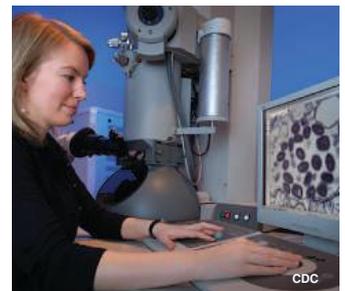
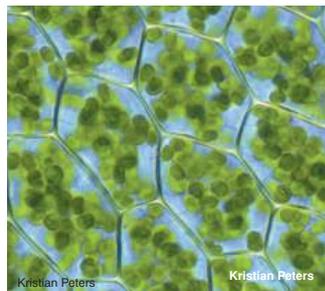
cell wall  
chloroplast  
cytoplasm  
eukaryote  
light microscope  
magnification  
mitochondrion  
nucleus  
organelle  
phospholipid  
plasma membrane  
prokaryote  
resolution

*Inquiry question: What distinguishes one cell from another?*

## Cellular structure

### Key skills and knowledge

- |                          |   |   |       |
|--------------------------|---|---|-------|
| <input type="checkbox"/> | 1 | Recognise cells as the basic unit of life on Earth and outline the basic principles of the cell theory.   | 8     |
| <input type="checkbox"/> | 2 | Explore the range of cell sizes and cellular variation. Express cell sizes in different units of measurement.   | 9 10  |
| <input type="checkbox"/> | 3 | Describe the distinguishing features of prokaryotic cells, including small size (relative to eukaryotic cells), lack of a nucleus and membrane-bound organelles, and the presence of a single, circular chromosome. Recognise that prokaryotes usually exist as single cells but may form colonies, with some specialisation of function. | 11    |
| <input type="checkbox"/> | 4 | 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.  | 12-15 |
| <input type="checkbox"/> | 5 | Describe the specialisations of plant and animal cellular organelles for specific functions.  |       |



## Investigating cells

### Key skills and knowledge

- |                          |    |  |       |
|--------------------------|----|--|-------|
| <input type="checkbox"/> | 6  | Understand the structure and basic principles of light (optical) microscopes. Explore the technology behind electron microscopes. Contrast light and electron microscopy in terms of magnification and resolution. | 16 18 |
| <input type="checkbox"/> | 7  | <b>PRAC</b> Construct a wet mount for viewing with a light microscope. Use a light microscope to locate prepared material and focus images.  | 17    |
| <input type="checkbox"/> | 8  | Calculate magnification and/or length of given images and in field of view of a light microscope.  | 19    |
| <input type="checkbox"/> | 9  | <b>PRAC</b> Draw scaled diagrams of a variety of cells including visible organelles as viewed under a microscope.  | 21    |
| <input type="checkbox"/> | 10 | Compare and contrast organelles and their function in different cells. Explain the reasons for the presence or absence of organelles in different cell types.  | 22 23 |

## The plasma membrane

### Key skills and knowledge

- |                          |    |   |       |
|--------------------------|----|---|-------|
| <input type="checkbox"/> | 11 | 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. | 24-26 |
| <input type="checkbox"/> | 12 | Describe technologies that helped develop the fluid mosaic model of the plasma membrane.  | 27    |
| <input type="checkbox"/> | 13 | Build a model of the plasma membrane to better understand its three dimensional nature.   | 28    |

# 8 The Cell is the Unit of Life

**Key Idea:** All living organisms are made 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 made 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

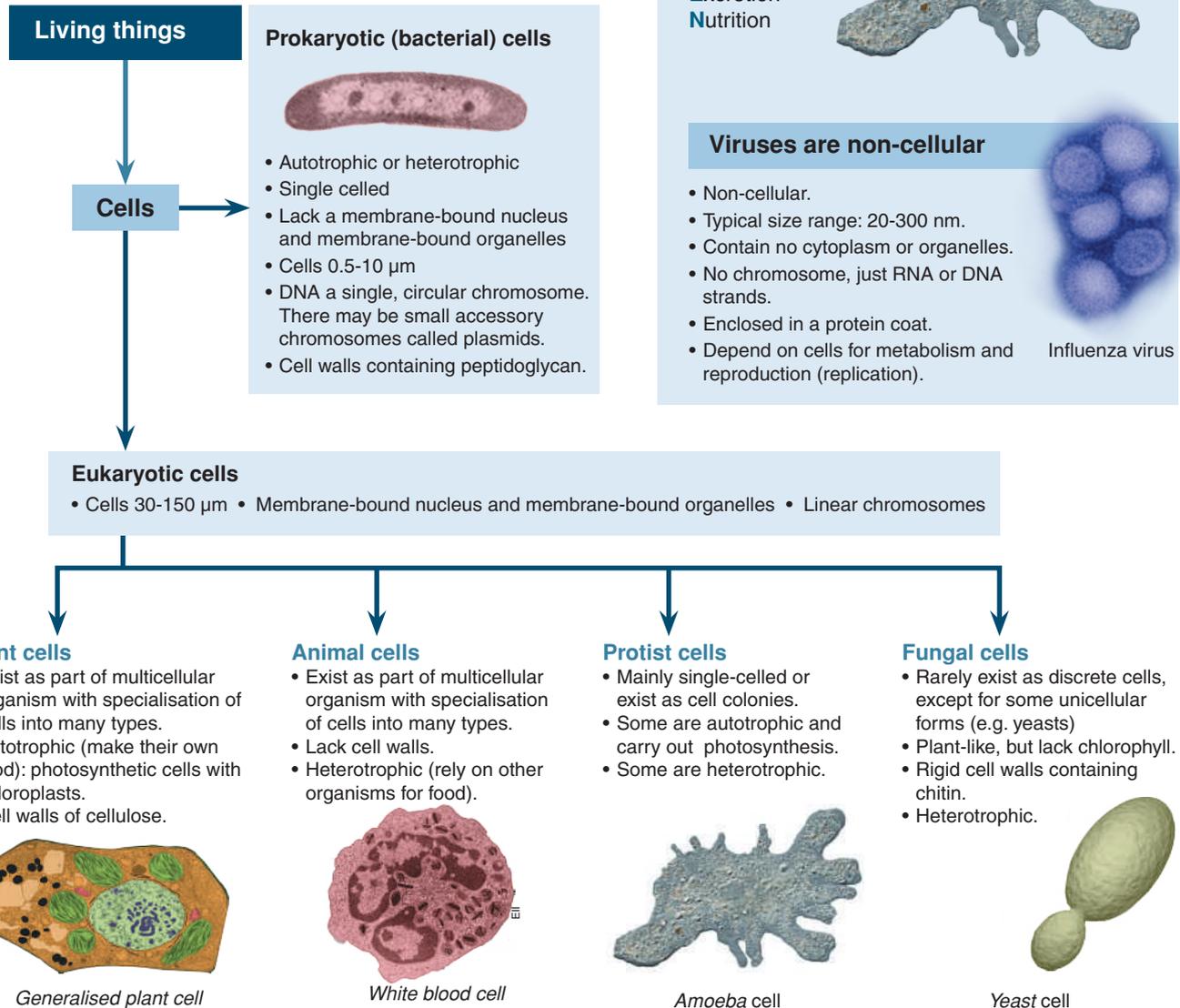
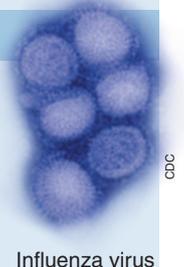
Cells use food (e.g. glucose) to maintain a stable internal environment, grow, reproduce, and produce wastes. The sum total of all the chemical reactions that sustain life is called metabolism.

- 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).



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)? \_\_\_\_\_

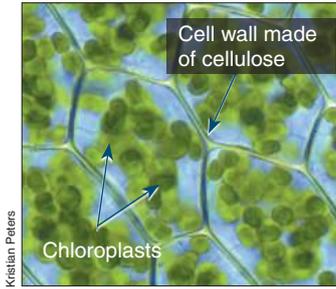


# 9 Types of Cells

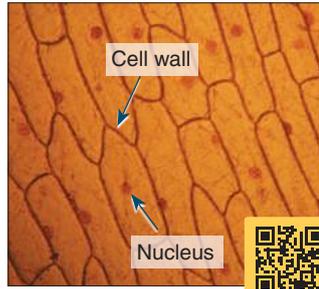
**Key Idea:** Cells come in a wide range of shapes and sizes. In multicellular organisms, cells are adapted for a specific role. Cells come in a wide range of types and forms. The images

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.

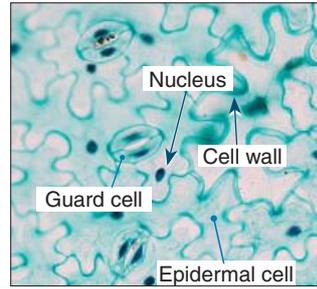
## Plant cells



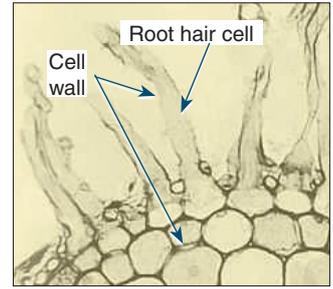
Palisade mesophyll cells



Epidermal cell

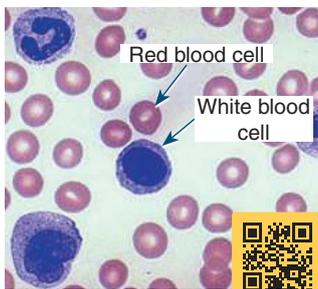


Guard cells and epidermal cells

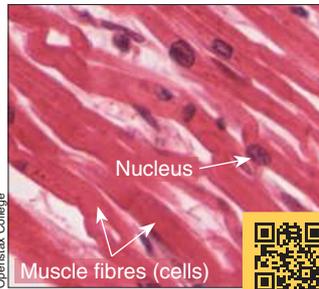


Root hair cell

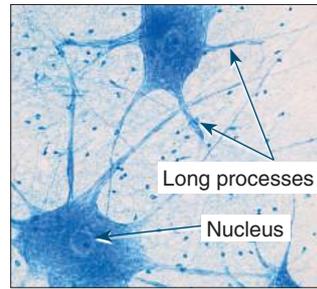
## Animal cells



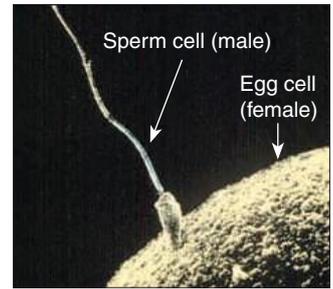
Blood cells



Muscle cells

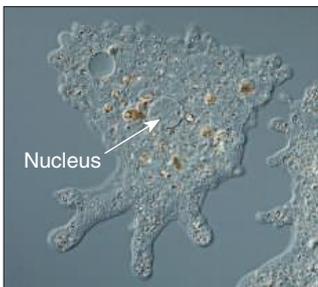


Nerve cells (neurons)

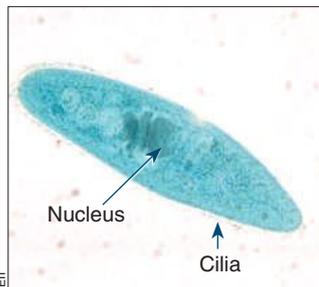


Reproductive cells

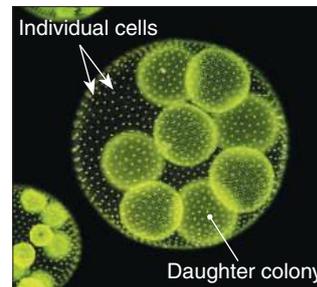
## Protists (single cells or colonies)



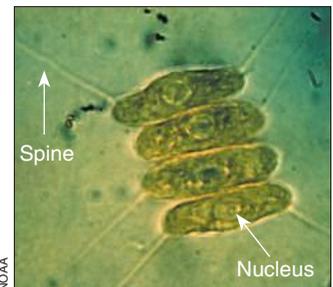
Amoeba



Paramecium

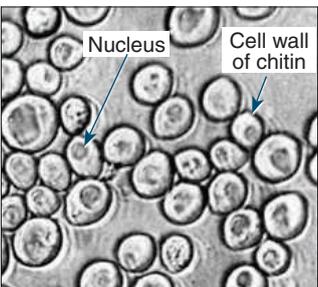


Volvox colony

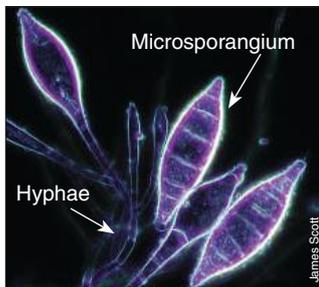


Scenedesmus colony

## Fungal cells

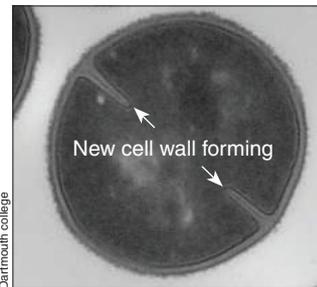


Yeast cells (*Saccharomyces*)

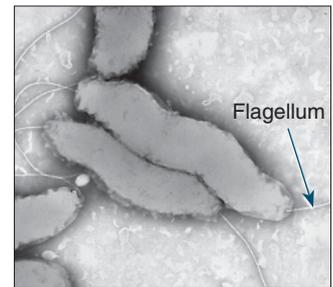


Microsporium cells

## 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? \_\_\_\_\_



# 10 Cell Sizes

**Key Idea:** Cells vary in size (2-100  $\mu\text{m}$ ), 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.

**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 ( $\mu\text{m}$ )	$10^{-6}$ 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.

**3  $\mu\text{m}$**   
SEM of *Giardia*, a protozoan that infects the small intestines of many vertebrate groups.

**50  $\mu\text{m}$**   
*Paramecium* is a protozoan commonly found in ponds.

**10  $\mu\text{m}$**   
*Salmonella* is a bacterium found in many environments and causes food poisoning in humans.

**100  $\mu\text{m}$**   
Onion epidermal cells: the nucleus (n) is just visible.

**50  $\mu\text{m}$**   
*Elodea* is an aquatic plant. In these leaf cells, the chloroplasts (c) can be seen around the inner edge of the cells.

**10 nm**  
*Coronavirus* is the virus responsible for Covid-19.

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  $\mu\text{m}$  and mm. Attach your working:

- (a) *Daphnia*: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (b) *Giardia*: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (c) Nucleus \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (d) *Elodea* leaf cell: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (e) Chloroplast: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (f) *Paramecium*: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (g) *Salmonella*: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm
- (h) *Coronavirus*: \_\_\_\_\_  $\mu\text{m}$  \_\_\_\_\_ mm

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



# 11 Prokaryotic Cells

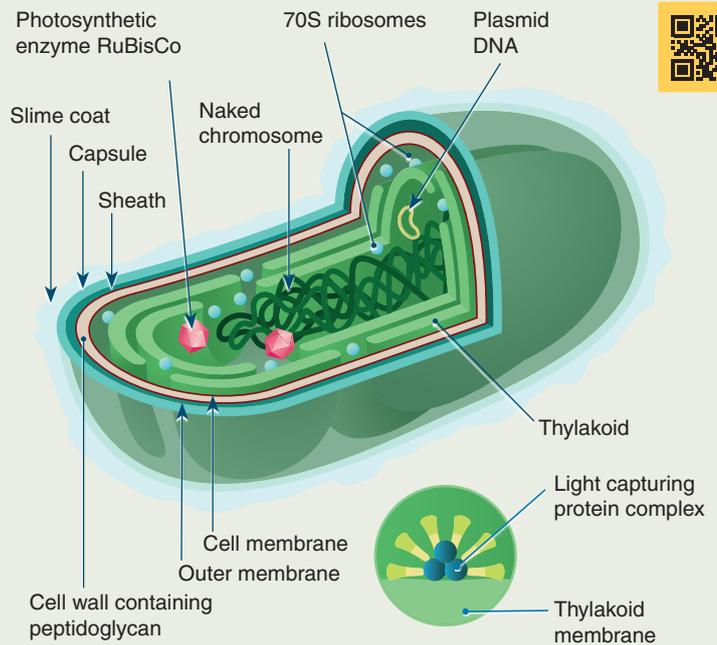
**Key Idea:** Prokaryotes are unicellular and have a relatively simple internal structure.

Prokaryotes include the groups Bacteria and Archaea. They are much smaller and simpler than the cells of eukaryotes

and lack distinct nucleus and membrane-bound cellular organelles. Despite their simplicity compared to eukaryotes, prokaryotes are extremely diverse and can be found living in some of the most extreme environments on Earth.

## Prokaryotic cells

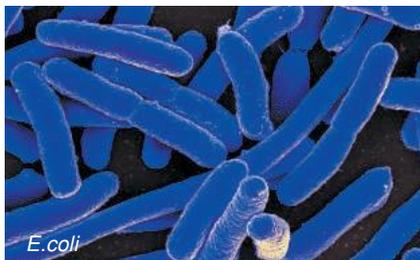
- ▶ Prokaryotic cells are small (~0.5-10 μm) single cells. They lack any membrane-bound organelles.
- ▶ They are relatively unstructured with little cellular organisation. Their DNA, ribosomes, and enzymes are free floating within the cell's cytoplasm. The ribosomes (70S) are smaller than eukaryotic ribosomes.
- ▶ They have a single, circular chromosome of naked DNA (not associated with protein). They commonly have small, circular accessory chromosomes called plasmids.
- ▶ Photosynthetic bacteria have enzymes and light capturing membranes like those in eukaryotic chloroplasts.
- ▶ Prokaryotes have cell walls, but they are different in composition to the cell walls of eukaryotes.
- ▶ Examples of bacterial cells include the gut bacterium *Escherichia coli* and the cyanobacterium *Anabaena*.



Structural features of a cyanobacterium

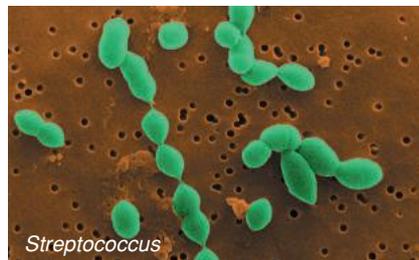
## Bacterial cell shapes

In terms of their appearance, there are only a few basic shapes found (shown below). The way in which members group together after division is often helpful in identifying certain species.

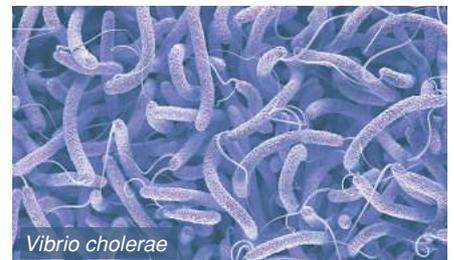


NIAID

**Bacilli:** Rod-shaped bacteria that divide only across their short axis. Most occur as single rods, although pairs and chains are also found.



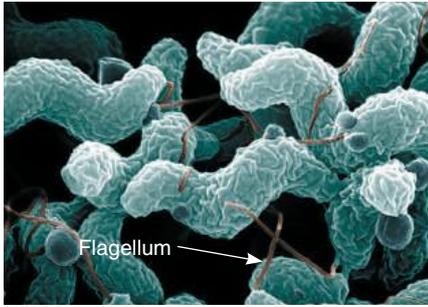
**Cocci:** usually round, but sometimes oval or elongated. When they divide, the cells stay attached to each other and may remain as pairs or clusters.



**Spirilla and vibrio:** Bacteria with one or more twists. Spirilla bacteria have a helical (corkscrew) shape. Bacteria that look like curved rods (comma shaped) are called vibrios.

1. Identify three distinguishing features of prokaryotes: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Cyanobacterial cells (shown top) are photosynthetic. Describe features that enable them to capture and store energy:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

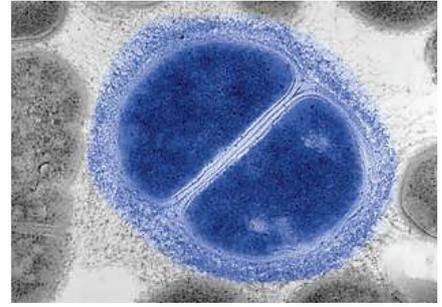


USDA

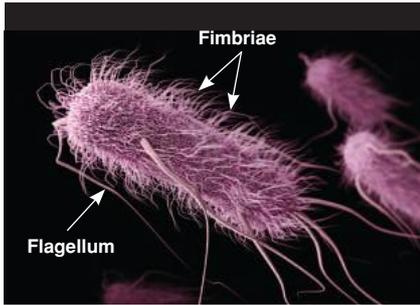
*Campylobacter jejuni* is a spiral bacterium responsible for foodborne intestinal disease. Note the single flagellum at each end for movement.



*Helicobacter pylori* is a comma-shaped vibrio bacterium that causes stomach ulcers in humans. This bacterium moves by means of multiple flagella.

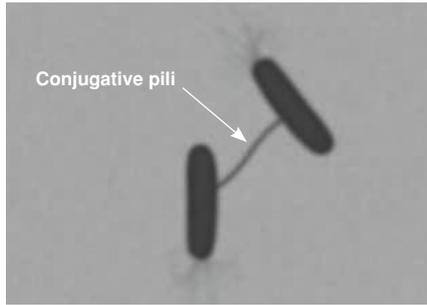


Bacteria usually divide by binary fission. During this process, DNA is copied and the cell splits into two cells, as seen in these gram positive cocci.

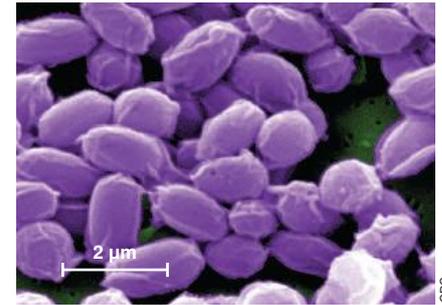


CDC

Some bacteria, such as *Escherichia coli*, a common gut bacterium (above), are covered with fimbriae which help it stick to surfaces (such as the gut wall). The flagellum helps it move about.



Bacteria are able to exchange genetic material via conjugative pili. The process, called conjugation, transfers plasmid DNA from one bacteria to another. This can help pass on useful genetic traits.



CDC

The Scanning electron micrograph above shows endospores of *Bacillus anthracis* bacteria, which cause the disease anthrax. These heat-resistant spores can survive for many years and enable the bacteria to survive in a dormant state.

3. (a) Describe the function of flagella in bacteria: \_\_\_\_\_

\_\_\_\_\_

(b) Explain how fimbriae differ structurally and functionally from flagella: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. (a) Describe the main method by which bacteria reproduce: \_\_\_\_\_

\_\_\_\_\_

(b) Explain how conjugation differs from this usual method: \_\_\_\_\_

\_\_\_\_\_

5. What shape would you expect the following bacteria to be?

(a) *Staphylococcus aureus*: \_\_\_\_\_

(b) *Bacillus cereus*: \_\_\_\_\_

(c) *Spirillum volutans*: \_\_\_\_\_

6. Bacteria are extremely useful for human purposes and are used in a wide range of industries. Using the links in **BIOZONE's Resource Hub** or your own, find an industry where bacteria are used and give a brief description of how the bacteria is used:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 12 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 (Activity 14). The plant cells activity provides further information on the organelles listed here but not described.

**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.

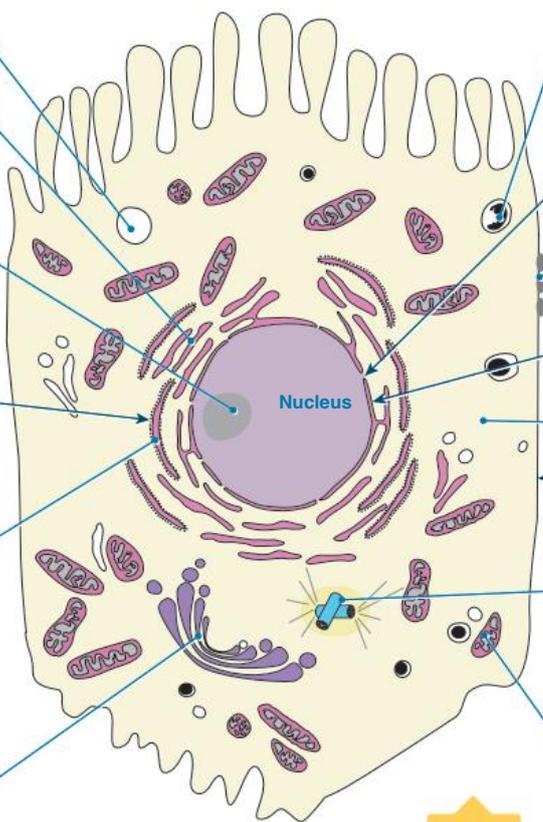
**Nucleolus:** A dense, solid structure composed of crystalline protein and nucleic acid. They are involved in ribosome synthesis.

**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.

## Generalised animal cell



**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  $\mu\text{m}$  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.

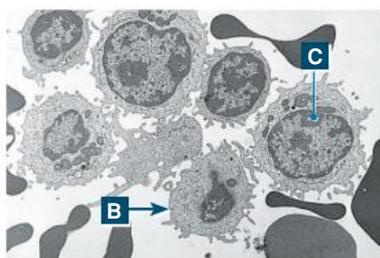


1. What is the difference between vacuoles in plant and animal cells? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. Name one structure or organelle present in generalised animal cells but absent from plant cells and describe its function:  
 \_\_\_\_\_  
 \_\_\_\_\_



Photos: ELL

Nerve cells in the spinal cord



White blood cells and red blood cells

3. The two photomicrographs below left show several types of animal cells. Identify the features indicated by the letters A-C:  
 (a) \_\_\_\_\_  
 (b) \_\_\_\_\_  
 (c) \_\_\_\_\_

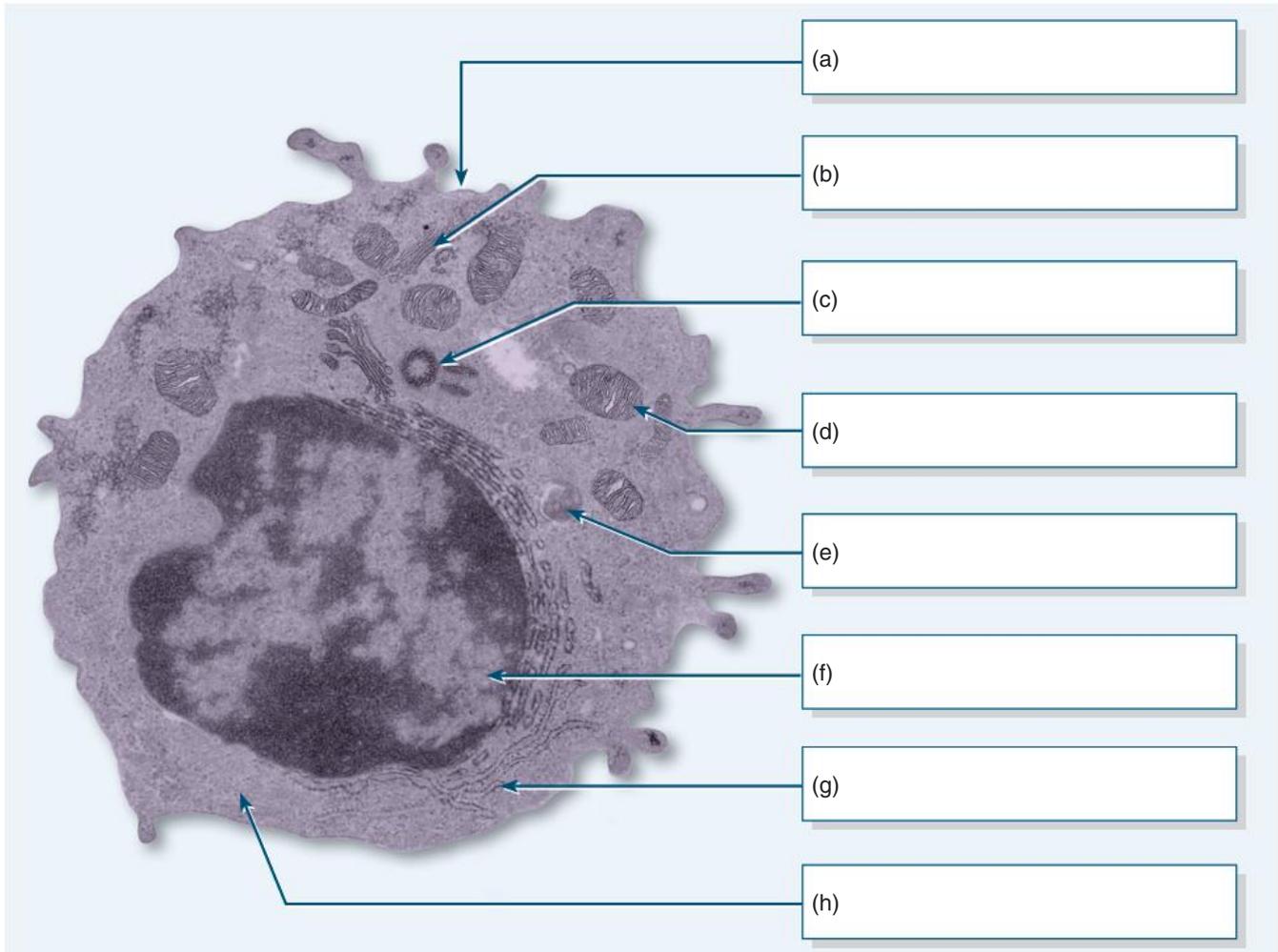
# 13 Identifying Structures in an Animal Cell

**Key Idea:** The position of the organelles in an electron micrograph can result in variations in their appearance.

Transmission electron microscopy (TEM) is the most frequently used technique for viewing cellular organelles.

When viewing TEMs, the cellular organelles may have quite different appearances depending on whether they are in transverse or longitudinal section.

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



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

\_\_\_\_\_

3. Why do plants lack any of the mobile phagocytic cells typical of animal cells? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

4. 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: \_\_\_\_\_

\_\_\_\_\_

5. What features of the lymphocyte cell above identify it as eukaryotic? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_



# 14 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 a lot 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 the molecule 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.



- What are the functions of the cell wall in plants? \_\_\_\_\_
  - Why is the middle lamella of the cell wall important? \_\_\_\_\_
- What distinguishes the tonoplast and the plasma membrane? \_\_\_\_\_
- What structure takes up the majority of space in the plant cell? \_\_\_\_\_
  - What are its roles? \_\_\_\_\_
- Identify two structures in the diagram that are not found in animal cells: \_\_\_\_\_

# 15

## Identifying Structures in a Plant Cell

**Key Idea:** The position and appearance of the organelles in an electron micrograph can be used to identify them.

1. 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) \_\_\_\_\_

2. State how many cells, or parts of cells, are visible in the electron micrograph above: \_\_\_\_\_

3. Describe the features that identify this cell as a plant cell: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. (a) Explain where cytoplasm is found in the cell: \_\_\_\_\_

\_\_\_\_\_

(b) Describe what cytoplasm is made up of: \_\_\_\_\_

\_\_\_\_\_

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

(a) \_\_\_\_\_

\_\_\_\_\_

(b) \_\_\_\_\_

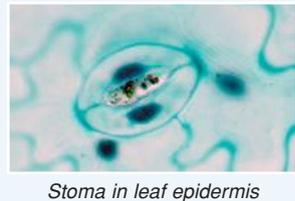
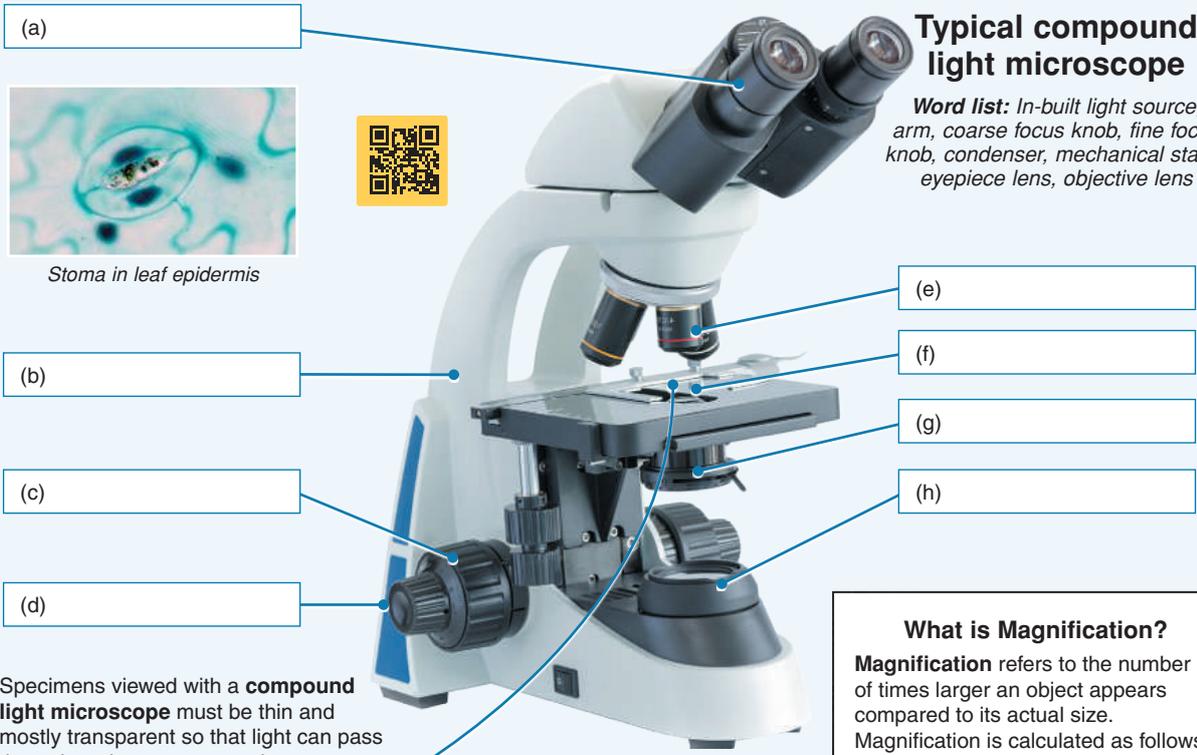
\_\_\_\_\_



# 16 Optical Microscopes

**Key Idea:** Optical microscopes use light focussed through a series of lenses to magnify objects up to several 100 times. The light (or optical) microscope is an important tool in biology and using it correctly is an essential skill. High power compound light microscopes use visible light and a

combination of lenses to magnify objects up to several 100 times. The resolution of light microscopes is limited by the wavelength of light and specimens must be thin and mostly transparent so that light can pass through. No detail will be seen in specimens that are thick or opaque.



## Typical compound light microscope

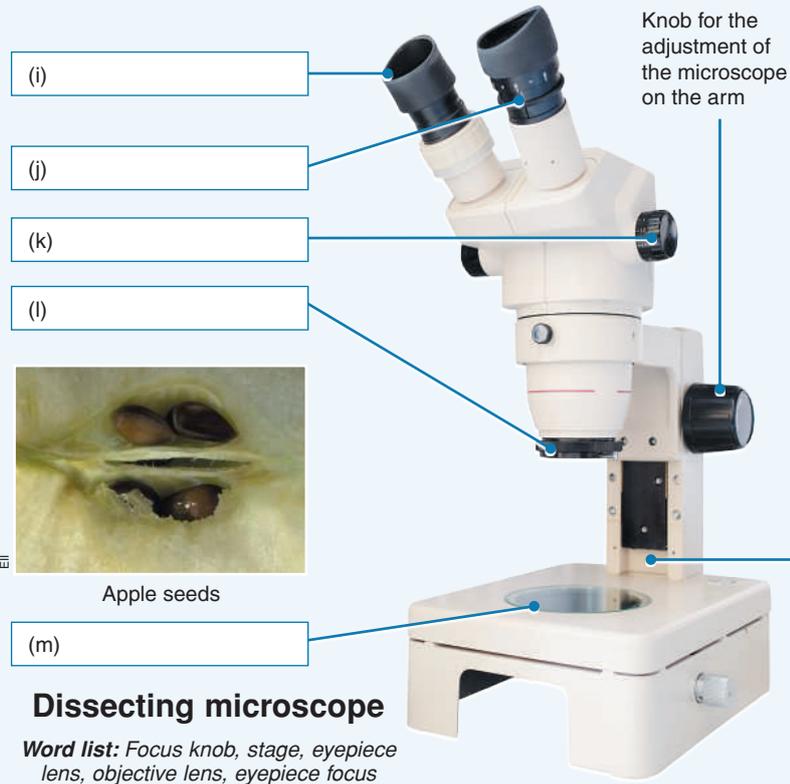
**Word list:** In-built light source, arm, coarse focus knob, fine focus knob, condenser, mechanical stage, eyepiece lens, objective lens

- (a)
- (b)
- (c)
- (d)

- (e)
- (f)
- (g)
- (h)

Specimens viewed with a **compound light microscope** must be thin and mostly transparent so that light can pass through and structures can be seen. Modern microscopes are binocular, i.e. they have two adjustable eyepieces.

**What is Magnification?**  
**Magnification** refers to the number of times larger an object appears compared to its actual size. Magnification is calculated as follows:

$$\text{Objective lens power} \times \text{Eyepiece lens power}$$


Knob for the adjustment of the microscope on the arm

- (i)
- (j)
- (k)
- (l)
- (m)

**What is Resolution?**  
**Resolution** is the ability to distinguish between close together but separate objects. Examples of high and low resolution for separating two objects viewed under the same magnification are given below.

**High resolution**

**Low resolution**

**Dissecting microscopes** are a special type of binocular microscope used for observations at low total magnification (X4 to X50), where a large working distance between the objectives and stage is required.

A dissecting microscope has two separate lens systems, one for each eye. Such microscopes produce a 3-D view of the specimen and are sometimes called stereo microscopes for this reason.

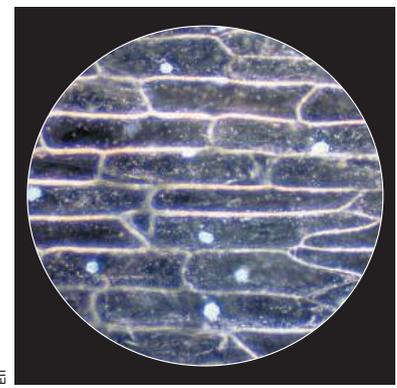
**Dissecting microscope**  
**Word list:** Focus knob, stage, eyepiece lens, objective lens, eyepiece focus



Dissecting microscopes are used for identifying and sorting organisms, observing microbial cultures, and dissections.



These onion epidermal cells are viewed with standard **bright field** lighting. Very little detail can be seen (only cell walls) and the cell nuclei are barely visible.



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

- Label the two photographs on the previous page, the compound light microscope (a) to (h) and the dissecting microscope (i) to (m). Use words from the lists supplied for each image.
- Determine the magnification of a microscope using:
  - 15 X eyepiece and 40 X objective lens: \_\_\_\_\_
  - 10 X eyepiece and 60 X objective lens: \_\_\_\_\_
- Describe the main difference between a compound light microscope and a dissecting microscope: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- What type of microscope would you use to:
  - Count stream invertebrates in a sample: \_\_\_\_\_
  - Observe cells in mitosis: \_\_\_\_\_
- (a) Distinguish between **magnification** and **resolution**: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Explain the benefits of a higher resolution: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Below is a list of ten key steps taken to set up a microscope and optimally view a sample. The steps have been mixed up. Put them in their **correct order** by numbering each step:
  - Focus and centre the specimen using the high objective lens. Adjust focus using the fine focus knob only.
  - Adjust the illumination to an appropriate level by adjusting the iris diaphragm and the condenser. The light should appear on the slide directly below the objective lens, and give an even amount of illumination.
  - Rotate the objective lenses until the shortest lens is in place (pointing down towards the stage). This is the lowest / highest power objective lens (delete one).
  - Place the slide on the microscope stage. Secure with the sample clips.
  - Fine tune the illumination so you can view maximum detail on your sample.
  - Focus and centre the specimen using the medium objective lens. Focus firstly with the coarse focus knob, then with the fine focus knob (if needed).
  - Turn on the light source.
  - Focus and centre the specimen using the low objective lens. Focus firstly with the coarse focus knob, then with the fine focus knob.
  - Focus the eyepieces to adjust your view.
  - Adjust the distance between the eyepieces so that they are comfortable for your eyes.

# 17 Preparing a Slide

**Key Idea:** Correctly preparing and mounting a specimen on a slide is important if structures are to be seen clearly under a microscope. A wet mount is suitable for most slides.

Specimens are usually prepared in some way before viewing in order to highlight features and reveal details. A wet mount is a temporary preparation in which a specimen and a drop of fluid are trapped under a thin coverslip. Wet mounts are

used to view thin tissue sections, live microscopic organisms, and suspensions such as blood. A wet mount improves a sample's appearance and enhances visible detail. Sections must be made very thin for two main reasons. A thick section stops light shining through making it appear dark when viewed. It also ends up with too many layers of cells, making it difficult to see any detail.

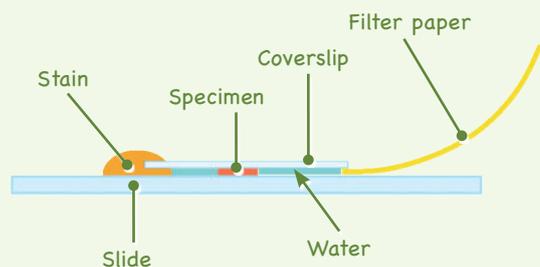
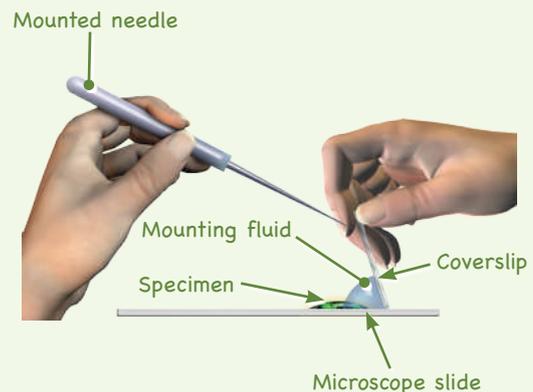
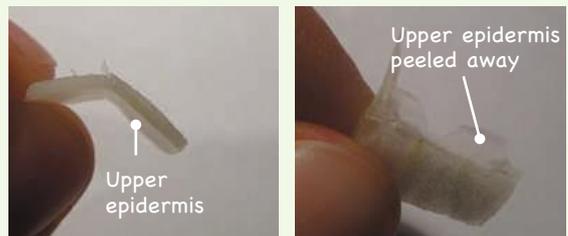


## Investigation 2.1 Preparing an onion slide

See appendix for equipment list.

**Caution is required when using scalpels or razors. Iodine stains skin and clothes, and irritates the eyes. You should wear protective eyewear.**

1. Onions make good subjects for preparing a simple wet mount. Cut a square segment from a thick leaf of the bulb using a razor or scalpel.
2. Bend the segment towards the upper epidermis until the lower epidermis and inner leaf tissue (the parenchyma) snaps so that just the upper epidermis is left attached.
3. Carefully peel off the parenchyma from one side of the snapped leaf and then the other, leaving a peel of just the upper epidermis.
4. Place peel in the centre of a clean glass microscope slide and cover it with a drop of water.
5. Carefully lower a coverslip over the peel. A mounted needle can be used for better precision. This avoids including air in the mount.
6. Use a small piece of tissue or filter paper to remove any excess water.
7. Place the slide on the microscope tray. Locate the specimen or region of interest at the lowest magnification. Focus using the lowest magnification first (remembering to move the lens away from the slide) before switching to the higher magnifications.
8. After viewing the slide under various magnifications, remove the slide and place it on the bench.
9. At the edge of the coverslip place a small drop of iodine stain.
10. On the opposite side of the coverslip use a piece of tissue or filter paper to draw the water out from under the coverslip. The iodine will be drawn under the coverslip.
11. Replace the slide on the microscope and view the stained onion peel.

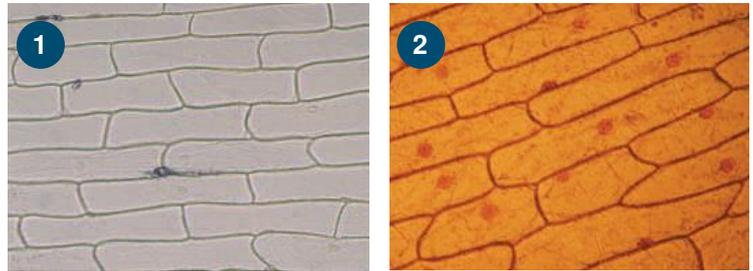


1. Why must sections viewed under a microscope be very thin? \_\_\_\_\_
2. Why do you think the specimen is covered with a coverslip? \_\_\_\_\_
3. Why would no chloroplasts be visible in an onion epidermis cell slide? \_\_\_\_\_

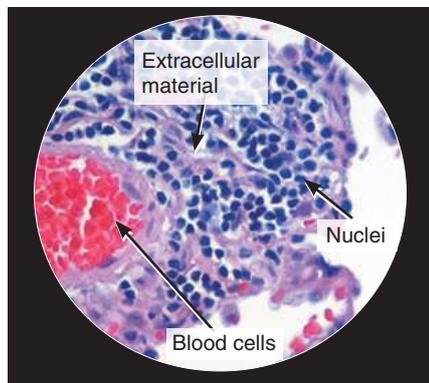
**Stains and their uses**

- ▶ Staining material for viewing under a microscope can make it easier to distinguish particular cell structures.
- ▶ **Stains** and dyes can be used to highlight specific components or structures. Stains contain chemicals that interact with molecules in the cell. Some stains bind to a particular molecule making it easier to see where those molecules are. Others cause a change in a target molecule, which changes their colour, making them more visible.
- ▶ Most stains are **non-viable**, and are used on dead specimens, but harmless **viable stains** can be applied to living material.

Some commonly used stains		
Stain	Final colour	Used for
Iodine solution	Blue-black	Starch
Crystal violet	Purple	Gram staining
Aniline sulfate	Yellow	Lignin
Methylene blue	Blue	Nuclei
Hematoxylin and eosin (H&E)	H=dark blue/violet E=red/pink	H=Nuclei E=Proteins



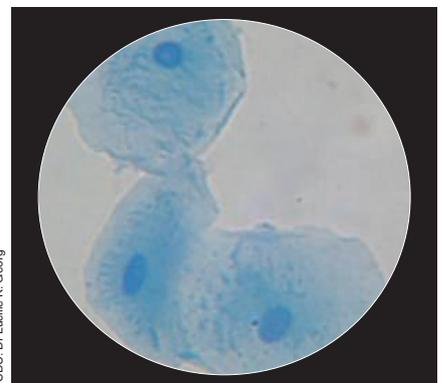
The light micrographs 1 and 2 (above) show how the use of a stain can enhance certain structures. The left image (1) is unstained and only the cell wall is easily visible. Adding iodine (2) makes the cell wall and nuclei stand out.



H&E stain is one of the most common stains for animal tissues. Nuclei stain dark blue, whereas proteins, extracellular material, and red blood cells stain pink or red.



Viable stains do not immediately harm living cells. Trypan blue is a vital stain that stains dead cells blue but is excluded by live cells. It is also used to study fungal hyphae.



Methylene blue is a common temporary stain for animal cells, such as these cheek cells. It stains DNA and so makes the nuclei more visible.

4. Why is it necessary to focus on the lowest magnification first, before switching to higher magnifications?

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5. Describe the difference the iodine stain made when viewing the onion cells under the microscope compared to when they were viewed without the stain:

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6. What is the main purpose of using a stain? \_\_\_\_\_

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7. What is the difference between a viable and non-viable stain? \_\_\_\_\_

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8. Identify a stain that would be appropriate for distinguishing each of the following:

(a) Live vs dead cells: \_\_\_\_\_ (c) Lignin in a plant root section: \_\_\_\_\_

(b) Red blood cells in a tissue preparation: \_\_\_\_\_ (d) Nuclei in cheek cells: \_\_\_\_\_

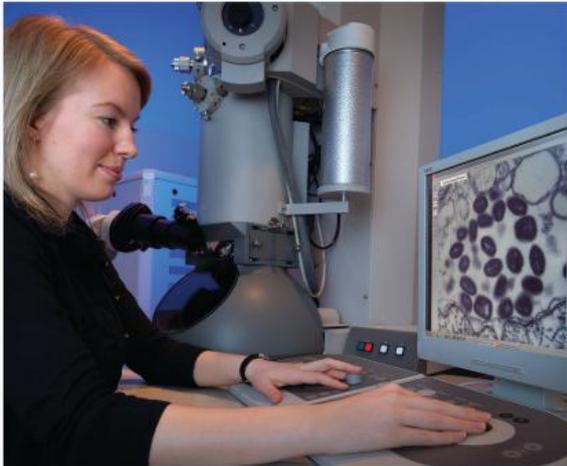
# 18 Electron Microscopes

**Key Idea:** Electron microscopes use the short wavelengths of electrons to produce high resolution images of extremely small objects.

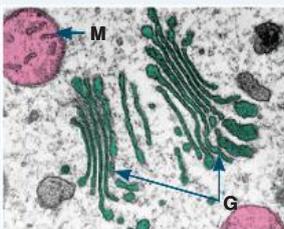
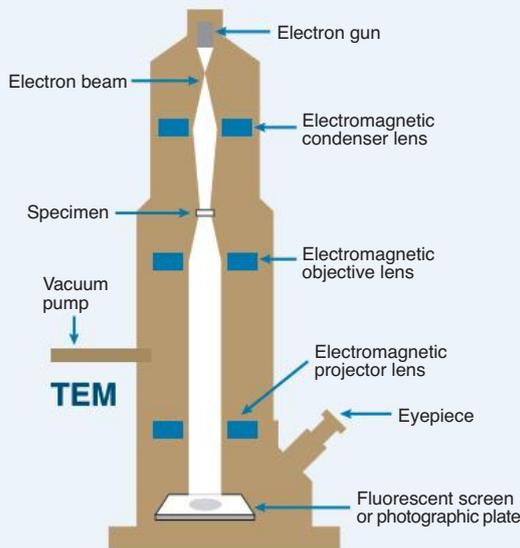
Electron microscopes (EMs) use a beam of electrons, instead of light, to produce an image. The higher resolution of electron microscopes is due to the shorter wavelengths of

electrons. There are two basic types of electron microscope: **scanning electron microscopes (SEM)** and **transmission electron microscopes (TEM)**. In SEMs, the electrons are bounced off the surface of an object to produce detailed images of the external appearance. TEMs produce very clear images of specially prepared thin sections.

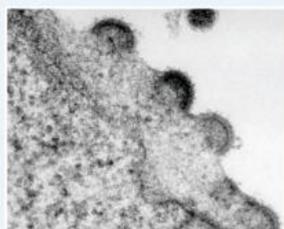
## Transmission electron microscope (TEM)



The transmission electron microscope is used to view extremely thin sections of material. Electrons pass through the specimen and are scattered. Magnetic lenses focus the image onto a fluorescent screen or photographic plate. The sections are so thin that they have to be prepared with a special machine, called an ultramicrotome, which can cut wafers to just 30 thousandths of a millimetre thick. It can magnify several hundred thousand times.



TEM photo showing the Golgi (G) and a mitochondrion (M).

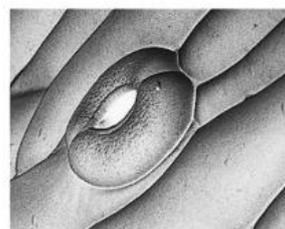
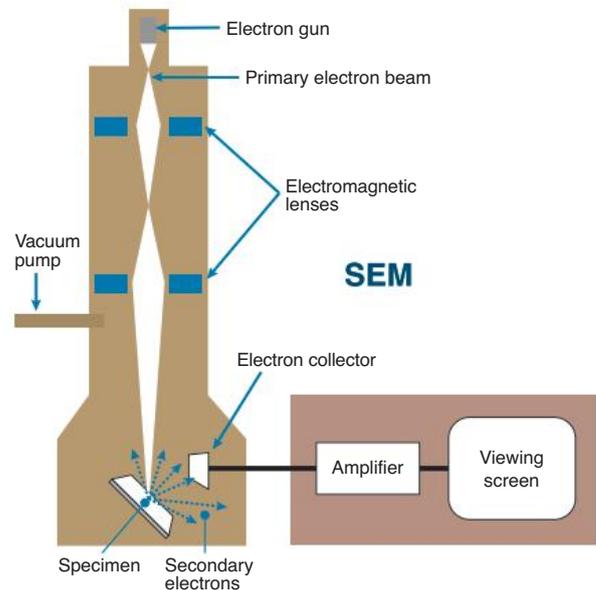


Three HIV viruses budding out of a human lymphocyte (TEM).

## Scanning electron microscope (SEM)



The scanning electron microscope scans a sample with a beam of primary electrons, which knocks electrons from the sample's surface. These secondary electrons are picked up by a collector, amplified, and transmitted onto a viewing screen or photographic plate, producing a 3-D image. A microscope of this power easily obtains clear images of very small organisms such as bacteria, and small particles such as viruses. The image produced is of the outside surface only.



SEM photo of stoma and epidermal cells on the upper surface of a leaf.

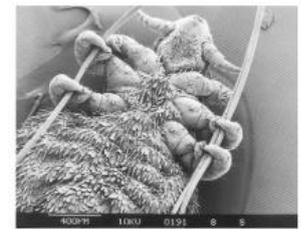


Image of hair louse clinging to two hairs on a Hooker's sealion (SEM).



	Light microscope	Transmission electron microscope (TEM)	Scanning electron microscope (SEM)
<b>Radiation source:</b>	light	electrons	electrons
<b>Wavelength:</b>	400-700 nm	0.005 nm	0.005 nm
<b>Lenses:</b>	glass	electromagnetic	electromagnetic
<b>Specimen:</b>	living or non-living supported on glass slide	non-living supported on a small copper grid in a vacuum	non-living supported on a metal disc in a vacuum
<b>Maximum resolution:</b>	200 nm	1 nm	10 nm
<b>Maximum magnification:</b>	1500 x	250 000 x	100 000 x
<b>Stains:</b>	coloured dyes	impregnated with heavy metals	coated with carbon or gold
<b>Type of image:</b>	coloured, surface or section	monochrome, section	monochrome, surface only

1. Explain why electron microscopes are able to resolve much greater detail than a light microscope: \_\_\_\_\_

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2. Which type of microscope [TEM, SEM, compound light microscope, or dissecting microscope] would you use for each of the following scenarios. Explain your choice in each case:

(a) Distinguishing extinct plant species on the basis of pollen surface features: \_\_\_\_\_

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(b) Imaging the ultrastructure of a chloroplast: \_\_\_\_\_

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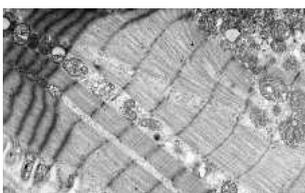
(c) Performing a count of white blood cells from the blood of a person with an infection: \_\_\_\_\_

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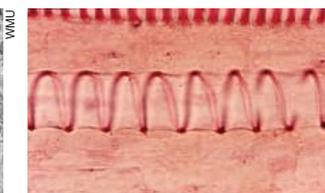


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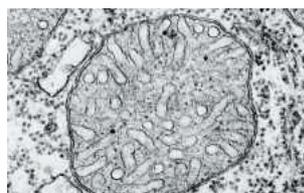
3. Identify which type of electron microscope (SEM or TEM) or optical microscope (compound light microscope or dissecting microscope) was used to produce each of the images in the photos below (A-H):



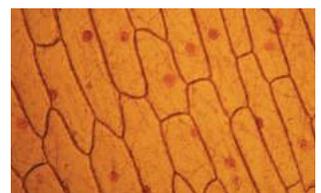
Cardiac muscle



Plant vascular tissue



Mitochondrion



Plant epidermal cells

A. \_\_\_\_\_

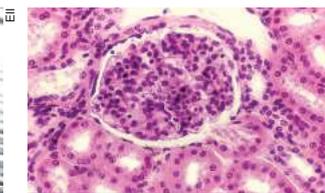
B. \_\_\_\_\_

C. \_\_\_\_\_

D. \_\_\_\_\_



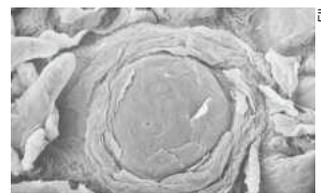
Head louse



Kidney cells



Body louse



Tongue papilla

E. \_\_\_\_\_

F. \_\_\_\_\_

G. \_\_\_\_\_

H. \_\_\_\_\_

4. Research and list some types of ultra high resolution microscopes: \_\_\_\_\_

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# 19

## Calculating Linear Magnification

**Key Idea:** Magnification is how much larger an object appears compared to its actual size. It can be calculated from the ratio of image height to object height.

Microscopes produce an enlarged (magnified) image of an object allowing it to be observed in greater detail than is possible with the naked eye. **Magnification** refers to the number of times larger an object appears compared to its

actual size. Linear magnification is calculated by taking a ratio of the image height to the object's actual height. If this ratio is greater than one, the image is enlarged. If it is less than one, it is reduced. To calculate magnification, all measurements are converted to the same units. Often, you will be asked to calculate an object's actual size, in which case you will be told the size of the object and the magnification.

### Calculating linear magnification: A worked example

- 1 Measure the body length of the bed bug image (right). Your measurement should be 40 mm (**not** including the body hairs and antennae).
- 2 Measure the length of the scale line marked 1.0 mm. You will find it is 10 mm long. The magnification of the scale line can be calculated using equation 1 (below right).

The magnification of the scale line is **10** (10 mm ÷ 1 mm)

\*NB: The magnification of the bed bug image will also be 10x because the scale line and image are magnified to the same degree.

- 3 Calculate the actual (real) size of the bed bug using equation 2 (right):

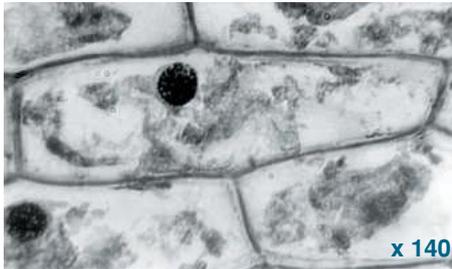
The actual size of the bed bug is **4 mm**  
(40 mm ÷ 10 x magnification)



### Microscopy equations

$$1. \text{ Magnification} = \frac{\text{measured size of the object}}{\text{actual size of the object}}$$

$$2. \text{ Actual object size} = \frac{\text{size of the image}}{\text{magnification}}$$



1. The bright field microscopy image on the left is of onion epidermal cells. The measured length of the onion cell in the centre of the photograph is 52,000 μm (52 mm). The image has been magnified 140 x. Calculate the actual size of the cell:

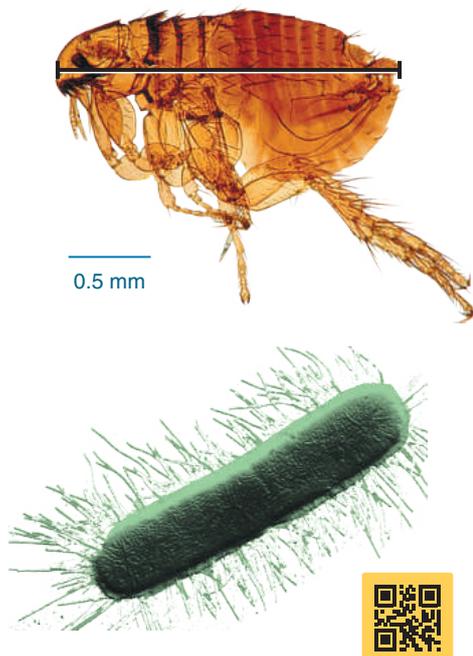
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2. The image of the flea (left) has been captured using light microscopy.
  - (a) Calculate the magnification using the scale line on the image:

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- (b) The body length of the flea is indicated by a line. Measure along the line and calculate the actual length of the flea:

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3. The image size of the *E.coli* cell (left) is 43 mm, and its actual size is 2 μm. Using this information, calculate the magnification of the image:

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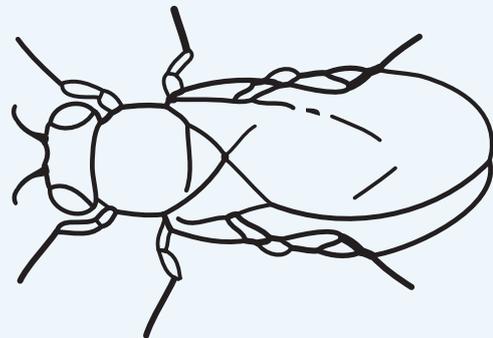
## 20 Biological Drawings

**Key Idea:** Good biological drawings provide an accurate record of the specimen you are studying and enable you to make a record of its important features.

Drawing is a very important skill to have in biology. Drawings record what a specimen looks like and give you an opportunity

to record its important features. Often drawing something will help you remember its features at a later date (e.g. in a test). Annotated drawings provide explanatory notes about the labelled structures, while plan diagrams label the main structures observed, but provide no additional detail.

- ▶ Biological drawings require you to pay attention to detail. It is very important that you draw what you actually see, and not what you think you should see.
- ▶ Biological drawings should include as much detail as you need to distinguish different structures and types of tissue, but avoid unnecessary detail which can make your drawing confusing.
- ▶ Attention should be given to the symmetry and proportions of your specimen. Accurate labeling, a statement of magnification or scale, the view (section type), and type of stain used (if applicable) should all be noted on your drawing.
- ▶ Some key points for making good biological drawing are described on the example below. The drawing of *Drosophila* (right) is well executed but lacks the information required to make it a good biological drawing.



This drawing of *Drosophila* is a fair representation of the animal, but has no labels, title, or scale.

All drawings must include a title. Underline the title if it is a scientific name.

Copepod

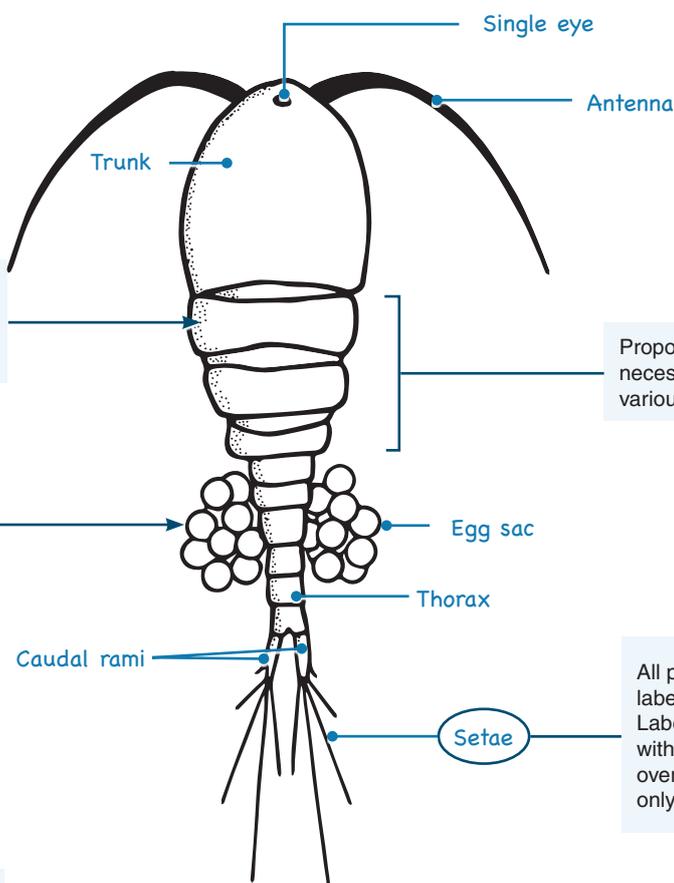
Centre your drawing on the page, not in a corner. This will leave room to place labels around the drawing.

If you need to represent depth, use stippling (dotting). Do not use shading as this can smudge and obscure detail.

Use simple, narrow lines to make your drawings.

Use a sharp pencil to draw with. Make your drawing on plain white paper.

Your drawing must include a scale or magnification to indicate the size of your subject.



Proportions should be accurate. If necessary, measure the lengths of various parts with a ruler.

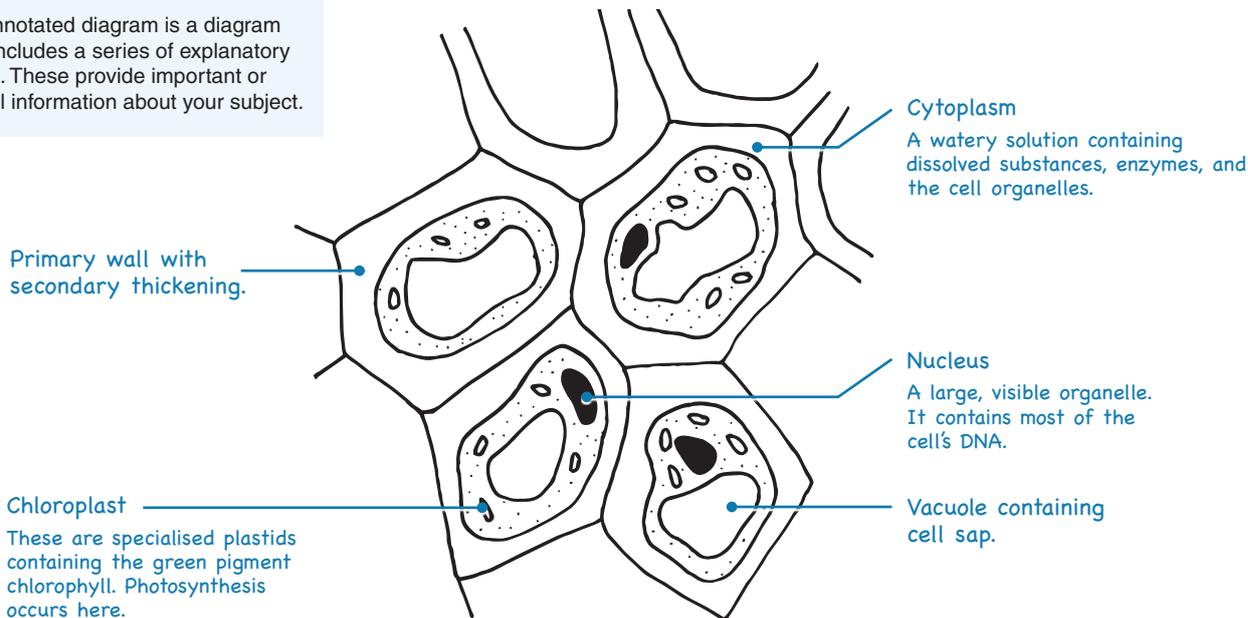
All parts of your drawing must be labelled accurately. Labeling lines should be drawn with a ruler and should not cross over other label lines. Try to use only vertical or horizontal lines.



### Annotated diagrams

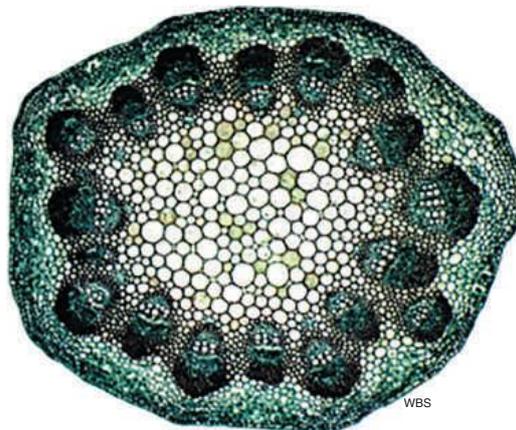
Transverse section through collenchyma of *Helianthus* stem.  
Magnification x 450

An annotated diagram is a diagram that includes a series of explanatory notes. These provide important or useful information about your subject.

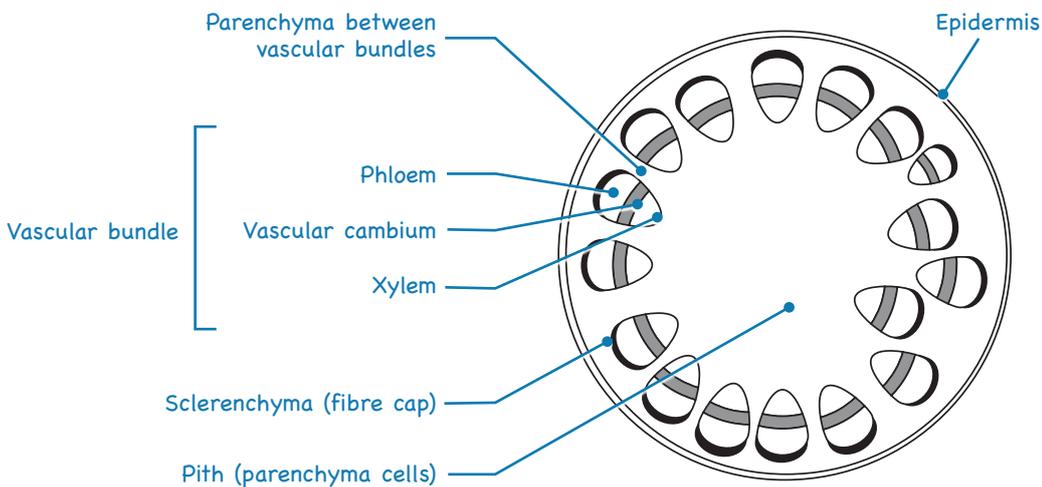


### Plan diagrams

Plan diagrams are drawings made of samples viewed with the naked eye, hand lens, or under a microscope at low or medium power. They are used to show the distribution of the different tissue types in a sample without any cellular detail. The tissues are identified, but no detail about the cells within them is included. The example here shows a plan diagram produced after viewing a light micrograph of a transverse section through a dicot stem.



Above: Light micrograph of a transverse section through a dicot stem.



# 21 Observing and Drawing Cells

**Key Idea:** Attention to detail is vital when making accurate and useful biological drawings.

Being able to draw what you see through a microscope is a useful skill. While using a camera will allow you to capture every detail and any colour, simple drawings, as described in

the previous activity, are often able to provide a much clearer image of the specimen. They can also focus on specific details or areas, such as just the cell wall, or how certain cells fit together. In this activity, you will practise the skills required to translate what is viewed into a good biological drawing.

## Drawing with a microscope

- ▶ Drawing what is in the field of view of a microscope can be tricky. If you need to turn away from the eyepiece to start drawing it can be difficult to find what you were looking at when you turn back to the eyepiece. Continually doing this can produce a disjointed drawing and is also time consuming.
- ▶ Being able to draw what you see without having to turn away to draw on paper is a skill that needs practice, but it can produce a better result overall.
- ▶ Drawing while still viewing the specimen through the eyepiece requires relaxed viewing. Getting your eyes to relax requires you to look in the microscope as if the field of view is in the distance, rather than close up (eyes are most relaxed when viewing distant images). Microscopes actually produce images that appear distant, but it may still take a few moments for your eyes to adjust.
- ▶ Use one eye (the left for right handers) to view and the other eye to look at your drawing.



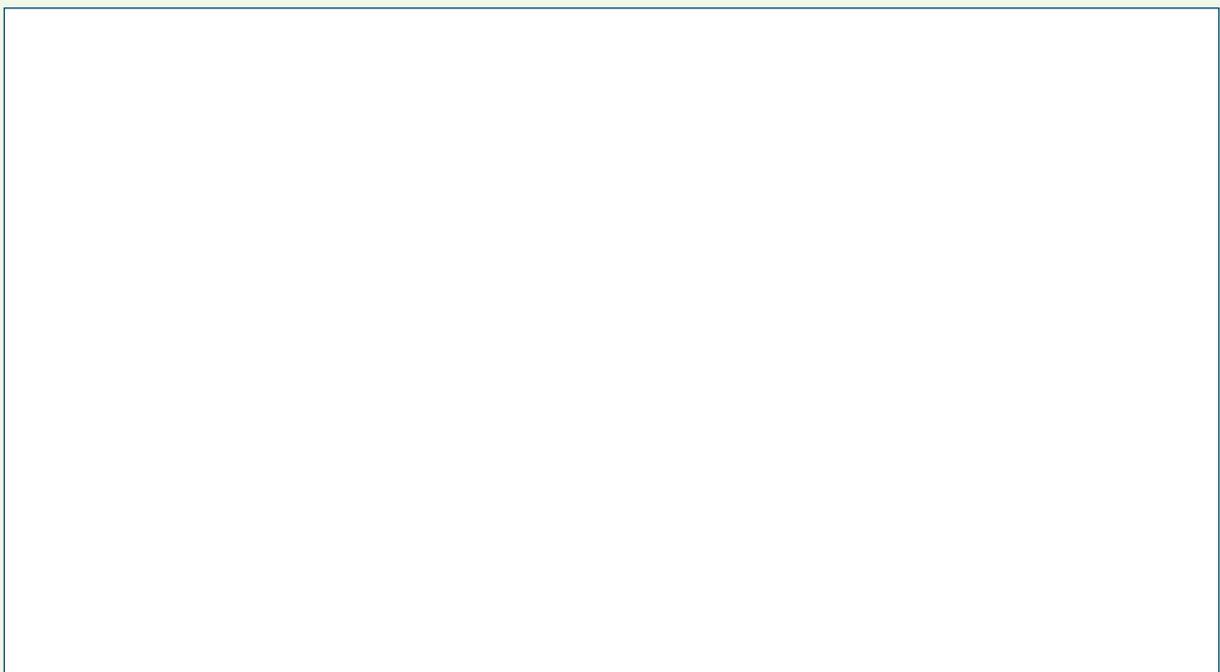
TG



## Investigation 2.2a Drawing onion peel cells using a microscope

*See appendix for equipment list.*

1. Start by producing a slide of an onion skin peel as in Activity 17. Staining the cells will help you see some features more clearly. As these are very simple and quite large cells they are a good specimen to practise drawing.
2. Use the space below to draw at least four cells in detail. The cells around them can be shown in less detail as they are all more or less the same. Include a scale and labels.





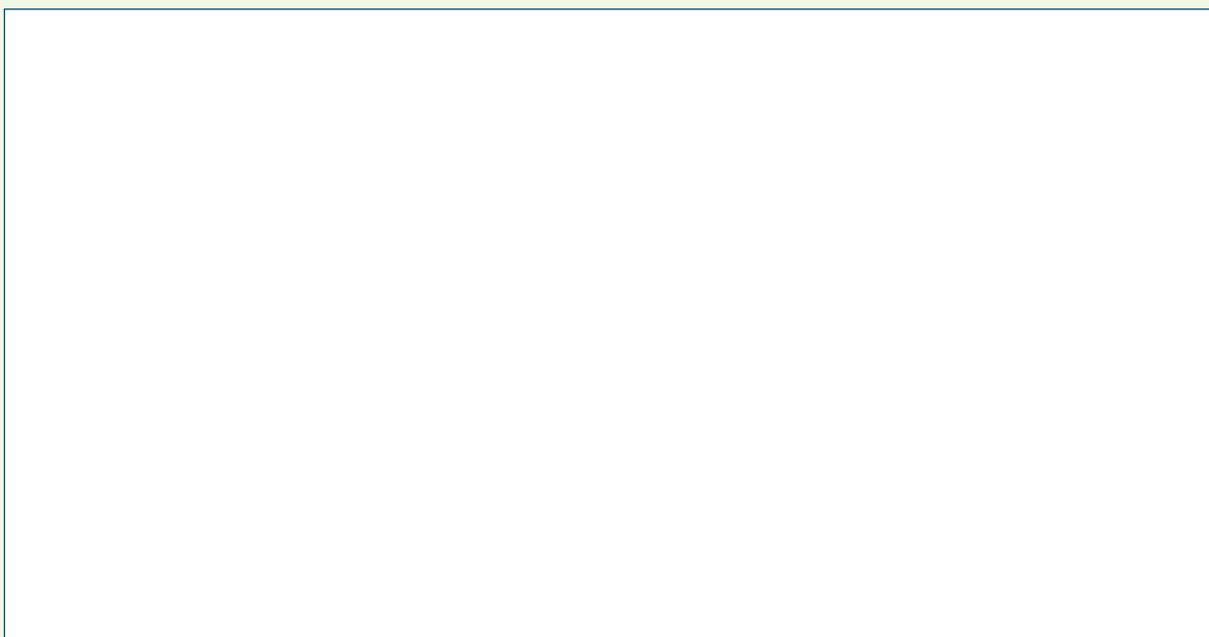
## Investigation 2.2b Drawing *Elodea* leaf cells using a microscope

See appendix for equipment list.

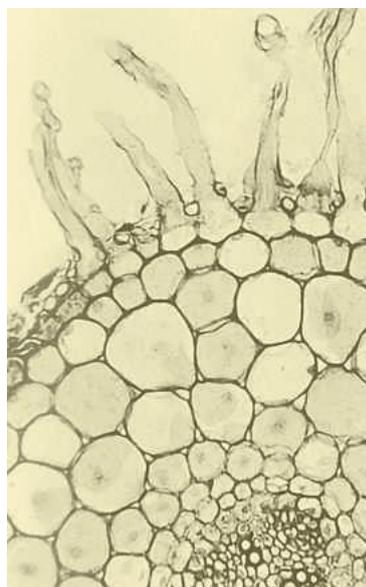
1. *Elodea* is a common aquarium plant. It has very thin leaves that contain cells with numerous chloroplasts that are easy to view under a microscope.
2. Place an *Elodea* leaf on a clean microscope slide. Add a drop of water and cover with a coverslip.
3. Focus on low magnification and observe.
4. Change to higher magnifications. Identify the chloroplasts. These are dark green and are usually close to the cell wall.
5. Use the space below to draw at least four cells in detail. The cells around them can be shown in less detail as they are all similar. Include a scale and labels.



Katrin Schneider CC 4.0



1. You may also need to draw more complex structures, including cross sections of stems or leaves. The image below is a light micrograph transverse section (TS) through a *Ranunculus* root. In the space practise your drawing by making a plan diagram of the image or you can make a biological drawing of your own slide by cutting a stem section (right) and using a microscope.



KP

Sections through stems or other soft objects are made with a razor blade or scalpel and must be very thin. Cutting at a slight angle produces a wedge shape with a thin edge. Ideally, specimens should be set in wax before sectioning. This stops crushing and makes it easy to cut the specimen.

## 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:

5. (a) Name this organelle:

(b) Structure and location:

(c) Function:

2. (a) Name this organelle:

(b) Structure and location:

(c) Function:

3. (a) Name this organelle:

(b) Structure and location:

(c) Function:

4. (a) Name this organelle:

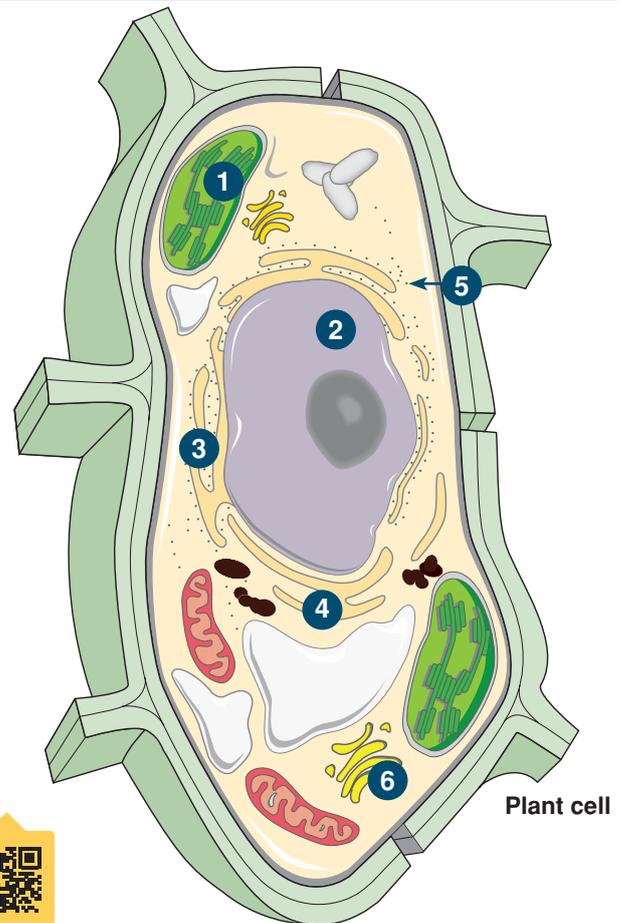
(b) Structure and location:

(c) Function:

6. (a) Name this organelle:

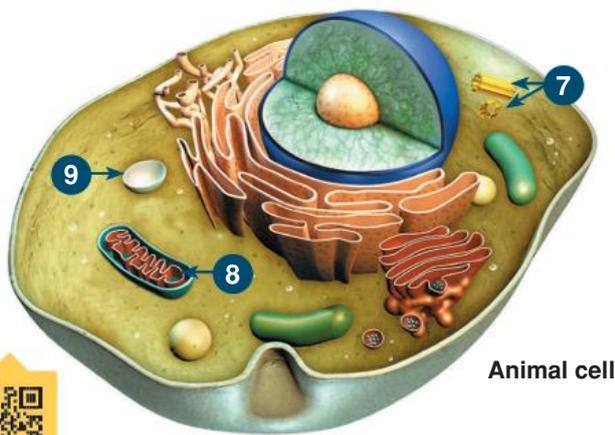
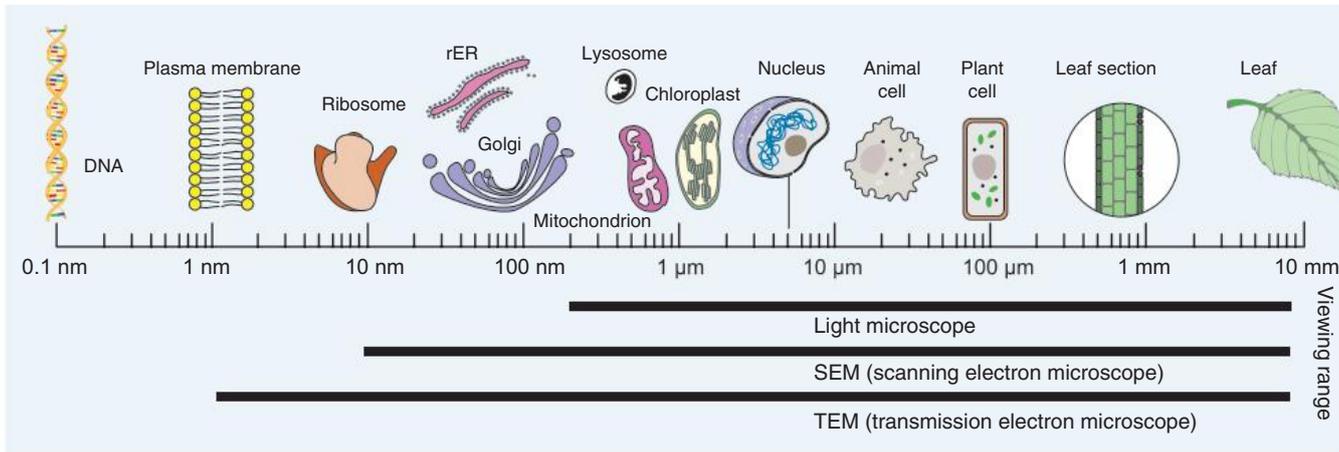
(b) Structure and location:

(c) Function:



Plant cell





Animal cell



7. (a) Name this organelle:

(b) Structure and location:

(c) Function:

8. (a) Name this organelle:

(b) Structure and location:

(c) Function:

9. (a) Name this organelle:

(b) Structure and location:

(c) Function:

10. Use the scale at the top of the page and the information on previous activities to identify which of the organelles (1-9):

(a) Can be seen with a high power light microscope: \_\_\_\_\_

(b) Require a TEM to be seen: \_\_\_\_\_

11. (a) Which of the organelles (1-9) is/are not found in animal cells: \_\_\_\_\_

(b) Which of the organelles (1-9) is/are not found in plant cells: \_\_\_\_\_

(c) Which organelles (1-9) is/are found in plant and animal cells: \_\_\_\_\_

12. Identify one unlabeled structure in the plant cell on the previous page and describe its function: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 23 Comparing the Features of Cells

**Key Idea:** The organelles and internal structure of a cell vary between different cell types.

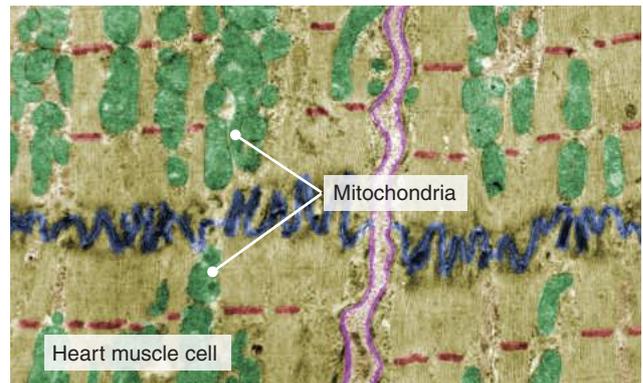
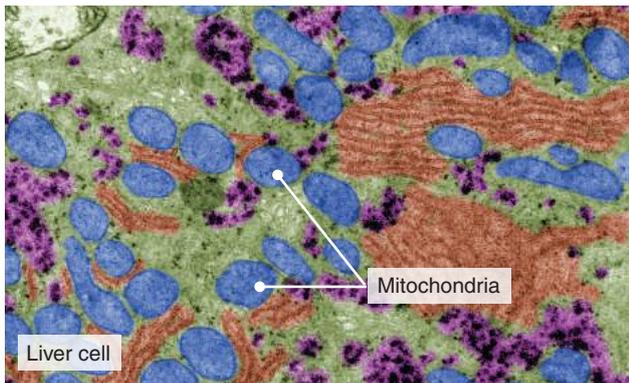
Different cell types have features that distinguish them from other cell types. This may be the presence or absence of

certain organelles or structures, or particular shapes they have. These features can be seen under the microscope. The information below compares and contrasts different cells and their features.

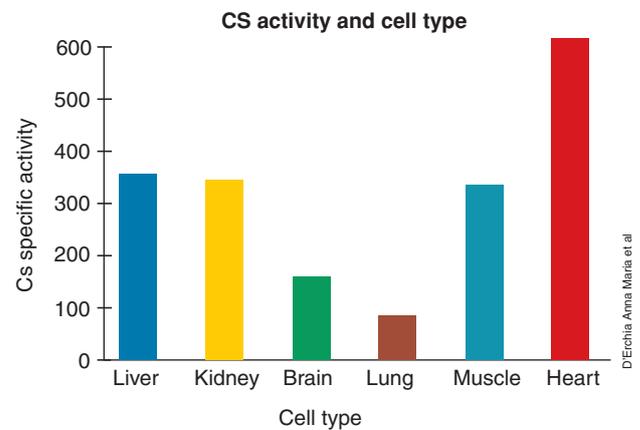
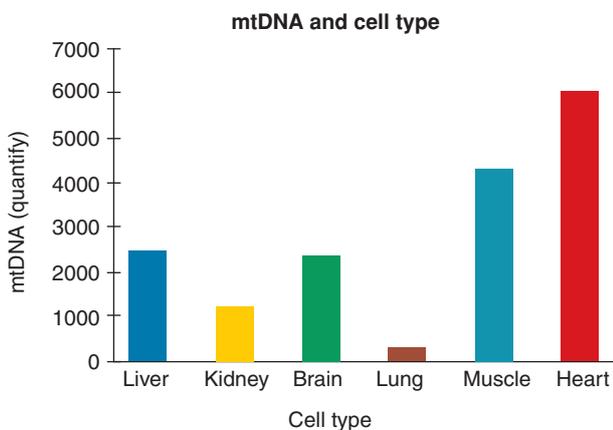
## Organelles and cell function

### Mitochondria and cell activity

- ▶ The presence or absence of certain organelles can give a clue about the function of the cell. Metabolically active cells use more energy than cells that are less active. As this energy comes from mitochondria (as ATP), we would expect that cells with a large number of mitochondria or a large proportion of their cytoplasm taken up by mitochondria to have high metabolic activity.
- ▶ Cardiac (heart) muscle cells have some of the highest amounts of mitochondria of all cells. Liver cells also have a very large number of mitochondria. Red blood cells have no mitochondria.



- ▶ Two methods of quantifying the mitochondria in a cell are shown below. On the left the amount of mitochondrial DNA (mtDNA) is quantified. High levels of mtDNA indicates larger numbers of mitochondria. On the right the activity of citrate synthase (CS) enzyme is measured. This is an important part of the Krebs cycle that takes place in the mitochondria. Greater CS activity indicates higher numbers of mitochondria.



## Nucleus and blood cells

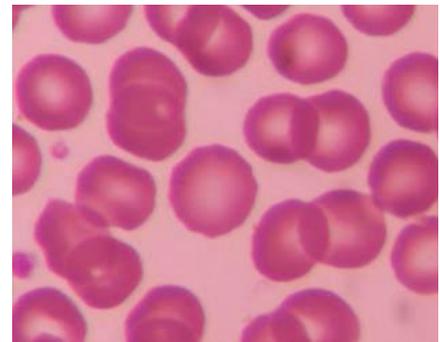
There are numerous types of blood cell, each with a different role. They can be distinguished by features seen in a light microscope.



Monocytes are a type of white blood cell. They can be identified by the large slightly curved nucleus present (arrowed above).



Neutrophils are also a type of white blood cell. One of their distinguishing features is the multilobed nucleus (arrowed).



Red blood cells appear red and mature red blood cells have no nucleus, leaving more room for oxygen transport.



12

14

22

1. (a) Why would heart muscle cells have very large amounts of mitochondria? \_\_\_\_\_  
 \_\_\_\_\_
- (b) Why would red blood cells have very few mitochondria? \_\_\_\_\_  
 \_\_\_\_\_

2. Identify the features in the cells right that distinguish these cells as plant or animal cells:

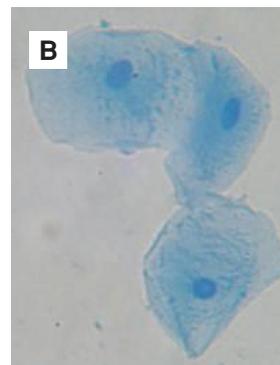
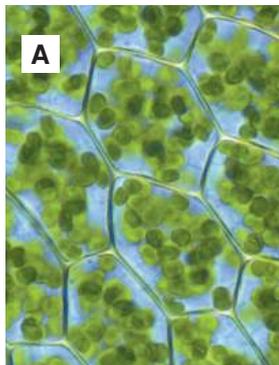
\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



3. In the microscope image right, identify the following:

- (a) A red blood cell:
- (b) A neutrophil:
- (c) A monocyte:

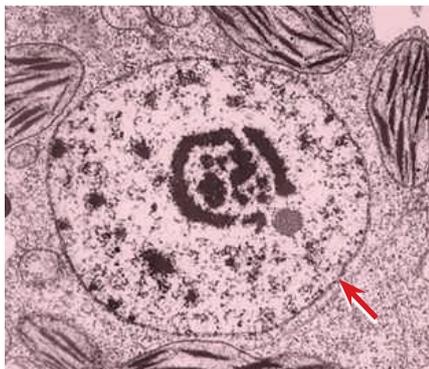


4. Why do red blood cells have no nucleus?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

5. Electron microscopes produce a magnified image at high resolution (distinguish between close together but separate objects). The transmission electron microscope (TEM) images below show the ultrastructure of some organelles.



- (a) i Name the large, circular organelle: \_\_\_\_\_
- ii State which kind of cell(s) this organelle would be found in:  
 \_\_\_\_\_
- iii Describe the function of this organelle: \_\_\_\_\_  
 \_\_\_\_\_
- iv Label two regions that can be seen inside this organelle.



- (b) i Name this large circular organelle (arrowed): \_\_\_\_\_
- ii State which kind of cell(s) this organelle would be found in:  
 \_\_\_\_\_
- iii Describe the function of this organelle: \_\_\_\_\_  
 \_\_\_\_\_
- iv Label three features relating to this organelle in the photograph.

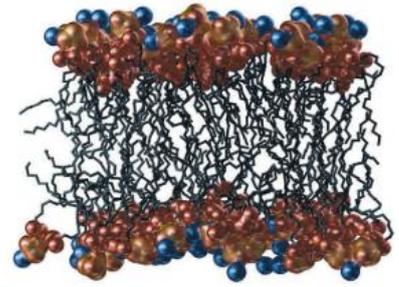
WMU

BF

# 24 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.

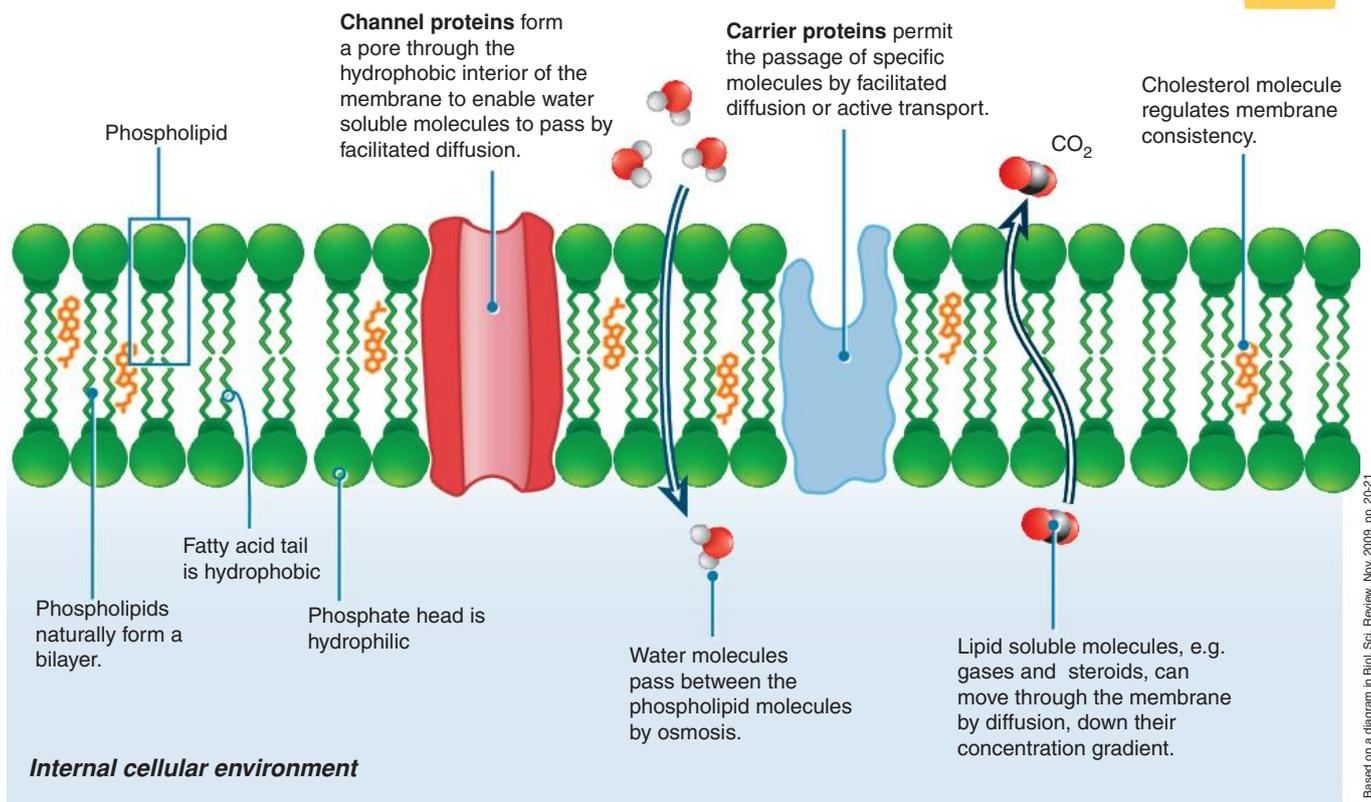


Molecular model showing how phospholipid molecules naturally orientate to form a bilayer.

## Simple membrane structure

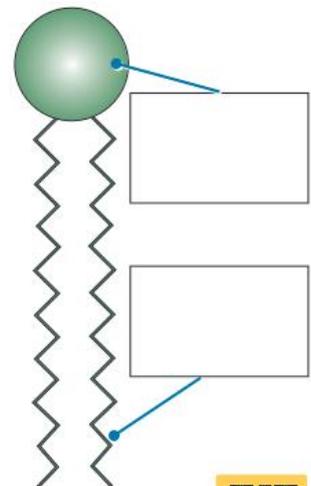


### External cellular environment



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

- List the important components of the plasma membrane: \_\_\_\_\_
- Identify the kind of molecule on the diagram above that can:
  - Move through the plasma membrane by diffusion: \_\_\_\_\_
  - Form a channel through the membrane: \_\_\_\_\_
- On the diagram (right) label the hydrophobic and hydrophilic ends of the phospholipid and indicate which end is attracted to water:
  - How does this structure make the phospholipid molecule behave?



# 25 Phospholipids and the Properties of Membranes

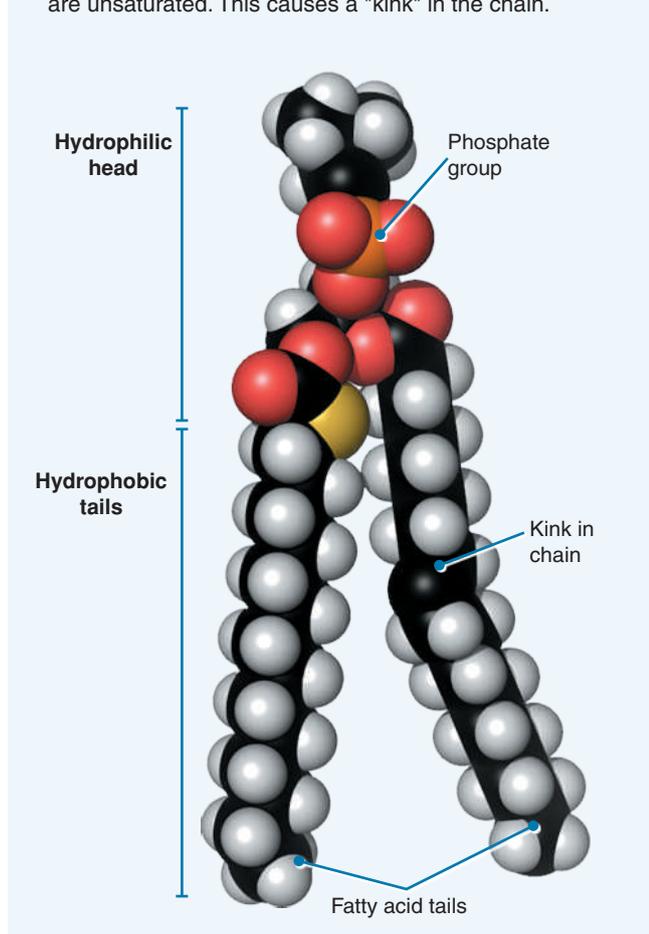
**Key Idea:** Phospholipids are important components of cellular membranes. They are made up of a hydrophilic head region and a hydrophobic tail region, making them amphipathic.

**Phospholipids** consist of a glycerol attached to two fatty acid chains and a phosphate ( $\text{PO}_4^{3-}$ ) 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.

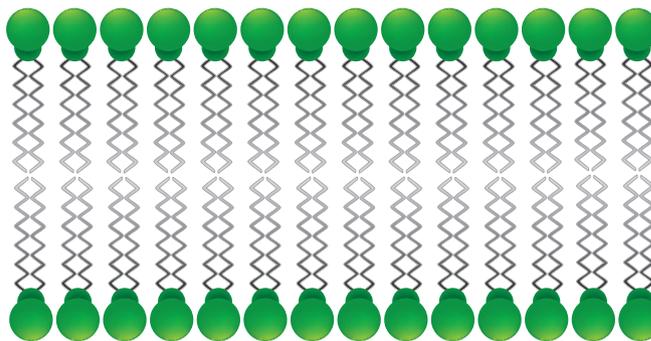
## Phospholipids

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.

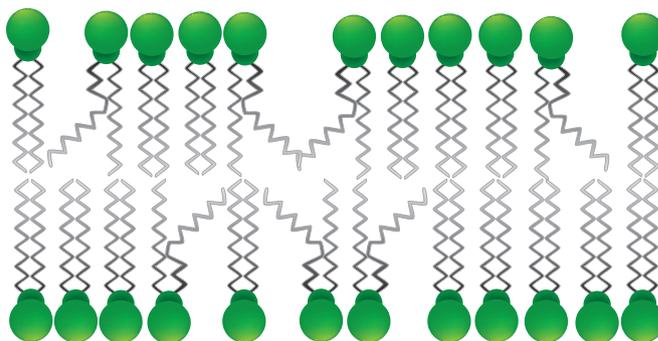


## Phospholipids and membranes

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. The straight chains pack together closely.



Membrane containing phospholipids with unsaturated fatty acid tails. The fact that the phospholipids have kinks means they do not stack neatly together nicely, and it 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?

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

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

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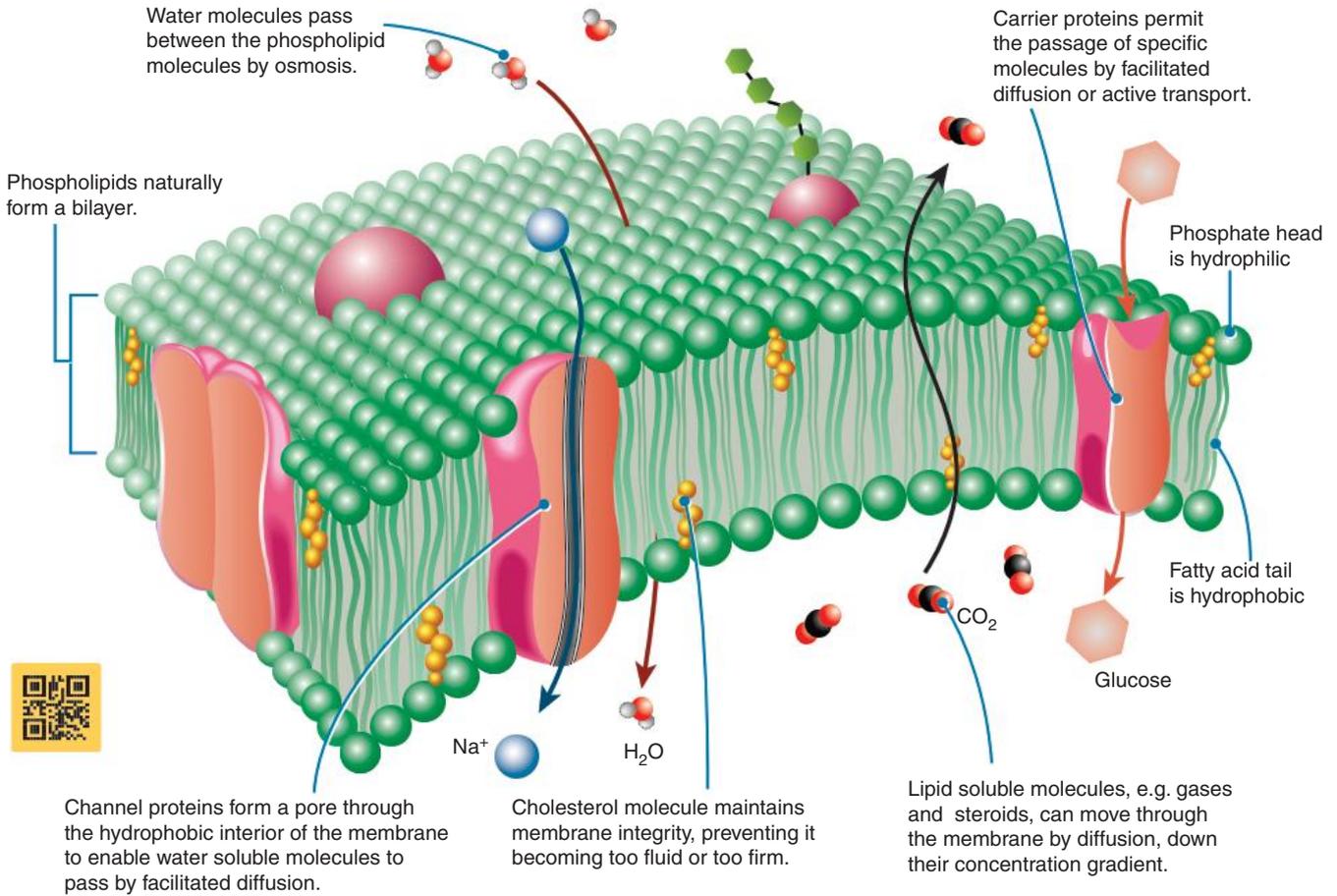


# 26 The Structure of the Plasma Membrane

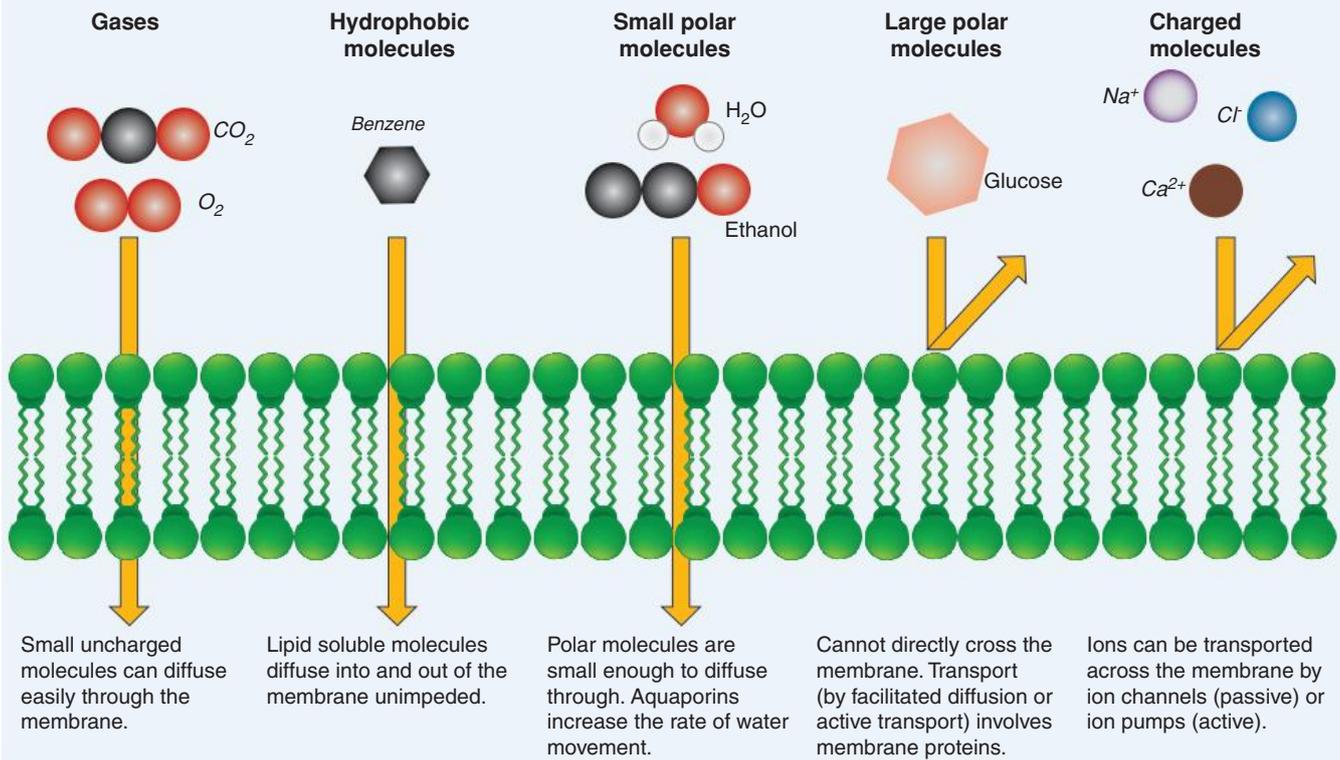
**Key Idea:** A cellular membrane is made of a phospholipid bilayer with proteins of different sorts embedded in it. The plasma (or cell surface) membrane encloses the

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

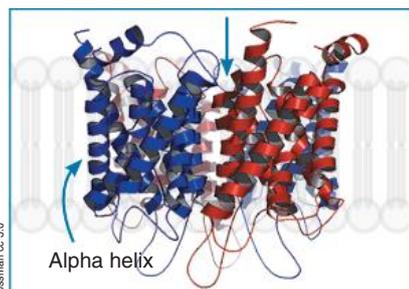


## What can cross a lipid bilayer?

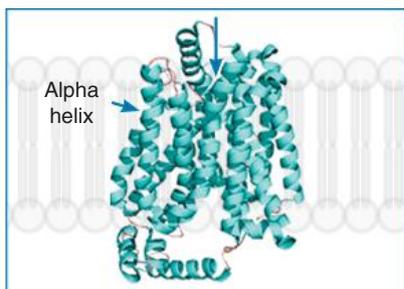


### What do proteins in the cell surface membrane really look like?

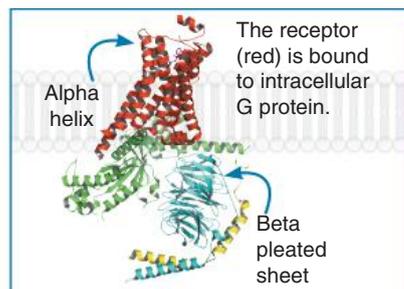
The structure of membrane proteins enables them to perform their particular function in transport, cell signalling, or cell recognition. The proteins are integral to the membrane, and often have parts of their structure projecting from both internal and external sides of the membrane. Note the two types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

**Key Idea:** The freeze-fracture technique for preparing and viewing cellular membranes has provided evidence to support the fluid mosaic model of the plasma membrane.

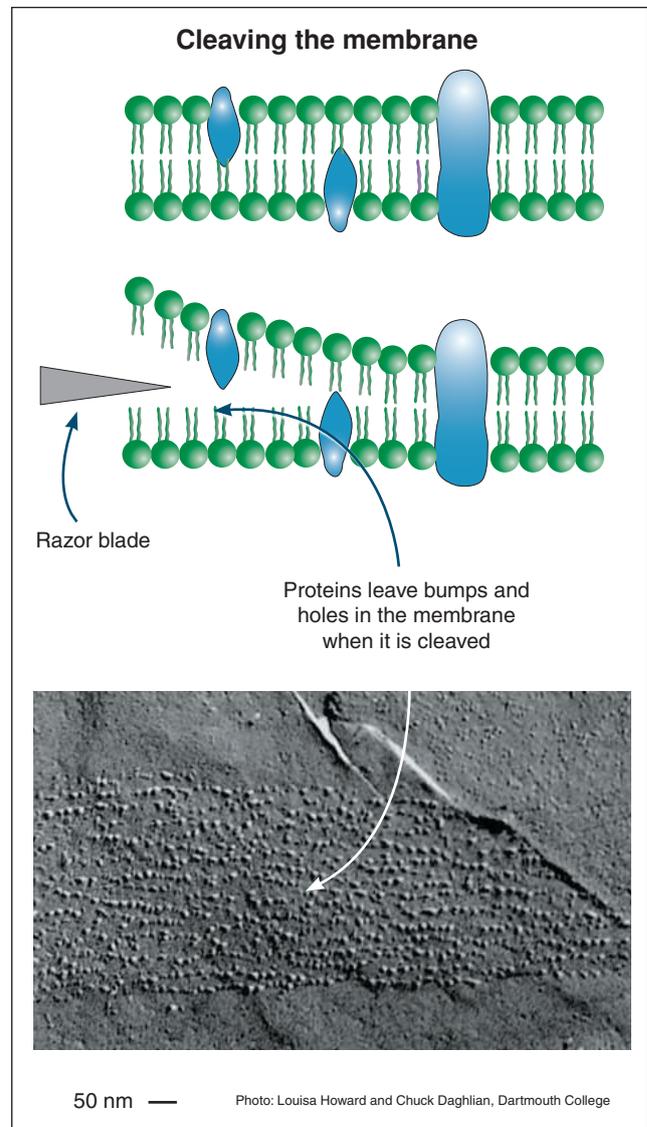
Cellular membranes play many important roles in cells and understanding their structure is important for understanding cellular function. Moreover, understanding the structure and function of membrane proteins is essential to understanding cellular transport processes, and cell recognition and signalling. Cellular membranes are far too small to be seen clearly using light microscopy, and certainly any detail is impossible to resolve. Since early last century, scientists have known that membranes were composed of a lipid bilayer with associated proteins. The original model of membrane structure, proposed by Davson and Danielli, was the unit membrane (a lipid bilayer coated with protein). This model was later modified by Singer and Nicolson after the discovery that the protein molecules were embedded *within* the bilayer rather than coating the outside. But how did they find out just how these molecules were organised?

The answers were provided with electron microscopy, and one technique in particular – **freeze fracture**. As the name implies, freeze fracture, at its very simplest level, is the freezing of a cell and then fracturing it so the inner surface of the membrane can be seen using electron microscopy. Membranes are composed of two layers of phospholipids held together by weak intermolecular bonds. These split apart during fracture.

The procedure involves several steps:

- ▶ Cells are immersed in chemicals that alter the strength of the internal and external regions of the plasma membrane and immobilise any mobile macromolecules.
- ▶ The cells are passed through a series of glycerol solutions of increasing concentration. This protects the cells from bursting when they are frozen.
- ▶ The cells are mounted on gold supports and frozen using liquid propane.
- ▶ The cells are fractured in a helium-vented vacuum at  $-150^{\circ}\text{C}$ . A razor blade cooled to  $-170^{\circ}\text{C}$  acts as both a cold trap for water and the fracturing instrument.
- ▶ The surface of the fractured cells may be evaporated a little to produce some relief on the surface (known as etching) so that a three-dimensional effect occurs.
- ▶ For viewing under an electron microscope (EM), a replica of the cells is made by coating them with gold or platinum to  $\sim 3$  nm thick. A layer of carbon around 30 nm thick is used to provide contrast and stability for the replica.
- ▶ The samples are then raised to room temperature and placed into distilled water or digestive enzymes, which separates the replica from the sample. The replica is then rinsed in distilled water before it is ready for viewing.

The freeze fracture technique provided the necessary supporting evidence for the current fluid mosaic model of membrane structure. When cleaved, proteins in the membrane left impressions that showed they were embedded into the membrane and not a continuous layer on the outside as earlier models proposed.



1. Explain how freeze-fracture studies provided evidence for our current model of membrane structure: \_\_\_\_\_

---



---



---



---

2. The Davson and Danielli model of membrane structure was the unit membrane; a phospholipid bilayer with a protein coat. Explain how the freeze-fracture studies showed this model to be flawed:

---



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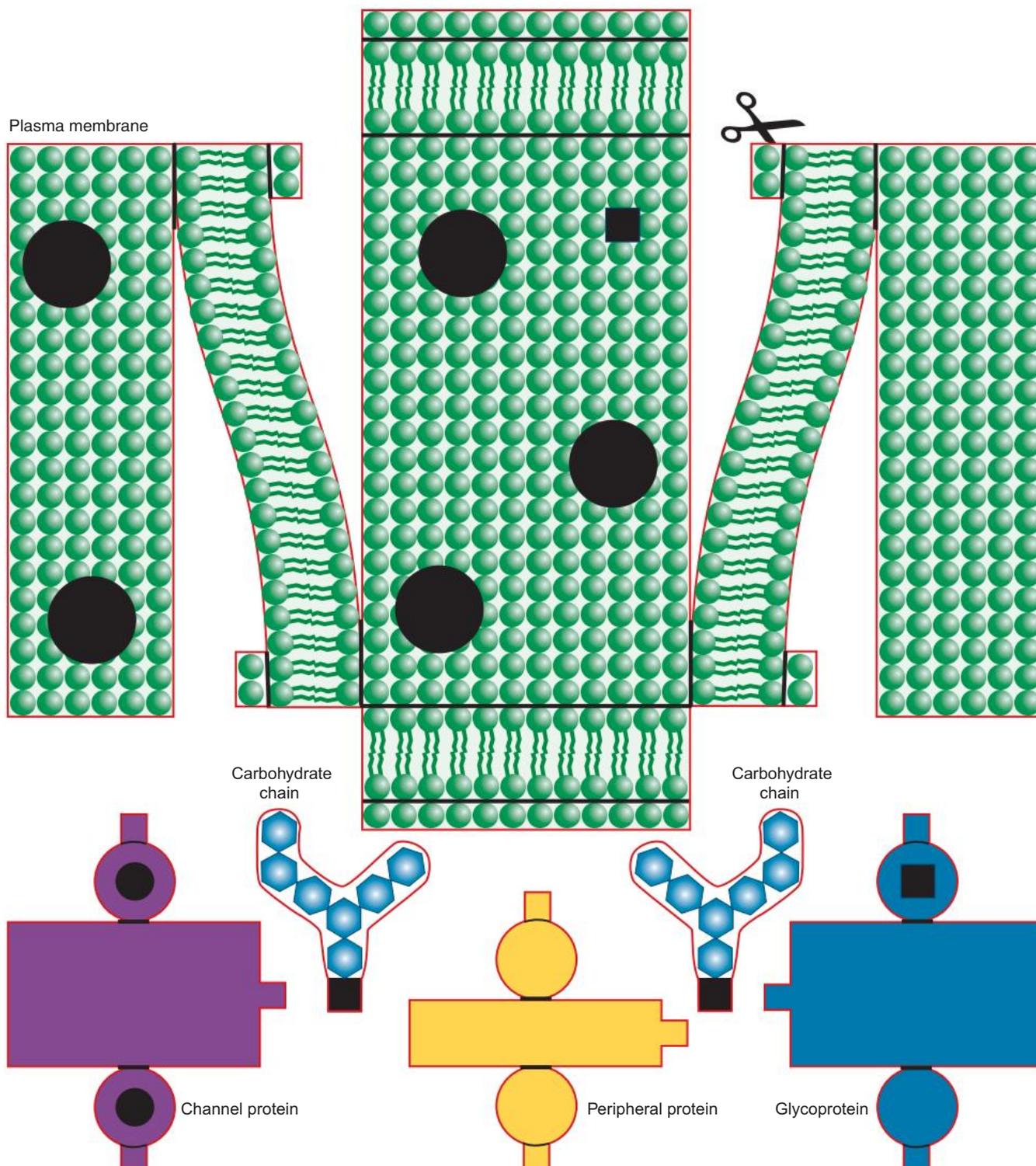
# Modelling the Plasma Membrane

**Key Idea:** Plasma membranes exist as dynamic 3D structures.

Plasma membranes are often shown as two dimensional structures. Even when drawn to represent a three dimensional

structure, the nature of the plasma membrane may not be obvious. In this activity you will build a simple three dimensional plasma membrane.

1. Cut out the plasma membrane along the red lines. Cut out the solid black circles. Fold along the black lines. Use clear tape to stick the sides together to produce a 3D, slightly curved box.
2. Cut out the three proteins along the red lines. Fold along the black lines and use clear tape to produce three cylinders.
3. Cut out both carbohydrate chains. Fold over the black squares. Stick one to the black square on the end of the glycoprotein. Stick the other to the black square on the plasma membrane surface to produce a glycolipid.
4. Slide the two transmembrane proteins into the channels created by cutting out the circles from the plasma membrane.
5. Slide the peripheral protein about halfway into the final hole. This completes your plasma membrane model.



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# 29

## Chapter Review: Did You Get It?

1. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

- cell wall .....
- chloroplast .....
- cytoplasm .....
- eukaryotic .....
- magnification .....
- mitochondrion .....
- nucleus .....
- organelle .....
- prokaryotic .....
- resolution .....

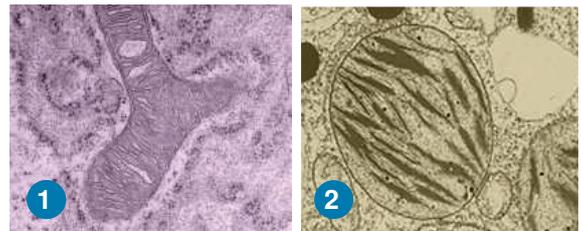
- A** Organelle responsible for producing the cell's ATP. It appears oval in shape with an outer double membrane and a convoluted interior membrane. Contains its own circular DNA.
- B** With reference to cells, lacking a distinct nucleus and with no membrane-bound organelles DNA is present as a single, circular, naked chromosome.
- C** Cell types with a distinct membrane-bound nucleus and membrane-bound organelles.
- D** The ability to distinguish between close together but separate objects.
- E** The watery contents of the cell within the plasma membrane, but excluding the contents of the nucleus.
- F** A structural and functional part of the cell usually bound within its own membrane. Examples include the mitochondria and chloroplasts.
- G** Membrane-bound region within a eukaryotic cell where the chromosomes are found.
- H** An organelle found in photosynthetic organisms such as plants, which contains chlorophyll and in which the reactions of photosynthesis take place.
- I** A structure, present in plants and bacteria, which is found outside the plasma membrane and gives rigidity to the cell.
- J** How many times larger an image is than the original object.

2. (a) Identify organelle 1: \_\_\_\_\_

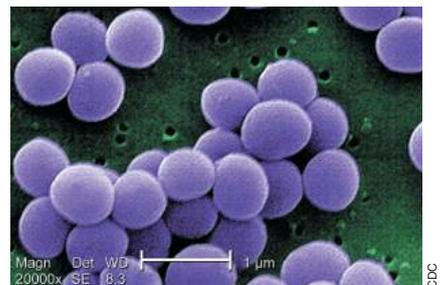
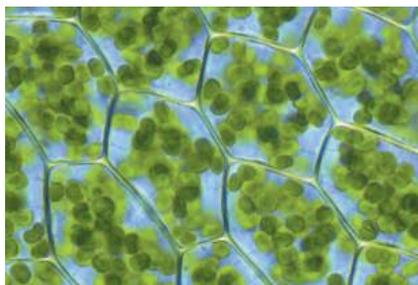
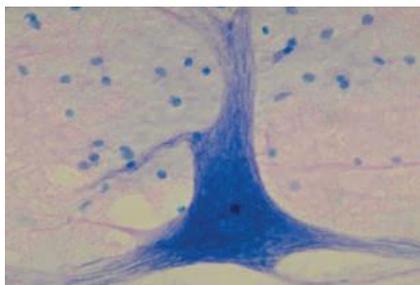
(b) The organelle in (a) is found in a plant cell / animal cell / both plant and animal cells (circle the correct answer).

(c) Identify organelle 2: \_\_\_\_\_

(d) The organelle in (c) is found in a plant / animal cell / plant and animal cell (circle the correct answer).



3. For each of the following images of cells, identify the cell type (plant, animal, bacterial), give a brief reason for your decision and note any organelles or structures visible.



- (a) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (c) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

4. Match the start of the sentences on the left below to the end of the sentences on the right:

- Cells are the basic...
- A cell is enclosed by a plasma membrane...
- Plant cells have...
- Animal cells do...
- Eukaryotic cells contain many different types of organelle...
- Each organelle carries out a specific function in the cell...
- Prokaryotic cells...

- ...such as photosynthesis or respiration.
- ...a cell wall of cellulose.
- ...do not contain membrane-bound organelles.
- ...units of life.
- ...not have a cell wall.
- ...some of which are composed of membranes.
- ...made of a phospholipid bilayer

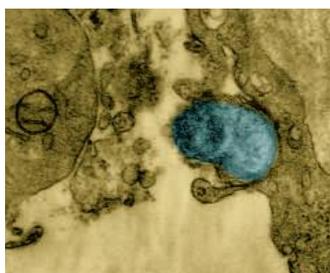
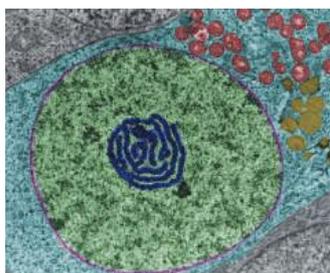
**Key terms**

acetyl coA  
 activation energy  
 active site  
 active transport  
 ATP  
 ATP synthase  
 Calvin cycle  
 catalyst  
 cellular respiration  
 chlorophyll  
 chloroplast  
 denaturation  
 diffusion  
 electron transport chain  
 enzyme  
 fermentation  
 glucose  
 glycolysis  
 grana  
 Krebs cycle  
 light dependent phase  
 light independent phase  
 link reaction  
 matrix  
 metabolic pathway  
 metabolism  
 mitochondrion  
 NAD/NADH  
 NADP/NADPH  
 osmosis  
 oxidative phosphorylation  
 passive transport  
 photosynthesis  
 photosystem  
 pyruvate  
 RuBisCo  
 substrate level phosphorylation  
 thylakoid discs

*Inquiry question: How do cells coordinate activities within their environment?*

**The movement of materials into and out of cells***Key skills and knowledge*

- |                          |   |                                 |
|--------------------------|---|---------------------------------|
| <input type="checkbox"/> | 1 Describe how cells exchange substances by diffusion (including facilitated diffusion) and osmosis. Relate the exchange of materials across membranes to the surface area-volume ratio, concentration gradient, and the characteristics of the materials being exchanged. Explain how cells overcome the limitations to cell size. | <b>31-34</b><br><b>36 38 43</b> |
| <input type="checkbox"/> | 2 <b>PRAC</b> Investigate diffusion across membranes using a model system.  | <b>31</b>                       |
| <input type="checkbox"/> | 3 <b>PRAC</b> Investigate the effect of cell size on the rate and efficiency of diffusion.  | <b>35</b>                       |
| <input type="checkbox"/> | 4 <b>PRAC</b> 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.   | <b>37</b>                       |
| <input type="checkbox"/> | 5 Examine the role of active transport (including ion pumps, cotransport, and exo- and endocytosis). What distinguishes active transport mechanisms from forms of passive transport and why is active transport important, despite its energetic costs.   | <b>39-43</b>                    |

**Cell requirements***Key skills and knowledge*

- |                          |  |                              |
|--------------------------|--|------------------------------|
| <input type="checkbox"/> | 6 Understand that cells exchange matter and energy with their environment. Describe the general requirements of cells, including but not limited to: <ul style="list-style-type: none"> <li>i The need for energy, including light and chemical energy in complex molecules.</li> <li>ii The need for matter, including nutrients, gases, and ions.</li> <li>iii The need to remove waste materials. What types of waste materials are produced by cells, what is their origin, and how do cells get rid of them?</li> </ul> | <b>30 44</b><br><b>45 60</b> |
|--------------------------|--|------------------------------|

**Investigating biochemical processes in cells***Key skills and knowledge*

- |                          |  |                 |
|--------------------------|--|-----------------|
| <input type="checkbox"/> | 7 Explain the production and role of ATP in cells, including aerobic and anaerobic ATP production. Describe ATP's central role in biochemical processes.                                 | <b>46 47</b>    |
| <input type="checkbox"/> | 8 Describe cellular respiration, including the inputs, outputs, and location of glycolysis, the Krebs cycle, and the electron transport chain, and the events occurring in those stages. | <b>48 50-51</b> |
| <input type="checkbox"/> | 9 <b>PRAC</b> Use a simple respirometer to measure respiration in a simple organism.   | <b>49</b>       |
| <input type="checkbox"/> | 10 <b>PRAC</b> Investigate the effect of different substrates on the rate of fermentation in yeast.  | <b>52</b>       |
| <input type="checkbox"/> | 11 Describe photosynthesis, including the main inputs, outputs, and location of the light dependent and light independent reactions, and the events occurring in those phases.           | <b>53 54 56</b> |
| <input type="checkbox"/> | 12 <b>PRAC</b> Use a simple system to investigate factors affecting rate of photosynthesis.  | <b>55</b>       |
| <input type="checkbox"/> | 13 <b>PRAC</b> Use simple chromatography to isolate and visualise photosynthetic pigments.   | <b>57</b>       |
| <input type="checkbox"/> | 14 Describe how enzymes work to control biochemical processes in cells, including removal of cellular products and wastes, such as hydrogen peroxide.                                    | <b>60-64</b>    |
| <input type="checkbox"/> | 15 <b>PRAC</b> Using turnip peroxidase, investigate factors affecting enzyme activity in cells.  | <b>65</b>       |

# 30 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.

- Plant and algal cells containing chloroplasts and some bacteria use light from the Sun to power chemical reactions that build organic molecules. These can then be used to power other reactions in the cell or build macromolecules.
- Animals and other consumers 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

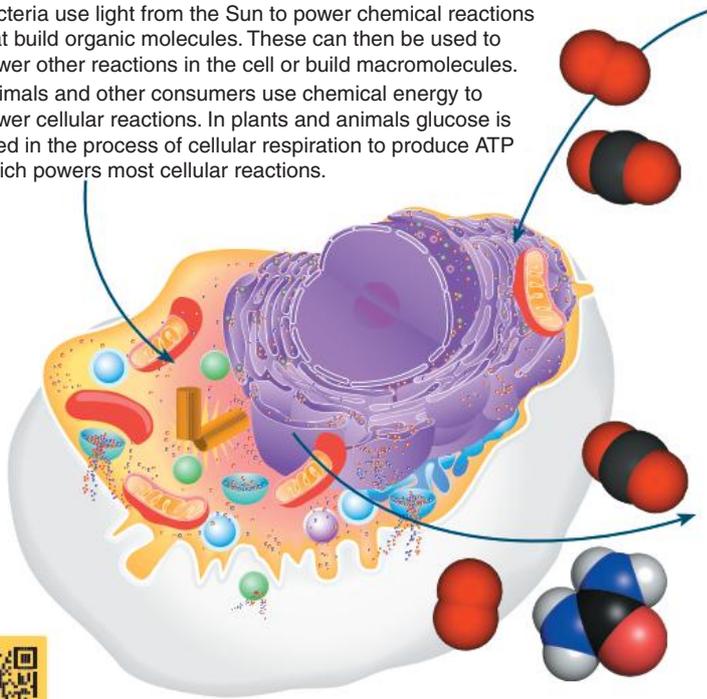
Cells require molecules and ions to build macromolecules and help carry out cellular reactions.

- 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 obtain these (by eating plants or plant eaters) to use as building blocks for their proteins.
- Various metal ions are also needed. Some are needed in relatively large amounts (e.g. such as  $\text{Na}^+$  for nerve cell function in animals). Other metal ions are only 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.



Thermophiles can survive in temperatures as high as 122°C. Their enzymes can not function at the lower temperatures experienced outside environments such as hot thermal pools. Many thermophiles are archaea, though they can be bacteria.



Halophiles are organisms that 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:  
\_\_\_\_\_  
\_\_\_\_\_

# 31 Cells Exchange Substances by Diffusion

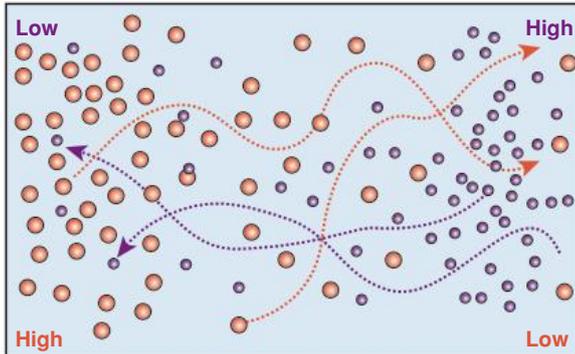
**Key Idea:** Diffusion is the movement of molecules down a concentration gradient.

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 helped 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.

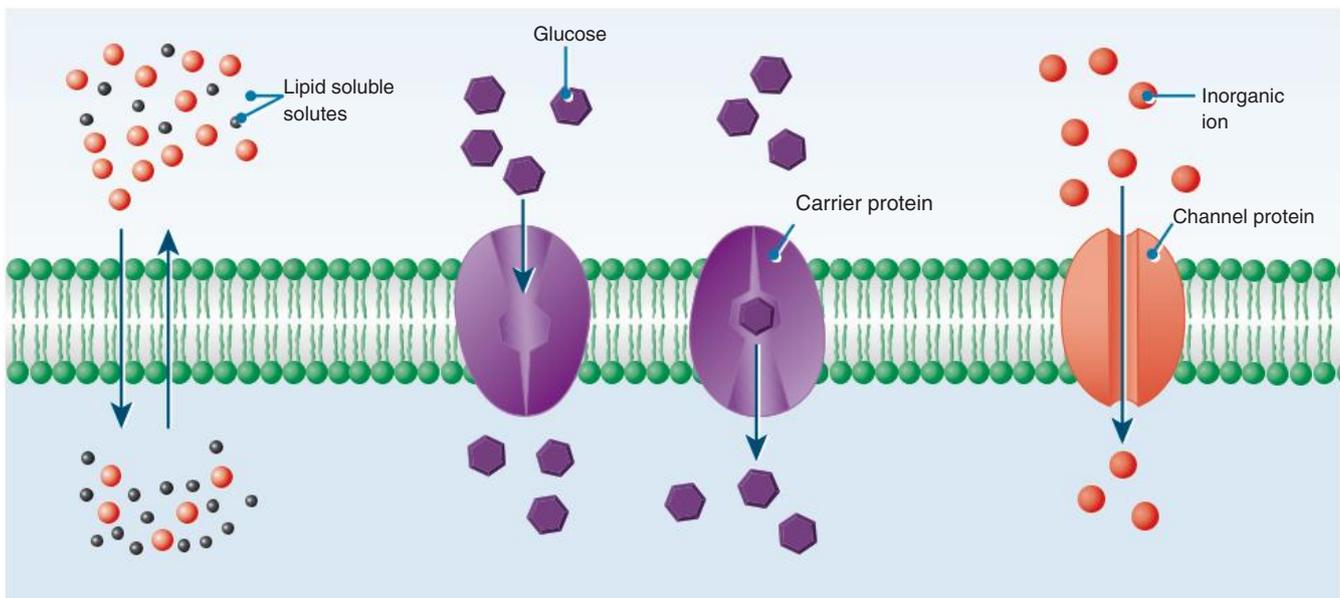


### Concentration gradient

*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.



1. What do the three types of diffusion described on the previous page 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

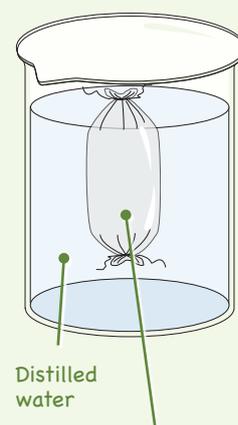
Diffusion through a partially permeable membrane can be modelled using dialysis tubing. The pores of the dialysis tubing determine the size of the molecules that can pass through. In the experiment described below, you will investigate how glucose will diffuse down its concentration gradient from a high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



### Investigation 3.1 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.



Distilled water  
Solution containing starch and glucose

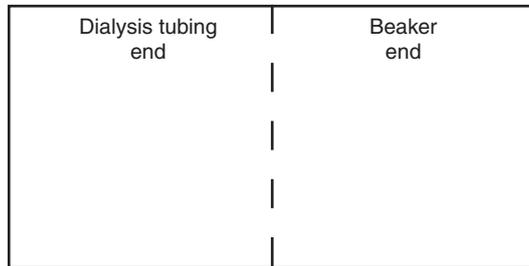
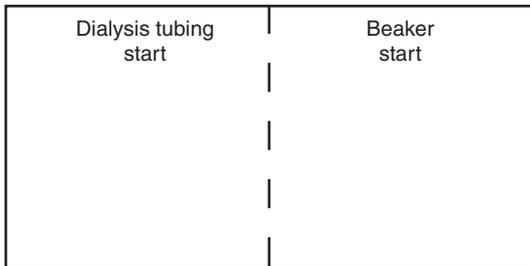
5. What is the aim of the experiment? \_\_\_\_\_  
 \_\_\_\_\_
6. What part of a cell does the dialysis tubing represent? \_\_\_\_\_
7. Why was it important to wash the dialysis tubing before placing it into the beaker of distilled water? \_\_\_\_\_  
 \_\_\_\_\_

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:



\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 32 Investigating Transport Across Membranes

**Key Idea:** The rate of diffusion of molecules through the plasma membrane can be determined by measuring the change in light absorbance as a solution of red blood cells haemolyses.

How a cell behaves when suspended in a solution depends on whether or not the molecules or ions in the solution can cross the plasma membrane. If red blood cells (RBCs) are suspended in a concentrated solution of molecules that can

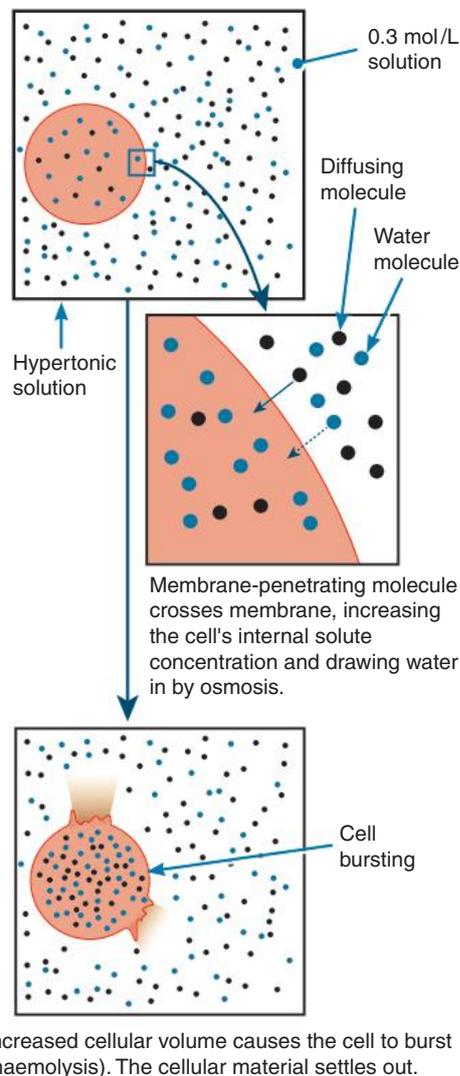
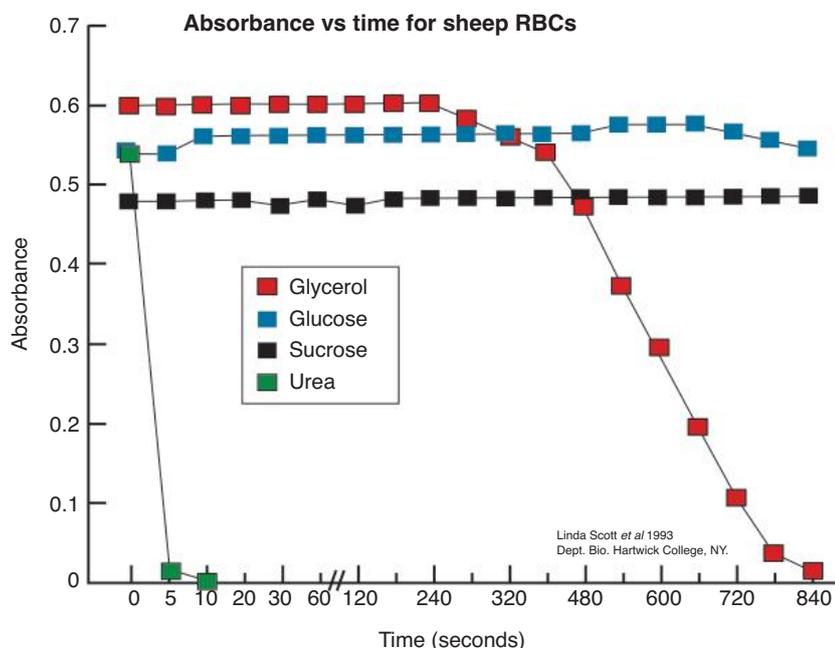
readily diffuse across the membrane, the molecules will enter the RBCs by diffusing down their concentration gradient. This will draw water into the RBCs (by osmosis) and they will burst (haemolyse). When the RBCs burst, the cellular material settles out of suspension and the solution becomes clear. By using a spectrophotometer to measure the rate at which the solution becomes clear, it is possible to determine the rate at which the molecules are crossing the plasma membrane.

## The aim

To investigate how the size and membrane solubility of molecules affects the rate of diffusion across the plasma membrane.

## The method

- ▶ 0.3 mol/L solutions of glucose, sucrose, urea, and glycerol were prepared (this concentration is greater than the cell internal concentration). A blank solution of distilled water was also prepared. Molecular weights (MW) are as follows: glucose (MW 180), sucrose (MW 342), urea (MW 60), and glycerol (MW 92).
- ▶ Both urea and glycerol readily diffuse across the plasma membrane. Glucose is transported across the membrane by a carrier protein.
- ▶ 3 mL of each solution was mixed with 0.1 mL of a sheep RBC suspension and added to cuvettes. The cuvettes were placed into a spectrophotometer and absorbance measured over 15 minutes. The results are plotted below:



- (a) Which molecule crosses the membrane the fastest? \_\_\_\_\_

(b) Which molecule appears to be unable to cross the plasma membrane? \_\_\_\_\_

(c) List the molecules in order of their ability to cross the plasma membrane (fastest to slowest):  
\_\_\_\_\_
- (a) What is the largest molecule used in the experiment? \_\_\_\_\_

(b) What is the smallest molecule used in the experiment? \_\_\_\_\_

(c) How does size affect the rate at which molecules can cross the plasma membrane? \_\_\_\_\_
- Why don't the RBCs in the glucose solution haemolyse even though glucose is transported across the membrane?  
\_\_\_\_\_  
\_\_\_\_\_



# 33 Diffusion and Cell Size

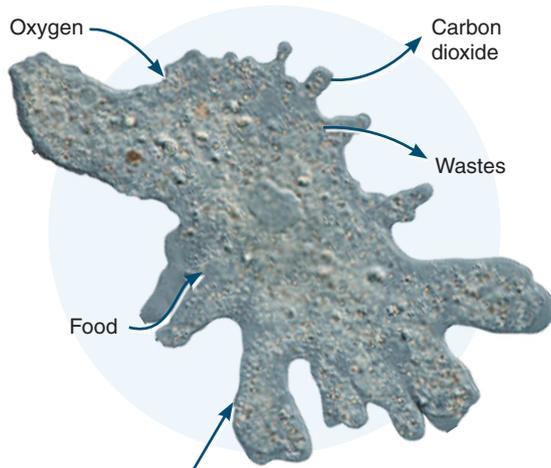
**Key Idea:** Diffusion is less efficient in cells with a small surface area relative to their volume than in cells with a large surface area relative to their volume.

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).



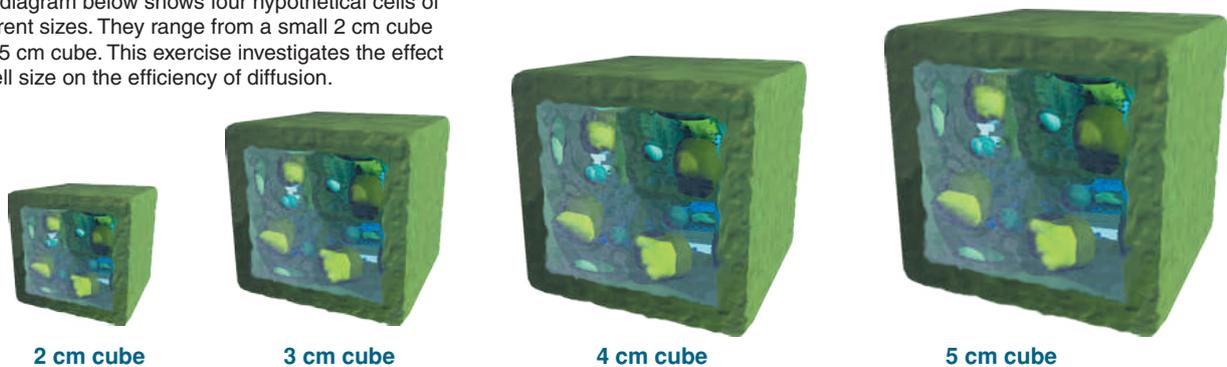
The **plasma membrane**, which surrounds every cell, regulates movements of substances into and out of the cell. For each square micrometre of membrane, only so much of a particular substance can cross per second.

## 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.



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.



- 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	Volume	Surface area to volume ratio
2 cm cube	$2 \times 2 \times 6 = 24 \text{ cm}^2$ (2 cm x 2 cm x 6 sides)	$2 \times 2 \times 2 = 8 \text{ cm}^3$ (height x width x depth)	24 to 8 = 3:1
3 cm cube			
4 cm cube			
5 cm cube			



# 34 Overcoming Limitations to Cell Size

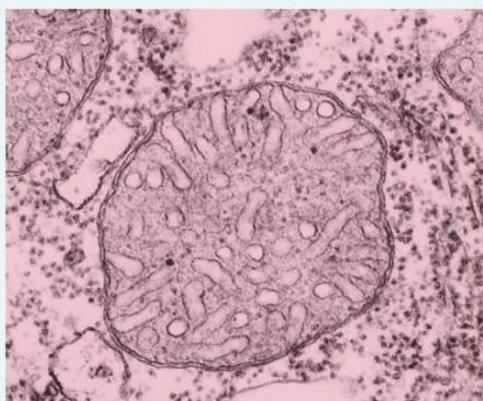
**Key Idea:** Larger cells can maintain high surface area to volume ratios by having a non-spherical shape and membrane extensions. Organelles also increase functional efficiency.

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 (SA:V). 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

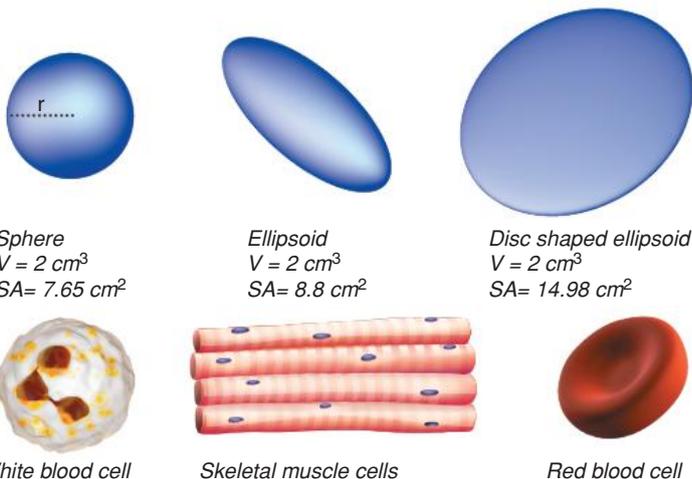
Cells have a wide range of sizes. Large eukaryotic cells may reach 100  $\mu\text{m}$  in diameter, whereas bacteria typically only reach a tenth of that. Eukaryotic cells can remain efficient at larger sizes in part because they contain **organelles**, which concentrate associated materials (such as 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

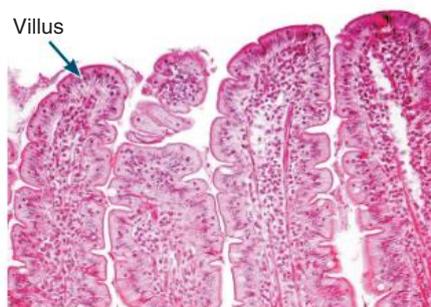
One way of increasing a cell's surface area while retaining the same volume is to elongate the cell. An elongated sphere (an ellipsoid, e.g. a rod shaped cell) has a greater surface area than a sphere of the same volume. In this way, a cell can grow larger while still gaining the materials it needs.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



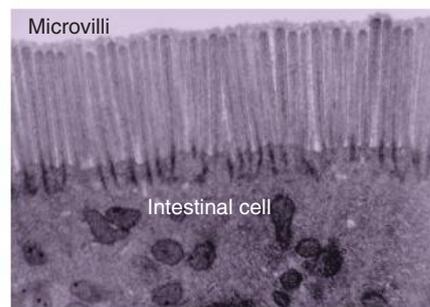
By flattening the ellipsoid along one axis and stretching it along the other two to form a disc, surface area increases while the volume remains the same.



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 nutrients and binding digestive enzymes.

1. Use the formulae **surface area** =  $4\pi r^2$  and **volume** =  $(\frac{4}{3})\pi r^3$  (where  $\pi = 3.14$ ) to calculate **surface area**, **volume**, and **SA:V ratio** of spherical cells 1 and 2 below:

(a) Cell 1 radius: 2  $\mu\text{m}$ , SA: \_\_\_\_\_ V: \_\_\_\_\_ SA:V ratio: \_\_\_\_\_

(b) Cell 2 radius: 10  $\mu\text{m}$ , SA: \_\_\_\_\_ V: \_\_\_\_\_ SA:V ratio: \_\_\_\_\_

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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# 35 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



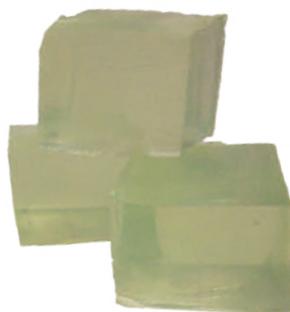
Glass beaker



Paper towel



Timer



Agar blocks infused with phenolphthalein

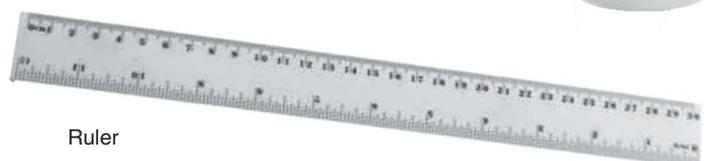


Laboratory tongs



Scalpel

Sodium hydroxide (NaOH) solution



Ruler



# 36 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

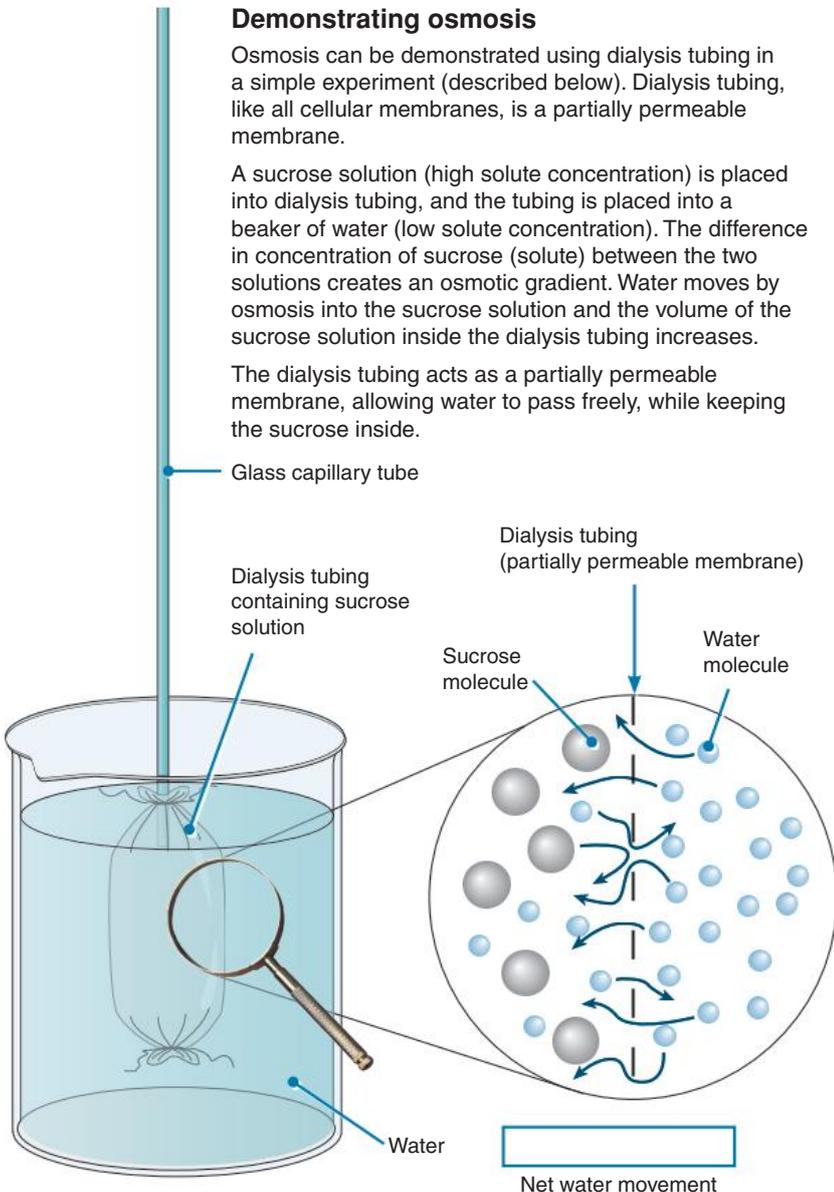
partially permeable membrane allows some molecules, but not others, to pass through. Water molecules will diffuse across a partially permeable membrane until an equilibrium is reached and net movement is zero. The plasma membrane of a cell is an example of a partially permeable membrane. Osmosis is a 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 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?  
 \_\_\_\_\_  
 \_\_\_\_\_



# 37 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.



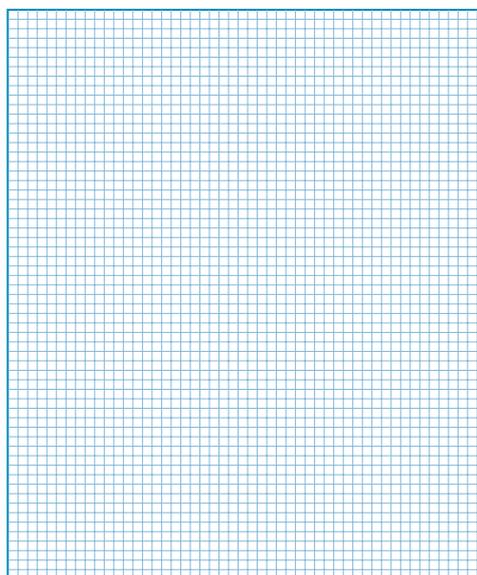
## Investigation 3.2 Estimating osmolarity

See appendix for equipment list.

- 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.
- Peel a potato and cut it into 18 identical cubes  $1\text{ cm}^3$  ( $1\text{ cm} \times 1\text{ cm} \times 1\text{ cm}$ ) or use a cork borer to produce 18 identical cylinders of potato. Pat the potato cubes dry with a paper towel.
- Weigh three cubes together, record their mass in the table below under initial mass. Place the cubes in the beaker of distilled water.
- 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.
- Leave the potato cubes in the solutions for at least 40 minutes (or up to 24 hours).
- 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.
- Repeat for all the other concentrations of sucrose.
- 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).
- 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)		

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



- Use the graph to estimate the osmolarity of the potato (the point where there is no change in mass):  
\_\_\_\_\_
- Which of the solutions are hypotonic? Which are hypertonic?  
\_\_\_\_\_  
\_\_\_\_\_



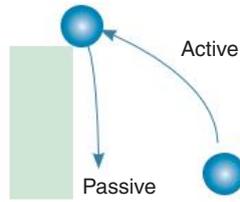
# 39 Active Transport

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

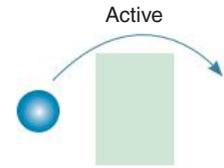
**Active transport** is the movement of molecules (or ions) from

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.

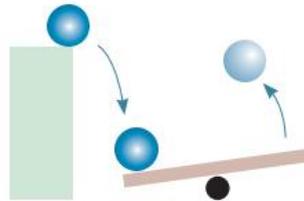
- ▶ The energy for active transport comes from ATP (adenosine triphosphate). Energy is released when ATP is hydrolysed (water is added) forming ADP (adenosine diphosphate) and inorganic phosphate (Pi).
- ▶ Transport (carrier) proteins in the membrane are used to actively transport molecules from one 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.



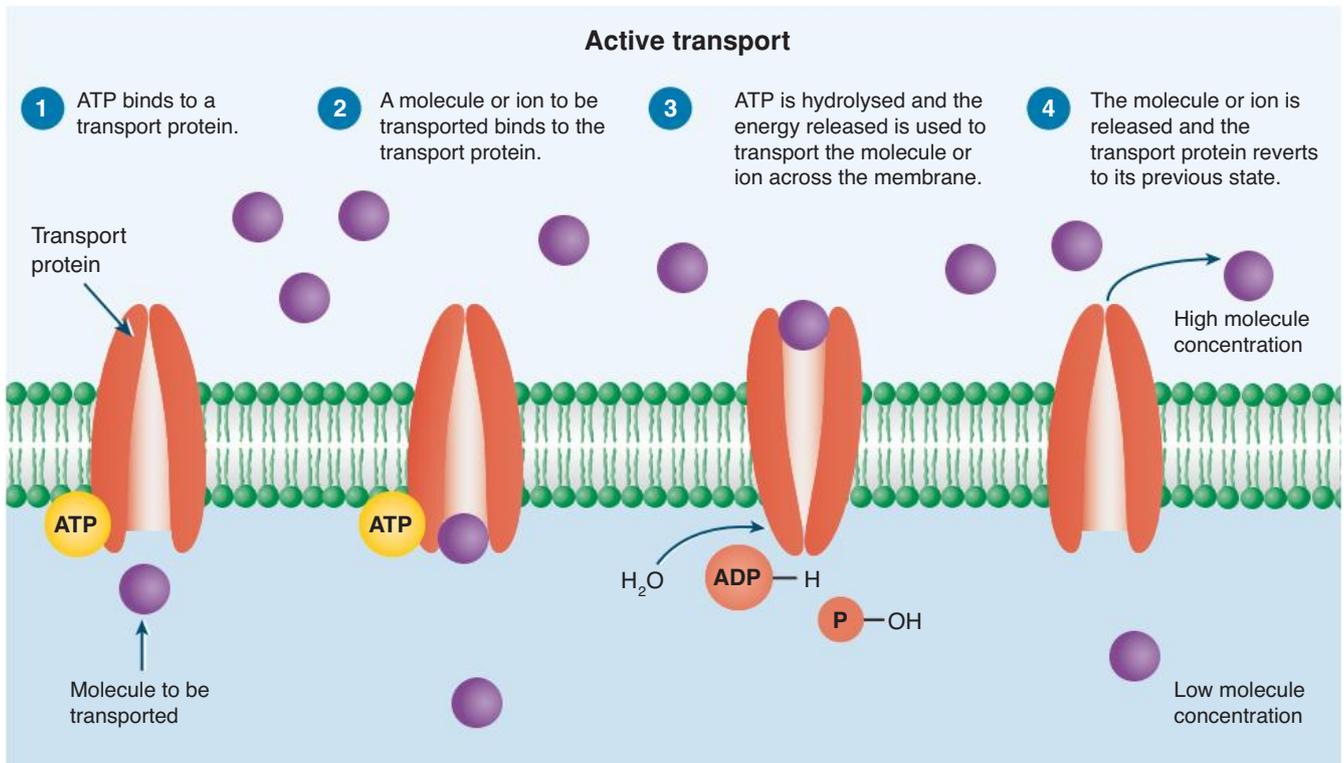
A ball falling is a passive process (it requires no energy input). Replacing the ball requires active energy input.



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).



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? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

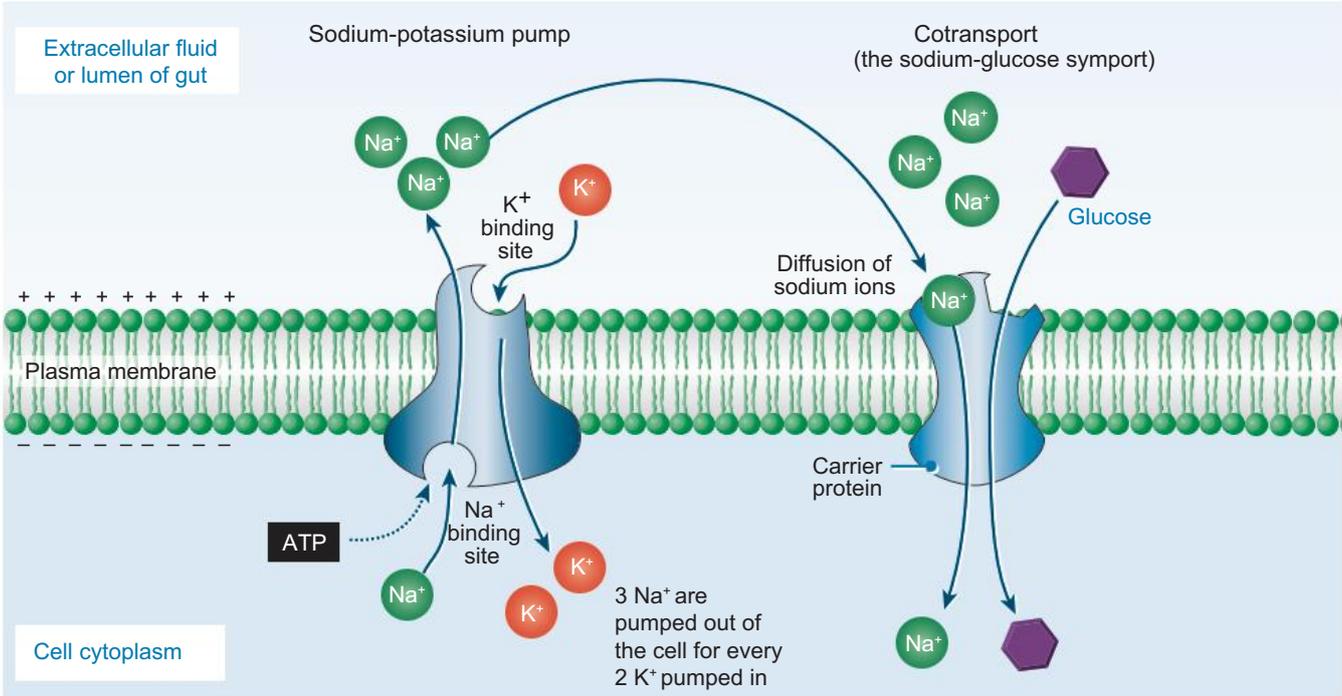


# 40 Ion Pumps and Cotransport

**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.

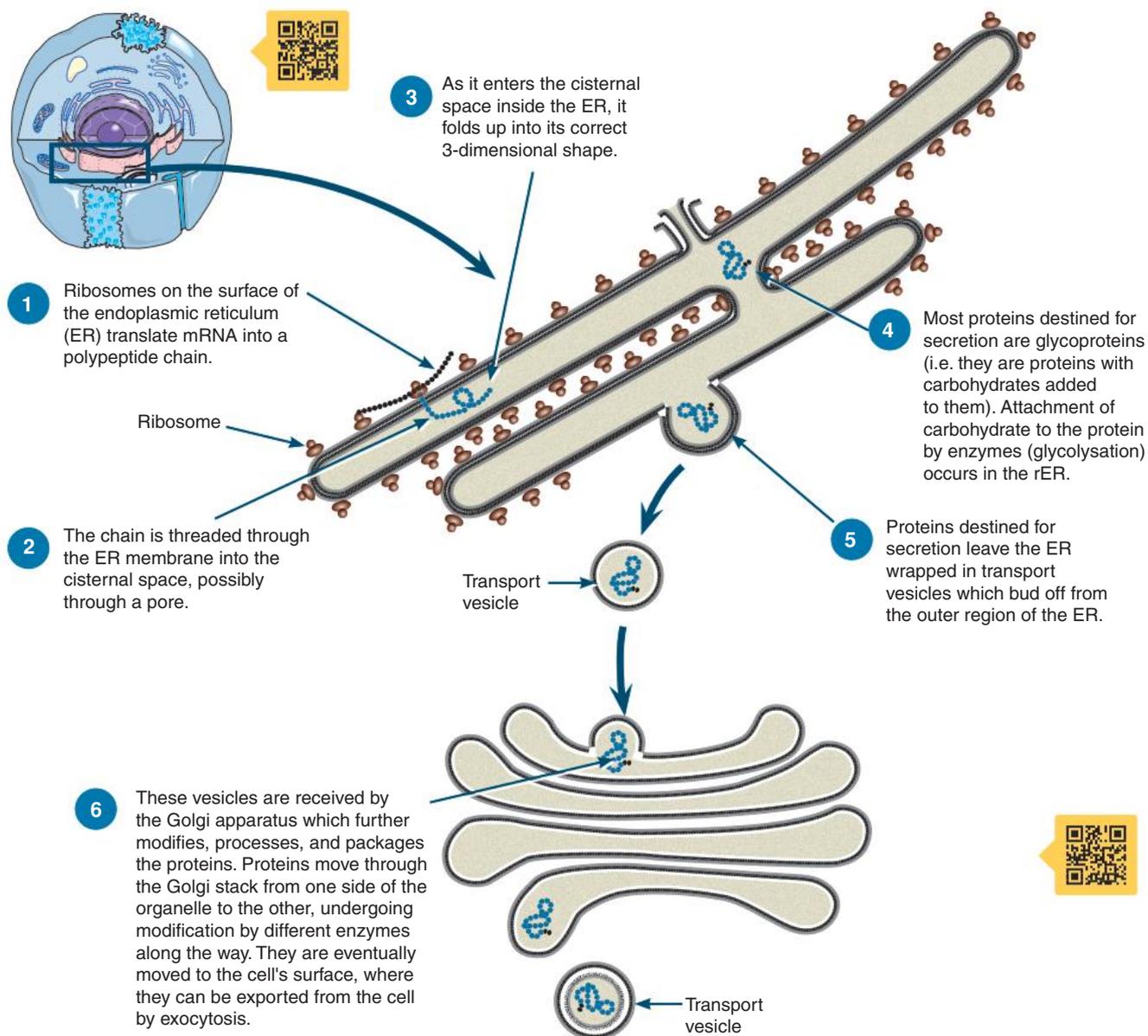
- Why is ATP required for membrane pump systems to operate? \_\_\_\_\_
- (a) Explain what is meant by cotransport: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (b) How is cotransport used to move glucose into the intestinal epithelial cells? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (c) What happens to the glucose that is transported into the intestinal epithelial cells? \_\_\_\_\_
- (a) The sodium-potassium pump uses primary/secondary (delete one) active transport.  
 (b) The sodium-glucose symport uses primary/secondary (delete one) active transport.

# 41 Membranes and the Export of Proteins

**Key Idea:** The synthesis, packaging and movement of macromolecules inside the cell involves coordination between several membrane-bound organelles.

Many proteins need to be modified in order to become

functional. This modification takes place in the rough endoplasmic reticulum (rER). From the rER, proteins are transported to the Golgi where the protein is further modified before being packaged and shipped to its final destination.



1. Explain the role of each of the following organelles in the production and transport of proteins:

(a) Ribosomes: \_\_\_\_\_

(b) Endoplasmic reticulum: \_\_\_\_\_

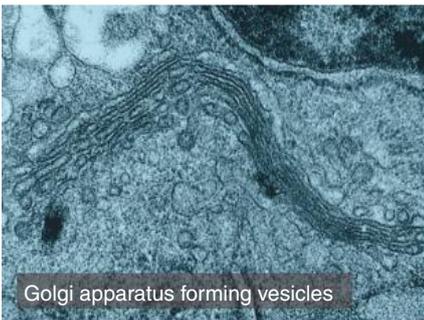
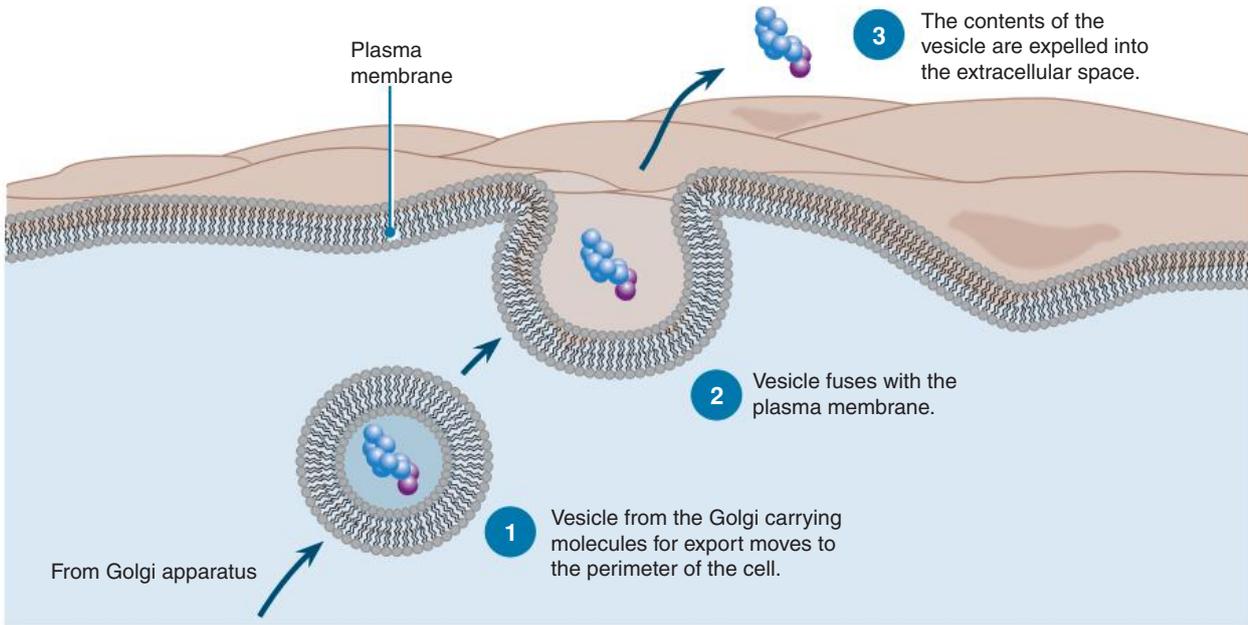
(c) Transport vesicles: \_\_\_\_\_

(d) Golgi apparatus: \_\_\_\_\_

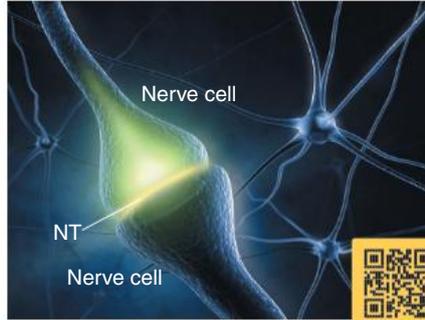


**Exocytosis**

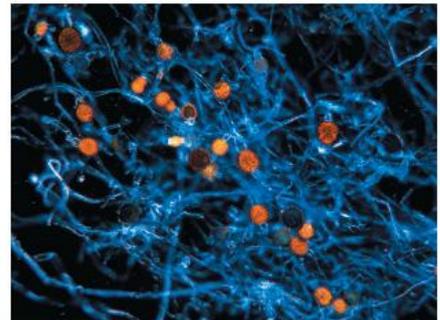
Exocytosis (below) is an active transport process in which a secretory vesicle fuses with the plasma membrane and expels its contents into the extracellular space. In multicellular organisms, various types of cells (e.g. endocrine cells and nerve cells) are specialised to manufacture products, such as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



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).



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).

2. (a) What is the purpose of exocytosis? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Outline what occurs during exocytosis: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. Name two examples of exocytosis within cells:

(a) \_\_\_\_\_

\_\_\_\_\_

(b) \_\_\_\_\_

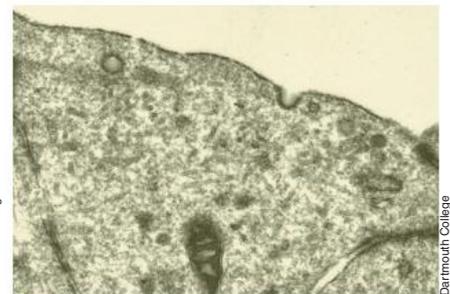
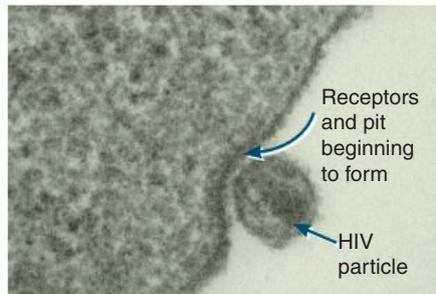
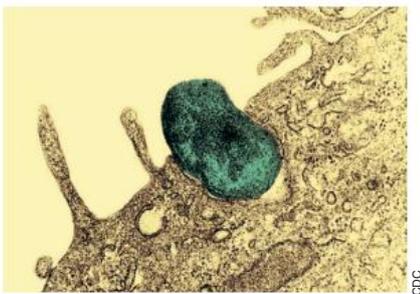
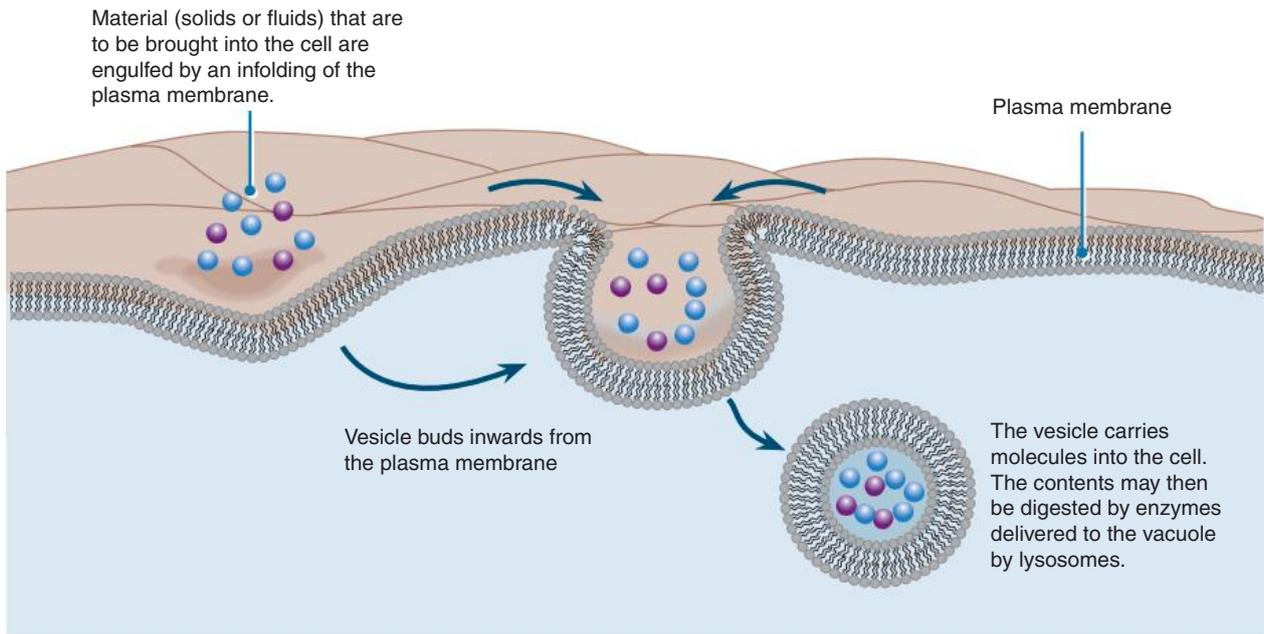
\_\_\_\_\_

# 42 Endocytosis

**Key Idea:** Endocytosis is an active transport process in which the cell engulfs material and draws it in.

**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 flexibility of the plasma membrane.



**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.

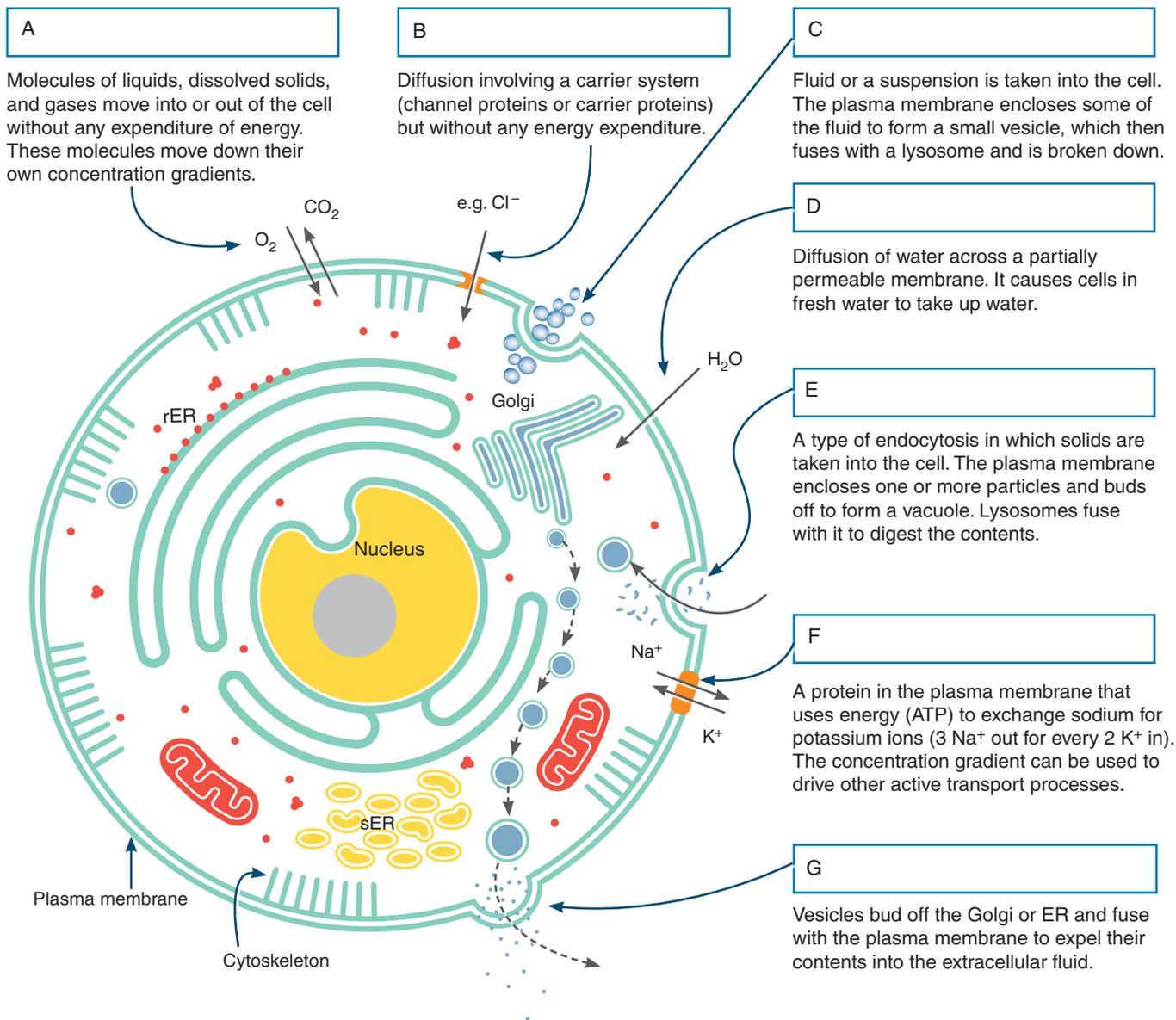
1. What is the purpose on endocytosis? \_\_\_\_\_
2. Is endocytosis active or passive transport? \_\_\_\_\_
3. Describe the following types of endocytosis:
  - (a) Phagocytosis: \_\_\_\_\_
  - (b) Receptor mediated endocytosis: \_\_\_\_\_
  - (c) Pinocytosis: \_\_\_\_\_
4. Explain how the plasma membrane can form a vesicle: \_\_\_\_\_

# 43 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 provided to complete the activity.

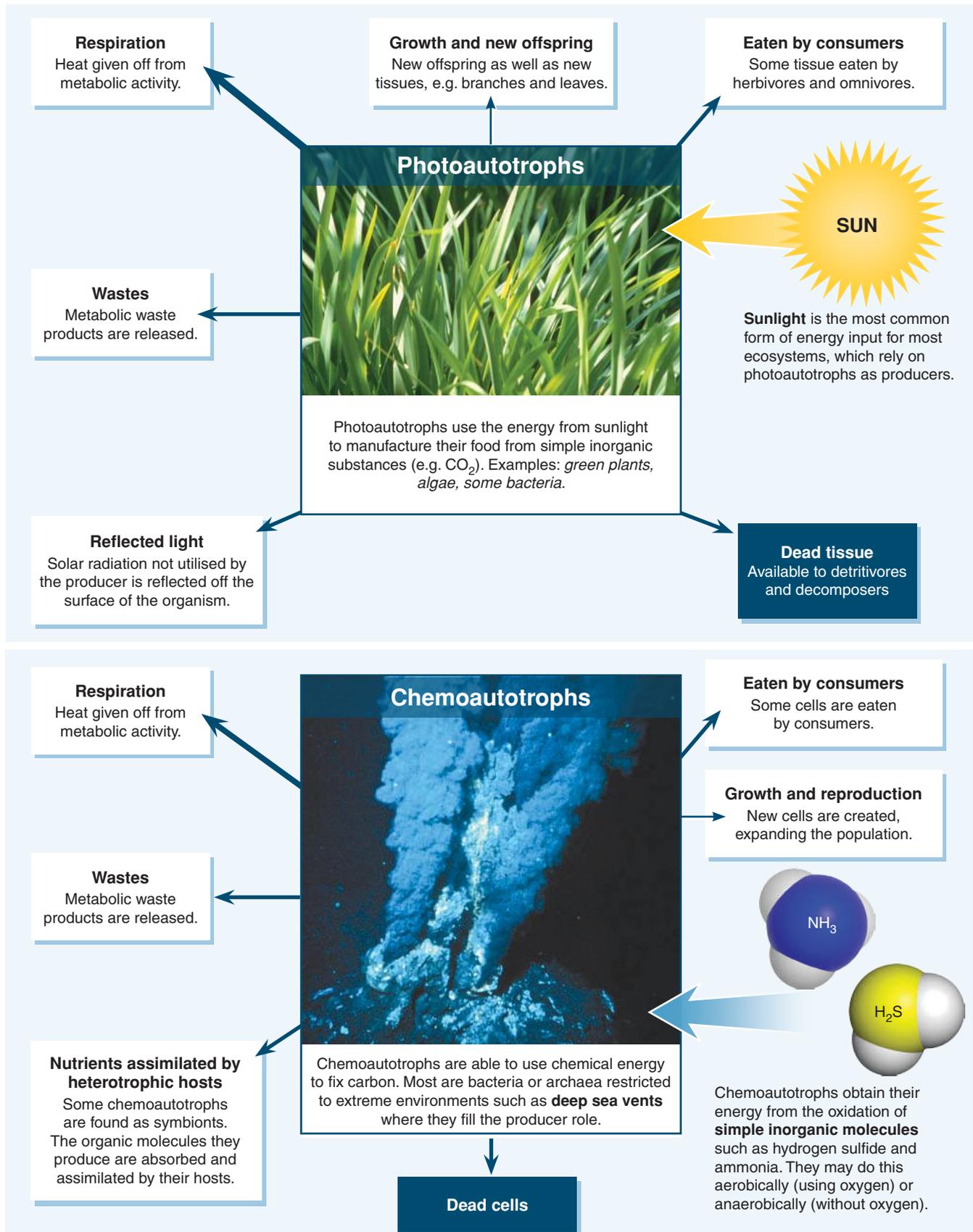


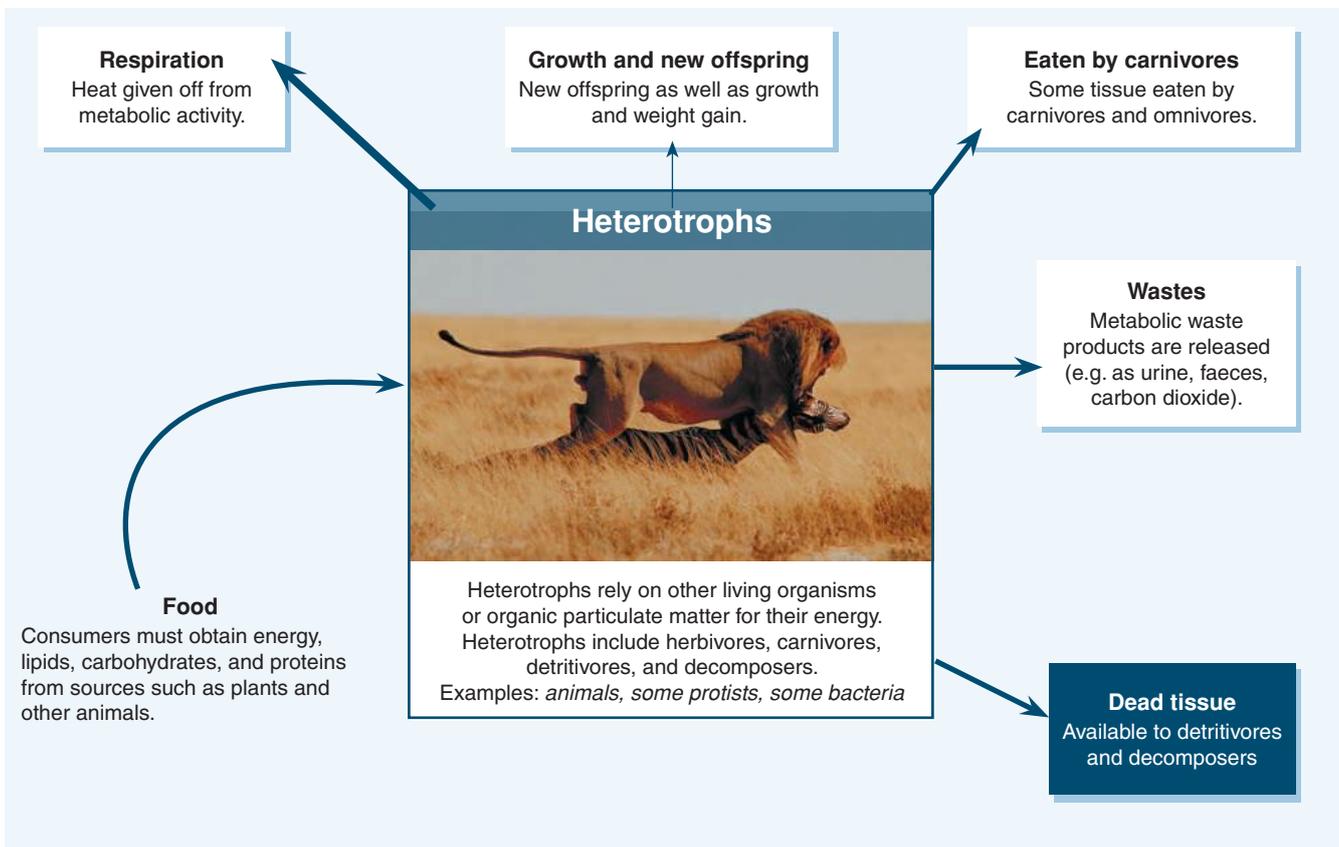
- Identify each of the processes (A-G) described in the diagram above in the spaces provided. Indicate whether the transport process is active or passive by using **A** for active and **P** for passive.
- Identify the transport mechanism involved in each of the following processes in cells:
  - Uptake of extracellular fluid by liver cells: \_\_\_\_\_
  - Capture and destruction of a bacterial cell by a white blood cell: \_\_\_\_\_
  - Movement of water into the cell: \_\_\_\_\_
  - Secretion of digestive enzymes from cells of the pancreas: \_\_\_\_\_
  - Moving H<sup>+</sup> against a concentration gradient to do work: \_\_\_\_\_
- In general terms describe the energy requirements of passive and active transport: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 44 Energy Inputs and Outputs

**Key Idea:** Organisms can be grouped according to how they obtain energy for metabolism. Autotrophs obtain energy from the Sun. Heterotrophs obtain energy from other organisms. Living things obtain their energy for metabolism in two main ways. **Autotrophs** (producers) use the energy in sunlight or inorganic molecules to make their own food. **Heterotrophs**

(consumers) rely on other organisms as a source of energy and carbon. All other organisms depend on producers, even if they do not consume them directly. The energy flow into and out of each trophic (feeding) level can be represented on a diagram using arrows of different sizes to represent relative amounts of energy lost from different trophic levels.





1. Study the diagrams on energy flow relating to **photoautotrophs**, **chemoautotrophs**, and **heterotrophs**. Describe the differences between these categories of organisms with respect to how they obtain their energy:

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2. Describe how energy may be lost from organisms in the form of:

(a) Wastes: \_\_\_\_\_

(b) Respiration: \_\_\_\_\_

3. Explain why so little energy is available for growth and reproduction, regardless of trophic group: \_\_\_\_\_

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4. Describe the ecological importance of chemoautotrophic organisms in deep sea environments: \_\_\_\_\_

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5. In what way is the chemoautotrophic system of the deep sea thermal vent linked to other ecological systems?

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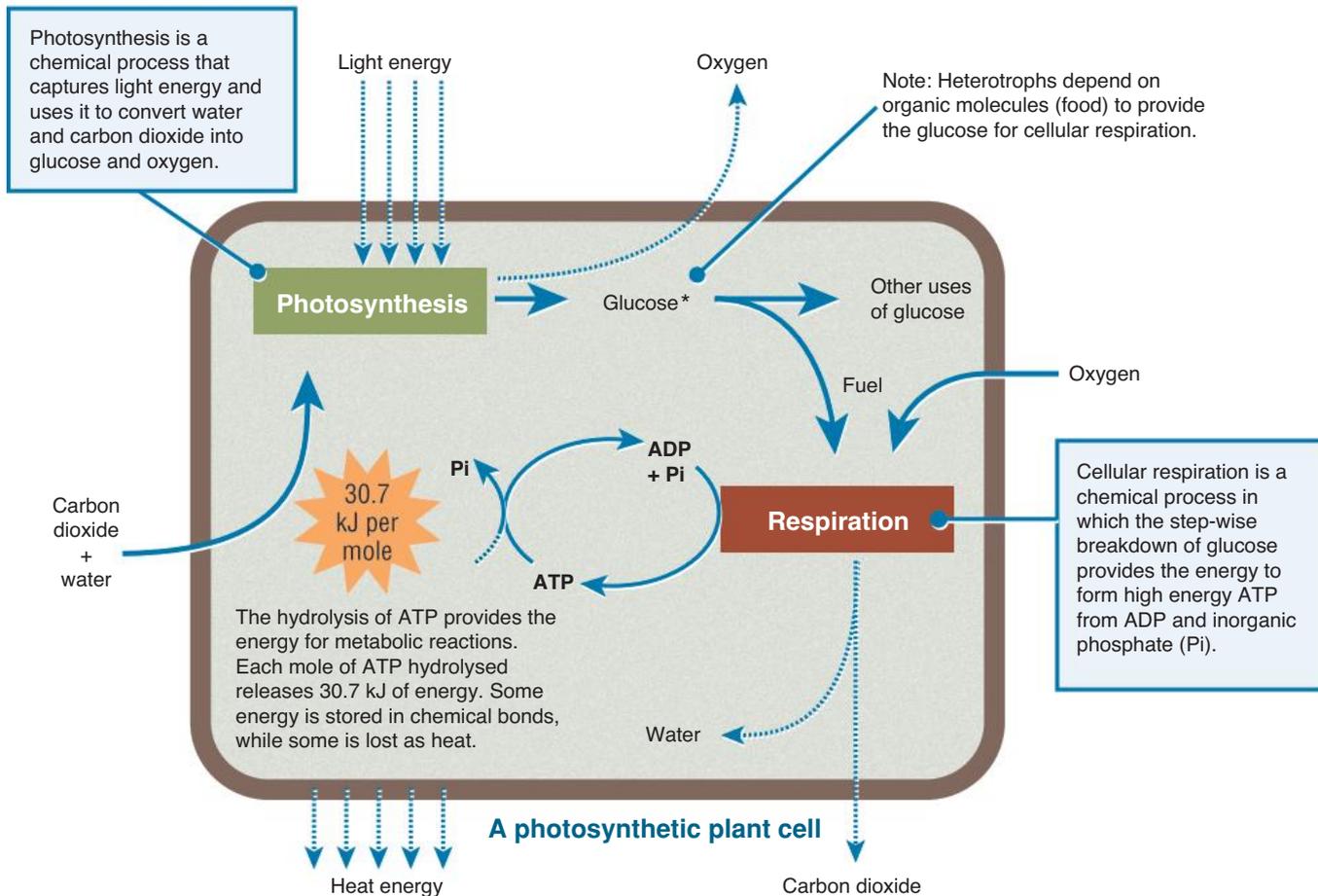


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# 45 Energy Transformation in Cells

**Key Idea:** The energy from sunlight is captured and stored as glucose, which powers the production of ATP in the process of cellular respiration. Hydrolysis of ATP provides the energy to power the chemical reactions in living systems.

Energy flow in the cell of an autotroph (a plant) is shown below. Note that ATP has a central role in acting as an energy carrier to power metabolic reactions. Some of the energy is lost as heat during these reactions.



**It takes energy to break bonds, so how does the hydrolysis of ATP provide energy for metabolic reactions?**

The hydrolysis of ATP is linked to the formation of a reactive intermediate, which can be used to do work. The reactions that make the energy in ATP available occur virtually simultaneously, so the reaction is simplified to omit the intermediates:



- How does ATP act as a supplier of energy to power metabolic reactions? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (a) Identify the ultimate source of energy for most autotrophs: \_\_\_\_\_  
 (b) Identify a group of autotrophic organisms that do not use this source of energy: \_\_\_\_\_  
 \_\_\_\_\_
- Identify the ultimate source of energy for most heterotrophs: \_\_\_\_\_
- In what way are the processes pictured above (photosynthesis and cellular respiration) connected? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



# 46 The Role of ATP in Cells

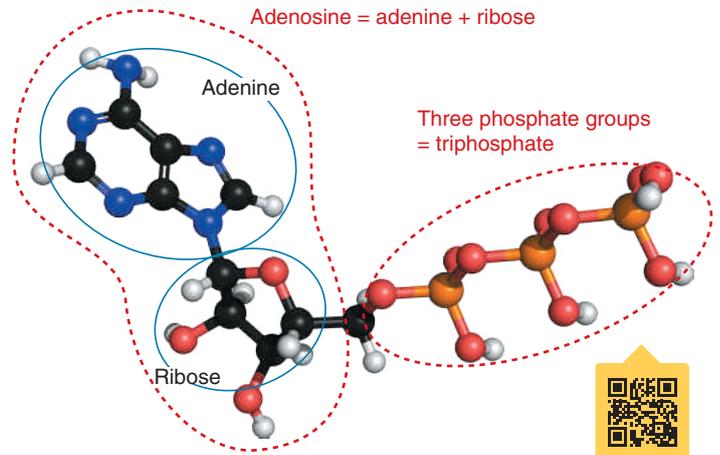
**Key Idea:** ATP transports chemical energy within the cell for use in metabolic processes.

All organisms require energy to perform the metabolic processes required to function and reproduce. This energy is obtained by cellular respiration, a set of metabolic reactions which ultimately convert biochemical energy from 'food'

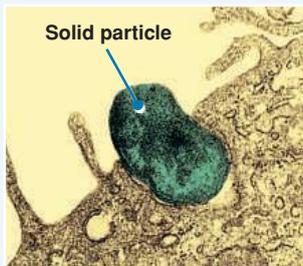
into the nucleotide **adenosine triphosphate (ATP)**. ATP is considered to be a universal energy carrier, transferring chemical energy within the cell for use in metabolic processes such as biosynthesis, cell division, cell signalling, thermoregulation, cell mobility, and active transport of substances across membranes.

## Adenosine triphosphate (ATP)

- ▶ The ATP molecule consists of three components; a purine base (**adenine**), a pentose sugar (**ribose**), and **three phosphate groups** which attach to the 5' carbon of the pentose sugar. Adenine + ribose form adenosine (the "A" in ATP). The structure of ATP is shown right.
- ▶ The bonds between the phosphate groups contain electrons in a high energy state which store a large amount of energy. The energy is released during ATP hydrolysis. Typically, hydrolysis is coupled to another cellular reaction to which the energy is transferred. The end products of the reaction are adenosine diphosphate (ADP) and an inorganic phosphate (Pi).
- ▶ Note that energy is released during the formation of bonds during the hydrolysis reaction, not the breaking of bonds between the phosphates (which requires energy input).



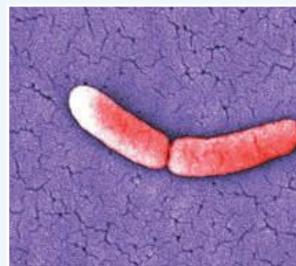
## ATP powers metabolism



The energy released from the removal of a phosphate group of ATP is used for active transport of molecules and substances across the plasma membrane e.g. **phagocytosis** (above) and other active transport processes.



**Mitosis**, as seen in the stained onion cell above, requires ATP to proceed. Formation of the mitotic spindle and chromosome separation both require the energy provided by ATP hydrolysis to occur.



ATP is required when bacteria divide by binary fission (above). For example, ATP is required in DNA replication and to synthesise components of the cell wall.



Not all of the energy released in the oxidation of glucose is captured in ATP. The rest is lost as heat. This heat energy can be used to maintain body temperature. Thermoregulatory mechanisms such as shivering and sweating also use ATP.

1. What process produces ATP in a cell? \_\_\_\_\_

2. Identify the three distinct elements of the space-filling model of ATP, labelled (a)-(c) below right:

(a) \_\_\_\_\_ (b) \_\_\_\_\_ (c) \_\_\_\_\_

3. Which two of the elements you labelled in question 2 make up adenosine? \_\_\_\_\_

4. Explain why thermoregulation requires the expenditure of energy:

\_\_\_\_\_

\_\_\_\_\_

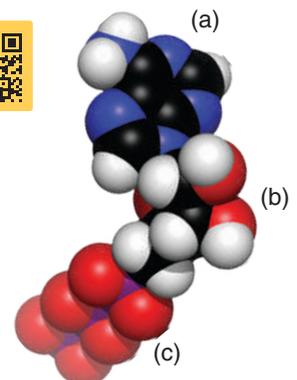
\_\_\_\_\_

\_\_\_\_\_

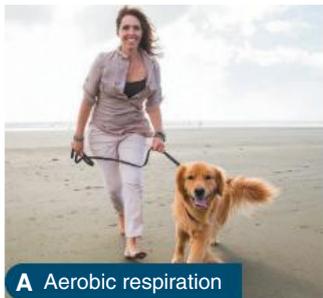
5. Describe one other process in a cell that requires ATP: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

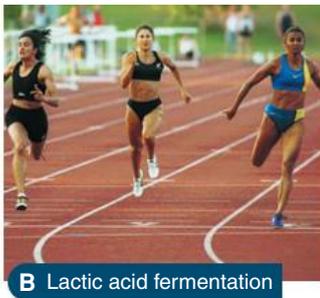


### Aerobic and anaerobic pathways for ATP production



**A Aerobic respiration**

Aerobic respiration produces the energy (as ATP) needed for metabolism. The rate of aerobic respiration is limited by the amount of oxygen available. In animals and plants, most of the time the oxygen supply is sufficient to maintain aerobic metabolism. Aerobic respiration produces a high yield of ATP per molecule of glucose (**path A**).



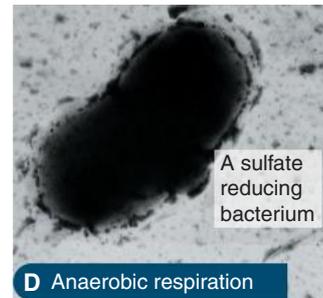
**B Lactic acid fermentation**

During maximum physical activity, when oxygen is limited, anaerobic metabolism provides ATP for working muscle. In mammalian muscle, metabolism of a respiratory intermediate produces lactate, which provides fuel for working muscle and produces a low yield of ATP. This process is called lactic acid fermentation (**path B**).



**C Alcoholic fermentation**

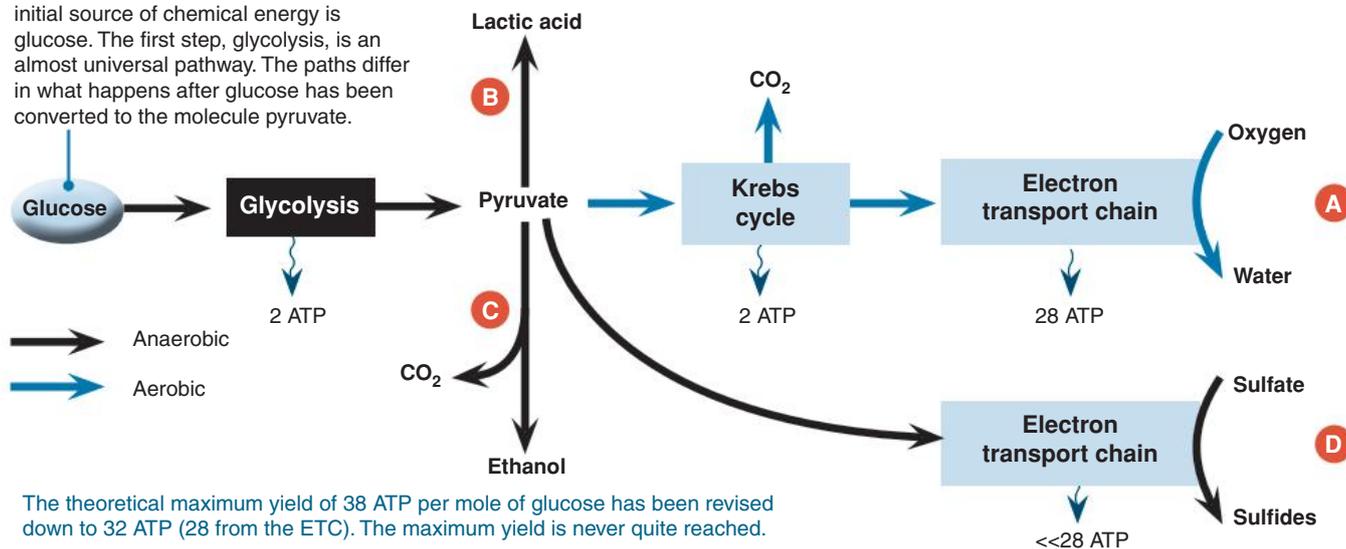
The process of brewing utilises the anaerobic metabolism of yeasts. Brewer's yeasts preferentially use anaerobic metabolism in the presence of excess sugars. This process, called alcoholic fermentation, produces ethanol and CO<sub>2</sub> from the respiratory intermediate pyruvate. It is carried out in vats that prevent entry of O<sub>2</sub> (**path C**).



**D Anaerobic respiration**

Many bacteria and archaea are anaerobic, using molecules other than oxygen (e.g. nitrate or sulfate) as a terminal electron acceptor of their electron transport chain. These electron acceptors are not as efficient as oxygen (less energy is released per oxidised molecule) so the energy (ATP) yield from anaerobic respiration is generally quite low (**path D**).

In most energy-yielding pathways the initial source of chemical energy is glucose. The first step, glycolysis, is an almost universal pathway. The paths differ in what happens after glucose has been converted to the molecule pyruvate.



The theoretical maximum yield of 38 ATP per mole of glucose has been revised down to 32 ATP (28 from the ETC). The maximum yield is never quite reached.

- What do all the ATP yielding pathways above have in common? \_\_\_\_\_
- Distinguish between anaerobic pathways in eukaryotes (e.g. yeasts) and anaerobic respiration in anaerobic microbes: \_\_\_\_\_
- When brewing alcohol, why is it important to prevent entry of oxygen to the fermentation vats? \_\_\_\_\_
- Rank the following processes from lowest to highest in terms of ATP produced (use = for processes you consider equal in yield): *lactic acid fermentation, anaerobic respiration, alcoholic fermentation, aerobic respiration, glycolysis*. \_\_\_\_\_

# 47 ATP and Energy

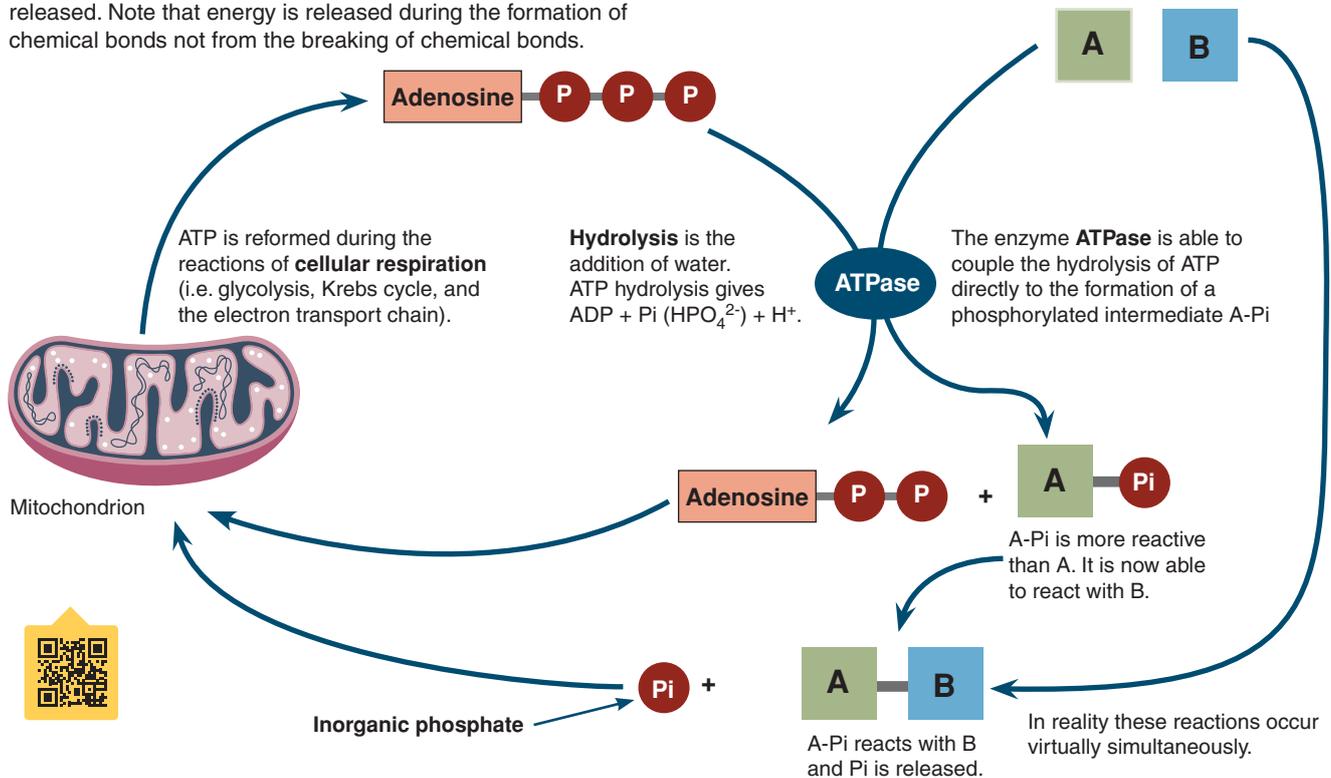
**Key Idea:** ATP is the universal energy carrier in cells. Energy is stored in the covalent bonds between phosphate groups. The molecule ATP (adenosine triphosphate) is the universal energy carrier for the cell. ATP can release its energy quickly by hydrolysis of the terminal phosphate. This reaction is

catalysed by the enzyme ATPase. Once ATP has released its energy, it becomes ADP (adenosine diphosphate), a low energy molecule that can be recharged by adding a phosphate. The energy to do this is supplied by the controlled breakdown of glucose in cellular respiration.

## How does ATP provide energy?

ATP releases its energy during hydrolysis. Water is split and added to the terminal phosphate group resulting in ADP and Pi. For every mole of ATP hydrolysed **30.7 kJ** of energy is released. Note that energy is released during the formation of chemical bonds not from the breaking of chemical bonds.

The reaction of  $A + B$  is endergonic. It requires energy to proceed and will not occur spontaneously.



**Note!** The phosphate bonds in ATP are often referred to as high energy bonds. This can be misleading. The bonds contain *electrons in a high energy state* (making the bonds themselves relatively weak). A small amount of energy is required to break the bonds, but when the intermediates recombine and form new chemical bonds a large amount of energy is released. The final product is less reactive than the original reactants.

In many textbooks the reaction series above is simplified and the intermediates are left out:



- (a) How does ATP supply energy to power metabolism? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (b) In what way is the ADP/ATP system like a rechargeable battery? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. What respiratory substrate provides the energy for reforming ATP? \_\_\_\_\_
3. During the many metabolic reactions occurring in the body, most of the energy in the initial respiratory substrate is lost as heat. What is the purpose of this heat?  
 \_\_\_\_\_



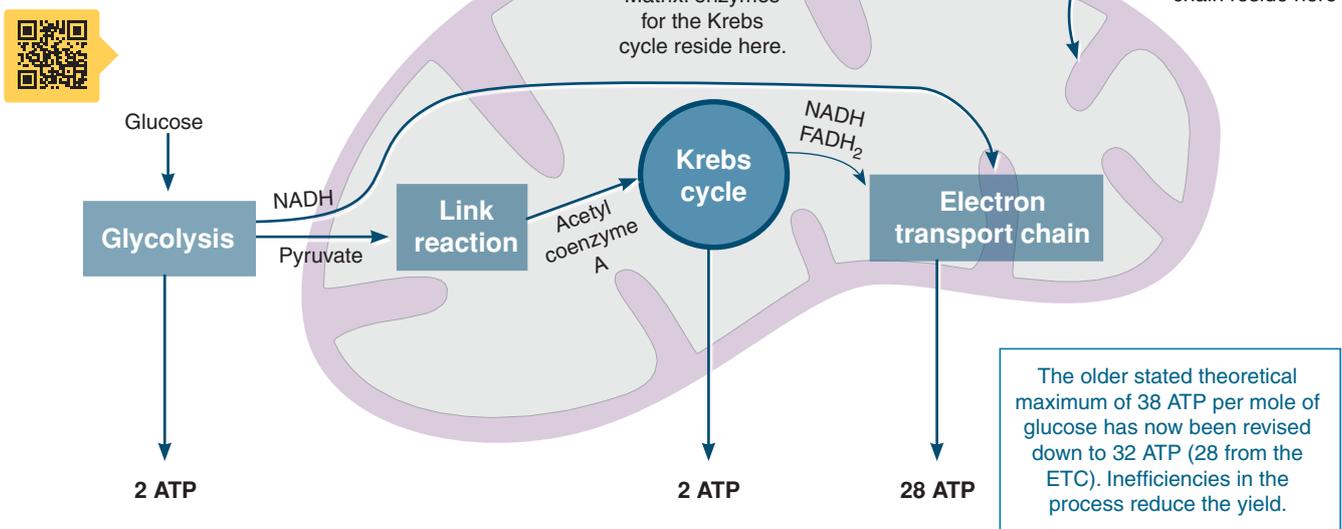
# 48 Cellular Respiration: Inputs and Outputs

**Key Idea:** During cellular respiration, the energy in glucose is transferred to ATP in a series of enzyme controlled steps. The oxidation of glucose is a catabolic, energy yielding pathway. The breakdown of glucose and other organic fuels to simpler molecules is coupled to ATP synthesis. Glycolysis and the Krebs cycle supply electrons to the electron transport chain (ETC), which drives **oxidative phosphorylation**. The

conversion of pyruvate (the end product of glycolysis) to **acetyl CoA** links glycolysis to the Krebs cycle. Most of the ATP generated in cellular respiration is produced by oxidative phosphorylation when  $\text{NADH} + \text{H}^+$  and  $\text{FADH}_2$  donate electrons to the electron carriers in the ETC. At the end of the chain, electrons are passed to molecular oxygen, reducing it to water. Electron transport is coupled to ATP synthesis.

## Overview of cellular respiration

Respiration involves three metabolic stages (plus a link reaction) summarised below. The first two stages are the catabolic pathways that decompose glucose and other organic fuels. In the third stage, the electron transport chain accepts electrons from the first two stages and passes these from one electron acceptor to another. The energy released at each stepwise transfer is used to make ATP.



## The general equation for cellular respiration



- Describe precisely in which part of the cell the following take place:
  - Glycolysis: \_\_\_\_\_
  - The link reaction: \_\_\_\_\_
  - Krebs cycle reactions: \_\_\_\_\_
  - Electron transport chain: \_\_\_\_\_
- Write a word equation for the general equation for cellular respiration: \_\_\_\_\_  
\_\_\_\_\_
- What is the total number of ATP produced from one glucose molecule? \_\_\_\_\_
- Describe three functions of glycolysis in the process of cellular respiration: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
- Describe two functions of the Krebs cycle in the process of cellular respiration: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



# 49 Measuring Respiration

**Key Idea:** Respiration is the process by which cells convert energy in glucose to usable energy, which is stored in the molecule ATP. The process uses oxygen, which can be quantified using a simple respirometer.

A respirometer can be used to measure the amount of oxygen consumed by an organism during cellular respiration and so can be used to measure respiration rate. A simple

respirometer is shown in the diagram below. The carbon dioxide produced during respiration is absorbed by the potassium hydroxide. As the oxygen is used up, the coloured bubble in the glass tube moves. Measuring the movement of the bubble (e.g. with a ruler or taped graph paper) allows an estimation of the change in volume of gas and therefore the rate of cellular respiration.



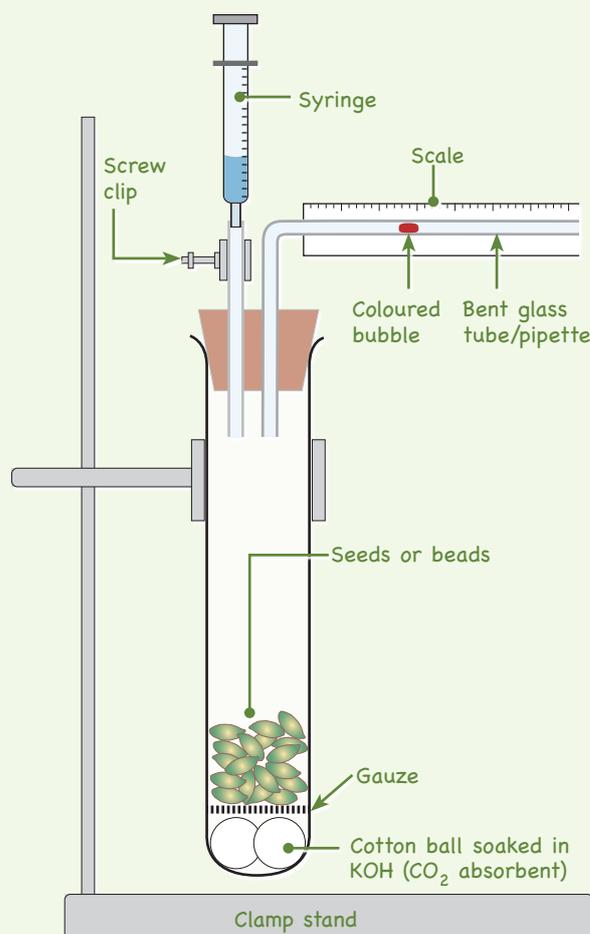
## Investigation 3.3 Measuring respiration in germinating seeds

See appendix for equipment list.



**Caution is required when handling potassium hydroxide as it is caustic and can cause chemical burns. You should wear protective eyewear and gloves.**

1. Work in groups of four to set up three respirometers using the set up shown right as a guide.
2. Collect three boiling tubes and place two cotton balls in the bottom of each. Label the tubes A, B, and C.
3. Use a dropper to add 15% potassium hydroxide (KOH) solution on the cotton balls until they are saturated (there should be no liquid in the boiling tube). Add the same amount of KOH to the cotton balls in each boiling tube.
4. Place gauze on top of the cotton balls in each tube. This prevents the KOH coming into contact with the seeds and killing them.
5. Quarter fill tube A with germinated bean seeds. These seeds will be damp because they have been germinated under damp paper towels for four days.
6. Quarter fill tube B with ungerminated (dry) seeds.
7. Quarter fill tube C with glass beads.
8. Place a two-hole stopper firmly in each boiling tube. In one hole insert a bent glass tube or bent pipette. In the second hole insert a tube that can be clamped shut using a screw clip.
9. Use a dropper or fine pipette to place a drop of coloured liquid into the bent tube/pipette of each set up. Attach a syringe to the clamped tube. Open the screw clip and use the syringe to draw the coloured bubble into the middle of the bent tube/pipette.
10. Place all three tubes in a water bath at 25°C. Secure them with a clamp stand or in racks.
11. Leave the apparatus to equilibrate for 10 minutes.
12. At the end of the equilibration period, close the screw clip on the boiling tubes. Mark the position of the bubble with a marker pen. This is your time zero position.
13. Start the timer.
14. Use a ruler or the pipette's scale (if there is one) to measure the distance the colored bubble moved at 5, 10, 15, 20, and 25 minutes.
15. Record your results on the table at the top of the next page.



Respirometers of this sort are very sensitive to poor procedure because the volumes involved are so small.

Be very careful with your set-up and when taking readings. Have one person responsible taking the measurements of the bubble movement.

Measuring respiration can be done using  $O_2$  and  $CO_2$  gas sensors. View the videos on the [BIOZONE Resource Hub](#) to see how.



A-2

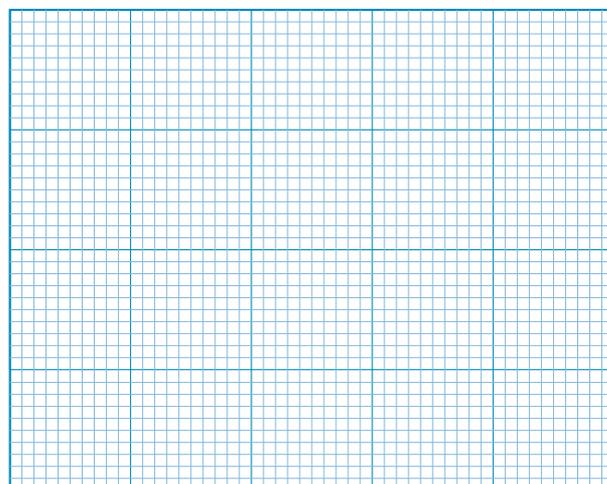
Time (minutes)	Distance bubble moved (mm)		
	Germinated seeds (A)	Ungerminated seeds (B)	Glass beads (C)
0			
5			
10			
15			
20			
25			

1. What is the purpose of the test tube with the beads? \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
2. (a) Calculate the corrected distance the bubble moved in tubes A and B by subtracting the distance moved in tube C from each value. Record these values in the table below.
- (b) Use the corrected distance the bubble moved to calculate the rate of respiration. Record this in the table below:

Time (minutes)	Corrected distance bubble moved (mm)		Rate (mm/min)	
	Germinated seeds (A)	Ungerminated seeds (B)	Germinated seeds (A)	Ungerminated seeds (B)
0				
5				
10				
15				
20				
25				

(c) Plot the rate of respiration on the grid (right). Include appropriate titles and axis labels:

- (d) What does your plot show? \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_



3. Why does the bubble in the capillary tube move? \_\_\_\_\_

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4. What conclusion can you make about cellular respiration in germinated and ungerminated seeds?

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5. How would you have to modify the experiment if you were measuring respiration in a plant instead of seeds?

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6. Explain the purpose of the following in the experiment:

(a) KOH: \_\_\_\_\_

---

(b) Equilibration period: \_\_\_\_\_

---

(c) The ungerminated seeds: \_\_\_\_\_

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7. A student decided to repeat the respirometer experiment but used maggots instead of seeds. Their results are shown on the table (right).

(a) Calculate the rates and record them in the table:

(b) Graph the rates:

(c) Describe the results: \_\_\_\_\_

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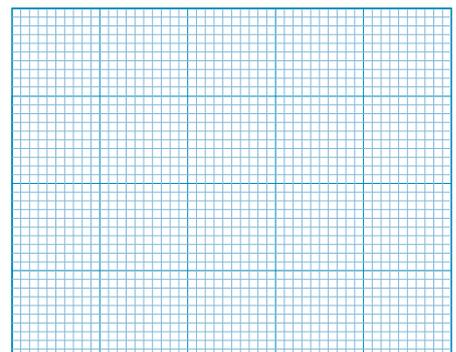


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Time (minutes)	Distance bubble moved (mm)	Rate (mm/min)
0	0	
5	25	
10	65	
15	95	
20	130	
25	160	



# 50 The Biochemistry of Respiration

**Key Idea:** During cellular respiration, the energy in glucose is transferred to ATP in a series of enzyme controlled steps.

The oxidation of glucose is a catabolic, energy yielding pathway. The breakdown of glucose and other organic fuels (such as fats and proteins) to simpler molecules releases energy for ATP synthesis. Glycolysis and the Krebs cycle supply electrons to the electron transport chain, which drives oxidative phosphorylation. Glycolysis nets two ATP. The conversion of pyruvate (the end product of glycolysis)

to acetyl CoA links glycolysis to the Krebs cycle. One "turn" of the cycle releases carbon dioxide, forms one ATP, and passes electrons to three  $\text{NAD}^+$  and one  $\text{FAD}$ . Most of the ATP generated in cellular respiration is produced by oxidative phosphorylation when  $\text{NADH} + \text{H}^+$  and  $\text{FADH}_2$  donate electrons to the series of electron carriers in the electron transport chain. At the end of the chain, electrons are passed to molecular oxygen, reducing it to water. Electron transport is coupled to ATP synthesis.

## Steps in cellular respiration

### Glycolysis

Glycolysis is the beginning of cellular respiration. Glycolysis initially uses two ATP but produces four ATP. It therefore produces a net of two pyruvate molecules, each of which can then enter the Krebs cycle.  $\text{NADH}$  is produced for use in the electron transport chain.

**The numbers shown are for one glucose molecule.**

### Link reaction

The link reaction removes  $\text{CO}_2$  from pyruvate and adds coenzyme A, producing the 2C molecule acetyl coenzyme A, which enters the Krebs cycle.  $\text{NADH}$  is also produced and flows to the electron transport chain.

### Krebs cycle

In the Krebs cycle, acetyl coenzyme A is attached to the 4C molecule oxaloacetate and coenzyme A is released. Oxaloacetate is eventually remade in a cyclic series of reactions that produce more  $\text{NADH}$  and  $\text{FADH}_2$  for the electron transport chain. Two ATP are also made by substrate level phosphorylation.

### Electron transport chain

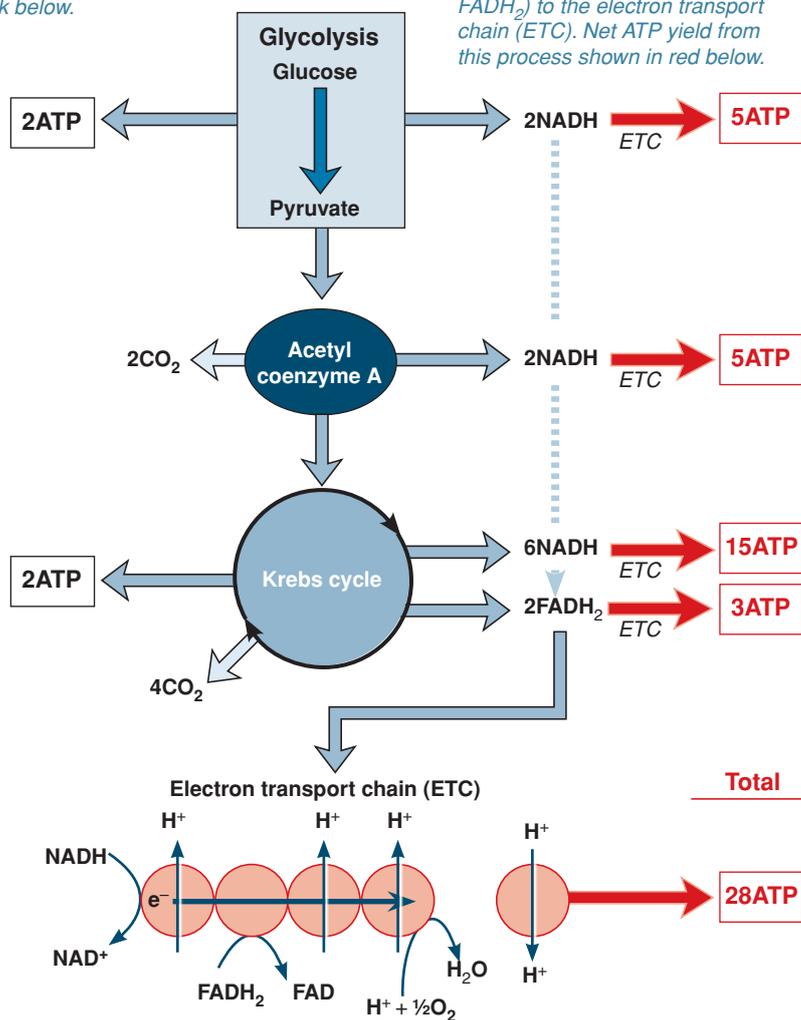
Electrons carried by  $\text{NADH}$  and  $\text{FADH}_2$  are passed to a series of electron carrier enzymes embedded in the inner membrane of the mitochondria. The energy from the electrons is used to pump  $\text{H}^+$  ions across the inner membrane from the matrix into the intermembrane space. These are allowed to flow back to the matrix via the enzyme ATP synthase which uses their energy to produce ATP. The electrons are coupled to  $\text{H}^+$  and oxygen at the end of the electron transport chain to form water.

## Substrate level phosphorylation

An enzyme transfers a phosphate group directly from a substrate (such as glucose) to ADP to form ATP. Net ATP yield from substrate level phosphorylation shown in black below.

## Oxidative phosphorylation

Glucose is oxidised in a series of reduction and oxidation reactions that provide the energy to form ATP. This is achieved by the flow of reducing power (as  $\text{NADH}$  and  $\text{FADH}_2$ ) to the electron transport chain (ETC). Net ATP yield from this process shown in red below.



- (a) What is substrate level phosphorylation? \_\_\_\_\_

\_\_\_\_\_

(b) How many ATP are produced this way during cellular respiration (per molecule of glucose)? \_\_\_\_\_
- (a) What is oxidative phosphorylation? \_\_\_\_\_

\_\_\_\_\_

(b) How many ATP are produced this way during cellular respiration (per molecule of glucose)? \_\_\_\_\_

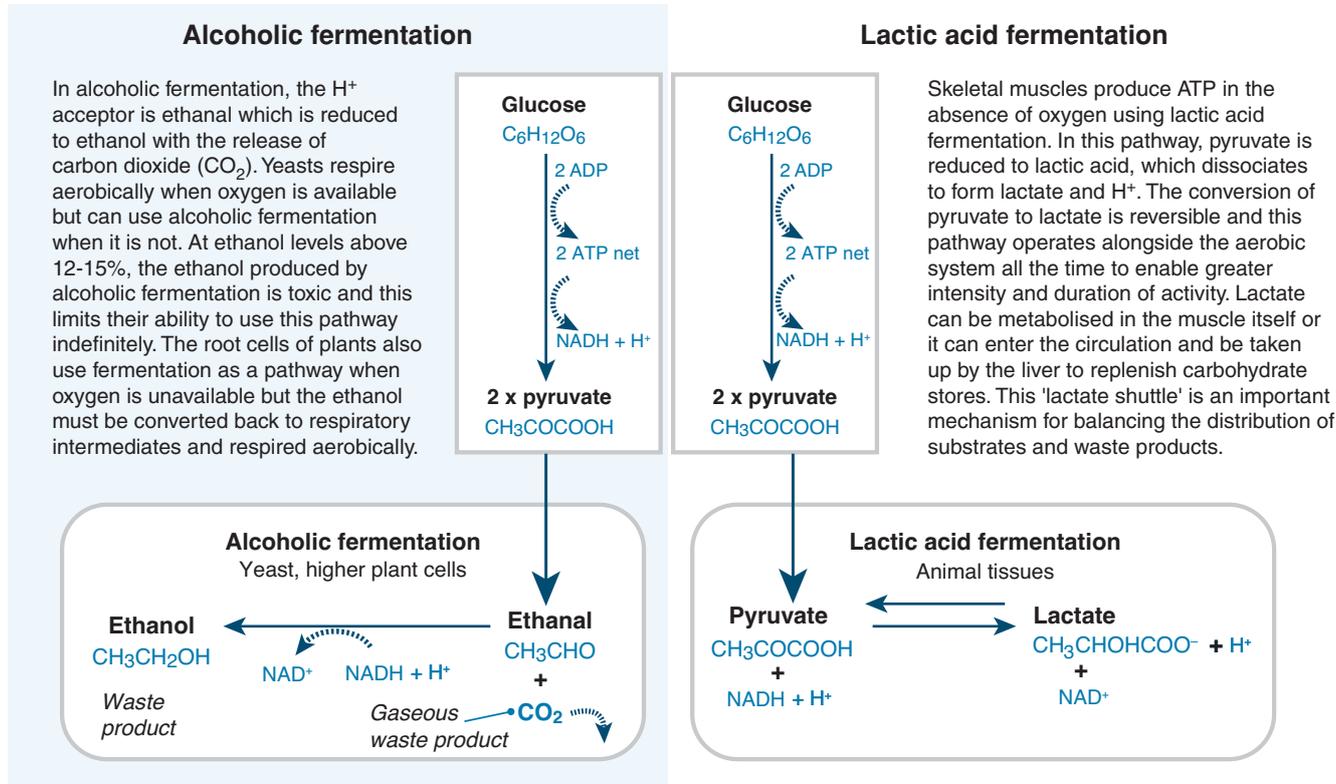




# 51 Anaerobic Pathways

**Key Idea:** Glucose can be metabolised aerobically and anaerobically to produce ATP. The ATP yield from aerobic processes is higher than from anaerobic processes. Aerobic respiration occurs in the presence of oxygen. Organisms can also generate ATP anaerobically (when oxygen is absent)

by using a molecule other than oxygen as the terminal electron acceptor for the pathway. In alcoholic fermentation in yeasts, the electron acceptor is ethanal. In lactic acid fermentation, which occurs in mammalian muscle even when oxygen is present, the electron acceptor is pyruvate.



The alcohol and CO<sub>2</sub> produced from alcoholic fermentation form the basis of the brewing and baking industries. In baking, the dough is left to ferment and the yeast metabolises sugars to produce ethanol and CO<sub>2</sub>. The CO<sub>2</sub> causes the dough to rise.



Yeasts are used to produce almost all alcoholic beverages (e.g. wine and beers). The yeast used in the process breaks down the sugars into ethanol (alcohol) and CO<sub>2</sub>. The alcohol produced is a metabolic by-product of fermentation by the yeast.



The lactate shuttle in vertebrate skeletal muscle works alongside the aerobic system to enable maximal muscle activity. Lactate moves from its site of production to regions within and outside the muscle (e.g. liver) where it can be respired aerobically.

1. Describe the key difference between aerobic respiration and fermentation: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. (a) Refer to pages 87-88 and determine the efficiency of fermentation compared to aerobic respiration: \_\_\_\_\_ %  
 (b) Why is the efficiency of these anaerobic pathways so low? \_\_\_\_\_  
 \_\_\_\_\_
3. Why can't alcoholic fermentation go on indefinitely? \_\_\_\_\_  
 \_\_\_\_\_



# 52 Investigating Yeast Fermentation

**Key Idea:** Brewer's yeast preferentially uses alcoholic fermentation when there is excess sugar. The  $\text{CO}_2$  released can be collected as a measure of fermentation rate.

Brewer's yeast is a facultative anaerobe (meaning it can respire aerobically or use fermentation). One would expect glucose to be the preferred substrate, as it is the starting molecule in cellular respiration, but brewer's yeast can use a

variety of sugars, including disaccharides (two unit sugars), which can be broken down into single units. The rate at which yeast (*Saccharomyces cerevisiae*) metabolises carbohydrate substrates is influenced by temperature, solution pH, and type of carbohydrate available. High levels of sugars suppress aerobic respiration in yeast, so yeast will preferentially use fermentation in the presence of excess substrate.

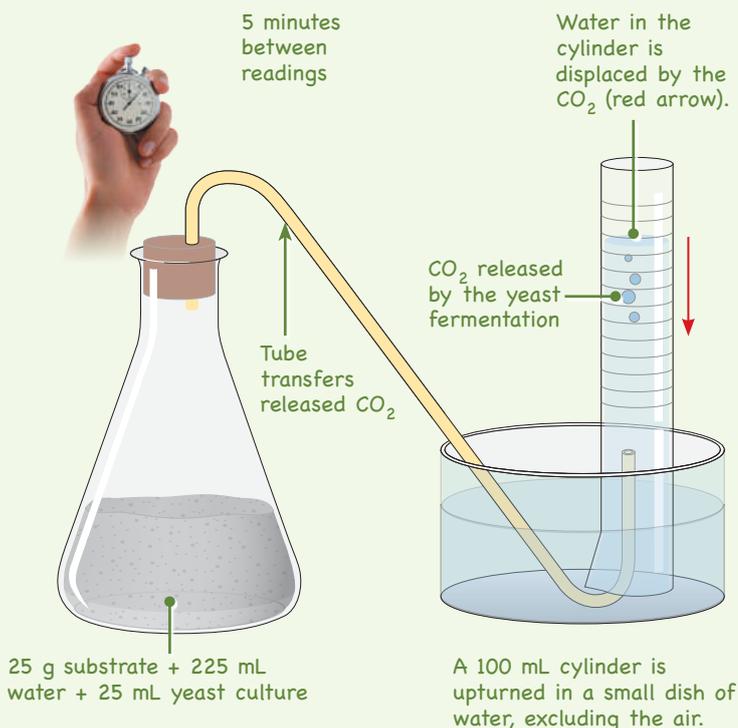


## Investigation 3.4 Investigating fermentation in yeast

See appendix for equipment list.

Work in pairs for this activity. Your teacher will assign you a substrate to investigate.

1. Make a yeast culture by dissolving 10 g of active yeast into 50 mL of water at 24°C.
2. In a conical flask boil 225 mL of tap water then cool to room temperature (24°C). This removes any dissolved oxygen from the water.
3. Add 25 g of substrate (glucose, maltose, sucrose, lactose, or none). Stir carefully to dissolve (stirring too vigorously will cause oxygen to dissolve back into the water).
4. Then add 25 mL of the source yeast culture to the conical flask solution.
5. Add a thin layer of paraffin oil over the solution in the conical flask to create an anaerobic environment.
6. Stopper the conical flask and set up a measuring cylinder to capture any gas as in the diagram right.
7. Start timing and record the change in gas volume every five minutes for 1 hour. Record the results for your substrate in the table. Pool data as a class and use it to complete the table below.



Substrate \ Time (min)	Cumulative volume of carbon dioxide collected (mL)				
	None	Glucose	Maltose	Sucrose	Lactose
0					
5					
10					
15					
20					
25					
30					
35					
40					
45					
50					
55					
60					

1. Write the equation for the fermentation of glucose by yeast:

---



---

2. Using the final values (60 minutes) collected from the class, calculate the rate of  $\text{CO}_2$  production per minute for each substrate:

(a) None: \_\_\_\_\_

(b) Glucose: \_\_\_\_\_

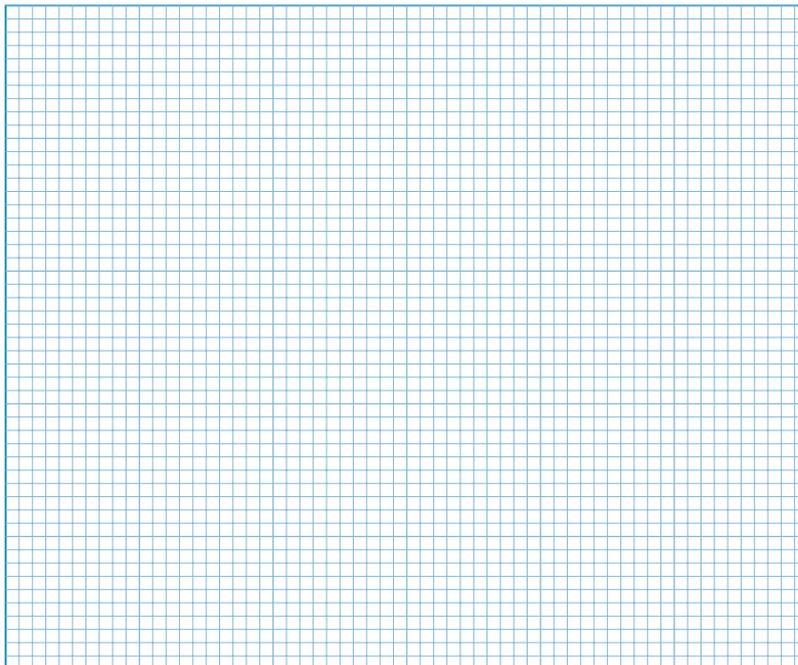
(c) Maltose: \_\_\_\_\_

(d) Sucrose: \_\_\_\_\_

(e) Lactose: \_\_\_\_\_



3. Use the tabulated data to plot an appropriate graph of the results on the grid provided:



4. Identify the independent variable: \_\_\_\_\_

5. (a) Identify the dependent variable: \_\_\_\_\_

(b) Name the unit for the dependent variable: \_\_\_\_\_

6. (a) Summarise the results of the fermentation experiment: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

(b) Which substrate produced the most CO<sub>2</sub>, and explain why: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

(c) Were fermentation rates lower on maltose and sucrose than on glucose? Was this what you expected? Suggest an explanation (you may have to do some research on these molecules to find out the answer):

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(d) Did any substrate produce no CO<sub>2</sub>? Can you suggest why? \_\_\_\_\_

\_\_\_\_\_

7. Predict what would happen to CO<sub>2</sub> production rates if the yeast cells were respiring aerobically: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

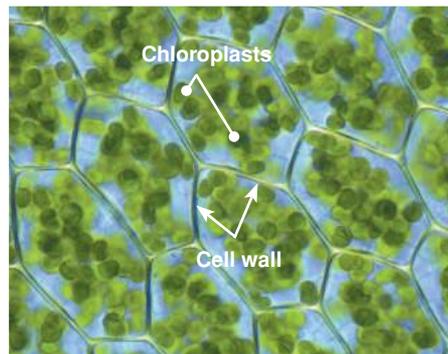
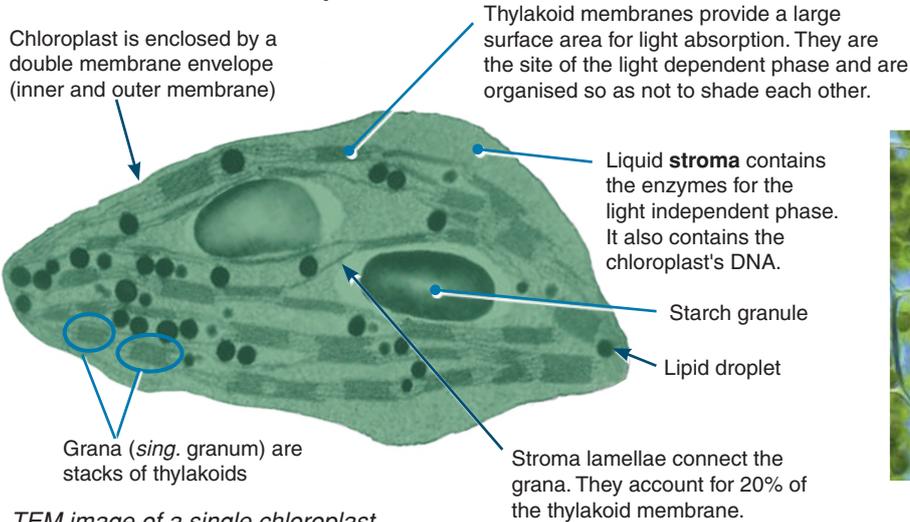
# 53 Chloroplasts

**Key Idea:** Chloroplasts have a complex internal membrane structure. They are the site of photosynthesis in plant cells.

**Chloroplasts** are the specialised plastids in which photosynthesis occurs. A photosynthetic leaf cell contains between 50-100 chloroplasts. The chloroplasts are generally aligned so that their broad surface runs parallel to the cell wall to maximise the surface area available for light absorption.

Chloroplasts have an internal structure characterised by a system of membranous structures called **thylakoids** arranged into stacks called **grana**. Special pigments, called **chlorophylls** and **carotenoids**, are bound to the membranes as part of light-capturing photosystems. Chlorophylls absorb light of specific wavelengths (blue and orange-red light) and thereby capture the sunlight energy.

## The structure of a chloroplast



Chloroplasts visible in plant cells

TEM image of a single chloroplast

1. Label the transmission electron microscope image of a chloroplast below:

2. (a) Where is chlorophyll found in a chloroplast? \_\_\_\_\_

\_\_\_\_\_

(b) Why is chlorophyll found there? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. Explain how the internal structure of chloroplasts helps absorb the maximum amount of light: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. Explain why plant leaves appear green: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



# 54

## Photosynthesis: Inputs and Outputs

**Key Idea:** Photosynthesis is the process by which light energy is used to convert CO<sub>2</sub> and water into glucose and oxygen. Photosynthesis is of fundamental importance to living things because it transforms sunlight energy into chemical energy stored in molecules, releases free oxygen gas, and absorbs carbon dioxide (a waste product of cellular metabolism). Photosynthesis has two sets of reactions, the light dependent phase and the light independent phase. In the light dependent

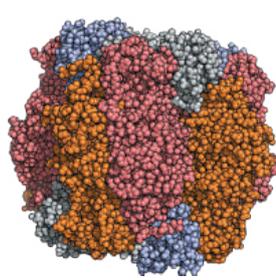
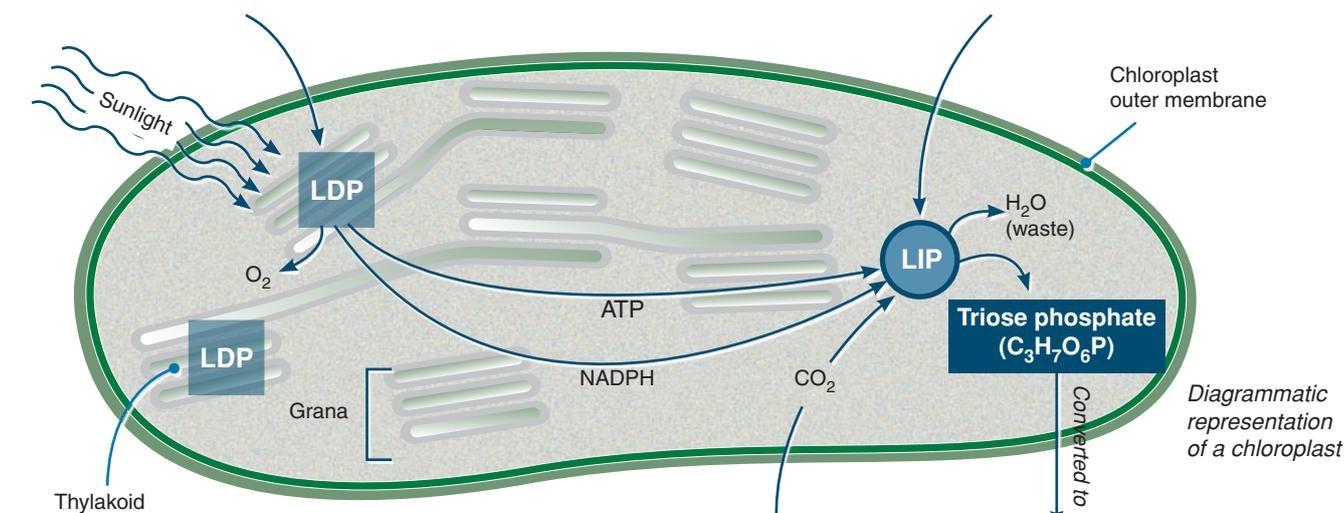
phase, light energy is converted to chemical energy (ATP and NADPH). This phase occurs in the thylakoid membranes of chloroplasts. In the light independent phase, the ATP and NADPH are used to synthesise carbohydrate. This phase occurs in the stroma of chloroplasts. In photosynthesis, water is split and electrons are transferred together with hydrogen ions from water to CO<sub>2</sub>, reducing it to triose phosphates (then converted to sugars).

### Light dependent phase (LDP):

In the first phase of photosynthesis, chlorophyll captures light energy, which is used to split water, producing O<sub>2</sub> gas (waste). Electrons and H<sup>+</sup> ions are transferred to the molecule NADPH. ATP is also produced. The light dependent phase occurs in the thylakoid membranes of the grana.

### Light independent phase (LIP):

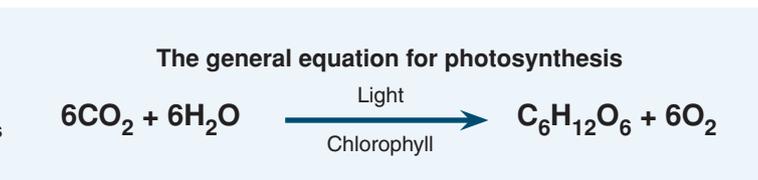
The second phase of photosynthesis occurs in the stroma and uses the NADPH and the ATP to drive a series of enzyme-controlled reactions (the **Calvin cycle**) that fix carbon dioxide to produce triose phosphate. This phase does not need light to proceed.



RuBisCo (left) is the central enzyme in the LIP of photosynthesis (carbon fixation) catalysing the first step in the Calvin cycle. However it is very inefficient, processing just three reactions a second. To compensate, RuBisCo makes up almost half the protein content of chloroplasts.

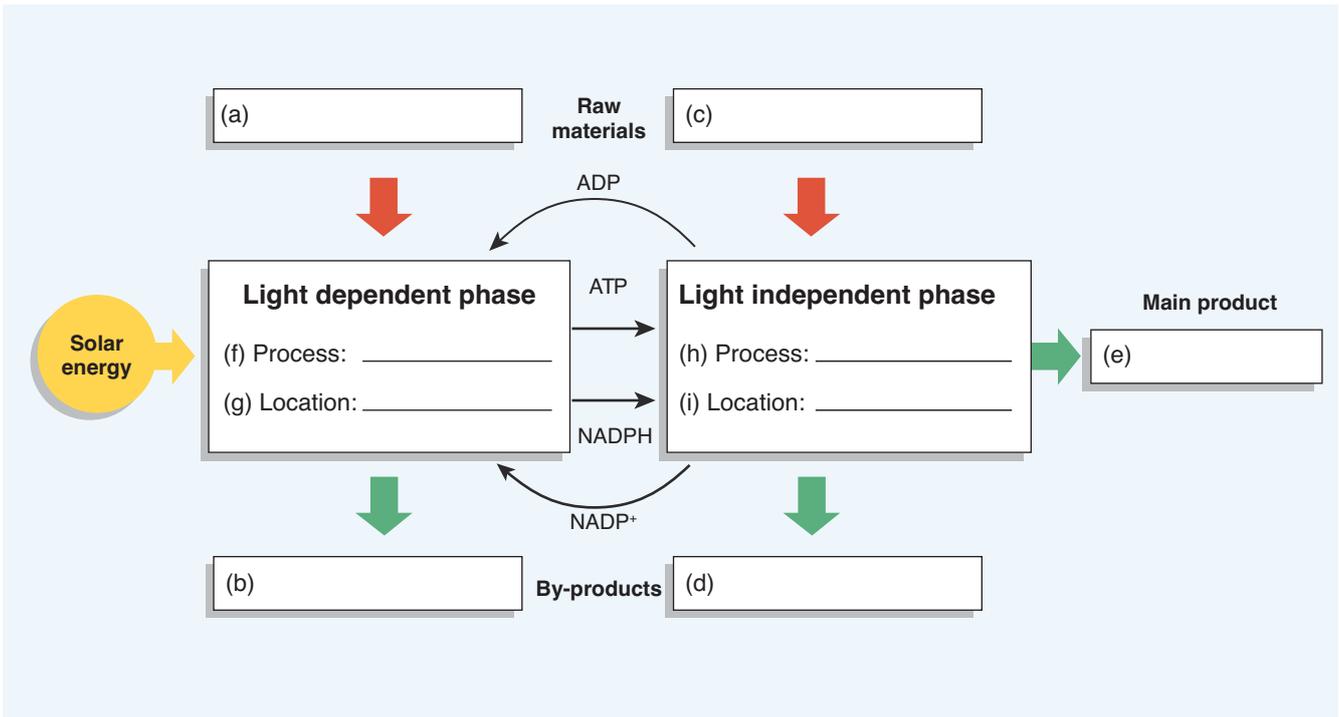
CO<sub>2</sub> from the air provides raw materials for glucose production.

Monosaccharides (e.g. glucose) and other carbohydrates, lipids, and amino acids.



- Identify the two phases of photosynthesis and their location in the cell:
  - \_\_\_\_\_
  - \_\_\_\_\_
- What is the role of the enzyme RuBisCo? \_\_\_\_\_
  - RuBisCo is the most abundant protein on Earth. Suggest a reason for this: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- State the origin and fate of the following molecules involved in photosynthesis:
  - Carbon dioxide: \_\_\_\_\_
  - Oxygen: \_\_\_\_\_
  - Hydrogen: \_\_\_\_\_

4. Use the information on the previous page to fill in the diagram below, including the raw material (inputs), products (outputs), and processes.



5. In two experiments, radioactively-labelled oxygen (shown in red) was used to follow oxygen through the photosynthetic process. The results of the experiment are shown below:



From these results, what would you conclude about the source of the oxygen in:

(a) The carbohydrate produced? \_\_\_\_\_

(b) The oxygen released? \_\_\_\_\_

6. Name the products that triose phosphate is converted into: \_\_\_\_\_  
 \_\_\_\_\_

7. Describe what happens during:

(a) The light dependent phase of photosynthesis: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) The light independent phase of photosynthesis: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

8. What is the function of each of the following in photosynthesis:

(a) ATP: \_\_\_\_\_

(b) NADPH: \_\_\_\_\_

(c) Light: \_\_\_\_\_

(d) Chlorophyll: \_\_\_\_\_

(e) Water: \_\_\_\_\_

# 55 Investigating Photosynthetic Rate

**Key Idea:** Measuring the production of oxygen provides a simple way to measure the rate of photosynthesis.

The rate of photosynthesis can be investigated by tracking the substances involved in photosynthesis. These include

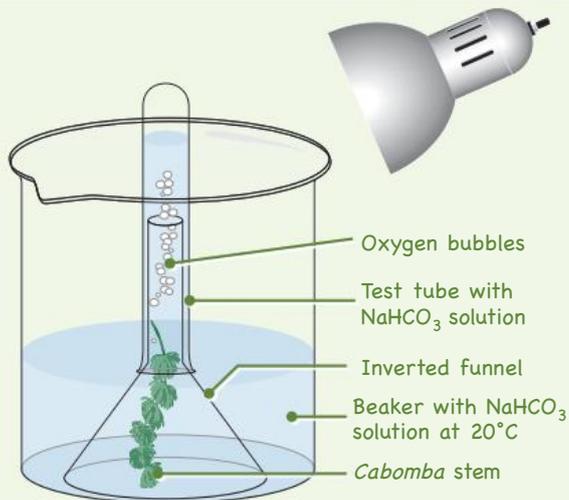
measuring the uptake of carbon dioxide, the production of oxygen, or the change in biomass over time. Measuring the rate of oxygen production provides a good approximation of the photosynthetic rate and is relatively easy to carry out.



## Investigation 3.5 Investigating photosynthetic rate

See appendix for equipment list.

1. Weigh 0.8–1.0 grams of *Cabomba aquatica* stem on a balance. Cut the stem underwater and invert to ensure a free flow of oxygen bubbles.
2. Place into a beaker filled (at approximately 20°C) with a solution containing 0.2 mol/L sodium hydrogen carbonate (to supply carbon dioxide).
3. Invert a funnel over the *Cabomba* and then invert a test tube filled with the sodium hydrogen carbonate solution on top to collect any gas produced.
4. Place the beaker at distances 20, 25, 30, 35, 40, 45, and 50 cm from a 60W light source. Measure the light intensity with a lux meter at each interval.
5. Leave the *Cabomba* stem to acclimatise to the new light level for 5 minutes before recording data. Count the bubbles for a period of three minutes at each distance and record.
6. Alternatively the volume of gas captured in the test tube can be measured and recorded.



Distance (cm)	Light intensity (lx)	Bubbles counted in three minutes	Bubbles per minute	Volume (mL)
50 cm				
45 cm				
40 cm				
35 cm				
30 cm				
25 cm				
20 cm				

1. Use the data to draw a graph of the bubble produced per minute vs light intensity:
2. Why is measuring light intensity directly in lux better than inferring light intensity from the measured distance?  


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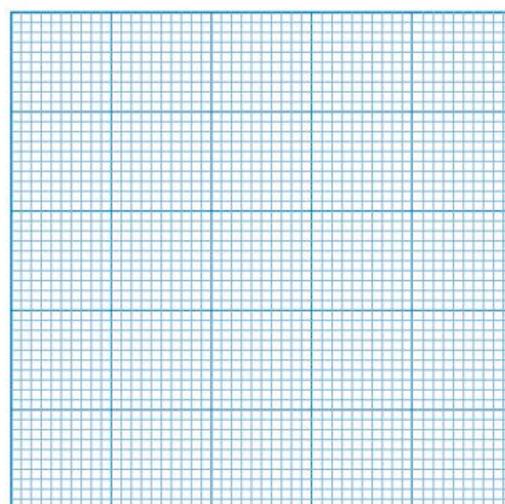

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3. The sample of gas collected during the experiment was tested with a glowing splint. The splint reignited when placed in the gas. What does this confirm about the gas produced?  


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4. Why is measuring gas collected rather than bubbles produced a more accurate way of recording data?  


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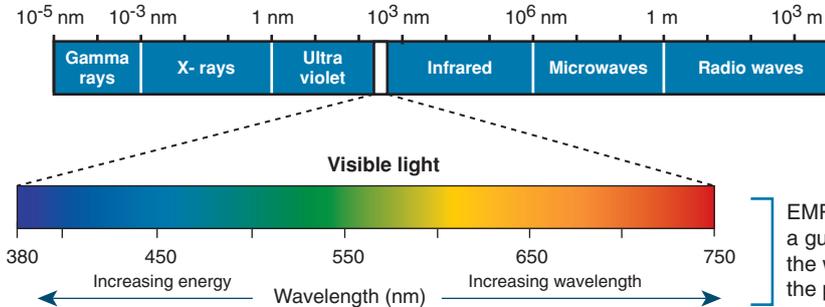
# 56 Pigments and Light Absorption

**Key Idea:** Chlorophyll pigments absorb light and capture light energy for photosynthesis.

The ability of phototrophic organisms to capture light energy is a function of the membrane-bound pigments they possess. **Pigments** are substances that absorb visible light, and different pigments absorb light of different wavelengths. The amount of light absorbed vs the wavelength of light is called

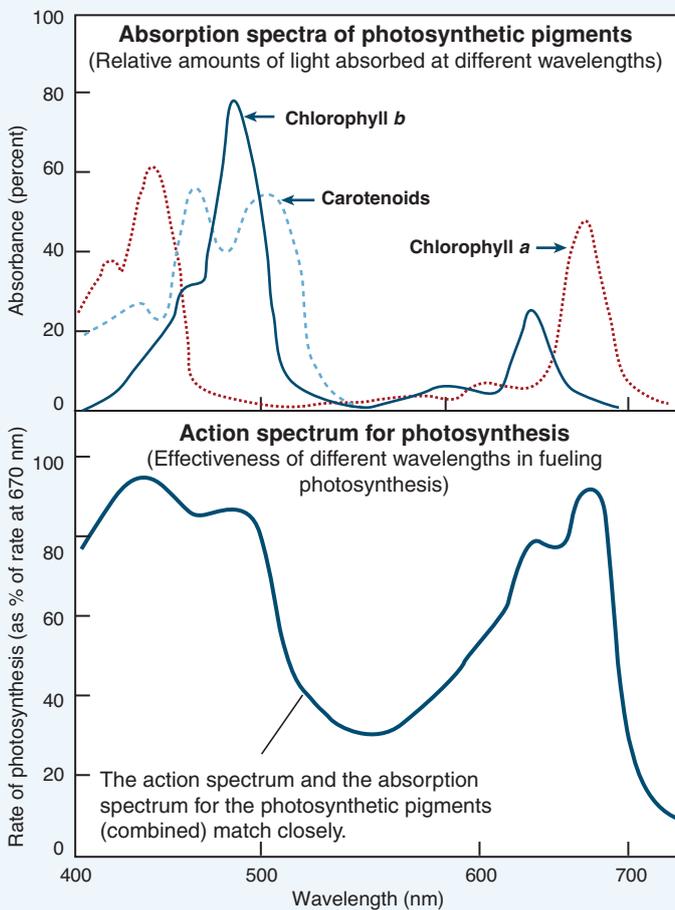
the **absorption spectrum** of that pigment. The absorption spectrum of different photosynthetic pigments provides clues to their role in photosynthesis, since light can only perform work if it is absorbed. An **action spectrum** profiles the effectiveness of different wavelengths of light in fueling photosynthesis. It is obtained by plotting wavelength against a measure of photosynthetic rate (e.g. O<sub>2</sub> production).

## The electromagnetic spectrum



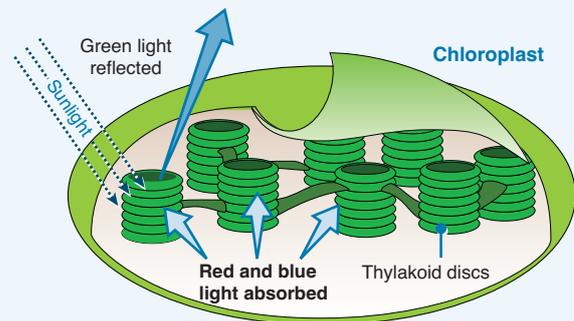
Light is a form of energy known as electromagnetic radiation (EMR). The segment of the electromagnetic spectrum most important to life is the narrow band between about 380 nm and 750 nm. This radiation is known as visible light because it is detected as colours by the human eye. It is visible light that drives photosynthesis.

EMR travels in waves, where wavelength provides a guide to the energy of the photons. The greater the wavelength of EMR, the lower the energy of the photons in that radiation.



## The photosynthetic pigments of plants

The photosynthetic pigments of plants fall into two categories: **chlorophylls** (which absorb red and blue-violet light) and **carotenoids** (which absorb strongly in the blue-violet and appear orange, yellow, or red). The pigments are located on the chloroplast membranes (the thylakoids) and are associated with membrane transport systems.



The pigments of chloroplasts in higher plants (above) absorb blue and red light, and the leaves therefore appear green (which is reflected). Each photosynthetic pigment has its own characteristic absorption spectrum (top left). Only chlorophyll a participates directly in the light reactions of photosynthesis, but the accessory pigments (chlorophyll b and carotenoids) can absorb wavelengths that chlorophyll a cannot and pass the energy (photons) to chlorophyll a, broadening the spectrum that can drive photosynthesis.

Left: Graphs comparing absorption spectra of photosynthetic pigments compared with the action spectrum for photosynthesis.

1. What is meant by the absorption spectrum of a pigment? \_\_\_\_\_
2. Use the graphs above to explain why the action spectrum for photosynthesis doesn't exactly match the absorption spectrum of chlorophyll a: \_\_\_\_\_

# Separation of Pigments by Chromatography

**Key Idea:** Photosynthetic pigments can be separated from a mixture using chromatography.

Chromatography involves passing a mixture dissolved in a mobile phase (a solvent) through a stationary phase, which separates the molecules according to their

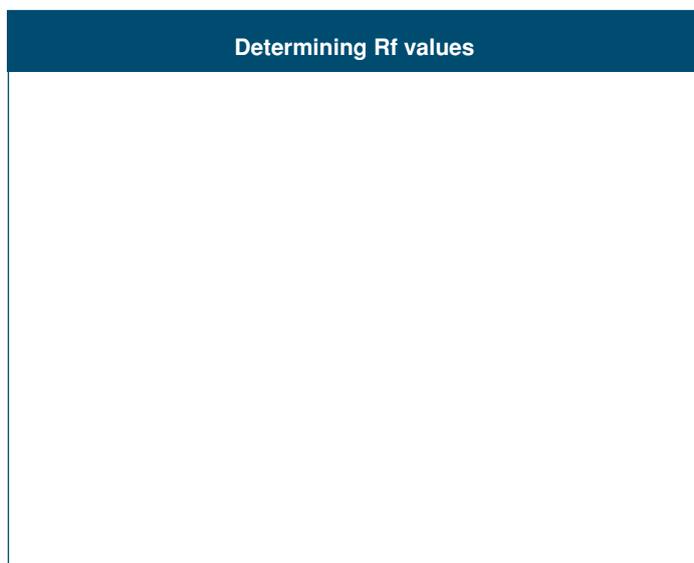
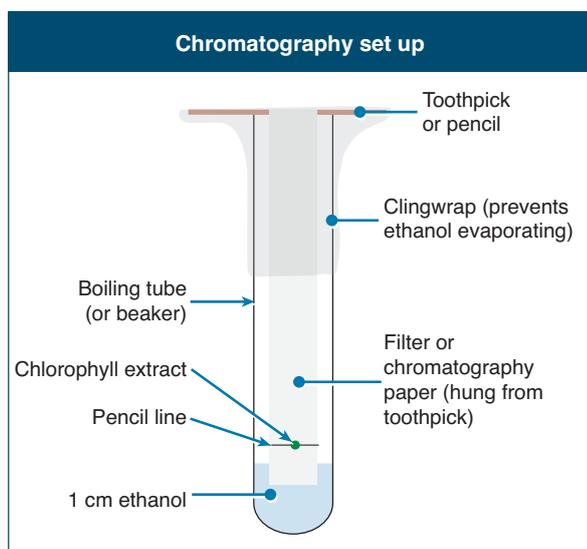
specific characteristics (e.g. size or charge). In thin layer chromatography, the stationary phase is a thin layer of adsorbent material (e.g. silica gel or cellulose) attached to a solid plate. A sample is placed near the bottom of the plate which is placed in an appropriate solvent (the mobile phase).



## Investigation 3.6 Separating photosynthetic pigments

See appendix for equipment list.

1. Tear leaves (e.g. spinach or silverbeet) into small sections and place in a pestle. Add a pinch of sand and 10 mL of ethanol. Grind up the leaves to form a dark green mixture.
2. Pour the mixture into a beaker or boiling tube, cover with cling film and leave for 5–10 minutes. This gives time for the chlorophyll pigments to better dissolve into the ethanol.
3. Cut a piece of filter paper or chromatography paper into a strip 1–2 cm wide. It should be long enough to reach from the top of a beaker or boiling tube to the bottom.
4. Use a pencil to draw a line across the width of the paper 1 cm from the bottom to mark the start position.
5. Use a micropipette to place a drop of the ground leaf mixture onto the middle of the line. You may need to do this a few times and air dry between each application to concentrate pigments on the spot.
6. Pour ethanol into a beaker or boiling tube to a depth of just over 1 cm. Set up the chromatography paper as in the diagram (below left).
7. Leave for long enough that the solvent front (ethanol) travels nearly to the top of the paper, or the pigments are well spread out. This may take up to 20 minutes.
8. Remove the paper and air dry. Calculate the  $R_f$  value for each pigment (below right).



1. How many pigments were you able to separate? \_\_\_\_\_
2. Calculate the  $R_f$  values for each pigment. Use the information in the *Determining  $R_f$  values* box above to identify each pigment on your chromatography paper:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. Staple your chromatography paper to this page.



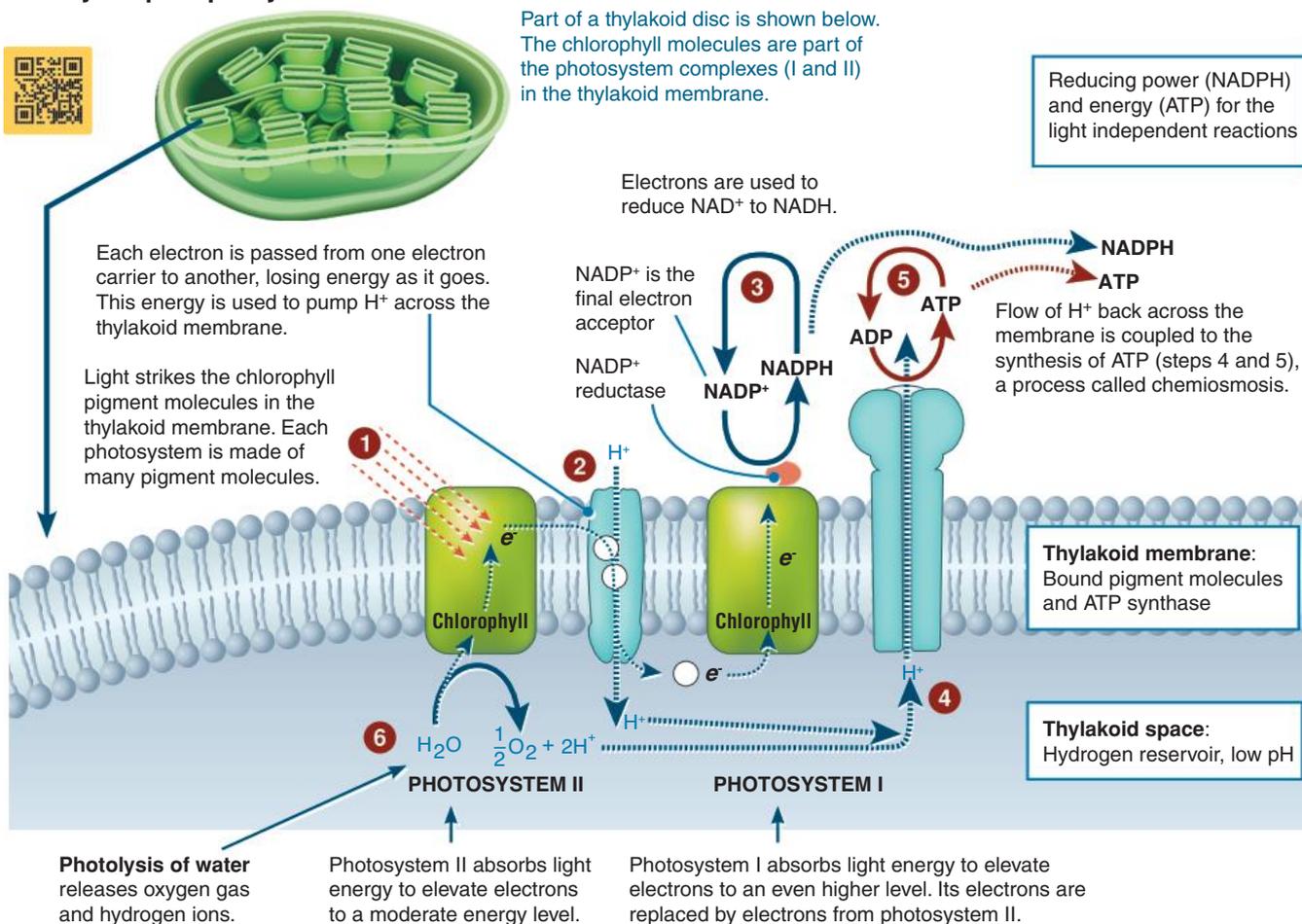
# 58 Light Dependent Reactions

**Key Idea:** Light energy is used to drive the reduction of  $\text{NADP}^+$  and the production of ATP.

Photosynthesis is a redox process where water is split, and electrons and hydrogen ions are transferred from water to  $\text{CO}_2$ , reducing it to sugar. The electrons increase in potential energy as they move from water to sugar. The energy to do this is provided by light. Photosynthesis has two phases. In the **light dependent reactions**, light energy is converted to

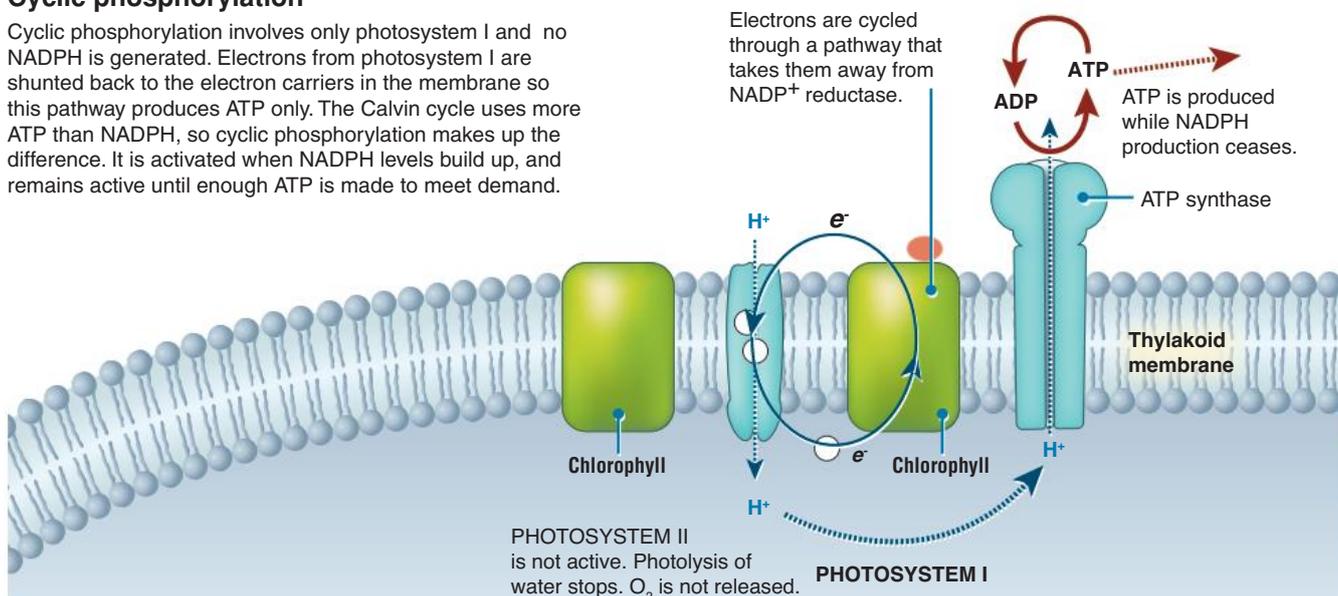
chemical energy (ATP and NADPH). In the **light independent reactions**, the chemical energy is used to synthesise carbohydrate. The light dependent reactions most commonly involve **non-cyclic phosphorylation**, which produces ATP and NADPH in roughly equal quantities. The electrons lost are replaced from water. In **cyclic phosphorylation**, the electrons lost from photosystem II are replaced by those from photosystem I. ATP is generated, but not NADPH.

## Non-cyclic phosphorylation



## Cyclic phosphorylation

Cyclic phosphorylation involves only photosystem I and no NADPH is generated. Electrons from photosystem I are shunted back to the electron carriers in the membrane so this pathway produces ATP only. The Calvin cycle uses more ATP than NADPH, so cyclic phosphorylation makes up the difference. It is activated when NADPH levels build up, and remains active until enough ATP is made to meet demand.



1. Describe the role of the carrier molecule NADP in photosynthesis: \_\_\_\_\_

\_\_\_\_\_

2. Explain the role of chlorophyll molecules in photosynthesis: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. (a) Where do the light dependent reactions occur? \_\_\_\_\_

(b) Summarise the events of the light dependent reactions: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. Explain how ATP generation is linked to the light dependent reactions of photosynthesis: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

5. (a) Explain what you understand by the term non-cyclic phosphorylation: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Suggest why this process is also known as non-cyclic photophosphorylation: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

6. (a) Describe how cyclic photophosphorylation differs from non-cyclic photophosphorylation: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Both cyclic and non-cyclic pathways operate to varying degrees during photosynthesis. Since the non-cyclic pathway produces both ATP and NAPH, explain the purpose of the cyclic pathway of electron flow:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. Bacteria that carry out anoxygenic photosynthesis lack a functional equivalent to photosystem II and use only cyclic phosphorylation. Explain how this accounts for their inability to generate oxygen from photosynthesis:

\_\_\_\_\_

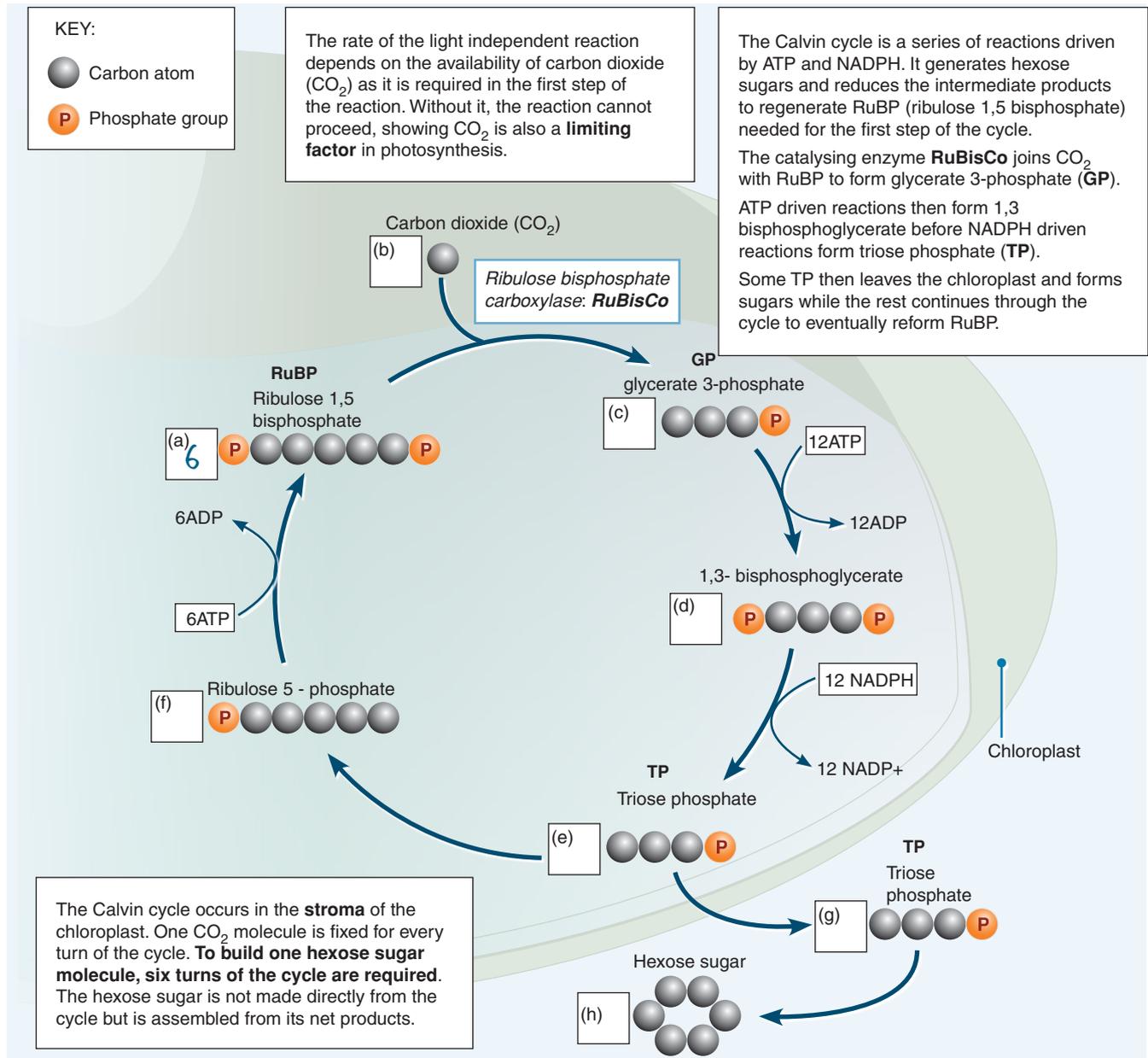
\_\_\_\_\_

# 59 Light Independent Reactions

**Key Idea:** The Calvin cycle uses ATP and NADPH from the light dependent reactions to produce organic carbon molecules.

In the **light independent reactions** (commonly also called the **Calvin cycle**) hydrogen ( $H^+$ ) is added to  $CO_2$  and a

5C intermediate to make carbohydrate. The  $H^+$  and ATP are supplied by the light dependent reactions. The Calvin cycle uses more ATP than NADPH, but the cell uses cyclic phosphorylation (which does not produce NADPH) when it runs low on ATP to make up the difference.



1. In the boxes on the diagram above, write the number of molecules formed at each step during the formation of **one hexose sugar molecule**. The first one has been done for you:

2. Explain the importance of RuBisCo in the Calvin cycle: \_\_\_\_\_

3. Identify the actual end product on the Calvin cycle: \_\_\_\_\_

4. Write the equation for the production of one hexose sugar molecule from carbon dioxide: \_\_\_\_\_

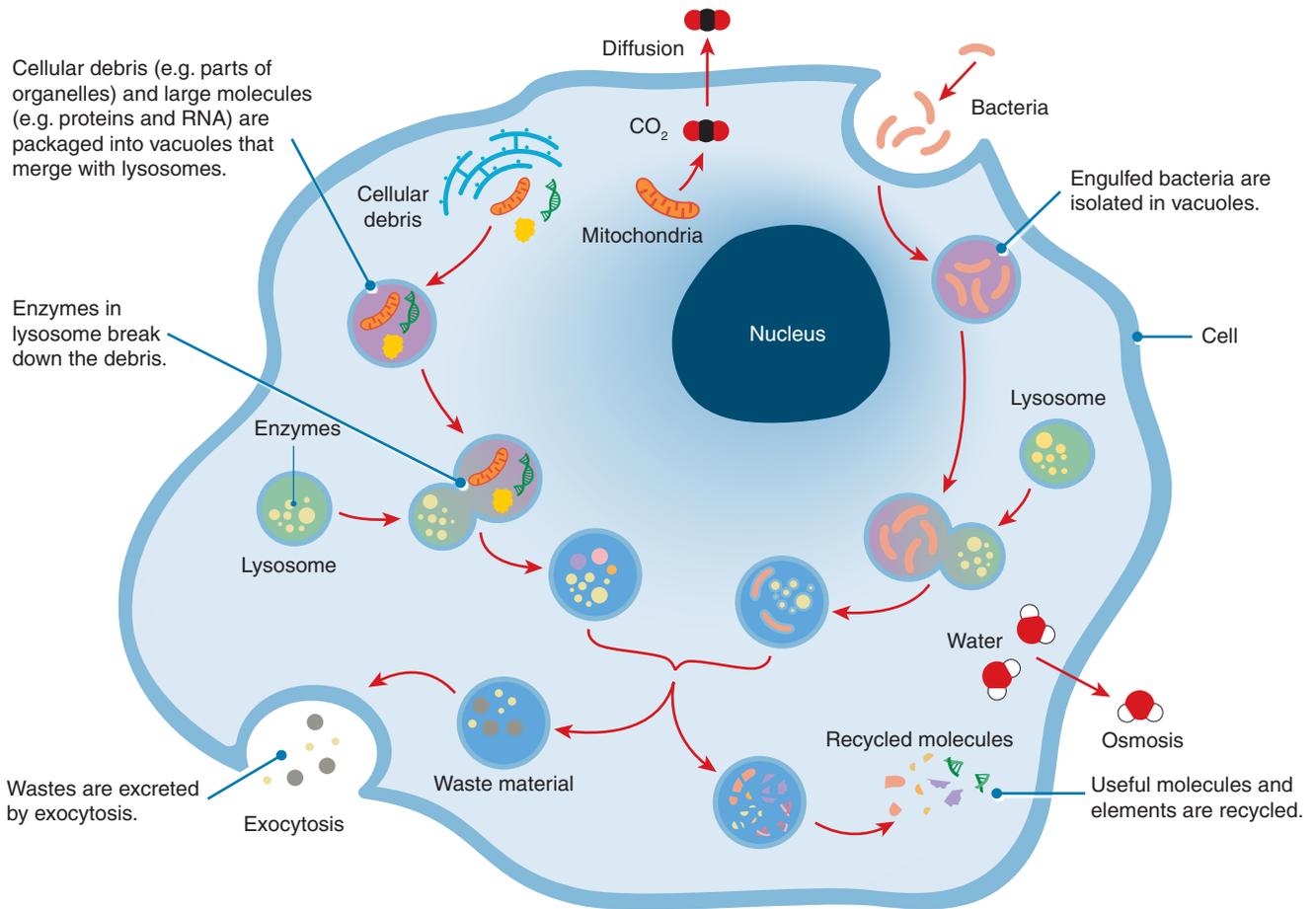
5. Explain why the Calvin cycle is likely to cease in the dark for most plants, even though it is independent of light: \_\_\_\_\_



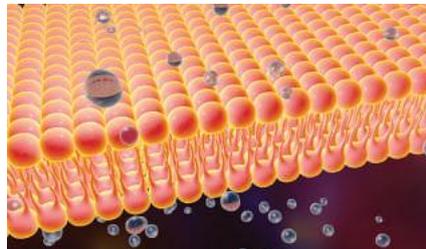
# 60 Dealing with Cellular Wastes

**Key Idea:** Enzymes break down waste materials and products. Metabolism produces waste products that must be dealt with by the cell in order for it to remain functional. Waste products

of respiration, such as CO<sub>2</sub>, diffuse out of the cell, but larger molecules and materials from other processes need to be broken down first by enzymes before being exported.



Carbon dioxide is a waste product of respiration. It diffuses out of the cell and is transported to the lungs by the blood where it is breathed out.



Water is also a waste product of respiration. Much of it is retained by the cell as a solute and medium for important reactions, but excess water leaves the cell by osmosis.



Oxygen is a waste product of photosynthesis. A plant cell can use some of the oxygen for respiration but excess oxygen diffuses out of the cell and leaves the plant via leaves.

- Summarise how the cell deals with cellular debris: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- How do plants deal with oxygen waste from photosynthesis? \_\_\_\_\_  
 \_\_\_\_\_
- What is the difference between how CO<sub>2</sub> is removed from the cell compared to larger molecules and cellular debris? \_\_\_\_\_  
 \_\_\_\_\_



# 61 Enzymes

**Key Idea:** Enzymes are biological catalysts. The active site is critical to this functional role.

Most enzymes are globular proteins. Enzymes are biological catalysts because they speed up biochemical reactions, but the enzyme itself remains unchanged. The substrate in a

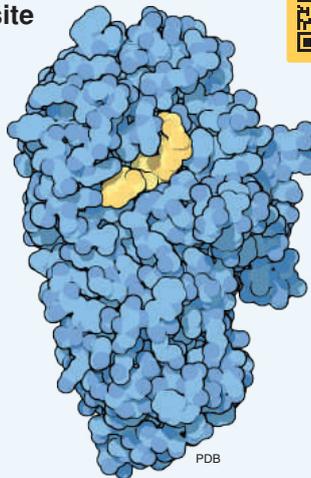
reaction binds to a region of the enzyme called the active site, which is formed by the precise folding of the enzyme's amino acid chain. Enzymes control metabolic pathways. One enzyme will act on a substance to produce the next reactant in a pathway, which will be acted on by a different enzyme.

## The active site

An enzyme acts on a specific chemical called a substrate. The substrate binds to a specific part of the enzyme called the **active site**.

The shape and chemistry of the active site is specific to an enzyme and is a function of the polypeptide's tertiary structure (the way the protein folds up). The amylase shown here breaks starch (a large molecule made of repeating glucose units) into smaller pieces with 2-3 glucose units.

Extremes of temperature or pH can alter the enzyme's active site and lead to loss of function. This process is called **denaturation**.



Amylase (blue) with bound glucose (yellow) in the active site



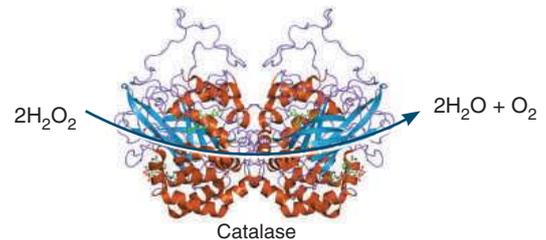
## Intracellular and extracellular enzymes

Enzymes can be defined based on where they are produced relative to where they are active.

An **Intracellular enzyme** performs its functions within the cell that produces it. Most enzymes are intracellular enzymes, e.g. respiratory enzymes.

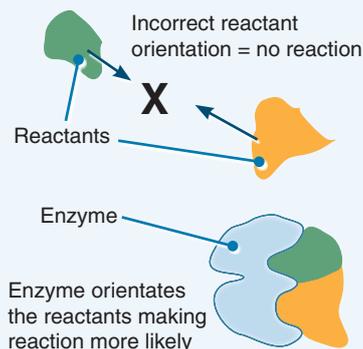
**Example:** Catalase (a type of peroxidase).

Many metabolic processes produce hydrogen peroxide, which is harmful to cells. Catalase converts hydrogen peroxide into water and oxygen gas (below) to prevent damage to cells and tissues.



## Substrates collide with an enzyme's active site

For a reaction to occur, reactants must collide with sufficient speed and with the correct orientation. Enzymes enhance reaction rates by providing a site for reactants to come together in such a way that a reaction will occur. They do this by orientating the reactants so that the reactive regions are brought together. They may also destabilise the bonds within the reactants making it easier for a reaction to occur.



An **extracellular enzyme** is an enzyme that functions outside the cell from which it originates (i.e. it is produced in one location but active in another).

**Example:**  $\alpha$ -amylase.

Alpha amylase is a digestive enzyme produced in the salivary glands and pancreas in humans. It acts in the mouth and small intestine to hydrolyse (split) starch by cleaving the  $\alpha$ -1,4 glycosidic bond. The end-products are sugars (maltose, dextrin).

1. (a) What is meant by the active site of an enzyme and relate it to the enzyme's tertiary structure: \_\_\_\_\_

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(b) Why are enzymes specific to one substrate (or group of closely related substrates)? \_\_\_\_\_

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2. How do substrate molecules come into contact with an enzyme's active site? \_\_\_\_\_

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3. (a) Suggest why digestion (the breakdown of large macromolecules) is largely performed by extracellular enzymes: \_\_\_\_\_

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(b) Some extracellular enzymes are produced and secreted from the cell in an inactive form. Why might this be? \_\_\_\_\_

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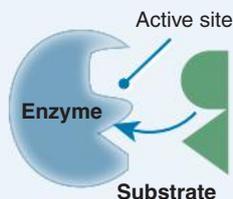
## 62 Models of Enzyme Activity

**Key Idea:** Enzymes catalyse reactions by providing a reaction site for a substrate. The model that describes the behaviour of enzymes the best is the induced fit model.

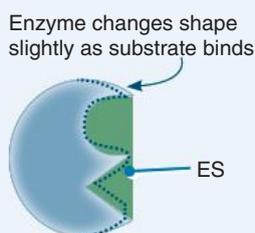
The initial model of enzyme activity was the lock and key model proposed by Emil Fischer in the 1890s. Fischer proposed that enzymes were rigid structures, similar to a

lock, and the substrate was the key. Although some aspects of this model were correct, it was not supported by empirical evidence. The model has been modified as techniques to study molecular structures improved. The current 'induced-fit' model of enzyme function (below) is supported by several lines of structural and functional evidence.

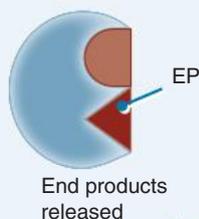
### The induced fit model of enzyme action



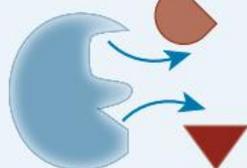
- 1 A substrate molecule is drawn into the enzyme's active site by its particular properties (resulting from its amino acid side chains). The active site is like a cleft into which the substrate molecule(s) fit.



- 2 The enzyme changes shape as the substrate binds, forming an enzyme-substrate (ES) complex. Chemical and electrostatic interactions are important in forming the ES complex. The shape change makes a change in the substrate more likely. In this way, the enzyme's interaction with its substrate is an induced fit.

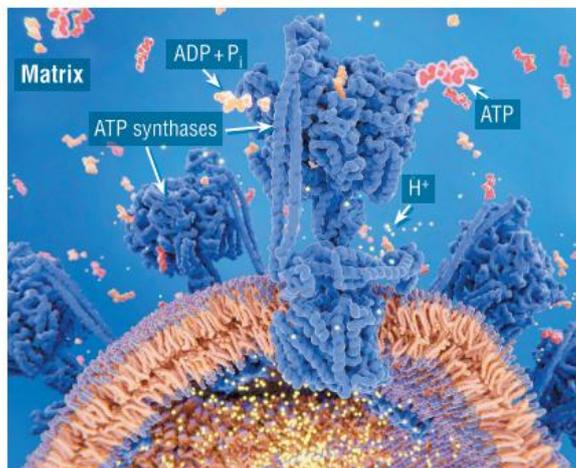


- 3 The ES interaction results in an intermediate enzyme-product (EP) complex. The substrate becomes bound to the enzyme by weak chemical bonds, straining bonds in the substrate and allowing the reaction to proceed more readily.

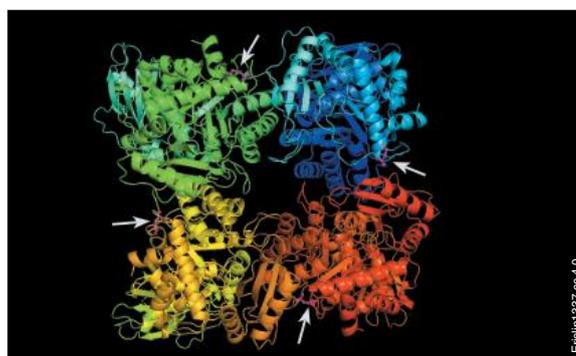


- 4 The end products are released and the enzyme returns to its previous shape.

Once the substrate enters the active site, the shape of the active site changes to form an active complex. The formation of an ES complex strains substrate bonds and lowers the energy required to reach the transition state, which allows the reaction to proceed. The **induced-fit model** is supported by X-ray crystallography, chemical analysis, and studies of enzyme inhibitors, which show that enzymes are flexible and change shape when interacting with the substrate.



ATP synthase is a transmembrane enzyme that catalyses the synthesis of ATP from ADP and inorganic phosphate. It is driven by a proton gradient generated by electron transfer. The image shows ATP synthase in the membrane of a mitochondrion. It is also found in the membranes of chloroplasts, where ATP is generated in the light dependent reactions of photosynthesis. ATP synthase is a type of ligase enzyme (an enzyme that joins smaller molecules together) because it joins ADP and P together to form ATP.



RuBisCo is an enzyme involved in the first main step of carbon fixation in plants and other photosynthetic organisms. It catalyses the attachment of  $\text{CO}_2$  to a 5-C sugar derivative called RuBP. The active sites are indicated by arrows.

1. Describe the key features of the 'induced' fit model of enzyme action: \_\_\_\_\_

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2. In the 1960s, it was proposed that ATP synthesis depended on a shape change in ATP synthase generated by rotation of membrane-bound subunits. This rotation has now been demonstrated experimentally. How does this provide evidence for the induced fit model of enzyme function?

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# 63 How Enzymes Work

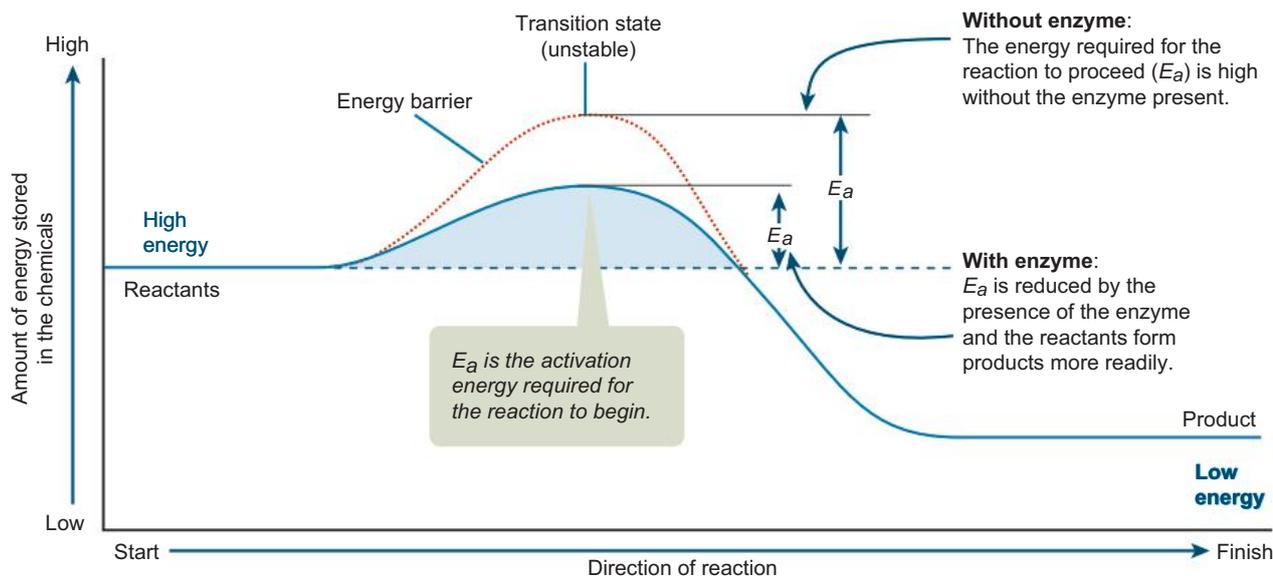
**Key Idea:** Enzymes increase the rate of biological reactions by lowering the reaction's activation energy.

Chemical reactions in cells are accompanied by energy changes. The amount of energy released or taken up is directly related to the tendency of a reaction to run to completion (for all the reactants to form products). Any reaction needs to raise the energy of the substrate to an unstable transition

state before the reaction will proceed (below). The amount of energy needed to do this is the **activation energy** ( $E_a$ ). Enzymes lower the  $E_a$  by destabilising bonds in the substrate so that it is more reactive. Enzyme reactions can break down a single substrate molecule into simpler substances (catabolic reactions), or join two or more substrate molecules together (anabolic reactions).

## Lowering the activation energy

The presence of an enzyme makes it easier for a reaction to take place. All catalysts speed up reactions by influencing the stability of bonds in the reactants. They may also provide an alternative reaction pathway, thus lowering the activation energy ( $E_a$ ) needed for a reaction to take place (see the graph below).



**Substrate** The substrate is drawn to the enzyme by the properties of the active site.

The substrate is cleaved (broken in two) and the two products are released to allow the enzyme to work again.

**Enzyme**

**Products**

Stress is applied to the substrate which will help break chemical bonds.

**Enzymes can catalyse the breakdown of molecules**

The properties of an enzyme's active site can draw in a single substrate molecule. Chemical bonds are broken, cleaving the substrate molecule to form two separate molecules. Reactions that break down complex molecules into simpler ones are called **catabolic reactions** and involve a net release of energy (they are **exergonic**).  
Examples: *cellular respiration, digestion.*

**Substrate** The substrate molecules are drawn to the active site.

The substrate molecules form a single product and are released, allowing the enzyme to work again.

**Enzyme**

**Product**

Stress is applied to the substrate, which will help form bonds.

**Enzymes can catalyse the building of molecules**

The properties of an enzyme's active site can draw in two substrate molecules. The two substrate molecules form bonds and become a single molecule. Reactions that build more complex molecules and structures from simpler ones are called **anabolic reactions** and involve a net use of energy (they are **endergonic**).  
Examples: *photosynthesis, protein synthesis.*

1. Why do reactants need energy added to them in order for them to react? \_\_\_\_\_

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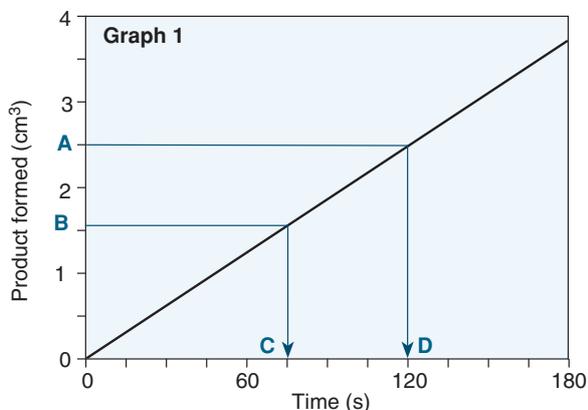


# 64 Factors Affecting Enzyme Activity

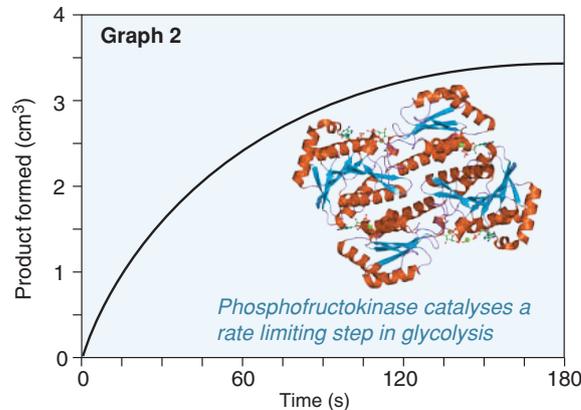
**Key Idea:** Enzymes operate most effectively within a narrow range of conditions. The rate of enzyme-catalysed reactions is influenced by both enzyme and substrate concentration. Enzymes usually have an optimum set of conditions (e.g. of pH and temperature) under which their activity is greatest. Many plant and animal enzymes show little activity at low

temperatures. Enzyme activity increases with increasing temperature, but activity falls off after the optimum temperature is exceeded and the enzyme may be denatured. Extremes in pH can also cause denaturation. Within their normal operating conditions, enzyme reaction rates are influenced by enzyme and substrate concentration in a predictable way.

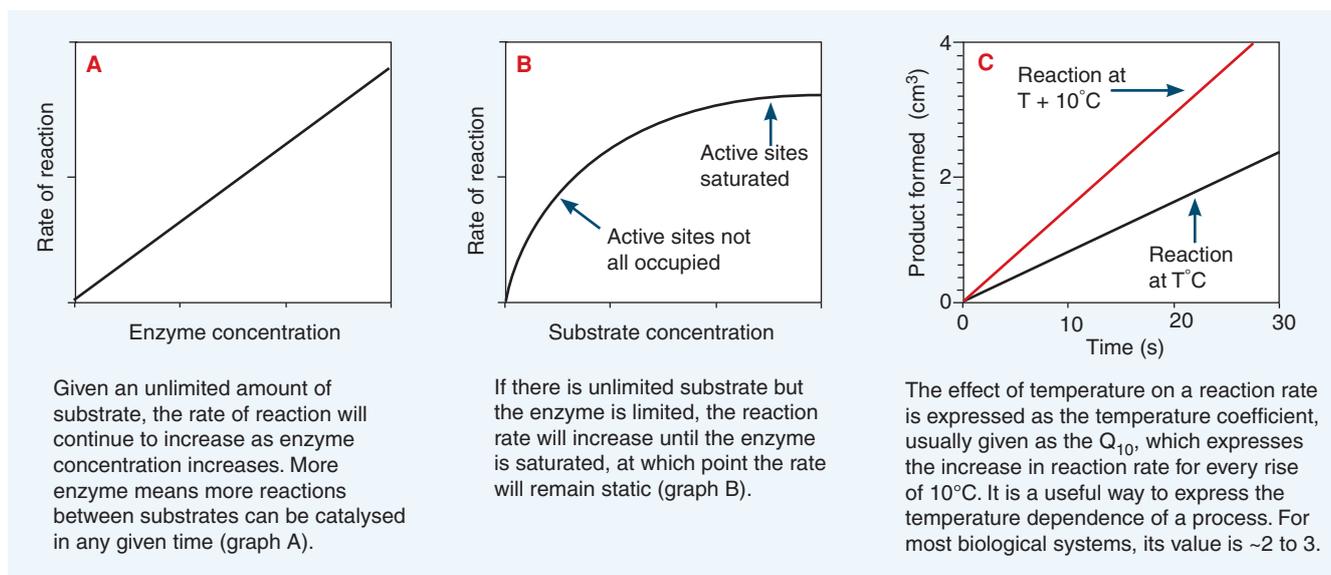
## Interpreting an enzyme catalysed reaction



If you plot the amount of product formed during a reaction against time, the rate of a reaction can be calculated from the amount of product made during a given time period. For a reaction in which the rate does not vary (above) the reaction rate calculated at any one point in time will be the same. For example:  $B \div C = A \div D$ .



In most biological systems, substrates are limiting, so the reaction rate often levels off over time (above). The enzyme forms product at an initial rate that is roughly linear for a short period after the start of the reaction. As the reaction proceeds and substrate is consumed, the rate continuously slows.



1. Use  $A \div D$  to calculate the reaction rate in the graph top left: \_\_\_\_\_

2. (a) What must be happening to the reaction mix in graph 1 to produce the straight line (constant reaction rate)?

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(b) Explain why the reaction rate in graph 2 changes over time: \_\_\_\_\_

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3. Explain why a reaction rate might drop off as the enzyme-catalysed reaction proceeds over time:

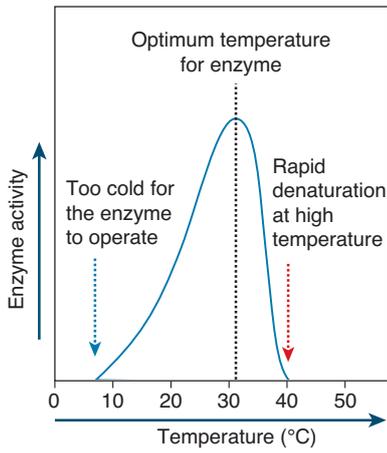
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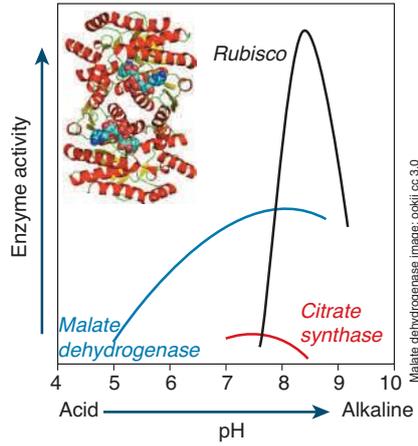
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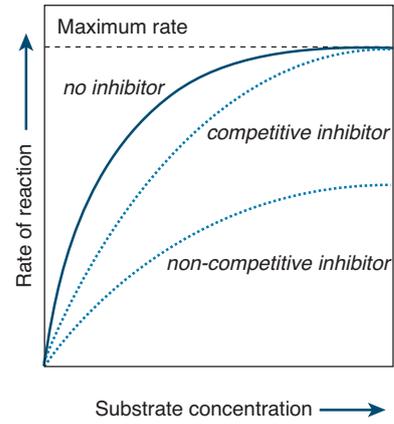
**Temperature and enzyme function**



**Acidity and enzyme function**



**Enzyme inhibition**



Higher temperatures speed up all reactions, but few enzymes can tolerate temperatures higher than 50–60°C. The rate at which enzymes are **denatured** (change their shape and become inactive) increases with higher temperatures. The temperature at which an enzyme works at its maximum rate is called the **optimum temperature**.

Like all proteins, enzymes are **denatured** by extremes of pH. Within these extremes, each enzyme has a pH range for optimum activity. For example, RuBisCo, the enzyme involved in fixing carbon in photosynthesis, has a relatively high optimal pH as it works in an environment where H<sup>+</sup> ions are used to create a proton gradient. Image shows malate dehydrogenase with bound sugars.

The action of enzymes can be affected by inhibitors. **Competitive inhibitors** compete with the substrate for the enzyme's active site. Their effect can be overcome by increasing the substrate concentration. **Non-competitive inhibitors** bind to the enzyme at a site other than the active site. Non-competitive inhibition cannot be overcome by increasing the substrate concentration.

4. (a) Describe the change in reaction rate when the enzyme concentration is increased and the substrate is not limiting:

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(b) Suggest how a cell may vary the amount of enzyme present: \_\_\_\_\_

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5. Describe the change in reaction rate when the substrate concentration is increased (with a fixed amount of enzyme):

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6. (a) Describe what is meant by an optimum temperature for enzyme activity: \_\_\_\_\_

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(b) Explain why most enzymes perform poorly at low temperatures: \_\_\_\_\_

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7. (a) State the optimum pH for each of the enzymes:

Malate dehydrogenase: \_\_\_\_\_ Citrate synthase: \_\_\_\_\_ RuBisCo: \_\_\_\_\_

(b) Why does RuBisCo have a high optimal pH? \_\_\_\_\_

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8. What is the difference between the binding of competitive and non-competitive inhibitions: \_\_\_\_\_

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# 65 Investigating Peroxidase Activity

**Key Idea:** The factors affecting peroxidase activity can be measured using the indicator guaiacol.

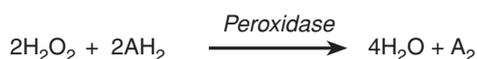
Enzymes control all the metabolic activities required to sustain life. Changes to environmental conditions (e.g. pH or temperature) may alter an enzyme's shape and functionality.

This may result in a reduction or loss of activity. In this exercise you will use the information provided and your own understanding of enzymes to investigate the effect of pH on enzyme activity and then design an experiment to investigate the effect of inhibitors on enzyme function.

## Background

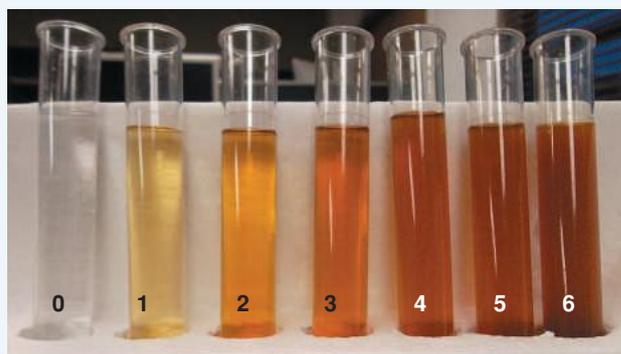
Hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) is a toxic by-product of respiration and must be broken down in order to avoid cellular damage.

**Peroxidase** acts in the presence of naturally occurring organic reducing agents (electron donors) to catalyse the breakdown of  $\text{H}_2\text{O}_2$  into water and oxidised organic substrates.



Like all enzymes, the activity of peroxidase is highest within specific ranges of pH and temperature, and activity drops off or is halted altogether when the conditions fall outside of the optimal range. The conversion of  $\text{H}_2\text{O}_2$  is also influenced by other factors such as the levels of substrate and enzyme.

The effect of peroxidase on  $\text{H}_2\text{O}_2$  breakdown can be studied using a common reducing agent called guaiacol. Oxidation of guaiacol (as in the equation above) forms tetraguaiacol, which is a dark orange colour. The rate of the reaction can be followed by measuring the intensity of the orange colour as a function of time.



Increasing levels of oxygen production over time (minutes)

A time-colour palette is shown above. You can use it as a reference against which to compare your own results from the investigation below. The palette was produced by adding a set amount of peroxidase to a solution containing hydrogen peroxide and water. The colour change was recorded at set time points (0-6 minutes).



## Investigation 3.7 Investigating peroxidase activity

See appendix for equipment list.

1. Prepare six substrate tubes by 7 mL of distilled water, 0.3 mL of 0.1%  $\text{H}_2\text{O}_2$  solution, and 0.2 mL of prepared guaiacol solution to a boiling tube. Cover the tubes with parafilm and mix.
2. Prepare six enzyme tubes by adding 6.0 mL of prepared buffered pH solution (one of pH 3, 5, 6, 7, 8, and 10) and 1.5 mL of prepared turnip peroxidase solution. Cover the tubes with parafilm and mix.
3. Combine the contents of substrate and enzyme tubes and cover with parafilm. Mix and place back on the rack.
4. Begin timing immediately. Record the colour change every minute (1-6 based on the colour palette above).
5. You can take photos with your phones or keep a written record of the colour changes.

Colour reference number							
	0 min	1 min	2 min	3 min	4 min	5 min	6 min
pH 3							
pH 5							
pH 6							
pH 7							
pH 8							
pH 10							

1. The colour palette (above) shows the relative amounts of tetraguaiacol formed when guaiacol is oxidised. How can this be used to determine enzyme activity?

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

active transport .....

concentration gradient .....

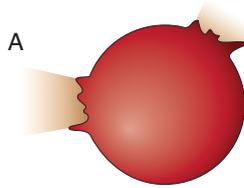
diffusion .....

osmosis .....

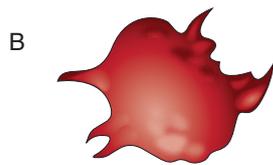
passive transport .....

- 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.

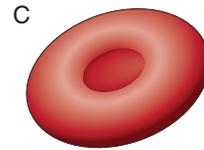
2. The diagrams below depict what happens when a red blood cell is placed into three solutions with differing concentrations of solutes. Describe the tonicity of the solution (in relation to the cell) and describe what is happening:



(a) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



(b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



(c) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

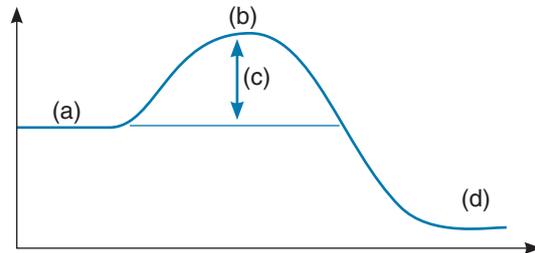
3. Explain how the properties of the phospholipid molecule result in the bilayer structure of membranes:

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

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. Identify the labels (a - d) on the graph, right, using the following labels: *Reactants*, *products*, *activation energy*, *transition state*.



- (a) \_\_\_\_\_ (b) \_\_\_\_\_
- (c) \_\_\_\_\_ (d) \_\_\_\_\_

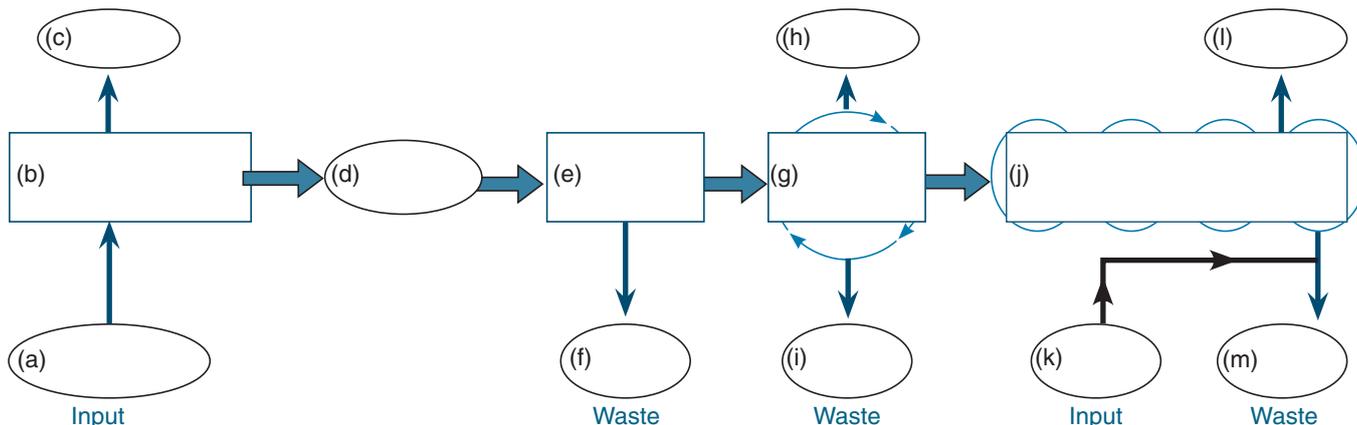
- 6. (a) Where does glycolysis occur in the cell? \_\_\_\_\_
- (b) Where does the Krebs cycle occur in the cell? \_\_\_\_\_
- (c) Where is the electron transport chain located in a cell? \_\_\_\_\_

7. Write the process of photosynthesis as:

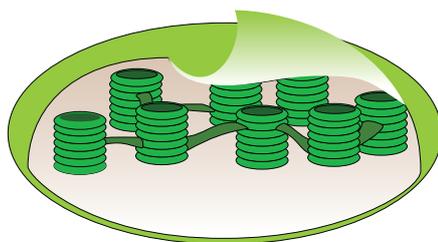
- (a) A word equation: \_\_\_\_\_
- (b) A chemical equation: \_\_\_\_\_



3. Cellular respiration is a continuous, integrated process. A simple diagram of the process in a eukaryote is shown below.
- (a) In the diagram, fill in the rectangles with the process and the ovals with the substance used or produced. Use the following word list (some words can be used more than once): *pyruvate, glycolysis, glucose, oxygen (O<sub>2</sub>), link reaction, electron transport chain (ETC), Krebs cycle, ATP, carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O)*
- (b) Add in a pathway to show fermentation. Write the two possible products of this pathway in eukaryotes.



4. (a) Label the following features of a chloroplast on the diagram below: *granum, stroma, thylakoid disc, stroma lamellae*.
- (b) Indicate on the diagram where the light dependent and light independent reactions occur.



5. Outline the differences between photosynthesis and cellular respiration, including reference to the raw materials used and the waste products produced:

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6. Enzymes are essential for catalysing biological reactions. Describe the induced fit model of enzyme action: \_\_\_\_\_

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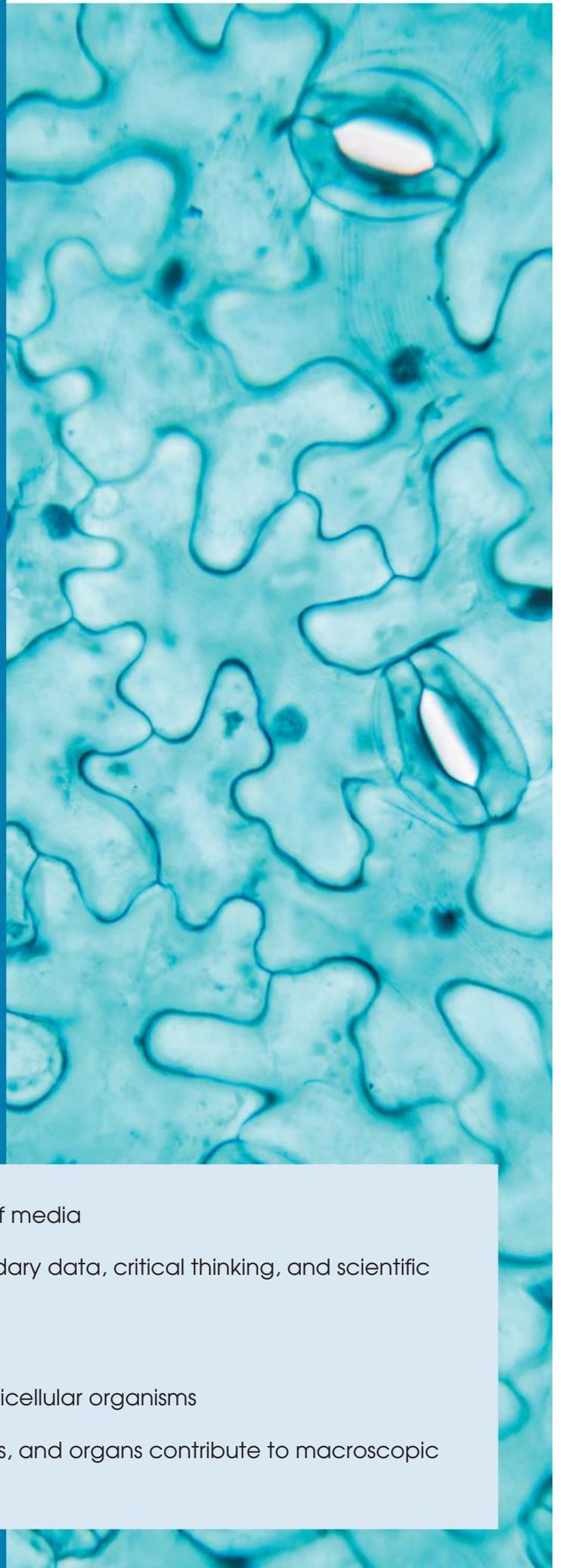
7. Identify the following statements as true or false (circle one)

- (a) Enzymes are biological catalysts. They lower the activation energy of a reaction. True / False
- (b) Competitive inhibition is when an inhibitor binds to a site other than the active site. True / False
- (c) The induced fit model states that the enzyme changes shape when a substrate fits into the active site. True / False

MODULE

# 02

Organisation of living things



## Student outcomes:

- ▶ Select and process data using a range of media
- ▶ Solve problems using primary and secondary data, critical thinking, and scientific processes
- ▶ Communicate scientific understanding
- ▶ Explain the structure and function of multicellular organisms
- ▶ Describe how the activities of cells, tissues, and organs contribute to macroscopic processes in organisms

# Organisation of Cells

Activity  
number

## Key terms

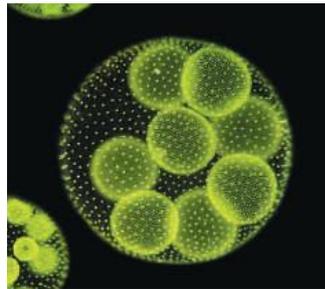
colonial  
connective tissue (animal)  
epidermal tissue (plant)  
epithelial tissue (animal)  
ground tissue (plant)  
multicellular  
muscle tissue (animal)  
nervous tissue (animal)  
organ  
organ system  
specialised cell  
tissue  
unicellular  
vascular tissue (plant)

*Inquiry question: How are cells arranged in a multicellular organism?*

## Unicellular, colonial, and multicellular organisms

### Key skills and knowledge

- 1 Distinguish between unicellular, colonial, and multicellular organisms. 68 69 70
- 2 Review the material you covered on prokaryotic cells and recall their defining features. Compare different types of unicellular eukaryotic organisms using light and electron micrographs, drawings, and/or live or mounted specimens. How are they different to prokaryotes? How are they different from each other and how are they alike? What are these differences and similarities related to? Suitable genera include protists such as *Amoeba*, *Chlamydomonas*, *Euglena*, and *Paramecium*. 11 68
- 3 Describe features of colonial organisms including colonial protists such as *Spirogyra* and *Volvox*, and colonial prokaryotes such as *Myxococcus xanthus*. Explain how colony formation provides benefits in terms of acquiring resources or reproducing. Do colonies show any differentiation of cell types? What does this mean for our distinction between colonial and multicellular organisms 69
- 4 Describe the features of multicellular organisms, and identify the taxa that are multicellular or have multicellular representatives. Describe the role of cell specialisation in multicellular organisms and its relationship to the efficient functioning of the organism. 70-72



## Structure and function of tissues, organs, and systems

### Key skills and knowledge

- 5 Describe the general role of specialised cells in tissues and organs. Use drawings, light and electron micrographs, prepared slides, and/or whole specimens to investigate the structure and function of tissues, organs, and organ systems. 71-74
- 6 Using examples, describe the specialised cells that make up the tissues and organs of a named organ system in a mammal such as humans. Recognise the four main tissue types (epithelial, muscle, nervous, and connective tissue) in histological slides or image galleries. How do the cell specialisations contribute to function of the tissue, the organ, and the organ system. 74
- 7 Explore the organisation of tissues and organs through a virtual dissection of a mammalian organ such as a heart. How does the arrangement of tissues produce the organ's structure and contribute to function? 74
- 8 Recognise that organ systems can cooperate and interact to deliver essential functions such as transport of respiratory gases and nutrients. 73

## The hierarchical structure of organisms

### Key skills and knowledge

- 9 Using examples, describe the hierarchical structure of multicellular organisms, including reference to cells, tissues, organs, and organ systems. 73-75
- 10 Explain how a hierarchical organisation builds structural complexity and contributes to the functional efficiency of the organism as a whole. Include reference to emergent properties (the whole is greater than the sum of the parts). 73-75

# 68 Unicellular Eukaryotes

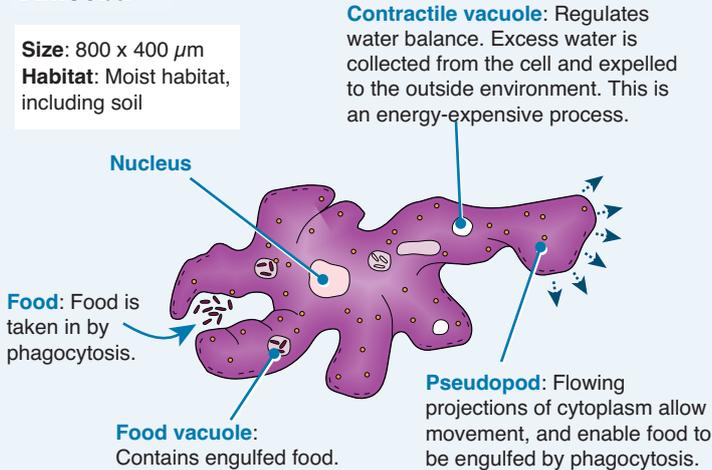
**Key Idea:** Unicellular eukaryotes show great variation in the ways in which they carry out the functions of life.

Most of life is unicellular (single-celled) prokaryotes (e.g. bacteria). Unicellular organisms must have all the structures needed for independent survival. Unicellular eukaryotes are much larger than prokaryotes and show some features typical of generalised eukaryotic cells, as well as specialised

or unique features. The genera below are representative of a group of single-celled eukaryotes called protists. Even within the genera shown there is considerable variation in size and appearance. *Amoeba* and *Paramecium* are both heterotrophic, ingesting food, which accumulates inside a vacuole. *Chlamydomonas* is an autotrophic alga. Its flagella help it stay in the sunlit parts of a pond.

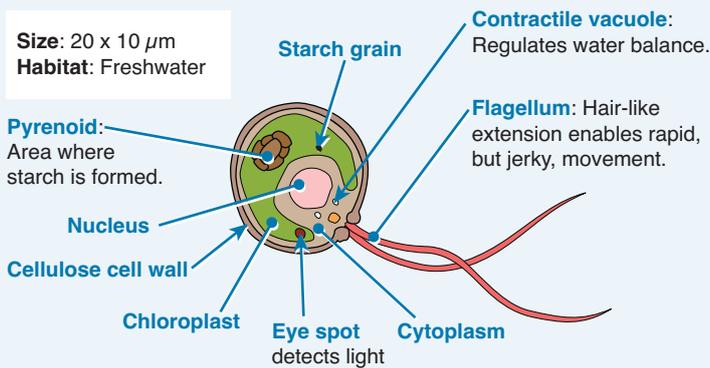
## Amoeba

**Size:** 800 x 400  $\mu\text{m}$   
**Habitat:** Moist habitat, including soil



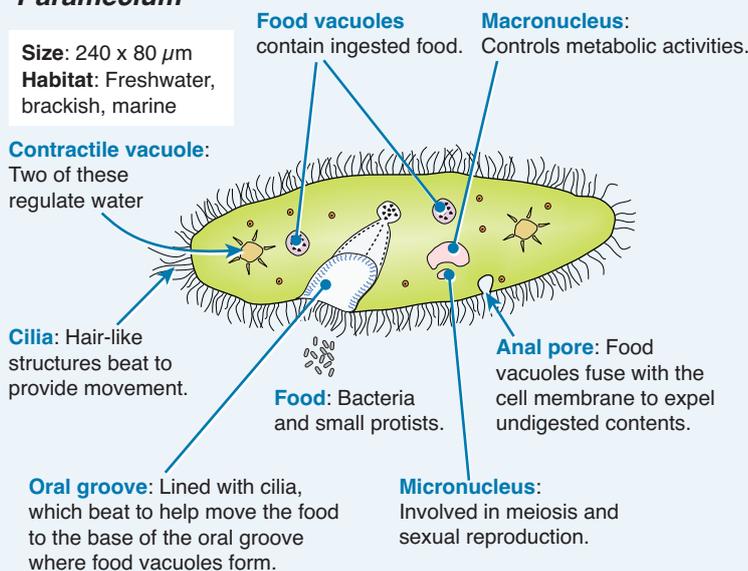
## Chlamydomonas

**Size:** 20 x 10  $\mu\text{m}$   
**Habitat:** Freshwater



## Paramecium

**Size:** 240 x 80  $\mu\text{m}$   
**Habitat:** Freshwater, brackish, marine



1. List the three organisms shown in the diagram in order of size (largest first):

- i \_\_\_\_\_
- ii \_\_\_\_\_
- iii \_\_\_\_\_

2. Why would an autotroph have an eye spot?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. For each of the organisms pictured left, identify the organelles or structures with a role in each of the life functions identified below and describe what they do:

(a) Nutrition: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Water balance: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Movement: \_\_\_\_\_

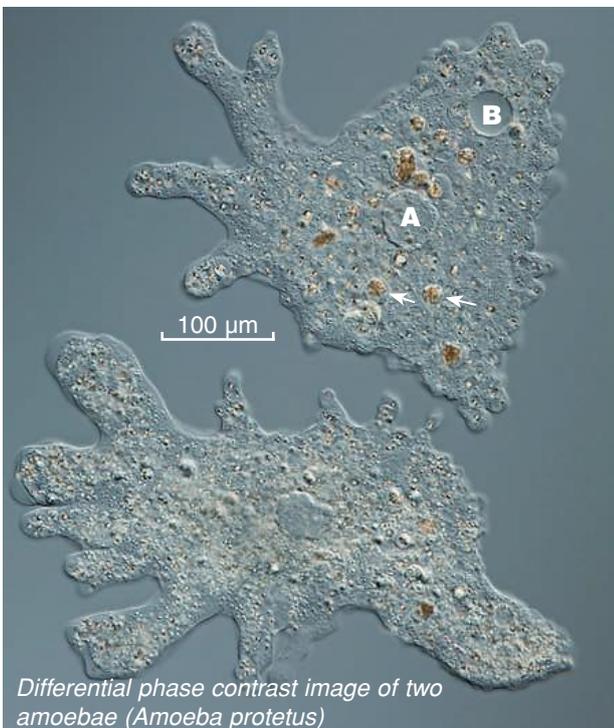
\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

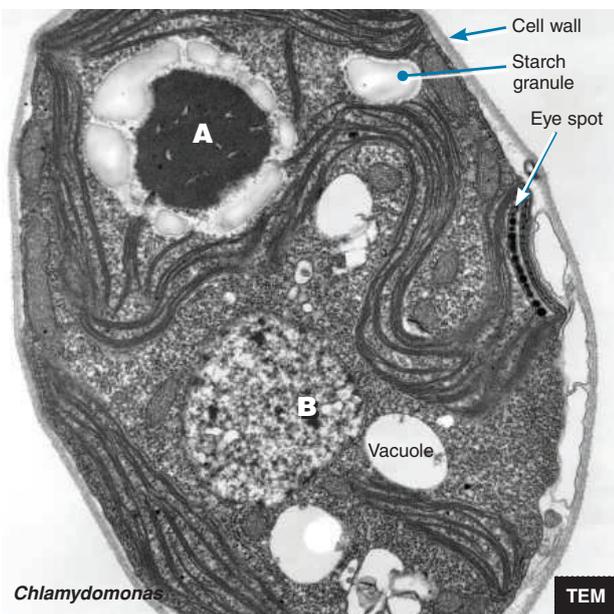
\_\_\_\_\_



4. (a) Identify the structure labelled **A**: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Circle the same structure in the unlabelled specimen:
- (c) What feature(s) helped you identify this organelle?  
 \_\_\_\_\_
- (d) Identify the structure labelled **B**:  
 \_\_\_\_\_
- (e) Describe the function of this structure:  
 \_\_\_\_\_  
 \_\_\_\_\_
- (f) Identify the structures labelled with arrows:  
 \_\_\_\_\_
- (g) Describe the function of these structures:  
 \_\_\_\_\_



5. (a) Identify this organism: \_\_\_\_\_
- (b) What feature(s) helped you make your identification?  
 \_\_\_\_\_  
 \_\_\_\_\_
- (c) Identify the organelle labelled **A**: \_\_\_\_\_  
 \_\_\_\_\_
- (d) Circle another organelle with the same function:
- (e) Identify the structures indicated by the arrows and describe their purpose:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



6. (a) Identify the organelle labelled **A**: \_\_\_\_\_
- (b) Describe the function of this organelle: \_\_\_\_\_  
 \_\_\_\_\_
- (c) Identify the organelle labelled B. What is the dark granular material you can see?  
 \_\_\_\_\_  
 \_\_\_\_\_
- (d) Identify the ribbon-like structures in this image, and explain how you came to your conclusion about what they are:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 69

# Colonial Organisms

**Key Idea:** Some unicellular organisms live as colonies. Some unicellular organisms group together to form colonies. The cells in these colonies act more or less independently. However, they can coordinate some actions to a certain

degree and, in some, there may be more than one cell type (the beginnings of being multicellular). The colony usually forms from the asexual reproduction of the founder cell. Both prokaryotes and eukaryotes can form colonies.

### Prokaryote colonies

▶ Prokaryotes generally exist as single cells but they sometimes form simple colonies. Under certain conditions, microbial communities can attach to surfaces, forming organised structures called biofilms. The soil bacterium *Myxococcus xanthus* usually lives as a biofilm. When there is plentiful bacterial food, cells show cooperative predatory behaviour with individual cells moving together as a "swarm". When in an aqueous environment (rather than on a surface), *M. xanthus* overcomes the dilution of its lytic enzymes by forming spherical colonies with bacterial prey trapped inside. The colony is then able to feed effectively altogether using the resource through multicellular behaviour.

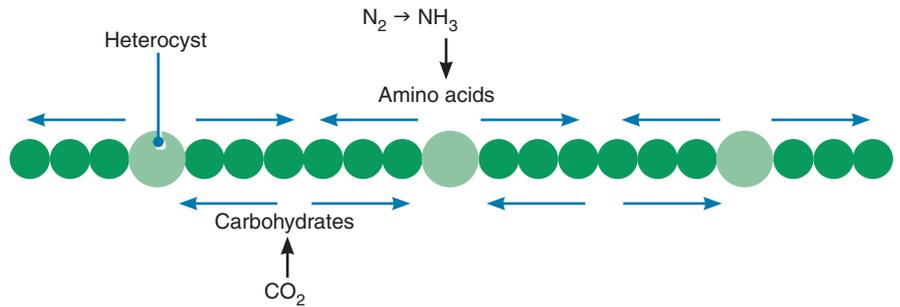
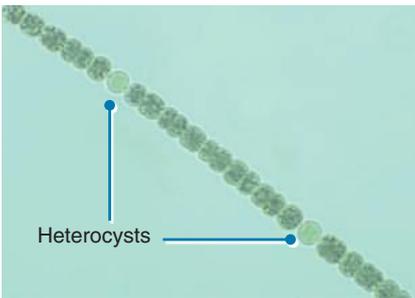
When resources are low, cells gather to form fruiting bodies composed of about 100,000 cells. The fruiting bodies produce spores that can be transported by wind to a new location.



*Myxococcus* fruiting bodies

Trance Gemini GFDL

▶ Cyanobacteria (e.g. *Anabaena* shown below) are a group of bacteria that carry out photosynthesis. The bacterium forms long filaments of individual cells joined together. Under low-nitrogen conditions, some of these cells will specialise to form heterocyst cells. Heterocysts are able to fix nitrogen from molecular N<sub>2</sub>. They show quite different gene expression from neighbouring unspecialised cells in that they produce the enzyme nitrogenase and cannot photosynthesise. The heterocysts share the nitrogen they fix with neighbouring cells and receive other nutrients from them, indicating basic cooperation.



1. Using the example of *Myxococcus xanthus*, suggest why prokaryotes might switch from a colony of individual cells to exhibiting multicellular behaviour:

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2. Explain how *Anabaena* benefits by some individuals cells becoming heterocysts:

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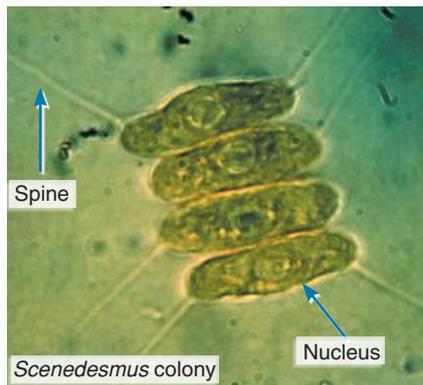
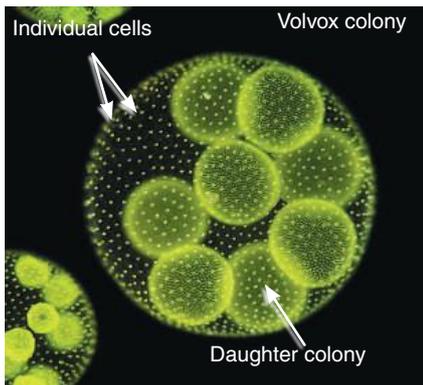


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### Eukaryote colonies

▶ Like bacterial colonies, the cells in eukaryote colonies are more or less independent. If separated they will divide and form another colony. A large number of eukaryotic colonial organisms are algae but some amoebas occasionally form colonies.



Volvox are a group of green algae that form spherical colonies of up to 50,000 cells. It diverged from unicellular ancestors about 200 million years ago. There are two types of cells in the colony, flagellate cells (movement) and germ cells (reproduction). The cells can swim in a coordinated way.

Scenedesmus is a green alga that can be unicellular or form colonies of up to 16 cells. Unlike volvox it does not have cells with flagella. Instead cells have long spines that deter grazers that may feed on it. All the cells in a colony are identical. Colonies form in conditions of low light and temperature.

Dictyostelium discoideum is a soil living amoeba. It spends part of its life cycle as a free living single cell. When food (bacteria) becomes scarce the individual cells begin to congregate forming a slug composed of about 100,000 cells. This moves to a more favoured area and forms a fruiting body, producing spores that produce new amoeba.

3. Using examples, explain the possible benefits of living in a colony: \_\_\_\_\_

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4. Go to [BIOZONE's Resource Hub](#) and watch the short video listed as a resource for this activity. Use the information and examples in the video to answer the question "How do colonies help microorganisms survive?" In your answer, discuss the role of any specialisation of cell function.

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# 70 Multicellular Organisms

**Key Idea:** True multicellularity allowed cells to specialise and form tissues, allowing organisms to evolve a vast range of body types and forms.

Multicellularity evolved about 600 million years ago and provided life with a way to escape the limitations of unicellularity, and exploit new habitats, food sources, and ways of life. Multicellularity allows cells to specialise

and use resources more efficiently and exchange their products with other specialised cells in the organism. For example exchanging glucose absorbed from food for oxygen transported to them benefits the group of cells (the organism) as a whole. The progression of multicellularity can be seen in the various types of animal groups alive today and found in fossils.



Sponges are some of the most primitive living (extant) multicellular organisms. They have no digestive, respiratory, nervous or other systems found in animals and are believed to be the first group to split from the animal family tree. They have no tissues or organs, just a few types of cells that can transform into other types or migrate between the layers of the body of the sponge. If mechanically separated (e.g. forced through a sieve) sponge cells can reform into new functional sponges. Yet their cells are able to coordinate to cycle water through their tube-like structure and sieve out food particles.



Sponges have no fixed body plan (although species may have characteristic shapes). Most multicellular organisms have a body plan with a front and back and show bilateral symmetry (i.e. divisible into symmetrical halves). Bilateral symmetry evolved relatively early in multicellular evolution. *Dickinsonia* (far left) evolved around 560 million years ago, only around 40 million years after the evolution of multicellularity. Its symmetry is not truly bilateral, although other organisms at the time were. *Kimberella* (left), an extinct organism (possibly a mollusc) from the same era, was bilateral and had three tissue layers.



Multicellular organisms have more than one cell. Most fungi, all land plants, and all animals are multicellular. Many other organisms, including the colonial protists we have already looked at, as well as marine siphonophores such as the Portuguese man o' war (bluebottle) show differentiation of cell types within a colony. In these cases, it is difficult to separate colonial organisms from true multicellular organisms.

Multicellularity allows organisms to exceed the size limits of single cells imposed by the diffusion of nutrients and it also allows increasing complexity. Multicellularity is accompanied by the specialisation of cells to carry out specific tasks. For example, in mammals, red blood cells carry oxygen whereas white blood cells fight infection. In this way, cells become efficient in one process and develop a degree of interdependence on other cell types.



Most life on Earth is unicellular, so whether or not multicellularity is an "advantage" is debatable. It may be better explained as another way of acquiring the materials needed for reproduction and maintaining the genetic lineage, with its own set of associated advantages, disadvantages, and trade-offs.

**Multicellular organisms show specialisation**

- ▶ One advantage of being multicellular is having cells that are specialised for a particular task. This results in those tasks being performed more efficiently and saves energy because unused organelles can be lost.
- ▶ Being multicellular also means an organism can become very large and get more resources, although a great many, such as *Caenorhabditis elegans*, are small and relatively simple.



*C. elegans* is a free living nematode about 1 mm long. It has been well studied and the fate of all of its 959 cells is known. Even with such a small number of cells, it has a mouth, pharynx, gut, reproductive cells, and a nervous system. Banded muscle tissue enables its movement. This differentiation enables the organism to move about and find food, reproduce, move to more favourable conditions, or evade predators.

Cell type	Number of cells
Hypodermis (part of body wall)	213
Nervous system	338
Body mesoderm (body cells)	122
Alimentary canal (intestines etc.)	143
Reproductive cells	143
Total	959

1. Why might sponges be "on the edge" of what can be could multicellular? \_\_\_\_\_

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2. How does multicellularity provide new opportunities that are unavailable to unicellular organisms? \_\_\_\_\_

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3. Explain how specialisation in the nematode *Caenorhabditis elegans* allows it to live a highly active lifestyle: \_\_\_\_\_

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4. Does multicellularity provide an advantage over unicellularity? Argue the case for both (advantages of multicellularity versus the advantages of remaining as a unicellular organism):

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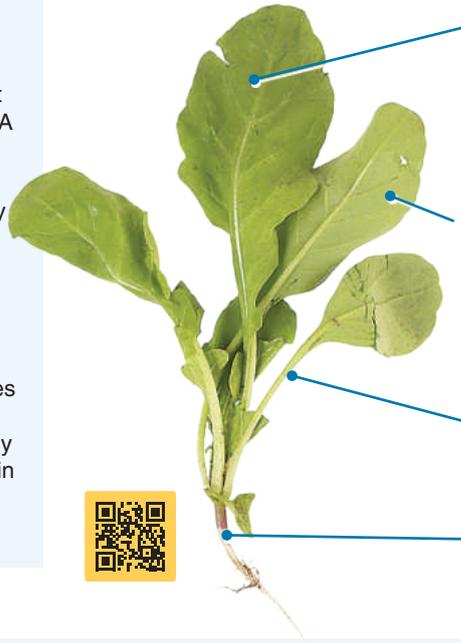
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# 71 Specialisation in Plant Cells

**Key Idea:** The specialised cells in a plant have specific features associated with their particular roles. In multicellular organisms, 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.

- ▶ Specialised cells have features needed to perform specific functions 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, whereas complex tissues contain more than one cell type.

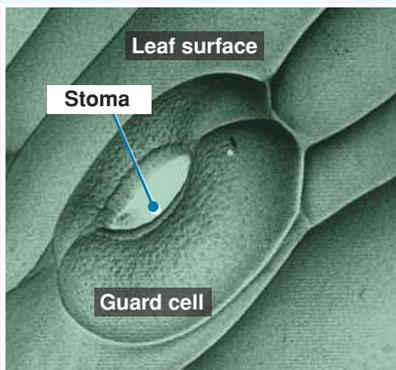


The **epidermal tissue** of a plant forms the outer surface of the leaves and the young plant body. The epidermal cells are not photosynthetic but have a waxy cuticle to prevent water loss.

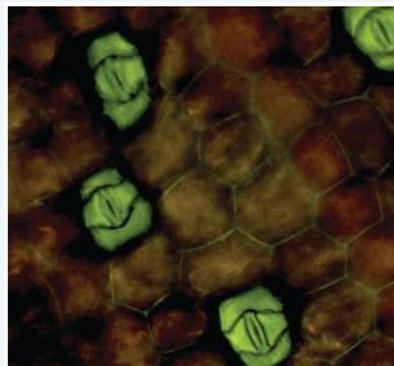
Much of the young plant body is **ground tissue**. Ground tissue is less differentiated than other tissues. The cells in ground tissue carry out photosynthesis and store nutrients.

**Vascular tissue** transports water and nutrients around the plant. Vascular tissue (xylem and phloem) is made up of collections of cells specialised to transport different substances.

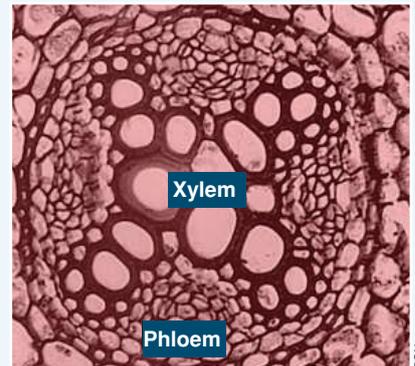
Some cells in the transport system are strengthened to provide support for the plant, allowing it to keep its shape and structure.



Specialised guard cells surround the pores (stomata) on plant leaves. The guard cells around the pore control the opening and closing of stomata and prevent too much water being lost from the plant.



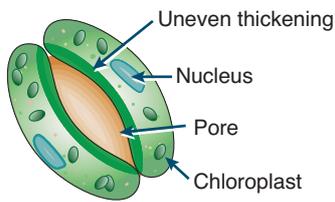
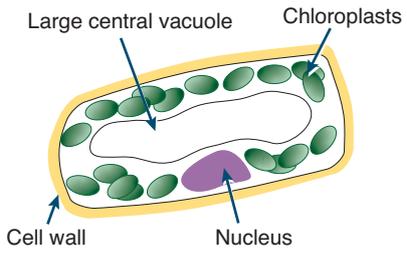
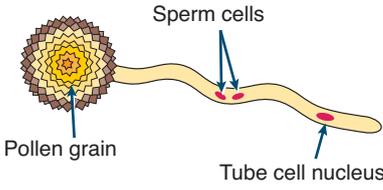
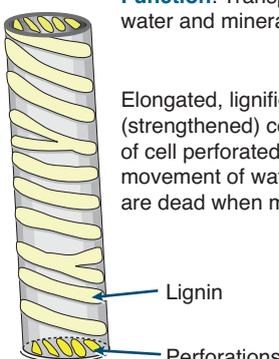
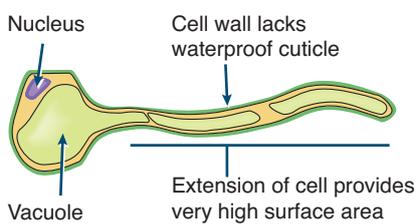
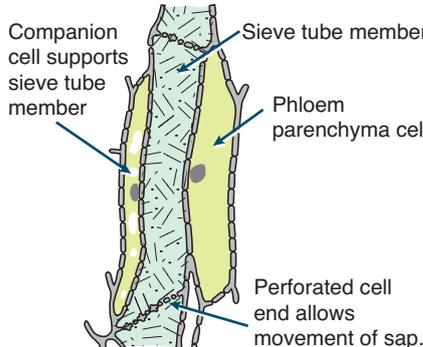
The semi-rigid cell wall gives many plant cells a regular shape. This *Tradescantia* epidermis has polyhedral epidermal cells with stomata flanked by guard cells and four more irregular epidermal cells.



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. Describe three important roles of the plant tissues below:
  - (a) Vascular tissue: \_\_\_\_\_  
\_\_\_\_\_
  - (b) Epidermis: \_\_\_\_\_  
\_\_\_\_\_
  - (c) Ground tissue: \_\_\_\_\_  
\_\_\_\_\_

Examples of specialised plant cells

<p><b>A</b></p> <p><b>Cell type:</b> Pair of guard cells  <b>Function:</b> Open and close stoma (pore), regulating entry and exit of gases from the leaf, and regulating water loss.</p>  <p>When the cells are turgid (tight), the uneven thickening makes the cells bend, opening the stoma (leaf pore).</p>	<p><b>B</b></p> <p><b>Cell type:</b> Palisade mesophyll cell  <b>Function:</b> Photosynthesis</p>  <p>Elongated cell. Dense chloroplasts located near outer edge of cell to gather light.</p>	<p><b>C</b></p> <p><b>Cell type:</b> Pollen tube cell  <b>Function:</b> Enables the sperm cell to reach the egg cell in flowers.</p>  <p>Tube produced by the pollen. Sperm cell travel down the tube to the egg cell.</p>
<p><b>D</b></p> <p><b>Cell type:</b> Xylem vessel  <b>Function:</b> Transports water and minerals.</p>  <p>Elongated, lignified (strengthened) cells. End of cell perforated to allow movement of water. Cells are dead when mature.</p>	<p><b>E</b></p> <p><b>Cell type:</b> Root hair cell  <b>Function:</b> Absorbs water and nutrients.</p>  <p>Increase surface area for absorbing water and mineral ions.</p>	<p><b>F</b></p> <p><b>Cell type:</b> Phloem sieve tube member  <b>Function:</b> Transports sap.</p>  <p>Perforated cell end allows movement of sap.</p>

3. For each of the cells (b) to (f) pictured above, describe how their structure relates to their function:

(a) Guard cells: Curved, unevenly thickened cells. When the cells are turgid, the thickening makes them bend to open the stoma. When flaccid, the pore is closed. Guard cells regulate the entry and exit of gases from the leaf, and regulate water loss.

- (b) \_\_\_\_\_
- (c) \_\_\_\_\_
- (d) \_\_\_\_\_
- (e) \_\_\_\_\_
- (f) \_\_\_\_\_

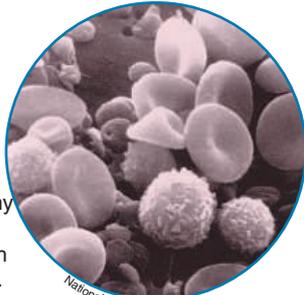
# Specialisation in Animal Cells

**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

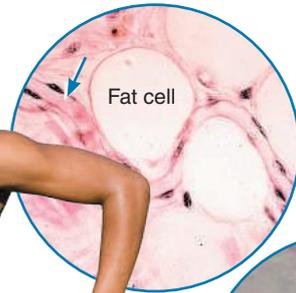
body. Animal cells lack a cell wall, so they can take on many different shapes. Some, e.g. white blood cells, are even mobile. The shape, size, and the internal structure of a specialised cell reflects its functional role in the body.

- ▶ Specialised cells often have modifications or exaggerations to a normal cell feature 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 is specialised to perform a specific task. They may have more (or fewer) of a particular organelle in order to perform their role most efficiently.



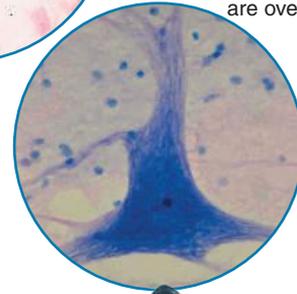
There are many types of blood cells, each with a specific task.

National Cancer Institute

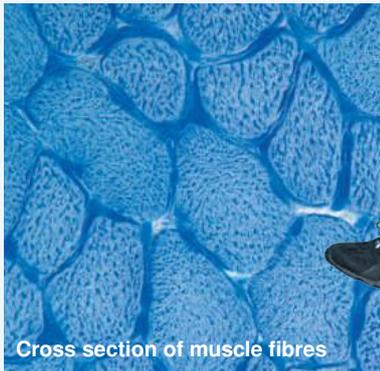
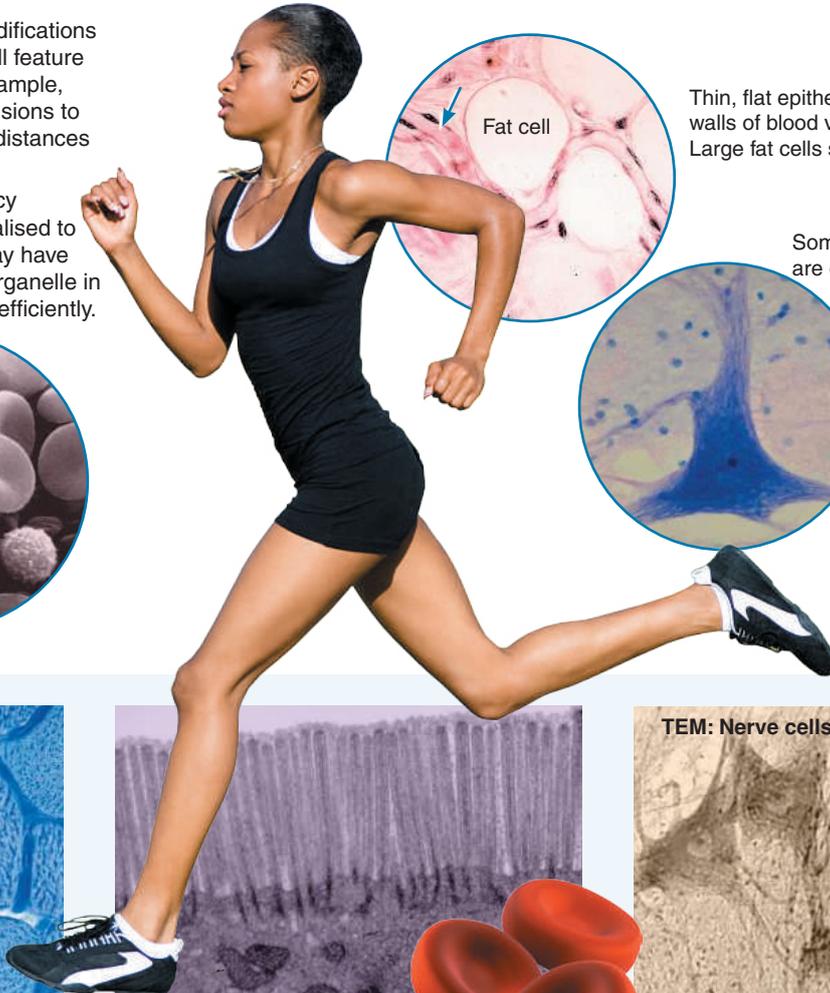


Fat cell

Thin, flat epithelial cells line the walls of blood vessels (arrow). Large fat cells store lipid.

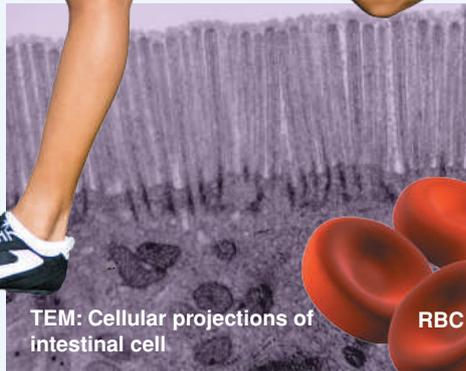


Some nerve cells are over 1 m long.



Cross section of muscle fibres

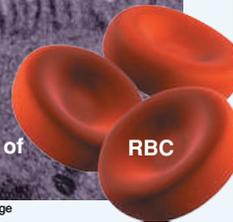
Some animal cells can move or change shape. Muscle cells, called fibres, are able to contract (shorten) as protein fibres within the cell move past each other. This action causes the movement of limbs, and of organs, such as the heart and intestine.



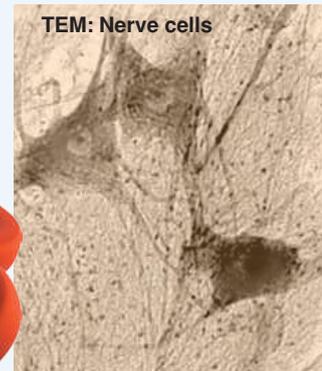
TEM: Cellular projections of intestinal cell

Louisa Howard, Katherine Connolly Dartmouth College

Cells that line the intestine have extended cell membranes. This increases their surface area so that food (nutrients) can be absorbed quickly and efficiently. Red blood cells (RBCs) have no nucleus so they have more room inside to carry oxygen.



RBC



TEM: 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. muscle) allowing responses to the environment.

1. What is the advantage of cell specialisation in a multicellular organism? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. For each of the following specialised animal cells, describe a feature that helps it carry out its function:

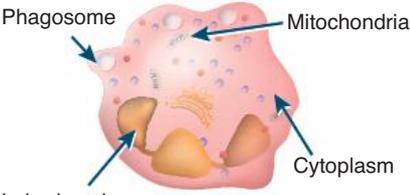
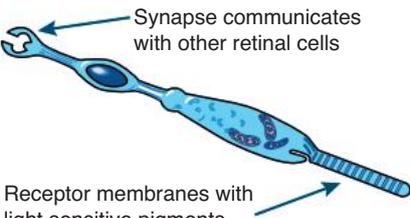
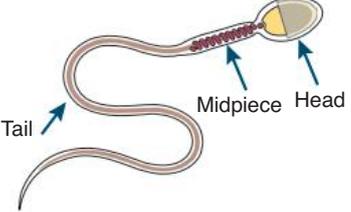
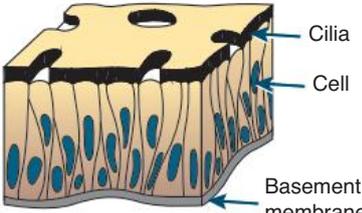
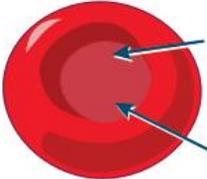
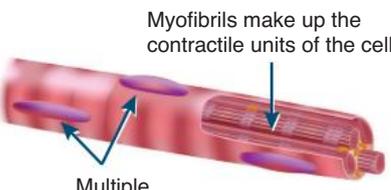
(a) Intestinal cell: \_\_\_\_\_

\_\_\_\_\_

(c) Nerve cell: \_\_\_\_\_

\_\_\_\_\_

**Examples of specialised animal cells**

<p><b>A</b></p> <p><b>Cell type:</b> White blood cell (neutrophil) <b>Function:</b> Internal defence</p>  <p>Phagosome Mitochondria Cytoplasm Lobed nucleus</p> <p>Large spheroid cell. Able to change shape and exhibit amoeba-like behaviour. Engulfs and destroys foreign material.</p>	<p><b>B</b></p> <p><b>Cell type:</b> Retinal cell <b>Function:</b> Detects and responds to light</p>  <p>Synapse communicates with other retinal cells Receptor membranes with light sensitive pigments</p> <p>Long cell that receives light energy and converts it into electrical nerve signals.</p>	<p><b>C</b></p> <p><b>Cell type:</b> Sperm cell <b>Function:</b> Transfers genetic material to egg cell.</p>  <p>Tail Midpiece Head</p> <p>Consists of a head carrying the genetic material, a midpiece with many mitochondria, and a tail for movement.</p>
<p><b>D</b></p> <p><b>Cell type:</b> Ciliated epithelial cells (trachea) <b>Function:</b> Moves mucus and trapped debris out of airways.</p>  <p>Cilia Cell Basement membrane</p> <p>Cilia wave in a way that moves mucus and debris up the trachea to the throat.</p>	<p><b>E</b></p> <p><b>Cell type:</b> Red blood cell (erythrocyte) <b>Function:</b> Carries oxygen in the blood and delivers it to the tissues.</p>  <p>Contains many haemoglobin molecules to carry oxygen Lack nucleus and most organelles.</p> <p>Small, biconcave shape can squeeze through capillaries. No nucleus so the cell is packed with haemoglobin.</p>	<p><b>F</b></p> <p><b>Cell type:</b> Muscle cell (fibre) <b>Function:</b> Contracts to create movement.</p>  <p>Myofibrils make up the contractile units of the cell Multiple nuclei per cell</p> <p>Cylindrical shape with banded myofibrils. Capable of contraction (shortening) to move bones at joints.</p>

2. For each of the cells (b) to (f) pictured above, describe how their structure relates to their function:

(a) Neutrophil. It is spheroid but can change shape (amoeba-like) which enables it to engulf bacteria and other foreign material and perform its role in defence.

(b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(d) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(e) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

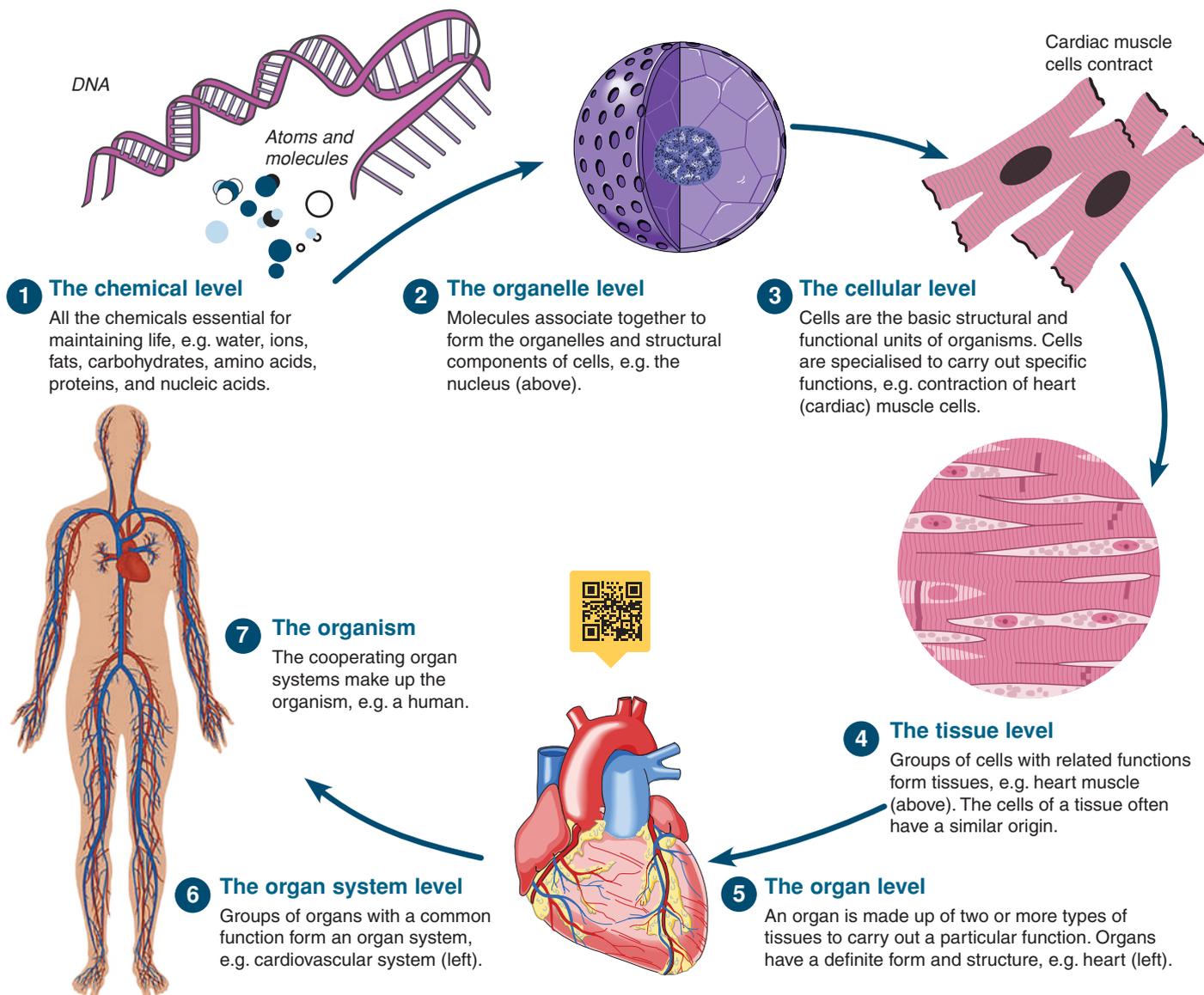
(f) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 73 The Hierarchy of Life

**Key Idea:** Structural organisation in multicellular organisms is hierarchical, with new properties arising at each level.

Multicellular organisms are organised according to a hierarchy of structural levels, where each level builds on the one below it. At each level, new properties, absent at the simpler level, emerge. Hierarchical organisation allows specialised cells

to group together into tissues and organs to perform a specific function or set of related functions. This improves efficiency in the organism. Organisation and the emergence of new properties in complex systems are two of the defining features of living organisms. The following diagrams explain this hierarchical organisation for a human and a plant.



## Specialised cells make up tissues and organs

Specialised cells often have modifications or exaggerations to a normal cell feature to help them perform a particular task. They may have more (or fewer) of a particular organelle in order to perform their role most efficiently.



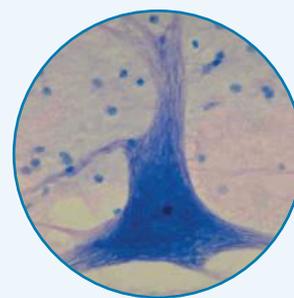
Muscle cells are able to contract (shorten) to bring about the movement of limbs and organs.



There are many types of blood cells, they each carry out a particular job.

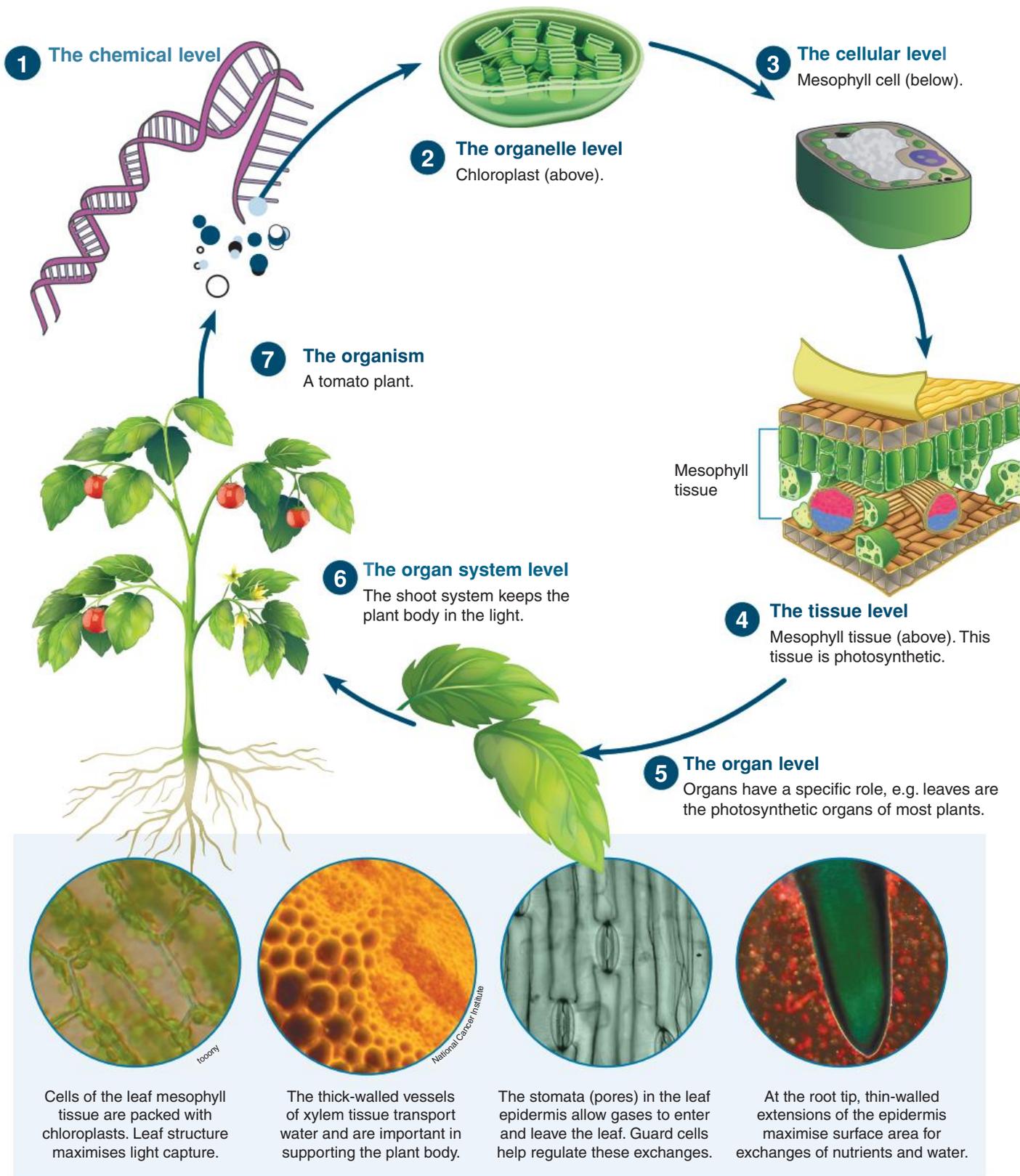


Thin, flat epithelial cells line the walls of blood vessels (arrow). Large fat cells store lipid.



Nerve cells conduct impulses around the body enabling responses to the environment.





- Assign each of the following emergent properties to the level at which it first appears:
 

(a) Metabolism: _____	(d) Internal transport: _____
(b) Behaviour: _____	(e) Surface protection: _____
(c) Replication: _____	(f) Nutrient processing: _____
- Explain how a hierarchical structure enables greater efficiency of function in the whole organism: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

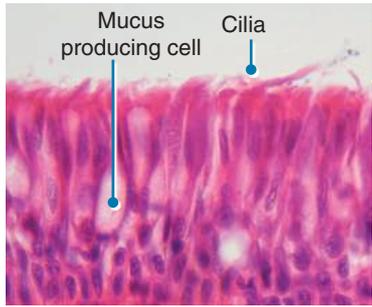
# 74 Exploring Tissues and Organs

**Key Idea:** Tissues come together to make organs. You can see this in an isolated organ, such as a heart. A tissue is a collection of related cell types that work together to carry out a specific function. Different tissues come

together to form organs. The cells, tissues, and organs of the body interact to meet the needs of the entire organism. You can explore the different tissues that make up an organ by examining an isolated organ, such as a sheep's heart.

<p><b>Muscle tissue</b></p> <ul style="list-style-type: none"> <li>▶ Contractile tissue</li> <li>▶ Produces movement of the body or its parts</li> <li>▶ Includes smooth, skeletal, and cardiac muscle</li> </ul>	<p><b>Epithelial tissue</b></p> <ul style="list-style-type: none"> <li>▶ Lining tissue</li> <li>▶ Covers the body and lines internal surfaces</li> <li>▶ Can be modified to perform specific roles</li> </ul>	<p><b>Nervous tissue</b></p> <ul style="list-style-type: none"> <li>▶ Receives and responds to stimuli</li> <li>▶ Makes up the structures of the nervous system</li> <li>▶ Regulates function of other tissues</li> </ul>	<p><b>Connective tissue</b></p> <ul style="list-style-type: none"> <li>▶ Supports, protects, and binds other tissues</li> <li>▶ Contains cells in an extracellular matrix</li> <li>▶ Can be hard or fluid</li> </ul>
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1. Research the type of tissue(s) that occur at the places in the body indicated below. State the types of tissues that occur in the spaces provided. Codes: E = epithelium, CT = connective tissue, SM = smooth muscle.

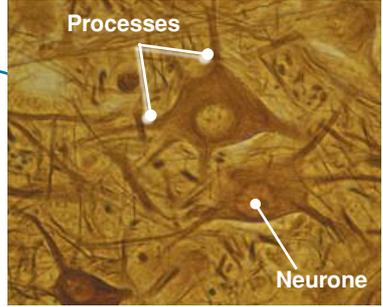


Upper respiratory tract:

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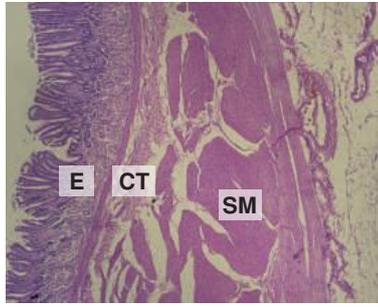


Brain:

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Digestive tract:

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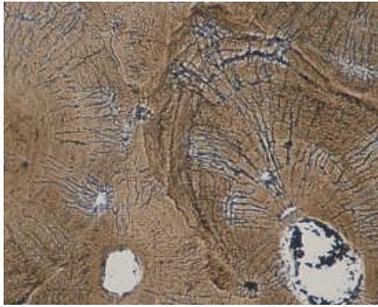


Bladder:

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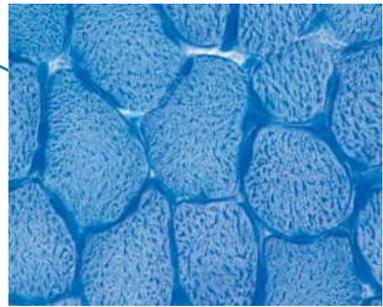


Bone:

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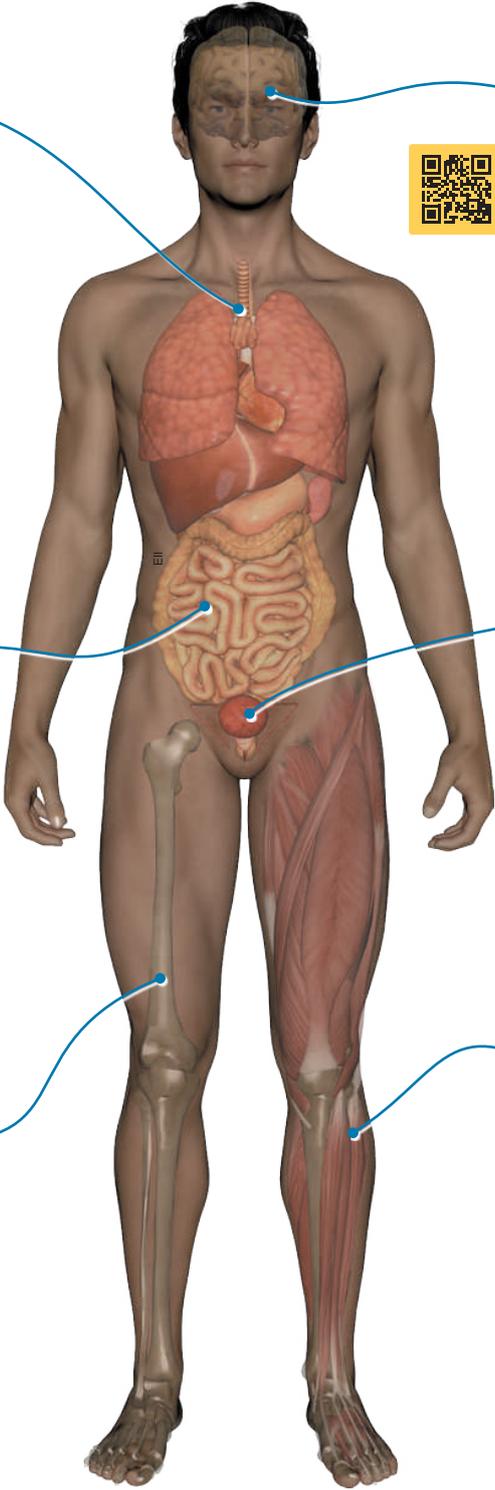


Skeletal muscle:

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# 75 Organ Systems Work Together

**Key Idea:** The circulatory and gas exchange systems interact to provide the tissues with oxygen and remove carbon dioxide.

## Circulatory system

### Function

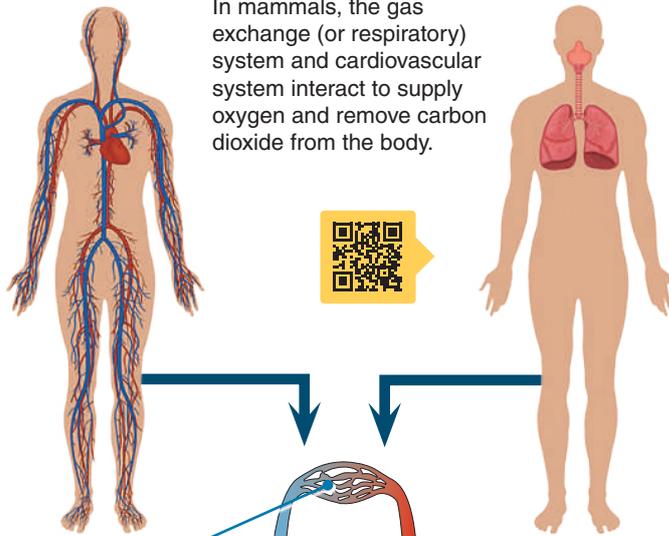
Delivers oxygen (O<sub>2</sub>) and nutrients to all cells and tissues. Removes carbon dioxide (CO<sub>2</sub>) and other waste products of metabolism. CO<sub>2</sub> is transported to the lungs.

### Components

- ▶ Heart
- ▶ Blood vessels:
  - Arteries
  - Veins
  - Capillaries
- ▶ Blood

## Interaction between systems

In mammals, the gas exchange (or respiratory) system and cardiovascular system interact to supply oxygen and remove carbon dioxide from the body.



## Gas exchange system

### Function

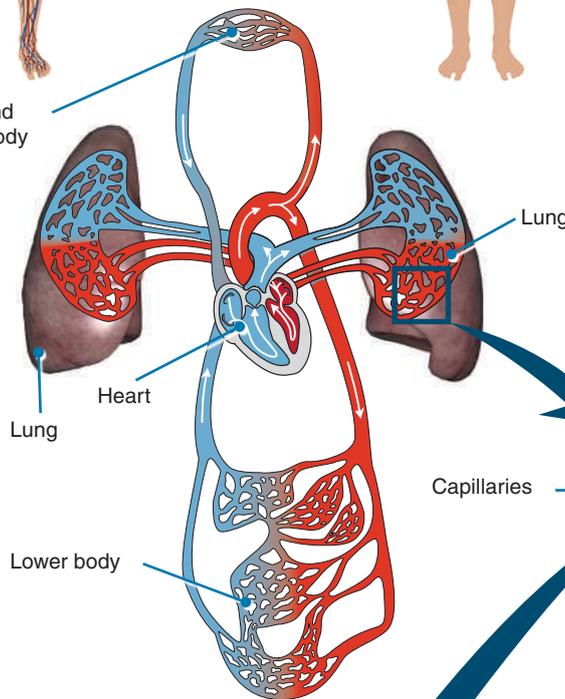
Provides surface for gas exchange. Moves fresh air into and stale air out of the body.

### Components

- ▶ Airways:
  - Pharynx
  - Larynx
  - Trachea
- ▶ Lungs:
  - Bronchi
  - Bronchioles
  - Alveoli
- ▶ Diaphragm

Oxygen (O<sub>2</sub>) from inhaled air moves from the lungs into the circulatory system and is transported within red blood cells to the heart. The heart pumps the blood to the body where O<sub>2</sub> is released and carbon dioxide (CO<sub>2</sub>) is picked up. The blood returns to the heart and is pumped to the lungs where CO<sub>2</sub> is released into the lungs to be breathed out.

Head and upper body



Bronchiole

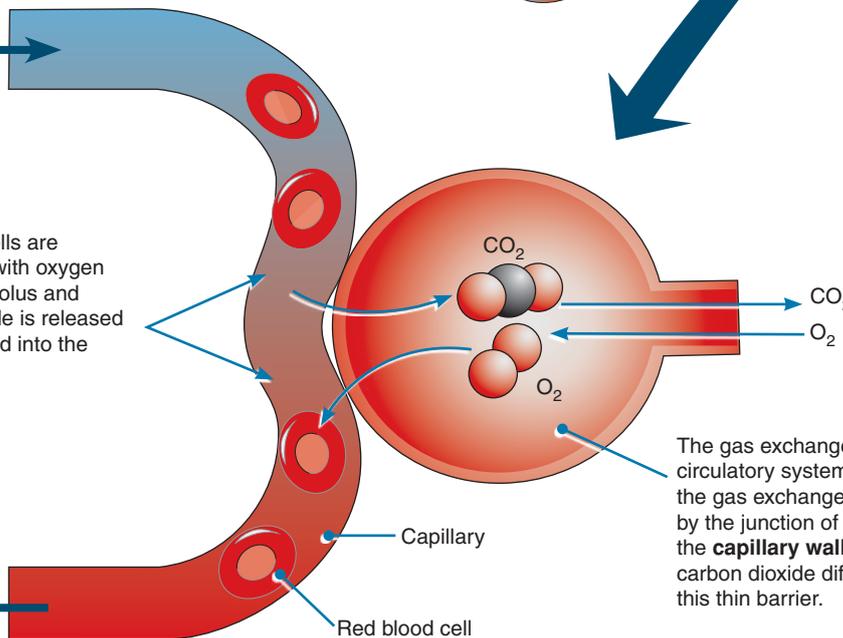
Capillaries

The airways of the lungs end at the **alveoli**, the microscopic air sacs that enable gas exchange.

From the heart to the lungs

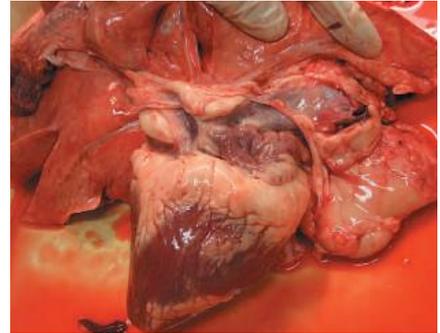
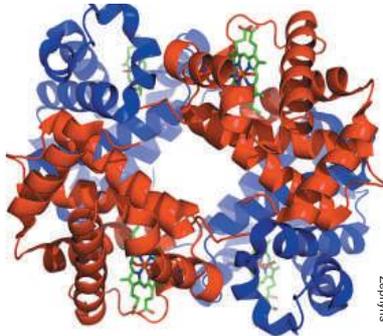
Red blood cells are replenished with oxygen from the alveolus and carbon dioxide is released from the blood into the alveolus.

From the lungs to the heart



The carbon dioxide released from the blood exits the body during exhalation. Inhalation brings in fresh air, containing oxygen.

The gas exchange system and the circulatory system come together at the gas exchange membrane formed by the junction of the **alveolus** and the **capillary wall**. Oxygen and carbon dioxide diffuse easily across this thin barrier.



The response to exercise shows the close link between the circulatory and gas exchange systems. During exercise, breathing rate increases to provide more oxygen, which is carried by the blood to supply respiration (ATP generation) in working muscles. Heart rate increases to increase the rate at which oxygen is delivered to the tissues and carbon dioxide is returned to the lungs.

Oxygen is transported in red blood cells by the protein haemoglobin (above). In the capillaries of the lungs (high oxygen), haemoglobin binds oxygen tightly. In the tissues, higher carbon dioxide levels cause haemoglobin to release its oxygen. CO<sub>2</sub> is carried in the blood as bicarbonate (CO<sub>2</sub> + H<sub>2</sub>O → H<sub>2</sub>CO<sub>3</sub> → H<sup>+</sup> + HCO<sub>3</sub><sup>-</sup>). In the lungs, this dissociates back into CO<sub>2</sub> and water.

As with all organ systems, the circulatory and gas exchange systems are interdependent. Organs in the circulatory system (e.g. the heart) need oxygen to keep working and this is supplied by the lungs. If the heart were to stop beating, it and all other organs would quickly run out of oxygen. Similarly, if breathing were to stop, all organs would quickly run out of oxygen.

1. (a) What happens to the rate of blood flow during exercise? \_\_\_\_\_  
 (b) What happens to the breathing rate during exercise? \_\_\_\_\_  
 (c) How do the circulatory and gas exchange systems interact to meet the metabolic demands of an exercising person?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
2. Lung diseases affect rates of gas exchange in the lung. Suggest how this would affect the body: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
3. (a) At which point in the body do the respiratory and circulatory systems directly interact? \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Explain what is happening at this point: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
4. In your own words, describe how the circulatory system and respiratory system work together to provide the body with oxygen and remove carbon dioxide:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

1. Identify the following organisms as unicellular, colonial, or multicellular:



Bobtail squid



Hydra



Diatoms (protists)

(a) \_\_\_\_\_

(b) \_\_\_\_\_

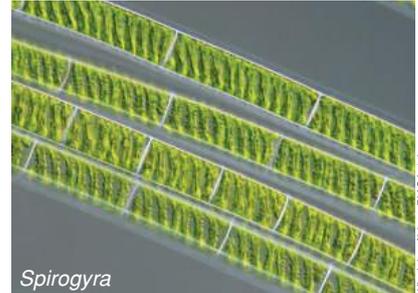
(c) \_\_\_\_\_



Euglena



Scenedesmus



Spirogyra

(d) \_\_\_\_\_

(e) \_\_\_\_\_

(f) \_\_\_\_\_

2. Describe the evidence for a continuum between unicellular and multicellular life: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. Distinguish between a cell, a tissue, and an organ: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. What is the purpose of:

(a) Muscle tissue: \_\_\_\_\_

\_\_\_\_\_

(b) Nervous tissue: \_\_\_\_\_

\_\_\_\_\_

(c) Connective tissue: \_\_\_\_\_

\_\_\_\_\_

5. State the hierarchy of structural organisation in a plant or animal and justify in terms of the functioning organism:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

# Nutrients and Gas Requirements

Activity number

## Key terms

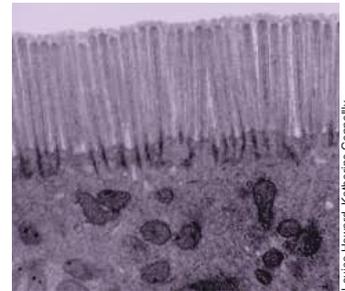
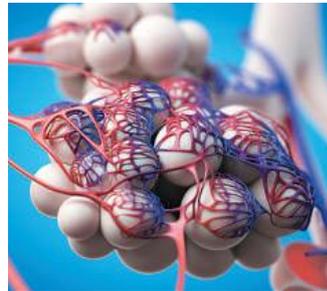
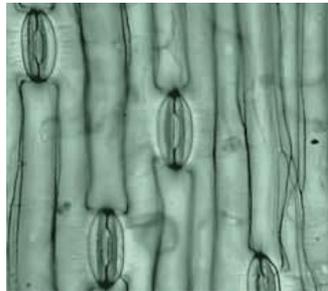
absorption  
alveoli  
autotroph  
breathing  
bronchi  
cuticle  
digestion  
digestive system  
egestion  
epidermis  
excretion  
guard cells  
heterotroph  
intestinal villi  
large intestine  
leaf  
lungs  
mesophyll  
small intestine  
stem  
stomach  
stomata  
tissue

*Inquiry question: What is the difference in nutrient requirements between autotrophs and heterotrophs?*

## Structure and function in plants

### Key skills and knowledge

- 1 Distinguish between autotrophs and heterotrophs. Compare their nutrient and gas requirements. **77 96**
- 2 Describe the function of plant structures including the leaves, stems, and roots. Explore different leaf adaptations for enhancing photosynthesis and gas exchange. **78 81**
- 3 Describe gas exchange in plants, including the internal structure of the leaf, the role of stomata and guard cells in controlling the movement of gases (oxygen, carbon dioxide, and water vapour) in plants. **79 80**
- 4 **PRAC** Investigate stomatal density in different plants. **82**
- 5 Describe excretion in plants. **83**



Louisa Howard, Katherine Connolly  
Dartmouth College

## Gas exchange in animals

### Key skills and knowledge

- 6 Describe the basic features of gas exchange surfaces in a range of animals including insects, fish, and mammals. Explain how each system is adapted to its particular environment. **84**
- 7 Describe the basic structure of the gas exchange system in insects including the role of spiracles and tracheal tubes. **85**
- 8 Describe the structure and function of fish gills, including reference to countercurrent exchange and its role in increasing oxygen uptake along the gill. **86**
- 9 Describe structure and function of the mammalian gas exchange system including macroscopic structures such as the bronchi and bronchioles, and microscopic structure such as the alveoli and their respective functions. **87 88**
- 10 **PRAC** Modelling lung ventilation. **89**
- 11 Explain how respiratory gases move across the gas exchange membrane. Use data presented in diagrams to predict the direction in which materials will be exchanged between capillaries and alveoli, and between capillaries and body tissues. **90**

## Mammalian digestive system

### Key skills and knowledge

- 12 Describe the basic structure and organisation of the mammalian digestive system. Trace the digestion of food including regions for physical and chemical digestion, absorption and elimination of wastes. **91 -93**
- 13 Identify the characteristics of the absorption surfaces in the digestive systems e.g. the small intestine. **93-95**
- 14 Describe how different products of digestion are absorbed across the epithelium of the small intestine. Describe how intestinal villi and the epithelial cells themselves increase surface area for absorption. **94**

# 77

## Autotrophs and Heterotrophs

**Key Idea:** Heterotrophs feed on other organisms to gain energy and carbon. Autotrophs use light or chemical energy to make their own food.

The nutritional mode of an organism describes how it obtains its energy and carbon. **Autotrophs** (self feeders) make their

food from simple inorganic substances using the free energy in sunlight or chemical energy. **Heterotrophs** (feeders on others) feed on other organisms to obtain their energy. They depend either directly on other organisms (dead or alive) or their by-products (e.g. faeces, cell walls, or food stores).

1. Distinguish between photoautotrophs, chemoautotrophs, and chemoheterotrophs in terms of their sources of energy and carbon:

(a) Photoautotroph

Source of energy: \_\_\_\_\_

\_\_\_\_\_

Source of carbon: \_\_\_\_\_

\_\_\_\_\_

(b) Chemoautotrophs

Source of energy: \_\_\_\_\_

\_\_\_\_\_

Source of carbon: \_\_\_\_\_

\_\_\_\_\_

(c) Chemoheterotroph

Source of energy: \_\_\_\_\_

\_\_\_\_\_

Source of carbon: \_\_\_\_\_

\_\_\_\_\_

2. Describe the three main nutritional modes of chemoheterotrophs:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. What is the main difference between parasites and saprotrophs in the way that they obtain their nutrition?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

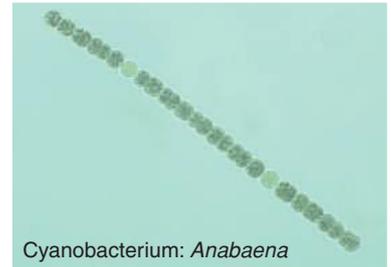
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\_\_\_\_\_

### Autotrophic nutrition (autotrophs)



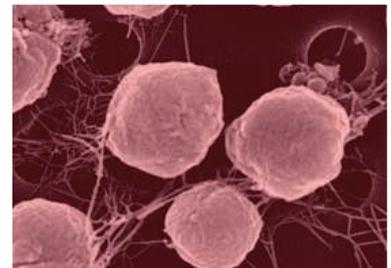
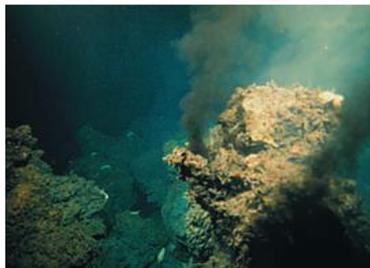
Green plant



Cyanobacterium: *Anabaena*

BH

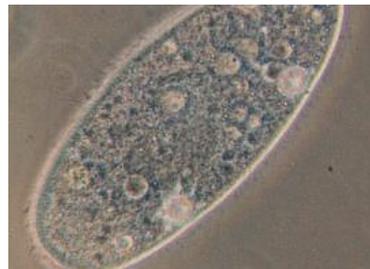
**Photoautotrophs** (photosynthetic organisms) use light as their energy source, and carbon dioxide as a source of carbon to make their own food. They include bacteria, cyanobacteria, algae (photosynthetic protists), and green plants.



UC Berkeley

**Chemoautotrophs** (chemosynthetic organisms) use inorganic compounds (e.g. elemental hydrogen) as a source of energy, and CO<sub>2</sub> as a source of carbon. Most are bacteria or archaea that live in hostile environments, such as geothermal and deep sea vents, e.g. *Methanococcus* (above) uses hydrogen to reduce CO<sub>2</sub> to methane.

### Heterotrophic nutrition (chemoheterotrophs)



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Brett Taylor cc 2.0

Heterotrophs need an organic source of carbon and energy (this is usually glucose). Many bacteria and many protists, e.g. *Paramecium* (above left) are heterotrophic. All fungi (above right) are chemoheterotrophs and most are decomposers (**saprotrophs**), obtaining nutrition from the extracellular digestion of dead organic material.



CDC PD



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All animals are heterotrophs, relying on glucose (from plants, dead material, or other animals) for energy and carbon. **Parasites**, e.g. tapeworms (above left), live on or within their living host organism for part or all of their life. Bacteria, fungi, protists, and animals all have parasitic representatives. The ingestion of solid or liquid organic material from other organisms (**holozoic nutrition**) is the main feeding mode of animals.

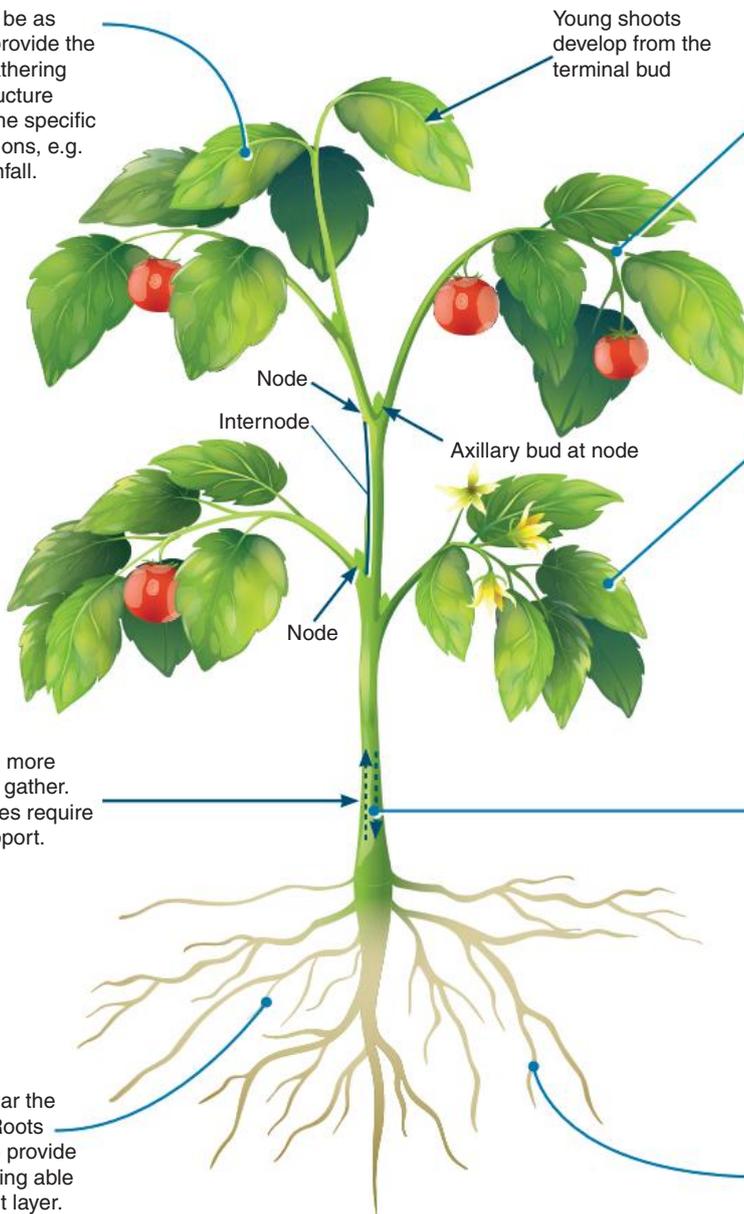
# 78 Plant Structure and Function

**Key Idea:** The plant body consists of connected shoot and root systems. The shoot system collects carbon dioxide, oxygen, and light and produces sugars. The root system collects water and nutrients from the soil.

As terrestrial organisms, plants have two interdependent systems to take advantage of and to solve the problems of living on land. The shoot system, consisting of stems, leaves and reproductive structures, has evolved to collect carbon dioxide, oxygen and light, and to disperse pollen and seeds. The root system has evolved to collect water and nutrients

from the soil and to provide anchorage to the ground or substrate. These systems are integrated to form the closely linked support and transport systems. If a plant is to grow to any size, it must have ways to hold itself up against gravity and to move materials around its body. Vascular tissues (xylem and phloem) link all plant parts. Water and minerals are transported in the xylem, while manufactured food is transported in the phloem. All plants rely on fluid pressure within their cells (turgor) to give some support to their less rigid structures e.g. leaves and flowers.

Ideally leaves should be as large as possible to provide the maximum area for gathering sunlight. But their structure must be adapted to the specific environmental conditions, e.g. high winds or low rainfall.



Functions of the stems:

Functions of the leaves:

Materials transported around the plant:

Specific functions of xylem:

Specific functions of phloem:

Functions of the roots:

The taller a plant, the more light it can potentially gather. However, tall structures require greater structural support.



Most nutrients are near the top of the soil layer. Roots must be structured to provide support, while still being able to access this nutrient layer.

- In the boxes provided in the diagram above:
  - Describe the main functions of the leaves, roots and stems (remember that the leaves themselves have leaf veins).
  - List the materials that are transported around the plant body.
  - Describe the functions of the transport tissues: xylem and phloem.
- Name the solvent for all the materials that are transported around the plant: \_\_\_\_\_
- What factors are involved in determining how tall a plant could potentially grow? \_\_\_\_\_

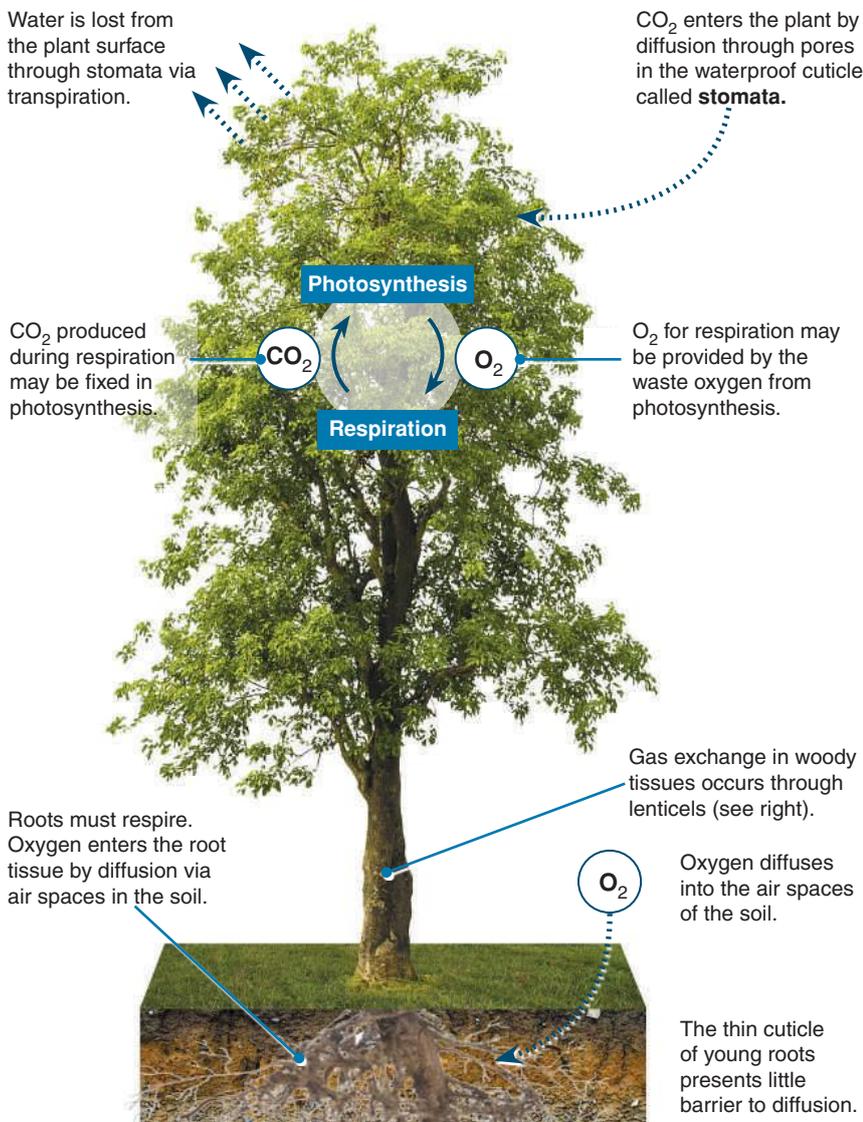
# 79

## Gas Exchange in Plants

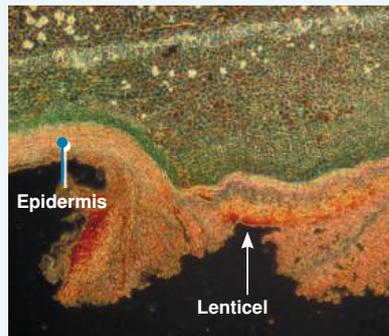
**Key Idea:** Gas exchange in plants occurs through stomata. Respiring tissues require oxygen, and the photosynthetic tissues of plants also require carbon dioxide in order to produce the sugars for growth and maintenance. The main gas exchange organs in plants are the leaves, and

sometimes the stems. In most plants, gases cannot diffuse directly across the leaf surface because of its waxy cuticle, so gases enter and leave the leaf via **stomata** (pores) in the leaf surface. The plant has to balance its need for CO<sub>2</sub> (stomata open) against its need to reduce water loss (stomata closed).

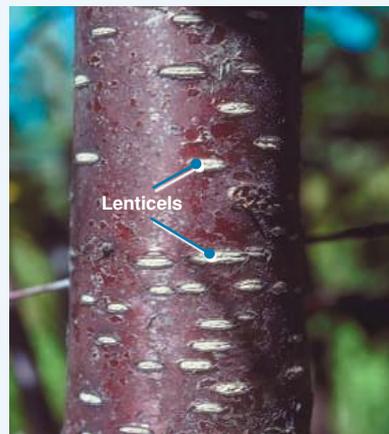
### Terrestrial environment



Most gas exchange in plants occurs through the leaves, but some also occurs through the stems and roots. Leaves are very thin with a high surface area and this assists gas exchange by diffusion.



In woody plants, the wood prevents gas exchange. A lenticel is a small area in the bark where the loosely arranged cells allow entry and exit of gases into the stem tissue underneath.



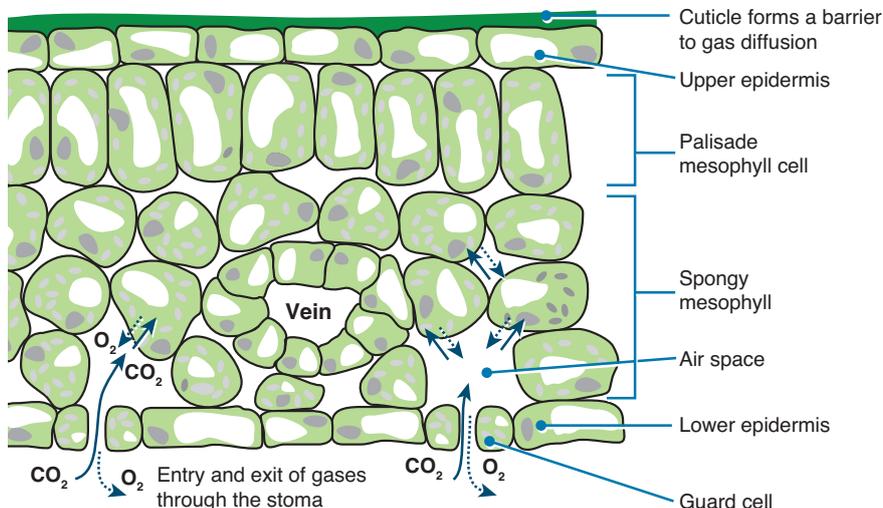
1. By which process does oxygen enter the plant tissues? \_\_\_\_\_
2. Where does most gas exchange occur in plants? \_\_\_\_\_
3. What is the role of lenticels in plant gas exchange? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
4. Identify two properties of leaves that assist gas exchange: \_\_\_\_\_
5. With respect to gas exchange and water balance, describe the most important considerations for:
  - (a) Terrestrial plants: \_\_\_\_\_
  - (b) Aquatic plants: \_\_\_\_\_
6. Identify two ways in which plants obtain CO<sub>2</sub>: \_\_\_\_\_

# 80 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 flowering plants (angiosperms) is covered with tiny pores, called **stomata**. Flowering plants have many air spaces between the cells of the stems, leaves, and roots. These air spaces are continuous and gases are

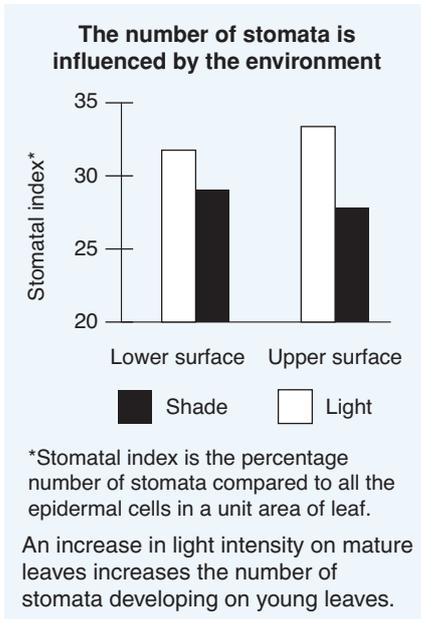
able to move freely through them and into the plant's cells via the stomata. Each stoma is bounded by two **guard cells**, which regulate the entry and exit of gases (including water vapour). Although stomata permit gas exchange between the air and the photosynthetic cells inside the leaf, they are also the major routes for water loss through transpiration.

## Gas exchanges and the function of stomata



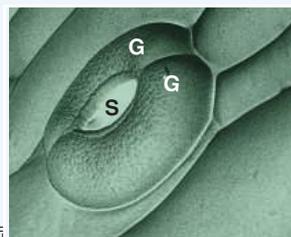
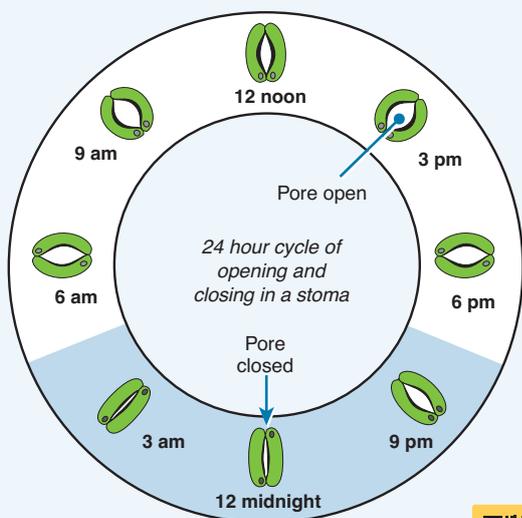
**Net gas exchanges** in a photosynthesising dicot leaf

- ▶ 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<sub>2</sub>) and produce carbon dioxide (CO<sub>2</sub>). 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<sub>2</sub> and net production of oxygen. Fixation of CO<sub>2</sub> maintains a gradient in CO<sub>2</sub> concentration between the atmosphere (high) and the leaf tissue (low).
- ▶ 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.



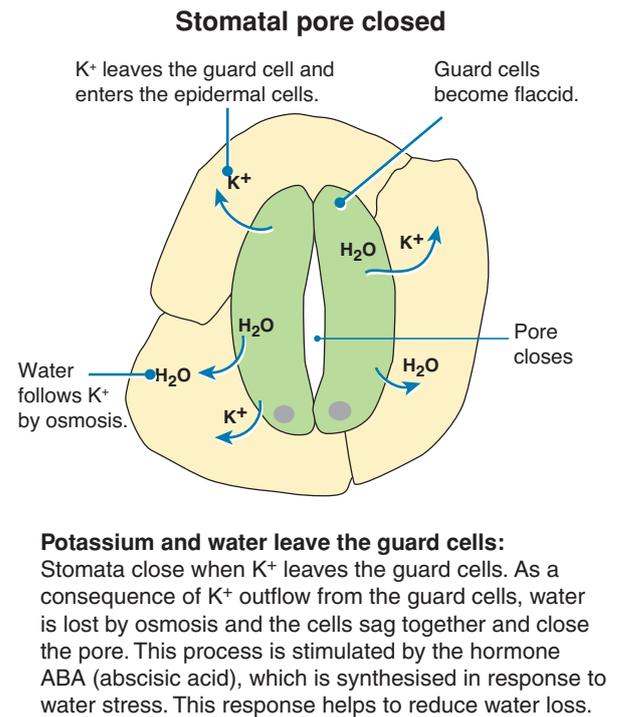
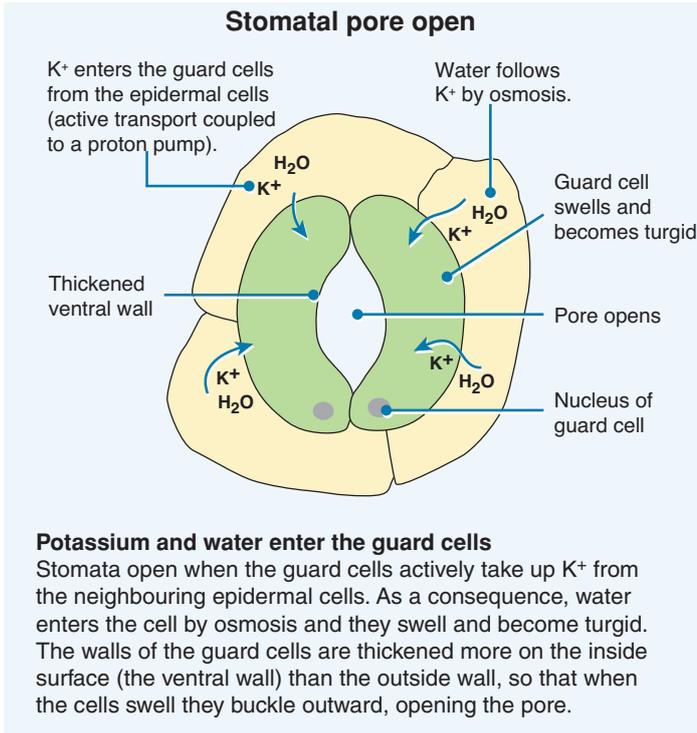
The image left shows a scanning electron micrograph (SEM) of a single stoma from the leaf epidermis of a dicot. Note the guard cells (G), which are swollen tight and open the pore (S) to allow gas exchange between the leaf tissue and the external environment.

## Factors influencing stomatal opening

Stomata	Guard cells	Daylight	CO <sub>2</sub>	Soil water
<b>Open</b>	Turgid	Light	Low	High
<b>Closed</b>	Flaccid	Dark	High	Low

The opening and closing of stomata depends on environmental factors, the most important being light, CO<sub>2</sub> 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<sub>2</sub> levels also promote stomatal opening. Conditions that induce water stress cause the stomata to close, regardless of light or CO<sub>2</sub> level.

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.



1. Describe two adaptive features of leaves: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
2. For a terrestrial flowering plant, with no special adaptations for water conservation (a mesophyte):
  - (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: \_\_\_\_\_  
 \_\_\_\_\_
  
3. Describe two ways in which the continuous air spaces through the plant facilitate gas exchange:
  - (a) \_\_\_\_\_
  - (b) \_\_\_\_\_
  
4. Outline the role of stomata in gas exchange in a flowering plant: \_\_\_\_\_  
 \_\_\_\_\_
  
5. (a) Explain how the guard cells open the stomata: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
- (b) Explain how the guard cells close the stomata: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 81 Leaf and Stem Adaptations

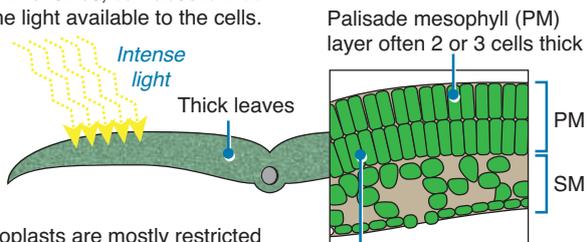
**Key Idea:** The shape and cellular structure of leaves are adaptations for collecting the optimum amount of light and carbon dioxide.

In order to photosynthesise, plants must obtain a regular supply of carbon dioxide gas (CO<sub>2</sub>); the raw material for the production of carbohydrate. In green plants, the systems for gas exchange and photosynthesis are linked. Without a regular supply of CO<sub>2</sub>, photosynthesis ceases. The leaf, as

the primary photosynthetic organ, is adapted to maximise light capture and facilitate the entry of CO<sub>2</sub>, while minimising water loss. There are various ways in which plant leaves are adapted to do this. The ultimate structure of the leaf reflects the environment of the leaf (sun or shade, terrestrial or aquatic), its resistance to water loss, and the importance of the leaf relative to other parts of the plant that may be photosynthetic, such as the stem.

## Sun plant

A sun leaf, when exposed to high light intensities, can absorb much of the light available to the cells.



Chloroplasts are mostly restricted to palisade mesophyll cells (few in spongy mesophyll (SM)).

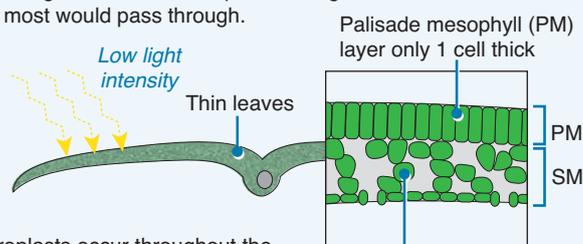


Sun leaves

**Sun plants** are adapted for growth in full sunlight. They have higher levels of respiration but can produce sugars at rates high enough to compensate for this. Sun plants include many weed species found on open exposed grassland. They expend more energy on the construction and maintenance of thicker leaves than do shade plants. The benefit of this investment is that they can absorb the higher light intensities available and grow rapidly.

## Shade plant

A shade leaf can absorb the light available at lower light intensities. If exposed to high light, most would pass through.



Chloroplasts occur throughout the mesophyll (as many in the spongy mesophyll (SM) as palisade mesophyll).



Shade leaves

**Shade plants** typically grow in forested areas, partly shaded by the canopy of larger trees. They have lower rates of respiration than sun plants, mainly because they build thinner leaves. The fewer number of cells need less energy for their production and maintenance. In competition with sun plants, they are disadvantaged by lower rates of sugar production, but in low light environments this is offset by their lower respiration rates.

- (a) Identify the structures in leaves that facilitate gas exchange: \_\_\_\_\_

(b) Explain their critical role in plant nutrition: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- (a) State which type of plant (sun or shade adapted) has the highest level of respiration: \_\_\_\_\_

(b) Explain how the plant compensates for the higher level of respiration: \_\_\_\_\_

\_\_\_\_\_
- Discuss the adaptations of leaves in sun and shade plants: \_\_\_\_\_

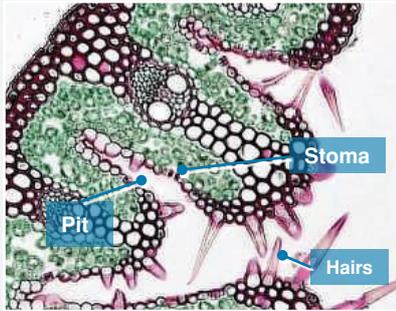
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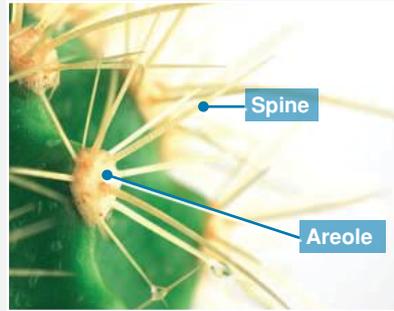
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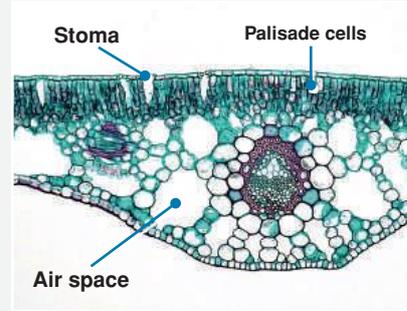
### Adaptations for photosynthesis and gas exchange in plants



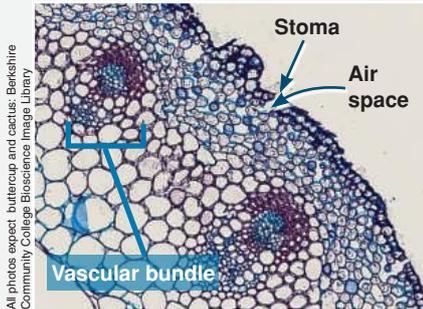
Ammophila (above) is an dry (arid)-adapted plant (xerophyte) and displays many water conserving features. The stomata are found in pits in the leaf's curled surface. The pits restrict water loss to a greater extent than they reduce CO<sub>2</sub> uptake.



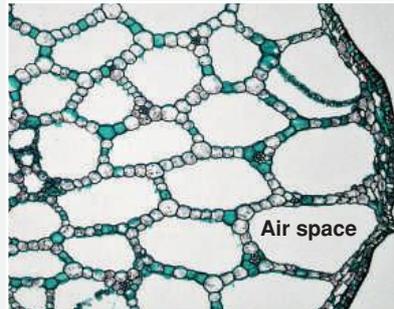
In most cacti, the enlarged stem is the only part of the plant that is photosynthetic and the leaves have been reduced to spines, which are produced from areoles, a kind of highly reduced branch. Spines lack stomata and greatly reduce water loss.



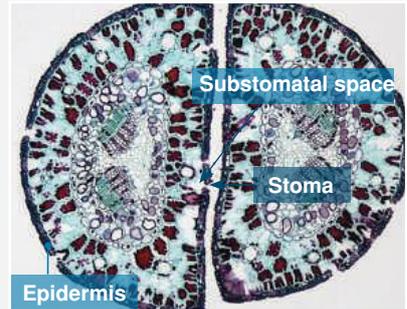
Aquatic plants (hydrophytes) have large air spaces in their leaves to help them float. The stomata are on the upper surface where gas exchange can take place. The palisade cells can be seen to have numerous chloroplasts to increase photosynthesis.



Some herbaceous plants (e.g. buttercup above) have photosynthetic stems, and CO<sub>2</sub> enters freely into the stem tissue through stomata in the epidermis.



Aquatic plants such as *Potamogeton* (above) have stems with massive air spaces. The presence of air in the stem means that they remain floating in the zone of light availability and photosynthesis is not compromised.



This transverse view of the twin leaves of a two-needle pine shows the sunken stomata and substomatal spaces. This adaptation for arid conditions reduces water loss by creating a region of high humidity around the stoma.

4. Describe two adaptations in plants for reducing water loss while maintaining entry of gas into the leaf:

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5. Describe two adaptations of photosynthetic stems that are not present in non-photosynthetic stems, and explain the reasons for these:

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6. The example of a photosynthetic stem above is from a buttercup, a plant in which the leaves are still the primary organs of photosynthesis.

(a) Identify an example of a plant where the stem is the **only** photosynthetic organ: \_\_\_\_\_

(b) Describe the structure of the leaves in your example and suggest a reason for their particular structure:

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7. Describe one role of the air spaces in the stems of *Potamogeton* related to maintaining photosynthesis: \_\_\_\_\_

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## 82 Investigating Stomatal Density

**Key Idea:** The density and distribution of leaf stomata in different plant species are related to the rate of water loss. Different plant species have different leaf shapes and structures and these can be correlated with the environment

in which they are found. Comparing the leaf area and stomatal density of different plant species helps to explain observed differences in transpiration rate but factors in the environment, such as shading and wind, are also important.

### Plant species show different leaf shapes and structures associated with their environments

#### Aloe (agave)

A succulent



Tropical species with thick, fleshy leaves. Its physiology allows it to fix CO<sub>2</sub> 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



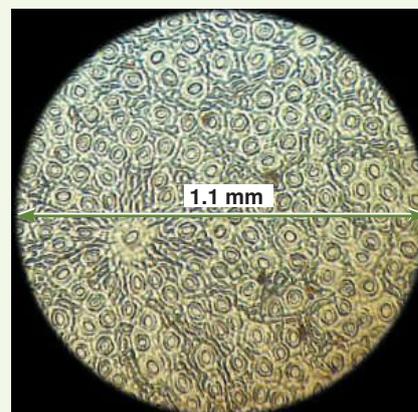
Widespread cultivated North American dicot with a showy flower head and very large soft leaves.



### Investigation 5.1 Comparing stomatal density

See appendix for equipment list.

- Your teacher will have up to four leaf types from four dicot plants adapted to different environments, or you may need to obtain samples of your own.
  - The number of stomata per mm<sup>2</sup> on the surface of a leaf can be determined by counting the stomata visible under a microscope\*. Use 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.
  - Carefully peel off the layer of nail varnish and place on a clean microscope slide.
  - 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  $18/(10 \times 40) = 0.045$  mm diameter. The area viewable is then  $\pi r^2$ .
  - You could also use a micrometer to measure the diameter of the field of view or use a thin clear ruler.
  - Place the slide with the layer of nail varnish 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.
  - You should also take note of where the stomata are on the leaf (are they scattered randomly or in specific places?)
  - Repeat on the upper surface of the leaf.
  - Repeat for the other leaf types.
- \* A digital microscope can be used to capture images on a computer which may improve counting.



	Number of stomata per mm <sup>2</sup> lower surface					Number of stomata per mm <sup>2</sup> 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<sup>2</sup> 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: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

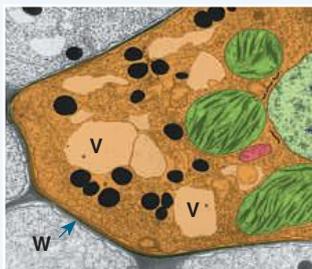
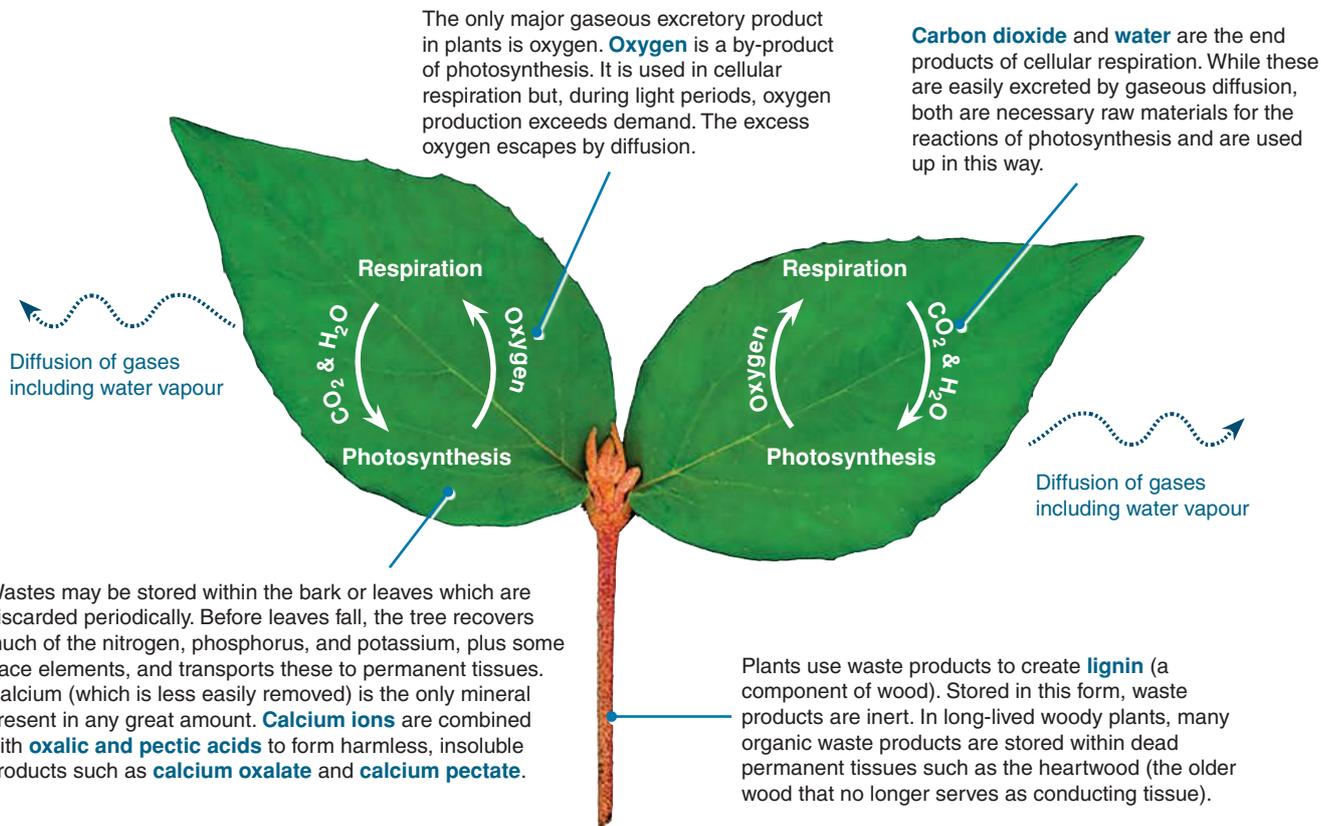
6. Explain your results in terms of the environment the plants are adapted for and the need to regulate water loss:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

## 83 Excretion in Plants

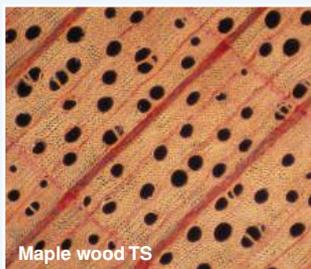
**Key Idea:** Plants may either store or excrete or reuse by-products of metabolic processes.

Plants are producers and synthesise all their organic requirements. They manufacture, from raw material (e.g.  $\text{NH}_4^+$ ), only the protein they require to meet immediate needs. There is rarely excess protein and therefore very little excretion of nitrogenous wastes. Three of the waste products of metabolic processes in plants (oxygen, carbon dioxide,

and water) are the raw materials for other reactions, and so excesses are used up in other reactions. Plants have very low metabolic rates compared with animals of the same size, so metabolic wastes in plants accumulate only slowly. Accumulated waste substances are important in the structure and seasonal activities of plants, and some have defence functions (e.g. prevent the plant being eaten). An overview of waste products is provided below.



Non-woody plants store wastes in the vacuoles (V) and walls (W) of their cells until they die back.



Compounds stored in wood, e.g. **oils, gums, resins,** and **tannins,** make the wood coloured and aromatic.



The colour of leaves in autumn is partly due to the breakdown of chlorophyll, which normally hides the colours of other pigments.



In some plants, e.g. eucalypts (above), toxins deposited in the cell walls make the old leaves tough and unpalatable.

- (a) Name the three primary waste products of plants: \_\_\_\_\_

(b) How are these excreted from the plant? \_\_\_\_\_
- Describe two purposes for the wastes that are stored in plant tissues:

(a) \_\_\_\_\_

(b) \_\_\_\_\_
- Identify two organelles where wastes in plants can be stored: \_\_\_\_\_

\_\_\_\_\_

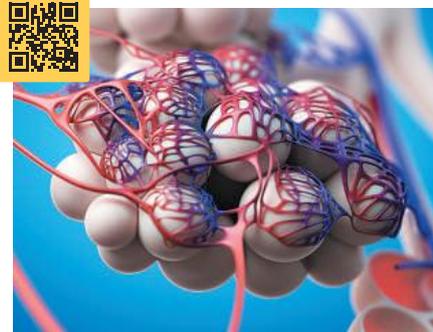
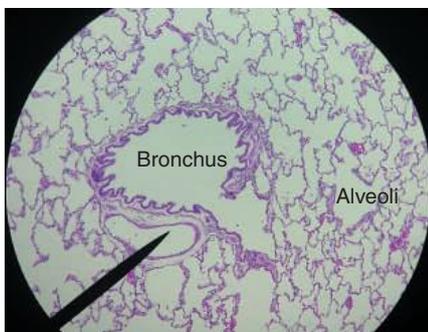
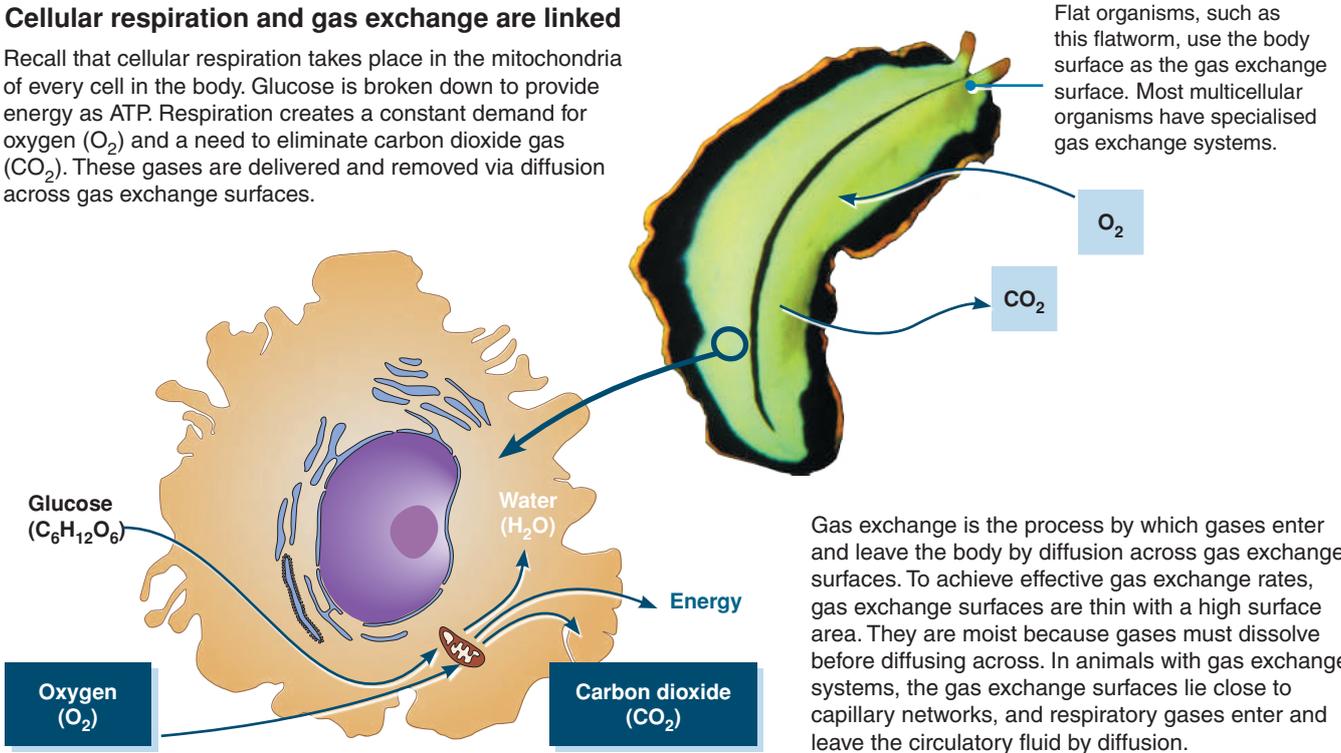
# 84 Gas Exchange

**Key Idea:** Animal gas exchange systems are suited to the animal's environment, body form, and metabolic needs. To meet the demands of aerobic metabolism, organisms must exchange gases with the environment. Some organisms can exchange gases directly across their body surface, but

most organisms have specialised gas exchange systems adapted to function in their specific environment. The type and complexity of the exchange system reflects the demands of metabolism for gas exchange (oxygen delivery and carbon dioxide removal) and the environment (aquatic or terrestrial).

## Cellular respiration and gas exchange are linked

Recall that cellular respiration takes place in the mitochondria of every cell in the body. Glucose is broken down to provide energy as ATP. Respiration creates a constant demand for oxygen (O<sub>2</sub>) and a need to eliminate carbon dioxide gas (CO<sub>2</sub>). These gases are delivered and removed via diffusion across gas exchange surfaces.



In mammalian lungs, the alveoli (microscopic air sacs) provide a large surface area for gas exchange. The walls of the alveoli are only one cell thick (tissue section above) and are covered by capillaries (model, centre). Respiratory gases move across the gas exchange surface by diffusion. Effective gas exchange relies on maintaining a concentration gradient for gas diffusion. Oxygen is transported away from the gas exchange surface by the blood (above right), reducing its concentration relative to the environmental side of the gas exchange surface. CO<sub>2</sub> is transported to the gas exchange surface, increasing its concentration relative to the environmental side of the membrane. It then diffuses out of the blood, across the membrane, and into the external environment.

1. What is the purpose of gas exchange? \_\_\_\_\_
2. How are gases exchanged with the environment? \_\_\_\_\_
3. How are gradients for diffusion maintained in a simple organism (one without a gas exchange system)? \_\_\_\_\_
4. How are gradients for diffusion maintained in an organism with a gas exchange system? \_\_\_\_\_

**Gas exchange systems and environment**

The way an animal exchanges gases with its environment is influenced by the animal's body form and by the environment in which the animal lives. Small or flat organisms, such as sponges and flatworms, living in moist or aquatic environments require no specialised structures for gas exchange. Larger or more complex animals have specialised systems to supply the oxygen to support their metabolic activities. The type of environment presents different gas exchange challenges to animals. In air, gas exchange surfaces will dry out. In water, the oxygen content is much lower than in air.

5. Describe two reasons why most animals require specialised gas exchange structures and systems:

- (a) \_\_\_\_\_  
\_\_\_\_\_
- (b) \_\_\_\_\_  
\_\_\_\_\_

6. Describe three ways the gas exchange surfaces of air breathers are kept moist:

- (a) \_\_\_\_\_  
\_\_\_\_\_
- (b) \_\_\_\_\_  
\_\_\_\_\_
- (c) \_\_\_\_\_  
\_\_\_\_\_

7. Explain why gills would not work in a terrestrial environment:

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

8. Why do animals have to ventilate their gas exchange surfaces:

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

9. Describe a difficulty associated with gas exchange:

- (a) In air: \_\_\_\_\_  
\_\_\_\_\_
- (b) In water: \_\_\_\_\_  
\_\_\_\_\_

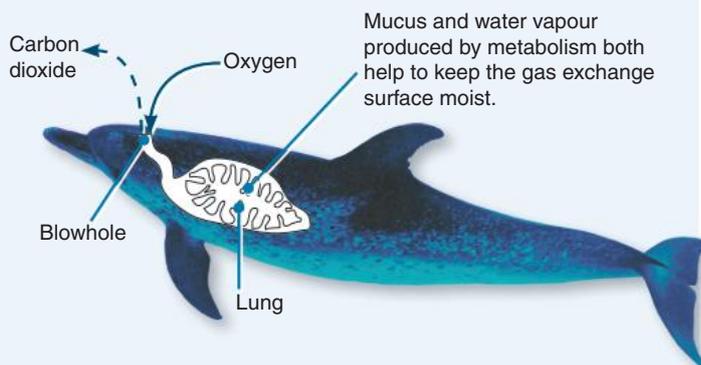
**Simple organisms**

The high surface area to volume ratio of very flat or very small organisms, such as this nematode, enables them to use the body surface as the gas exchange surface.



**Air breathing vertebrates**

The gas exchange surface in mammals and other air breathing vertebrates is located in internal lungs. Their internal location within the body protects the lungs from the dry environment of the air and keeps the exchange surfaces moist. The many alveoli of the lungs provide a large surface area to maximise gas exchange rates. Exchange rates for the diffusion of gases are maintained by ventilation of the gas exchange surface (breathing in and out).



**Bony fish, sharks, and rays**

Fish extract oxygen dissolved in water using **gills**. Gills achieve high extraction rates of oxygen from the water. This is important because water contains only 1% dissolved oxygen by volume, whereas air (at sea level) is 21% oxygen. Bony fish ventilate the gill surfaces by movements of the gill cover. The water supports the gills, and the gill lamellae (the gas exchange surface) can be exposed directly to the environment without drying out.





# 86

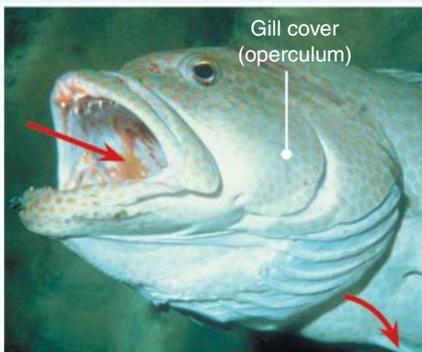
## Gas Exchange in Fish

**Key Idea:** Fish gills are thin, vascular structures just behind the head. Countercurrent flow enables efficient exchange of gases between the water and the blood in the gill capillaries. Fish obtain the oxygen they need from the water using **gills**, which are membranous structures supported by cartilaginous or bony struts. As water flows over the gill surface, respiratory

gases are exchanged between the blood and the water. In fish, high oxygen extraction rates are achieved using countercurrent exchange and by pumping water across the gill surface (most bony fish) or swimming continuously with the mouth open (called ram ventilation, seen in sharks, rays, and some bony fish, e.g. tuna).

### Fish gills

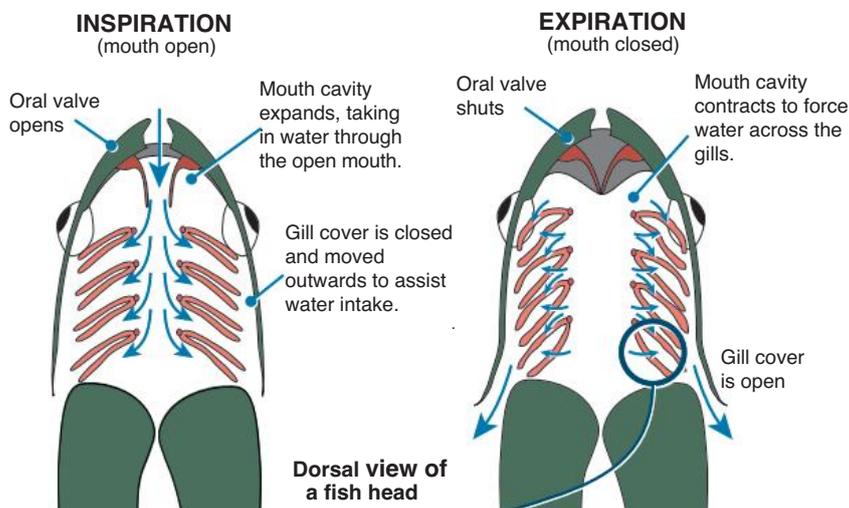
The gills of fish are very thin, filamentous structures, with individual filaments supported and kept apart from each other by the water. This gives them a high surface area for gas exchange. The outer surface of the gill is in contact with the water, and blood flows in vessels inside the gill. Gas exchange occurs by diffusion between the water and blood across the gill membrane and capillaries. The gill cover (operculum) permits exit of water and acts as a pump, drawing water past the gill filaments. The gills of fish are very efficient and achieve an 80% extraction rate of oxygen from water; over three times the rate of human lungs from air.



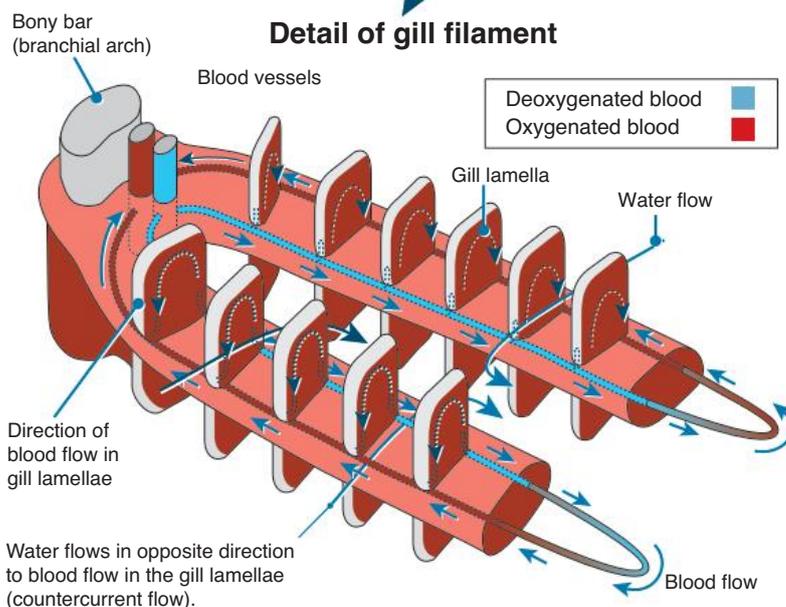
### Ventilation of the gills

Most bony fish ventilate the gills by opening and closing the mouth while opening and closing the gill cover. The mouth opens, increasing the volume of the mouth cavity, causing water to enter. The gill cover bulges slightly, moving water into the opercular cavity. The mouth closes and the gill cover opens and water flows out over the gills. These pumping movements keep oxygenated water flowing over the gills, maintaining the concentration gradient for diffusion. Other fish (e.g. sharks and tuna) must swim continuously to achieve the same gill ventilation.

### Breathing in bony fish



### Detail of gill filament



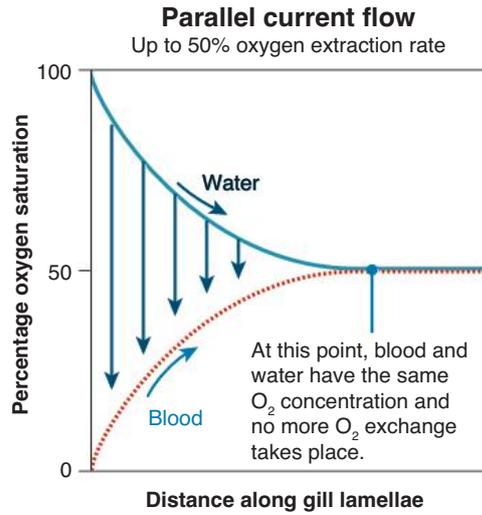
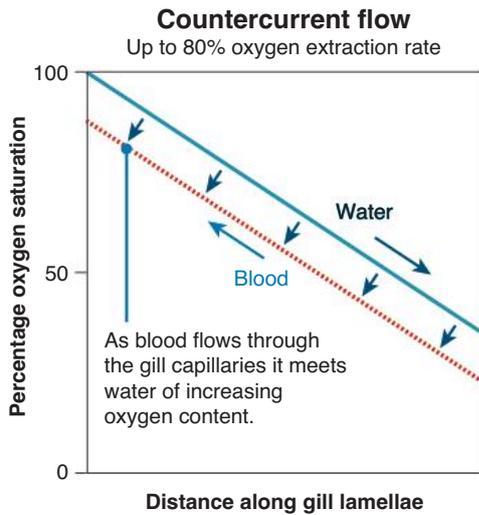
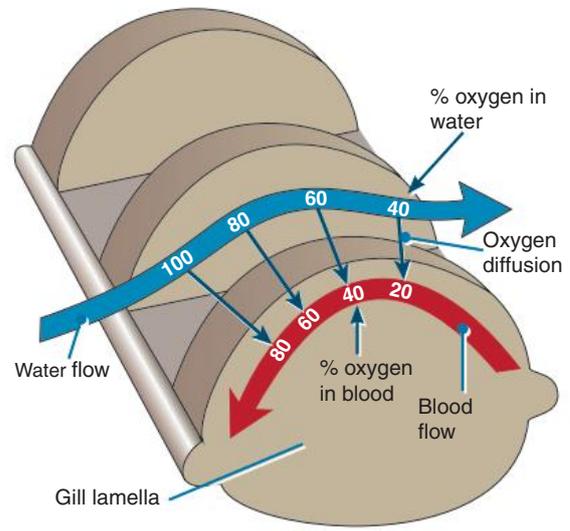
Source: C.J. Clegg & D.G. McKean (1994)

- Describe three features of a fish gas exchange system (gills and related structures) that facilitate gas exchange:
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
- Describe how fish achieve adequate ventilation of the gills through:
  - Pumping (mouth and gill cover): \_\_\_\_\_



**Countercurrent flow**

- ▶ The structure of fish gills and their physical arrangement in relation to the blood flow maximises gas exchange rates. A constant stream of oxygen-rich water flows over the gill filaments in the opposite direction to the blood flowing through the gill filaments.
- ▶ This is called countercurrent flow (right and below left) and it is an adaptation for maximising the amount of oxygen removed from the water. Blood flowing through the gill capillaries encounters water of increasing oxygen content. The concentration gradient (for oxygen uptake) across the gill is maintained across the entire distance of the gill lamella and oxygen continues to diffuse into the blood (CO<sub>2</sub> diffuses out at the same time).
- ▶ A parallel current flow (below, far right) could not achieve the same oxygen extraction rates because the concentrations across the gill would quickly equalise).



(b) Continuous swimming (mouth open): \_\_\_\_\_

3. Describe countercurrent flow: \_\_\_\_\_

4. (a) How does the countercurrent system in a fish gill increase the efficiency of oxygen extraction from the water?  
 \_\_\_\_\_

(b) Explain why parallel flow would not achieve the same rates of oxygen extraction: \_\_\_\_\_

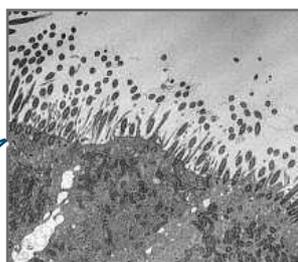
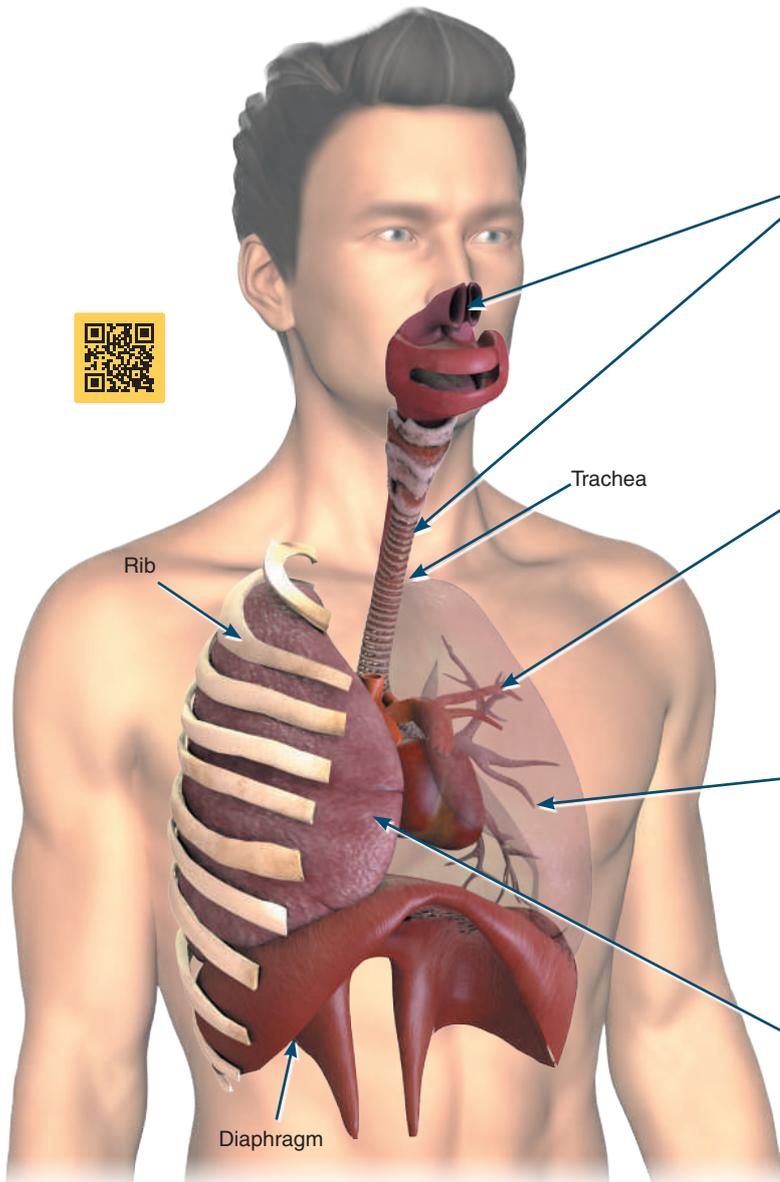
5. Warmer water holds less oxygen than colder water. Given this, suggest why many fish are very sensitive to increases in water temperature:  
 \_\_\_\_\_

# 87 The Mammalian Gas Exchange System

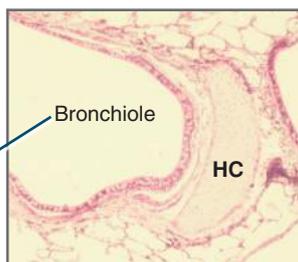
**Key Idea:** The tissues and organs of the human gas exchange work together to enable the exchange of gases between the body's cells and the environment.

The gas exchange system consists of the passages of the mouth and nose, the trachea, and the tubes and air sacs of

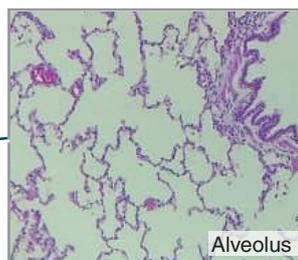
the lungs. Cooperation with the muscles of the diaphragm and ribcage contribute to its function. Each region is specialised to perform a particular role in the organ system's overall function, which is to exchange respiratory gases (O<sub>2</sub> and CO<sub>2</sub>) between the body's cells and the environment.



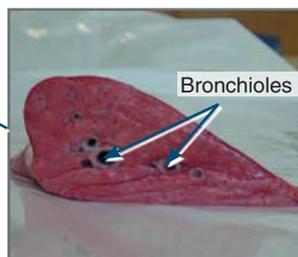
Goblet cells in the nasal cavity produce mucus, which traps dust particles. Ciliated epithelial cells sweep the mucus towards the throat (pharynx) where it is swallowed. The trachea is also lined with goblet cells and ciliated epithelium.



Rings of hyaline cartilage (HC) provide support for the trachea, bronchi, and the larger bronchioles.



The lungs contain air spaces surrounded by alveolar epithelial cells (pneumocytes), forming alveoli (air sacs), where gas exchange takes place. The alveoli receive air from tubes, called bronchioles.



The **lungs** have a soft, spongy texture made up of the epithelium of the alveoli. Bronchioles form a network of small tubes to transport gases to and from the alveoli. The larger bronchioles are supported by connective tissue (e.g. cartilage).

1. Name three types of cells in the respiratory system and their function:

- (a) \_\_\_\_\_
- \_\_\_\_\_
- (b) \_\_\_\_\_
- \_\_\_\_\_
- (c) \_\_\_\_\_
- \_\_\_\_\_

2. What is the primary organ of gas exchange? \_\_\_\_\_

3. Which cells form the alveoli? \_\_\_\_\_

4. What is the purpose of the hyaline cartilage in the gas exchange system? \_\_\_\_\_

# 88 The Lungs

**Key Idea:** Lungs are internal sac-like organs connected to the outside by a system of airways. The smallest airways end in thin-walled alveoli, where gas exchange occurs. The respiratory system includes all the structures needed

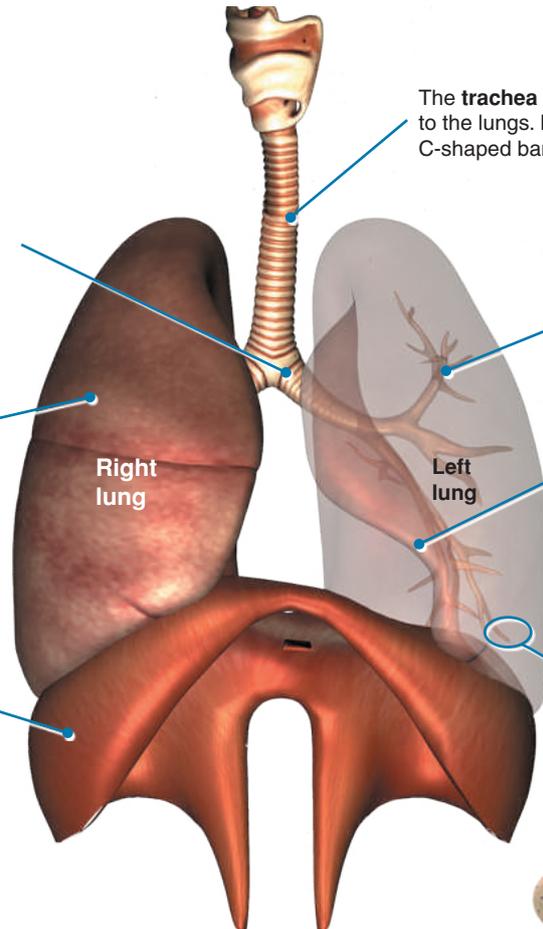
for exchanging respiratory gases with the environment. In mammals, the gas exchange organs are paired lungs connected to the outside air by way of a system of tubular passageways: the trachea, bronchi, and bronchioles.



The trachea divides into two **bronchi**. These are also supported by cartilage bands.

The right lung is slightly larger than the left. It takes up 55-60% of the total lung volume.

The **diaphragm** is a dome shaped muscle that works with the intercostal muscles of the ribcage to bring about lung ventilation (breathing). When it contracts, it moves down, reducing pressure in the lung so that air flows in.



The **trachea** (windpipe) transfers air to the lungs. It is strengthened with C-shaped bands of stiff cartilage.

**Bronchioles** branch from the bronchi and divide into progressively smaller branches. The cartilage is gradually lost as the bronchioles decrease in diameter.

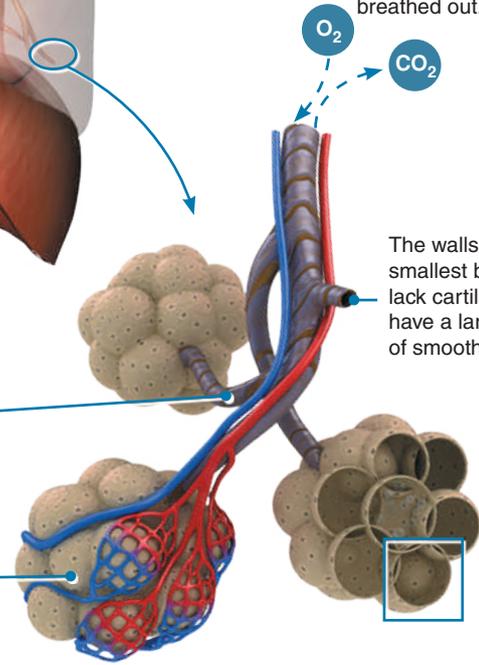
The "cardiac notch" in the left lung makes space for the heart.

Oxygen enters the blood from air in the **alveoli**. Carbon dioxide leaves the blood and is breathed out.

The walls of the smallest bronchioles lack cartilage but have a large amount of smooth muscle.

The smallest respiratory bronchioles subdivide into the alveolar ducts. The alveoli are found at the end of these.

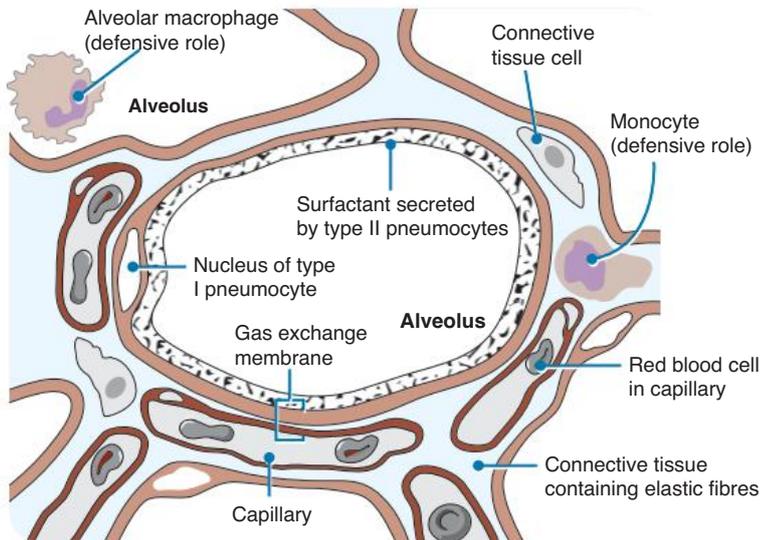
The **alveoli** are the site of gas exchange. They provide a large surface area (70 m<sup>2</sup>) for the exchange of respiratory gases by diffusion between the air in the lungs and the blood in the capillaries. The alveoli deflate after each breath out. A phospholipid **surfactant** helps to prevent collapse of the alveoli by decreasing surface tension.



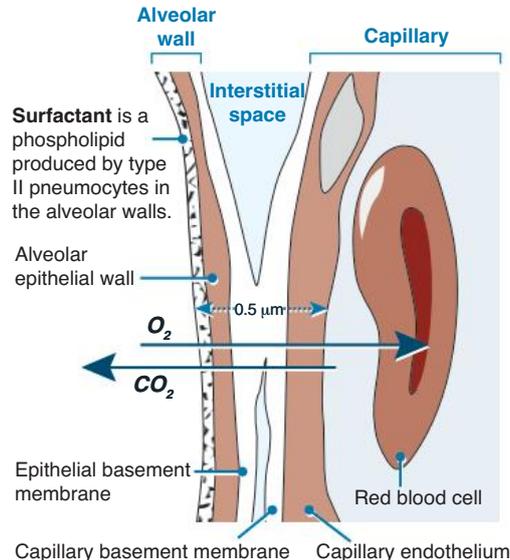
Alveolar cross section at top of next page

1. What is the purpose of the trachea, bronchi, and bronchioles? \_\_\_\_\_
2. What is the purpose of the diaphragm? \_\_\_\_\_
3. (a) Explain how the basic structure of the human gas exchange system provides such a large area for gas exchange: \_\_\_\_\_
- (b) In what region of the lung does the actual exchange of gases take place? \_\_\_\_\_

### Cross section through an alveolus



### The gas exchange membrane



**Above:** The physical arrangement of the alveoli to the capillaries through which the blood moves. The alveolus is lined with **pneumocytes** (alveolar epithelial cells). Phagocytes (monocytes and macrophages) are present to protect the lung tissue. Elastic connective tissue gives the alveoli their ability to expand and recoil.

The **gas exchange membrane** is the layered junction between the alveolar epithelial cells, the endothelial cells of the capillary, and their associated basement membranes (thin connective tissue layers under the epithelia). Gases move freely across this membrane.

4. Describe the structure and purpose of the alveolar-capillary (gas exchange) membrane: \_\_\_\_\_

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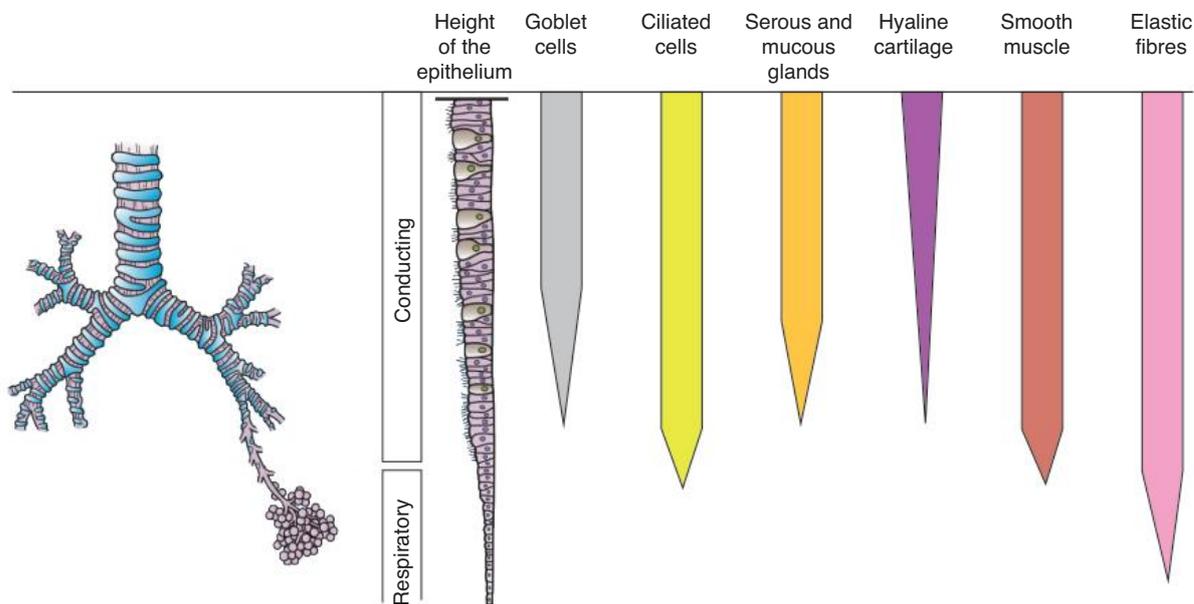


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5. The diagram below shows the different types of cells and their positions and occurrence in the lungs. Use it to answer the following questions:



(a) Why does the epithelium become very thin in the respiratory zone? \_\_\_\_\_

---



---

(b) Why would elastic fibres be present in the respiratory zone, whereas hyaline cartilage is not? \_\_\_\_\_

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# 89 Modelling Lung Ventilation

**Key Idea:** The lungs are ventilated by changes in the air pressure in chest cavity.

Respiratory gases enter the body via the lungs. Breathing in is achieved by the diaphragm moving downwards and the ribcage moving upwards and outwards. This increases

the volume of the chest cavity and causes the air pressure inside the cavity to become lower than the atmospheric air pressure. Air rushes into the lung and causes them to expand. When the diaphragm relaxes and the ribcage moves back downwards air is pushed back out of the lungs.



## Investigation 5.2 Modelling lung ventilation

See appendix for equipment list.

**Take care using a utility knife as they are very sharp. Cut on a flat firm surface or cutting board.**

You can work in pairs for this activity if you wish.

1. Take a 500 mL (approximately) plastic bottle and use a utility knife to cut the bottom off.
2. Hang one of the balloons inside the neck end of the bottle and stretch the open end of the balloon over the neck of the bottle. It should fit tightly, but secure it with a rubber band if needed.
3. Cut the lower third off the second balloon and keep the two-thirds with the open end. Tie a knot in the neck of this balloon.
4. Stretch the wide opening of the cut balloon over the wide end of the cut bottle so that the knot hangs down. It should fit tightly over the bottle but secure it with a rubber band if needed.
5. Pull and release the knot. What happens? \_\_\_\_\_

\_\_\_\_\_

What do you think happens to the pressure inside the bottle when you pull and release the knot?

\_\_\_\_\_

How does this explain what happens in the model? \_\_\_\_\_

\_\_\_\_\_

1. (a) What does the balloon in the bottle represent? \_\_\_\_\_
- (b) What does the cut balloon with the knot in it represent? \_\_\_\_\_
- (c) Pulling down on the knot is like breathing in / breathing out (delete one)
- (d) Releasing the knot is like breathing in / breathing out (delete one)
2. (a) How is your model like the human gas exchange system? \_\_\_\_\_
- \_\_\_\_\_
- (b) How is it different? \_\_\_\_\_
- \_\_\_\_\_
3. Use your model to describe how breathing is achieved in relation to air pressure: \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
4. When you breath in, what structure(s) in the lungs is/are actually expanding? \_\_\_\_\_



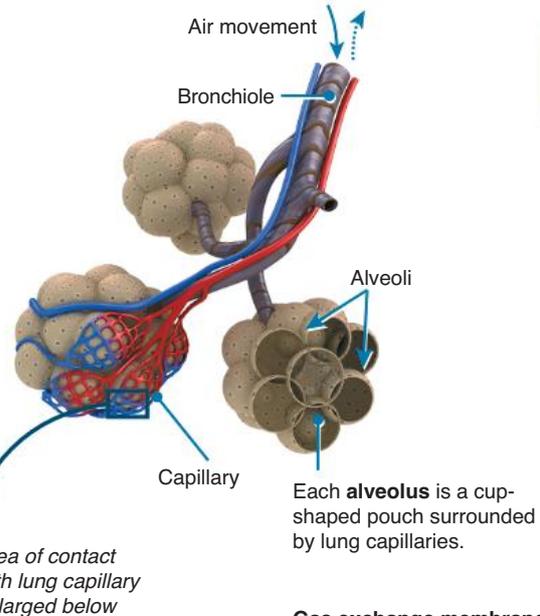
# 90 Gas Transport in Humans



**Key Idea:** Haemoglobin is a respiratory pigment in red blood cells, which binds oxygen and increases the efficiency of its transport and delivery to tissues throughout the body.

The transport of respiratory gases around the body is the role of the blood and its respiratory pigment, haemoglobin. Most of the carbon dioxide in the blood is carried as bicarbonate in the plasma. Oxygen does not dissolve in blood easily, so in vertebrates, e.g. humans, it is transported throughout the body chemically bound to the respiratory protein **haemoglobin** (Hb) inside the red blood cells.

In the muscles, oxygen from haemoglobin is transferred to and retained by **myoglobin**, a molecule that is chemically similar to haemoglobin except that it consists of only one heme-globin unit. Myoglobin has a greater affinity for oxygen than haemoglobin and acts as an oxygen store within muscles, releasing the oxygen during periods of prolonged or extreme muscular activity.



**Gas exchange membrane:** Formed by the epithelial cells of the alveolus and capillary together. It is only  $0.5\ \mu\text{m}$  thick so gases diffuse rapidly across.

Most  $\text{CO}_2$  in the blood (85%) is carried as bicarbonate ( $\text{HCO}_3^-$ ) formed in the red blood cells from  $\text{CO}_2$  in a reversible, enzyme-catalysed reaction.  $\text{HCO}_3^-$  diffuses out of the red blood cells and into the plasma where it contributes to the buffer capacity of the blood.

When  $\text{CO}_2$  levels rise too quickly,  $\text{H}^+$  can accumulate in the blood, reducing pH. This provides a strong stimulus to increase breathing rate.

Carbon dioxide diffuses from the body's cells into the capillary.

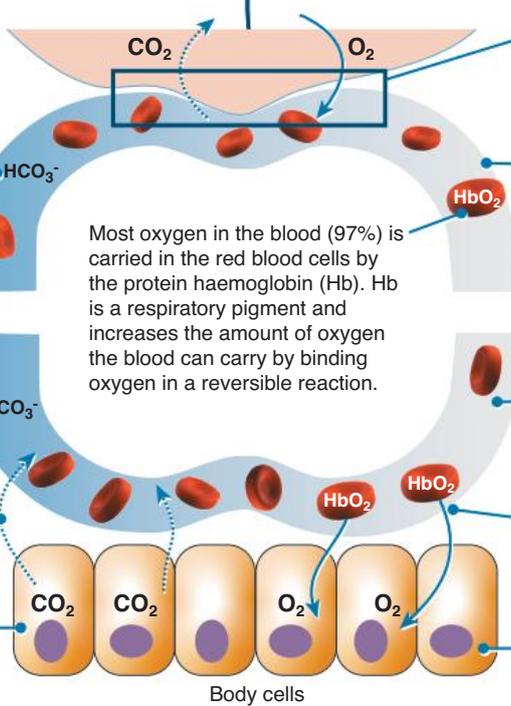
Most oxygen in the blood (97%) is carried in the red blood cells by the protein haemoglobin (Hb). Hb is a respiratory pigment and increases the amount of oxygen the blood can carry by binding oxygen in a reversible reaction.

When oxygen levels are high (lungs and surrounding blood vessels) haemoglobin binds with a lot of oxygen (the Hb is saturated).

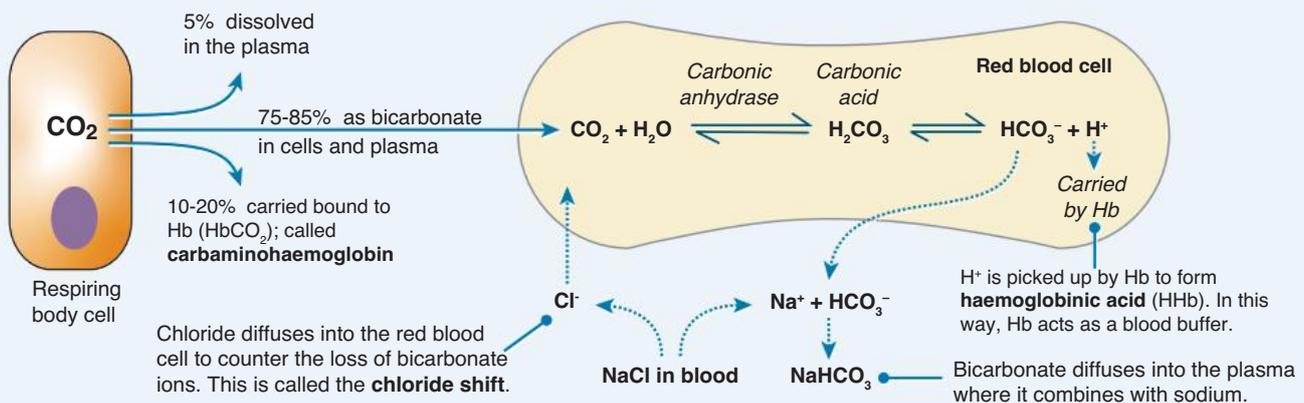
**Body tissue capillary:** The capillaries in the tissues are very close to the body's cells, allowing for rapid diffusion back and forth.

When carbon dioxide levels are high (body tissues) haemoglobin releases its oxygen.

Oxygen diffuses into the body's cells from the capillary.

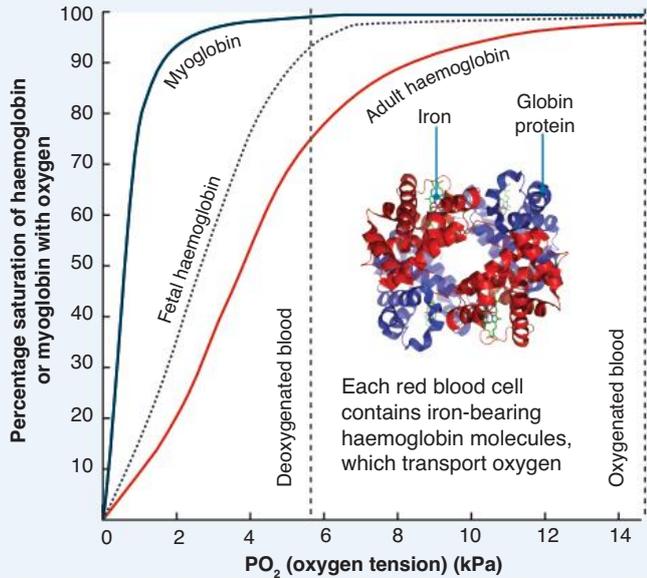


## Transport of carbon dioxide in the blood



## Respiratory pigments and the transport of oxygen

Fig.1: Dissociation curves for haemoglobin and myoglobin at normal body temperature for fetal and adult human blood.



- ▶ The most important factor determining how much oxygen is carried by haemoglobin (Hb) is the level of oxygen in the blood. The greater the oxygen tension, the more oxygen will combine with Hb.
- ▶ This relationship can be illustrated in an **oxygen-haemoglobin dissociation curve** (left). In the lung capillaries (high O<sub>2</sub>), a lot of oxygen is picked up and bound by Hb. In the tissues (low O<sub>2</sub>), oxygen is released.
- ▶ Myoglobin in skeletal muscle has a very high affinity for oxygen and will take up oxygen from Hb in the blood. It can therefore act as an oxygen store.
- ▶ Fetal Hb has a high affinity for oxygen and carries 20-30% more than maternal Hb.
- ▶ The release of oxygen to the tissues is enhanced by the effect of pH. As pH increases (lower CO<sub>2</sub>), more oxygen combines with Hb. As the blood pH decreases (higher CO<sub>2</sub>), Hb binds less oxygen and releases more to the tissues. This is called the Bohr effect.

1. (a) Identify two regions in the body where oxygen levels are relatively high: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Identify two regions where carbon dioxide levels are relatively high: \_\_\_\_\_  
 \_\_\_\_\_
2. (a) What is the function of haemoglobin? \_\_\_\_\_  
 \_\_\_\_\_
- (b) Explain the significance of the reversible binding of oxygen by haemoglobin: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. (a) How is haemoglobin saturation affected by the oxygen level in the blood? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (b) What is the significance of this relationship to oxygen delivery to the tissues? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
4. At low blood pH, less oxygen is bound by haemoglobin and more is released to the tissues:
  - (a) Name this effect: \_\_\_\_\_
  - (b) What is its significance? \_\_\_\_\_  
 \_\_\_\_\_
5. (a) Compare the affinity of myoglobin and haemoglobin for oxygen: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Why is the very high affinity of myoglobin for oxygen important? \_\_\_\_\_  
 \_\_\_\_\_

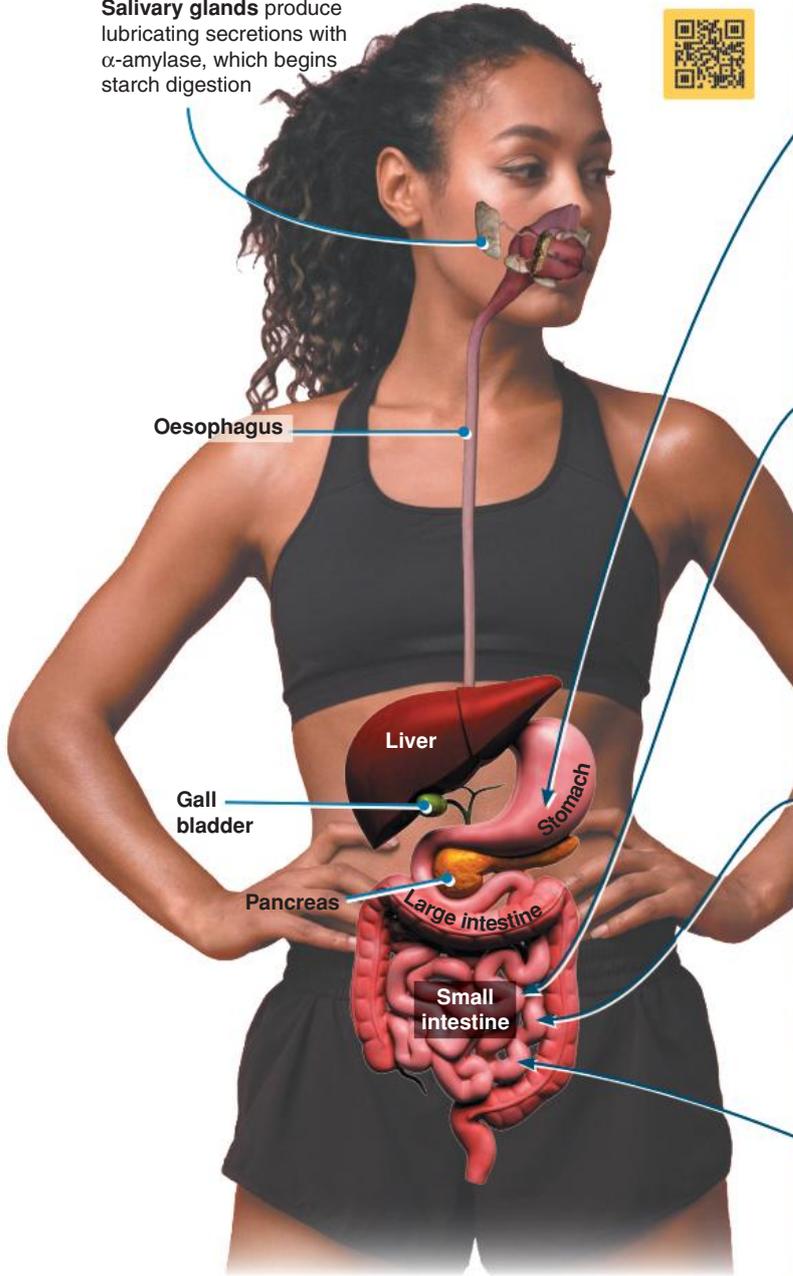
# 91 The Digestive System

**Key Idea:** The digestive tract is specialised to maximise the digestion of food, absorption of nutrients, and elimination of undigested material.

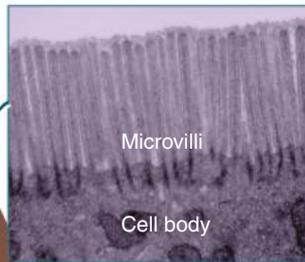
The human digestive system (gut) is a tubular tract, which is regionally specialised into a complex series of organs and glands. These work in sequence to maximise the efficiency with which food is processed. Collectively, the organs of the

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.

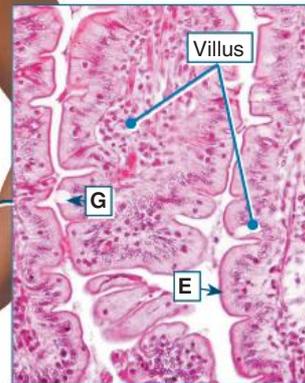
**Salivary glands** produce lubricating secretions with  $\alpha$ -amylase, which begins starch digestion



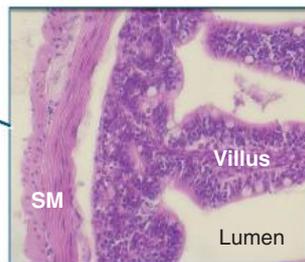
In the stomach, gastric glands contain parietal cells, which produce hydrochloric acid, and chief cells, which produce a protein-digesting enzyme. Scattered endocrine cells secrete a hormone to regulate gastric activity.



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.



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.



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**.

- (a) How are villi formed? : \_\_\_\_\_

\_\_\_\_\_

(b) What is the purpose of microvilli \_\_\_\_\_

\_\_\_\_\_
- What is the purpose of the smooth muscle surrounding the intestine? \_\_\_\_\_

\_\_\_\_\_

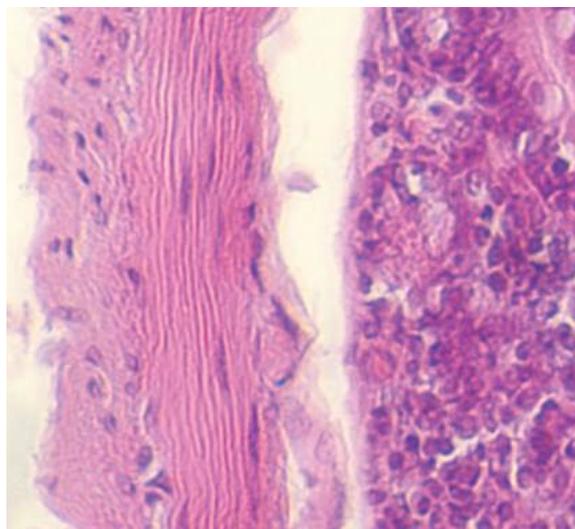
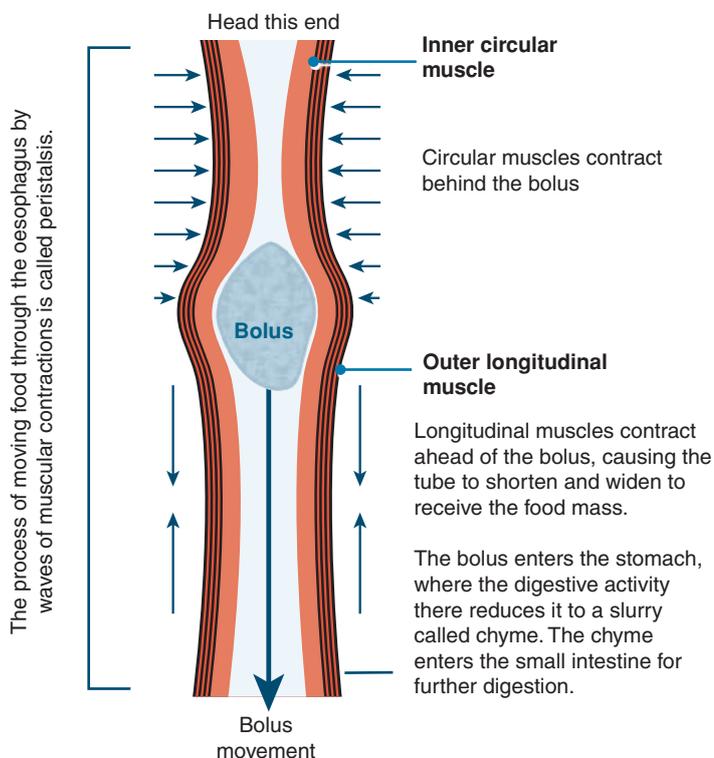
\_\_\_\_\_

# 92 Moving Food Through the Gut

**Key Idea:** Solid food is chewed into a small mass called a bolus and swallowed. Further digestion produces chyme. Food is moved through the gut by waves of muscular contraction called peristalsis.

Ingested food is chewed and mixed with saliva to form a small mass called a bolus. Wave-like muscular contractions called **peristalsis** moves the food, first as a bolus and then as semi-fluid chyme, through the digestive tract as described below.

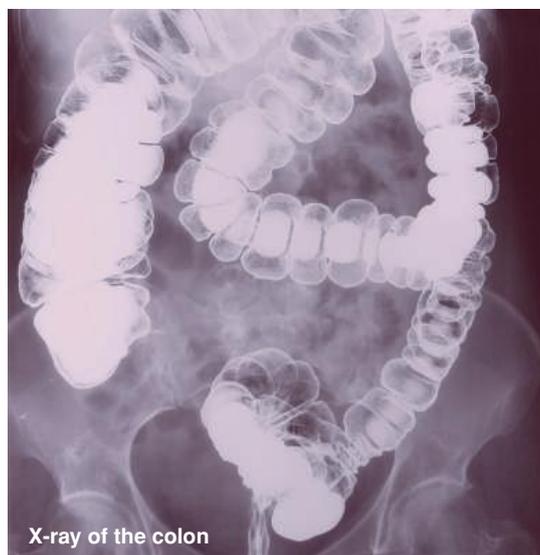
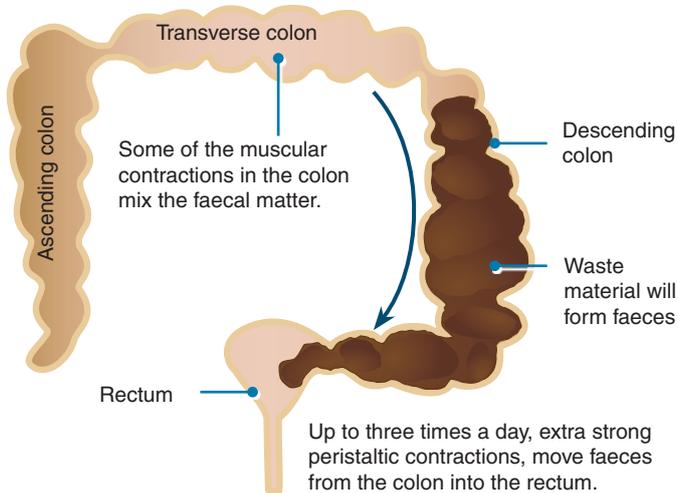
## Peristalsis



## Cross section through the small intestine

A cross section through the small intestine shows the outer longitudinal and inner circular muscles involved in peristalsis. In a cross sectional view, the longitudinal muscles appear circular because they are viewed end on, whereas the circular muscle appears in longitudinal section.

## Peristaltic movement in the colon

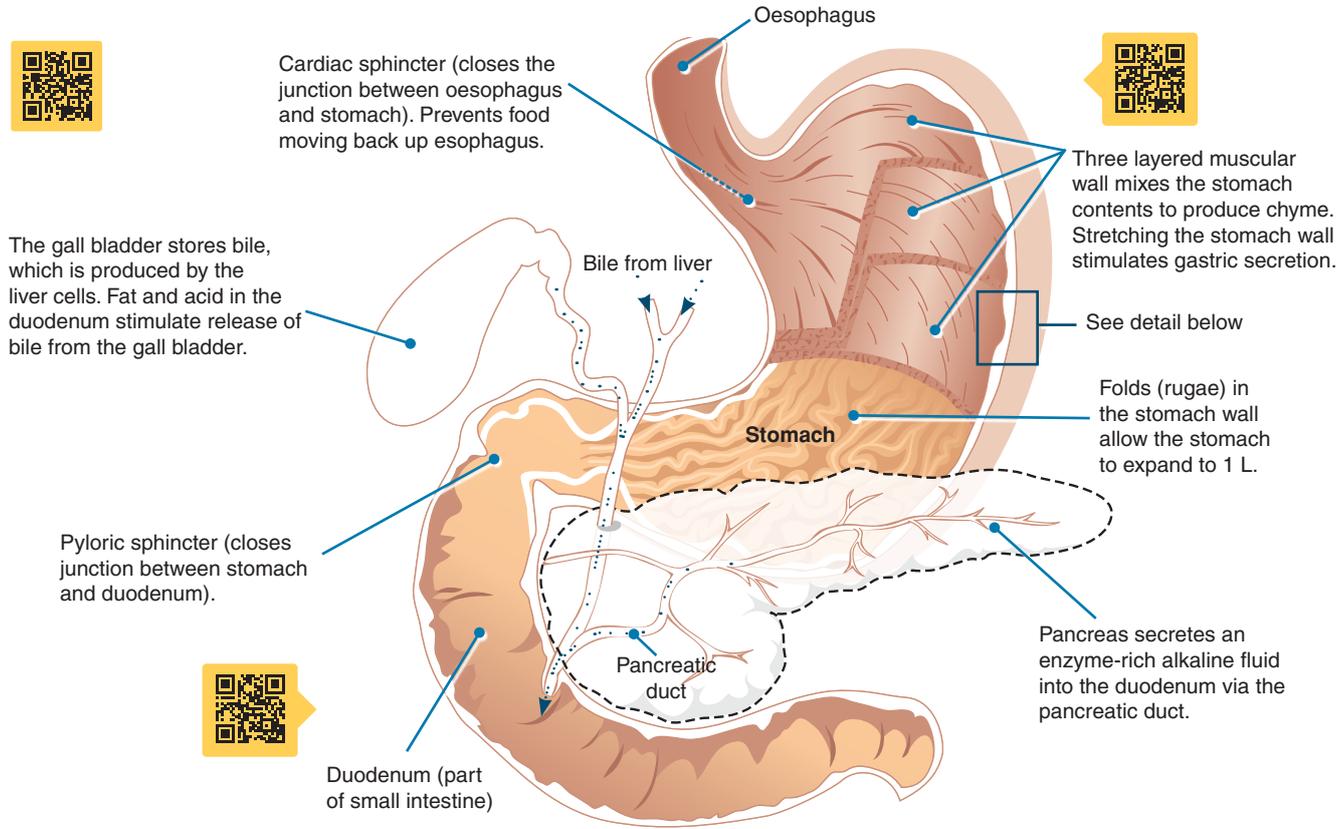


- Describe how peristalsis moves food through the gut: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- What are the two main functions of peristalsis? \_\_\_\_\_  
 \_\_\_\_\_
- Draw arrows on the X-ray of the colon (above right) to show the direction of movement of the waste matter through the colon. Circle the areas of waste matter.

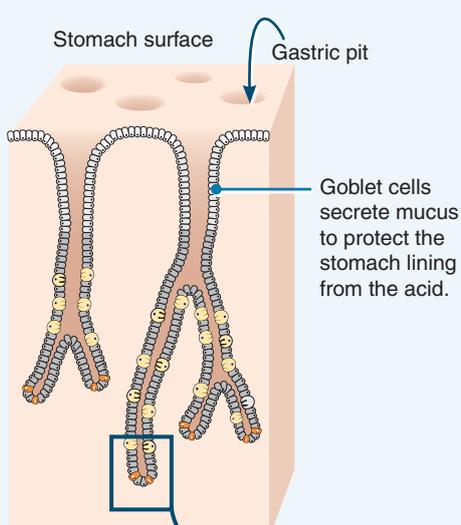
# 93 The Stomach and Small Intestine

**Key Idea:** The stomach produces acid and a protein-digesting enzyme, which break food down into a slurry, called chyme. 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

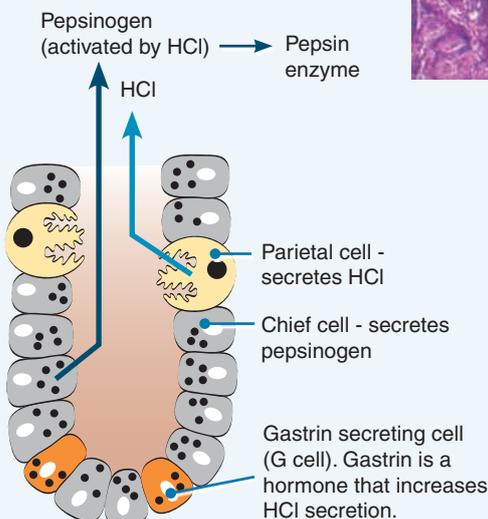
called chyme. The low pH of the stomach destroys microbes, denatures proteins, and activates a protein-digesting enzyme precursor. There is very little absorption in the stomach, although small molecules (glucose, alcohol) are absorbed across the stomach wall into the surrounding blood vessels.



## Detail of a gastric gland (stomach wall)



Right: High powered light micrograph of the stomach epithelium showing the gastric glands



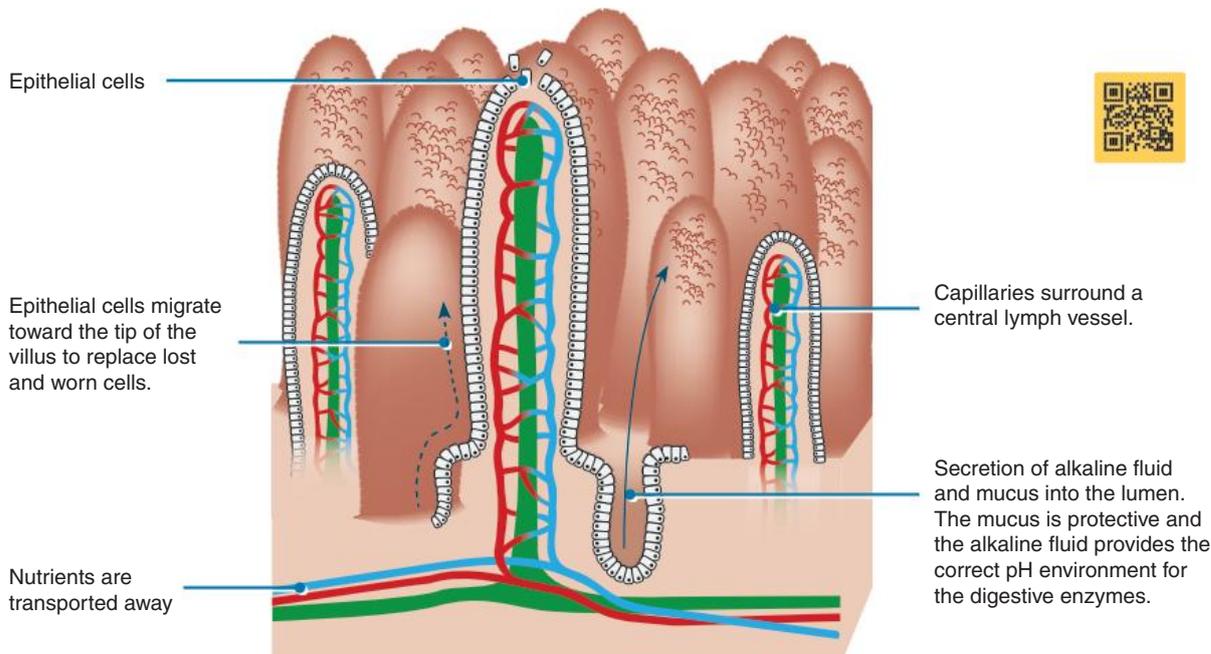
In the stomach, gastric glands contain parietal cells, which produce hydrochloric acid, chief cells, which produce enzymes to break down protein, and endocrine cells.

## Stomach secretions

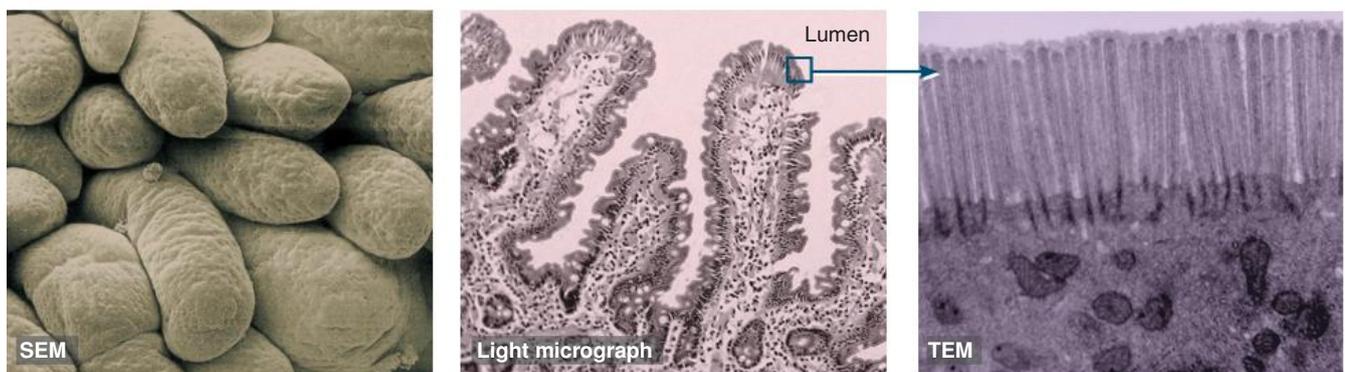
Gastric juice
Acid (HCl) secretion
Pepsin enzyme (optimal pH 1.5-2.0) Acts on proteins and breaks them down into peptides (short chains of amino acids).

### The small intestine

- ▶ The small intestine receives the chyme directly from the stomach. The small intestine is divided into three regions, which are distinguished by the cell types present: the **duodenum**, where most chemical digestion occurs, and then the **jejunum** and finally the **ileum**. Most absorption occurs in the jejunum and ileum.
- ▶ 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. This neutralises the acidity of the chyme entering the small intestine from the stomach and protects the lining of the intestine from damage.



**Photographs below:** The intestinal villi are shown projecting into the gut lumen in a scanning electron micrograph (left image) and in a light microscope image (center image). The microvilli forming the brush border of a single intestinal epithelial cell are shown in the transmission electron micrograph (right image).



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 are bound to the surfaces of the intestinal epithelial cells.

Enzymes in pancreatic juice		
Enzyme	Optimal pH	Action
Pancreatic amylase	6.7-7.0	Starch → maltose
Trypsin*	7.8-8.7	Protein → peptides
Chymotrypsin*	7.8	Protein → peptides
Pancreatic lipase	8.0	Fats → fatty acids & glycerol

\* Secreted in an inactive form

Enzymes in intestinal juice (IJ) and epithelium (E)		
Enzyme	Optimal pH	Action
Maltase (E)	6.0-6.5	Maltose → glucose
Peptidases (IJ, E)	~ 8.0	Polypeptides → amino acids
Sucrase (E)	~6.0	Protein → peptides
Enteropeptidase (IJ)	8.0	Activates trypsin**

\*\*Once activated, trypsin activates chymotrypsin

1. Summarise the structure and role of each of the following regions of the human digestive tract:

(a) Stomach: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) Small intestine: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. (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:  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Identify an endocrine cell in the stomach epithelium and state its purpose: \_\_\_\_\_  
 \_\_\_\_\_

4. How does the stomach achieve the mixing of acid and enzymes with food? \_\_\_\_\_  
 \_\_\_\_\_

5. (a) What is the purpose of the intestinal villi? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) What is the purpose of the microvilli (brush border) on intestinal epithelial cells? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

6. Identify two sites for secretion of enzymes active in the small intestine. Identify an enzyme produced there and its role:

(a) Site: \_\_\_\_\_ Enzyme: \_\_\_\_\_  
 Enzyme's role: \_\_\_\_\_  
 \_\_\_\_\_

(b) Site: \_\_\_\_\_ Enzyme: \_\_\_\_\_  
 Enzyme's role: \_\_\_\_\_  
 \_\_\_\_\_

(c) In general, do the enzymes act in acidic or alkaline conditions? \_\_\_\_\_  
 \_\_\_\_\_

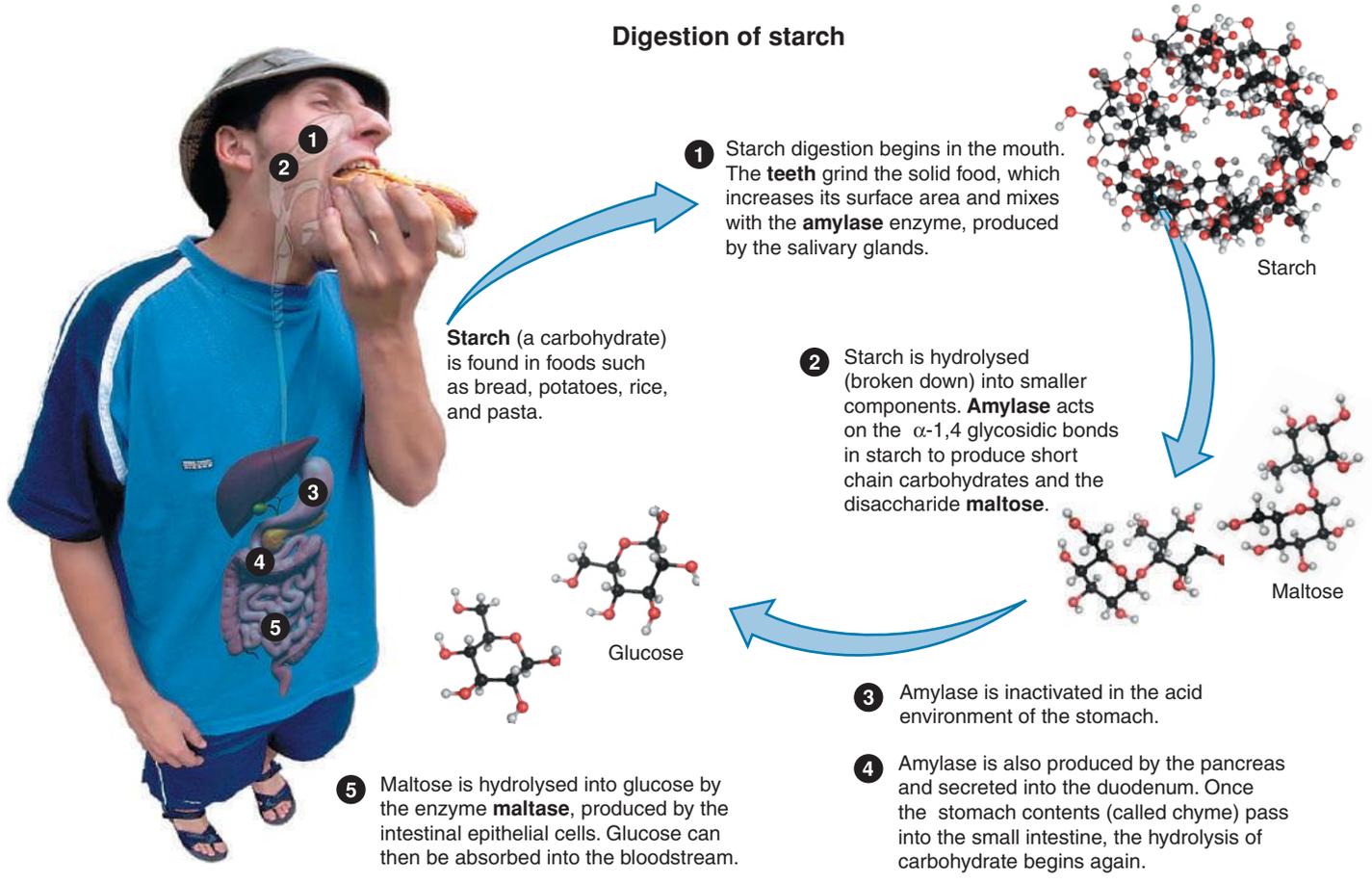
(d) How is this pH environment generated? \_\_\_\_\_

7. Suggest why the small intestine is so long: \_\_\_\_\_  
 \_\_\_\_\_

# 94 Digestion, Absorption, and Transport

**Key Idea:** Food must be digested into components small enough to be absorbed by the body's cells and assimilated. Nutrient absorption involves both active and passive transport. Digestion breaks down food molecules into small molecules that can pass through the intestinal lining into the underlying blood and lymph vessels. For example, starch is broken down first into maltose and short chain carbohydrates such as dextrose, before being hydrolysed to the simple sugar

glucose (below). Breakdown products of other foods include amino acids (from proteins), and fatty acids, glycerol, and monoglycerides (from fats). The passage of these molecules from the gut into the blood or lymph is called absorption. Nutrients are then transported directly or indirectly to the liver for storage or processing. After they have been **absorbed** nutrients can be **assimilated**, i.e incorporated into the substance of the body itself.



1. Explain the roles of amylase and maltase in starch digestion: \_\_\_\_\_

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2. Salivary and pancreatic secretions contain amylase. Why do two digestive organs produce the same enzyme?

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3. Based on the diagram opposite, predict what would happen to nutrient absorption if the villi were damaged. Explain:

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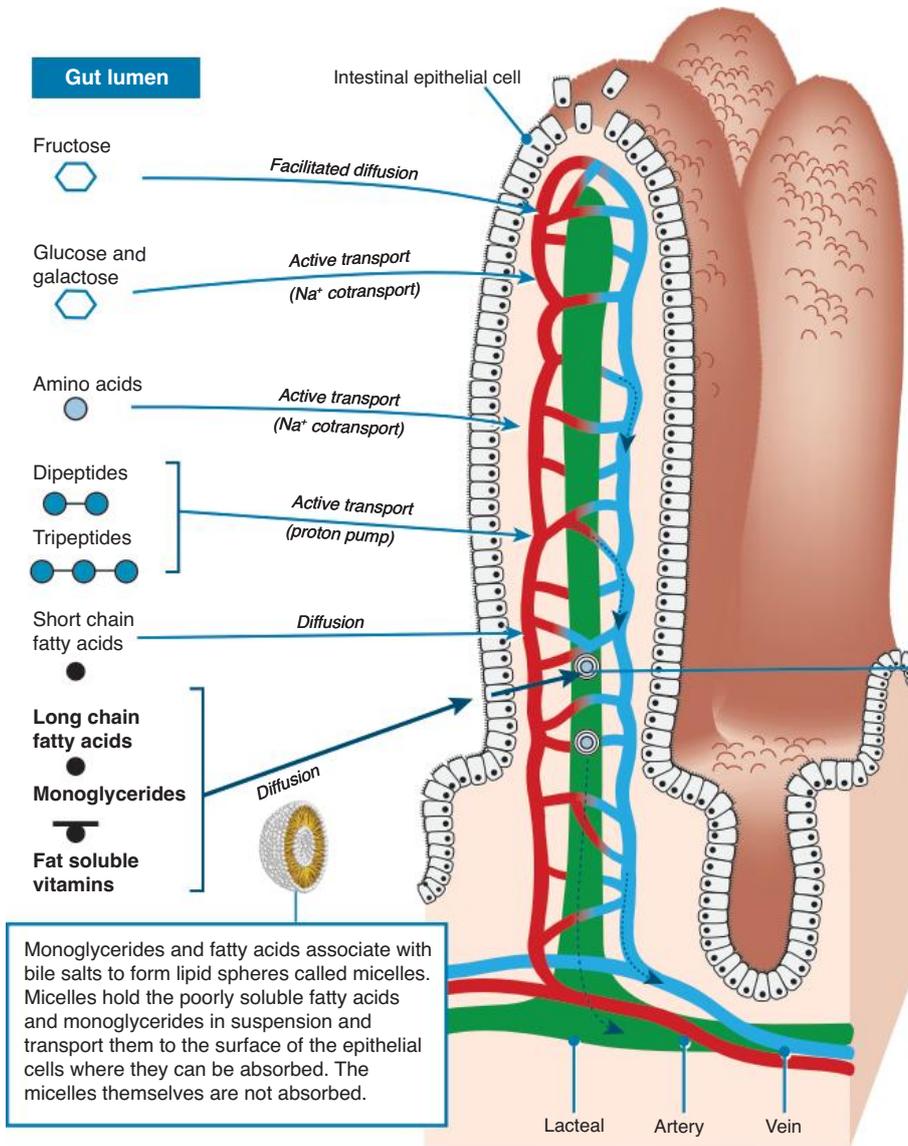
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### Nutrient absorption by intestinal villi



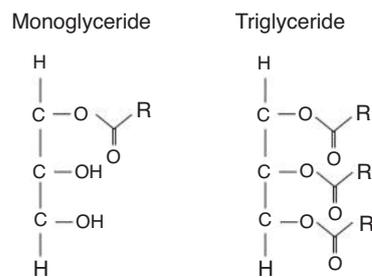
*Cross section through a villus, showing how the products of digestion are absorbed across the intestinal epithelium into the capillaries or into the lacteals of the lymphatic system. The nutrients are delivered to the liver.*

Glucose and amino acids are actively transported by cotransport proteins along with sodium (sodium symport). This maintains a sodium gradient which helps with the absorption of water.

Active transport of di- and tripeptides is coupled to the downhill movement of H<sup>+</sup> across the plasma membrane of the intestinal epithelial cells.

Once the monoglycerides and fatty acids are absorbed, triglycerides are re-formed and transported to the liver lacteals of the lymphatic system.

Monoglycerides and fatty acids associate with bile salts to form lipid spheres called micelles. Micelles hold the poorly soluble fatty acids and monoglycerides in suspension and transport them to the surface of the epithelial cells where they can be absorbed. The micelles themselves are not absorbed.



R = hydrocarbon chain



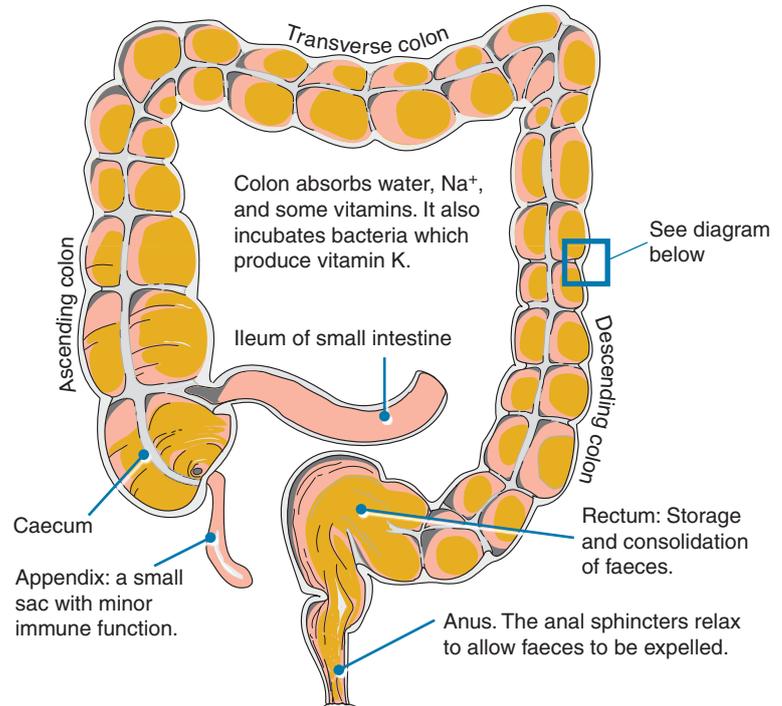
4. Describe how each of the following nutrients are absorbed by the intestinal villi:
  - (a) Glucose: \_\_\_\_\_
  - (b) Fructose: \_\_\_\_\_
  - (c) Amino acids: \_\_\_\_\_
  - (d) Di- and tripeptides: \_\_\_\_\_
5. Describe the two purposes of the sodium symport in the intestinal epithelium: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
6. What is the role of micelles in the absorption of lipids? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
7. How are concentration gradients maintained for the absorption of nutrients by diffusion? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 95 The Large Intestine

**Key Idea:** The large intestine absorbs water and solidifies the indigestible material before passing it to the rectum. Undigested waste are egested as faeces from the anus. After most of the nutrients have been absorbed in the small intestine, the remaining semi-fluid contents pass into the

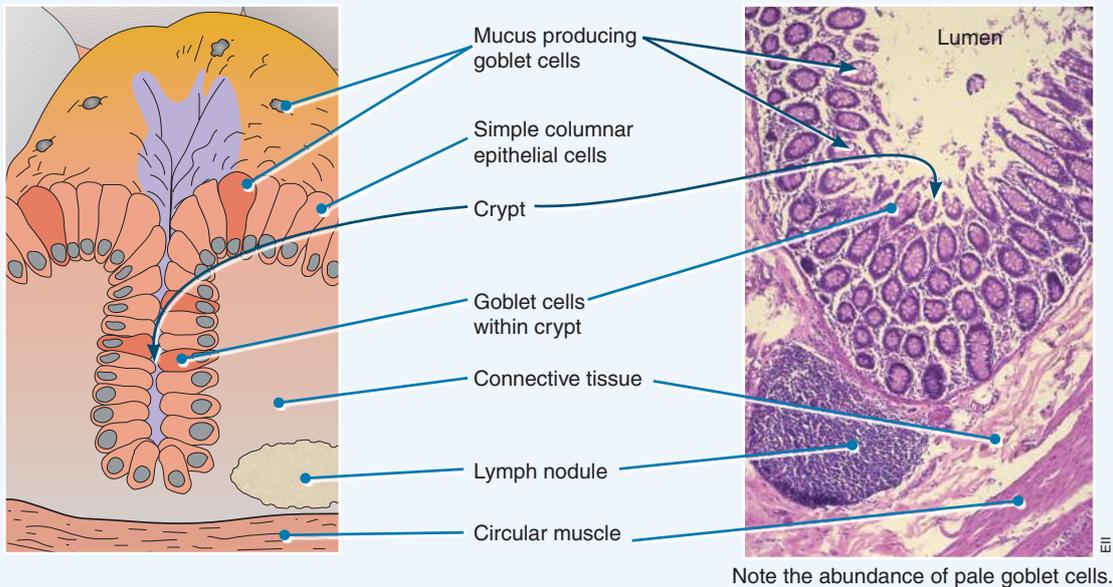
large intestine (consisting of the appendix, caecum, colon, and rectum). The large intestine's main role is to reabsorb water and electrolytes and to consolidate the waste material into faeces, which are eliminated from the anus in a process called egestion.

- ▶ After most of the nutrients have been absorbed in the small intestine, the remaining semi-fluid contents pass into the large intestine (appendix, caecum, and colon). This mixture includes undigested or indigestible food, (such as **cellulose**), bacteria, dead cells, mucus, bile, ions, and water. 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.
- ▶ The rectum stores the waste faecal material before it is discharged out the anus. Fullness in the rectum produces the urge to defecate. If too little water is absorbed, the faeces will be watery as in diarrhoea. If too much water is absorbed the faeces will become compacted and difficult to pass.
- ▶ 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 many mucus-secreting cells. The mucus lubricates the colon wall and helps to form and move the faeces. In the photograph, some of the crypts are in cross section and some are in longitudinal section.



1. What is the main purpose of the large intestine? \_\_\_\_\_
2. What are the effects of absorbing too little and too much water in the large intestine? \_\_\_\_\_



1. Complete the table below to show how autotrophs and heterotrophs obtain or produce, and use the different nutrients and gases they need or produce as wastes:

Nutrient/gas requirements	Autotroph	Heterotroph
Oxygen gas		
Carbon dioxide gas		
Water		
Glucose		
Lipids/proteins		

2. (a) What process moves food through the gut? \_\_\_\_\_

(b) In what region of the digestive system does most nutrient absorption occur? \_\_\_\_\_

(c) What structures from the small intestine of a mammal are shown in the photograph (right)?

\_\_\_\_\_

(d) What is their function? \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



3. (a) The photograph shows a structure on a plant leaf. Identify the structure arrowed in the photograph:

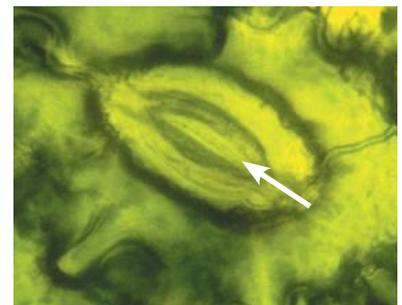
\_\_\_\_\_

(b) When is this structure likely to be open (day or night)?

\_\_\_\_\_

(c) What happens when the cells surrounding the structure take up water?

\_\_\_\_\_



4. How do mammals maintain the concentration gradient of oxygen between the lungs and the blood, and why is the maintenance of this gradient important?

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

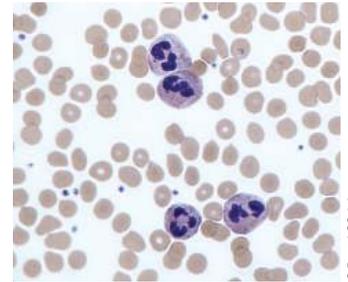
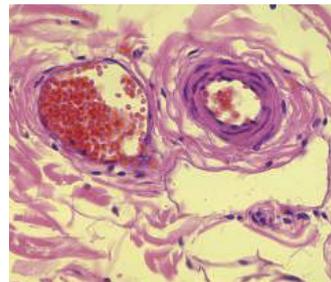
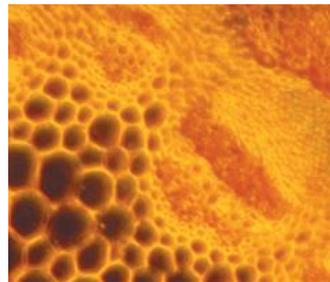
**Key terms**

artery  
blood  
capillary  
closed circulatory system  
cohesion-tension hypothesis  
mass flow hypothesis  
open circulatory system  
phloem  
respiratory gas  
root  
stem  
translocation  
transpiration  
vascular tissue  
vein  
xylem

**Inquiry question:** *How does the composition of the transport medium change as it moves around an organism?*

**Plant transport systems***Key skills and knowledge*

- |                          |   |                |
|--------------------------|---|----------------|
| <input type="checkbox"/> | 1 Investigate the structure of the vascular system in the roots, stems, and leaves of plants.   | <b>97-99</b>   |
| <input type="checkbox"/> | 2 Describe and contrast the structure of xylem and phloem tissue. Include reference to vessels and tracheids in xylem and sieve tubes, sieve plates, and companion cells in phloem.               | <b>100-102</b> |
| <input type="checkbox"/> | 3 <b>PRAC</b> Produce slides to investigate the microscopic structure of plant vascular tissue.   | <b>98</b>      |
| <input type="checkbox"/> | 4 Explain the movement of water and dissolved minerals through the xylem (the transpiration stream). Include reference to transpiration pull, the cohesion-tension hypothesis, and root pressure. | <b>103</b>     |
| <input type="checkbox"/> | 5 Identify the factors affecting the rate of transpiration and describe and explain their effects. Include reference to light, temperature, wind, and humidity.                                   | <b>104</b>     |
| <input type="checkbox"/> | 6 <b>PRAC</b> Investigate factors affecting transpiration.  | <b>104</b>     |
| <input type="checkbox"/> | 7 Explain the source to sink transport of the sugars and some minerals via translocation in the phloem. Investigate evidence for phloem movement.   | <b>105 106</b> |



G Beard CC 3.0

**Animal transport systems***Key skills and knowledge*

- |                          |  |                        |
|--------------------------|--|------------------------|
| <input type="checkbox"/> | 8 Describe the structure and function of the circulatory system, including how blood is moved around the body and the role of the heart and different blood vessels.   | <b>107</b>             |
| <input type="checkbox"/> | 9 Describe composition of blood and its function in the body.  | <b>108</b>             |
| <input type="checkbox"/> | 10 Recognise differences in the structure and function of blood vessels in mammals, including arteries, veins, and capillaries. Understand the importance of capillary networks (beds) as exchange surfaces. | <b>107 109<br/>110</b> |
| <input type="checkbox"/> | 11 Describe the changes that occur in the blood as it moves around the body.   | <b>112</b>             |
| <input type="checkbox"/> | 12 Compare the structures of mammalian and fish hearts.  | <b>111 114</b>         |
| <input type="checkbox"/> | 13 Compare open, closed single, and closed double circulatory systems. Describe the differences between them and identify the groups of animals where each occurs.   | <b>113</b>             |

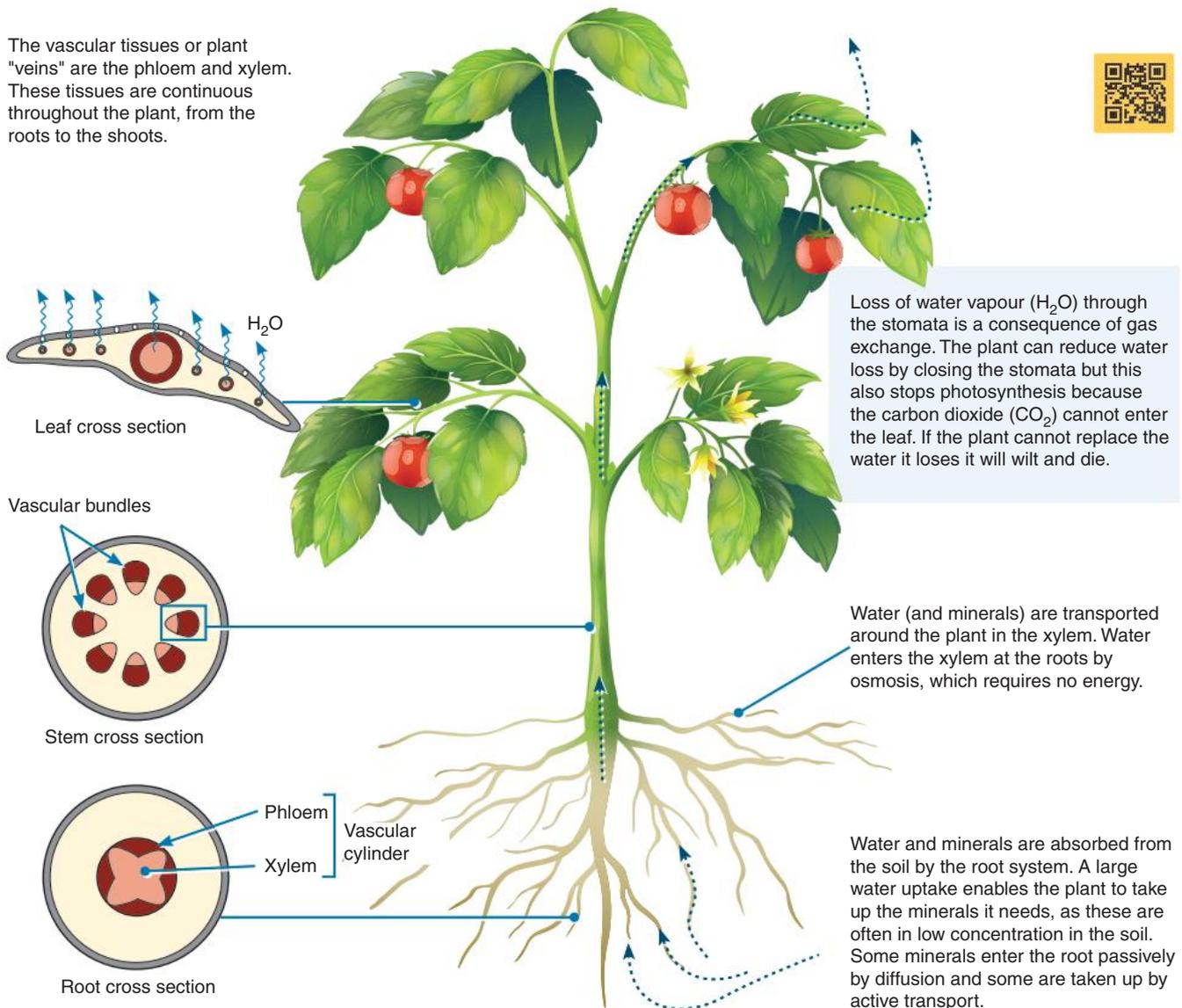
# The Plant Transport System

**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 a 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.

- Name the two vascular tissues in plants: \_\_\_\_\_
- Briefly describe why plants need a transport system: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (a) What is the function of xylem? \_\_\_\_\_  
 \_\_\_\_\_  
 (b) How does water enter the xylem? \_\_\_\_\_  
 (c) Why is water loss a consequence of gas exchange? \_\_\_\_\_  
 \_\_\_\_\_

# 98 Plant Dissection

**Key Idea:** The arrangement of vascular tissue in plants changes in different parts of the plants. The arrangement of vascular tissue also differs between monocot and dicot plants. The angiosperms (flowering plants) are commonly divided into two groups, the monocots (plants that produce seeds with one embryonic leaf), and the dicots (plants that produce seeds with two embryonic leaves). The arrangement of the

vascular tissue is quite different between these two groups. In the stem this difference can be clearly seen. The vascular bundles in dicots are arranged around the periphery of the stem, while in monocots they appear more scattered. These arrangements can best be seen by making slides of herbaceous plants for viewing under a microscope.



## Investigation 6.1 Investigating vascular tissue

See appendix for equipment list.

1. Your teacher may provide you with prepared slides or you may need to make them yourself. Refer to investigation 2.1 if you need to make your own slides. You will also be provided with two unknown prepared slides. One will be a monocot and one will be a dicot. They will be slides showing vascular tissue in either stems or roots.
2. You will need to prepare slides with transverse sections (cut across the stem or root) of stems and roots or use the slides provided by your teacher. Dicot plants that are useful for this are buttercups and sunflowers and for monocots plants corn or maize are good examples.
3. Go to the **BIOZONE Resource Hub**. This contains weblinks for the Berkshire Community College Bioscience Image Library. There are four links:  
*Angiosperm morphology: monocotyledonous roots,*  
*Angiosperm morphology: monocotyledonous stems,*  
*Angiosperm morphology: herbaceous dicotyledonous roots,*  
*Angiosperm morphology: herbaceous dicotyledonous stems.*  
 These links have many high quality images. They will help you identify the vascular tissue in your slides.
4. Place a slide on the microscope stage and focus on low power, and then on high power. In the space below record whether the specimen is a dicot or monocot, stem or root, and write a brief description of or draw the arrangement of the vascular tissue. Use extra paper is needed.
5. Repeat for all the plant roots and stems available.

6. Identify the unknown slides provided by your teacher. For each slide state whether it is a monocot or dicot, a root or stem slide and the reasons for your decision.

Slide 1: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Slide 2: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



# 99 Stems and Roots

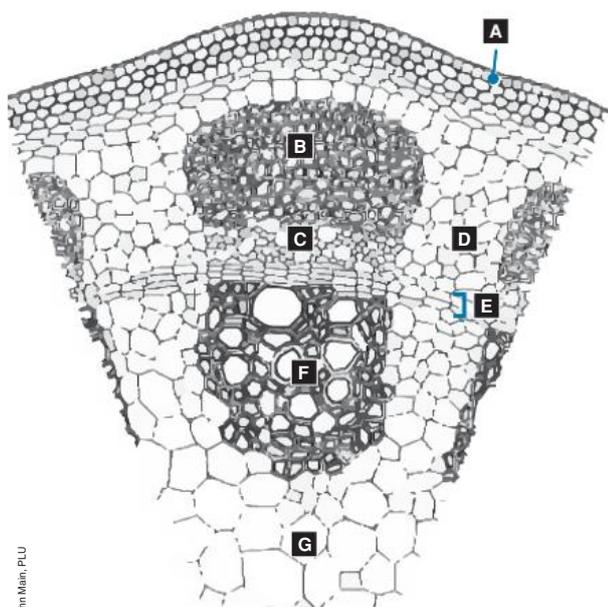
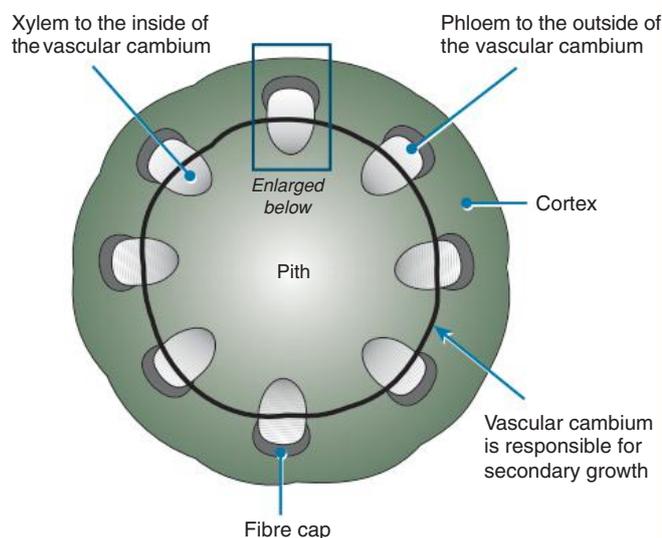
**Key Idea:** In dicots, the vascular tissue in the stem is distributed around the periphery of the stem. In the roots, the vascular tissue is found near the centre of the root.

Stems are the primary organs for supporting the plant. Roots anchor the plant in the ground, absorb water and minerals from the soil, and transport these materials around the plant. Roots may also store excess food. The vascular tissues of stems and roots are organised in bundles containing the

xylem and phloem and strengthening fibres. The entire plant body, including the roots and stems, is covered in an epidermis but, unlike most of the plant, the root epidermis has only a thin cuticle that presents no barrier to water entry. Young roots are also covered with root hairs. Compared with stems, roots are relatively simple and uniform in structure, and their features are associated with aeration of the tissue and transport of water and minerals from the soil.

## Dicot stem structure

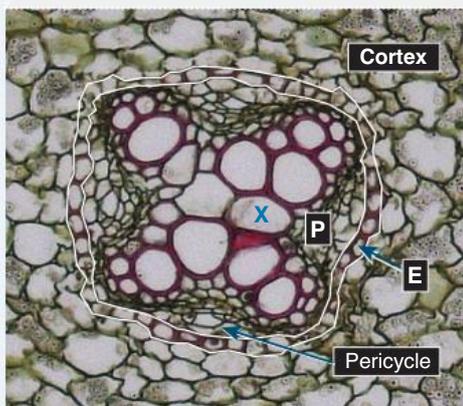
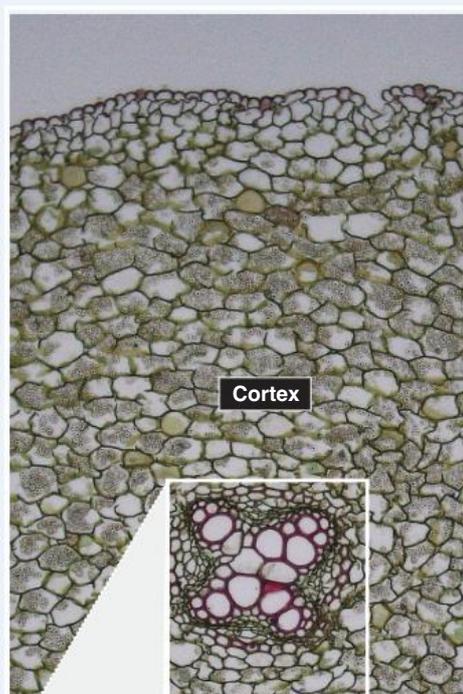
In dicots, the vascular bundles are arranged in an orderly fashion around the stem. Each vascular bundle contains **xylem** (to the inside) and **phloem** (to the outside). Between the phloem and the xylem is the **vascular cambium**; a layer of cells that divide to produce the thickening of the stem. The middle of the stem, called the **pith**, is filled with thin-walled parenchyma cells. The vascular bundles in dicots are arranged in an orderly way around the periphery of the stem (below).



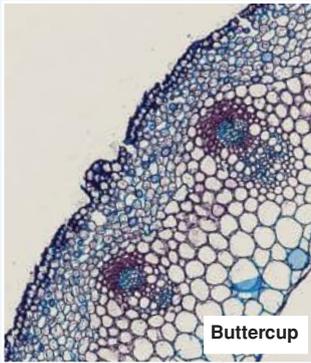
John Main, PLU

## Dicot root structure

The primary tissues of a dicot root are simple in structure. The large cortex is made up of parenchyma (packing) cells, which store starch and other substances. The air spaces between the cells are essential for aeration of the root tissue, which is non-photosynthetic. The vascular tissue, xylem (**X**) and phloem (**P**) forms a central cylinder through the root and is surrounded by the **pericycle**, a ring of cells from which lateral roots arise.



The primary xylem (**X**) of dicot roots forms a star shape in the centre of the vascular cylinder with usually 3 or 4 points. The phloem (**P**) is located between the regions of xylem tissue. The endodermis (**E**) regulates the flow of water into the root.



Buttercup

In plants with photosynthetic stems, CO<sub>2</sub> enters the stem through stomata in the epidermis. The air spaces in the cortex are more typical of leaf mesophyll than stem cortex.



Strawberry plants send out runners. These are above-ground, trailing stems that form roots at their nodes. The plant uses this mechanism to spread vegetatively over a wide area.



FCN

Root hairs are located just behind the region of cell elongation in the root tip. The root tip is covered by a slimy root cap. This protects the dividing cells of the tip and lubricates root movement.



The roots and their associated root hairs provide a very large surface area for the uptake of water and ions, as shown in this photograph of the roots of a hydroponically grown plant.

1. Use the information provided to identify the structures **A-G** in the photograph of the dicot stem on the previous page:

- (a) A: \_\_\_\_\_
- (b) B: \_\_\_\_\_
- (c) C: \_\_\_\_\_
- (d) D: \_\_\_\_\_

- (e) E: \_\_\_\_\_
- (f) F: \_\_\_\_\_
- (g) G: \_\_\_\_\_

2. Describe a distinguishing feature of stem structure in dicots: \_\_\_\_\_

3. What is the role of the vascular cambium? \_\_\_\_\_

4. Describe three functions of roots: \_\_\_\_\_

5. Describe two distinguishing features of internal anatomy of a primary dicot root:

- (a) \_\_\_\_\_
- (b) \_\_\_\_\_

6. What is the role of the parenchyma cells of the root cortex? \_\_\_\_\_

7. What is the purpose of the root hairs? \_\_\_\_\_

8. Why is the root tip covered by a cap of cells? \_\_\_\_\_

**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?

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(b) What other cells are present in xylem tissue and what are their roles?

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2. (a) How does water pass between vessels?

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(b) How does water pass between tracheids:

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(c) Which cell type do you think provides the most rapid transport of water and why?

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(d) Why do you think the tracheids and vessel elements have/need secondary thickening?

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3. How can xylem vessels and tracheids be dead when mature and functional?

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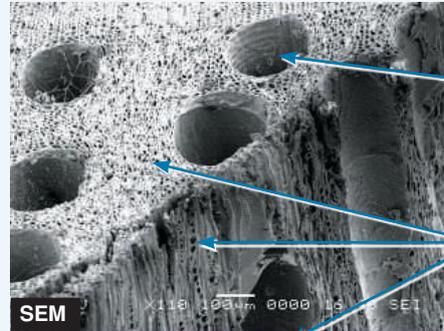
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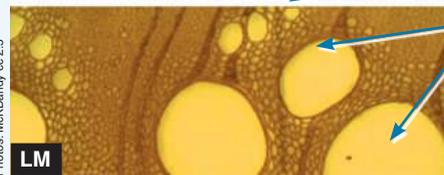


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Water moves through the continuous tubes made by the vessel elements of the xylem.

Smaller tracheids are connected by pits in the walls but do not have end wall perforations.

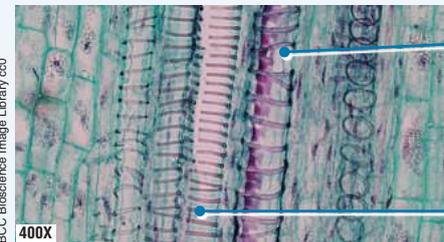


Vessels

Xylem is dead when mature. Note how the cells have lost their cytoplasm.

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.



The xylem cells form continuous tubes through which water is conducted.

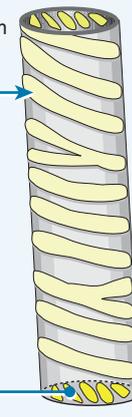
Spiral thickening of **lignin** around the walls of the vessel elements give extra strength and rigidity.

BCC Bioscience Image Library cco

**Vessel element**

Diameter up to 500 µm  
Secondary walls of cellulose are laid down after the cell has elongated or enlarged and lignin is deposited to add strength. This thickening is a feature of tracheids and vessels.

Vessels connect end to end. The end walls of the vessels are perforated to allow rapid water transport.



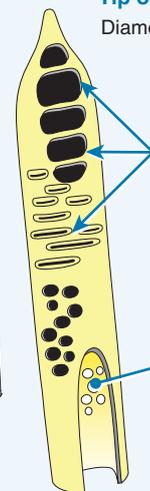
**Tip of tracheid**

Diameter ~80 µm

Pits and bordered pits allow transfer of water between cells but there are no end wall perforations.

No cytoplasm or nucleus in mature cell.

Tracheids are longer and thinner than vessels.



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.



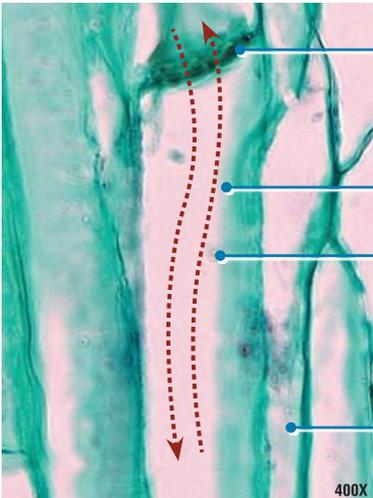
# 101 Phloem

**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.

## Longitudinal section through a sieve tube end plate



### Sieve tube end plate

Tiny holes (arrowed in the photograph below) perforate the sieve tube elements allowing the sugar solution to pass through.

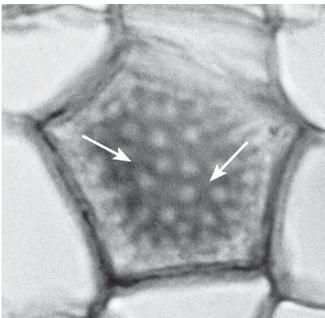
*Sugar solution flows in both directions*

The sieve tube elements (also called sieve tube members) lose most of their organelles but are still alive when mature.

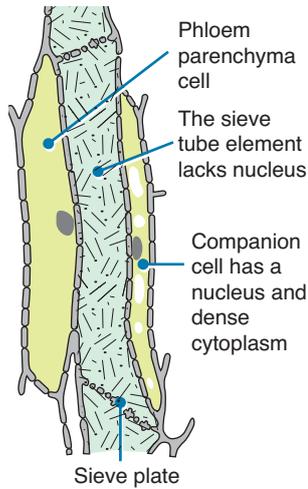
### Companion cell

A cell next to the sieve tube member, responsible for keeping it alive.

## Transverse section through a sieve tube end plate



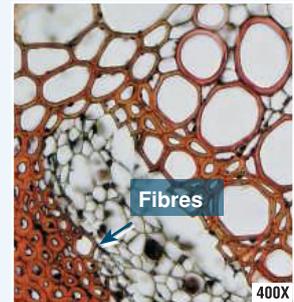
Adjacent sieve tube elements are connected through **sieve plates** through which phloem sap flows.



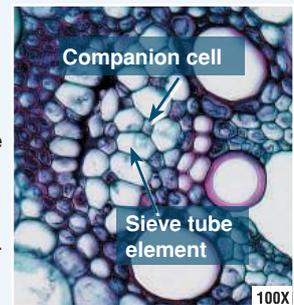
## The structure of phloem tissue

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.

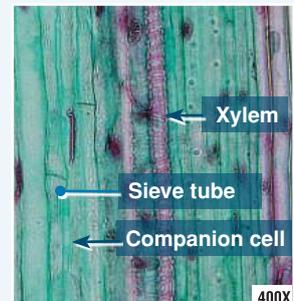
**Fibres** are associated with phloem as they are in xylem. Here they are seen in cross section where you can see the extremely thick cell walls and the way the fibres are clustered in groups.



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.



- (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: \_\_\_\_\_
- 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? \_\_\_\_\_
- What is the role of fibres and sclereids in phloem? \_\_\_\_\_
- What are the large open cells next to the phloem in the centre photo above right? \_\_\_\_\_

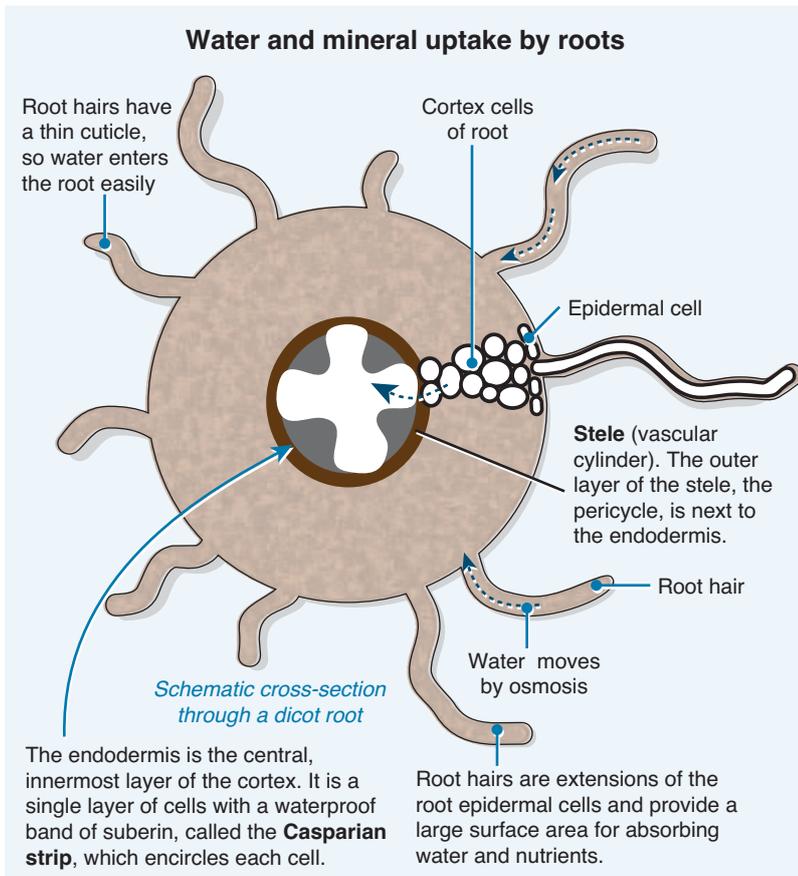


# 102 Uptake at the Root

**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.



1. (a) What two mechanisms do plants use to absorb nutrients?

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(b) Describe the two main pathways by which water moves through a plant:

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2. Plants take up water constantly to compensate for losses due to transpiration. Describe a benefit of a large water uptake:

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3. (a) How does the Casparian strip affect the route water takes into the stele?

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(b) Why might this feature be an advantage in terms of selective mineral uptake?

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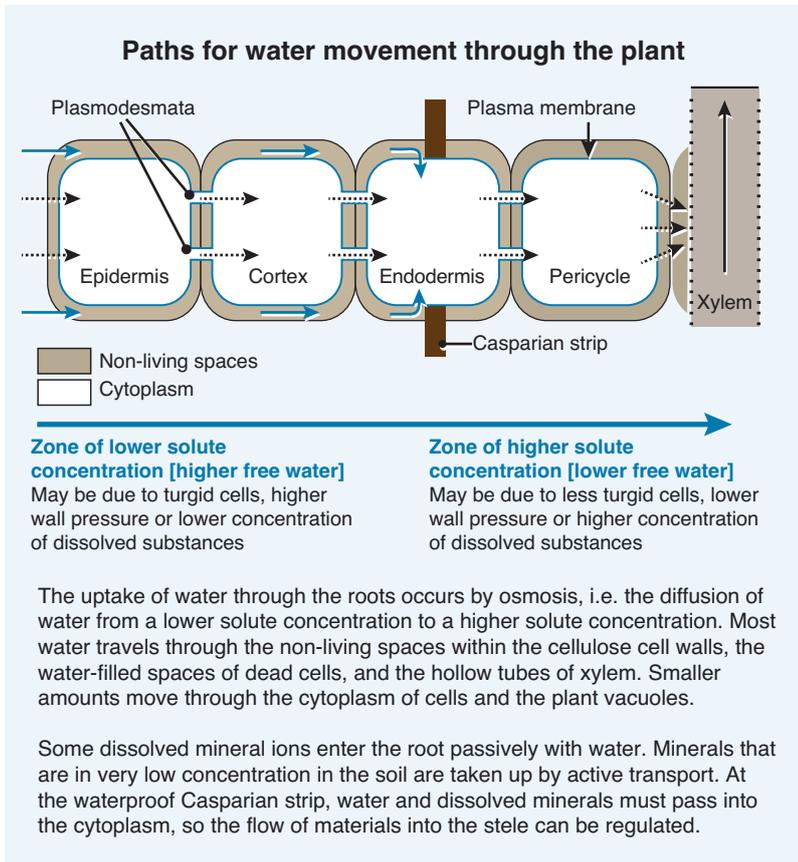
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# 103 Transpiration

**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 a

gradient in solute concentration that increases 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.

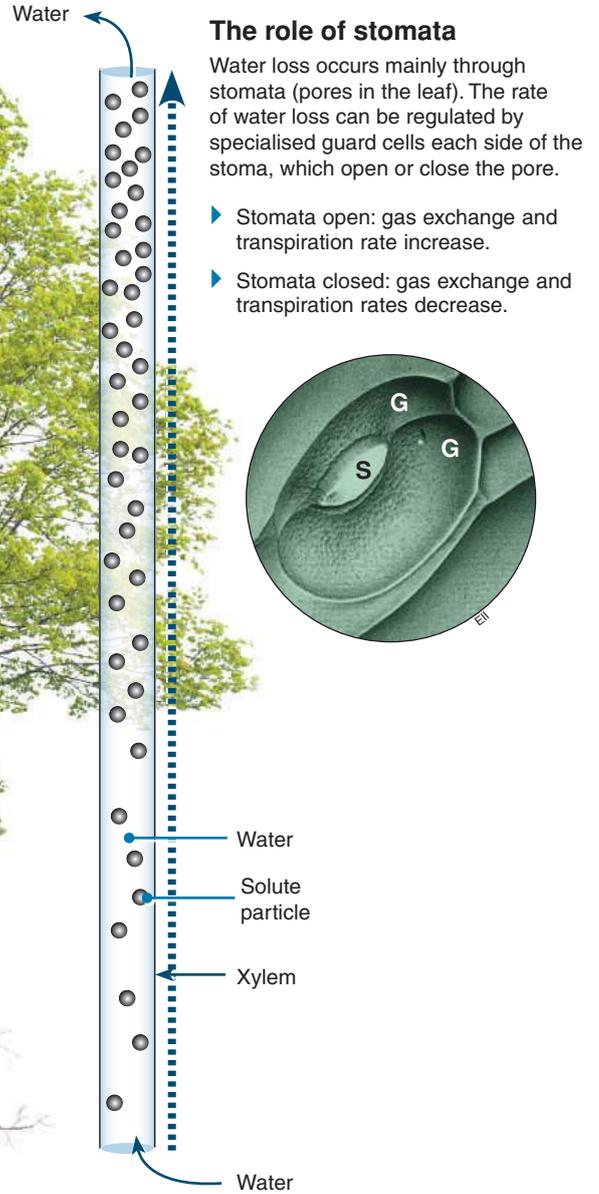
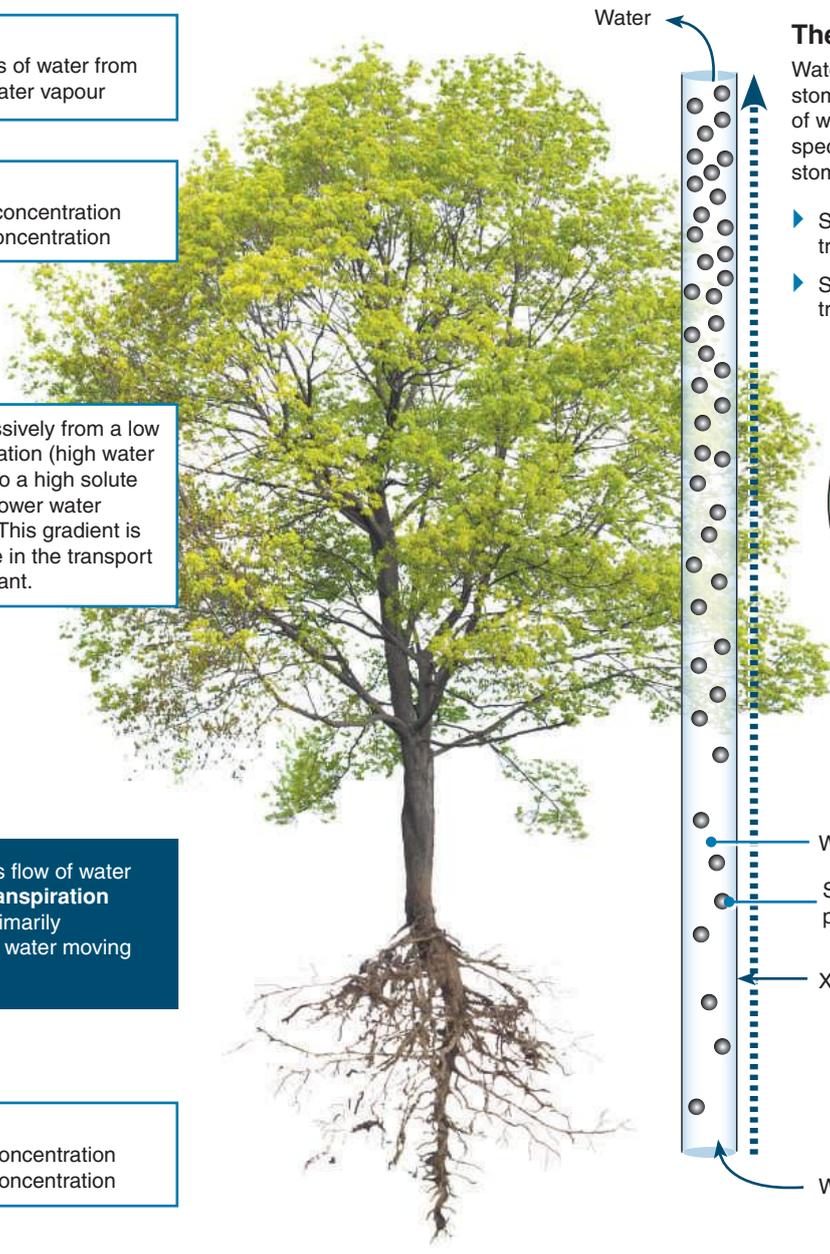
**Air**  
Evaporative loss of water from the leaves as water vapour

**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



- (a) What is transpiration? \_\_\_\_\_

\_\_\_\_\_

(b) Describe one benefit of the transpiration stream for a plant: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- How does the plant regulate the amount of water lost from the leaves? \_\_\_\_\_

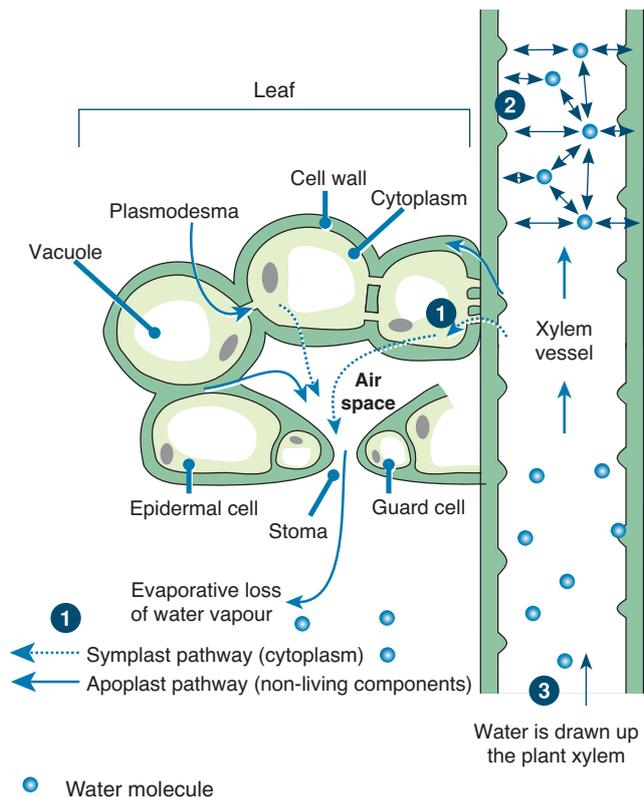
\_\_\_\_\_

**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?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 104 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.



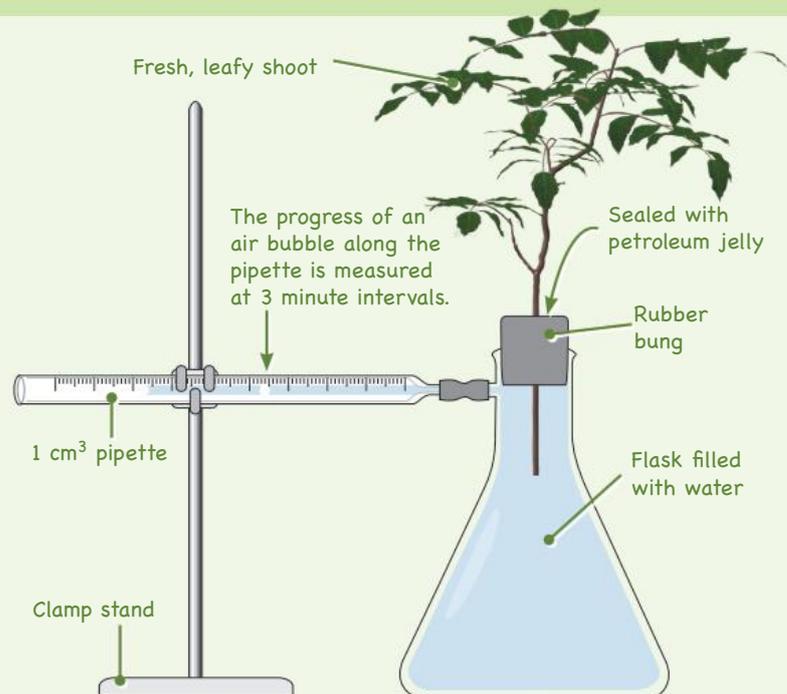
A potometer attached to a data logger

Prisco

## Investigation 6.2 Investigating factors affecting transpiration

See appendix for equipment list.

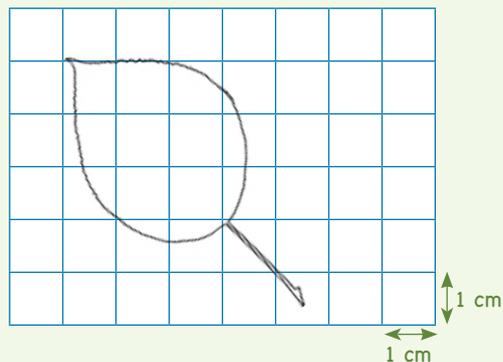
1. Four different conditions that influence transpiration will be tested: room conditions (ambient), wind, bright light, and high humidity.
2. Before starting, your teacher will decide if your group is to test one of these conditions (and which one) and pool class data for all four.
3. Set up the potometer\* and plant as in the diagram (right). It is best if the plant leaves used are large and few (4–6 leaves) rather than small and many. Alternatively the plant can be 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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A-2

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<sup>2</sup>).
  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/cm<sup>2</sup> can be calculate for each time recording and record in Table 2.
- \* A potometer with a data logger attached can be used to improve accuracy of readings.



**Table 1. Potometer readings (in mL water loss)**

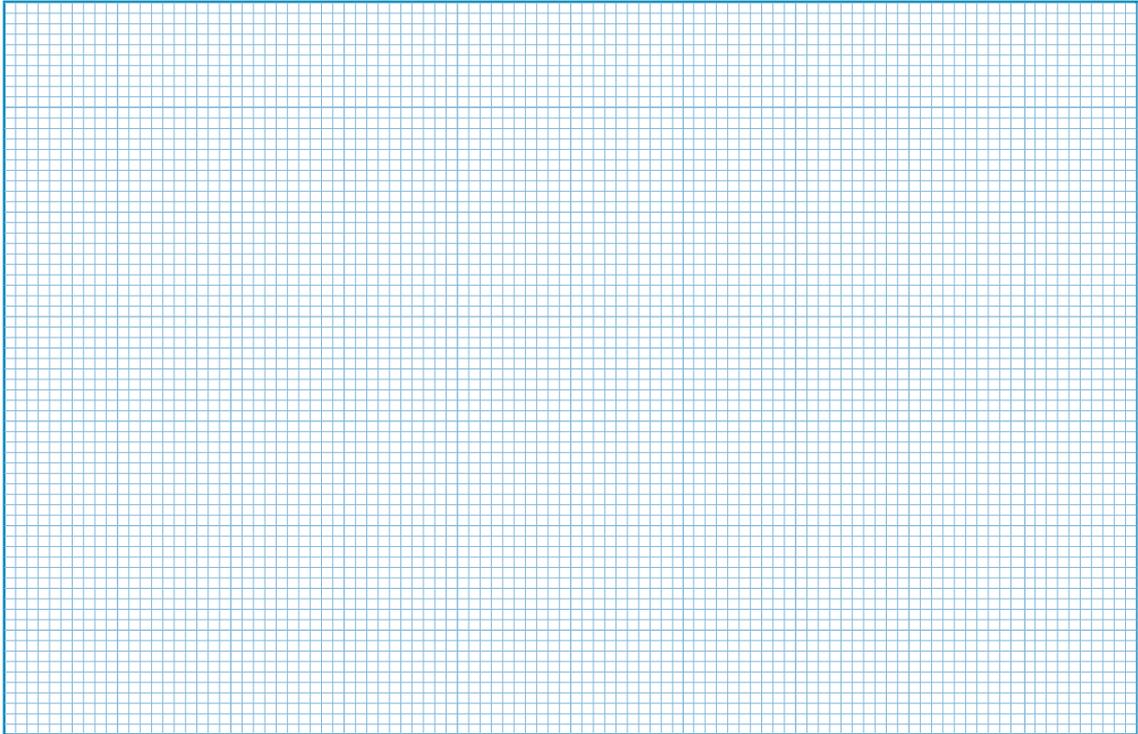
Time (min) \ Treatment	0	3	6	9	12	15	18	21	24	27	30
Ambient											
Wind											
High humidity											
Bright light											

**Table 2. Potometer readings in mL per cm<sup>2</sup>**

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?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

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? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

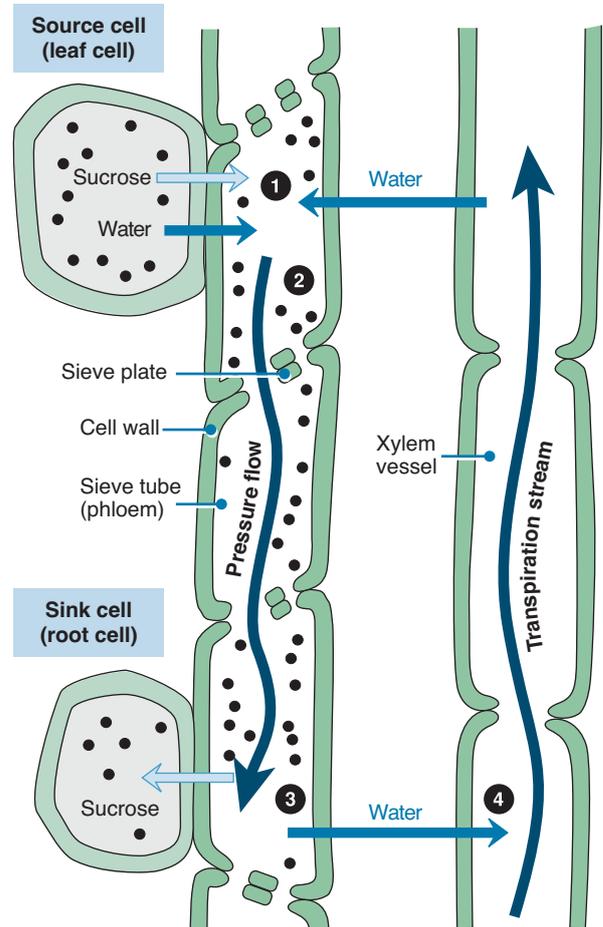
**Key Idea:** Phloem transports the organic products of photosynthesis (sugars) through the plant by translocation. In vascular plants, the products of photosynthesis move as phloem sap. Apart from water, phloem sap contains mainly sucrose (up to 30%). It may also contain minerals, hormones, and amino 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 known 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.



Source: Modified after Campbell Biology 1993



**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.

1. (a) From what you know about osmosis, explain why water follows the sugar as it moves through the phloem:
 

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- (b) What is meant by 'source to sink' flow in phloem transport?
 

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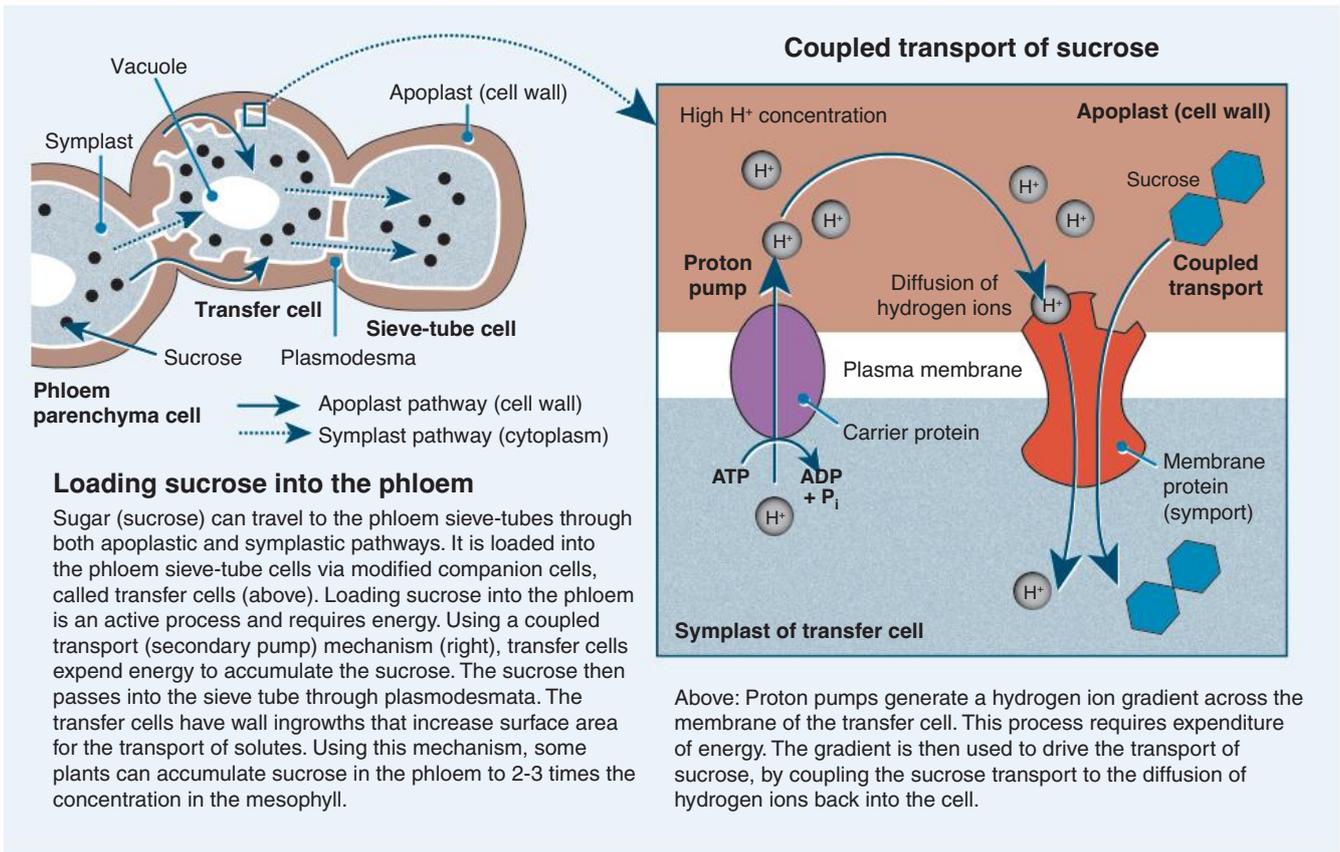
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2. Why does a plant need to move food around, particularly from the leaves to other regions?
 

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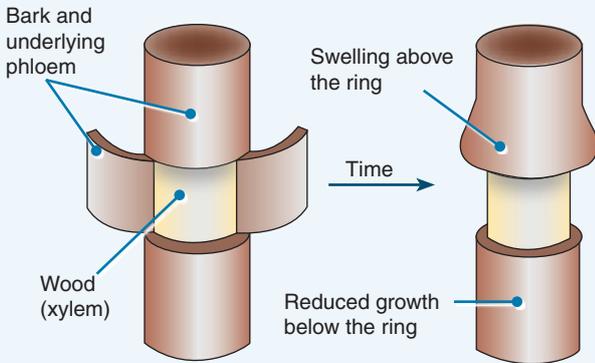
3. In your own words, describe what is meant by the following:
  - (a) Translocation: \_\_\_\_\_
  - \_\_\_\_\_
  - (b) Pressure-flow movement of phloem: \_\_\_\_\_
  - \_\_\_\_\_
  - (c) Coupled transport of sucrose: \_\_\_\_\_
  - \_\_\_\_\_
4. Briefly explain how sucrose is transported into the phloem: \_\_\_\_\_
- \_\_\_\_\_
5. Explain the role of the companion (transfer) cell in the loading of sucrose into the phloem: \_\_\_\_\_
- \_\_\_\_\_
6. (a) What does the flow of phloem sap from a severed aphid stylet indicate? \_\_\_\_\_
- \_\_\_\_\_
- (b) Where would you expect the flow rate to be greatest and why? \_\_\_\_\_
- \_\_\_\_\_
- (c) Why do you think aphid stylets are particularly useful for studying the rate of flow in phloem? \_\_\_\_\_
- \_\_\_\_\_

**Key Idea:** The mass flow hypothesis is supported by experiments involving ringing and autoradiographs. The transport of materials including sugars through the

phloem has been established by a number of experiments which include using radioactively labelled atoms and severing the phloem tissue by ring barking a plant.

### Ringing

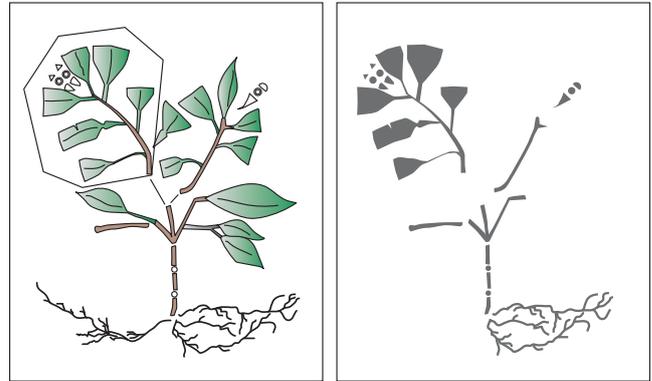
A classic experiment in studying the flow of phloem sap is the removal of a ring of bark from the plant along with the underlying phloem. The experiment is described below:



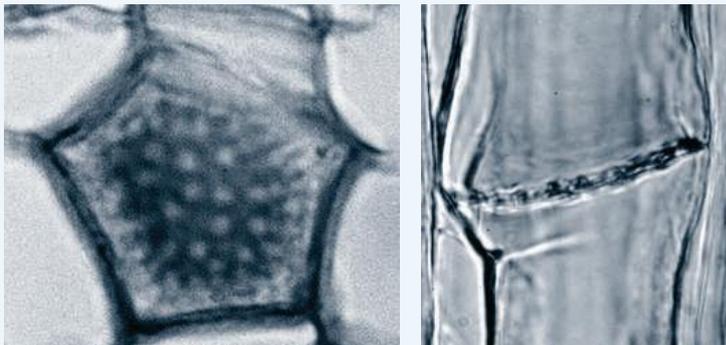
Sap (from the phloem) oozes out of the wound above the ring showing the phloem is under pressure. Growth continues above the ring but is impeded below it, and leaves are unaffected, showing phloem originates in the leaves and moves down the plant.

### Tracers

The radioactive carbon isotope  $^{14}\text{C}$  has been used to investigate the site of sugar manufacture and transport.  $^{14}\text{C}$  labelled  $\text{CO}_2$  was supplied to one leaf of a plant for 20 minutes (left box). The plant was then used to make an autoradiograph on X-ray film and the location of  $^{14}\text{C}$  noted (right box).



The autoradiograph shows evidence for translocation. Sugars are manufactured in the leaves and transported throughout the plant, including the stem, roots, and fruit.



Photos RCN

Phloem sieve plate in TS and LS. The sieve plate is an apparent barrier to mass flow.

### Mass flow hypothesis doesn't explain everything

Flow of material through the phloem appears to be bidirectional, and sugars and amino acids move at different rates (mass flow cannot account for the transport of substances in different directions or at different rates). In addition, sieve plates in the phloem represent a barrier (a mechanical resistance) to flow, yet they have not been lost during plant evolution.

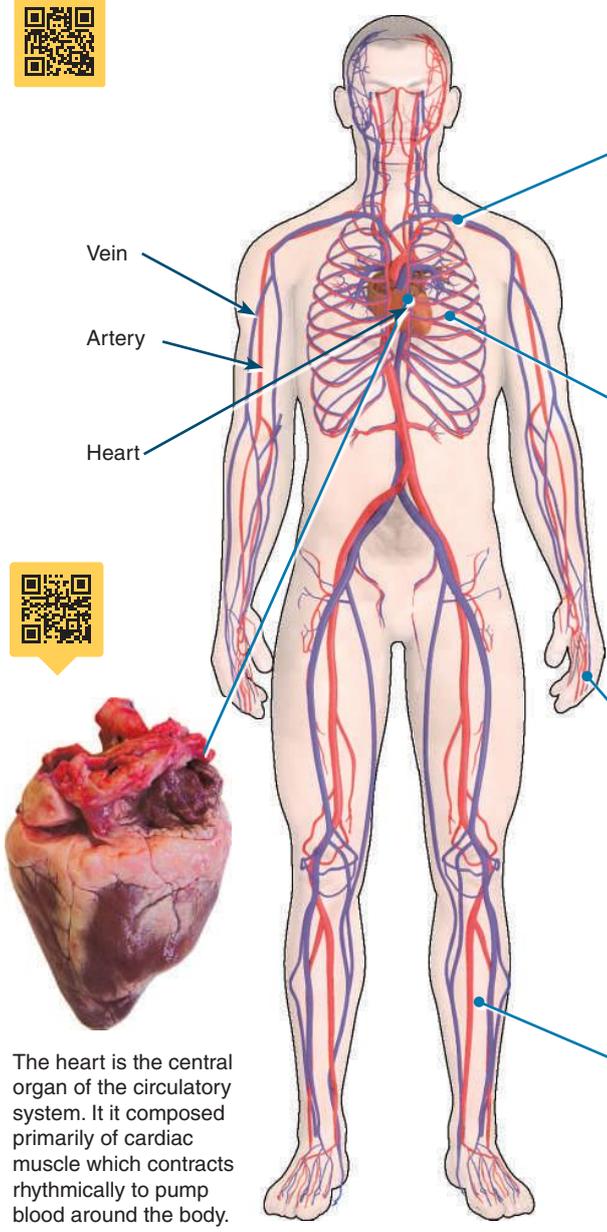
1. What does the ringing experiment show about the phloem and the material in it? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. What does the autoradiograph show about the movement of sugars? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. Why does the apparent bi-directional flow in the phloem provide a case against the mass flow hypothesis?  
 \_\_\_\_\_  
 \_\_\_\_\_
4. Suggest why the presence of the sieve plate is often cited as evidence against the mass flow hypothesis:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



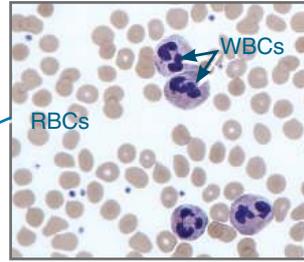
# 107 The Circulatory System

**Key Idea:** The circulatory system is responsible for the transport of nutrients, respiratory gases, and wastes in the blood to and from the body's cells via a network of vessels. The circulatory system comprises the heart, arteries, veins,

capillaries, and blood. The blood transports oxygen and nutrients to the cells, carbon dioxide to the lungs, and metabolic wastes to the kidneys. It is also moves cells of the immune system (the white blood cells) about the body.



The heart is the central organ of the circulatory system. It is composed primarily of cardiac muscle which contracts rhythmically to pump blood around the body.



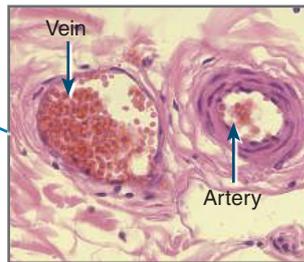
Red blood cells (RBCs) carry oxygen to the body's cells. The oxygen binds to the protein haemoglobin, which gives RBCs their colour. The larger white blood cells (WBCs) or leucocytes are part of the immune system and also circulate in the blood.



Blood is a liquid tissue. Blood cells are suspended in a watery material called plasma, which carries dissolved materials, e.g. blood proteins, electrolytes (salts) and nitrogenous waste.



Blood moves through blood vessels, the smallest of which are the capillaries. These are only one cell thick, allowing oxygen and other molecules to easily move out of or into the blood from the cells of the body's tissues.



Blood is transported away from the heart in arteries, blood vessels with thick walls of elastic connective tissue and smooth muscle. Blood returns to the heart in veins, which have thinner walls but a larger lumen (inside space).

1. Name three components of the circulatory system and state their function:

- (a) \_\_\_\_\_
- \_\_\_\_\_
- (b) \_\_\_\_\_
- \_\_\_\_\_
- (c) \_\_\_\_\_
- \_\_\_\_\_

2. (a) Which component of the blood carries oxygen to the body's cells? \_\_\_\_\_

(b) Which component of the blood carries metabolic wastes to the kidneys? \_\_\_\_\_

**Key Idea:** Blood transports nutrients, wastes, hormones, and respiratory gases around the body.

Blood is a complex connective tissue made up of cellular components suspended in a matrix of liquid plasma. It makes up about 8% of body weight. If a blood sample is taken, the cells can be separated from the plasma by centrifugation. The cells (formed elements) settle as a dense red pellet below the transparent, straw-coloured

plasma. Blood performs many functions. It transports nutrients, respiratory gases, hormones, and wastes and has a role in thermoregulation through the distribution of heat. Blood also defends against infection and its ability to clot protects against blood loss. The examination of blood is also useful in diagnosing disease because the cellular components of blood are normally present in specified ratios. Deviations from these ratios may indicate disease.

## Mammalian blood

### CELLULAR COMPONENTS

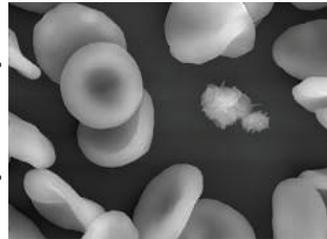
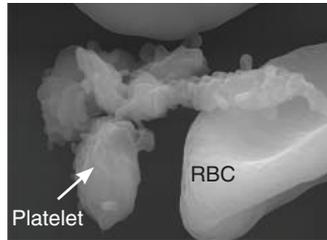
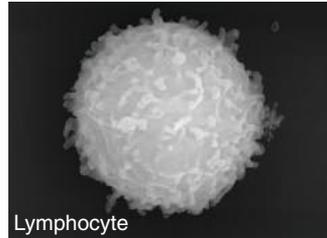
The cellular (or formed) elements of blood float in the plasma and make up 40-50% of the total blood volume.

White blood cells and platelets make up 2-3% of the total blood volume.

White blood cells are involved in internal defence. Lymphocytes are important in immunity and make up 24% of the white cell count.

Platelets are small, membrane-bound cell fragments with a role in blood clotting.

Red blood cells (RBCs) account for 38-48% of total blood volume. RBCs transport oxygen (carried bound to haemoglobin) and a small amount of carbon dioxide. Unlike other blood cells, RBCs have no nucleus and lack most organelles. They are packed full of haemoglobin protein.

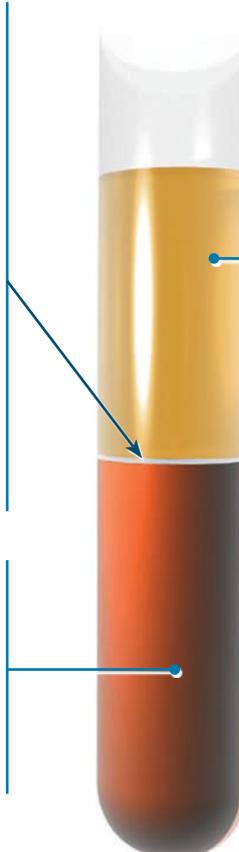


### NON-CELLULAR COMPONENTS

The non-cellular part of the blood is the plasma, a watery matrix making up 50-60% of blood volume. Most of the blood is water. It transports dissolved substances, provides cells with water, distributes heat, and maintains blood volume. Most of the plasma is water, but it also contains dissolved proteins, glucose, amino acids, vitamins, minerals, urea, uric acid, CO<sub>2</sub>, hormones, and antibodies.



Blood plasma



1. Describe one feature distinguishing red and white blood cells in mammalian blood: \_\_\_\_\_

\_\_\_\_\_

2. Describe two functions of the blood plasma: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. What is the function of platelets in the blood? \_\_\_\_\_

\_\_\_\_\_

4. Explain why the blood can be called a "liquid tissue": \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

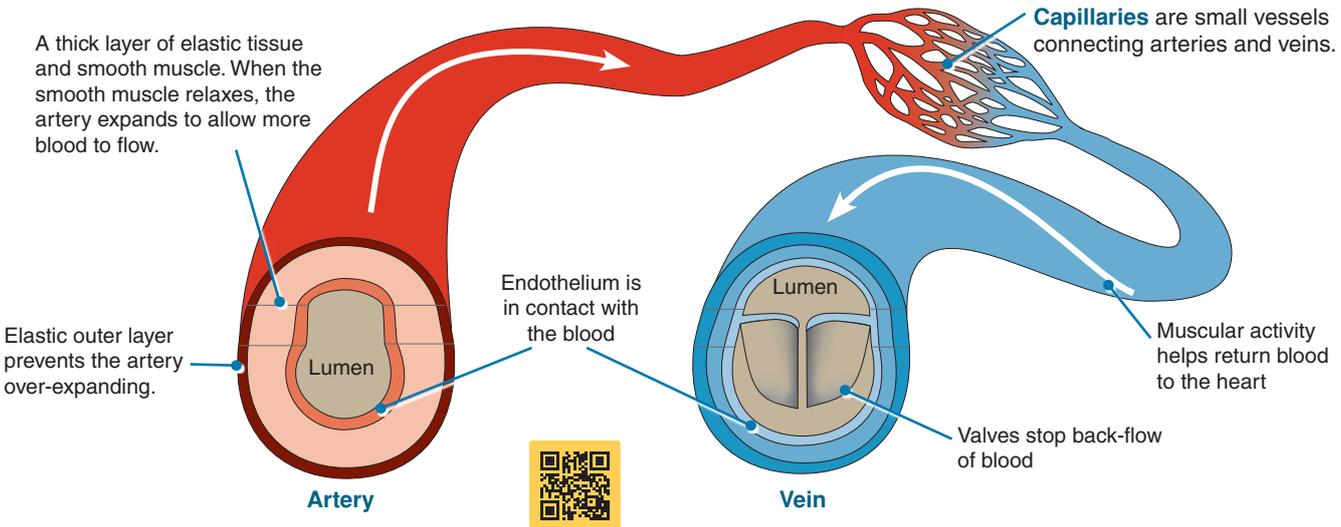


# 109 Blood Vessels

**Key Idea:** The blood vessels of the circulatory system connect the body's cells to the organs that exchange gases, absorb nutrients, and dispose of wastes.

In vertebrates, **arteries** are the blood vessels that carry blood away from the heart to the capillaries within the tissues. The large arteries that leave the heart divide into medium-sized (distributing) arteries. Within the tissues and organs, these distributing arteries branch to form **arterioles**, which deliver blood to capillaries. Blood flow to the tissues is altered by contraction (**vasoconstriction**) or relaxation (**vasodilation**)

of the blood vessel walls. Vasoconstriction increases blood pressure whereas vasodilation has the opposite effect. **Veins** are the blood vessels that return blood to the heart from the tissues. The smallest veins (**venules**) return blood from the capillaries to the veins. Veins and their branches contain about 59% of the blood in the body. The structural differences between veins and arteries are mainly associated with differences in the relative thickness of the vessel layers and the diameter of the lumen (space within the vessel). These, in turn, are related to the vessel's functional role.



### Arteries

Arteries have an elastic, stretchy structure that enables them to withstand and maintain the high pressure of blood being pumped from the heart. At the same time, their ability to contract (a feature of the central muscle layer) helps regulate blood flow and pressure.

Arteries nearer the heart have more elastic tissue to resist the higher pressures of the blood leaving the left ventricle. Arteries further from the heart have more muscle to help them maintain blood pressure. Between heartbeats, the elastic walls of the artery recoil, maintaining an even pressure despite the pulsing nature of blood flow.

### Veins

Veins are made up of the same three layers as arteries but they have less elastic and muscle tissue, a relatively thicker external layer, and a larger, less defined lumen.

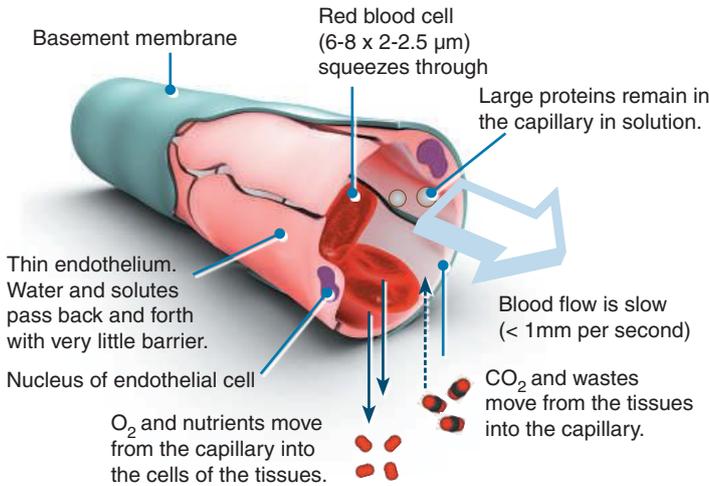
Although veins are less elastic than arteries, they can still expand enough to adapt to changes in the pressure and volume of the blood passing through them. Blood flowing in the veins has lost a lot of pressure because it has passed through the narrow capillaries. The lower pressure flow means that many veins, especially those in the limbs, have valves to prevent backflow of the blood as it returns to the heart.

1. What is the function of blood vessels? \_\_\_\_\_  
\_\_\_\_\_
2. Why do the artery walls need to be thick with a lot of elastic tissue? \_\_\_\_\_  
\_\_\_\_\_
3. What is the role of valves in assisting the veins to return blood back to the heart? \_\_\_\_\_  
\_\_\_\_\_
4. How do the structural differences between arteries and veins relate to their functional roles? \_\_\_\_\_  
\_\_\_\_\_

# 110 Capillaries and Capillary Networks

**Key Idea:** Capillaries are small, thin-walled vessels that allow the exchange of material between the blood and the tissues. In vertebrates, capillaries are very small vessels that connect arterial and venous circulation and allow efficient exchange

of nutrients and wastes between the blood and tissues. Capillaries form networks or beds and are abundant where metabolic rates are high. Fluid that leaks out of the capillaries has an essential role in bathing the tissues.



## Exchanges in capillaries

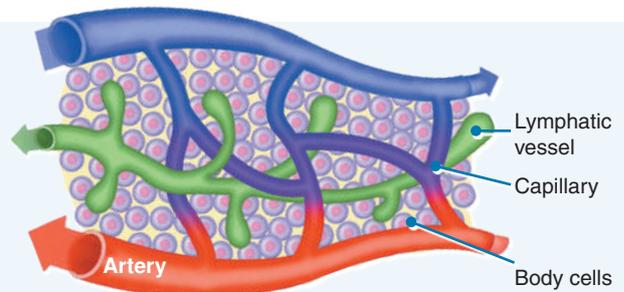
Blood passes from the arterioles into the capillaries where the exchange of materials between the body cells and the blood takes place. Capillaries have a diameter of just 5-10 μm. The only tissue present is an endothelium of squamous epithelial cells. Capillaries are so numerous that no cell is more than 25 μm from any capillary.

Blood pressure causes fluid to leak from capillaries through small gaps where the endothelial cells join. This fluid bathes the tissues, supplying nutrients and oxygen, and removing wastes (left).

The density of capillaries in a tissue is an indication of that tissue's metabolic activity. For example, cardiac muscle has a high demand for blood flow and is well supplied with capillaries. Smooth muscle is far less active than cardiac muscle and does not need such an extensive blood supply.

## Comparing blood, tissue fluid, and lymph

	Blood	Tissue fluid	Lymph
<b>Cells</b>	Red blood cells, white blood cells, platelets	Some white blood cells	White blood cells
<b>Proteins</b>	Hormones and plasma proteins	Some hormones and proteins	None
<b>Glucose</b>	High	None	Low
<b>Amino acids</b>	High	Used by body cells	Low
<b>Oxygen</b>	High	Used by body cells	Low
<b>Carbon dioxide</b>	Low	Produced by body cells	High



The fluid that leaks from the capillaries is called tissue fluid. Some of it returns to the blood at the venous end of the capillary bed, but some is drained by lymph vessels to form lymph.

- ▶ Blood transports nutrients, wastes, and respiratory gases to and from the tissues.
- ▶ Tissue fluid facilitates the transport of these between the blood and the tissues.
- ▶ Lymph drains excess tissue fluid and returns it to the general circulation. It has a role in the immune system.

1. What is the role of capillaries? \_\_\_\_\_  
\_\_\_\_\_
2. (a) Describe the structure of a capillary: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
  - (b) Explain how the structure and position of capillaries (relative to the body's cells) is important in allowing the exchange of materials: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



▶ The flow of blood through a capillary bed is called **microcirculation**. In most parts of the body, there are two types of vessels in a capillary bed: the true capillaries, where exchanges take place, and a vessel called a vascular shunt, which connects the arteriole and venule at either end of the bed. The shunt diverts blood past the true capillaries when the metabolic demands of the tissue are low. When tissue activity increases, the entire network fills with blood.

3. Describe the structure of a capillary network:

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4. Explain the role of the smooth muscle sphincters and the vascular shunt in a capillary network:

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5. (a) Describe a situation where the capillary bed would be in the condition labeled **A**:

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(b) Describe a situation where the capillary bed would be in the condition labeled **B**:

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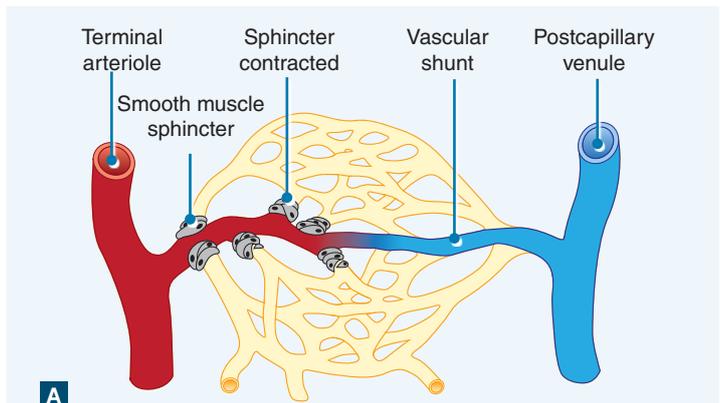
6. On the photograph right, identify:

A: \_\_\_\_\_

B: \_\_\_\_\_

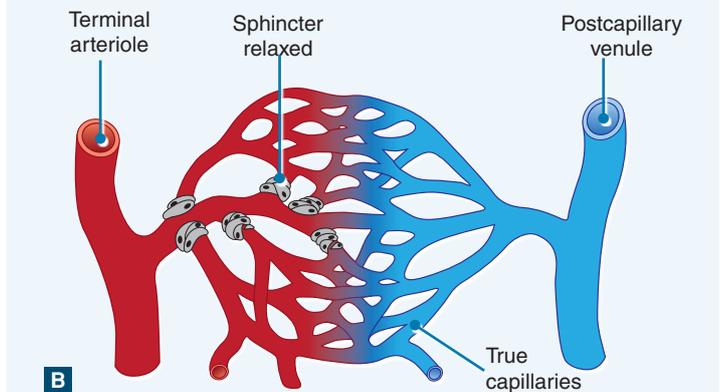
C: \_\_\_\_\_

D: \_\_\_\_\_



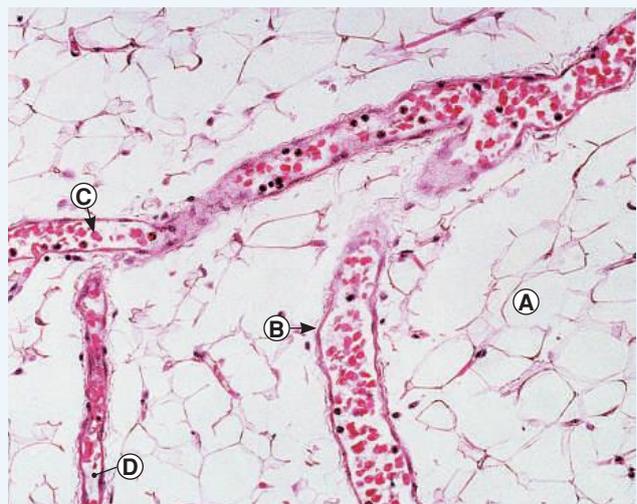
**A**

When the sphincters contract (close), blood is diverted via the vascular shunt to the postcapillary venule, bypassing the exchange capillaries.



**B**

When the sphincters are relaxed (open), blood flows through the entire capillary bed allowing exchanges with the cells of the surrounding tissue.



Capillaries supply all the tissues of the body, creating extensive networks to supply cells with the nutrients and oxygen they need and remove carbon dioxide and other metabolic wastes. This capillary is moving through fat tissue.

# 111 Structure of the Mammalian Heart

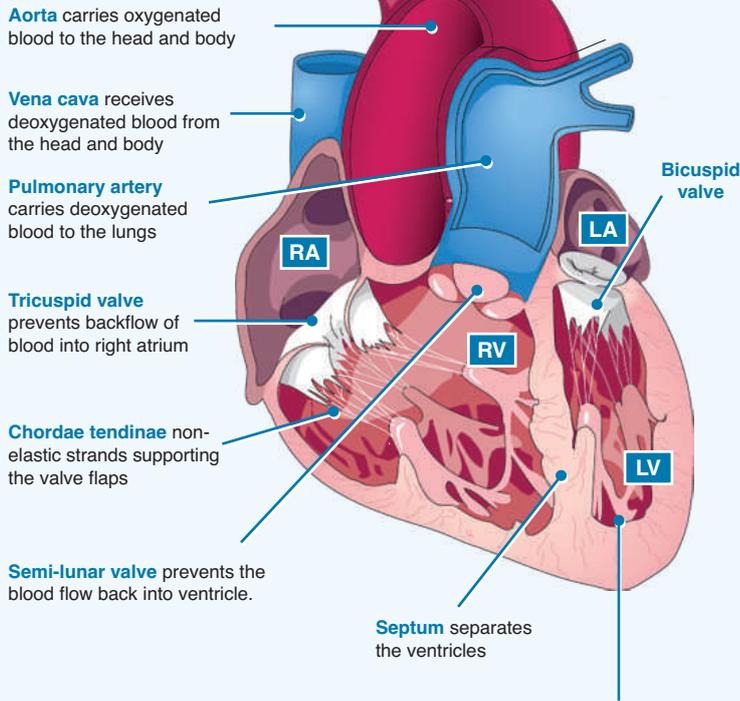
**Key Idea:** Humans have a four chambered heart divided into left and right halves. It acts as a double pump.

The heart is the centre of the human cardiovascular system. It is a hollow, muscular organ made up of four chambers (two **atria** and two **ventricles**) that alternately fill and empty of blood, acting as a double pump. The left side (systemic

circuit) pumps blood to the body tissues and the right side (pulmonary circuit) pumps blood to the lungs. The heart lies between the lungs, to the left of the midline, and is surrounded by a double layered pericardium of connective tissue, which prevents over distension of the heart and anchors it within the central compartment of the thoracic cavity.

## Human heart structure

(sectioned, anterior view)

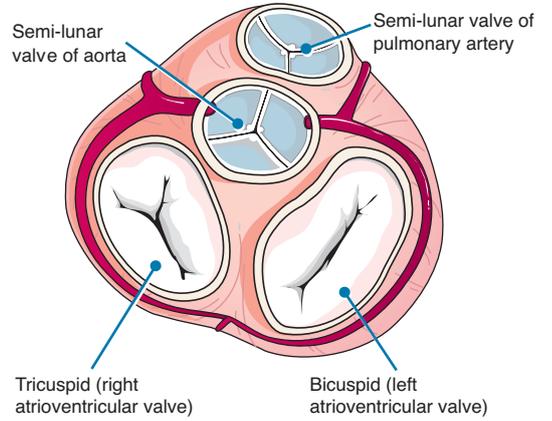


The heart is not a symmetrical organ. Although the quantity of blood pumped by each side is the same, the walls of the left ventricle are thicker and more muscular than those of the right ventricle. The difference affects the shape of the ventricular cavities, so the right ventricle is twisted over the left.

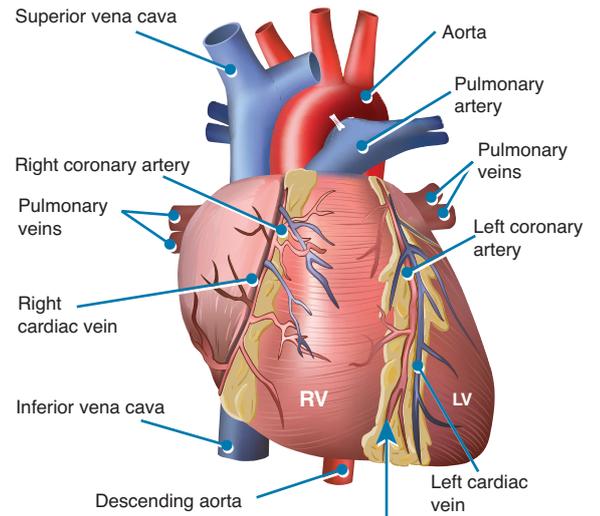
### Key to abbreviations

- RA** Right atrium: receives deoxygenated blood via the anterior and posterior vena cava
- RV** Right ventricle: pumps deoxygenated blood to the lungs via the pulmonary artery
- LA** Left atrium: receives blood returning to the heart from the lungs via the pulmonary veins
- LV** Left ventricle: pumps oxygenated blood to the head and body via the aorta

## Top view of a heart in section, showing valves

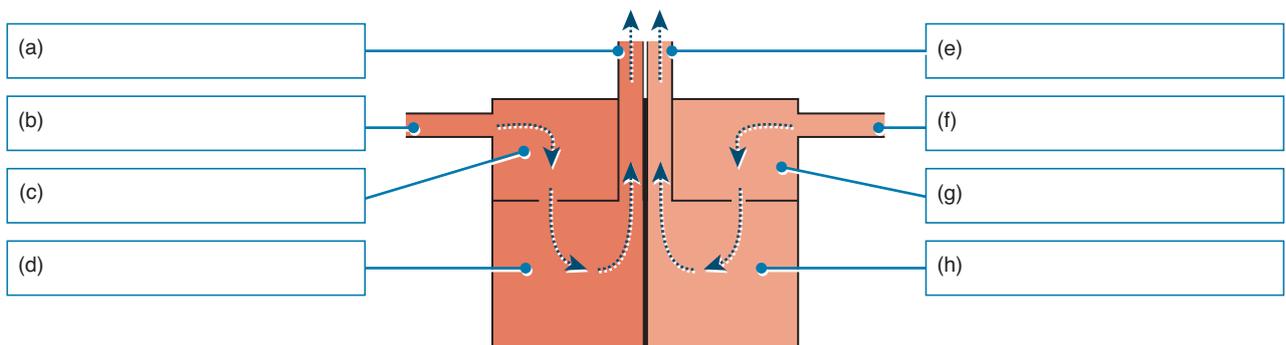


## Anterior view of heart to show coronary arteries



**Coronary arteries:** The high oxygen demands of the heart muscle are met by a dense capillary network. Coronary arteries arise from the aorta and spread over the surface of the heart supplying the cardiac muscle with oxygenated blood. Deoxygenated blood is collected by cardiac veins and returned to the right atrium via a large coronary sinus.

- In the schematic diagram of the heart, below, label the four chambers and the main vessels entering and leaving them. The arrows indicate the direction of blood flow. Use large coloured circles to mark the position of each of the four valves.



# 112 Changes in the Blood

**Key Idea:** Materials are transferred into and out of the blood as it moves around the body.

The heart pumps blood through arteries and capillaries that lead to the organs and tissues of the body. The organs add or remove materials from the blood modifying the concentrations of various transported materials such as glucose, oxygen, and carbon dioxide. Each organ changes the blood in some way. These are shown below.



**Muscles and tissues:**  
Remove oxygen and glucose from the blood.  
Add carbon dioxide and metabolic wastes.

**Lungs:**  
Adds oxygen to the blood and removes carbon dioxide.

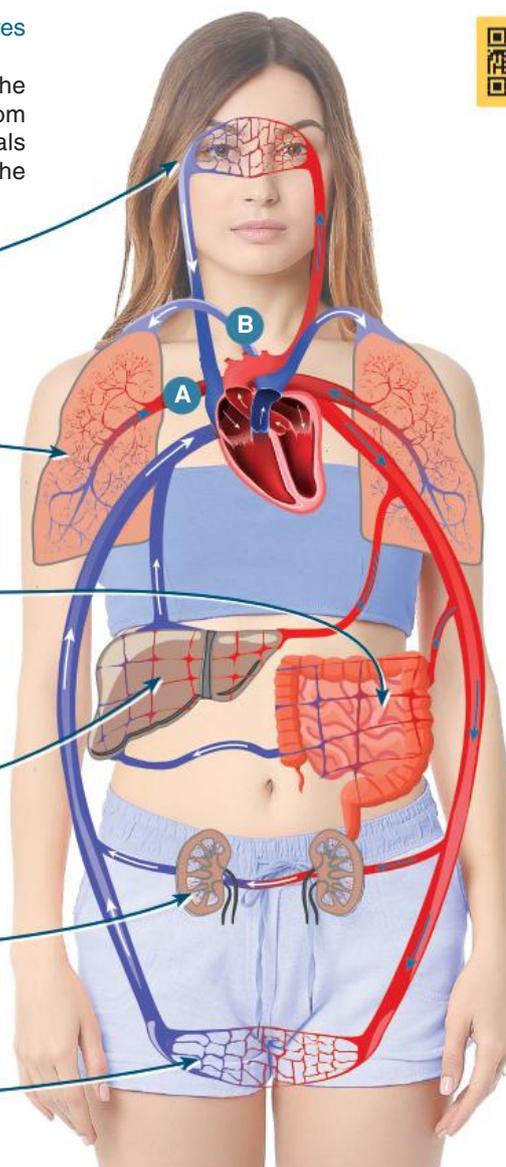
**Stomach and small intestines:**  
Adds nutrients to the blood, including glucose and amino acids.

**Large intestines:**  
Adds water, salts, vitamins.

**Liver:**  
Removes or adds glucose, adds urea (from breakdown of proteins). Removes many products of digestion, breaks them down and returns useful products to the blood.

**Kidneys:**  
Filter the blood. Remove nitrogenous wastes (e.g. urea), excess salt and water from the blood.

**Muscles and tissues:**  
Remove oxygen and glucose to the blood.  
Add carbon dioxide and metabolic wastes.



1. Complete the table to show the important changes each organ makes to the blood:

Organ	Adds	Removes
Muscles		
Stomach and small intestine		
Large intestine		
Kidneys		
Liver		
Lungs		

2. Describe the levels of oxygen and carbon dioxide in the blood at points **A** and **B** in the diagram above and explain why they are at that level:

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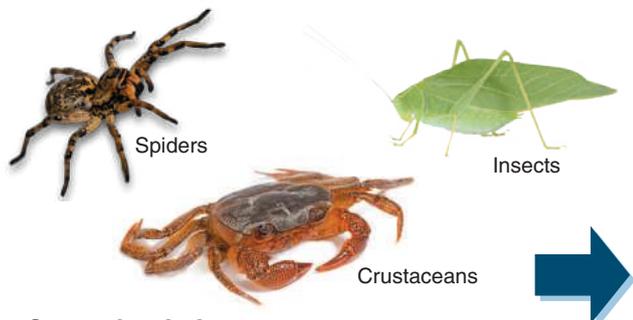
# 113 Open Circulatory Systems

**Key Idea:** In open circulatory systems, the haemolymph circulates in the body cavity, not enclosed in vessels.

The circulatory systems of animals may be open or closed.

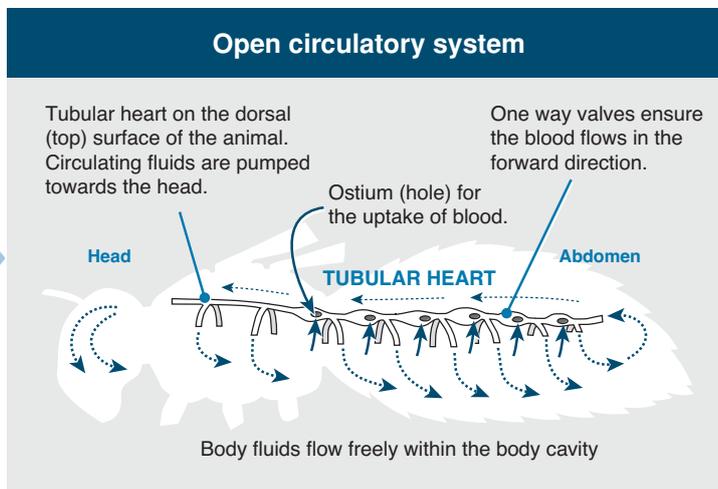
**Open circulatory systems**, in which the body fluid circulates freely in the body cavity, are typical of most invertebrates. Insects, unlike most other arthropods, do not use the circulatory system to transport oxygen, which is delivered

directly to the tissues via a system of tracheal tubes. In addition to its usual transport functions, the circulatory system may also be important in hydraulic movements of the whole body (e.g. many molluscs) or its parts (e.g. butterflies expand the wings after moulting). Haemolymph is a blood like substance found in all invertebrates with open circulatory systems.



## Open circulation systems

Arthropods and molluscs (except cephalopods) have open circulatory systems in which the blood is pumped by a tubular, or sac-like, heart through short vessels into large spaces in the body cavity. The blood bathes the cells before reentering the heart through holes (**ostia**). Muscle action may assist the circulation of the blood.



The circulatory system of crabs is best described as incompletely closed. The thoracic heart has three pairs of ostia and a number of arteries, which leave the heart and branch extensively to supply various organs before draining into discrete channel-like sinuses.



In spiders, arteries from the dorsal heart empty the haemolymph into tissue spaces and then into a large ventral sinus that bathes the book lungs where gas exchange takes place. Venous channels conduct the haemolymph back to the heart.



The haemolymph occupies up to 40% of the body mass of an insect and is usually under low pressure due its lack of confinement in vessels. The circulation of the haemolymph is aided by body movements such as the ventilating movements of the abdomen.

- How does an open circulatory system move fluid (haemolymph) about the body? \_\_\_\_\_  
\_\_\_\_\_
- Describe one disadvantage of an open circulatory system: \_\_\_\_\_  
\_\_\_\_\_
- Compare insects and decapod crustaceans (e.g. crabs) in the degree to which the circulatory system is closed:  
\_\_\_\_\_  
\_\_\_\_\_
- (a) Why is the crab's circulatory system usually described as an open system? \_\_\_\_\_  
\_\_\_\_\_  
(b) In what way is this description not entirely accurate? \_\_\_\_\_  
\_\_\_\_\_

# 114 Closed Circulatory Systems

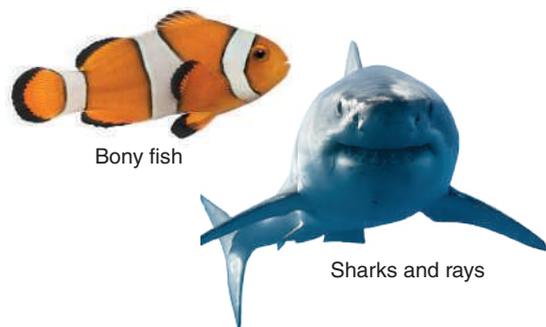
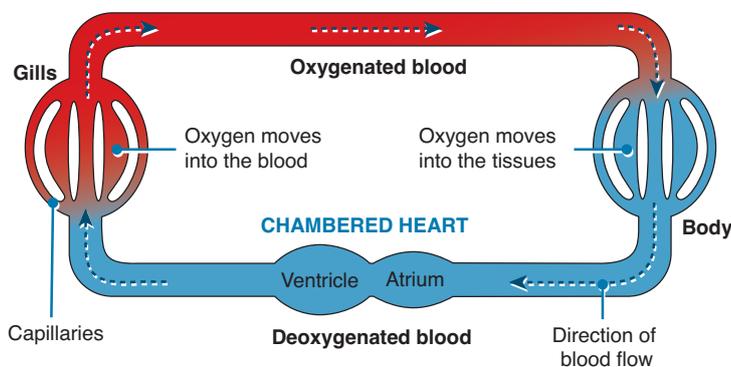
**Key Idea:** Closed circulatory systems occur as single or double circuit systems. The single circuit system of fish operates at lower pressure than the double circuit system of mammals.

All vertebrates have closed circulatory systems in which the body's blood flows entirely within blood vessels. Exchanges between the blood and tissues occur by diffusion across thin capillary walls. In fish, blood moves in a single circuit, leaving the gills at low pressure to flow around the body

before returning to the heart. In all other vertebrates, there is a double circuit system and blood passes from the heart to the lungs (the pulmonary circuit), returning to the heart before being pumped to the body's tissues (the systemic circuit). This double pump system produces much higher pressure in the systemic circuit than in the pulmonary circuit, preventing fluid accumulation in the lungs and providing the pressure to supply the brain and maintain kidney filtration rates.

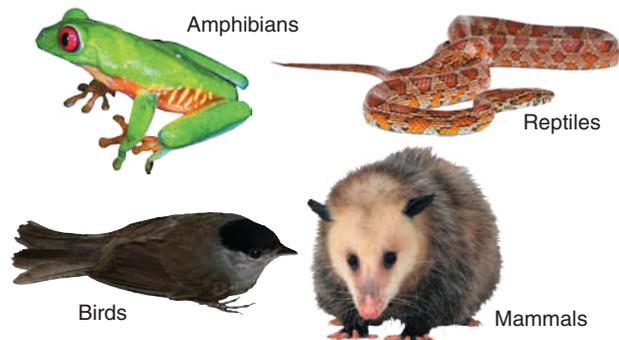
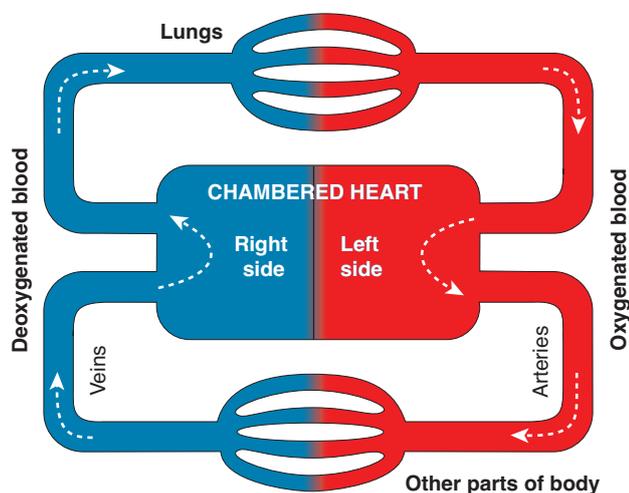
## Closed, single circulatory systems

- ▶ In the **single circulatory system** of fish, the blood is pumped from the heart to the gills, then directly to the body.
- ▶ The blood loses pressure at the gills and flows at low pressure around the body. The low pressure reduces blood flow through the body and thus reduces the rate of oxygen delivery to the body's cells. However most fish have relatively low metabolic rates and this system adequately meets their needs.
- ▶ Water has much lower oxygen content than air (about 12 parts per million maximum compared with 210,000 ppm in air). This limits the amount of oxygen fish can extract even with efficient gills. The low oxygen content in the water would not support a higher metabolic rate, but because most fish do not use metabolism to maintain body temperature (a large energy cost), a lower metabolic rate still allows a relatively active lifestyle.



## Closed, double circulatory systems

- ▶ Because oxygen is relatively abundant in the air, metabolic rates in air breathing animals can be relatively high (although they are not necessarily so). **Double circulatory systems** develop higher pressure than single circuit systems, delivering oxygenated blood to the body at a rate sufficient to meet higher metabolic demands.
- ▶ Double circulatory systems occur in all vertebrates other than fish. They are most efficient in mammals and birds where the heart is fully divided into two halves and the two circuits are completely divided. These animals rely on metabolism to maintain body temperature, so their metabolic demands are necessarily high.
- ▶ Double circulatory systems have two distinct circuits, the **pulmonary circuit**, which circulates blood between the lungs and the heart, and the **systemic circuit**, which pumps oxygenated blood to the rest of the body. The return of oxygenated blood from the lungs to the heart means that the blood can be pumped to the rest of the body at the higher pressures needed to supply organs and maintain kidney filtration rates, while the blood in the lungs (the pulmonary circuit) remains at a low pressure, suitable for facilitating gas exchange.



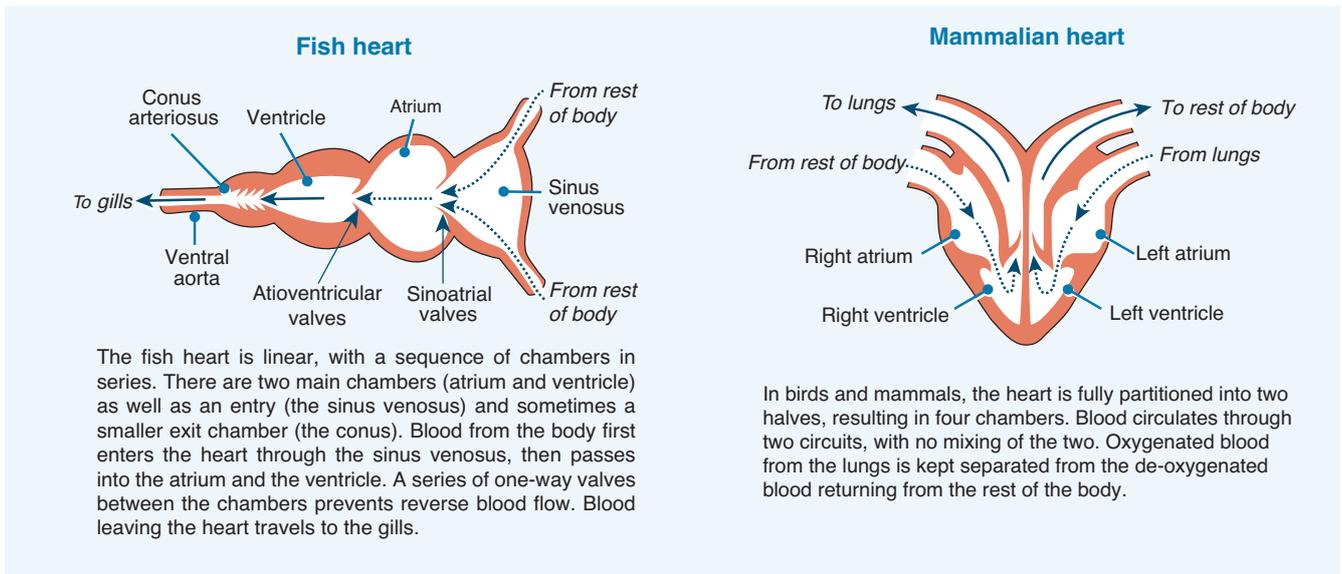
Double systems are also found in birds, amphibians, and reptiles. Birds, like mammals, use metabolism to maintain body temperature (a high energy cost) and maintain high metabolic rates.



107

111

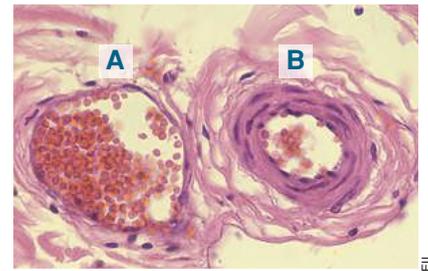
A-1



1. What is the main difference between closed and open systems of circulation? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. (a) Where does the blood flow to immediately after it has passed through the gills in a fish? \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Relate this to the pressure at which the blood flows in the systemic circulation: \_\_\_\_\_  
 \_\_\_\_\_
3. (a) Where does the blood flow to immediately after it has passed through the lungs in a mammal? \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Relate this to the pressure at which the blood flows in the systemic circulation: \_\_\_\_\_  
 \_\_\_\_\_
4. Explain the higher functional efficiency of a double circuit system, relative to a single circuit system: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
5. Hearts range from being simple contractile structures to complex chambered organs. Describe basic heart structure in:
  - (a) Fish: \_\_\_\_\_  
 \_\_\_\_\_
  - (b) Mammals: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
6. How does a closed circulatory system give an animal finer control over the distribution of blood to tissues and organs?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 115 Chapter Review: Did You Get It?

1. Identify the blood vessels labelled **A** and **B** on the photo (right). Give reasons for your answer:



**A:** \_\_\_\_\_

\_\_\_\_\_

**B:** \_\_\_\_\_

\_\_\_\_\_

2. Identify the type of circulatory system (*open, closed single, closed double*) in the following animals:

(a) A human: \_\_\_\_\_

(b) A grasshopper: \_\_\_\_\_

(c) A goldfish: \_\_\_\_\_

3. Transpiration in a hydrangea shoot was investigated using a potometer. The experiment was set up and the plant left to stabilise (environmental conditions: still air, light shade, 20°C). The plant was then placed in different environmental conditions and the water loss was measured each hour. Finally, the plant was returned to original conditions, allowed to stabilise and transpiration rate measured again. The results are presented below:

Experimental conditions	Temperature (°C)	Humidity (%)	Transpiration rate (g/h)
(a) Still air, light shade, room temperature	20	70	1.20
(b) Moving air, light shade	20	70	1.60
(c) Still air, bright sunlight	23	70	3.75
(d) Still air and dark, moist chamber	19.5	100	0.05

(a) What conditions acted as the control in this experiment? \_\_\_\_\_

(b) Which factors increased transpiration rate and why? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Why did the plant have such a low transpiration rate in humid, dark conditions? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. (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? \_\_\_\_\_

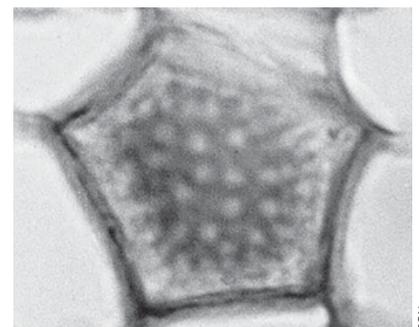
5. (a) What does the image (right) show: \_\_\_\_\_

(b) In what tissue would you find it? \_\_\_\_\_

(c) Is this tissue alive or dead? \_\_\_\_\_

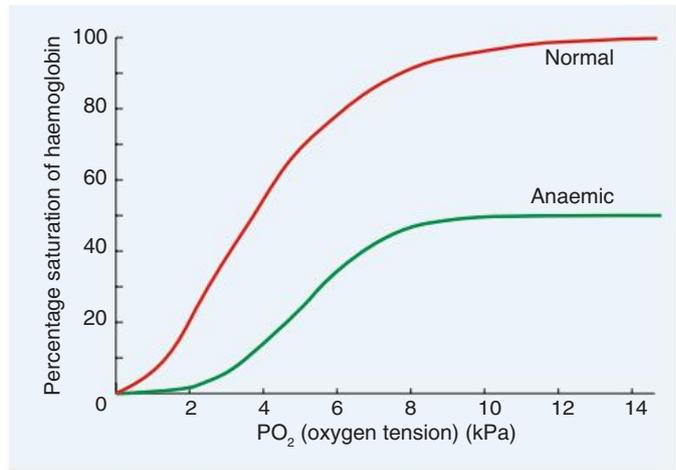
(d) What transport process is it associated with? \_\_\_\_\_

(e) What is being moved in this process? \_\_\_\_\_





4. People with iron-deficient anaemia lack haemoglobin in the blood. The graph right shows the oxygen-haemoglobin dissociation curves for a person with iron deficient anaemia compared to a person with normal haemoglobin levels.



(a) What does an oxygen-haemoglobin dissociation curve show?

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(b) What has happened to the oxygen-haemoglobin dissociation curve in the anaemic person and why?

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5. 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

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Stems

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Roots

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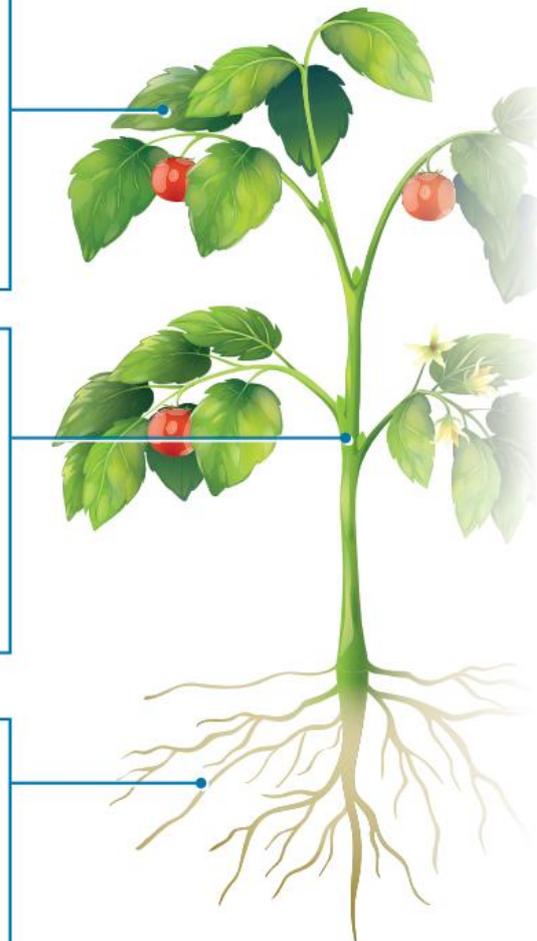
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MODULE

# 03

Biological diversity



## Student outcomes:

- ▶ Develop and evaluate questions and hypothesis for scientific investigation
- ▶ Design and evaluate investigations to collect primary and secondary data and information
- ▶ Communicate scientific understanding using appropriate language and terminology
- ▶ Describe biological diversity
- ▶ Explain relationships between organisms in terms of specialisation for habitat and evolution of species

# Effects of the Environment on Organisms

Activity  
number

## Key terms

abiotic factor  
biocontrol  
biotic factor  
selection pressure

**Inquiry question:** *How do environmental pressures promote a change in species diversity and abundance?*

## Selection pressures

### Key skills and knowledge

- 1 Define the term selection pressure. Understand that selection pressures act on the variation within populations, affecting the ability of an individual to survive and reproduce. Describe how selection pressures can be positive (increase the chances of an individual's survival) or negative (decrease the chances of an individual's survival). 117
- 2 Selection pressures can be abiotic factors or biotic factors. Distinguish between abiotic and biotic factors and give examples of each. 117
- 3 Study the peppered moth case study data. How did the proportion of light and dark forms change over time as pollution levels in their environment changed? Describe how the moth's ability to camouflage acts as a selection pressure for predation. Predict what effect this will have on the ratio of dark and light forms in the population. 118
- 4 Describe (generally) the role disease plays as a selection pressure in the human population. Understand that disease usually acts as a negative selection pressure, but in some instances it can provide an advantage. 119
- 5 In some populations, having one disease may protect against contracting another. 119
  - i Describe when having a specific variation in the IFIH1 gene (a gene coding for a protein involved in the immune response) is a beneficial selection pressure even though it may increase the chances of a person developing type 1 diabetes.
  - ii Explain how in some regions of the world having sickle cell trait (a serious illness affecting red blood cells) provides an advantage because it provides protection against contracting malaria.



## Investigate changes in a population

### Key skills and knowledge

- 6 Introducing a new species into an environment can have disastrous effects on the resident species if there are insufficient biotic or abiotic controls to keep the introduced species numbers in check. 120-121
- 7 Describe why the prickly pear was introduced into Australia and the effects of its uncontrollable spread on the environment. Describe the methods attempted to control its spread, including the successful use of biocontrol methods. How were other species affected by the presence of prickly pear? 120
- 8 Cane toads were introduced into Queensland to protect sugar cane crops from being eaten by sugar cane beetles. Explain the effect of their introduction on native species, and describe how they have acted as a selection pressure for some native species. 121

# 117 Types of Selection Pressures

**Key Idea:** Biotic and abiotic factors can act as selection pressures and direct the evolution of a population.

**Selection pressures** are factors which affect an organism's ability to survive in a certain environment. Selection pressures are always acting on the variation present in populations. Some variations are more favourable under certain conditions than others, so organisms with variations suited to the selection pressures operating are more likely to survive and

reproduce. Therefore, selection pressures can influence the direction and rate at which a population or species will evolve. Selection pressures can be biotic or abiotic. **Biotic factors** are the living components of the environment (e.g. animals, plants, bacteria). This also includes the way organisms interact with other organisms. **Abiotic factors** are the physical, non-living components of the environment. Examples include temperature, light, wind, soil, and availability of water.

## Biotic factors as selection pressures



Biotic factors play an important role in evolution. All organisms must compete with others to gain the resources they need. Those that compete more successfully will have greater reproductive success. For example, in a predatory species, better hunters will obtain more food and so can successfully raise more young.

Biotic factors create selection pressures that can result in species evolving together. For example, a predator exerts selection pressure on its prey and vice versa so predators and prey coevolve: the predators becoming better adapted to hunt and the prey better adapted to escape. This type of reciprocal evolution is common.

Other interactions also affect the direction of evolution in a species. Examples include symbioses such as plants attracting pollinators, or parasites living in or on a host. Changes in one of the symbionts (e.g. a redder flower) may ultimately affect the reproductive success of another symbiont and so influence its evolutionary path.

## Abiotic factors as selection pressures



Abiotic factors also play a part in the direction and rate of which species evolve. Rapid changes in the environment can increase the rate of evolution by creating new selection pressures.

A gradual increase in the environment's temperature may favour individuals with characteristics (phenotypes) that enable them to tolerate the increased heat. These phenotypes will become more common in the population as individuals with unfavourable phenotypes do not survive.

Increased water temperature has caused coral-bleaching on the Great Barrier Reef. Staghorn corals (above) are more sensitive to the change in temperature than some coral species. As a result, the reef composition may change over time.

- (a) Biotic factors are the living / non-living components of the environment (circle the correct answer).

(b) Abiotic factors are the living / non-living components of the environment (circle the correct answer).
2. What is a selection pressure? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
3. Why is population variation important when a new selection pressure is introduced? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 118 Predicting the Effects of Selection Pressure

**Key Idea:** Selection pressures on the peppered moth during the Industrial Revolution shifted the common colour from the grey form to the dark form.

Many animal populations show a wide range of colours. A famous example is the peppered moth, it has a light grey form and a dark (melanic) form. During the Industrial Revolution,

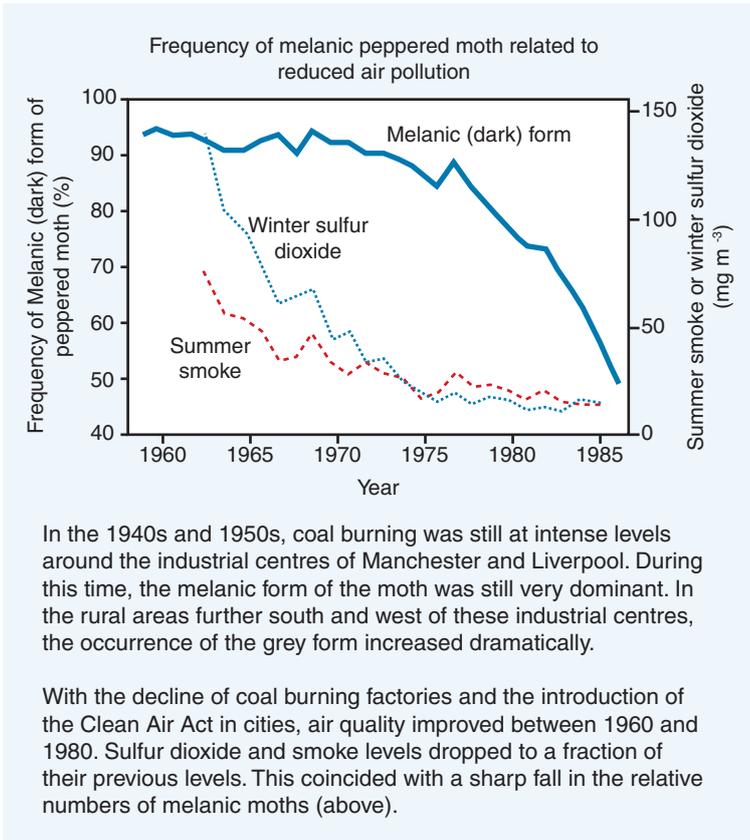
large amounts of coal was burnt in England causing the trees to become dark with soot. Dark (melanic) moths survived more than the light moths. It was thought the soot camouflaged the dark moths from being seen (and eaten) by predatory birds. The shift in appearance (phenotype) is an example of how one phenotype is favoured over another.



The peppered moth has two forms: a dark melanic form, and a lighter grey form. During the Industrial Revolution, the relative abundance of the two forms changed to favour the dark form. The change was thought to be the result of selective predation by birds. It was proposed that the grey form was more visible to birds in industrial areas where the trees were dark with soot. As a result, birds preyed upon the lighter form more often, resulting in higher numbers of the dark form surviving.

- ▶ The colour of the peppered moth is controlled by a single gene, but it has two versions (alleles).
- ▶ The version for the dark (melanic) form is **M**. The version for the grey (light) form is **m**.
- ▶ The dark (**M**) form is dominant over the grey (**m**) form. This means when at least one **M** allele is present the moth will be dark.

**Genotype:** The genetic makeup of an organism.  
**Phenotype:** The observable appearance of an organism.



In the 1940s and 1950s, coal burning was still at intense levels around the industrial centres of Manchester and Liverpool. During this time, the melanic form of the moth was still very dominant. In the rural areas further south and west of these industrial centres, the occurrence of the grey form increased dramatically.

With the decline of coal burning factories and the introduction of the Clean Air Act in cities, air quality improved between 1960 and 1980. Sulfur dioxide and smoke levels dropped to a fraction of their previous levels. This coincided with a sharp fall in the relative numbers of melanic moths (above).

1. Identify the phenotypic character studied in the example of the peppered moths: \_\_\_\_\_
  
2. (a) Identify the selection pressure in the example of the peppered moth: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Explain how the selection pressure affected the grey form of peppered moth: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
3. (a) Study the graph above (right). What is happening to the frequency of the dark (melanic) form? \_\_\_\_\_  
 \_\_\_\_\_
- (b) What has caused this change in frequency? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
  
4. Predict what would happen to the frequency of the **M** allele in the population as the frequency of dark forms increased: \_\_\_\_\_  
 \_\_\_\_\_

# 119 Disease as a Selection Pressure

**Key Idea:** Disease acts as a selection pressure. It is usually a negative selection pressure, but in some instances it can act positively.

Disease provides a significant selection pressure on the human population. There are many examples in human history where disease has killed large numbers of the human population (e.g. the Spanish flu pandemic). But why do some

people die and others survive? The human population shows genetic variation in our ability to resist and combat specific diseases. Individuals with favourable variations survive while those who don't have it die, so the favourable genetic variations are passed on. Sometimes having one disease provides protection against another disease. In this instance, having the first disease is a positive selection pressure.



As modern humans travelled out of Africa and spread around the world, they encountered new disease-causing organisms (pathogens). These diseases acted as new selection pressures.



Settlements gathered humans together and enabled disease to spread to more people, more easily. For example, diseases spread by coughing and sneezing (e.g. influenza) can be transmitted to many more people in high density situations.



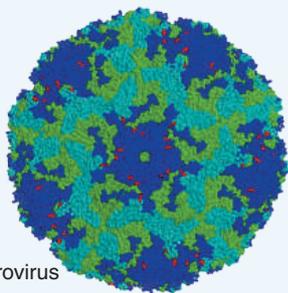
Domestication of animals and farming livestock also increased the diseases humans were exposed to. This is because some diseases originated in livestock or pets and could transfer to, and infect, humans.

## Selection pressures make some diseases more common

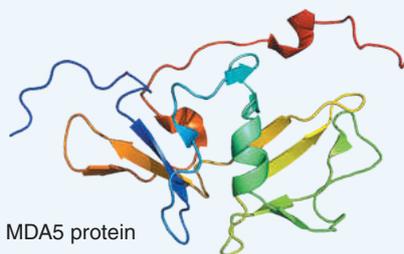
**Enteroviruses** cause a wide range of diseases including some very dangerous diseases such as polio, heart inflammation, and inflammation of the brain.

The **IFIH1 gene** codes for a protein called MDA5. MDA5 protein is involved in the body's immune response to fight off infection from certain pathogens (including enteroviruses).

People with a particular variation of the IFIH1 gene are more likely to develop **type 1 diabetes**. This disease prevents the body from producing insulin to lower blood glucose levels. There is no cure, patients must inject themselves with insulin several times a day.



Enterovirus



MDA5 protein



Type 1 diabetic injecting insulin

*What is the advantage of having the IFIH1 gene variant if it increases the likelihood of developing type 1 Diabetes?*

The benefits of having the IFIH1 gene variant depends on how likely a population is to come in contact with an enterovirus. Even though the IFIH1 gene variant increase the chances of developing type 1 diabetes (a disease with serious health effects), it may still be advantageous if the probability of being exposed to a dangerous, life threatening enterovirus was high (the benefits outweigh the risk).

1. Describe how human travel out of Africa exposed populations to new diseases: \_\_\_\_\_

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2. A particular IFIH1 gene variation is linked to an increase in type 1 diabetes. Under what circumstances would it be beneficial to have this variation?

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## Sickle cell trait provides resistance to malaria

### Sickle cell disease

- ▶ Red blood cells are usually disc shaped (right). A mutation (change in DNA sequence) to the gene coding for haemoglobin (the oxygen carrying protein inside red blood cells) causes it to fold incorrectly, and the red blood cells are sickle-shaped (far right).
- ▶ The variations in the haemoglobin gene means within a population different combinations of red blood cells can exist. Depending on the genes inherited from their parents, a person can have all normal red blood cells (normal phenotype), all sickle cells (sickle cell disease), or a mixture of normal and sickle cells (sickle cell trait).
- ▶ **Sickle cell disease** is an inherited condition and is a serious disease. The misshapen red blood cells can become stuck in blood vessels and restrict blood flow and oxygen transport around the body. Other serious health conditions may arise, and people with sickle cell disease often die early. NOTE: A person with sickle cell trait generally doesn't have the same problems as a person with sickle cell disease because their normal red blood cells function normally.

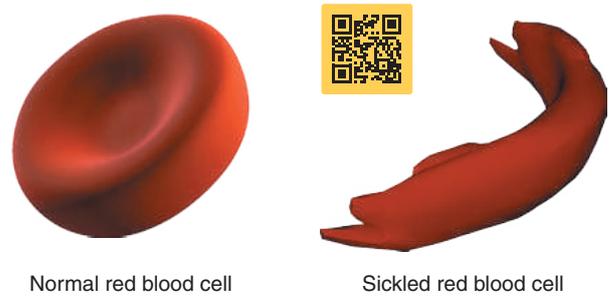


Fig. 1: Incidence of falciparum malaria

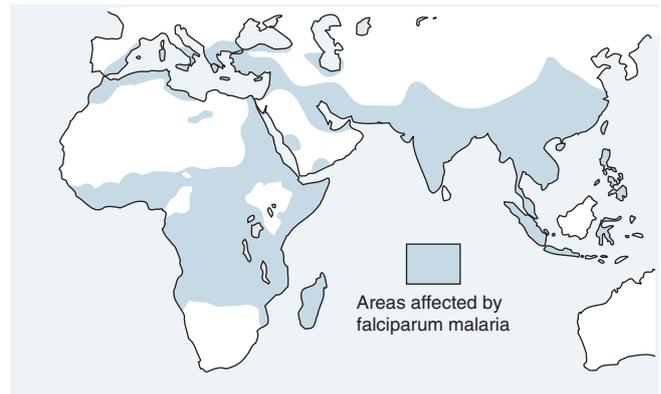
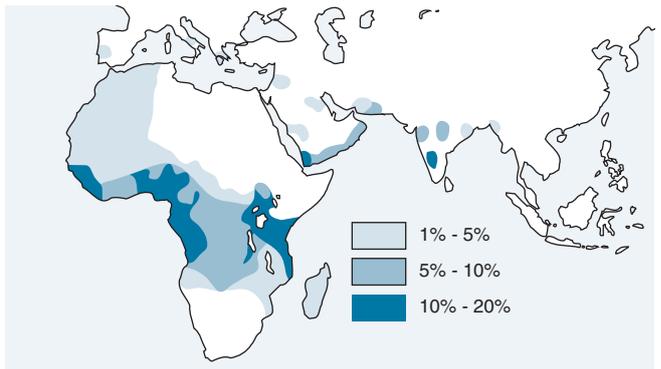


Fig. 2: Frequency of the sickle cell allele



### Sickle cell trait is common in malaria regions

- ▶ **Malaria** is a serious disease and can result in death. Humans develop malaria if they are bitten by *Anopheles* mosquitoes infected with the malaria-causing parasite. One particular type of malaria (falciparum malaria) is widely distributed throughout central Africa, the Mediterranean, Middle East, and parts of Asia (Figure 1).
- ▶ The frequency of people with sickle cell variations is higher in areas of the world where falciparum malaria occurs (Figure 2).
- ▶ Why is this? Sickle cells have low potassium levels, which causes the malaria parasites inside sickle cells to die. People with only normal red blood cells are more likely to get malaria, but those with a combination of normal and sickle cells are much less likely to get malaria.
- ▶ Therefore, having a combination of normal and sickle cell red blood cells provides an advantage in areas of the world where malaria occurs.

3. Having sickle cell trait would provide a positive / negative selective pressure in areas where falciparum malaria does not occur (circle the correct answer).

4. Why does having sickle cell trait (a mix of normal and sickle cells) provide a selective advantage in areas of the world where falciparum malaria occurs?

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5. Why would having only sickle cells (sickle cell disease) not provide a selective advantage? \_\_\_\_\_

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# 120 The Rise and Fall of the Prickly Pear

**Key Idea:** Introduced prickly pear spread rapidly throughout NSW and Queensland. The introduction of a biocontrol measure finally proved effective in controlling its spread. Prickly pear refers to a number of related cacti species. The plants were originally found in the Americas and were first introduced into Australia at Port Jackson (NSW) in 1788. With no natural pests in Australia, and favourable growing conditions, the cacti spread uncontrollably covering

240,000 km<sup>2</sup> of land (about the size of the UK) in NSW and Queensland. Prickly pear growth was so dense and so widespread it covered all other plants. Land was often abandoned because it was too difficult and expensive to remove the plants. Serious attempts to control and remove prickly pear began in 1886. Many attempts failed, but eventually a **biocontrol** measure (using natural enemies or pests to control prickly pear numbers) produced good results.

### An unusual reason for introducing prickly pear

In the 1700s the Spanish controlled the production of a high value red dye made by crushing up the cochineal insect which fed on the prickly pear. The British wanted to have their own dye supply to make red coats for the army, so the British introduced the cacti (and insect) to Australia to make the dye themselves. Chemical dyes soon made producing dye this way unnecessary.



Frank Vincentz CC 3.0



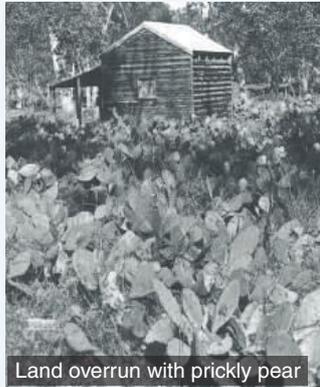
Aviceda CC 3.0

### Spread of the prickly pear

Other uses for the prickly pear were soon found. It was widely used as hedge plants and as animal feed during droughts (when no other food was available). Plants established easily in new areas, their hard seeds were widely distributed by birds (crows, magpies, and emus) and from grazing animals. In addition, segments of the plants could be carried long distances by wind or water, and grew easily in the new locations.

### Control of the prickly pear

In 1886, the NSW government passed the Prickly-pear Destruction Act making landowners responsible for its destruction. However, digging it up, burning the plants, or crushing them with heavy rollers all proved ineffective and many landowners left their land in defeat. Attempts to poison the plants with arsenic-based product had limited success but it was expensive and toxic to the environment and user.



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USDA

### Success through biocontrol

In the Americas, the prickly pear population is controlled by insect pests, such as the cactus moth. Females lay eggs on the plants, and the hatched larvae (caterpillars) feed off the cactus, destroying a plant in weeks. After checking the cactus moth would not harm other crops or native plants, they were introduced to Australia. Within 10 years large areas of land were free of prickly pear. Prickly pear is still a problem in some parts of Australia, but far less so than before

1. Why was prickly pear able to spread so far in New South Wales and Queensland? \_\_\_\_\_

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2. (a) Define biocontrol: \_\_\_\_\_

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(b) Why did the cactus moth succeed in controlling prickly pear when other methods failed? \_\_\_\_\_

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# 121 The Influence of Cane Toads on Native Species

**Key Idea:** Cane toads were introduced into Australia to control sugar cane beetles. Instead they preyed on many Australian native species, and have been declared a pest. The cane toad is an aggressive predator and was introduced into Queensland in 1935 to control beetles destroying sugarcane crops. However, this strategy failed for a number of reasons, and instead cane toads began preying on a

variety of native insects, frogs, and small lizards. In its native South America, the cane toad has many predators, so its numbers are kept in control. However, in Australia it has no predators so its numbers rapidly increased. In addition, the toads began to disperse from where they were originally introduced, out-competing native species for habitat and resources. Cane toads are a pest species in several states.



Cane toads are very tough and can survive in a number of habitats. They are now found in several Australian states.

## Why are the cane toad so dangerous to biodiversity?

Around 2400 cane toads were released into Australia in 1935, today they number over 200 million. They have several adaptations and features which allow them to occupy many habitats and out-compete many native species.

- ▶ They produce a toxin throughout all stages of their life cycle. Any animal (including larger animals such as quolls and dogs) which comes in contact with the toxin usually dies, so it has no predators in Australia.
- ▶ They are aggressive predators. A cane toad will attack and eat almost anything that will fit in its mouth, including a wide range of native species.
- ▶ They reproduce in large numbers. They lay 30,000 eggs at once, and often lay eggs twice a year.
- ▶ They can tolerate a wide range of temperatures (5-40°C) and survive in a wide variety of habitats.

## Cane toads act as a selection pressure on native species



Oliver Neuman CC 4.0

Red-bellied black snake

Red-bellied black snakes will eat cane toads. Most of the snakes die because of the cane toad's toxin, but some live. Researchers found that larger snakes with a smaller head compared to its overall body length were less likely to die. They most likely survived because the size of a snake's head limits the size of its prey, so snakes with smaller heads probably can't eat a large enough cane toad to be poisoned by its toxin. The cane toad is providing a selection pressure, and those snakes with advantageous body shape have a selective advantage.



A quoll

Northern quolls are carnivorous marsupials, feeding on a wide range of animals including frogs and toads. Their numbers have declined by 75%, partly due to the introduction of the cane toad (the toxin kills the quolls if they eat them). Researchers noticed that some Queensland Northern quoll populations avoid eating cane toads. They think this avoidance behaviour is caused by the presence of a particular gene. When individuals with the gene breed, it is passed on to their offspring, modifying the behaviour of the offspring so they also avoid eating cane toads.

1. Summarise why cane toads are a threat to many native Australian species: \_\_\_\_\_

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2. How has the introduction of cane toads acted as a selection pressure for the red-bellied black snake? \_\_\_\_\_

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# Chapter Review: Did You Get It?

1. Explain the difference between an abiotic and biotic selection pressure: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Categorise the following examples as either a biotic factor or an abiotic factor and name the factor being shown:

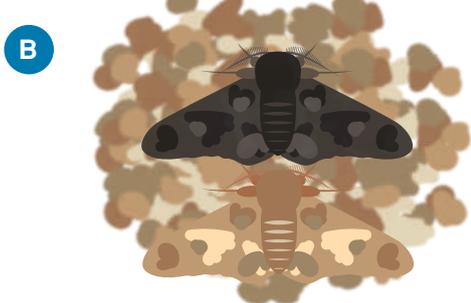


(a) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Study the images below. The moths are eaten by predatory birds. Describe what would happen to the proportion of dark and light moths for each scenario:



(a) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) Explain the reason for the changes you described above: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

4. What is meant when an organism is described as having a selective advantage? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# Adaptations

Activity  
number

## Key terms

aestivation  
adaptation  
behavioural adaptation  
countercurrent exchange  
ectotherm  
endotherm  
fauna  
fitness  
flora  
hibernation  
hydrophyte  
natural selection  
physiological adaptation  
structural adaptation  
thermoregulation  
torpor  
xerophyte

**Inquiry question:** How do adaptations increase the organism's ability to survive?

## Animal and plant adaptations

### Key skills and knowledge

- |                          |   |         |
|--------------------------|---|---------|
| <input type="checkbox"/> | 1 Define adaptations as heritable characteristics that equip individuals to survive and exploit their habitat and contribute to successful reproduction.                          | 123     |
| <input type="checkbox"/> | 2 Describe the adaptations in animals to their environment including adaptations of diving animals and Australian animal species.   | 123-125 |
| <input type="checkbox"/> | 3 Compare and contrast thermoregulation in ectotherms and endotherms. Describe the role of structural, physiological, and behavioural adaptations in regulating body temperature. | 126     |
| <input type="checkbox"/> | 4 Describe adaptations for thermoregulation, including the role of countercurrent exchange systems in temperature regulation.   | 127-129 |
| <input type="checkbox"/> | 5 <b>PRAC</b> Investigate body shape and temperature regulation.  | 129     |
| <input type="checkbox"/> | 6 Describe the adaptations in plants that help them survive in their environment including adaptations of Australian plant species.   | 132     |
| <input type="checkbox"/> | 7 <b>PRAC</b> Investigate adaptations in an aquatic plant.  | 131 132 |



Robert Kerton CSIRO CC 3.0



## Adaptations and the theory of evolution by natural selection

### Key skills and knowledge

- |                          |  |     |
|--------------------------|--|-----|
| <input type="checkbox"/> | 8 Investigate the observations made by Charles Darwin that supported his Theory of Evolution by Natural Selection.                           | 130 |
| <input type="checkbox"/> | 9 Use data on the Galápagos Island finches to show the heritability of adaptive features.  | 130 |
| <input type="checkbox"/> | 10 Explore Darwin's travels in Australia, the organisms he observed, and how they helped shape his Theory of Evolution by Natural Selection. | 131 |

# 123 Adaptation and Fitness

**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<sup>2</sup> (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.

### Structural 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.

### 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.

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: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Number of horns in rhinoceroses**

Not all differences between species can be convincingly interpreted as adaptations to particular environments. Rhinoceroses charge rival males and predators, and the horn(s), when combined with the head-down posture, add effectiveness to this behaviour. Horns are obviously adaptive, but it is not clear that the possession of one (Indian rhino) or two (black rhino) horns is necessarily related directly to the environment in which those animals live.



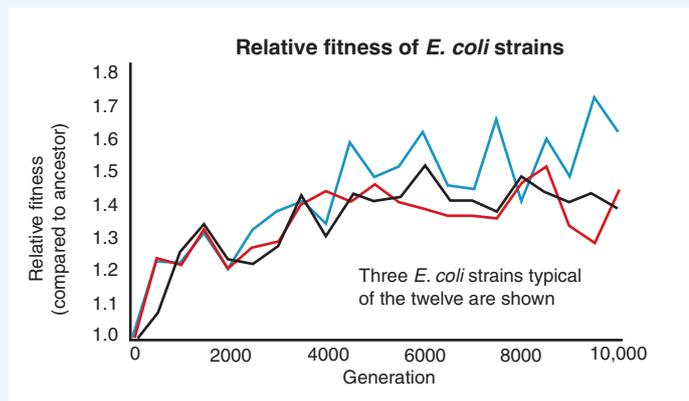
**Ear length in rabbits and hares**

The external ears of many mammals are used as important organs to assist in thermoregulation (controlling loss and gain of body heat). The ears of rabbits and hares native to hot, dry climates, such as the jack rabbit of south-western USA and northern Mexico, are relatively large. The Arctic hare lives in the tundra zone of Alaska, northern Canada and Greenland, and has ears that are relatively short. This reduction in the size of the extremities (ears, limbs, and noses) is typical of cold adapted species.



**Fitness and adaptation in *E. coli***

The Long Term *E. Coli* Experiment has been running since 1988. Its goal is to track the evolution or 12 populations of the bacteria *E. coli*, kept in a minimal glucose growth medium. The fitness of the 12 populations relative to the original 12 populations has been measured every 500 generations. The graph on the right shows how the fitness of the populations changed over the first 10,000 generations. Note that the features evolved by the *E. coli* provide them with greater fitness only in the low glucose environment. Placed in a different environment, their relative fitness is actually lower than the original population's.



4. How is fitness related to genetics? \_\_\_\_\_

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5. How is fitness related to the environment? \_\_\_\_\_

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6. The three *E. coli* strains shown above have a greater fitness than the ancestral strain in the low glucose medium. What would happen if all four strains were placed in a high glucose environment and why?

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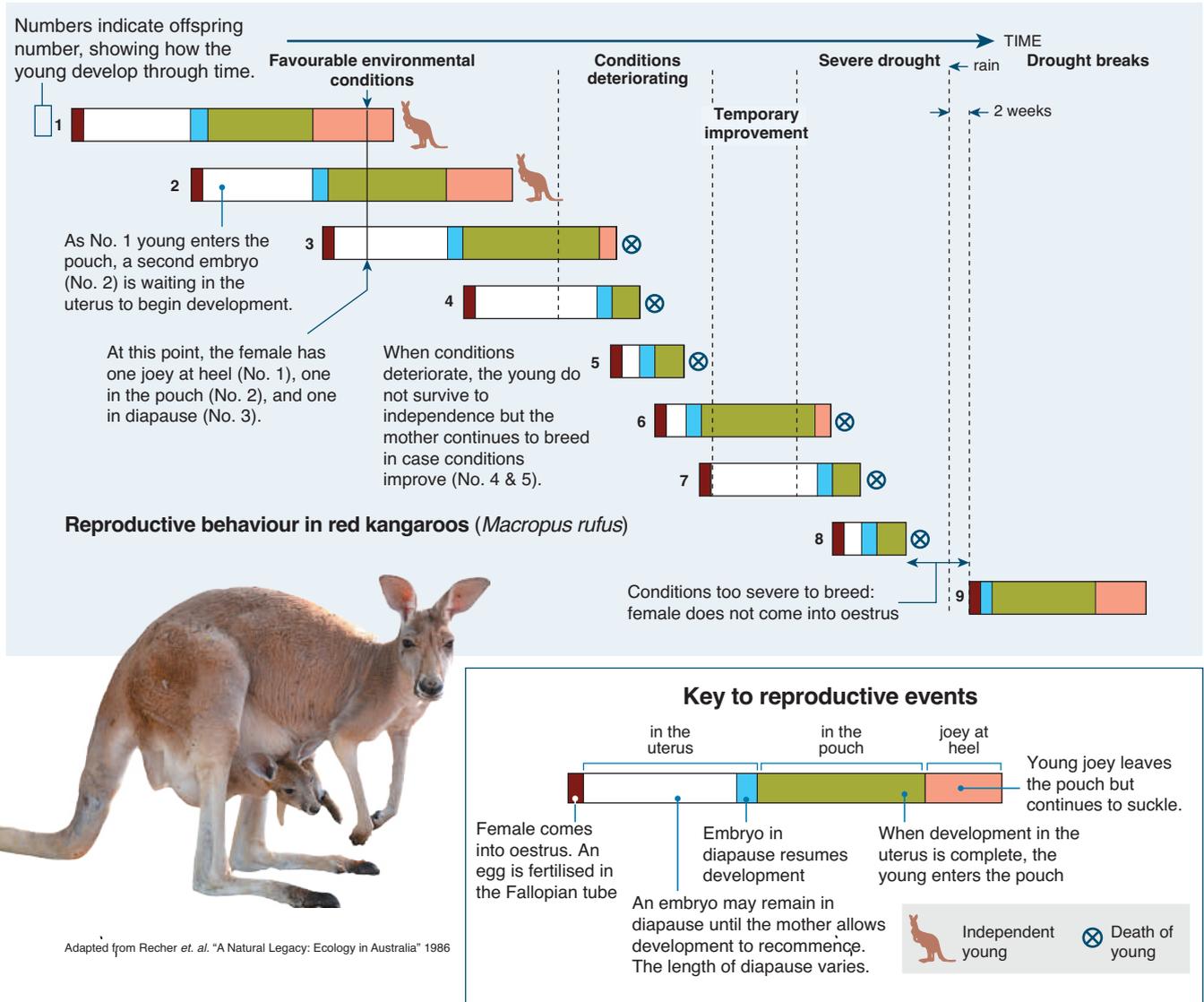
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# 124 Reproductive Strategies for Survival

**Key Idea:** The reproductive strategies of animals are adapted to the environment in which they live.

Reproductive strategies vary from animal to animal and are partly influenced by the environment. The red kangaroo lives in parts of Australia which can be arid and the availability of food and water are often low. It has a reproductive strategy that enables it to make the most of favourable conditions without compromising survival when conditions are difficult. In favourable conditions, it produces young in rapid succession.

The female may have a joey at heel, one in the pouch, and an embryo in **diapause** (suspended development) ready to replace the pouch offspring when it leaves (below). The timing of reproduction is an important adaptation. The breeding cycles of organisms are normally timed so that young are produced when the food available (energy) is most abundant and conditions are favourable for survival of the young (spring and summer). Emperor penguins begin breeding at the beginning of winter, because of the short Antarctic summer.



1. Study the diagrams above and then answer the following questions:

- (a) At what stage of development did offspring number 3 die? \_\_\_\_\_
- (b) What stage of development did offspring 4 and 5 reach before they died? \_\_\_\_\_
- (c) How many young were in progress during the period of temporary improvement and what were their stages?  
\_\_\_\_\_
- (d) Describe the progression of four events occurring during the severe drought: \_\_\_\_\_  
\_\_\_\_\_
- (e) What step was missed out after the drought broke? Briefly explain why: \_\_\_\_\_  
\_\_\_\_\_

2. When conditions deteriorate, the joey at heel (still suckling) dies first, then the pouch young, then the diapausing embryo. Why does the mother withdraw nourishment from the young in this order when times are hard?

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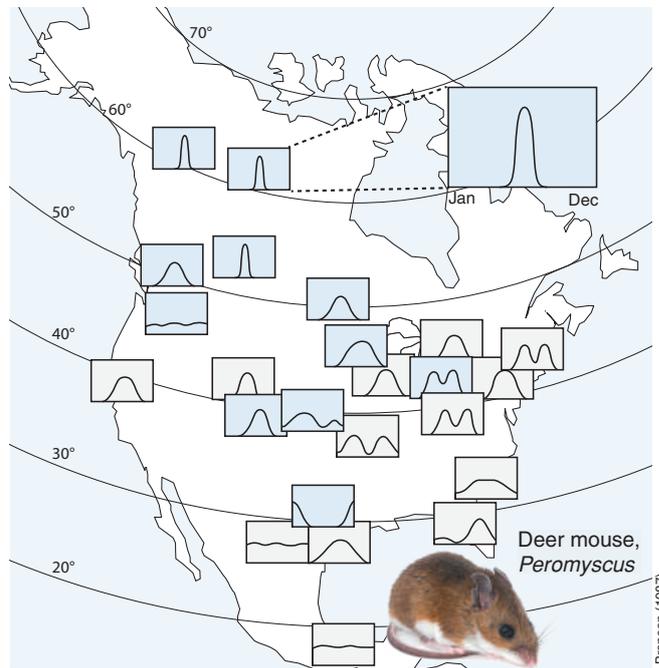
**Timing reproduction**



The reproductive cycle for animals that breed seasonally often begins in late autumn, with a winter gestation and birth of the young in spring. This maximises the time available for raising young before the next winter and coincides with the time of maximum food availability.

For Antarctic penguins, the environment dictates a slightly different strategy. Emperor penguins spend their summer feeding and begin their reproductive cycle in March, at the beginning of the Antarctic winter. They move to breeding colonies where the chicks are raised through the winter, becoming independent by the start of the Antarctic summer in November-December. Raising chicks through the harsh Antarctic winter allows them to be independent by summer and so be better able to survive the following winter.

Emperor penguins must also have enough time after raising their chick to feed before their annual moult, during which they cannot enter the sea and so must again rely on their fat stores.



This diagram shows the relative proportions of female deer mice pregnant at any one time of the year (January on the left side of each graph, December on the right). At higher latitudes, females breed during summer months only, whereas at lower latitudes they breed throughout the year (the blue boxes show one single species).

Bronson (1987)



- ▶ In many animals, male-male competition develops where the benefits (access to females or resources) outweigh the energy costs (fighting or territory defense). The amount of energy expended by males in attracting or monopolising several females needs to be weighed against the assistance the females might need to raise the young and how far they range.
- ▶ It is energetically uneconomic for males to defend a large number of females if they require male assistance to rear the young or travel a great distance to find food. Generally, the most energy expensive reproductive activities for males involve courtship and mating. In females, it is in pregnancy and rearing young.

3. Explain why many animals and plants have seasonal reproductive cycles: \_\_\_\_\_

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4. Suggest why deer mice at 50°-60° latitude have a strict summer breeding period, unlike the deer mice at 20° latitude: \_\_\_\_\_

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5. (a) In which part of the reproductive process do males tend to spend the most energy? Explain: \_\_\_\_\_

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- (b) In which part of the reproductive process do females tend to spend the most energy? \_\_\_\_\_

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# 125 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

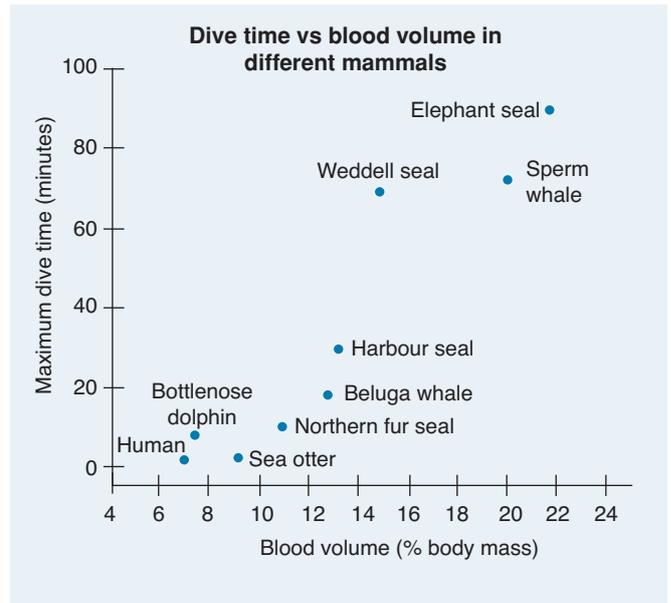
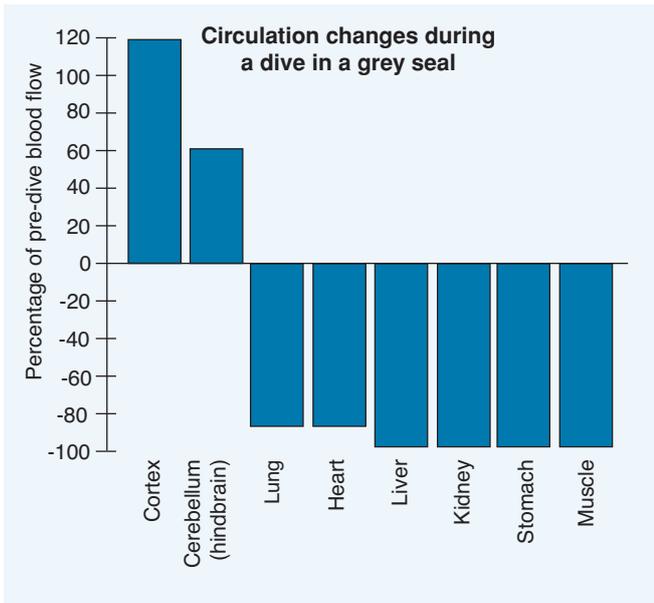
rates and oxygen demands are high. In addition, resurfacing from dives of 20 m or more carries a risk of decompression sickness, where dissolved gases in the blood produce bubbles as pressure reduces. Primates (including humans) are one of the few orders of mammals without diving representatives.



### 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, next 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 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.

1. Mammals that have evolved adaptations for diving exhale before they dive (humans don't do this, we inhale). How might this be an advantage to diving mammals?

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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?

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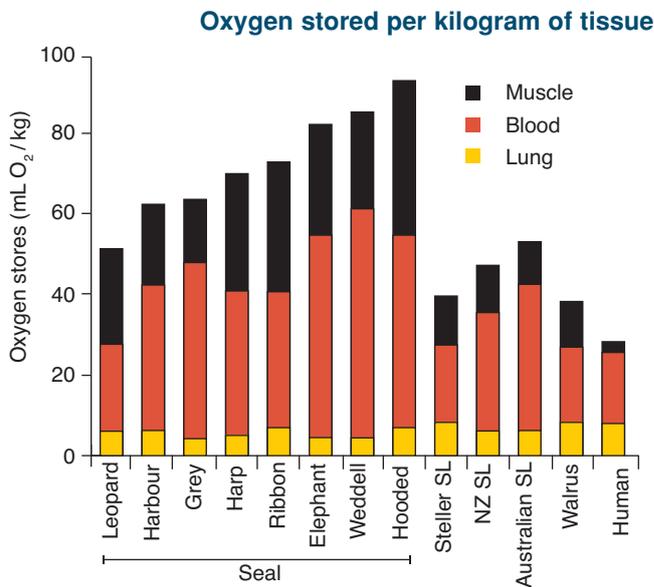
3. Describe the blood flow in a seal during a dive: \_\_\_\_\_

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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: \_\_\_\_\_

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(b) How does this compare to a human? \_\_\_\_\_

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(c) The seals are more specialised for a life in water than the sea lions. Does the evidence above support this?

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# 126 Adaptations for Controlling Body Temperature

**Key Idea:** Ectotherms depend on heat from the environment whereas endotherms generate heat through metabolic activity. Endotherms and many ectotherms thermoregulate to maintain an optimum temperature for functioning. Animals are classified into two broad groups based on the source of their body heat. **Ectotherms** depend on the environment for their heat energy (e.g. heat from the sun)

and their metabolic demands are relatively low. **Endotherms** generate their body heat from metabolism. All endotherms and many ectotherms **thermoregulate** (control body temperature) in order to maintain an optimum temperature for functioning. Ectotherms rely on behavioral mechanisms to do this, whereas in endotherms both behavioural and physiological responses are involved.



Most fish and all amphibians are ectothermic (they rely on environmental sources of heat energy). Unlike many reptiles, they do not thermoregulate, so their body temperature fluctuates with the environment (they are poikilothermic) and they are usually restricted to thermally stable environments.



Reptiles, such as snakes, lizards, and crocodiles, are also ectothermic but regulate body temperature using behaviour. They bask and use body positioning to raise their body temperature for activity and seek shade when temperatures are too high. Some larger reptiles are able to maintain a relatively elevated body temperature for much of the time.



Birds and mammals are endotherms and achieve a high body temperature through metabolic activity and reduction of heat exchanges. They can function independently of the environmental temperature (within the species-specific tolerance range) and maintain high metabolic rates. Their body temperature remains stable (they are homeothermic) and their energy costs are high.

## Controlling body temperature

▶ Animals use a variety of behavioural, physiological, and structural adaptations to regulate and maintain their body temperature.



The behaviour of panting to lose accumulated heat is important in dogs, which have sweat glands only on the pads of their feet.



Physiological mechanisms such as circulation changes slow heat loss in water and speed heat gain when basking on land in marine iguanas.



Structural features like thick blubber and large body size in seals and other marine mammals provide insulation.



Many mammals and birds cluster together in cold climates, like the musk oxen above. This behaviour helps to retain body heat.



Behaviours to reduce heat uptake via conduction, e.g. standing on two legs, are important in desert lizards.



Primates and horses are among the few animals that use sweat to cool the body. This absorbs body heat as it evaporates.



Thick hair, fur or wool traps air next to the skin. This insulating air layer reduces heat loss and slows heat gain.



The plumage of birds acts similarly to fur or hair in mammals. The feathers trap air which slows heat gain and loss.

1. Distinguish between ectotherms and endotherms in terms of their sources of body heat: \_\_\_\_\_

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2. Explain why ectotherms that do not thermoregulate are restricted to environments with relatively stable temperatures: \_\_\_\_\_

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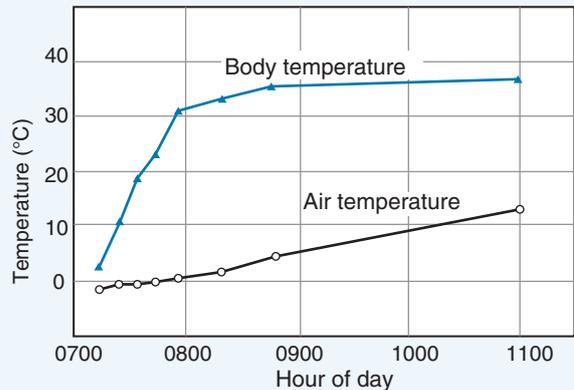


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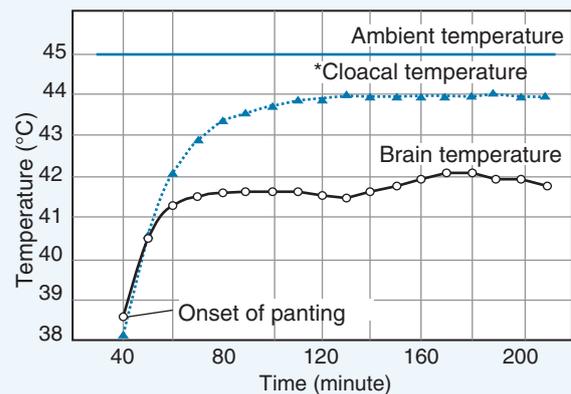


3. (a) Identify two behaviours that animals might use to thermoregulate: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Identify two structural adaptations that animals use to thermoregulate: \_\_\_\_\_  
 \_\_\_\_\_
- (c) Identify two physiological mechanisms that animals use to thermoregulate: \_\_\_\_\_  
 \_\_\_\_\_

The Peruvian mountain lizard (*Liolaemus*) lives at altitudes of ~4000 m in Peru, where the air temperature is low, even in summer. It emerges in the morning when the air temperature is below freezing. By exposing itself to the sun, it rapidly heats up to a body temperature that enables it to be fully active. Once warm, the lizard maintains its preferred body temperature of around 35°C by changing posture and orientation to the sun and thereby controlling the amount of heat energy absorbed.



The chuckwalla (*Sauromalus*) is a widespread lizard species in the deserts of the southwestern United States and northern Mexico and is active in the temperature range 26-39°C (higher for basking). If moved from 15°C to 45°C, cloacal and brain temperatures increase rapidly. At ~41°C, these temperatures diverge and the brain stays at ~2°C below the cloacal temperature and 3°C below air temperature. The chuckwalla achieves this by panting. Its carotid arteries supplying the brain run close to the surface of the pharynx and heat is lost there by evaporative cooling. \*Cloacal temperature measures deep body temperature through the cloaca. It is equivalent to rectal temperature in mammals.



Source: Schmidt-Nielsen: Animal Physiology: Adaptation and Environment, 1979

4. Compare and contrast the thermoregulatory strategies of the Peruvian mountain lizard and the desert chuckwalla, relating any differences to the difference in their respective environments:
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
5. Human body temperature ranges between 36.2°C - 37.2°C. Use a digital thermometer or wrist monitor e.g. Fitbit to measure your body temperature every hour from when you wake (e.g. 6 am) to when you go to sleep (e.g. 10 pm). Enter your data into a spreadsheet and produce a graph of body temperature over time. How does your body temperature vary through the day? Compare your body temperature to others in your class. Describe your findings below:
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
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- \_\_\_\_\_
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# 127 Structural Adaptations for Thermoregulation

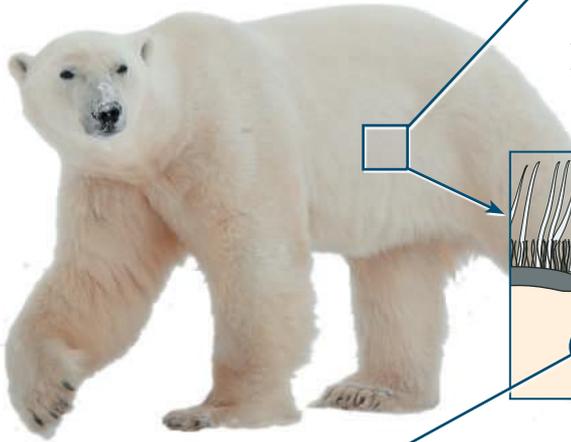
**Key Idea:** Structural features for thermoregulation are those involving how the animal is built, such as long or short ears, blubber, or fur.

Structural mechanisms for thermoregulation are those that arise from the physical structure of the animal, its size and build and features of the skin and body coverings. A common

structural feature for thermoregulation in mammals is fur (except in some marine mammals). In birds, this role is taken by feathers. Physiological adaptations usually accompany structural features, such as the ability to moult from a winter to summer coat and the ability to raise and lower the hair or feathers to increase or decrease insulation.

## Keeping warm

Preventing heat loss is important for small animals and those in very cold environments. This includes animals that live in the polar regions and marine animals.



### Fur

Fur (hair) is a mammalian characteristic. It is a very good insulator in terrestrial environments. There is often a double layer of fur, an outer long layer and an inner (and very thick) insulating layer. Oils in the fur help to waterproof it. Both fur and feathers work by trapping air close to the body, warming it and preventing it escaping.

Sea otters are one of the furiest mammals with more than 124,000 hairs per cm<sup>2</sup> in their inner coat.

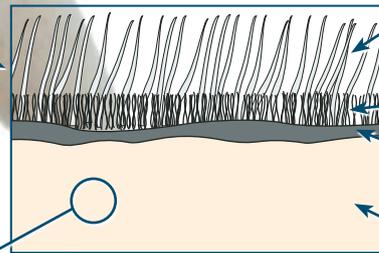
### Polar bear fur

**Guard hairs:** Long and transparent. Scatter light, enhancing camouflage but also allow some light through to heat the skin.

**Dense underfur:** Traps air and prevents body heat from escaping.

**Dark pigment:** Helps the absorption of heat from sunlight.

**Fat layer:** Thick fat layer aids insulation especially when swimming, when the fur loses much of its insulation value.



## Blubber and fat

Blubber is found in marine mammals including whales and seals. It is a highly vascularised (many blood vessels) fat tissue just below the skin and surrounds most of the body, acting as a thermal insulator. The higher the lipid concentration in the blubber the better its effect as an insulator. Fat is less vascularised and has less structure but acts in a similar way by trapping heat in the body.



## Feathers

Feathers evolved primarily as insulation rather than as a flight surface. They still carry out the function of insulation very well. Down feathers (left) are found below the outer feathers. They are such effective insulators that birds such as emperor penguins are at risk of over heating when out of water. Down (e.g. eiderdown) is used by humans as an insulator in jackets and sleeping bags.

## Keeping cool

Although animals need to keep warm in some environments, they need to keep cool in others. Structural features to help prevent overheating include large exposed areas of highly vascularised skin, localisation of fat stores, and fur and feather colouration.



### Ears

The external ears of desert mammals provide a structural mechanism to assist heat loss. Elephants, jack rabbits, and fennec foxes have huge ears relative to their body size, and the ears are covered in highly vascularised skin. As blood passes through the blood vessels it loses heat to the environment. Having large ears helps to catch a breeze which increases evaporative cooling. Elephants are able to flap their ears, further increasing their cooling ability.



### Feathers

Not only do feathers keep heat in but they can be just as effective at keeping heat out. Desert birds often have dark coloured feathers, especially on their dorsal surface (back). These absorb heat near their surface, preventing it reaching the skin. A breeze, especially when flying, can easily remove the heat. Feathers on the breast and belly are often thinner to increase heat loss. The bald head of the vulture above may also have some thermoregulatory function.

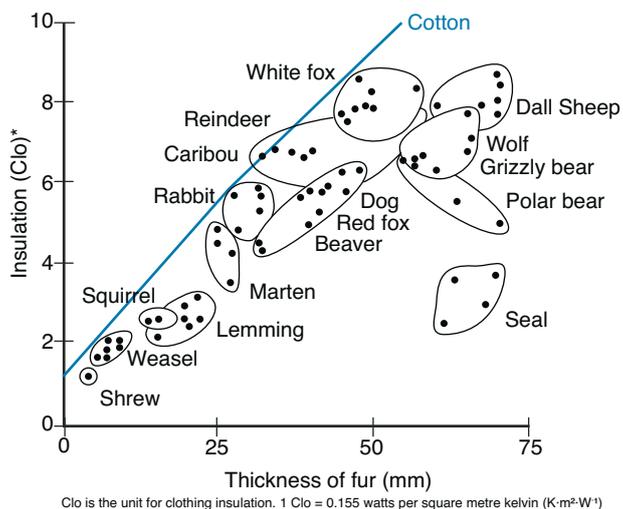


### Localisation

One strategy to help lose heat is to localise fat stores and hair cover. Instead of having fat reserves evenly distributed over the body they are concentrated in certain areas, such as the back hump in camels. This reduces the insulating effect of the fat to a small region on the back (which may also help reduce heat absorption from the sun). Hair is found mainly on the dorsal surface to protect the skin from the sun but the belly may be relatively naked.

1. Why are feathers good insulators? \_\_\_\_\_  
\_\_\_\_\_
2. How do feathers help protect a desert bird from overheating? \_\_\_\_\_  
\_\_\_\_\_
3. (a) In what way is blubber different from fat? \_\_\_\_\_  
\_\_\_\_\_
- (b) How do blubber and fat help an animal retain heat? \_\_\_\_\_  
\_\_\_\_\_
4. How does fur or hair help to insulate the body? \_\_\_\_\_  
\_\_\_\_\_
5. In what way can ears be used as thermoregulatory structures? \_\_\_\_\_  
\_\_\_\_\_
6. How does localising structures such as fur and fat deposits help in the regulation of body temperature? \_\_\_\_\_  
\_\_\_\_\_

7. Study the graph below:

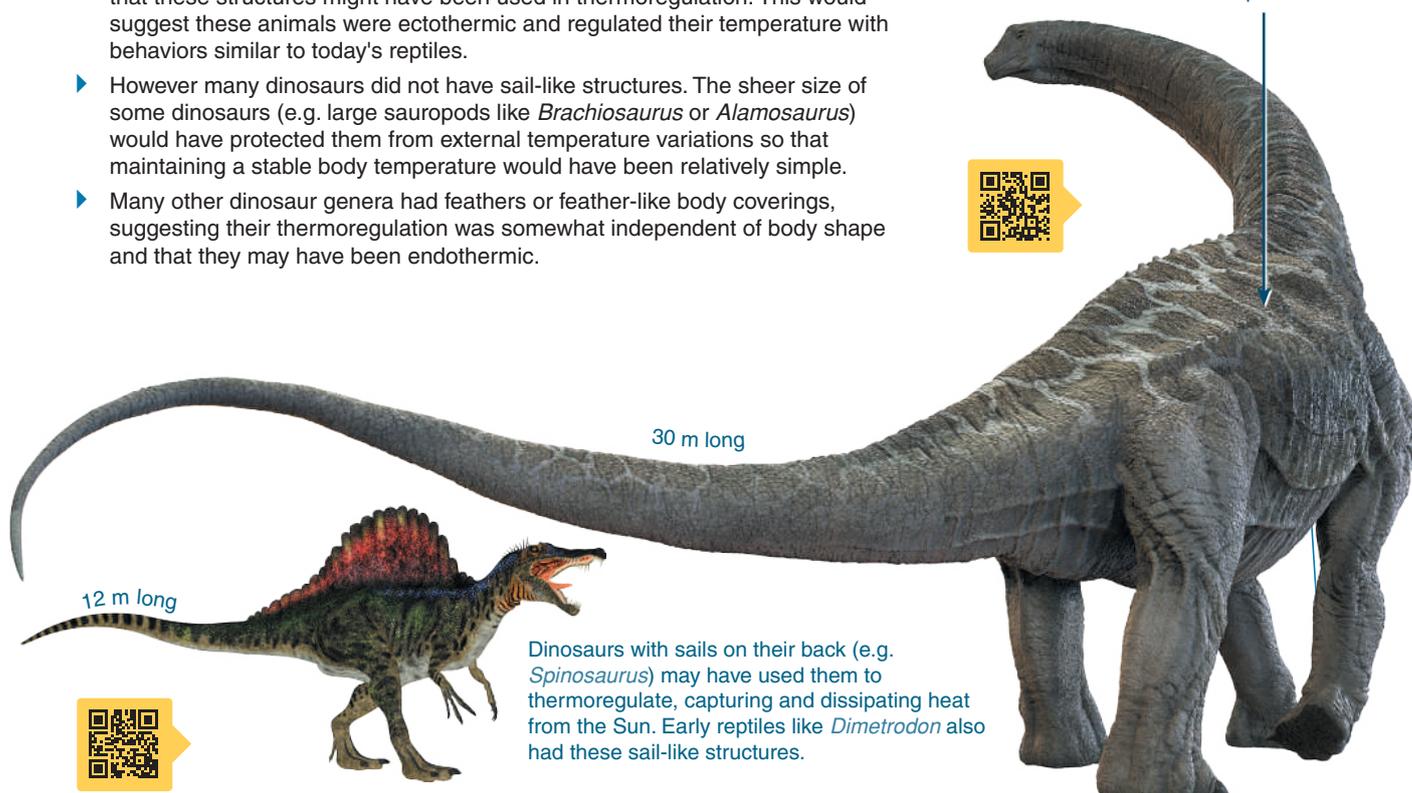


- (a) What is the relationship between fur (hair) length and insulation effect: \_\_\_\_\_  
\_\_\_\_\_
- (b) Seal fur appears to provide little insulation. Why would this not affect the seal in a cold environment?  
\_\_\_\_\_

## How does body shape help regulate temperature?

- ▶ It is often debated whether the dinosaurs were endothermic or ectothermic and to what degree they maintained a stable body temperature. Some dinosaurs had large sail-like structures on their backs or heads. One hypothesis is that these structures might have been used in thermoregulation. This would suggest these animals were ectothermic and regulated their temperature with behaviors similar to today's reptiles.
- ▶ However many dinosaurs did not have sail-like structures. The sheer size of some dinosaurs (e.g. large sauropods like *Brachiosaurus* or *Alamosaurus*) would have protected them from external temperature variations so that maintaining a stable body temperature would have been relatively simple.
- ▶ Many other dinosaur genera had feathers or feather-like body coverings, suggesting their thermoregulation was somewhat independent of body shape and that they may have been endothermic.

The enormous bulk of some dinosaurs (e.g. *Alamosaurus*) may have protected their internal temperature against changes in environmental temperature.

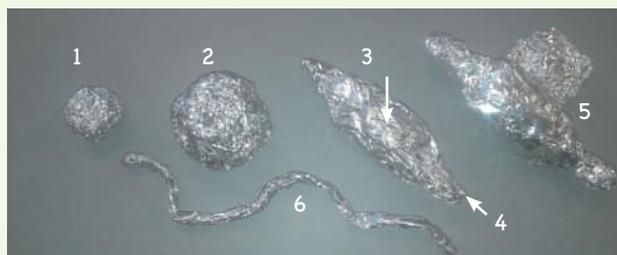


## Investigation 8.1 Investing body shape and temperature regulation

See appendix for equipment list.

1. Divide the class into six groups. Each group should choose a shape/orientation from the descriptions below. You will pool class results to complete the table on the next page.

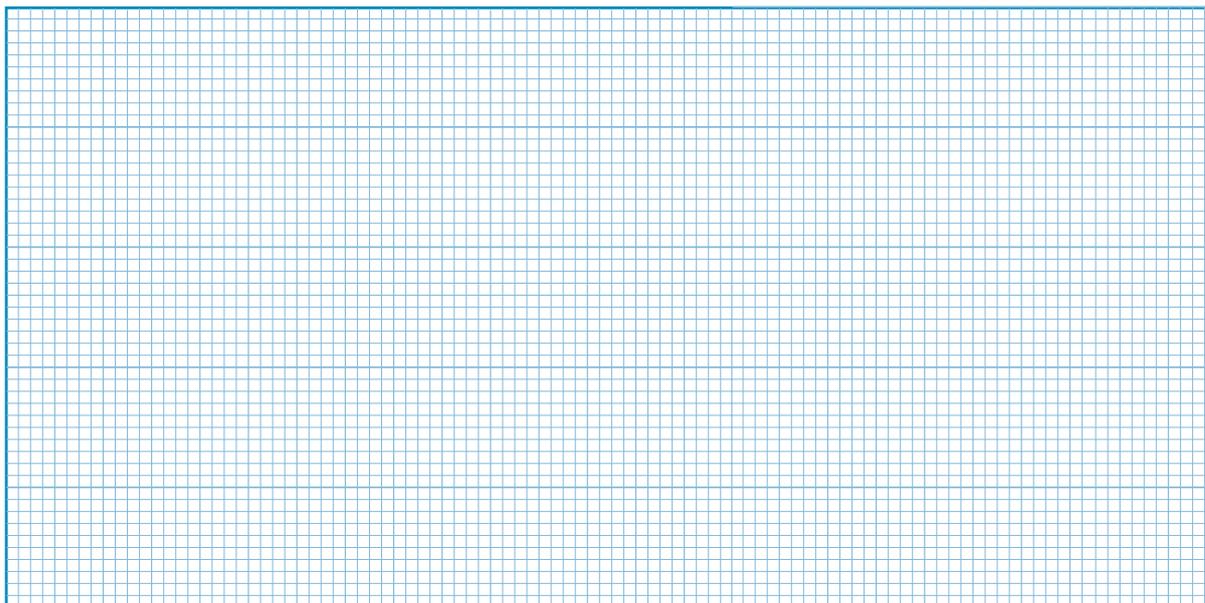
- Shape 1: Foil sphere 3 cm diameter
- Shape 2: Foil sphere 6 cm diameter
- Shape 3: Fusiform (tapered), long side to heat
- Shape 4: Fusiform (tapered), end on to heat
- Shape 5: Fusiform (tapered) with a sail
- Shape 6: Snake-like (thin roll)



2. Record the shape your group is using: \_\_\_\_\_
3. Create your shape using aluminum foil. Use scissors or a compass to make a small entry hole and push a thermometer\* into the center of the shape. Switch the heat lamp on and place the shape 30 cm from it. If you are using shape 3 or 4, you will need to orientate the shape long side (3) or end on (4) to the heat lamp. In the table below, record the temperature every minute for a total of 6 minutes.
  - a. Switch the lamp OFF and record the temperature after 2 minutes in the table on the next page.
  - b. Switch it back ON and record the temperature after 2 minutes in the table on the next page
  - c. Repeat this ON/OFF sequence twice more, recording the temperature in the table on the next page.
4. Switch the lamp OFF and record the temperature every minute for 6 minutes in the table on the next page.
5. Share the results among the class so that you can complete the table for all six aluminum shapes.
6. On the grid on the next page, plot the internal temperature over time for your shape.

\* A datalogger or digital thermometer could be used for more accurate temperature recording.

Shape	Temperature change																	
	Lamp ON 6 minutes						OFF	ON	OFF	ON	OFF	ON	Lamp OFF 6 minutes					
1																		
2																		
3																		
4																		
5																		
6																		



8. Which shape heated up and cooled down the fastest? \_\_\_\_\_

9. Which shape heated up and cooled down the slowest? \_\_\_\_\_

10. (a) Which shape had the most stable temperature during the phase of switching the lamp on and off?

\_\_\_\_\_

(b) Why do you think this was? \_\_\_\_\_

\_\_\_\_\_

11. Does body shape or size have any effect on temperature regulation? Explain: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

12. It is now thought that most Coelurosauria (a group of theropod dinosaurs that included *Tyrannosaurus rex*) had feathers of some kind. What advantage might these have given these dinosaurs over non-feather dinosaurs?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 128 Behavioural Responses for Thermoregulation

**Key Idea:** Thermoregulation is related to energy balance and animals have behavioural responses to reduce energy consumption when energy sources are scarce.

Animals have many different behavioural responses to help them regulate their body temperature. These may be very simple, such as moving out of the sun into the shade, or they may be more complex, such as hibernation over winter or periods of torpor. Endotherms expend large amounts of

energy to maintain a high constant body temperature and high metabolic rate. Periods of reduced activity and low body temperature, such as occur during hibernation, conserve large amounts of energy and enable survival through periods when food is scarce. Such energy savings are particularly important for many small endotherms, because they lose heat very quickly and their per gram metabolic costs are much higher than for larger animals.



Bernard DUPONT CC 2.0

Regulating body temperature can be as simple as moving in or out of the shade. In some cases the shade can be carried around with you as with these cape ground squirrels.



Many animals huddle together in cold conditions to conserve body heat. This behaviour is called **kleptothermy** and it occurs in both endotherms and ectotherms.

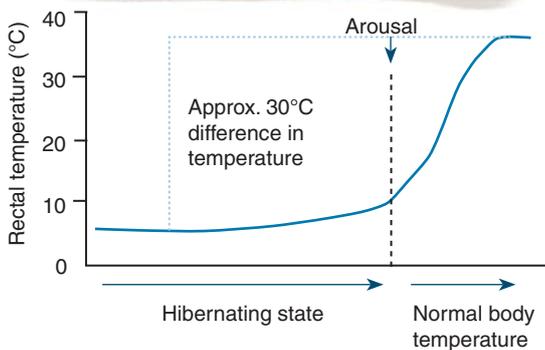


Panting evaporates water from the lining of the oral cavity. In dogs, it is an important way to lose accumulated heat because they only have sweat glands on the pads of their feet.

## Hibernation

Hibernation is a prolonged (usually seasonal) state of reduced activity and reduced metabolic activity, during which body temperature drops. It greatly reduces energy expenditure, allowing the animal to survive winter. Short daylength, low temperatures, and low food availability are strong cues for entering hibernation.

The graph (below) shows body temperature in golden hamsters during hibernation. Note the difference between the animal's normal and hibernating body temperature (~30°C). During hibernation, metabolic activity (blood flow to the brain and respiration rate) significantly decreases. It increases to a maximum during arousal and tapers off once normal body temperature is achieved. The elevated metabolic rate during the arousal period speeds up arousal and rapidly clears waste products from the body.



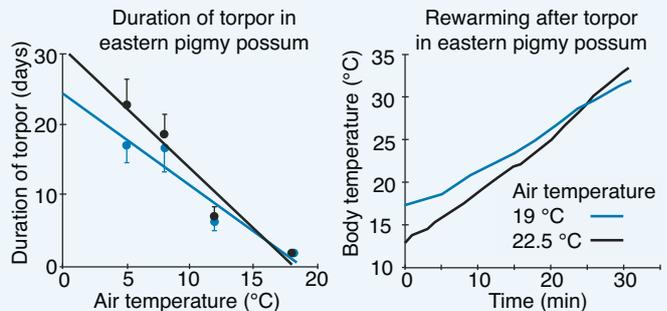
Source: Osborne <http://www.asahikawa-med.ac.jp/dept/mc/phys1/profiles/osborne.html>

## Torpor

Some animals reduce their metabolic activity on a daily (or rather nightly) basis during their sleep. This is called **torpor**. The eastern pigmy possum is found throughout the eastern coast and south of Australia. It weighs up to 43 grams. During winter it carries out daily torpor. The period of the torpor depends on the air temperature. The possum may remain in a torpid state for up to 35 days at a time during winter hibernation and its body temperature may fall as low as 1°C.



Phil Spark CC 2.0

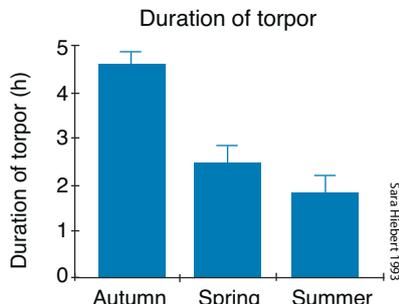
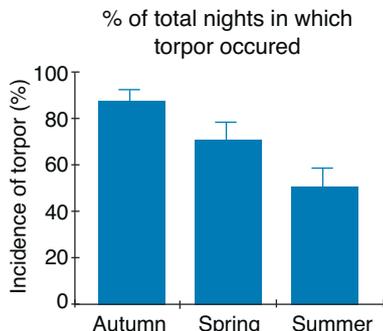


- Two longest bouts of torpor at each temp.
- Undisturbed bouts of torpor

Source: Australian Journal of Zoology, 1993

### Aestivation

Aestivation is a form of hibernation or torpor that occurs during the warmer months of the year rather than the cooler months. In endotherms, it is physiologically difficult to distinguish from torpor (except that occurs in the warmer months). It occurs in many mammals including echidnas, dunnarts (a mouse-sized marsupial), possums, and bats. Many mammals that aestivate enter daily torpor for most months of the year and are constantly active only during the most favourable months (be they the hottest or coolest months depending on the environment). Aestivation is often a response to a lack of food in dry environments. It reduces the need to expend energy keeping cool and can reduce the amount of water lost due to evaporation (by between 20-40% in dunnarts). Aestivation also occurs in some birds, although it is much rarer. Rufous hummingbirds (below) enter a nocturnal torpor during the summer months to reduce thermoregulatory energy expenditure.



- What is the difference between hibernation, torpor, and aestivation? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (a) What are the survival advantages of hibernation? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (b) What are the common environmental cues triggering hibernation and why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (a) What happens to the body temperature of the golden hamster during hibernation? \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Why does this change in temperature occur? \_\_\_\_\_  
 \_\_\_\_\_  
 (c) Explain why blood flow to the brain and respiration rate may peak during arousal from hibernation:  
 \_\_\_\_\_  
 \_\_\_\_\_
- (a) How does air temperature affect the length of bouts of torpor in the eastern pigmy possum? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (b) Why does torpor enhance survival of small endotherms in cold conditions: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- What is often the trigger for aestivation? \_\_\_\_\_  
 \_\_\_\_\_

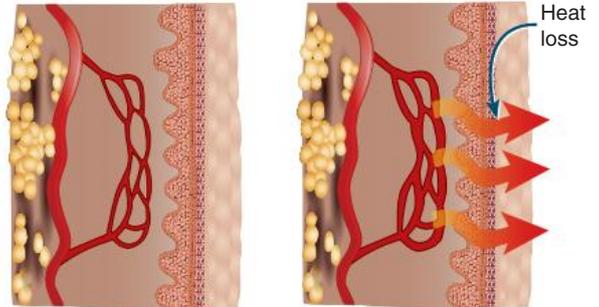
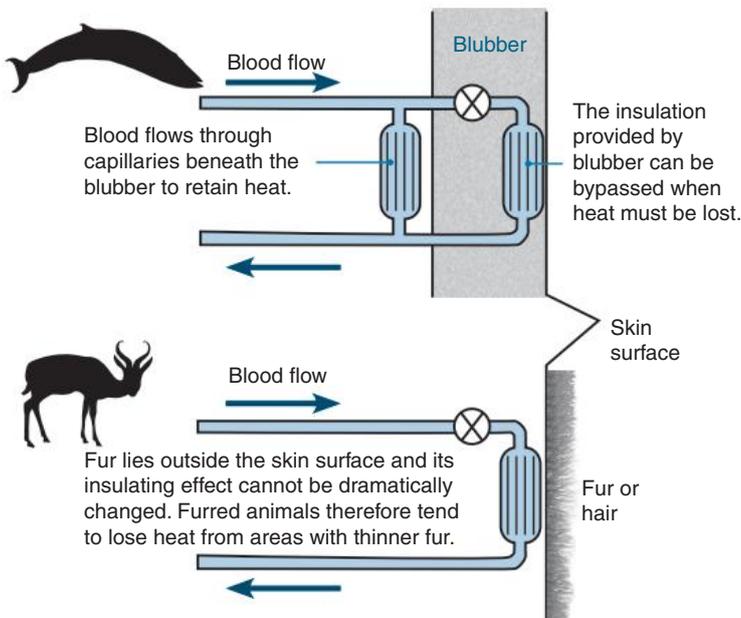
# 129 Physiological Adaptations for Thermoregulation

**Key Idea:** Temperature can be regulated and maintained by internal mechanisms that control energy use and blood flow. Physiological mechanisms are internal mechanisms that affect how the body operates. Mechanisms of physiological

thermoregulation include the use of energy resources (e.g. metabolising fat), changing aspects of metabolism (redirecting chemical reactions), and changing aspects of blood flow (vasoconstriction and countercurrent flows).

## Regulating blood flow to the skin

The blubber in marine mammals provides good insulation against heat loss but presents a problem in warmer waters or during exertion when a lot of metabolic heat is generated. In these situations, blood flows through the blubber to the skin surface where excess heat is dissipated. Cold adapted land mammals have insulation outside the skin and have thinly covered areas on the face and feet, where heat can be lost during exertion.



Vasoconstriction

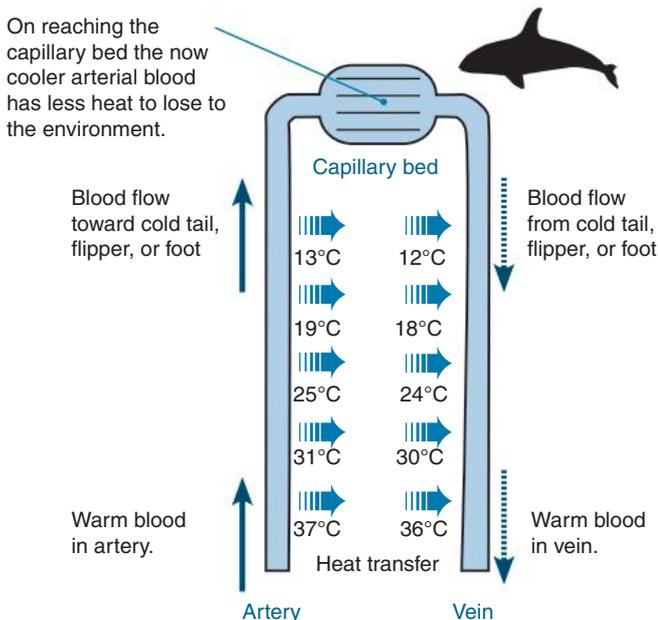
Vasodilation

*Constriction of the capillaries (vasoconstriction) restricts blood flow. Vasodilation allows blood to flow through the capillaries and transport heat from the body to the skin.*

To regulate heat loss or gain from the skin, the blood vessels beneath the skin's surface constrict (**vasoconstriction**) to reduce blood flow or dilate (**vasodilation**) 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 as the hands and feet have additional vascular controls, which can reduce blood flow to them in times of severe cooling. These controls are mediated through the vasomotor centre in the hindbrain and are autonomic (occur without conscious thought).

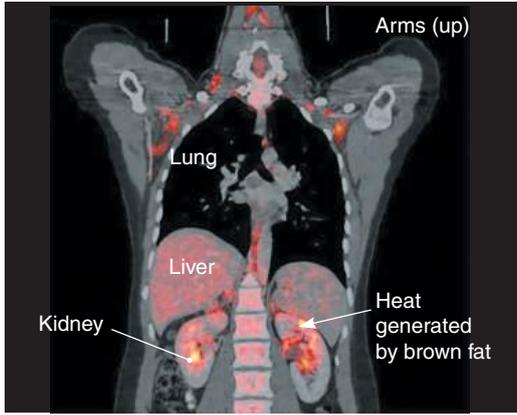
## Countercurrent heat exchangers

Countercurrent systems are found in many homeostatic systems including in the gills of fish and the kidneys and peripheral circulation of mammals. The operation of these systems depends on the animal's environment. Mammals in cold environments use countercurrent exchange to reduce heat losses to the environment. Those in hot environments may use countercurrent exchange to cool arterial blood supply to the brain during intense activity.



**Countercurrent heat exchange systems** occur in both aquatic and terrestrial animals as an adaptation to maintaining a stable core temperature. In the flippers and fins of whales and dolphins, and the legs of aquatic birds, and the feet and tail of platypus, they minimise heat loss. For example many birds are able to stand on ice or swim in ice cold water with no negative cooling effects. In some terrestrial animals adapted to hot climates (e.g. gazelles), heat exchangers work in the opposite way to prevent the brain from overheating. Before it flows to the brain, the arterial blood passes (in small arteries) through a pool of cooler venous blood draining from the nasal area where evaporative cooling occurs.

1. Explain why cold adapted terrestrial mammals have regions of the body with thinner fur: \_\_\_\_\_



**Uncoupling H<sup>+</sup> flow and ATP generation**

In some cells, such as the brown fat cells of mammals, 'uncoupling' proteins in the inner mitochondrial membrane act as channels, allowing protons to pass directly to the matrix of the mitochondria without being used to generate ATP. This allows the energy of the proton gradient to be dissipated, generating body heat (bright spots above).

**Evaporative heat loss**

Evaporative heat loss is an effective way of losing heat. In humans this happens via the production of sweat from sweat glands in the skin. The sweat absorbs heat from the skin which causes it to evaporate. People in warm climates tend to sweat in a more uniform way than those who live in cooler climates. People not acclimatised to warm climates can sweat up to 2 L/hr less than those in warmer climate and the sweat usually beads up and drips off the body.

Not all animals are able to sweat but still carry out evaporative heat loss. Dogs pant, using saliva on the tongue for evaporative cooling. Kangaroos lick their forearms, which have blood vessels close to the surface the skin. Heat is transferred from the skin to the saliva which absorbs the heat and evaporates.

2. (a) Explain how countercurrent heat exchangers help retain body heat in marine mammals: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Explain the thermoregulatory changes a marine mammal would make when moving from colder to warmer waters:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. (a) What is the purpose of sweating and how does it achieve its effect? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Why does a dab of methanol or ethanol on the skin feels cold, even if the liquid is at room temperature? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. How do the blood vessels help to regulate the amount of heat lost from the skin and body?

\_\_\_\_\_

\_\_\_\_\_

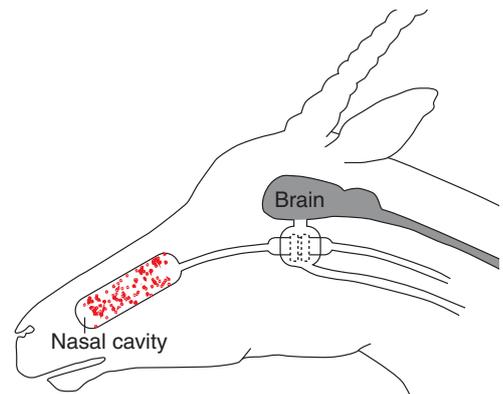
\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

5. The diagram right shows the countercurrent system of blood flow supplying the head of a gazelle. Draw arrows to show the direction of blood flow and label *cooled arterial blood*, *evaporation*, *cool venous blood*, and *warm arterial blood*.



Redrawn from Schmidt-Nielsen, Animal Physiology (1979)

# Adaptation: Galápagos Finches and Darwin

**Key Idea:** The diversity of the Galápagos finches and their adaptations helped Darwin develop his theory of evolution by natural selection.

The Galápagos Islands, 970 km west of Ecuador, are the home of 17 species of related birds known as Darwin's finches or Galápagos finches (one related species is found on Cocos island to the north). They are not related to true finches but in fact related to the grassquits of South America. About 2 million years ago an ancestral species reached the islands and underwent an adaptive radiation (rapid diversification) in response to the availability of numerous unexploited feeding habitats or niches. This can be seen in the beak shape of

the finches, which are adapted for a range of feeding styles, from crushing seeds, to probing holes in branches for insects. Different seed feeding finch species are adapted for feeding on different sized seeds. Larger beaked birds feed on larger seeds, whereas smaller beaked birds feed on smaller seeds. Although, in 1835, Charles Darwin collected the birds and observed their beaks were adapted for different feeding styles, it was John Gould who classified them. It was only after this that the bird's importance was realised. Along with other evidence, the variety of adaptations arising from a single ancestral species helped Darwin develop his theory of evolution by natural selection.

## Beak adaptations and feeding in Galápagos finches

The five species of **tree finches** are largely arboreal (tree dwelling). Their sharp beaks are well suited to grasping insects which form the most of their diet. The sharp beaked finches use tools to extract insects.

The beak of the **warbler finches** are the thinnest of the Galápagos finches. They are used to spear insects and probe flowers for nectar.

The **cactus ground finches** have evolved probing beaks to extract seeds and insects from cacti.

The **vegetarian finch** feeds on buds, leaves, flowers and fruit. Its parrot-like beak is evolved for food manipulation.

**Ground finches**, have crushing type beaks for seed eating. They differ mainly in body size and in the size of their beaks.

Genus: *Platyspiza*, *Canarythraupis*, *Certhidea*, *Geospiza*

Finch: Vegetarian finch, Tree finches, Sharp beaked tree finches, Warbler finches, Sharp beaked ground finches, Cactus finches, Ground finches

Beak type: Grasping beak, Tool Use, Probing beak, Crushing beak

Diet: Fruit eater, Insect eaters, Nectar, blood, Cactus, Seeds

1. What are the main factors that contributed to the adaptive radiation of the Galápagos finches?  


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2. Given that the ancestral finch species radiated into so many different species, what might be said about the feeding and behaviour of the ancestral species?  


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3. Why is the adaptive radiation of the Galápagos finches important in providing evidence for evolution by natural selection?  


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### Adaptations are heritable

Of all the Galápagos Island finches, the medium ground finch (*Geospiza fortis*) is particularly well studied. A population on the island Daphne Major had their beak depth measured shortly before the island experienced a severe drought. Researchers were interested in how the drought had affected the birds and measured the beak depth of the survivors and their offspring.

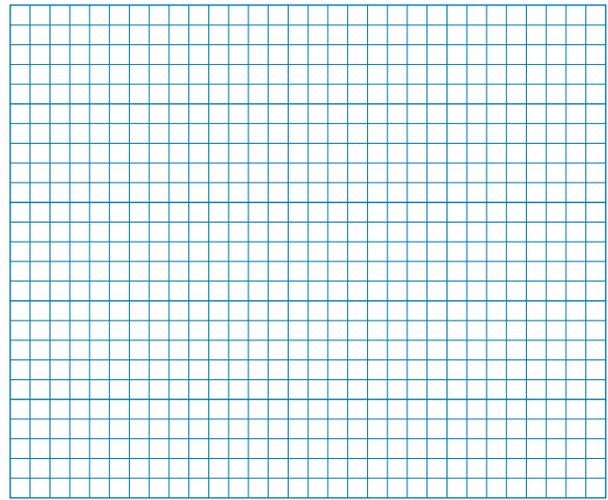
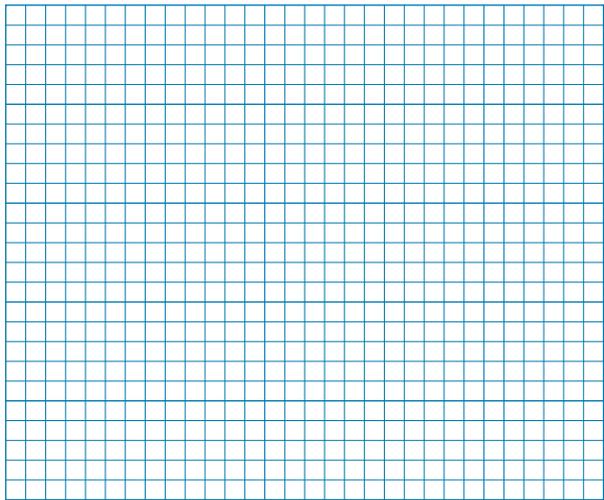
Medium ground finches are seed eaters. Greater beak depths allow the birds to eat larger seeds. In this activity you will analyse data from the measurement of beaks depths of the medium ground finch (below) on the island of Daphne Major near the centre of the Galápagos Islands. The measurements were taken in 1976 before a major drought hit the island and in 1978 after the drought (survivors and survivors' offspring).



Beak depth (mm)	No. 1976 birds	No. 1978 survivors	Beak depth of offspring (mm)	Number of birds
7.30-7.79	1	0	7.30-7.79	2
7.80-8.29	12	1	7.80-8.29	2
8.30-8.79	30	3	8.30-8.79	5
8.80-9.29	47	3	8.80-9.29	21
9.30-9.79	45	6	9.30-9.79	34
9.80-10.29	40	9	9.80-10.29	37
10.30-10.79	25	10	10.30-10.79	19
10.80-11.29	3	1	10.80-11.29	15
11.30+	0	0	11.30+	2

4. Use the data above to draw two separate sets of histograms:

- (a) On the left hand grid draw side-by-side histograms for the number of 1976 birds per beak depth and the number of 1978 survivors per beak depth.
- (b) On the right hand grid draw a histogram of the beak depths of the offspring of the 1978 survivors.



5. (a) Mark the approximate mean beak depth on the graphs of the 1976 beak depths and the 1978 offspring.

(b) How much has the average moved from 1976 to 1978? \_\_\_\_\_

(c) Is beak depth heritable? What does this mean for the process of natural selection in the finches?  
 \_\_\_\_\_  
 \_\_\_\_\_

6. The 1976 drought resulted in plants dying back and not producing seed. Based on the graphs, what can you say about competition between the birds for the remaining seeds, i.e. in what order were the seeds probably used up?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# Adaptation: Australian Flora and Fauna

**Key Idea:** The adaptations of Australian flora and fauna were key to Darwin developing his theory of evolution by natural selection.

Plants and animals have adaptations that help them survive in their natural environment. Unrelated organisms in very similar environments may carry out the same roles and look

superficially similar because the similar adaptations produce similar survival qualities. Therefore some plants and animals native to Australia may look or behave in a similar way to unrelated species elsewhere in the world. Darwin noticed this and wondered why a Creator would produce different animals with the same or similar adaptations.

## Darwin's observations in Australia

### Of the fauna:

▶ Charles Darwin arrived in Sydney, Australia, on the *Beagle* in early 1836. The *Beagle* spent 19 days in Sydney and during that time Darwin travelled inland to the Blue Mountains and locations including Wallerawang and Wentworth Falls. During this trip he made observations of the flora and fauna that, like his observations in the Galápagos Islands, help him develop his theory of evolution by natural selection.

▶ Darwin's journal details encounters with various Australian animals, including the platypus and rat kangaroo (potoroo).

▶ At Wallerawang Darwin encountered a rat kangaroo which he noted was '*an animal as big as a rabbit, but with the figure of a kangaroo.*'

▶ While there he also saw a number of platypus, noting that '*I... had the good fortune to see several of the famous platypus.... They were diving & playing about the surface of the water; but showed very little of their bodies, so that they might easily have been mistaken for many water rats.*' (Note that here Darwin was actually referring to water voles).

▶ Darwin's observations included even the smallest animals. '*I observed the conical pitfall of a Lion-Ant... Without a doubt this predacious larva belongs to the same genus, but to a different species from the European one.*'

▶ Darwin also observed many birds which he described as similar to English birds, such as magpie and crows.

▶ These observations were all made in the space of a few days and made Darwin wonder why a Creator would bother creating different animals that seemed to serve the same ecological purpose: '*An unbeliever in everything beyond his own reason, might exclaim "Surely two distinct Creators must have been [at] work"...* and after observing the lion-ant's nest: '*Now what would the Disbeliever say to this? Would any two workmen ever hit on so beautiful, so simple & yet so artificial a contrivance?*'

### Of the flora:

▶ Darwin collected few plants while in Australia and his notes are few. However he does record a good description of the adaptations of eucalypts and notes their differences compared to European trees: '*the foliage is... of a rather peculiar light green tint; it is not periodically shed and the surface of the leaves are placed in a vertical, instead of as in Europe a nearly horizontal position.*'

▶ Darwin also noted that the bark of the trees was annually shed, and often hung in long shreds swinging in the wind, giving the landscape an 'untidy' and 'desolate appearance'.



1. Why might eucalypts have leaves that hang vertically, instead of being held horizontal? \_\_\_\_\_

\_\_\_\_\_

2. What was the importance of Darwin's observations of the different adaptations of plants and animals? \_\_\_\_\_

\_\_\_\_\_

# 132 Plant Adaptations

**Key Idea:** Plants, like animals are adapted to survive in the environment they live and grow in. Many Australian plants are adapted to arid environments.

Many Australian plants are unique and adapted to the uniquely Australian environment. Arid land, prone to fire,

makes up a large part of the country and many plants are adapted to take advantage of this. Mangroves are found all round the coast of Australia, except in a few parts of the southern coast, and these are adapted to deal with the high levels of salt and the tidal environment.

## Plant adaptations to 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.



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.



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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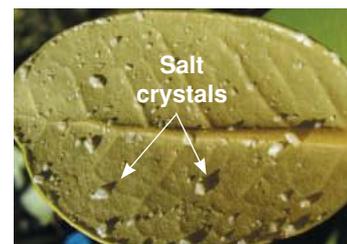
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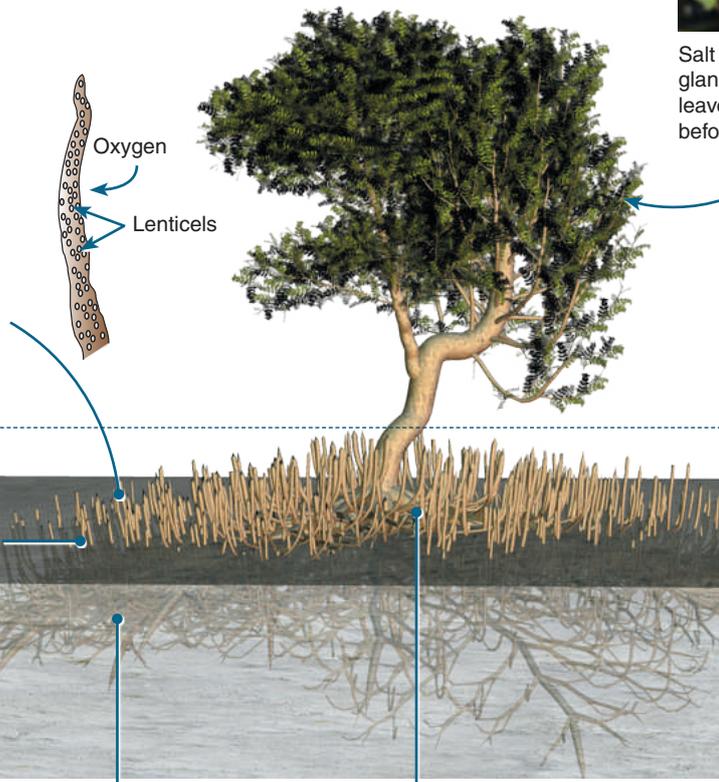
### Adaptations in mangroves

- ▶ 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.

3. What two physical adaptations of mangroves provide support for the plant in the soft mud?
  - (a) \_\_\_\_\_
  - (b) \_\_\_\_\_
4. What is the purpose of pneumatophores? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
5. Describe a physiological problem associated with living in a high-salt substrate: \_\_\_\_\_  
 \_\_\_\_\_
6. Describe three methods by which various mangrove species solve the problem of a high salt environment:
  - (a) \_\_\_\_\_
  - (b) \_\_\_\_\_
  - (c) \_\_\_\_\_



## Investigation 8.2 Exploring aquatic plant adaptations

See appendix for equipment list.

You can work in pairs for this activity if you wish.

1. Your teacher will provide you with samples of a hydrophyte (a water living plant) such as a water lily.
2. Using microscope slides and observation of macroscopic features identify adaptations that help the plant survive in an aquatic environment.
3. Refer to activity 17 on making and observing slides to make slides of the stem and leaves.
4. Take notes and draw diagrams in the space below to show the general structure of the stem.
5. Take notes and draw diagrams in the space below showing the placement of the stomata on the leaves.

Stephen Moore



*Myriophyllum*'s submerged leaves are well spaced and taper to the surface to help with gas exchange and distribution of sunlight.



Aquatic plants still bear flowers above the water so they are still accessible to pollinators.



Duckweed is a common Australian aquatic plant. It is often seen floating on the surface of ponds. Its leaves are just a few mm across.

7. What did you notice about the placement of stomata on the leaves of aquatic plants? \_\_\_\_\_  
\_\_\_\_\_
8. What did you notice about the general structure of the stem? \_\_\_\_\_  
\_\_\_\_\_
9. Why do hydrophytic plants retain an aerial (above water) flowering system? \_\_\_\_\_  
\_\_\_\_\_



# Theory of Evolution by Natural Selection

Activity  
number

## Key terms

adaptive radiation  
 allopatric speciation  
 convergent evolution  
 divergent evolution  
 directional selection  
 disruptive selection  
 DNA  
 gene flow  
 gene pool  
 microevolution  
 natural selection  
 phenotype  
 phyletic gradualism  
 punctuated equilibrium  
 speciation  
 stabilising selection  
 sympatric speciation

*Inquiry question: What is the relationship between evolution and biodiversity?*

## Natural selection and changes in gene pools

### Key skills and knowledge

- |                          |   |         |
|--------------------------|---|---------|
| <input type="checkbox"/> | 1 Examine Earth's evolutionary history. Understand that evolution is a continuous process and that the present biodiversity on Earth is the result of billions of years of natural selection.   | 134     |
| <input type="checkbox"/> | 2 Define microevolution. Recognise natural selection as one of the four important microevolutionary processes in gene pools. Explain how natural selection sorts natural variation and establishes adaptive phenotypes (physical characteristics). Understand that natural selection is simply the differential survival and reproduction of individuals due to differences in phenotype. It selects for adaptive phenotypes and against phenotypes that are less well suited to the environment at the time. | 135 136 |
| <input type="checkbox"/> | 3 Explain biological diversity in terms of Darwin's theory of evolution by natural selection. Show how natural selection can result in genetic changes in a population over time.   | 137     |
| <input type="checkbox"/> | 4 Interpret data and describe the three main types of natural selection: stabilising selection, directional selection, and disruptive selection. Using examples, explain how each type affects the phenotypic mean and the environmental conditions under which each type is likely to operate.   | 137     |



## Species formation

### Key skills and knowledge

- |                          |  |         |
|--------------------------|--|---------|
| <input type="checkbox"/> | 5 Examine the stages of speciation. Recognise that the gradual changes brought about by natural selection can result in larger changes over times, and may result in the formation of new species. | 138     |
| <input type="checkbox"/> | 6 Identify and describe different modes of speciation: allopatric and sympatric. Interpret data from different populations as evidence for speciation. Explain how instant speciation can occur.   | 139 140 |
| <input type="checkbox"/> | 7 Explain how new species result from the accumulations of small changes over time using the examples of horses, whales, and platypus.   | 141-143 |

## Patterns of evolution

### Key skills and knowledge

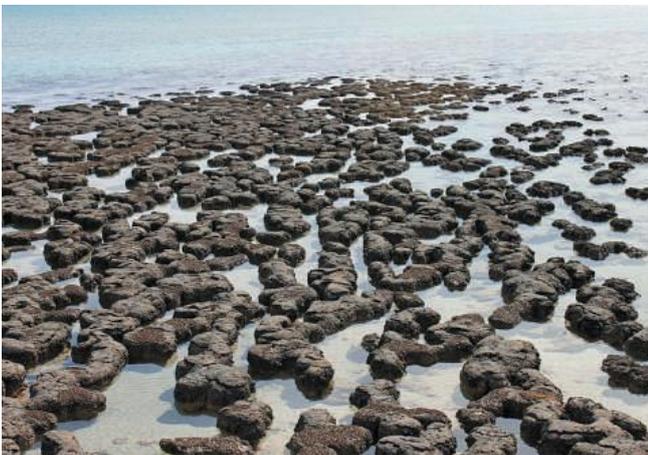
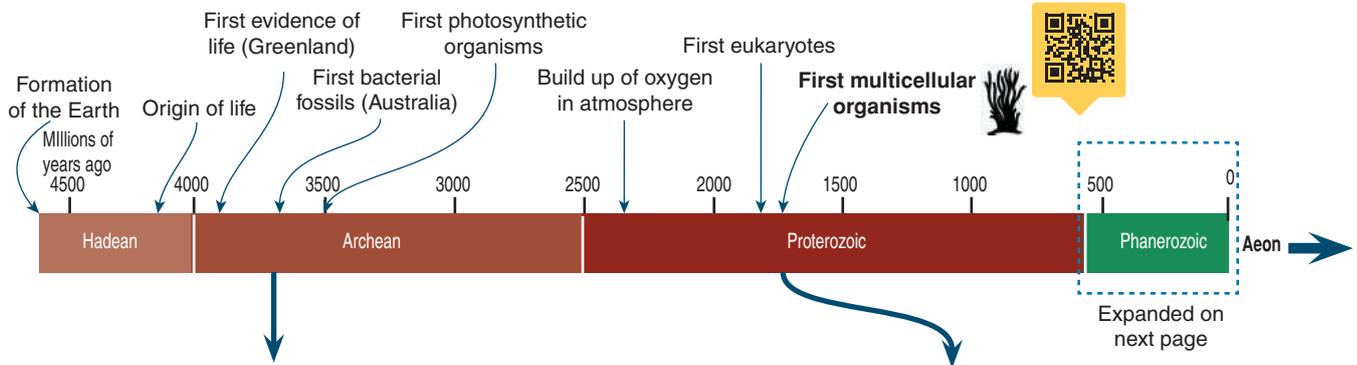
- |                          |   |                |
|--------------------------|---|----------------|
| <input type="checkbox"/> | 8 Understand that speciation can result from the accumulation of microevolutionary changes over time. Distinguish between main patterns of evolution and describe the features of each: <ul style="list-style-type: none"> <li>• divergent evolution (including radiations)</li> <li>• convergent evolution (including analogous structures)</li> </ul> | 144            |
| <input type="checkbox"/> | 9 Understand that the pace of speciation can vary, as described by the punctuated equilibrium and the phyletic gradualism models.   | 146            |
| <input type="checkbox"/> | 10 Recognise and describe examples of divergent evolution, including evolutionary radiations such as the adaptive radiation of the mammals. How does the theory of evolution account for divergent evolution?   | 145 147<br>148 |
| <input type="checkbox"/> | 11 Recognise and describe examples of convergent evolution. Explain how the theory of evolution accounts for convergent evolution.  | 149 150        |

# 134 Earth's Evolutionary History

**Key Idea:** Life on Earth originated about 4100 million years ago, but complex life evolved much more recently than this. Life forms on Earth originally arose from primitive cells living some 4100 million years ago in conditions quite different to those on Earth today. The earliest fossil records of living things show only simple cell types. It is thought that the first cells arose as a result of evolution at the chemical level in a 'primordial soup' (a rich broth of chemicals in a warm pool of

water, perhaps near a volcanic vent). Life appears very early in Earth's history, but did not evolve beyond the single cell stage until much later (about 600 mya). This would suggest that the evolution of complex life forms required greater hurdles to be overcome. The build up of free atmospheric oxygen, released as a by-product of oxygenic photosynthesis, was important for the evolution of eukaryotes and paved the way for the evolution of multicellular life.

## Time line of Earth's biodiversity



**Stromatolites**, such as the ones shown above from Shark Bay, Western Australia, represent some of the most ancient living things on Earth. Few examples exist today, but fossil remains can be dated back to 3.7 billion years ago. Stromatolites are rock like structures formed from the accretion of sediment by microorganisms, especially cyanobacteria (blue-green photosynthetic bacteria). Ancient representatives of cyanobacteria are thought to have been responsible for the production of oxygen in the atmosphere after they evolved oxygenic photosynthesis (light capture and carbon fixation resulting in oxygen production). It resulted in what is called the Great Oxygenation Event (a rise in atmospheric oxygen), which caused the extinction of many anaerobic bacteria but eventually led to the rise of multicellular life forms.



**Multicellular organisms** arose soon after the evolution of eukaryotes. Multicellularity was a major evolutionary event as it allowed organisms to diversify the tissues and cells of their bodies to perform specialised tasks. The origin of multicellularity is much debated but one hypothesis is that unicellular organisms began to associate together (e.g. cyanobacteria stick together after they divide and form long chains called filaments). Different cells in the group produced molecules useful to others and so the group benefited by staying together. As the different cell lines became more dependent on others for certain molecules, a greater need to remain together also developed (in low nitrogen conditions, some of the cells in filamentous cyanobacteria transform into nitrogen-fixing cells, and this benefits the other cells in the filament).

- (a) What was the significance of the buildup of free oxygen in the atmosphere for the evolution of life?

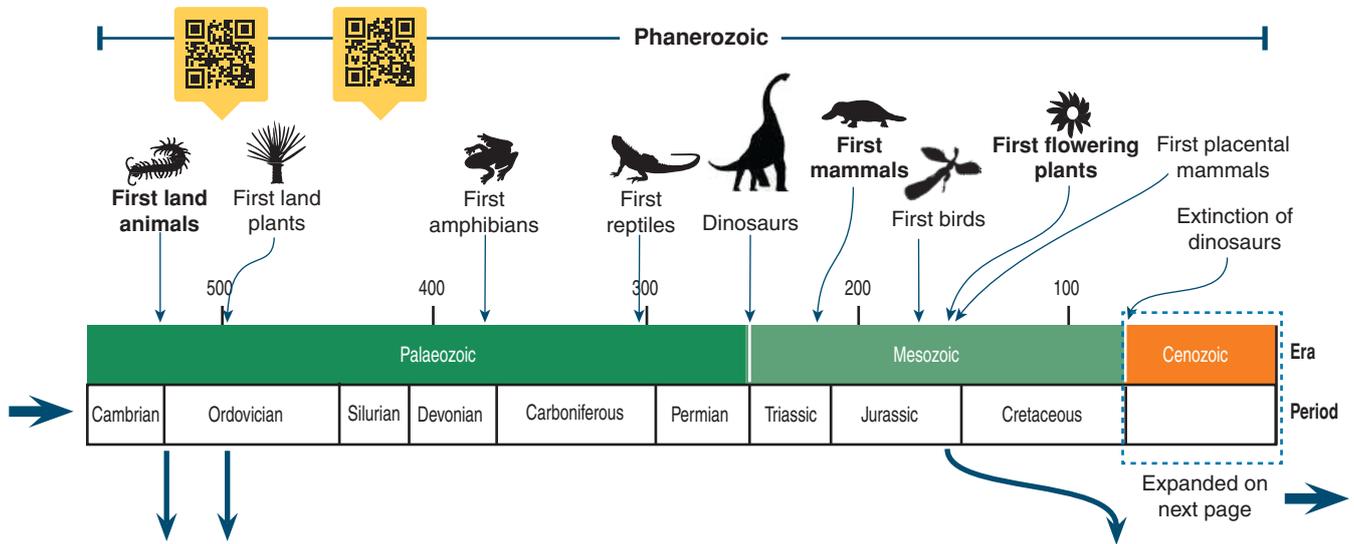
\_\_\_\_\_

\_\_\_\_\_
- (b) How long did it take for free oxygen to build up in the atmosphere? \_\_\_\_\_
- Explain how multicellular life evolved: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_





Ashley Dacey

*Arthropleura* (extinct millipede) tracks



**Animals** may have ventured onto land before plants, with evidence suggesting they did so about 530 million years ago. The earliest land animals were invertebrates, perhaps similar to horseshoe crabs, which come ashore to lay eggs on the sand. Strategies like this would have been an advantage at a time when there were no land animals to eat the eggs. Similarly, some of the first excursions onto land may have been to take refuge from aquatic predators. **Plants** may have arrived soon after animals, possibly as early as 500 million years ago. The earliest terrestrial plants had no vascular tissue, like mosses and liverworts today. Vascular plants (e.g. ferns) did not appear until about 425 million years ago but (like many animal taxa) underwent a number of **evolutionary radiations** (increases in taxonomic diversity) once they colonised land.

**Flowering plants** (angiosperms) are the most successful terrestrial plants. With at least 350,000 species, they make up 90% of all living plant species. Flowering plants first appeared about 160 million years ago. They began to diversify rapidly about 120 million years ago. The evolution of flowers helped to make sexual reproduction more efficient. Flowers attracted insects (and later birds) with the use of colours and rewards (such as nectar). The insects and birds then spread pollen from flower to flower. This system has become so successful that many insects and birds now rely on flowers for food and plants rely on their pollinators for reproduction. Genetic evidence suggests the evolution of flowers was linked to at least two rounds of whole genome duplication, which might explain why angiosperms appeared suddenly in the fossil record.

3. What were the earliest land animals and what circumstances may have caused them to come on to the land?

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4. Explain why the evolution of flowers was an advantage to plants. What was the result?

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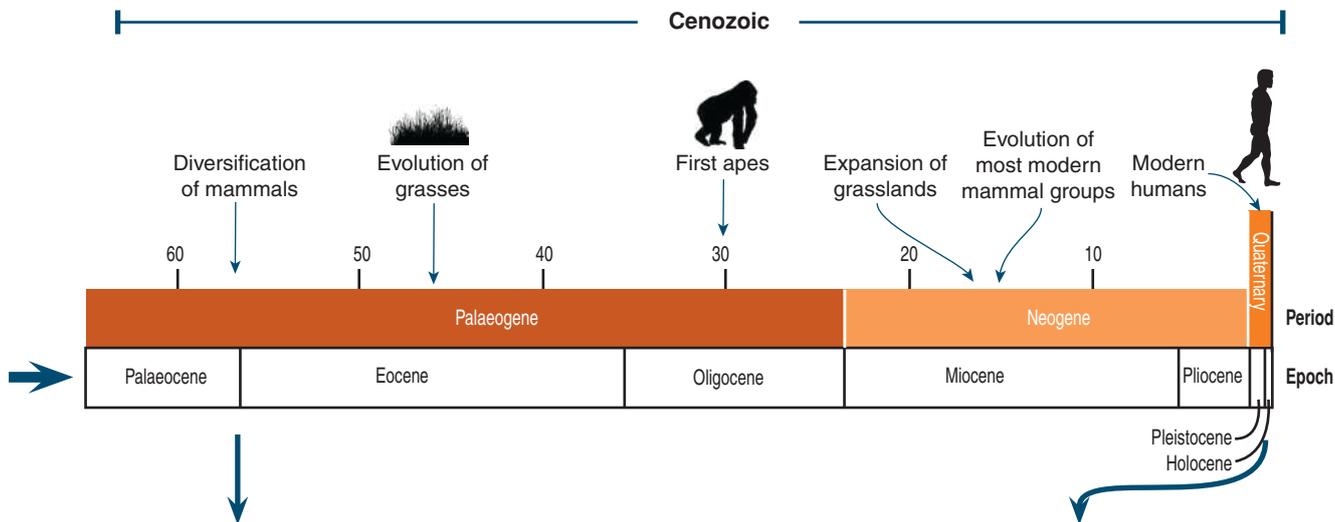
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Both photos NASA

**Mammalian** evolution can be traced back to the Carboniferous period with the appearance of the synapsids (e.g. *Dimetrodon*), one of the two major groups of tetrapod vertebrates (the other clade gave rise to the reptiles and birds). However it was not until the Triassic period that the first true mammals appeared. The monotremes (egg laying mammals) appeared about 210 million years ago. Marsupials and placentals probably split about 160 million years ago. Today marsupials are found almost exclusively in Central and South America and Australia (the North American opossum being the exception). While there are 334 species of marsupials, there are over 5000 known species of placental mammal. The evolutionary radiation of the mammal lineage happened after the extinction of the dinosaurs at the end of the Cretaceous. Mammals diversified rapidly to occupy the vacant niches and give rise to the many taxa we see today.

**Human** ancestors first appeared about 4 million years ago, with the genus *Homo* appearing about 2 million years ago. Modern humans evolved in Africa about 200,000 years ago. In the short time since then, humans have spread across the globe and now influence every single part of the planet in a way no other living thing ever has since photosynthetic organisms changed the nature of the atmosphere 3 billion years ago. Humans, however, have changed the planet in a much shorter time scale, so much so that it has been suggested that the epoch of recent human existence should be called the Anthropocene. This would have begun the same time that humans began to change the Earth on a large scale, perhaps 12,000 years ago, although some proposals would define it as beginning with the Trinity nuclear test in 1945. In many cases, evidence of human activity can be seen in changes in sediments, especially in lake beds (above).

5. Explain why mammals did not diversify until the Palaeocene epoch, even though they first appeared in the Triassic period.

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6. The evolution of life on Earth is a history of some lineages diversifying over time and some lineages dying out. Use some examples to explain why diversification takes place:

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# 135 Mechanism of Natural Selection

**Key Idea:** Natural selection is the evolutionary mechanism by which organisms that are better adapted to their environment survive to produce a greater number of offspring. Evolution is simply the change in inherited characteristics in a population over generations. Darwin recognised this as

the consequence of four interacting factors: (1) the capacity of populations to increase in numbers, (2) the phenotypic (physical characteristics) variation of individuals, (3) that there is competition for resources, and (4) proliferation of individuals with better survival and reproduction.

**Natural selection** is the varying survival and reproduction of individuals due to differences in phenotype. Organisms with more favourable phenotypes will survive in greater numbers to produce a greater number of viable offspring. The proportion of their genetic material (DNA) in subsequent generations will therefore increase. This is the basis of Darwin's theory of evolution by natural selection. Natural selection is one of the most important microevolutionary processes.

We can demonstrate the basic principles of evolution using the analogy of a 'population' of M&M's candy.



#1  
In a bag of M&M's, there are many colours, which represents the variation in a population. As you and a friend eat through the bag of candy, you both leave the blue ones, which you both dislike, and return them to the bag.



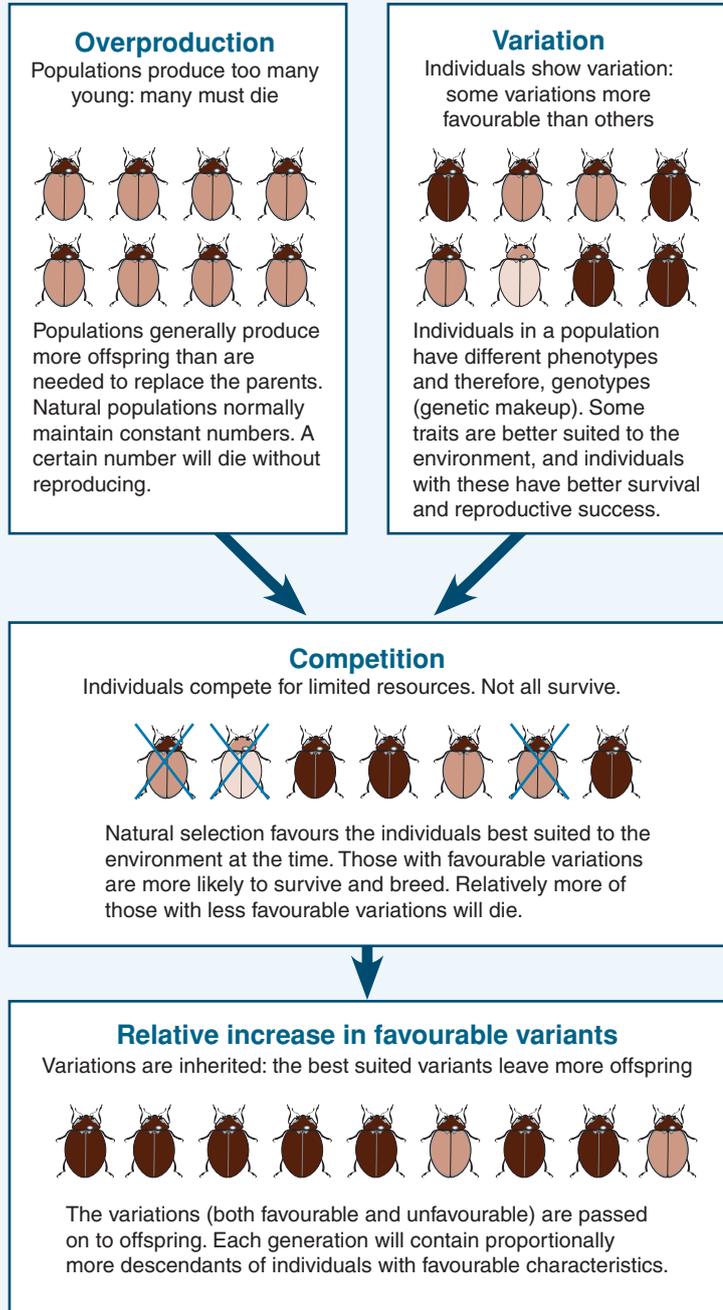
#2  
The blue candy becomes more common...



#3  
Eventually, you are left with a bag of blue M&M's. Your selective preference for the other colours changed the make-up of the M&M's population. This is the basic principle of selection that drives evolution in natural populations.

## Darwin's theory of evolution by natural selection

Darwin's theory of evolution by natural selection is outlined below. It is widely accepted by the scientific community today and is one of founding principles of modern science.



1. Identify the four factors that interact to bring about evolution in populations: \_\_\_\_\_

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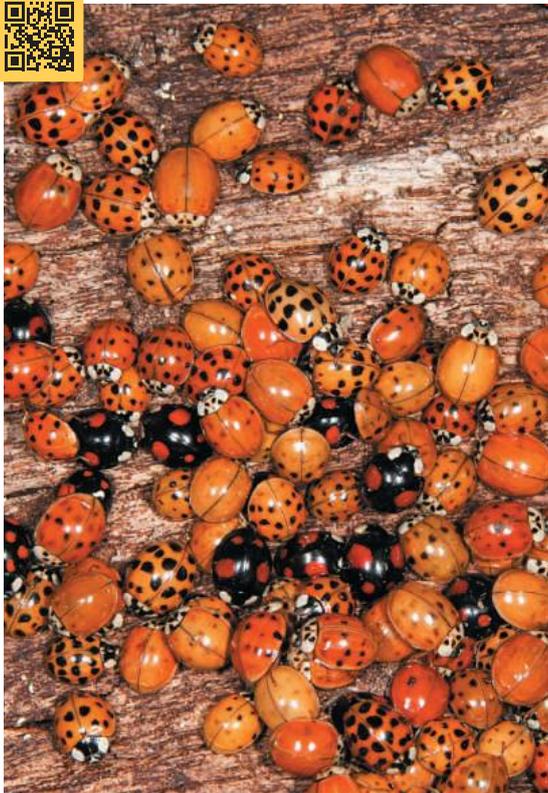


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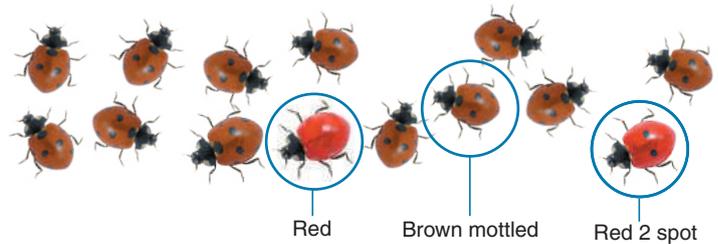
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### Variation, selection, and population change



**1. Variation through mutation and sexual reproduction:**

In a population of brown beetles, mutations independently produce red colouration and 2 spot marking on the wings. The individuals in the population compete for limited resources.



**2. Selective predation:**

Brown mottled beetles are eaten by birds but red ones are avoided.



**3. Change in the genetics of the population:**

Red beetles have better survival and fitness and become more numerous with each generation. Brown beetles have poor fitness and become rare.



Natural populations, like the ladybird population above, show genetic variation (and therefore different phenotypes). This is a result of **mutation** (which alters and creates new genetic material) and **sexual reproduction** (which produces new combinations of genetic material). Some phenotypic variants are more suited to the environment of the time than others. These variants will leave more offspring, as described for the hypothetical population (right).

2. What process creates new genetic material? \_\_\_\_\_
3. Give your own definition of evolution: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
4. Explain how the genetic make-up of a population can change over time: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
5. Complete the table below by calculating the percentage of beetles in the example above right.

Beetle population	% Brown beetles	% Red beetles	% Red beetles with spots
1	(a)	(b)	(c)
2	(d)	(e)	(f)
3	(g)	(h)	(i)

# 136 Microevolutionary Processes in Gene Pools

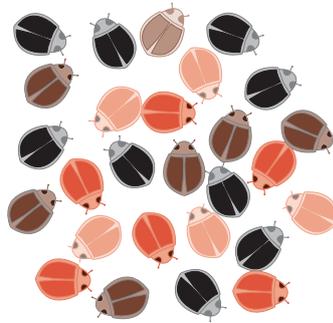
**Key Idea:** Mutations, gene flow, genetic drift, and natural selection all contribute to changes in the genetic makeup of a population.

The total genetic material of a population is called its **gene pool**. Changes in a population's gene pool over time is what we call **evolution**. Four microevolutionary processes can contribute to genetic change in populations. **Mutation** alters the genetic material and produces new genetic variations.

Migration creates **gene flow** as genetic material enters or leaves a population. **Natural selection** sorts variation and establishes adaptive phenotypes (physical characteristics) and is a major agent of evolution. **Genetic drift** alters the frequency of genetic variants randomly and its effects are due to chance events. Increasingly, genetic drift is being recognised as an important agent of change, especially in small, isolated populations (e.g. island colonisers).

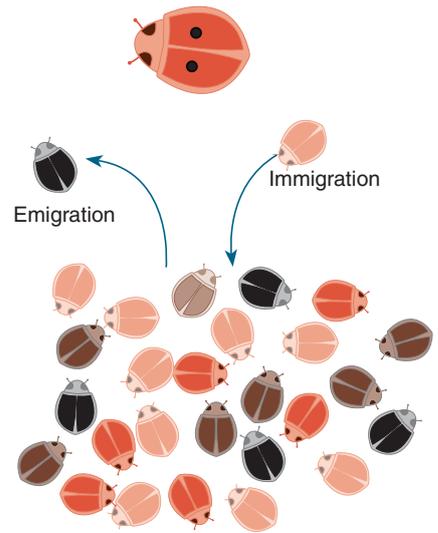
## Genetic variation

Genetic variation produces **phenotypic variation** (e.g. colour of ladybirds). It is this phenotypic variation that is the raw material for natural selection. This ladybird population has five different phenotypes (black, dark brown, tan, brick red, and pale).



Genetic variation arises through mutations and the recombination of genetic material through sexual reproduction.

For example, a **mutation** produces a ladybird with a new spotted phenotype (below).



## Natural selection

Natural selection acts on populations to maintain favourable phenotypes and eliminate unfavourable phenotypes. Over time, favourable phenotypes become more common in the population because those individuals reproduce more.

For example, black ladybirds are more easily seen by birds and are eaten more often than the other phenotypes. The lighter phenotypes become more common in the next generation.

## Genetic drift

Genetic drift is the change in the frequency of specific genetic variations due to random events. Genetic drift has a more pronounced effect in small populations.

For example, falling rocks kill a number of ladybirds, but more of the dark brown ladybirds are crushed than any other phenotype. The proportion of dark brown ladybirds remaining in the population is drastically reduced, and their representation in the next generation is also reduced.

## Migration (gene flow)

Migration is the movement of individuals into and out of a population. Through immigration or emigration, genetic variants can enter or leave the population. Gene flow tends to decrease the genetic differences between populations because genetic material is being exchanged.

In the example above, several black ladybirds have left and some very pale ladybirds have arrived changing the proportion of remaining phenotypes in the population.

1. Clearly explain what is meant by the following terms:

(a) Gene flow: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) Genetic drift: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) Natural selection: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. In the examples below right a hypothetical population is made up of individuals that may be one of two different colours, brown or light brown. Colour is the result of an individual's genetic make up. Brown individuals have a genetic make up represented by the letters **AA** or **Aa**. Light brown individuals have the genetic make up represented by the letters **aa**. The interbreeding of the different individuals affects the proportion of **AA**, **Aa**, and **aa** individuals in the next generation, and so can affect the evolution of a population. For each of the factors below explain why the factor that favours evolution does so. Use the diagrams to help you.

(a) Population size: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Mate selection: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Gene flow: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(d) Mutation: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(e) Natural selection: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. Identify a factor that tends to:

(a) Increase genetic variation in populations:

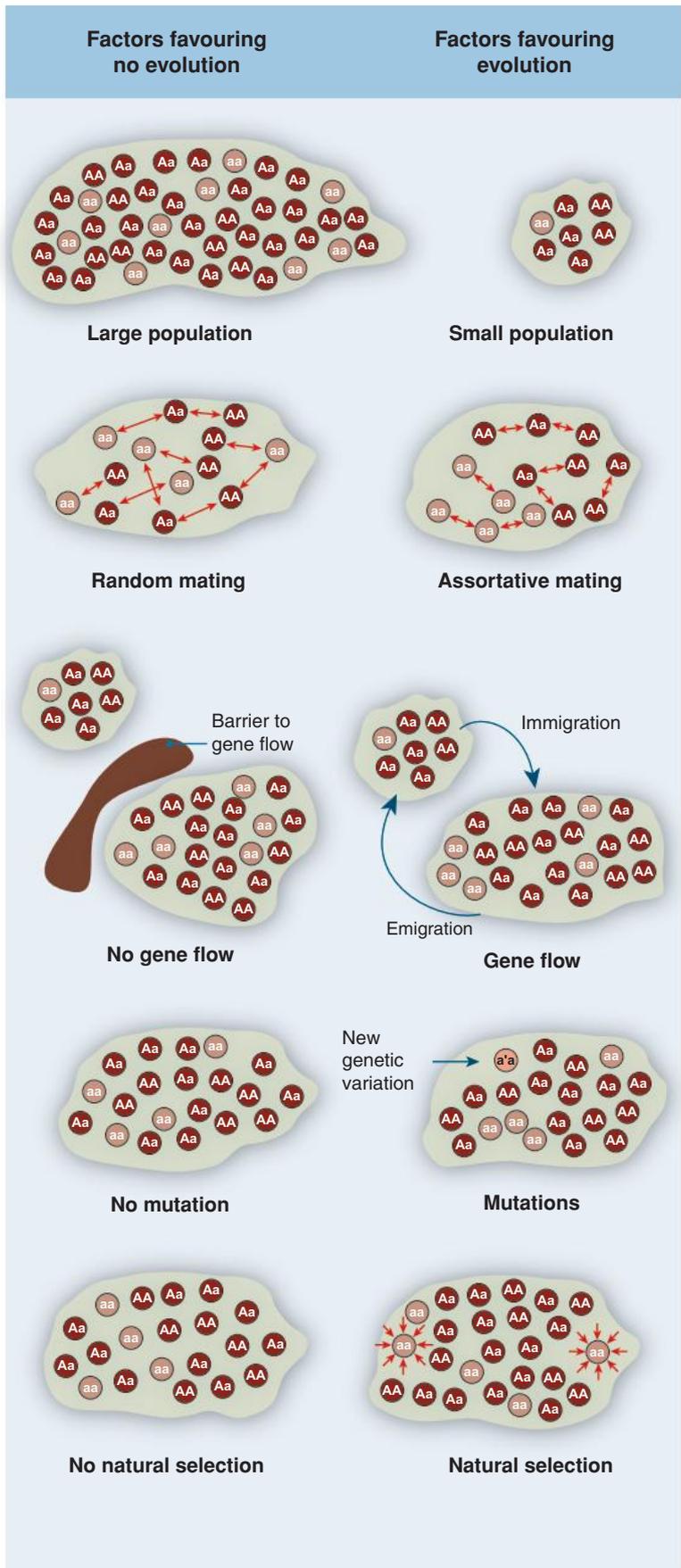
\_\_\_\_\_

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(b) Decrease genetic variation in populations:

\_\_\_\_\_

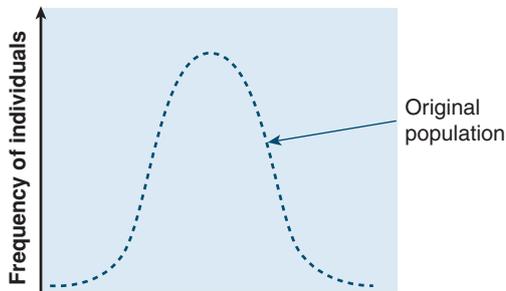
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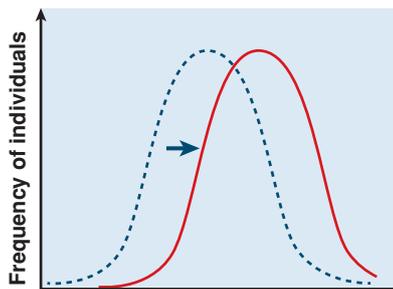
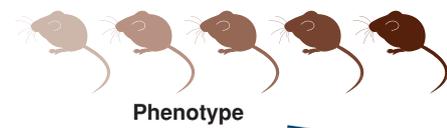
# 137 Natural Selection and Evolutionary Change

**Key Idea:** Natural selection is responsible for the differential survival of some phenotypes (and the associated DNA) over others. It is an important cause of genetic change in populations. Natural selection operates on the phenotypes of individuals, produced by their particular genetic make up in the particular environment. It results in the differential survival of some phenotypes over others. Individuals with phenotypes better

suited to the environment at the time will become relatively more numerous in the population. Over time, natural selection may lead to a permanent change in the genetic makeup of a population. Natural selection is always linked to the suitability of the phenotype to the current environment so it is a dynamic process. It may favour existing phenotypes or shift the phenotypic median, as is shown below.

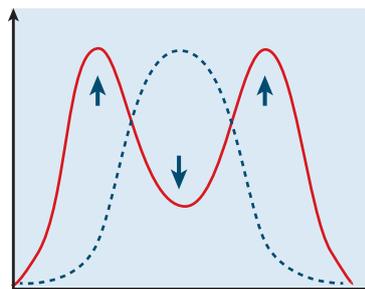


Natural selection acts on phenotypic variation. Even slight variations may be enough for selection to occur. The white streak on the mouse on the right may make it stand out to predators. The darker mouse may be able to more easily hide in the shadows.



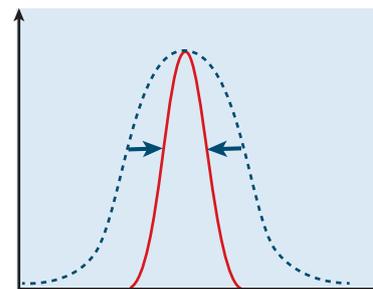
**Directional selection**

An environmental pressure, e.g. predation, or higher temperatures, selects against one of the phenotypic extremes. The adaptive phenotype is shifted in one direction and one phenotype is favoured over others.



**Disruptive selection**

Disruptive selection favours two phenotypic extremes at the expense of intermediate forms. Disruptive selection may occur when environments or resources are fluctuating or distinctly divergent.



**Stabilising selection**

Extreme variations are selected against and the middle range (most common) phenotypes are retained in greater numbers. Stabilising selection decreases variation for the phenotypic character involved.

1. Explain why fluctuating (as opposed to stable) environments favour disruptive (diversifying) selection:

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2. What would be the likely effect of rapid environmental change on a population with very low phenotypic variation?

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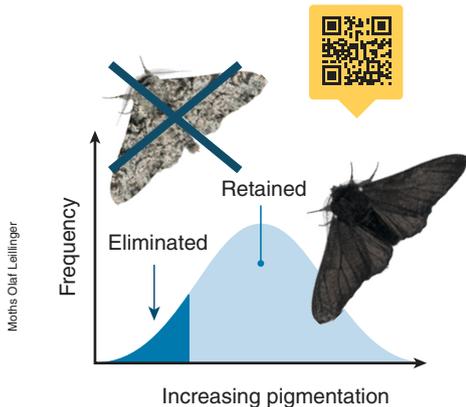
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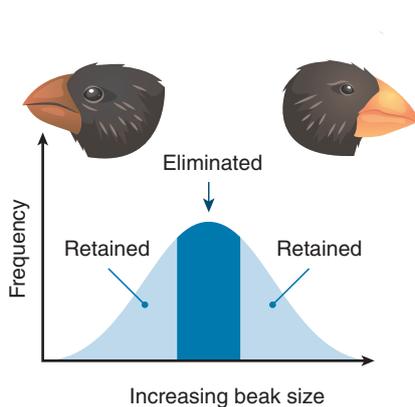
### Examples of selection

#### Directional selection



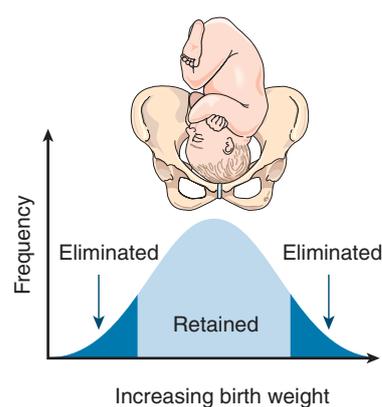
Directional selection was observed in peppered moths in England during the Industrial Revolution when soot-covered trees were common. In England's current environment, the selection pressures on the moths are more balanced, although lighter morphs predominate.

#### Disruptive selection



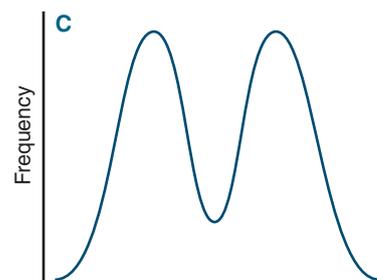
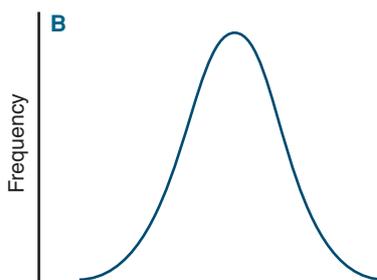
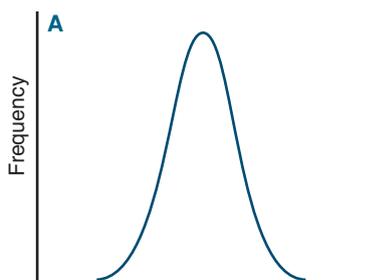
During a prolonged drought on Santa Cruz Island in the Galápagos, it resulted in a population of ground finches that was bimodal for beak size. Competition for the usual medium-sized seed sources was so intense that selection favoured birds able to exploit either small or large seeds.

#### Stabilising selection



Stabilising selection operates most of the time in most populations and acts to prevent divergence from the adaptive phenotype, e.g. birth weight of human infants or number of eggs laid in a nest.

3. Which of the graphs below relate to the examples above:



- A: \_\_\_\_\_
- B: \_\_\_\_\_
- C: \_\_\_\_\_

4. Disruptive selection can be important in the formation of new species:

(a) Describe the evidence from the ground finches on Santa Cruz Island that provides support for this statement:

\_\_\_\_\_

\_\_\_\_\_

(b) The ground finches on Santa Cruz Island are one interbreeding population with a strongly bimodal distribution for the phenotypic character beak size. Suggest what conditions could lead to the two phenotypic extremes diverging further:

\_\_\_\_\_

(c) Predict the consequences of the end of the drought and an increased abundance of medium sized seeds as food:

\_\_\_\_\_

5. Explain why the number of eggs in a bird's nest is most likely governed by stabilising selection:

\_\_\_\_\_

\_\_\_\_\_

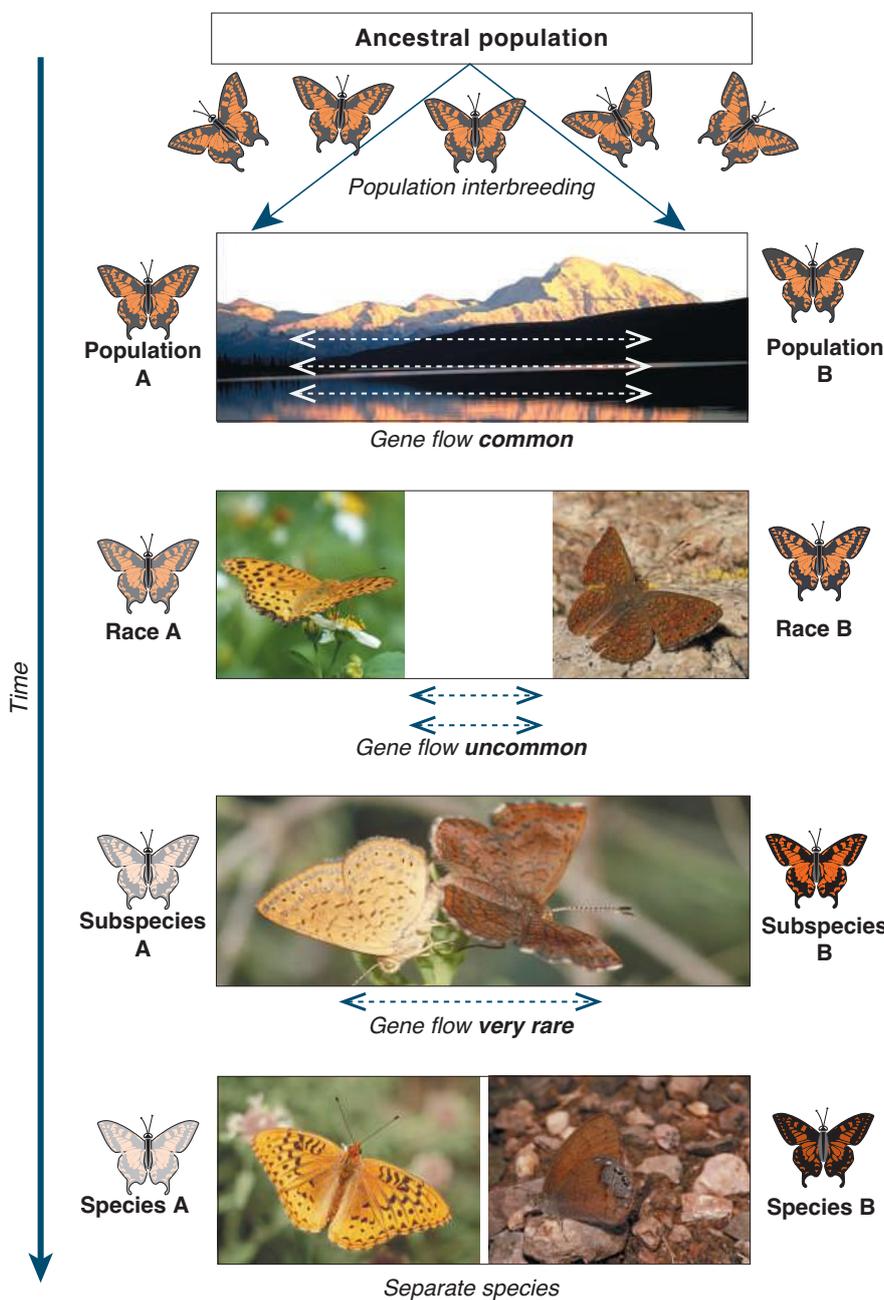
\_\_\_\_\_

# 138 Stages in Species Formation

**Key Idea:** Speciation may occur in stages marked by increasing isolation of diverging gene pools. Physical separation is followed by increasing reproductive isolation.

Enough microevolutionary changes in a population can eventually lead to the formation of a new species. The diagram below shows a possible sequence of events in the origin of two new species from an ancestral population.

Over time, the genetic differences between two populations increase and the populations become increasingly isolated from each other. The isolation of the two gene pools may begin with a geographical barrier. This may be followed by progressively greater reduction in gene flow between the populations until the two gene pools are isolated and they each attain species status.



A species of butterfly lives on a plateau. The plateau is covered with grassland strewn with boulders. During colder weather, some butterflies sit on the sun-heated boulders to absorb the heat, while others retreat to the lower altitude grassland to avoid the cold.

Continued mountain building raises the altitude of the plateau, separating two populations of butterflies, one in the highlands the other in the lowlands.

In the highlands, boulder-sitting butterflies (BSBs) do better than grass-sitting butterflies (GSBs). In the lowlands, the opposite is true. BSBs only mate on boulders with other BSBs. Darker BSBs have greater fitness than light BSBs. (they can absorb more heat from the boulders). In the lowlands, light GSBs blend in with the grass and avoid predators better than darker butterflies.

Over time, only boulder-sitting butterflies are found in the highlands and grass-sitting butterflies in the lowlands. Occasionally wind brings members of the two groups together, but if they mate, the offspring are usually not viable or have a much lowered fitness.

Eventually gene flow between separated populations ceases as variation between the populations increases. They fail to recognise each other as members of the same species.

1. Identify the variation in behaviour in the original butterfly population: \_\_\_\_\_

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2. What were the selection pressures acting on BSBs in the highlands and GSBs in the lowlands respectively?

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# 139 Allopatric Speciation

**Key Idea:** Allopatric speciation is the genetic divergence of a population after it becomes subdivided and isolated.

Allopatric speciation refers to the genetic divergence of a species after a population becomes split and then isolated geographically. It is probably the most common mechanism

by which new species arise and has certainly been important in regions where there have been cycles of geographical fragmentation, e.g. as a result of ice expansion and retreat (and accompanying sea level changes) during glacial and interglacial periods.

## Stage 1: Moving into new environments

There are times when the range of a species expands for a variety of different reasons. A single population in a relatively homogeneous environment will move into new regions of their environment if there is intense competition for resources. Competition between members of the same species is the most intense because they are competing for identical resources in the same habitat. In the diagram on the right there is a 'parent population' of a single species with a common gene pool with regular 'gene flow'. Theoretically any individual can mate with any other individual of the opposite sex.

## Stage 2: Geographical isolation

Parts of the population may become isolated by **physical barriers**, such as mountains, deserts, or stretches of water. These barriers may cut off those parts of the population that are at the extremes of the range and gene flow becomes rare or stops altogether. Climate change (e.g. ice ages and a consequent rise and fall in sea level) can leave 'islands' of habitat separated by large inhospitable zones that the species cannot traverse.

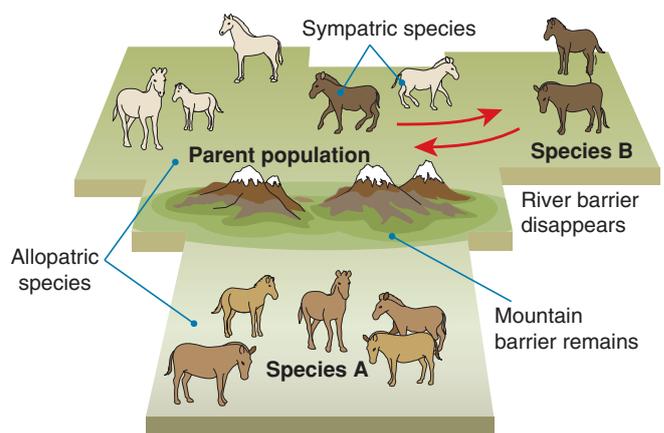
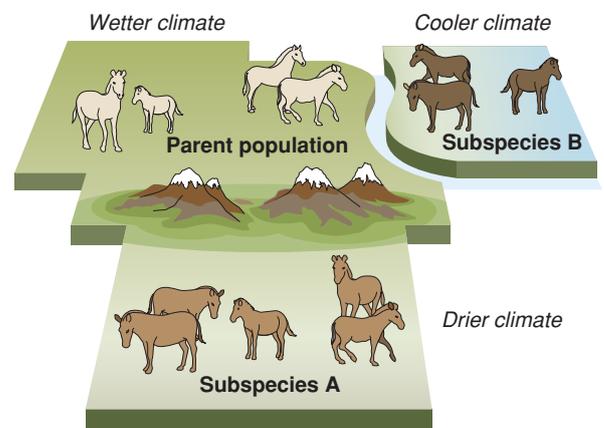
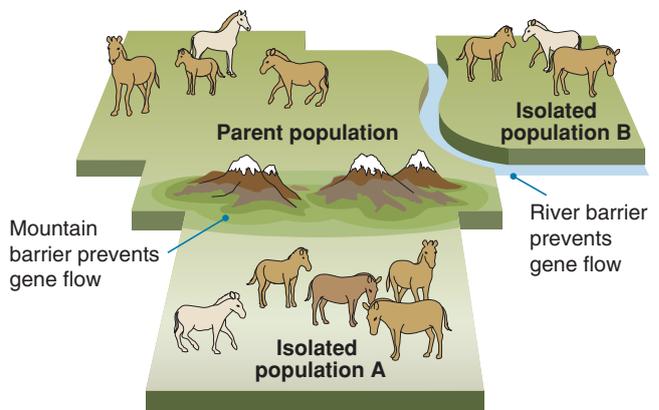
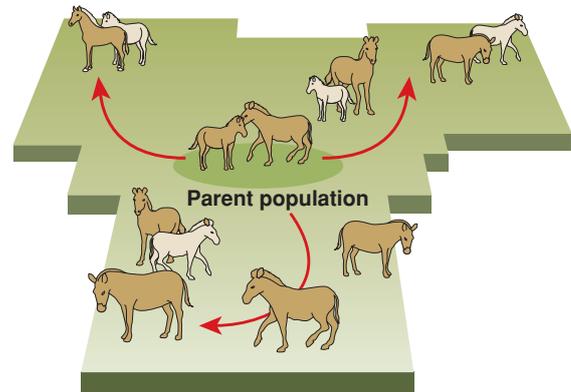
**Example:** In mountainous regions, alpine species can populate extensive areas of habitat during cool climatic periods. During warmer periods, they may become isolated because their habitat is reduced to 'islands' of high ground surrounded by inhospitable lowland habitat.

## Stage 3: Different selection pressures

The isolated populations (A and B) may be subjected to quite different selection pressures. These will favour individuals with traits suited to each particular environment. For example, population A will be subjected to selection pressures found in drier conditions, favouring individuals with phenotypes (and genotypes) suited to dry conditions (e.g. better ability to conserve water). This would result in improved survival and reproductive performance. As new genetic variation arises, the population takes on the status of a subspecies. Reproductive isolation is not yet established but the subspecies are significantly different, genetically, from related populations.

## Stage 4: Reproductive isolation

The separated populations (isolated subspecies) undergo genetic and behavioural changes. These ensure that the gene pool of each population remains isolated and 'undiluted' by genetic material from other populations, even if the two populations should be able to reunite at a later time if the geographical barrier is removed. Gene flow does not occur but there is a zone of overlap between two species after species B has moved back into the range of the parent population. Closely-related species with an overlapping distribution like this are called **sympatric**. Those that remain geographically isolated are called **allopatric** species.



1. Why do some animals, given the opportunity, move into new environments? \_\_\_\_\_

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2. Plants are unable to move. How might plants disperse to new environments? \_\_\_\_\_

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3. Describe the amount of gene flow within a parent population prior to and during the expansion of a species' range:

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4. Explain how cycles of climate change can cause large changes in sea level (up to 200 m): \_\_\_\_\_

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5. (a) What kinds of physical barriers could isolate different parts of the same population? \_\_\_\_\_

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(b) How might emigration achieve the same effect as geographical isolation? \_\_\_\_\_

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6. (a) How might selection pressures differ for a population that becomes isolated from the parent population? \_\_\_\_\_

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(b) Describe the general effect of the change in selection pressures on the isolated gene pool:

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7. The graph on the right shows the difference in escape acceleration in two populations of mosquitofish (*Gambusia*) in the Bahamas. One population is subject to heavy predation, the other is not. Suggest how this difference could lead to speciation over time if the populations remain separate:

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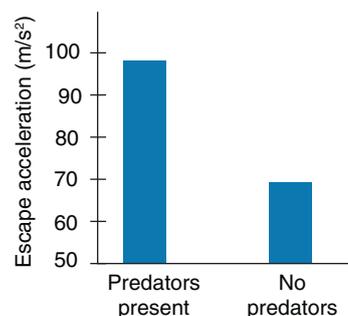
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# 140 Sympatric Speciation

**Key Idea:** Sympatric speciation is speciation which occurs even when there is no physical barrier separating gene pools. In sympatric (same place) speciation, a new species evolves from a single ancestral species while inhabiting the same

geographic region. Sympatric speciation is rarer than allopatric speciation, although it is not uncommon in plants. There are two situations where sympatric speciation is thought to occur. These are described below.

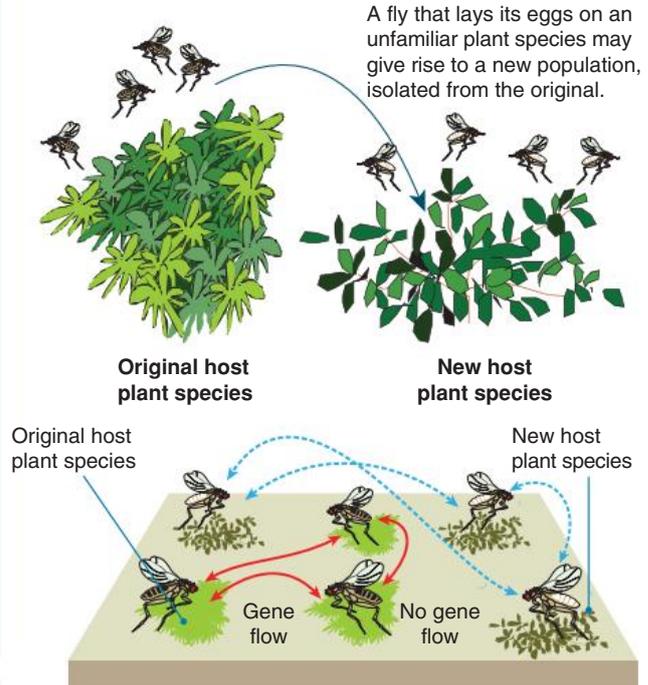
## Speciation through niche differentiation

### Niche isolation

There are many microhabitats within a heterogeneous environment (one that is not the same everywhere). Some individuals in a population may preferentially occupy one particular microhabitat, only rarely coming in contact with those that select other microhabitats. Some organisms become so dependent on the resources offered by their particular microhabitat that they never interact with others of their species in different microhabitats.

### Reproductive isolation

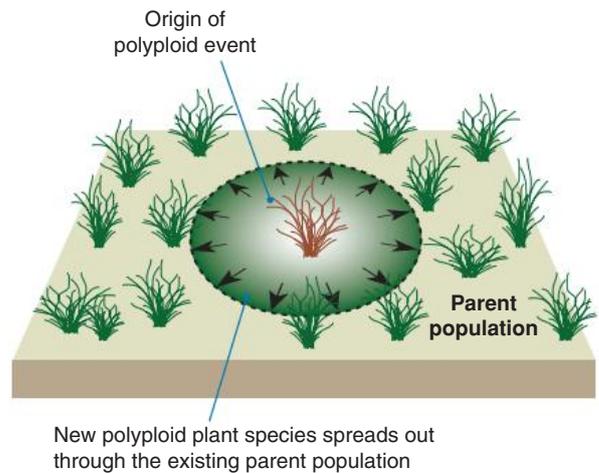
Sub-populations, which have remained genetically isolated because of their microhabitat preferences, become reproductively isolated. They have become new species with subtle differences in behaviour, structure, and physiology. Gene flow (via sexual reproduction) is limited to organisms that share similar microhabitat preferences (as shown right). **Example:** Some host-specific phytophagous insects (insects that feed on plants) lay eggs on plants identical to the species they themselves hatched on. Host plant preference leads to isolation despite the populations being sympatric.



## Instant speciation

Occasionally a new species may appear without first being isolated from the parent species. This happens when the amount of DNA changes (e.g. it is doubled). This can occur during reproduction. Instant speciation rarely occurs in animals because the disturbance to the DNA is usually lethal or the new individual is normally sterile. Many plants, on the other hand, are able to reproduce vegetatively, or self pollinate. This ability to reproduce on their own enables such plants to produce a breeding population.

Instant speciation may also occur when species hybridise. Again this is much more common in plants than in animals. Example of plant hybrids can be seen in many crops, including bananas, strawberries, and wheat.



1. Explain what is meant by sympatric speciation: \_\_\_\_\_  
\_\_\_\_\_
2. What is the mechanism for instant speciation? Explain why it is more common in plants than in animals: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
3. Explain how niche preference could result in the formation of a new species: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



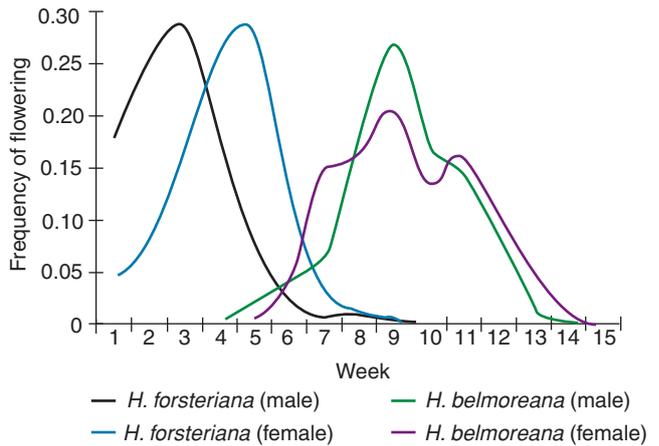
### Sympatric speciation in *Howea* palms

▶ The palms *Howea forsteriana* (below) and *Howea belmoreana* are endemic to Lord Howe Island. Studies show differences between the species in flowering times, tolerance of soil pH, and altitude preference. Hybrids are rare.

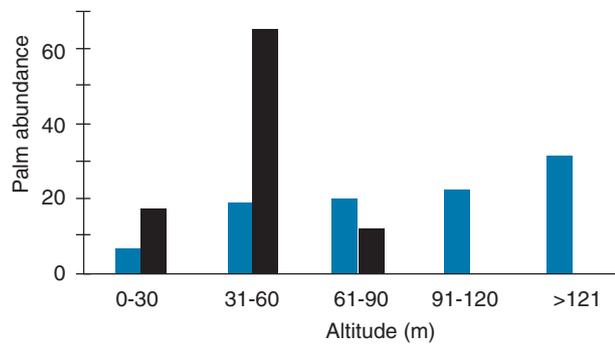
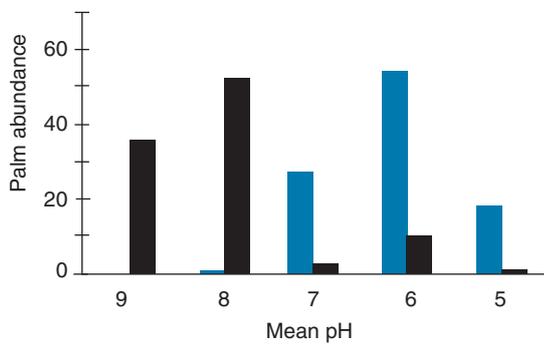


Black Diamond Images, CC 2.0

Differences in flowering times



Palm distribution by soil pH and by altitude



Source: V. Savolainen, et al (2006). See credits for full reference



David Stanley CC 3.0

- ▶ Lord Howe Island is the eroded remains of a 7 million year old volcano. It is located in the Tasman sea about 700 km from Sydney.
- ▶ The island is about 10 km long and 2 km wide at its widest point and covers 14.5 km<sup>2</sup>. The highest point is 875 m above sea level.
- ▶ About half the island's plants are endemic. *Howea* palms are found throughout the island. They are also cultivated and exported.
- ▶ As the island is so small, the palms are believed to have evolved by sympatric speciation.

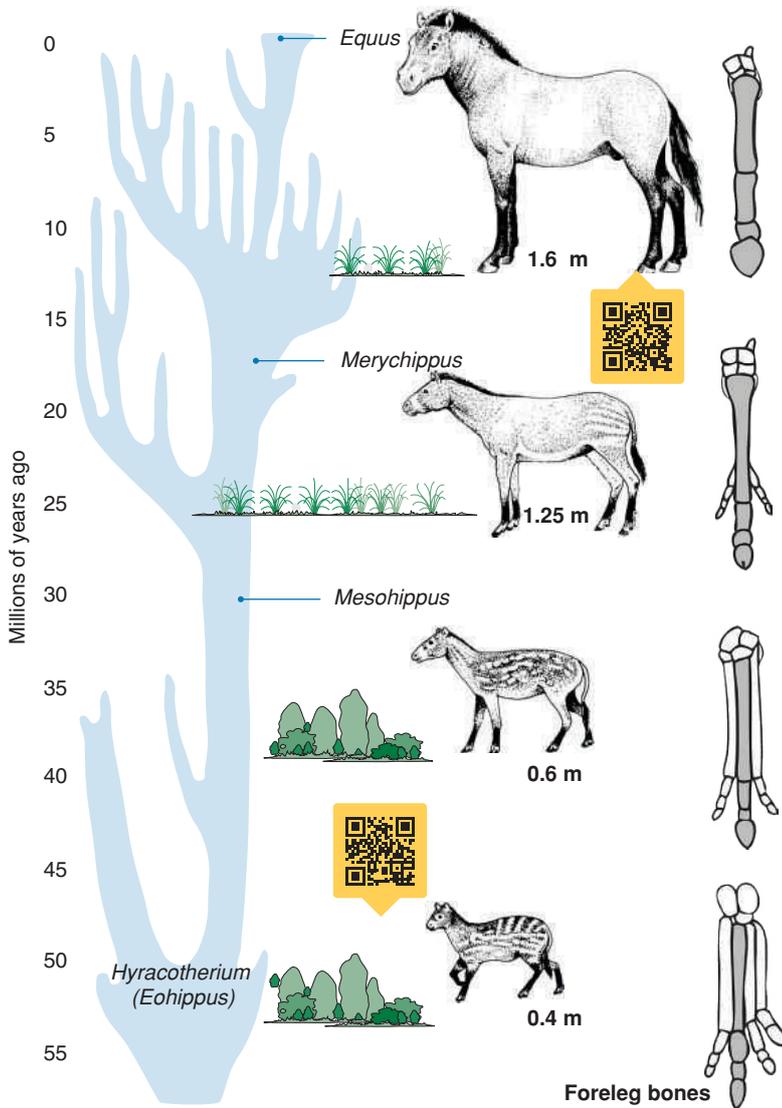
With respect to the palm species *H. forsteriana* and *H. belmoreana*:

4. Approximately how many weeks' difference is there in flowering times between the species? \_\_\_\_\_
5. Describe the difference in preference for soil pH between the two palm species: \_\_\_\_\_  
\_\_\_\_\_
6. Describe the difference in altitude preference between the two palm species: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
7. In what way are the observations above consistent with sympatric speciation? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

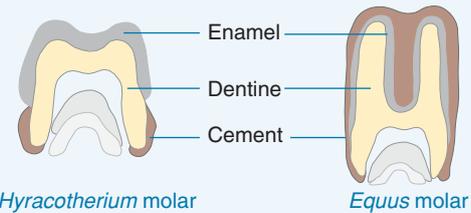
# 141 The Evolution of Horses

**Key Idea:** The evolution of the horse is one of the most robust examples of evolution documented in the fossil record. The evolution of the horse from the ancestral *Hyracotherium* to modern *Equus* is well documented in the fossil record. The rich fossil record, which includes numerous **transitional fossils**, has enabled scientists to develop a robust model

of horse phylogeny. It is a complex tree-like lineage with many divergences (below), and a diverse array of often coexisting species. The environmental transition from forest to grasslands drove many of the changes observed in the fossil record. These include reduction in toe number, increased size of cheek teeth, and increasing body size.

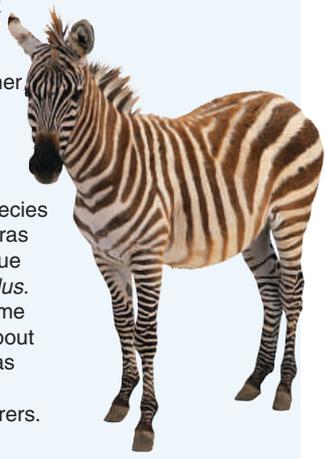


The cooler climates that prevailed in the Miocene (23 -5 mya) brought about a reduction in forested areas with grasslands becoming more abundant. The change in vegetation resulted in the equids developing more durable teeth to cope with the harsher diet. Over time the equid molar became longer and squarer with a hard cement-like covering to enable them to grind the grasses which became their primary diet.



The equids also became taller and faster to enable them to view and escape their predators. This is evident in their overall increase in size and the elongation of their limbs. The reduction in the number of toes from four to one (left) also enabled them to run faster and more efficiently.

Most equid evolution took place in North America, although now extinct species did migrate to other regions at various times. During the late Pliocene (2.6 mya) *Equus* spread into the Old World and diversified into several species including the modern zebras of Africa (right) and the true horse, *Equus ferus caballus*. Ironically, the horse became extinct in the Americas about 11,000 years ago, and was reintroduced in the 16th century by Spanish explorers.



1. Explain how the environmental change from forest to grassland influenced the following aspects of equid evolution:
  - (a) Change in tooth structure: \_\_\_\_\_
  - (b) Limb length: \_\_\_\_\_
  - (c) Reduction in number of toes: \_\_\_\_\_
2. In which way does the equid fossil record provide a good example of the evolutionary process? \_\_\_\_\_





# 143 The Evolution of Platypus

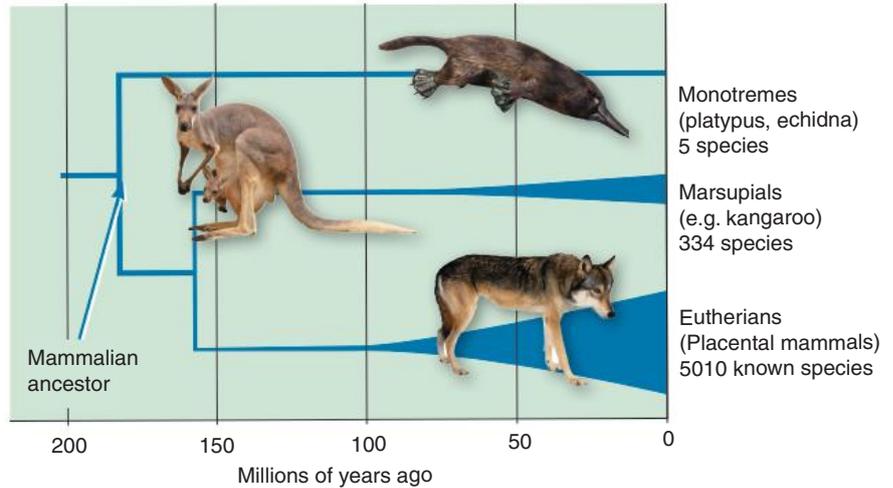
**Key Idea:** The ancestry of the platypus can be dated back to the Cretaceous period.

The platypus is one of only five monotremes species (the other four being echidnas). It is the last surviving member of the family Ornithorhynchidae. The fossil record contains many closely related species, and shows the Ornithorhynchidae

inhabited parts of the ancient supercontinent Gondwana, including the southern part of South America. The oldest platypus-like fossils found in Australia date to about 123 million years ago. The oldest modern platypus fossils date to about 100,000 years ago. Modern platypus have no teeth, unlike their fossil ancestors.

## Monotreme ancestry

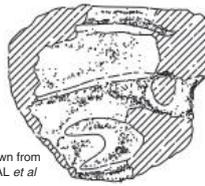
- ▶ Monotremes have a number of features that show their mammal-like reptile ancestry. They lay eggs, have a lower body temperature than other mammalian groups, have a reptile-like shoulder girdle, and possess a cloaca (common chamber into which the digestive, urinary, and reproductive tracts open). Monotremes split from the rest of the mammalian lineage during the Jurassic period, between 201 and 145 million years ago.
- ▶ Exactly when platypus diverged from echidna is still debated; with molecular studies suggesting between 17 and 80 million years ago, but the fossil record suggests a much earlier split.



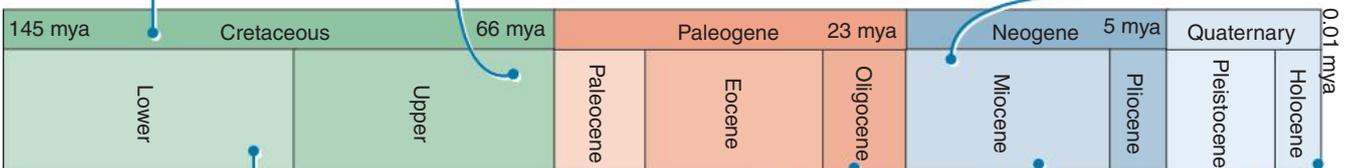
## Platypus evolution

**Teinolophus trusleri.** Dated to about 123 million years ago *Teinolophus trusleri* represents the most primitive fossil found. Fossil is a partial jaw bone, including teeth.

**Monotrematum sudamericanum.** Fossils of teeth (right) found in south Argentina date to about 63 million years ago.



**Obdurodon dicksoni.** The most complete fossil skull found, dated to between 10 and 15 million years ago.



**Steropodon galmani,** a platypus-like animal that lived about 110 million years ago. Fossil is a partial of a jaw bone.



**Obdurodon insignis.** Dated to 25 million years ago, fossil teeth were found in South Australia.

**Obdurodon tharalkooschild.** A molar tooth found in 2013 was dated to between 5 and 15 million years ago. This platypus species may have been over a metre long.

**Ornithorhynchus anatinus.** Modern platypus

1. List three features that monotremes share with reptiles that other mammals no longer do: \_\_\_\_\_
2. Where have fossils of platypus and platypus-like animals been found? What does this say about its range over time? \_\_\_\_\_
3. Identify the anatomical trend the various fossils of ancient platypus fossils show over 130 million years: \_\_\_\_\_

# 144 Patterns of Evolution

**Key Idea:** Populations moving into a new environment may follow particular patterns of evolution.

The diversification of one species into one or more separate species can follow particular patterns. **Divergent evolution** occurs when two species diverge from a common ancestor. Divergence is common in evolution and is responsible for

evolutionary radiations. When divergent evolution involves the formation of a large number of species to occupy different niches, this is called an **adaptive radiation**. When unrelated species evolve similar forms as a result of similar selection pressures it is called **convergent evolution** (convergence).

### Divergent evolution

A lineage splits and evolves independently due to different selection pressures in different environments. Species may later occupy the same environment, e.g. black swan and mute swan.



### Sequential evolution.

A species accumulates enough genetic changes over time to form new species (remaining interbreeding).

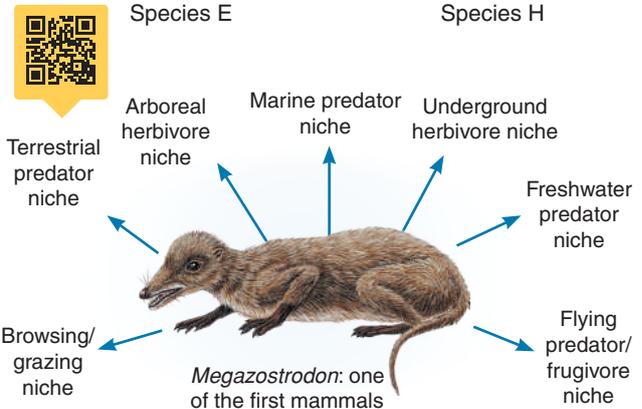
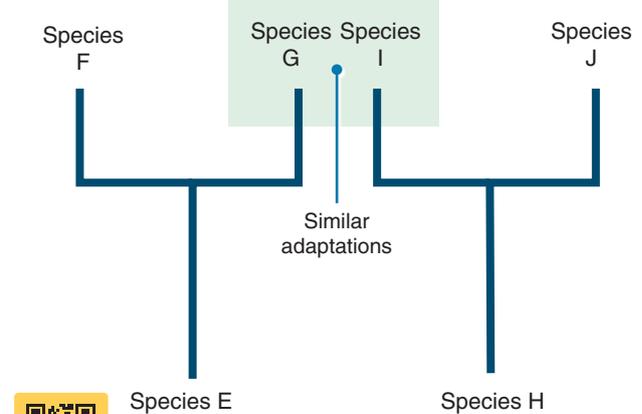


### Adaptive radiation

- ▶ The earliest true mammals evolved about 195 million years ago, long before they underwent their major adaptive radiation some 65-50 million years ago. These ancestors to the modern forms were very small (12 cm) with a similar form to modern shrews. Many were nocturnal and fed on insects and other invertebrates. *Megazostrodon* is a typical example. This animal is known from fossil remains in South Africa and first appeared in the Early Jurassic period, about 195 million years ago.
- ▶ It was climatic change as well as the extinction of the dinosaurs and their related forms that suddenly left many niches vacant for exploitation by such adaptable 'generalists'. All modern mammal orders developed very quickly and early.

### Convergent evolution

Unrelated or distantly related species in similar environments and under similar selection pressures evolve similar features, e.g. streamlined swimming form in aquatic birds and mammals.



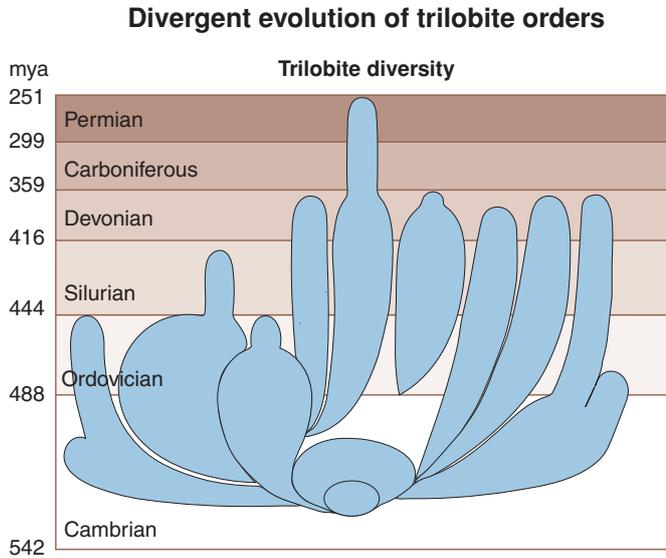
1. What is the difference between divergent evolution and adaptive radiation? \_\_\_\_\_
2. What is the difference between divergence and sequential evolution? \_\_\_\_\_
3. Penguins and dolphins have converged on a streamlined body form for moving through the water. What other groups of animals have also converged on this body shape? \_\_\_\_\_



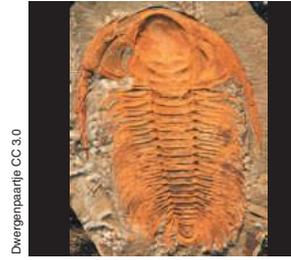
# 145 Divergence is an Evolutionary Pattern

**Key Idea:** Divergent evolution describes the accumulation of differences between initially more similar lineages so that new species arise from a common ancestor. Divergent evolution is a common evolutionary pattern. This

is the divergence of two or more species from a common ancestor. It arises through the accumulation of genetic differences in diverging lines, usually following isolation, so that gene flow between them stops and new species arise.



Trilobites are extinct marine arthropods. They were one of the earliest arthropod groups and were highly successful, diverging many times during their history to exploit a wide range of niches. They appeared in the fossil record near the beginning of the Cambrian and disappeared in the Permian mass extinction. Each blue shape represents an order. Its width indicates its diversity.



*Paradoxides*, late Cambrian



*Dalmanites*, Silurian



*Cheirurus*, Ordovician



*Walliserops*, middle Devonian

Divergenceparafje CC 3.0

DanielCD CC 3.0

Ghiesbreghts CC 3.0

Daderot

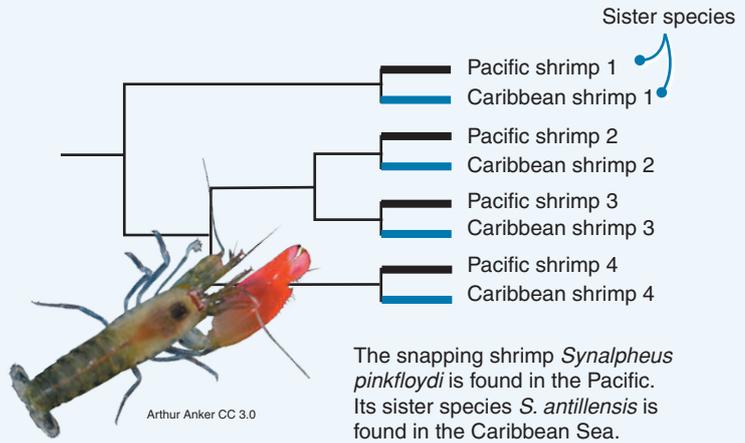
Because trilobites had a hard exoskeleton they fossilised well and have left an extensive fossil record. These fossils show that trilobites rapidly diversified early in their evolution. As many as 50,000 species of trilobite may have existed.

1. Define divergent evolution: \_\_\_\_\_  
\_\_\_\_\_
2. Why do populations diverge to eventually form new species? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
3. (a) How would you describe the evolution of the trilobites? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
- (b) When was the trilobite group most diverse? \_\_\_\_\_
4. (a) Suggest why the trilobites diversified so quickly: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
- (b) Considering the trilobites existed from 521 million years ago to 252 million years ago, approximately what percentage of their time in existence was spent in the evolution of new trilobite orders:  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
5. How do we know there were so many different trilobites? \_\_\_\_\_



### Divergent evolution in snapping shrimp

- ▶ The Isthmus of Panama separates the Pacific Ocean and Caribbean Sea in the region of Central America. The isthmus closed about 3 million years ago.
- ▶ On either side of the isthmus are numerous species of snapping shrimp. Every species on the Pacific side has a sister species on the Caribbean side.
- ▶ Genetic studies suggest that before the appearance of the isthmus there were already numerous species of snapping shrimps. After the isthmus formed, each species diverged, creating two new species, one on either side of the isthmus.



6. What evidence is there that the closing of the Isthmus of Panama was a factor in the divergence of snapping shrimps?

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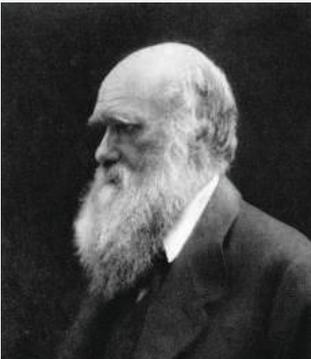
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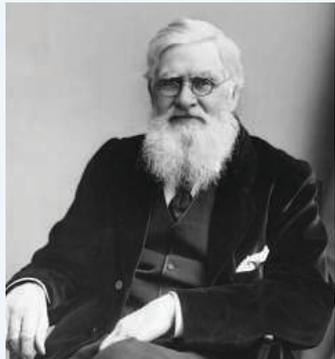
### Divergence and the theory of evolution by natural selection

- ▶ An important part of Darwin's theory of natural selection is that individuals of the same species compete for resources. Variations between individuals may lead to some being better able to use a specific resource, while others will be better at using a slightly different resource, such as eating different sized seeds. This ability to gain different resources may eventually lead to divergence.
- ▶ Alfred Russell Wallace independently proposed a theory of natural selection at the same time as Darwin. Although many of his ideas were similar to Darwin's, one difference was that Wallace put more emphasis on the effect of environmental pressures on natural selection. In this case, a population moving into a new environment would have some individuals with features that helped them survive, while others would not and so die.
- ▶ Both cases can result in divergence as the difference in ability to gain resources or survive in an environment result in the differential survival of individuals which affects their ability to reproduce.



Julia, Margaret, Cameron, 2 PD

Darwin formulated his theory of evolution after his voyage on the Beagle. He spent many more years gathering evidence before receiving a letter from Wallace that covered many of his own ideas. It was this that prompted him to publish his theory of evolution by natural selection.



Alfred Russel Wallace spent many years collecting and studying species from tropical regions, especially South America and Indonesia. From his studies he realised that new species arose by adapting to their environment. He expressed this in a letter to Darwin but did not use the term natural selection.

7. How does natural selection account for divergence? \_\_\_\_\_

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8. What were the differences between Darwin's and Wallace's theories of natural selection? \_\_\_\_\_

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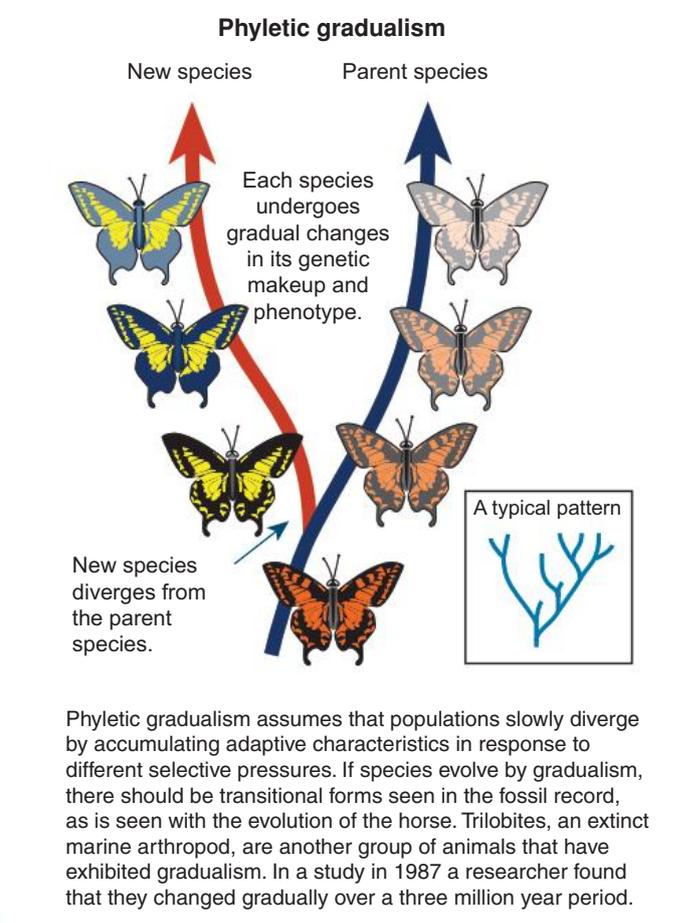
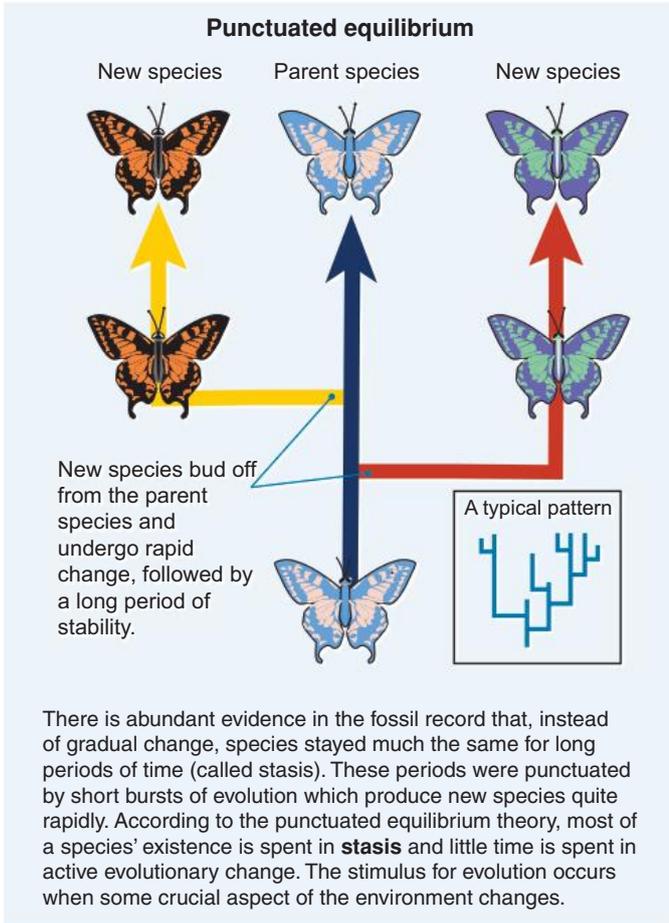
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# 146 The Rate of Evolutionary Change

**Key Idea:** A new species may form gradually either over a long period of time, or relatively suddenly.

Two main models have been proposed for the rate at which evolution occurs: **gradualism** and **punctuated equilibrium**. It is likely that both mechanisms operate at different times and in different situations. Interpretations of the fossil record vary

depending on the time scales involved. During its formative millennia, a species may have accumulated changes gradually (e.g. over 50,000 years). If that species survives for 5 million years, the evolution of its defining characteristics would have been compressed into just 1% of its evolutionary history. In the fossil record, the species would appear quite suddenly.



- What rate of environmental change would support the following paces of evolution?
  - Punctuated equilibrium: \_\_\_\_\_
  - Gradualism: \_\_\_\_\_
- In the fossil record of early human evolution, species tend to appear suddenly, linger for often very extended periods before disappearing suddenly. There are few examples of smooth inter-gradations from one species to the next. Which of the above models best describes the rate of human evolution? \_\_\_\_\_
- Some species show apparently little evolutionary change over long periods of time (hundreds of millions of years).
  - Name two examples of such species: \_\_\_\_\_
  - What term is given to this lack of evolutionary change? \_\_\_\_\_
  - Such species are often called 'living fossils'. Why might they have been described in this way? \_\_\_\_\_
  - Why would such species change so little over evolutionary time? \_\_\_\_\_

# 147 Divergent Evolution in Ratites

**Key Idea:** The ratites are group of birds descended from a single common ancestor. They lost the power of flight very early on in their evolution.

Ratites are flightless birds that possess two features that distinguish them from other birds; a flat breastbone (instead of the more usual keeled shape) and a primitive palate (roof to the mouth). Fossil evidence indicates that the ancestors

of ratites were flying birds living about 80 million years ago. These ancestors also had a primitive palate, but they possessed a keeled breastbone. Flightlessness in itself is not unique to ratites; there are other birds that have lost the power of flight, particularly on remote, predator-free islands. All ratites have powerful legs, and many, such as the emu, can run very quickly.

**Elephant bird**  
Two species, extinct, Madagascar

**Ostrich**  
*Struthio camelus*, Africa

**Emu**  
*Dromaius novaehollandiae*, Australia.

**Cassowary**  
Three species, Australia & New Guinea.

**Rhea**  
Two species, South America.

**Kiwi**  
Five species, New Zealand.

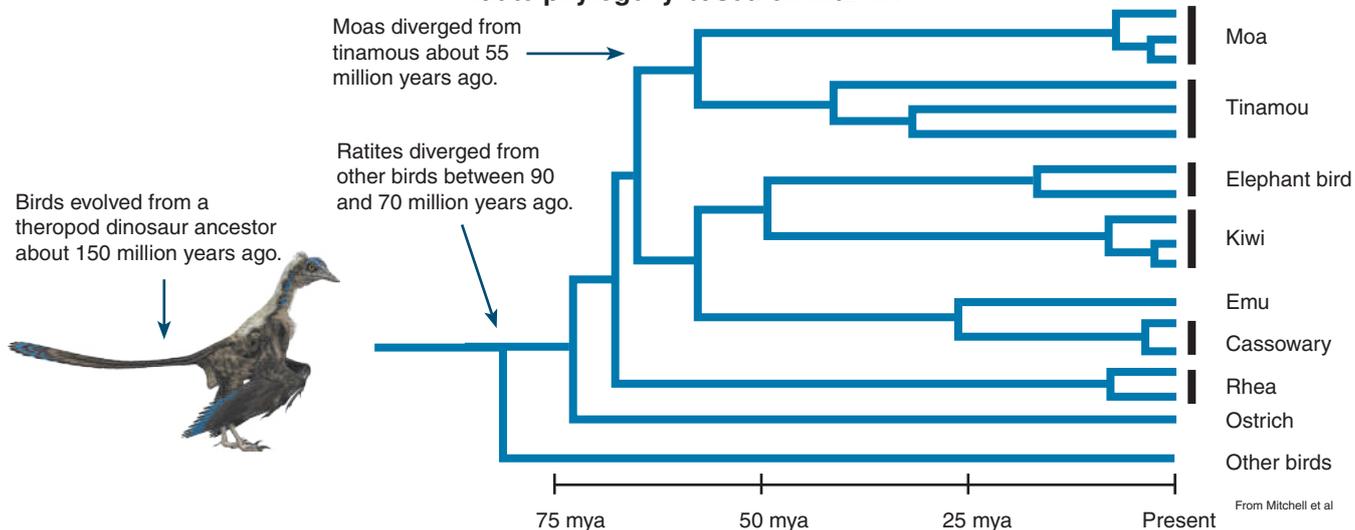
**Moa**  
Eleven species (Lambert *et al.* 2004\*), all extinct, New Zealand.

\*Tinamous from South America were until recently thought to be related to but not part of the ratite group. New evidence suggests they should be included in ratites.

It had long been thought that the geographical distribution of modern day and extinct ratite species could be explained by continental drift. The 'rafting hypothesis' suggests that the ancestral ratite population existed when the southern continents of South America, Africa, and Australia (and their major offshore islands) were joined as a single land mass called Gondwana. As the continents moved apart as a result of plate tectonics, the early ratite populations were carried with them.

Mitochondrial DNA (mtDNA) evidence now suggests kiwis are most related to the extinct elephant bird from Madagascar and slightly less closely related to emus in Australia. However, the ancestor to the kiwi arrived in New Zealand long after New Zealand separated from the rest of Gondwana. Ancestral kiwi must therefore have flown there. Moas are now thought to be closely related to tinamou (South America), which can fly. Ostriches were thought to be closely related to elephant birds but mtDNA now suggests they diverged from the other ratites early. The conclusions from these new findings suggest that the ratites evolved from flighted birds that flew between continents and independently evolved flightlessness at least six times.

**Ratite phylogeny based on mtDNA**



1. (a) Describe three physical features distinguishing all ratites (excluding tinamous) from most other birds:

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(b) Why should tinamous be included in ratites? \_\_\_\_\_

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2. Describe two anatomical changes, common to all ratites (excluding tinamous), which have evolved as a result of flightlessness. For each, describe the selection pressures for the anatomical change:

(a) Anatomical change: \_\_\_\_\_

Selection pressure: \_\_\_\_\_

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(b) Anatomical change: \_\_\_\_\_

Selection pressure: \_\_\_\_\_

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3. (a) Name two other flightless birds that are not ratites: \_\_\_\_\_

(b) Why are these other flightless species not considered part of the ratite group? \_\_\_\_\_

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4. Kiwis are ratites that have remained small. They arrived in New Zealand long after the moa. What part might this late arrival have played in kiwi species remaining small?

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5. (a) On the phylogenetic tree opposite, circle the branching marking the common ancestor of moa and kiwi.

(b) On the phylogenetic tree opposite, circle the branching marking the common ancestor of emus and kiwi.

6. (a) Based on the rafting hypothesis which ratite would you expect to be most closely related to ostriches?

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(b) Which ratite group is actually the closest relative of the ostrich? \_\_\_\_\_

7. The diversification of ratites from a Gondwanan ancestor may still be explained in part by continental drift. Use the data opposite to suggest a possible sequence of events for the distribution of ratites, assuming the phylogeny is accurate:

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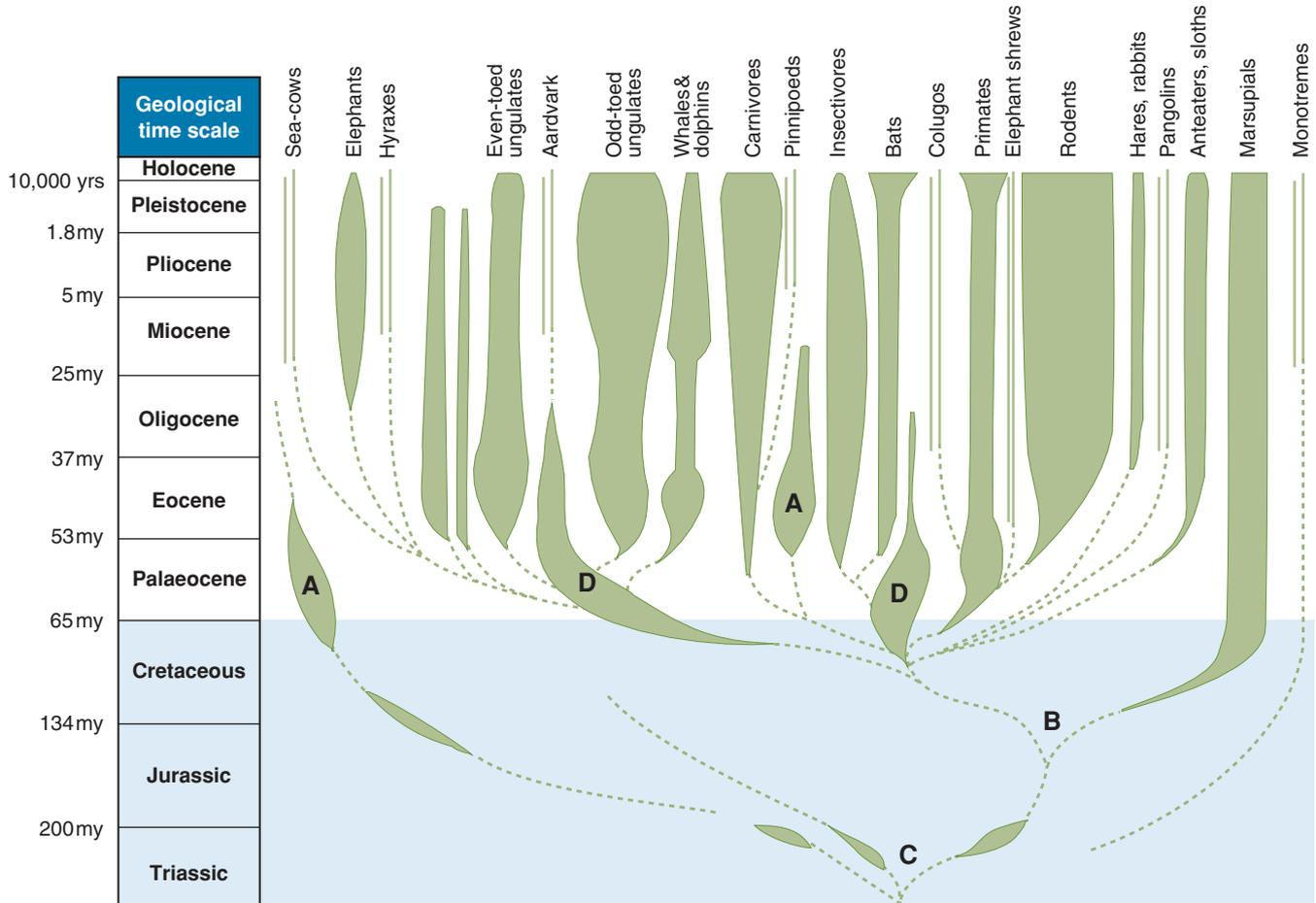
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# 148 Adaptive Radiation in Mammals

**Key Idea:** Adaptive radiation of an ancestral mammal lineage about 80 million years ago resulted in the great diversity of mammal taxa we see today.

**Adaptive radiation** is diversification among the descendants of a single ancestral group (one lineage) to occupy different niches. Mammals underwent an extensive adaptive radiation following the extinction of the dinosaurs. Most of the modern mammalian groups became established very early on. The

diagram below shows the divergence of the mammals into major orders, many occupying niches left vacant by the dinosaurs. The vertical extent of each green shape shows the time span for which a particular order has existed. Those that reach the top of the chart have survived to the present day. The width of a green shape shows how many species existed at any given time. The dotted lines indicate possible links between the orders for which there is no direct fossil evidence.



- In general terms, describe the adaptive radiation that occurred in mammals: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Name the term that you would use to describe the animal groups at point **C** (above): \_\_\_\_\_
- Explain what occurred at point **B** (above): \_\_\_\_\_  
 \_\_\_\_\_
- Describe one thing that the animal orders labelled **D** (above) have in common: \_\_\_\_\_  
 \_\_\_\_\_
- Identify the two orders that appear to have been most successful in terms of the number of species produced: \_\_\_\_\_  
 \_\_\_\_\_
- Explain what has happened to the mammal orders labelled **A** in the diagram above: \_\_\_\_\_  
 \_\_\_\_\_
- Name the geological time period during which the most adaptive radiation took place: \_\_\_\_\_

# 149 Convergent Evolution

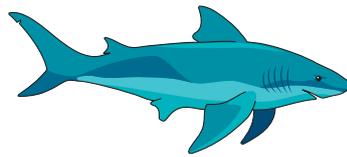
**Key Idea:** Evolution in response to similar selection pressures can result in unrelated species appearing very similar.

**Convergent evolution** describes the process by which

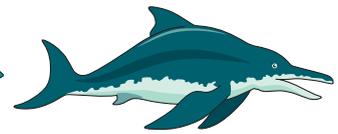
species from different evolutionary lineages come to resemble each other because they have similar habitats and ecological roles and natural selection has produced similar adaptations.

## Convergence: same look, different origins

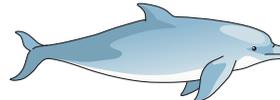
- ▶ We have seen how artificial selection applies selection pressure to bring about phenotypic change in a population. In natural environments, selection pressures to solve similar problems in particular environments can result in similar phenotypic characteristics in unrelated (or very distantly related) species.
- ▶ The evolution of succulence in unrelated plant groups (*Euphorbia* and cacti) is an example of convergence in plants. In the example (right), the selection pressures of the aquatic environment have produced a similar streamlined body shape in unrelated vertebrates. Ichthyosaurs, penguins, and dolphins each evolved from terrestrial species that took up an aquatic lifestyle. Their body form has evolved similarities to that of the shark, which has always been aquatic. Note that flipper shape in mammals, birds, and reptiles is a result of convergence, but its origin from the pentadactyl limb is an example of common ancestry.



Fish: Shark



Reptile: Ichthyosaur (extinct)



Mammal: Dolphin



Bird: Penguin

## Analogous structures arise through convergence

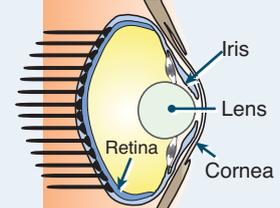
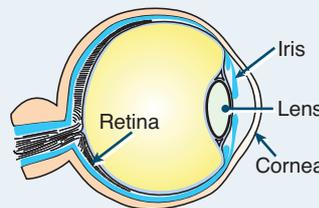
- ▶ Analogous structures have the same function and often the same appearance, but different origins.
- ▶ The example (right) shows the structure of the **camera eye** in two unrelated taxa (mammals and cephalopod molluscs). The eyes appear similar, but have different embryonic origins and have evolved independently.
- ▶ The **wings** of birds and insects are also analogous. The wings have the same function, but the two taxa do not share a common ancestor. *Longisquama*, an extinct reptile, also had 'wings' that probably allowed gliding between trees. These 'wings' were highly modified long scales extending from its back and not a modification of the forearm (as in birds).



Mammalian eye



Octopus eye



1. In the example above illustrating convergence in swimming form, describe two ways in which the body form has evolved in response to the particular selection pressures of the aquatic environment:

- (a) \_\_\_\_\_
- (b) \_\_\_\_\_

2. Describe two of the selection pressures that have influenced the body form of the swimming animals above:

- (a) \_\_\_\_\_
- (b) \_\_\_\_\_

3. When early taxonomists encountered new species in the Pacific region and the Americas, they were keen to assign them to existing taxonomic families based on their apparent similarity to European species. In recent times, many of the new species have been found to be quite unrelated to the European families they were assigned to. Explain why the traditional approach did not reveal the true evolutionary relationships of the new species:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. For each of the paired examples, briefly describe the adaptations of body shape, diet and locomotion that appear to be similar in both forms, and the likely selection pressures that are acting on these mammals to produce similar body forms:



Australia

**Convergence between marsupials and placentals**

**Marsupial** and **placental** mammals diverged very early in mammalian evolution (about 120 mya), probably in what is now the Americas. Marsupials were widespread throughout the supercontinent of Gondwana as it began to break up through the Cretaceous, but became isolated on the southern continents, while the placentals diversified in the Americas and elsewhere, displacing the marsupials in most habitats around the world. Australia's isolation from other landmasses in the Eocene meant that the Australian marsupials escaped competition with placentals and diversified into many species, ecologically equivalent to the placental species in North America.



North America



Wombat

(a) Adaptations: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Selection pressures: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



Woodchuck (groundhog or marmot)



Sugar glider (flying phalanger)

(b) Adaptations: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Selection pressures: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



Flying squirrel



Marsupial mouse (antechinus)

(c) Adaptations: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Selection pressures: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



Deer mouse



Long eared bandicoot (bilby)

(d) Adaptations: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Selection pressures: \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



Jack rabbit

Patrick KGP, cc 2.0

# 150 Chapter Review: Did You Get It?

1. Outline the features of the four factors involved in evolutionary change in a population:

- (i) Species population: \_\_\_\_\_  
\_\_\_\_\_
- (ii) Genetic variation: \_\_\_\_\_  
\_\_\_\_\_
- (iii) Competition: \_\_\_\_\_  
\_\_\_\_\_
- (iv) Increase in favourable variants: \_\_\_\_\_  
\_\_\_\_\_

2. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

- adaptive radiation .....
- allopatric speciation .....
- convergent evolution .....
- divergent evolution .....
- phyletic gradualism .....
- punctuated equilibrium .....

- A** The division of one species into two or more separate species
- B** A model for the evolution of lineages in which long periods of stasis are interrupted by brief periods of rapid speciation.
- C** Evolution in unrelated species occupying similar niches that causes them to arrive at similar structural, physiological, and behavioural adaptations.
- D** A form of divergent evolution in which there is rapid speciation of a lineage to fill many different ecological niches.
- E** A model for the evolution of different forms over a long period of time but with only slight changes occurring between successive generations.
- F** Speciation in which the populations are physically separated.

3. Study the graphs below right.

(a) What kind of selection is occurring? \_\_\_\_\_

(b) Describe an example of this type of selection:

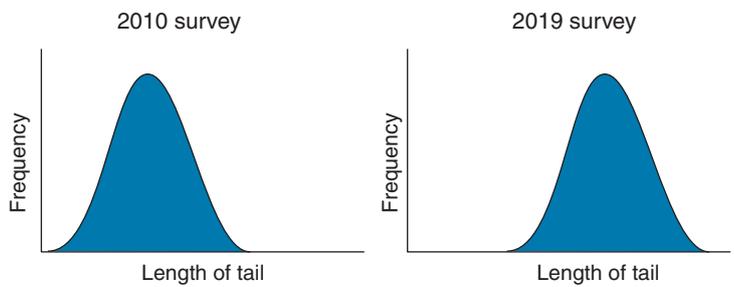
\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



4. The two plants shown right are unrelated. The left hand image shows a cactus from North America, while the right hand image shows a Euphorbia from Africa. Both these plants live in deserts.

Explain how the theory of evolution accounts for the similarity in these unrelated plants:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



# Evolution - The Evidence

Activity  
number

## Key terms

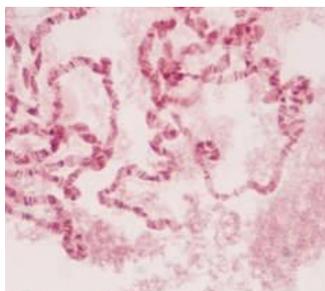
absolute dating  
(= chronometric dating)  
antibiotic resistance  
biogeographical evidence  
common ancestor  
DNA  
DNA hybridisation  
fossil  
fossil record  
geologic time scale  
gene  
homology  
molecular clock  
mutation  
phylogeny  
radiometric dating  
relative dating  
rock strata  
transitional fossil

*Inquiry question: What is the evidence that supports the theory of evolution by natural selection?*

## Fossils and the record of species change over time

### Key skills and knowledge

- |                          |   |                |
|--------------------------|---|----------------|
| <input type="checkbox"/> | 1 Understand that the evidence for evolution and the relatedness of species comes from many scientific disciplines. Identify these lines of evidence and their contribution to our understanding of species relatedness.  | <b>151 152</b> |
| <input type="checkbox"/> | 2 Investigate the palaeontological evidence for the change in species over time. Describe types of fossils and explain how fossils are formed. Explain what is meant by the fossil record and how it records change over time. Explain the importance of index fossils in interpreting the fossil record. | <b>153</b>     |
| <input type="checkbox"/> | 3 Distinguish between relative and absolute dating of fossils, including recognising some of the methods used and the date ranges for which they are appropriate. Explain the importance of superposition when applying relative dating techniques.   | <b>155 156</b> |



## Evidence for evolution

### Key skills and knowledge

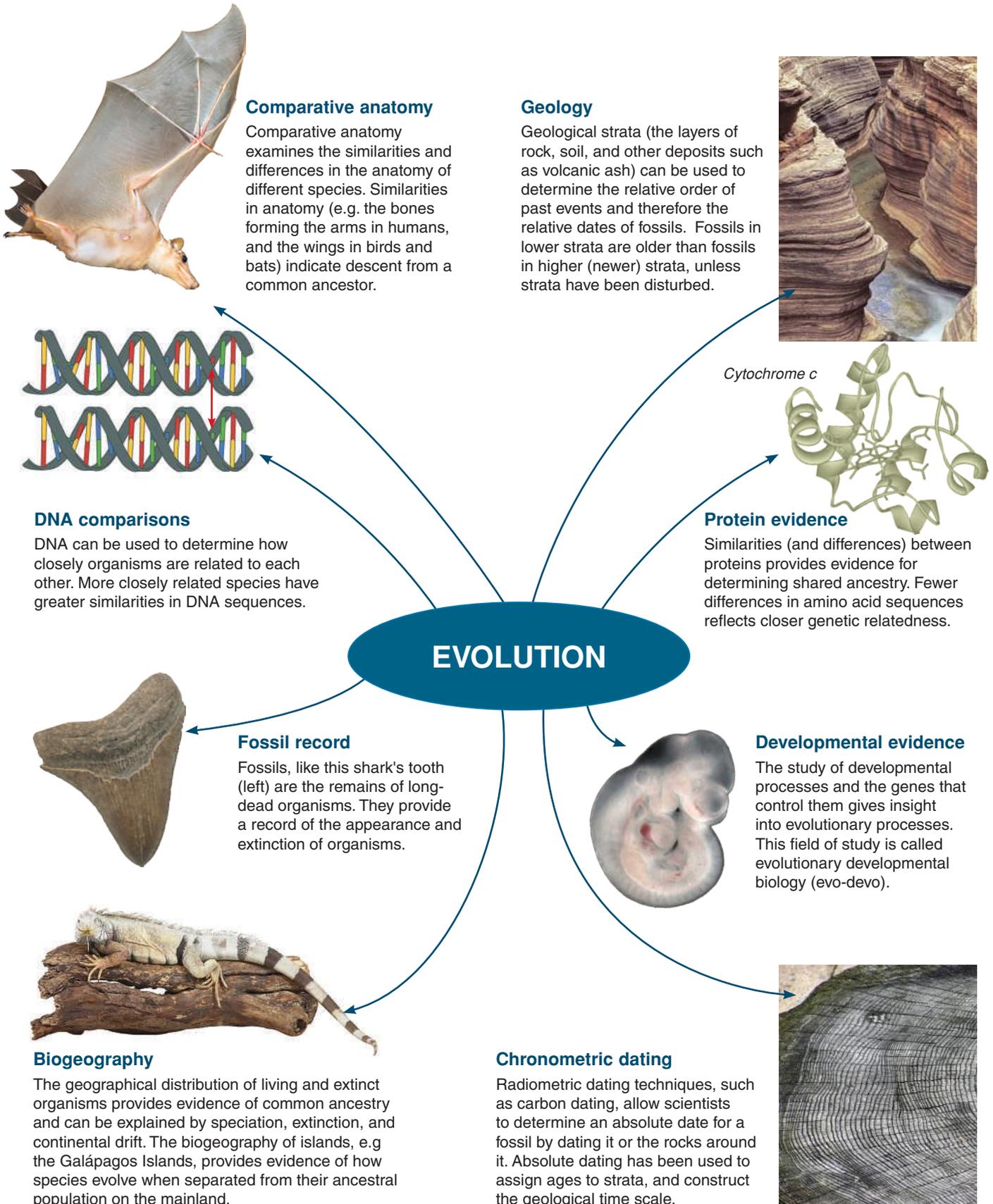
- |                          |  |                        |
|--------------------------|--|------------------------|
| <input type="checkbox"/> | 4 Explain the significance of transitional fossils. Describe the trends that transitional fossils record in the evolution of related taxa.   | <b>141 142<br/>157</b> |
| <input type="checkbox"/> | 5 Explain how the geographical distribution of living and extinct organisms (biogeography) provides evidence of dispersal from a point of origin.  | <b>158 160</b>         |
| <input type="checkbox"/> | 6 Describe features of typical oceanic island colonisers and give examples of where this has been important in the evolution of new species.   | <b>159</b>             |
| <input type="checkbox"/> | 7 Explain how comparisons of structural morphology and physiology have contributed to our understanding of evolutionary relationships among organisms. Investigate and describe examples of homologous structures and recognise them as evidence of common ancestry. | <b>161</b>             |
| <input type="checkbox"/> | 8 Explain how evolutionary developmental biology has provided strong evidence for the mechanisms of evolution and the evolution of novel forms.  | <b>162</b>             |
| <input type="checkbox"/> | 9 Appreciate that evidence for evolution is not confined to the past. Use modern-day examples of antibiotic resistance in bacteria and changes in cane toads to demonstrate evolutionary change.   | <b>163 164</b>         |
| <input type="checkbox"/> | 10 Describe the biochemical evidence that reveals similarities between closely related organisms including protein sequence data, DNA sequence analysis, DNA hybridisation and mitochondrial DNA (mtDNA).  | <b>165-169</b>         |
| <input type="checkbox"/> | 11 Describe how biochemical variations can be used as a molecular clock to determine the probable dates of divergence from a common ancestor. How are molecular clocks calibrated and what are their benefits and disadvantages?                                     | <b>168</b>             |

# 151 The Evidence for Evolution

**Key Idea:** Evidence for the fact that populations evolve from a common ancestor comes from many fields of science.

Evolution is simply the heritable genetic changes occurring in a population over time. There are two important points to take from this definition: that evolution refers to populations, not individuals, and that the changes must be inherited.

The evidence for evolution and the relatedness of species comes from many diverse branches of science and includes evidence from both past and present populations. Drawing on evidence from a number of scientific disciplines helps to build a robust explanation for the relatedness and evolutionary history (phylogeny) of taxa.

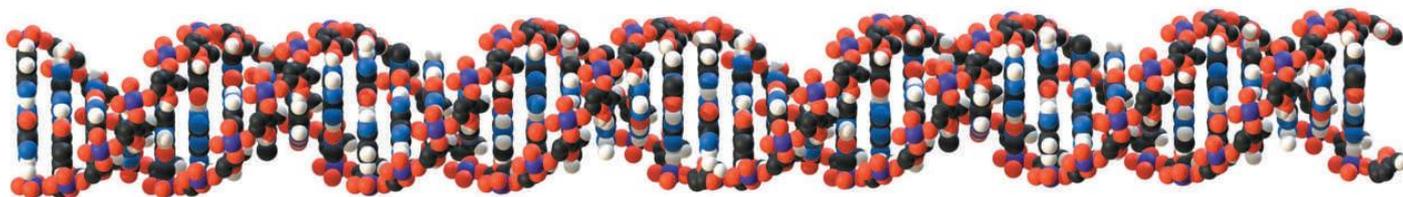


# 152 Descent and Common Ancestry

**Key Idea:** Molecular studies have enabled scientists to clarify the earliest beginnings of the eukaryotes. Such studies provide powerful evidence of the common ancestry of life.

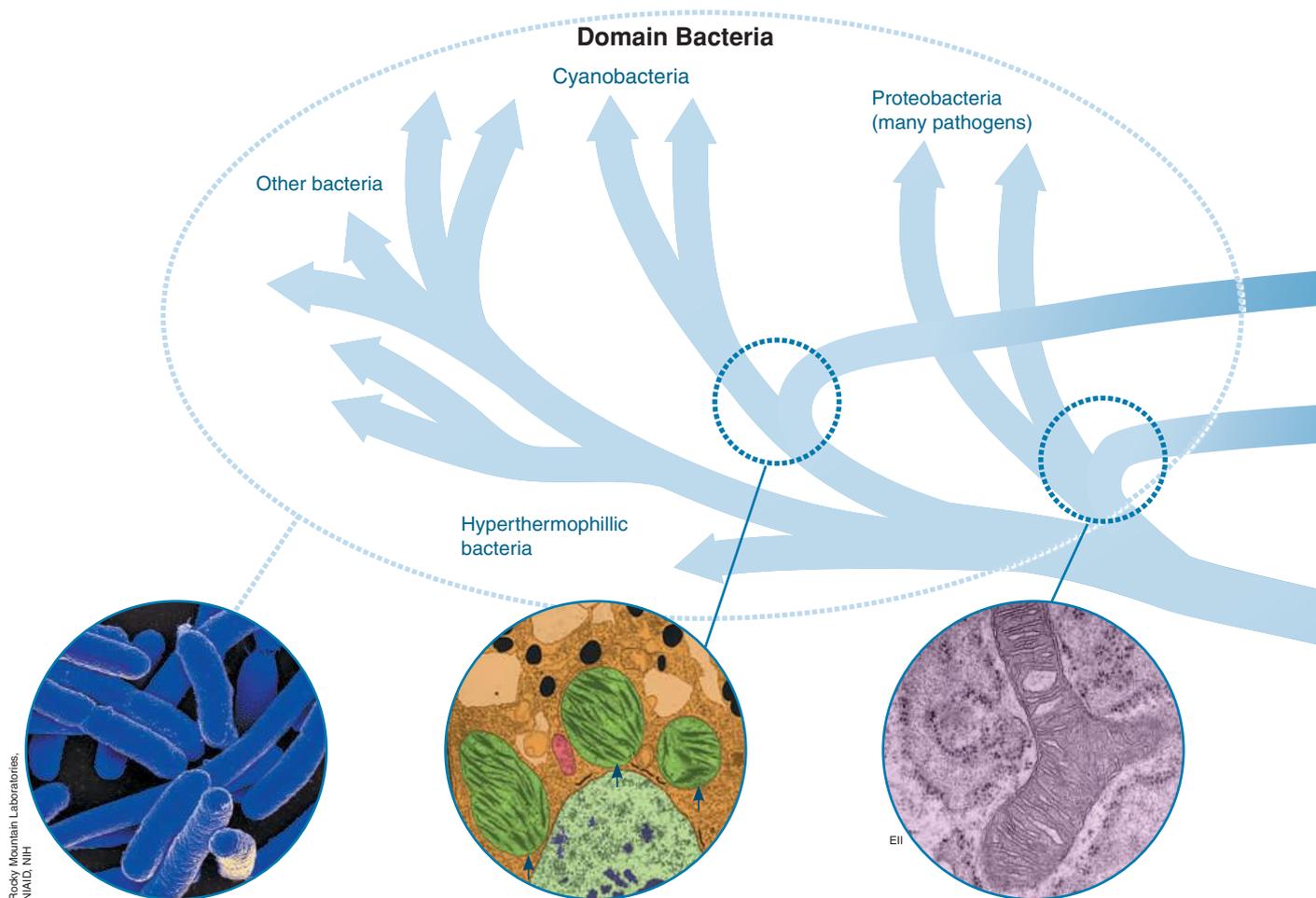
Traditionally, the phylogeny (evolutionary history) of organisms was established using morphological comparisons. In recent decades, molecular techniques involving the analysis of DNA, RNA, and proteins have provided more information about

how all life on Earth is related. These newer methods have enabled scientists to clarify the origin of the eukaryotes and to recognise two prokaryote domains. The universality of the genetic code and the similarities in the molecular machinery of all cells provide powerful evidence for a common ancestor to all life on Earth.



## There is a universal genetic code

DNA encodes the genetic instructions of all life. The form of these genetic instructions, called the **genetic code**, is effectively universal, i.e. the same combination of three DNA bases code for the same amino acid in almost all organisms. The very few exceptions in which there are coding alternatives are restricted to some bacteria and to mitochondrial DNA.



Rocky Mountain Laboratories,  
NIH, NIH

Bacteria lack a distinct nucleus and cell organelles. Features of the cell wall are unique to bacteria and are not found among archaea or eukaryotes. Typically found in less extreme environments than archaea.

### Chloroplasts have a bacterial origin

Cyanobacteria are considered to be the ancestors of chloroplasts. The evidence for this comes from similarities in the ribosomes and membrane organisation, as well as from genomic studies. Chloroplasts were acquired independently of mitochondria, from a different bacterial lineage, but by a similar process.

### Mitochondria have a bacterial origin

Evidence from mitochondrial gene sequences, ribosomes, and protein synthesis indicate that mitochondria have a prokaryotic origin. Mitochondria were probably symbiotic inclusions in an early eukaryotic ancestor.



134

A-1

1. Identify three features of the metabolic machinery of cells that support a common ancestry of life:

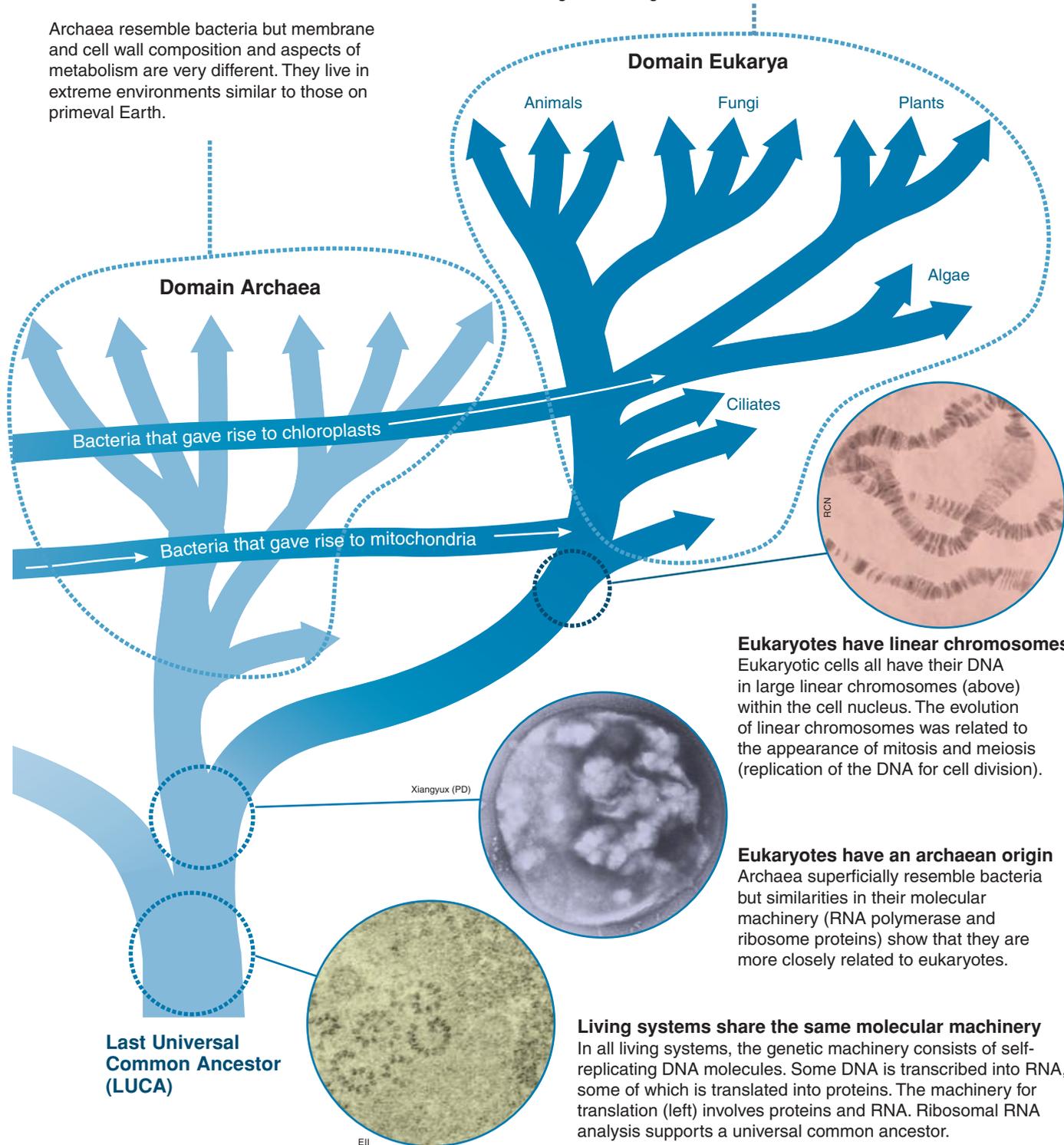
- (a) \_\_\_\_\_
- (b) \_\_\_\_\_
- (c) \_\_\_\_\_

2. Suggest why scientists believe that mitochondria were acquired before chloroplasts: \_\_\_\_\_

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

Eukarya (the eukaryotes) are characterised by complex cells with organelles and a membrane-bound nucleus. This domain contains four of the kingdoms recognised under a traditional scheme.

Archaea resemble bacteria but membrane and cell wall composition and aspects of metabolism are very different. They live in extreme environments similar to those on primeval Earth.



**Eukaryotes have linear chromosomes**  
Eukaryotic cells all have their DNA in large linear chromosomes (above) within the cell nucleus. The evolution of linear chromosomes was related to the appearance of mitosis and meiosis (replication of the DNA for cell division).

**Eukaryotes have an archaean origin**  
Archaea superficially resemble bacteria but similarities in their molecular machinery (RNA polymerase and ribosome proteins) show that they are more closely related to eukaryotes.

**Living systems share the same molecular machinery**  
In all living systems, the genetic machinery consists of self-replicating DNA molecules. Some DNA is transcribed into RNA, some of which is translated into proteins. The machinery for translation (left) involves proteins and RNA. Ribosomal RNA analysis supports a universal common ancestor.

# 153 Fossils and Fossil Formation

**Key Idea:** Fossils are the remains of long-dead organisms that have escaped decay and have, after many years, become part of the Earth's crust.

A fossil may be the preserved remains of the organism itself, the impression of it in the sediment (a mould), or marks made by it during its lifetime (trace fossils). For fossilisation to occur, rapid burial of the organism is required (usually in water-borne sediment). This is followed by chemical alteration, whereby minerals are added or removed. Fossilisation

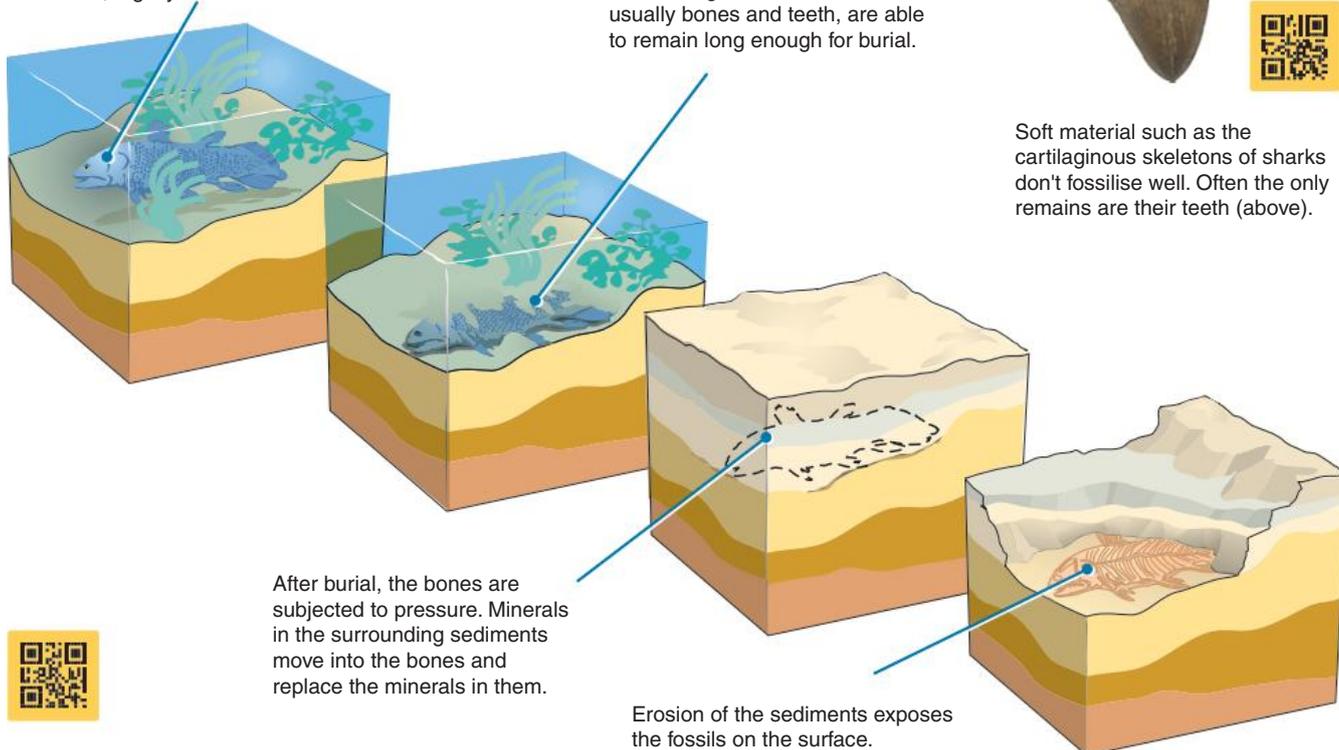
requires the normal processes of decay to be permanently stopped. This can occur if the organism's remains are isolated from the air or water and decomposing microbes are prevented from breaking them down. Fossils provide a record of the appearance and extinction of organisms, from species to whole taxonomic groups. Once this record is calibrated against a time scale, by using a broad range of dating techniques, it is possible to build up a picture of the evolutionary changes that have taken place.

Fossilisation occurs best when an organism dies in a place where sediment can be laid down relatively quickly. This is often an aquatic environment, e.g. an estuary, but it can be caused by rapid burial, e.g. by a landslide or volcanic ash.

After death, the flesh may rot or be scavenged, but hard materials, usually bones and teeth, are able to remain long enough for burial.



Soft material such as the cartilaginous skeletons of sharks don't fossilise well. Often the only remains are their teeth (above).



After burial, the bones are subjected to pressure. Minerals in the surrounding sediments move into the bones and replace the minerals in them.

Erosion of the sediments exposes the fossils on the surface.



- Describe how a fossil forms: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Explain why the rapid burial of an organism is important in the formation of fossils: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Explain why the fossil record is biased towards marine organisms with hard parts: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Some fossils act as index fossils**

- ▶ An **index fossil** is a fossil that is characteristic of a particular span of geological time or environment. Index fossils help scientists with relative dating (placing rock layers in a relative order to each other), define boundaries in the geologic time scale, and correlate strata from different regions.
- ▶ Trilobites make excellent index fossils because they are easily recognisable, abundant in the fossil record, and different families are characteristic of different geographical distributions and different time periods.
- ▶ Trilobites (meaning three lobes) are a fossil group of extinct marine arthropods. They first appeared in the fossil record near the beginning of the Cambrian (520 mya) and disappeared in the mass extinction at the end of the Permian (250 mya).
- ▶ Trilobites were a very diverse group and underwent several radiations during the Cambrian, inhabiting a wide range of marine environments and exhibiting diverse life strategies. The wide diversity in their appearance reflects this.
- ▶ The trilobite fossil record provides evidence of several evolutionary trends in the different lineages. These included streamlined shape in swimming forms, broadening of the head in filter feeders, improvement in the ability to curl up into a defensive ball, decreased size, and the evolution of spines as defences (below).



Moussa Direct Ltd

			
Loss of surface detail could have helped with burrowing. A decrease in size allowed exploitation of new microhabitats.	Spines provided defence from attack and stabilisation on loose surfaces.	An enlargement of the head region was probably an adaptation to filter feeding.	Elongated and streamlined bodies aided swimming in pelagic (open ocean) forms.

4. (a) Explain the importance of index fossils in determining relative time lines: \_\_\_\_\_

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(b) Why do trilobites make good index fossils? \_\_\_\_\_

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5. Carry out an investigation into trilobite diversity. Use an internet or literature search to find images of various trilobites. What can be said about their diversity and adaptations?

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# 154 Methods of Dating Fossils

**Key Idea:** Accurate dating of fossils is important in being able to piece together evolutionary sequences. Radiometric dating provides absolute dates for constructing a fossil record.

**Radiometric dating** methods allow an **absolute date** to be assigned to fossils, most commonly by dating the rocks around the fossils. Multiple dating methods for samples provides cross-referencing, which gives confidence in a given

date. Absolute, or **chronometric**, dating methods most often involve radiometric dating (e.g. **radiocarbon**, **potassium-argon**, **fission track**), which relies on the known rates of radioisotopic decay of elements to their stable isotopes. Non-radiometric methods can also be used to provide relative dates including the chemical analysis of bones, biostratigraphy, and even using tree rings.

## Radiometric dating methods

### Uranium-lead

Measures the decay of the two main isotopes of uranium ( $^{235}\text{U}$  and  $^{238}\text{U}$ ) into lead in igneous rocks. The ratio of these elements can be used to determine the time since the rocks formed.

### Uranium series

Measures the decay of uranium-234 into thorium-230 in marine carbonates (e.g. corals). Uranium-234 is soluble and is incorporated into coral skeletons. As it decays, it produces thorium-230. The age of the coral is determined by the uranium to thorium ratio.

### Fission track

When uranium decays, the subatomic particles emitted leave tracks through the mineral. The number of tracks increases over time and this can be used to calculate the time since the rock formed. Fission track dating is useful for dating pottery, glass, and volcanic minerals.

### Potassium/argon (K-Ar)

Measures the decay of potassium-40 to argon-40 in volcanic rocks above or below fossil bearing strata. Argon is inert, so it only builds up in minerals by radioisotopic decay of potassium. The amount of argon is therefore related to the age of the rock.

### Radiocarbon dating (carbon-14 or $^{14}\text{C}$ )

Measures the amount of the radioisotope carbon-14 (taken up by an organism when it was alive) within its fossilized remains. The older a sample is, the less  $^{14}\text{C}$  there is to be detected.

## Relative dating methods

### Chemical analysis

Bones buried in the ground can absorb elements such as uranium and fluorine. The rate of absorption depends on factors in the immediate environment. This means that bones from the same site can be compared but bones from different sites cannot.

### Stratigraphy

Layers of rock laid down oldest at the bottom to youngest at the top. Thus in areas where the layers are not severely deformed the order of deposition can be determined. Displaced deposits can be ordered using knowledge of the order of nearby deposits.

### Biostratigraphy

The remains of organisms are incorporated as fossils as deposits are laid down. Older fossils are therefore found below younger ones. Some fossils are characteristic of various layers and times and can be used to date newly found rock layers.

### Palaeomagnetism

Magnetic minerals in rocks lock-in a record of the Earth's magnetic field when they form. The record of geomagnetic reversals preserved in rock sequences provides a time-scale that is used as a geochronological tool.

### Obsidian hydration

Obsidian is a natural volcanic glass used by prehistoric humans to produce blades. The manufacture of these blades zeros the mineral hydration clock. Over time, the mineral becomes hydrated. If the hydration rate is known, an age can be obtained.

1. When the date of a sample has been determined, it is common practice to express it in the following manner:  
Example:  $1.88 \pm 0.02$  million years old. Explain what the  $\pm 0.02$  means in this case:

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2. Explain why it is best to test many small samples to find a date when dating a specimen using radiometric dating:

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3. Suggest a possible source of error that could account for an incorrect dating measurement using radiocarbon dating:

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4. Explain why relative dating methods can not give exact dates of when specimens formed or died: \_\_\_\_\_

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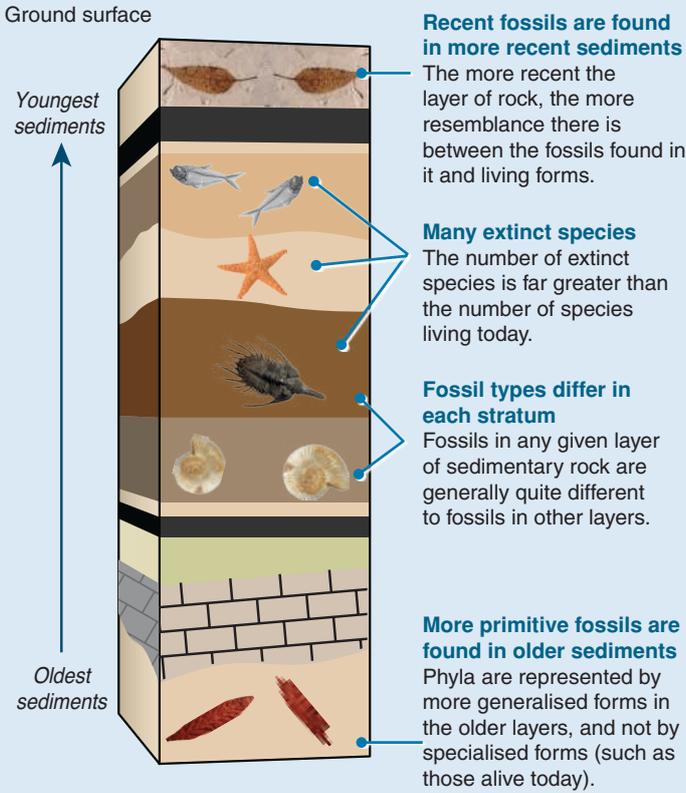
# 155 Relative Dating and the Fossil Record

**Key Idea:** Fossils found in rock at the bottom of a rock profile are older than those found at the top of the rock profile.

**Relative dating** establishes the sequential (relative) order of past events in a rock profile, but it cannot provide an absolute date for an event. Each rock layer (**stratum**) is unique in terms of the type of rock (sedimentary or volcanic) and the

type of fossils it contains. Rock layers (**strata**) are arranged in the order that they were deposited, with the oldest layers at the bottom, unless disturbed by geological events. This is called the **law of superposition**. Strata from widespread locations with the same fossils or characteristics can thus be correlated, even when their absolute date is unknown.

## Profile with sedimentary rocks containing fossils



### What is relative dating?

Relative dating is a way to determine the relative order of past events without necessarily determining absolute (chronometric) age. The same rocks and fossils can then be used to correlate stratigraphic records in different places. Material that can't be dated using absolute methods can therefore be correlated with the same material elsewhere for which an absolute date may be available.

### New fossil types mark changes in environment

In the rocks marking the end of one geological period, it is common to find many new fossils that become dominant in the next. Each geological period had an environment very different from those before and after. Their boundaries coincided with drastic environmental changes and the appearance of new niches. New selection pressures resulted in new adaptive features as species responded to the changes. An absolute age can be assigned to fossils, usually by dating the rocks around them. Most often, this involves radiometric dating (e.g. radiocarbon, K-Ar).

## The fossil record of proboscidea

African and Asian elephants have descended from a diverse group known as **proboscideans** (named for their long trunks). The first pig-sized, trunkless members of this group lived in Africa 40 million years ago. From Africa, their descendants invaded all continents except Antarctica and Australia. As the group evolved, they became larger, an effective evolutionary response to deter predators. Examples of extinct members of this group are illustrated below:

### Columbian mammoth

Pleistocene, Costa Rica to northern US. Range overlap with woolly mammoths in the north.  
~4 m at the shoulder



### Deinotherium

Miocene-Pleistocene, Asia, Africa  
~4 m at the shoulder



### Gomphotherium

Miocene, Europe, Africa  
~3 m at the shoulder



### Platybelodon

One of several genera of shovel-tuskers. Middle Miocene, Northern Asia, Europe, Africa  
~3 m at the shoulder



- **Modern day species can be traced:** The evolution of many present-day species can be very well reconstructed. For instance, the evolutionary history of the modern elephants is exceedingly well documented for the last 40 million years. The modern horse also has a well understood fossil record spanning the last 50 million years.

- **Fossil species are similar to but differ from today's species:** Most fossil animals and plants belong to the same major taxonomic groups as organisms living today. However, they do differ from the living species in many features.

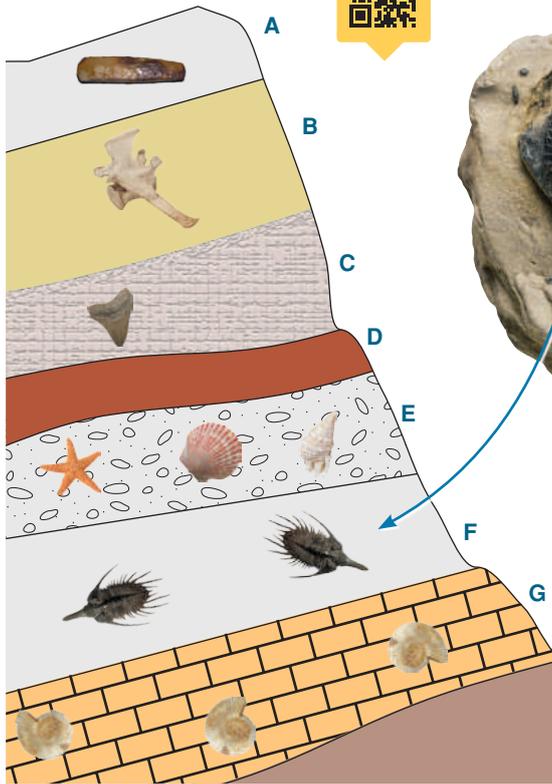
1. Explain the importance of fossils in relative dating: \_\_\_\_\_

\_\_\_\_\_

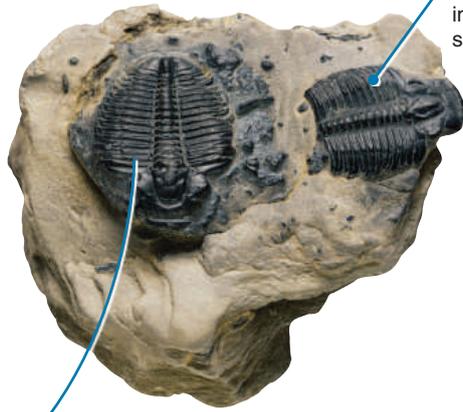
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\_\_\_\_\_

Rock profile at location 1

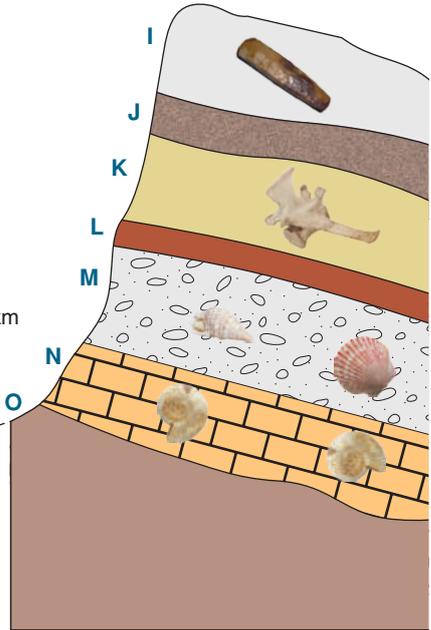


Trilobite fossil  
Dated at 375 million years



Fossils are embedded in the different layers of sedimentary rock

Rock profile at location 2



A distance of 67 km separates these rock formations

The questions below relate to the diagram above, showing a hypothetical rock profile from two locations separated by a distance of 67 km. There are some differences between the rock layers at the two locations. Apart from layers D and L which are volcanic ash deposits, all other layers comprise sedimentary rock.

2. Assuming there has been no geologic activity (e.g. tilting or folding), state in which rock layer (A-O) you would find:
  - (a) The youngest rocks at location 1: \_\_\_\_\_
  - (b) The oldest rocks at location 1: \_\_\_\_\_
  - (c) The youngest rocks at location 2: \_\_\_\_\_
  - (d) The oldest rocks at location 2: \_\_\_\_\_
3. (a) State which layer at location 1 is of the same age as layer M at location 2: \_\_\_\_\_  
 (b) Explain the reason for your answer above: \_\_\_\_\_  
 \_\_\_\_\_
4. The rocks in layer H and O are sedimentary rocks. Explain why there are no visible fossils in these layers:  
 \_\_\_\_\_  
 \_\_\_\_\_
5. (a) State which layers present at location 1 are missing at location 2: \_\_\_\_\_  
 (b) State which layers present at location 2 are missing at location 1: \_\_\_\_\_
6. Using radiometric dating, the trilobite fossil was determined to be approximately 375 million years old. The volcanic rock layer (D) was dated at 270 million years old, while rock layer B was dated at 80 million years old. Give the approximate age range (i.e. greater than, less than, or between given dates) of the rock layers listed below:
  - (a) Layer A: \_\_\_\_\_
  - (b) Layer C: \_\_\_\_\_
  - (c) Layer E: \_\_\_\_\_
  - (d) Layer G: \_\_\_\_\_
  - (e) Layer L: \_\_\_\_\_
  - (f) Layer O: \_\_\_\_\_
7. Suggest why gaps in the fossil record can make it difficult to determine an evolutionary history? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

# 156 What is Absolute Dating?

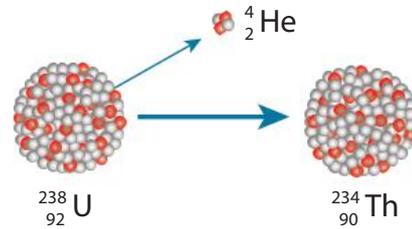
**Key Idea:** Absolute dating uses radioisotopes to produce dates for when a specimen was formed. These dates can be used to calibrate relative dating methods.

Many absolute dating methods rely on the decay of radioactive isotopes (radioisotopes) to calculate the age of a specimen. A radioisotope may go through multiple decay events (a decay series) before reaching a stable non-radioactive isotope. The ratio of the original radioisotope to the stable isotope can be

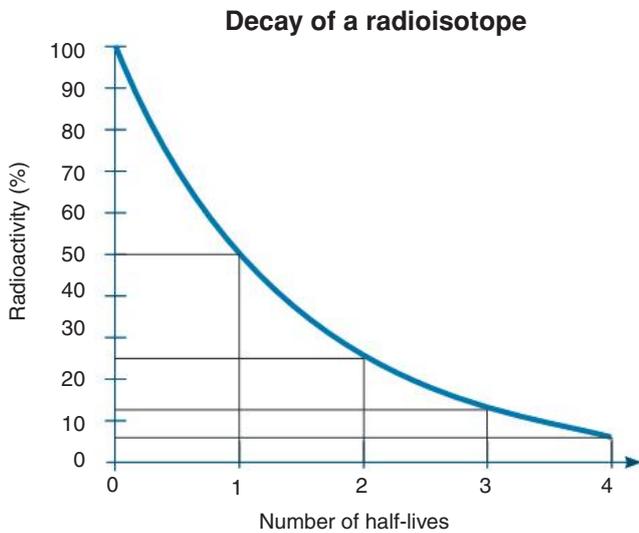
used to calculate the age of the specimen. In some cases the ratios of the different elements within the decay series can be used. Radioactivity can be used to date both once living (e.g. bone) or nonliving (e.g. volcanic rocks) materials. Isotopes are taken up by living organisms at relatively constant rates so that when they die the amount of radioisotope left in the body can be compared to that of living organisms to find a date of death.

## Radioactive decay

The rate of decay of a radioisotope is measured by its half-life. **A half-life** is the time it takes for half the atoms in a sample of radioactive substance to decay into a new element, or the time in which there is a 50% chance any particular atom will have decayed. For example, uranium-238 has a half life of 4.5 billion years. Starting with a sample of 10 g of uranium-238, after 4.5 billion years there would be 5 g of uranium-238 and 5 g of various other elements (mostly lead) in the sample.



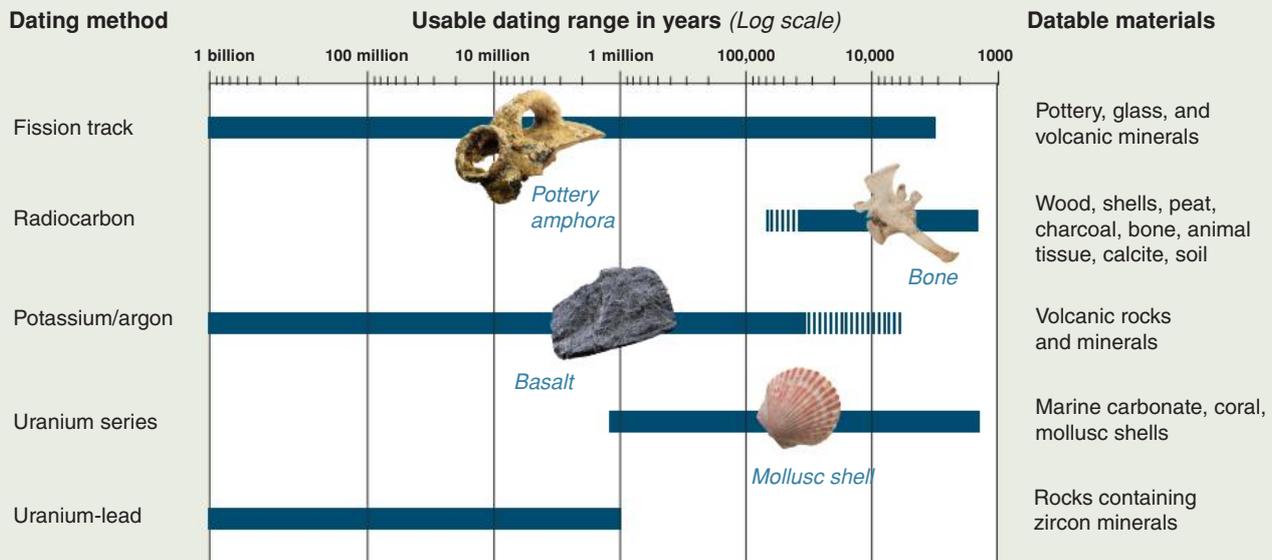
Uranium-238 has a half life of 4.5 billion years and decays to thorium-234. Thorium-234 has a half life of just 24.5 days.



Isotope	Half-life
Uranium-238	4.5 billion years
Uranium-235	700 million years
Thorium-234	24.5 days
Thorium-230	76,000 years
Radium-226	1600 years
Lead-210	22 years
Potassium-40	1.25 billion years
Carbon-14	5730 years

## Dating using radioactivity

The length of the half-life and the type of sample being dated are important when considering which dating method to use. Beyond a certain number of half-lives, the amount of radioisotope left may become so small that accurate dating becomes impossible.



### Non-isotopic methods

Some methods for chronometric dating do not rely on measuring half-lives. They instead use other properties of atoms in the sample, including electron spins and emission of light.

#### Electron spin resonance (ESR)

When minerals are exposed to radiation (e.g. cosmic rays or radioactive decay) their electrons may be knocked from one energy level to a higher energy level. As they return to the lower energy level they may become trapped between energy levels. Under ESR, these electrons can be detected and the number of electrons relates to the length of time since the sample formed. This method is useful for dating objects such as burnt flints, cave sediments, bone, teeth, and loess (wind-blown deposits).

#### Thermoluminescence

This method is useful for dating objects including ceramics, quartz, feldspar, and carbonates. It works by measuring the accumulated radiation dose (e.g. radioactivity or sunlight) of a crystalline sample. When the sample is heated, it emits light in proportion to the radiation dose. The larger the dose the older the object. Measurements of surrounding radiation can be used to identify the annual dose. The method is relatively cheap but requires the destruction of a significant amount of the sample.

- Examine the diagram on the bottom of the previous page and determine the approximate dating range and datable materials for each of the methods listed below (Note the logarithmic time scale on the diagram):

#### Dating range

#### Datable materials

- |                             |       |       |
|-----------------------------|-------|-------|
| (a) Potassium-argon method: | _____ | _____ |
| (b) Radiocarbon method:     | _____ | _____ |
| (c) Uranium series:         | _____ | _____ |

- Radiocarbon dating compares the amount of carbon-14 in dead material to the amount in living material (adjusted to natural variations).

- A piece of tree branch found in sediments of an ancient swamp is radiocarbon dated and found to have about 3% of the expected amount of <sup>14</sup>C in a living tree. Calculate the age of the tree:

\_\_\_\_\_

\_\_\_\_\_

- Another tree branch from the same sediments is radiocarbon dated to 150,000 years. Is this date likely to be accurate? Explain your answer:

\_\_\_\_\_

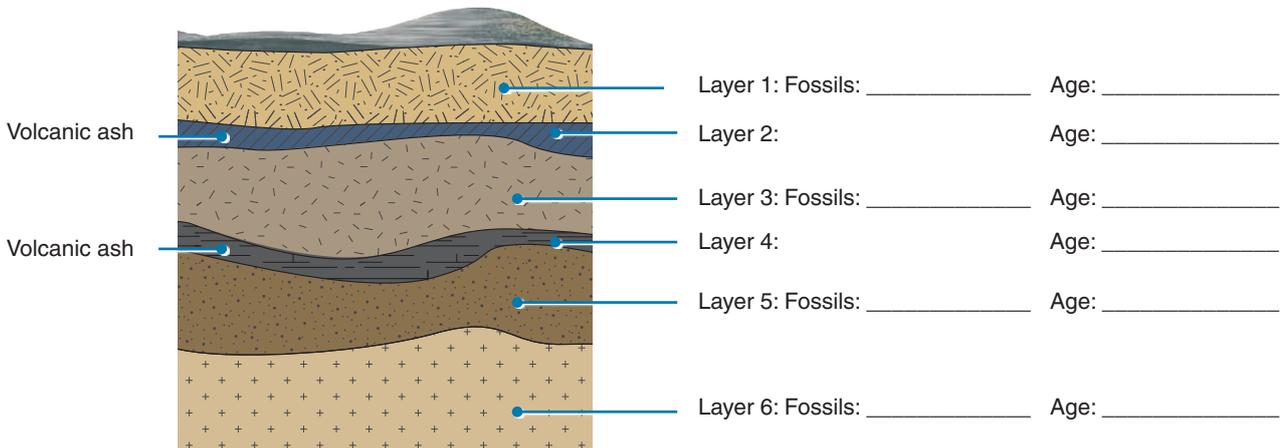
\_\_\_\_\_

\_\_\_\_\_

- Based on the graph on the previous page create a spreadsheet to show the relationship between time (t) and radioactivity (r). Use the spreadsheet to create a graph showing radioactivity to t = 10. Show the equation for the line on the graph and use it to work out the time t for r = 33%. You may need to do some research on rearranging equations.

\_\_\_\_\_

- Use the following data to place the fossils A to E in the correct layers along with the age of the layers:  
 Fossil C is never found with fossils A, B, D, and E. Fossil B is found in the same layers as fossil D. Fossil D is found below a layer of volcanic ash dated at 20 million years old. Fossil A is found above a layer of volcanic ash dated at 10 million years old. Fossil E is never found with any other fossils, but it resembles a fossil found elsewhere below a layer of rock dated at 27 million years old. Fossil B shows more derived skeletal features than fossil E.



# 157 Transitional Fossils

**Key Idea:** Transitional fossils show intermediate states between two different, but related, groups. They provide important links in the fossil record

Transitional fossils are fossils with a mixture of features found in two different, but related, groups. Transitional fossils provide important links in the fossil record and provide evidence to support how one group may have given rise to the other by evolutionary processes. Important examples of transitional

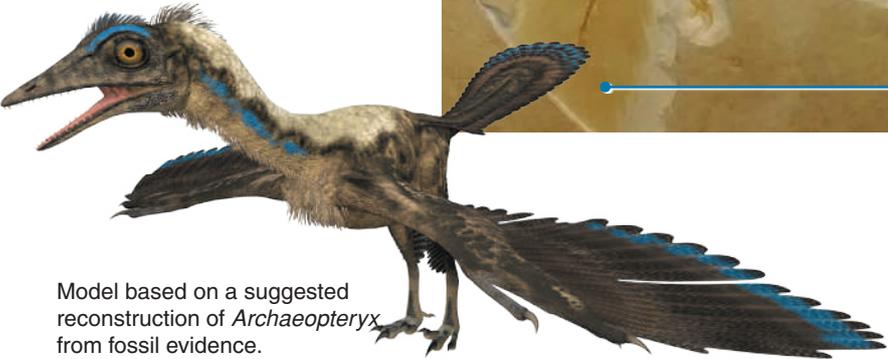
fossils include horses, whales, and *Archaeopteryx* and other non-avian feathered dinosaurs (below). *Archaeopteryx* was a transitional form between non-avian dinosaurs and birds. *Archaeopteryx* was crow-sized (50 cm length) and lived about 150 million years ago. It is regarded as the first primitive bird and had a number of birdlike (avian) features, including feathers. However, it also had many non-avian features, which it shared with theropod dinosaurs of the time.

**Non-avian features**

**Archaeopteryx**



**Avian features**



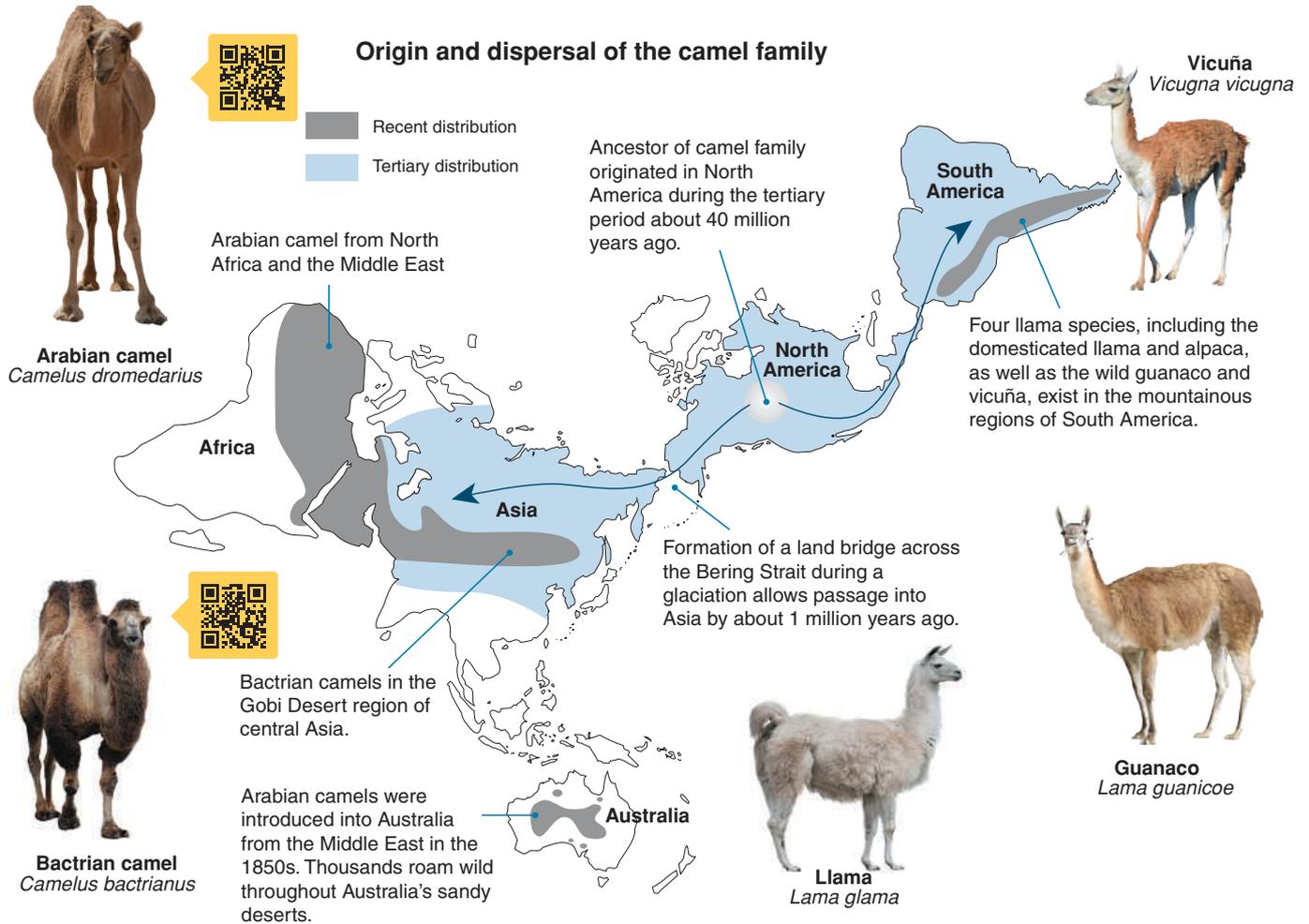
Model based on a suggested reconstruction of *Archaeopteryx* from fossil evidence.

1. (a) What is a transitional fossil? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (b) Why are transitional fossils important in understanding evolution? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. (a) Identify one feature of *Archaeopteryx* that clearly shows it is related to reptiles: \_\_\_\_\_  
 \_\_\_\_\_
- (b) Identify one feature of *Archaeopteryx* that clearly shows it is related to modern birds: \_\_\_\_\_  
 \_\_\_\_\_

# 158 Biogeographical Evidence

**Key Idea:** The current fragmented distribution of the camel family can be explained by natural phenomena such as migration, plate tectonics, and changes in sea level. The camel family, Camelidae, consists of six modern-day species on three continents: Asia, Africa and South America. Geophysical phenomena such as plate tectonics and glacial cycles have determined their present, fragmented distribution. Three principles about the dispersal and distribution of land animals are:

- ▶ When very closely related animals were present at the same time in widely separated parts of the world, it is highly probable that there was no barrier to their movement in between the localities in the past.
- ▶ The most effective barrier to movement of land animals (especially mammals) was a sea between continents.
- ▶ The scattered distribution of living species can be explained by migration out of their original range or extinction in regions between the current populations.



1. Arabian camels are found wild in the Australian outback.
  - (a) How did they get there? \_\_\_\_\_
  - (b) Why were they absent during prehistoric times? \_\_\_\_\_
2. The camel family originated in North America. Suggest why there are no members of the family in North America now: \_\_\_\_\_
3. Suggest how early camels managed to get to Asia from North America: \_\_\_\_\_
4. (a) Describe the present distribution of the camel family: \_\_\_\_\_
- (b) Explain why it is scattered (discontinuous): \_\_\_\_\_

# 159 Oceanic Island Colonisers

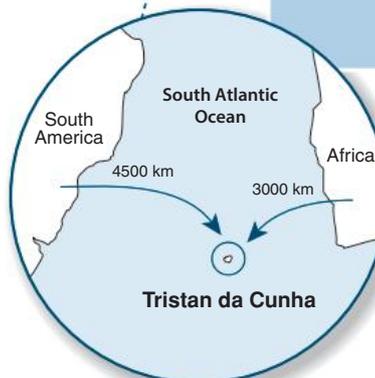
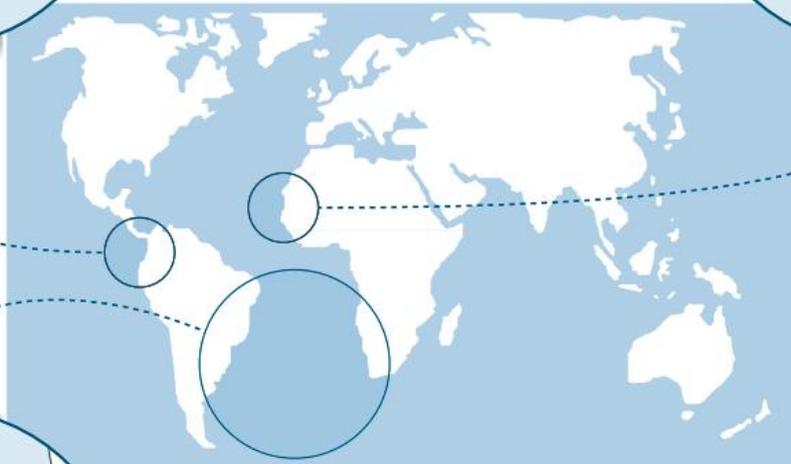
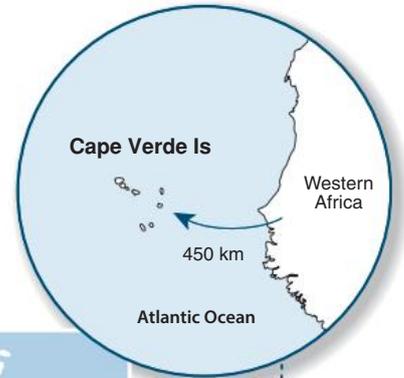
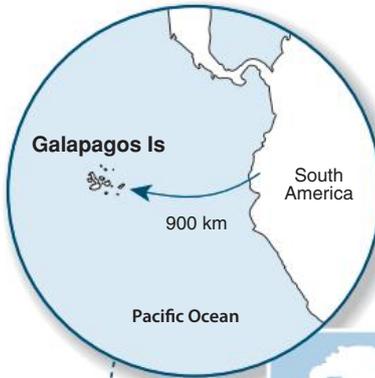
**Key Idea:** The biodiversity of oceanic islands often depends on the distance to the mainland and the ability of plants and animals to survive dispersal.

Oceanic islands have a unique biota because only certain groups of plants and animals tend to colonise them. The animals that successfully colonise oceanic islands have to

be marine in habit or able to survive long periods at sea or in the air. Plants also have limited capacity to reach distant islands. Only some have seeds and fruit that are salt water tolerant. Many plants are transferred to the islands by wind or migrating birds. The biota of the Galápagos islands provide a good example of the result of such a colonisation event.

## Galápagos and Cape Verde islands

Biologists did not fully appreciate the uniqueness and diversity of tropical island biota until explorers began to bring back samples of flora and fauna from their expeditions in the 19th century. The Galápagos Islands, the oldest of which arose 3-4 million years ago, had species similar to but distinct from those on the South American mainland. Similarly, in the Cape Verde Islands, species had close relatives on the West Africa mainland. This suggested to biologists that ancestral forms found their way from the mainland to the islands where they then underwent evolutionary changes.



## Tristan da Cunha

The island of Tristan da Cunha in the South Atlantic Ocean is a great distance from any other land mass. Even though it is closer to Africa, there are more species closely related to South American species found there (see table on right). This is probably due to the predominant westerly trade winds from the direction of South America. The flowering plants of universal origin are found in both Africa and South America and could have been introduced from either land mass.

### Tristan da Cunha species

#### South American origin

- 7 Flowering plants
- 5 Ferns
- 30 Liverworts

#### African origin

- 2 Flowering plants
- 2 Ferns
- 5 Liverworts

#### Universal origin

- 19 Flowering plants



Elizabeth Bay



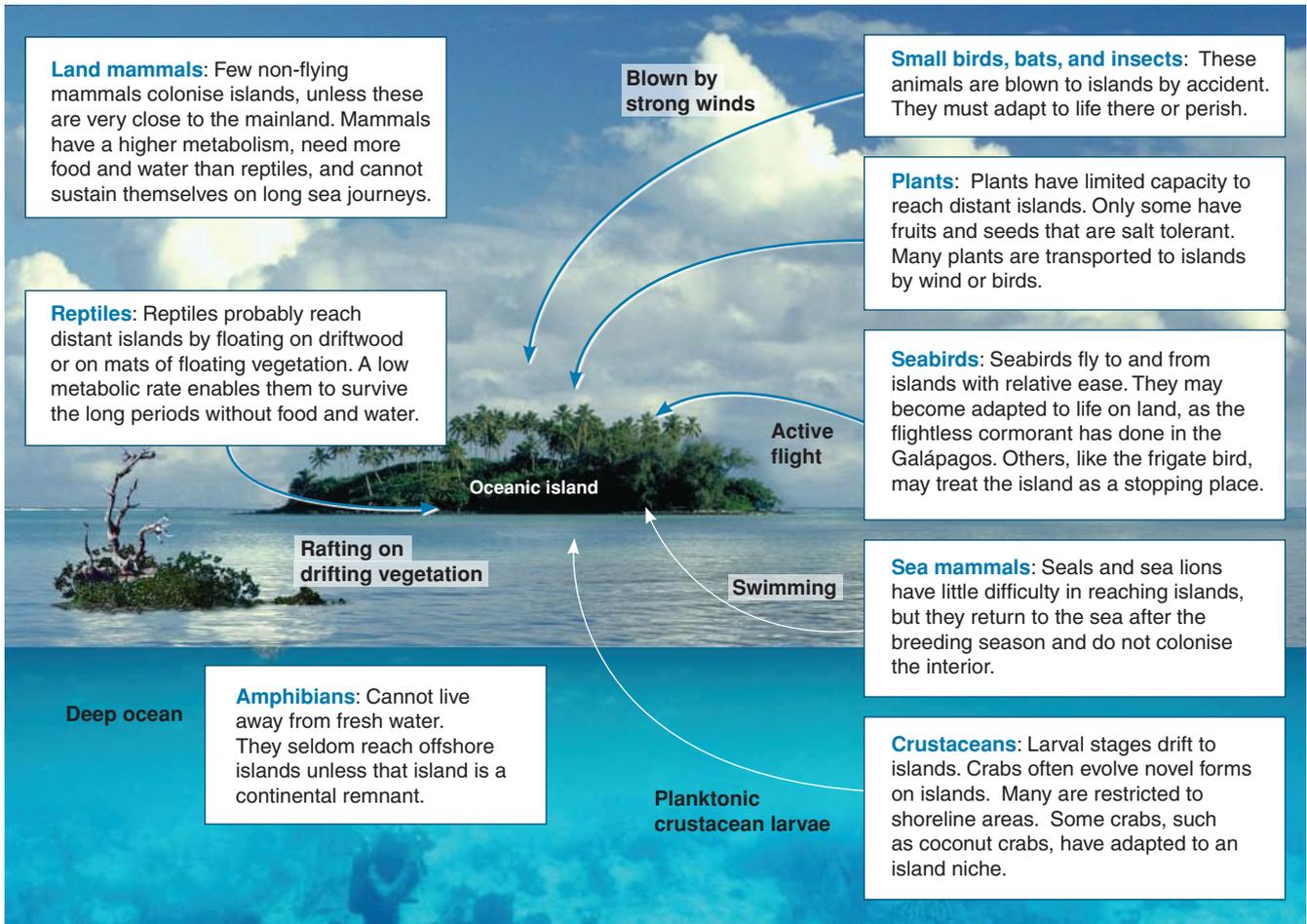
Mfield cc3.0



The flightless cormorant (above) is one of a number of bird species that lost the power of flight after becoming an island resident. Giant tortoises, such as the 11 subspecies remaining on the Galápagos today (centre) were, until relatively recently, characteristic of many islands in the Indian Ocean including the Seychelles archipelago, Reunion,

Mauritius, Farquhar, and Diego Rodriguez. These were almost completely exterminated by early Western sailors, although a small population remains on the island of Aldabra. Another feature of oceanic islands is the adaptive radiation of colonising species into different specialist forms. The three species of Galápagos iguana almost certainly arose,

through speciation, from a hardy traveller from the South American mainland. The marine iguana (above) feeds on shoreline seaweeds and is an adept swimmer. The two species of land iguana (not pictured) feed on cacti, which are numerous. One of these (the pink iguana) was identified as a separate species only in 2009.



The diversity and uniqueness of island biota is determined by migration to and from the island and extinctions and diversifications following colonisation. These events are themselves affected by a number of other factors. The organisms that successfully colonise islands have to be marine in habit, or able to survive long periods

at sea or in the air. The biota of the **Galápagos Islands** provide a good example of the results of such a colonisation process. For example, all the subspecies of giant tortoise evolved in Galápagos from a common ancestor that arrived from the mainland, floating with the ocean currents.

1. The Galápagos and the Cape Verde Islands are both tropical islands close to the equator, yet their biotas are quite different. Explain why this is the case:

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2. Explain why the majority of the plant species found on Tristan da Cunha originated from South America, despite its greater distance from the island:

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3. Using one of more examples, describe how biogeography provides support for the theory of evolution:

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4. Describe one feature typical of an oceanic island coloniser and explain its significance: \_\_\_\_\_

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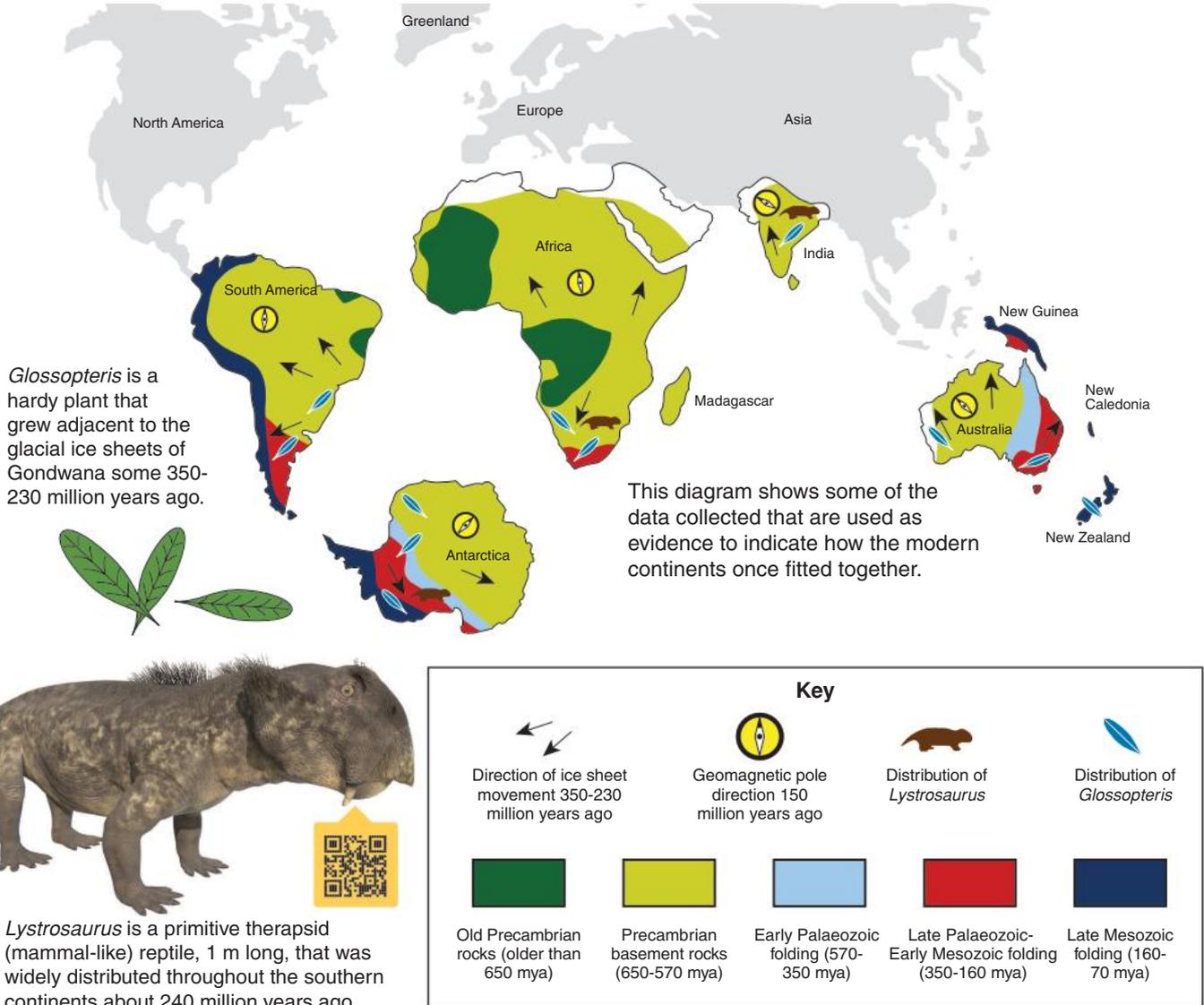
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# 160 Continental Drift and Evolution

**Key Idea:** Fossils of related organisms found on separated continents can be explained by continental drift.

**Continental drift** is the movement of the Earth's continents relative to each other and is a measurable phenomenon; it has happened throughout Earth's history and continues today. Movements of up to 2-11 cm a year have been recorded between continents using laser technology. The

movements of the Earth's 12 major crustal plates are driven by a geological process known as plate tectonics. Some continents are drifting apart while others are moving together. Many lines of evidence show that the modern continents were once joined together as 'supercontinents'. One supercontinent, **Gondwana**, was made up of the southern continents some 200 million years ago.



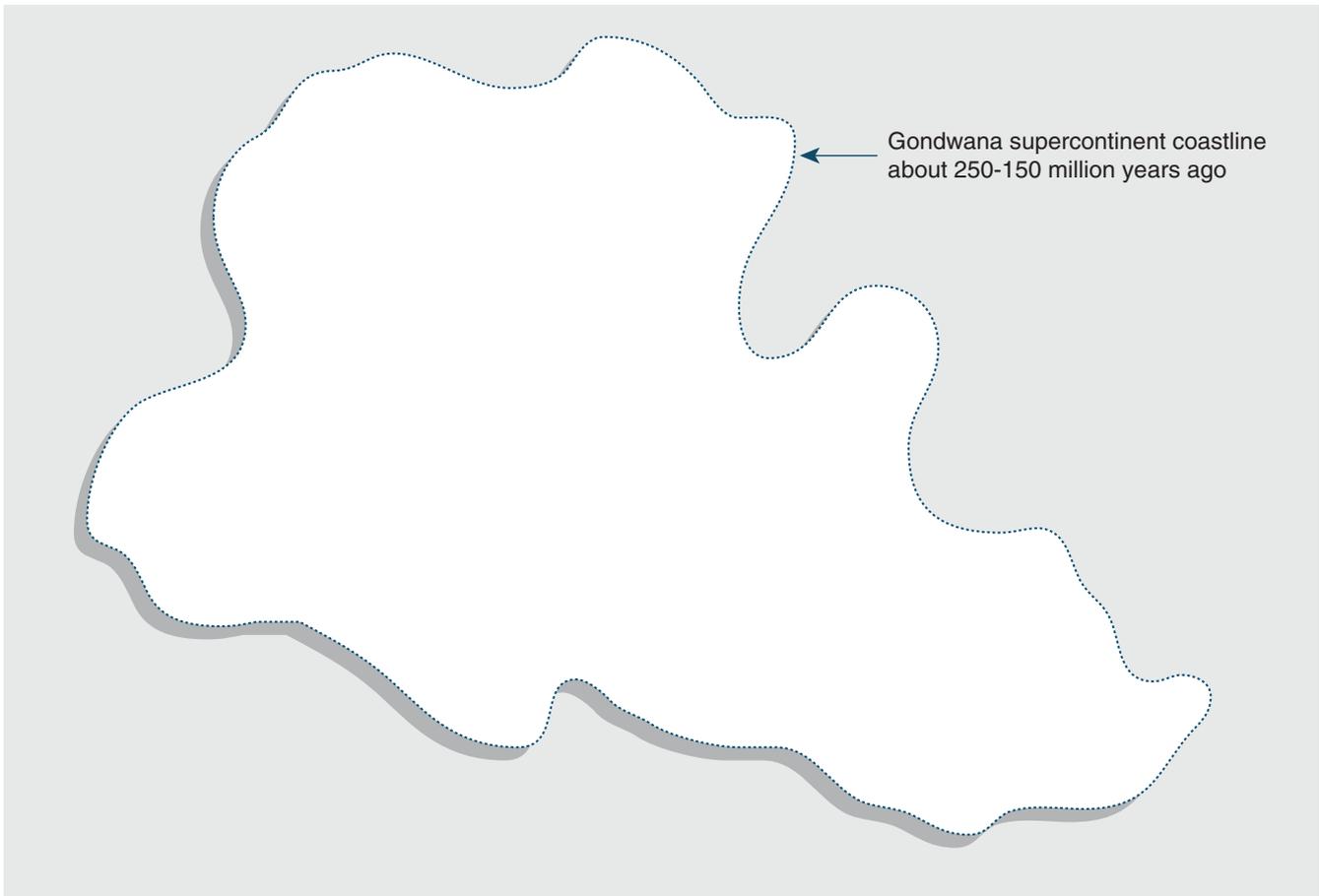
- Name the modern landmasses (continents and large islands) that made up the supercontinent of Gondwana:

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- Cut out the southern continents on page 269 and arrange them to recreate the supercontinent of Gondwana. Take care to cut the shapes out close to the coastlines. When arranging them into the space showing the outline of Gondwana on page 268, take into account the following information:
  - The location of ancient rocks and periods of mountain folding during different geological ages.
  - The direction of ancient ice sheet movements.
  - The geomagnetic orientation of old rocks (the way that magnetic crystals are lined up in ancient rock gives an indication of the direction the magnetic pole was at the time the rock was formed).
  - The distribution of fossils of ancient species such as *Lystrosaurus* and *Glossopteris*.
- Once you have positioned the modern continents into the pattern of the supercontinent, mark on the diagram:
  - The likely position of the South Pole 350-230 million years ago (as indicated by the movement of the ice sheets).
  - The likely position of the geomagnetic South Pole 150 million years ago (as indicated by ancient geomagnetism).
- State what general deduction you can make about the position of the polar regions with respect to land masses:

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5. Fossils of *Lystrosaurus* are known from Antarctica, South Africa, India and Western China. With the modern continents in their present position, *Lystrosaurus* could have walked across dry land to get to China, Africa and India. It was not possible for it to walk to Antarctica, however. Explain the distribution of this ancient species in terms of continental drift:

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6. The southern beech (*Nothofagus*) is found only in the southern hemisphere, in such places as New Caledonia, New Guinea, eastern Australia (including Tasmania), New Zealand, and southern South America. Fossils of southern beech trees have also been found in Antarctica. They have never been distributed in South Africa or India. The seeds of the southern beech trees are not readily dispersed by the wind and are rapidly killed by exposure to salt water.

(a) Suggest a reason why *Nothofagus* is not found in Africa or India: \_\_\_\_\_

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(b) Use a coloured pen to indicate the distribution of *Nothofagus* on the current world map (on the previous page) and on your completed map of Gondwana above.

(c) State how the arrangement of the continents into Gondwana explains this distribution pattern:

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7. The Atlantic Ocean is currently opening up at the rate of 2 cm per year. At this rate in the past, calculate how long it would have taken to reach its current extent, with the distance from Africa to South America being 2300 km (assume the rate of spreading has been constant):

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8. Explain how continental drift provides evidence to support evolutionary theory: \_\_\_\_\_

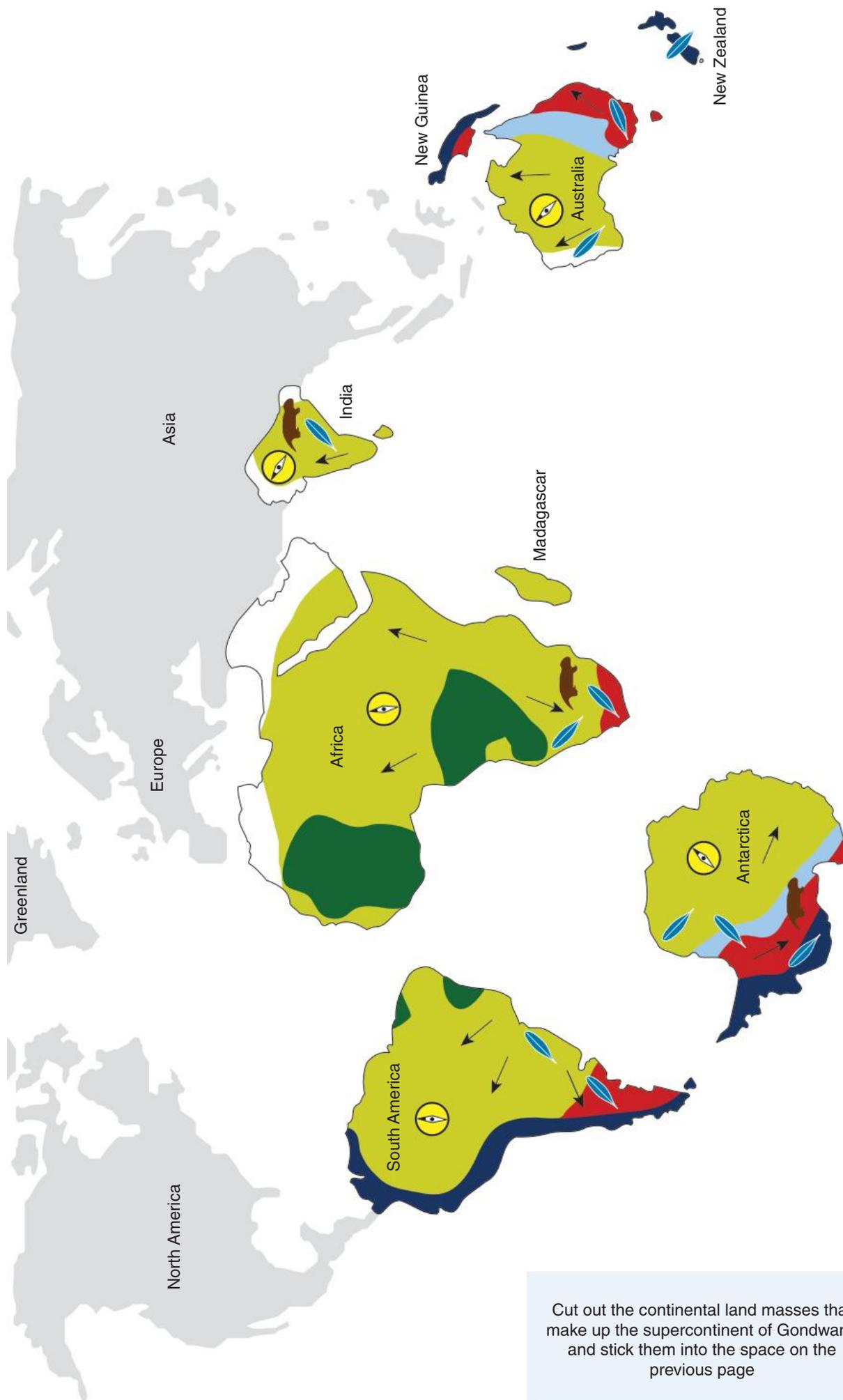
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Cut out the continental land masses that make up the supercontinent of Gondwana and stick them into the space on the previous page

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# 161 Homologous Structures

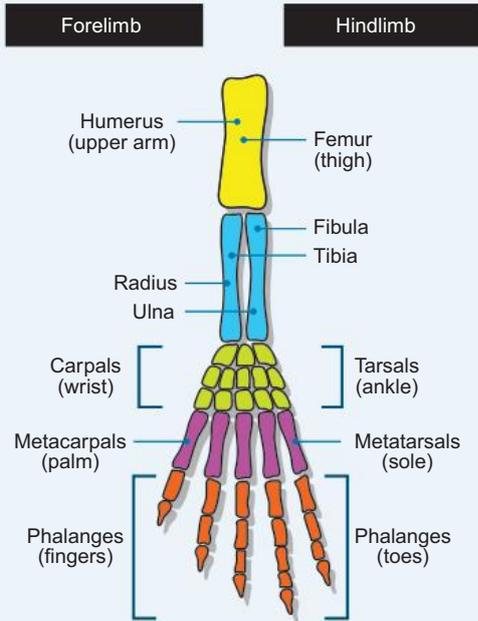
**Key Idea:** Homologous structures (homologies) are structural similarities present as a result of common ancestry. The common structural components have been adapted to different purposes in different taxa.

The bones of the forelimb of air-breathing vertebrates are composed of similar bones arranged in a comparable pattern. This is indicative of common ancestry. The early

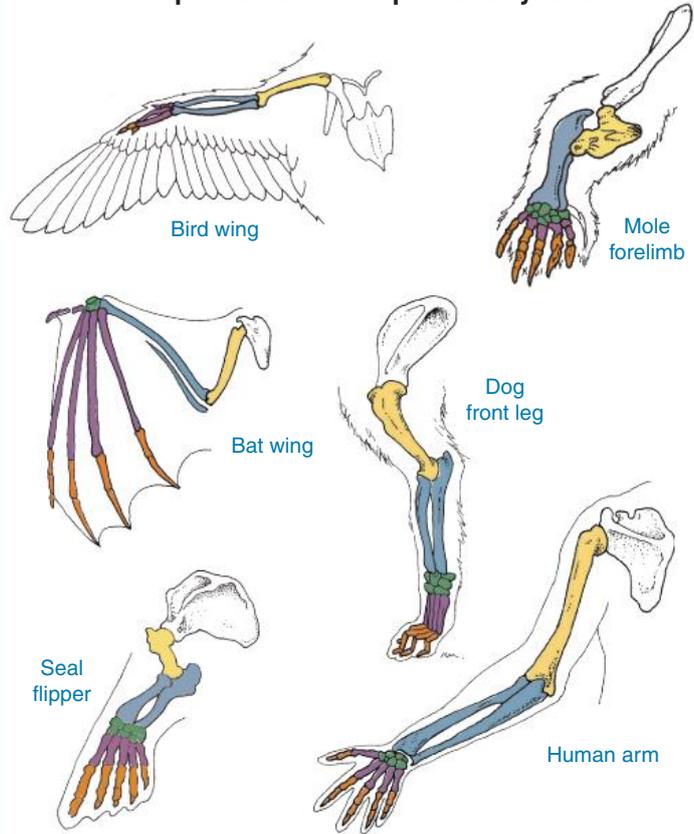
land vertebrates were amphibians with a **pentadactyl limb** structure (a limb with five fingers or toes). All vertebrates that descended from these early amphibians have limbs with this same basic pentadactyl pattern. They also illustrate the phenomenon known as **adaptive radiation**, since the basic limb plan has been adapted to meet the requirements of different niches.

## Generalised pentadactyl limb

The forelimbs and hind limbs have the same arrangement of bones but they have different names. In many cases, the basic limb plan has been adapted (e.g. by loss or fusion of bones) to meet the requirements of different niches (e.g. during adaptive radiation of the mammals).



## Specialisations of pentadactyl limbs



1. Briefly describe the purpose of the major anatomical change that has taken place in each of the limb examples above:

- (a) Bird wing: Highly modified for flight. Forelimb is shaped for aerodynamic lift and feather attachment.
- (b) Human arm: \_\_\_\_\_
- (c) Seal flipper: \_\_\_\_\_
- (d) Dog front leg: \_\_\_\_\_
- (e) Mole forelimb: \_\_\_\_\_
- (f) Bat wing: \_\_\_\_\_

2. Explain how homology in the pentadactyl limb is evidence for adaptive radiation: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Homology in the behaviour of animals (for example, sharing similar courtship or nesting rituals) is sometimes used to indicate the degree of relatedness between groups. How could behaviour be used in this way: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

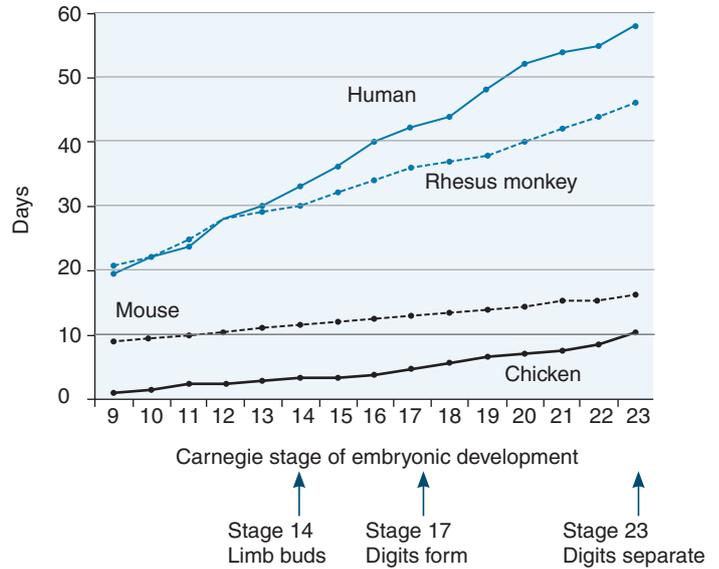
# 162 Developmental Evidence for Evolution

**Key Idea:** Similarities in the development of embryos, including the genetic control of that development, provides strong evidence for evolution. Developmental biology studies the processes by which organisms grow and develop. In the past, it was restricted to

the appearance of a growing embryo. Today, developmental biology focuses on the genetic control of development and its role in producing the large differences we see in the adult appearance of different species. Differences in genetic control during development are behind these differences.

## Developmental biology

During development, vertebrate embryos pass through the same stages, in the same sequence, regardless of the total time period of development. This similarity is strong evidence of their shared ancestry. The stage of embryonic development is identified using a standardised system based on the development of structures, not by size or the number of days of development. The Carnegie stages (right) cover the first 60 days of development.



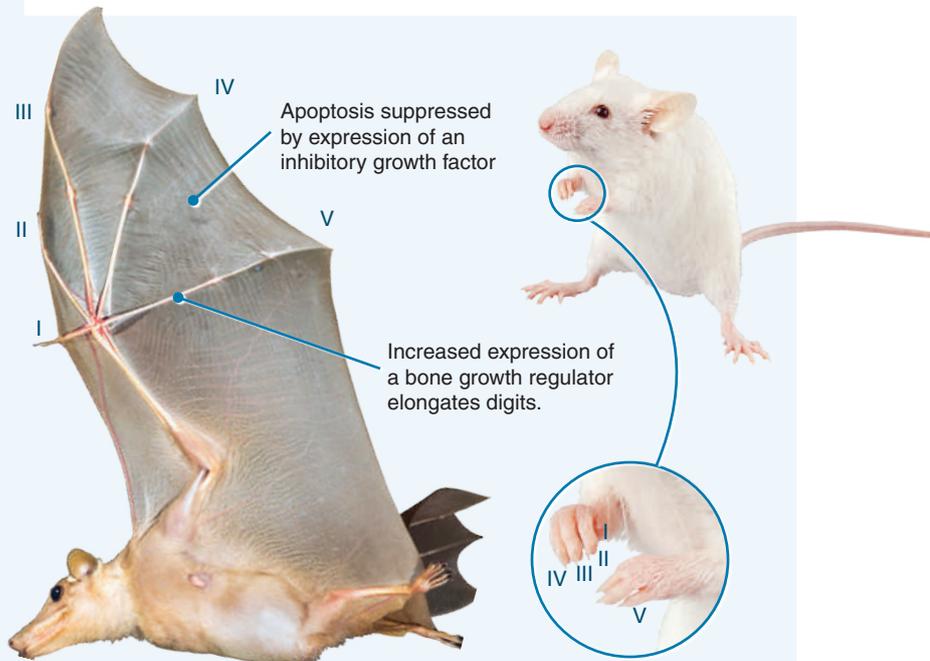
## Limb homology and the control of development

As we have seen, homology (e.g. in limb structure) is evidence of shared ancestry. How do these homologous structures become so different in appearance? The answer lies in the way the same genes are regulated during development.

All vertebrate limbs form as buds at the same stage of development. At first, the limbs resemble paddles, but **apoptosis** (programmed cell death) of the tissue between the developing bones separates the digits to form fingers and toes.

Like humans, mice have digits that become fully separated by interdigital apoptosis during development. In bat forelimbs, this controlled destruction of the tissue between the forelimb digits is inhibited. The developmental program is the result of different patterns of expression of the same genes in the two types of embryos.

*Bat wings are highly specialised structures with unique features, such as elongated wrist and fingers (I-V) and membranous wing surfaces. The forelimb structures of bats and mice are homologous, but how the limb looks and works is quite different.*



1. Describe a feature of vertebrate embryonic development that supports evolution from a common ancestor:

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2. Explain how different specialised limb structures can arise from a basic pentadactyl structure:

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# 163 Evolution of Drug Resistance

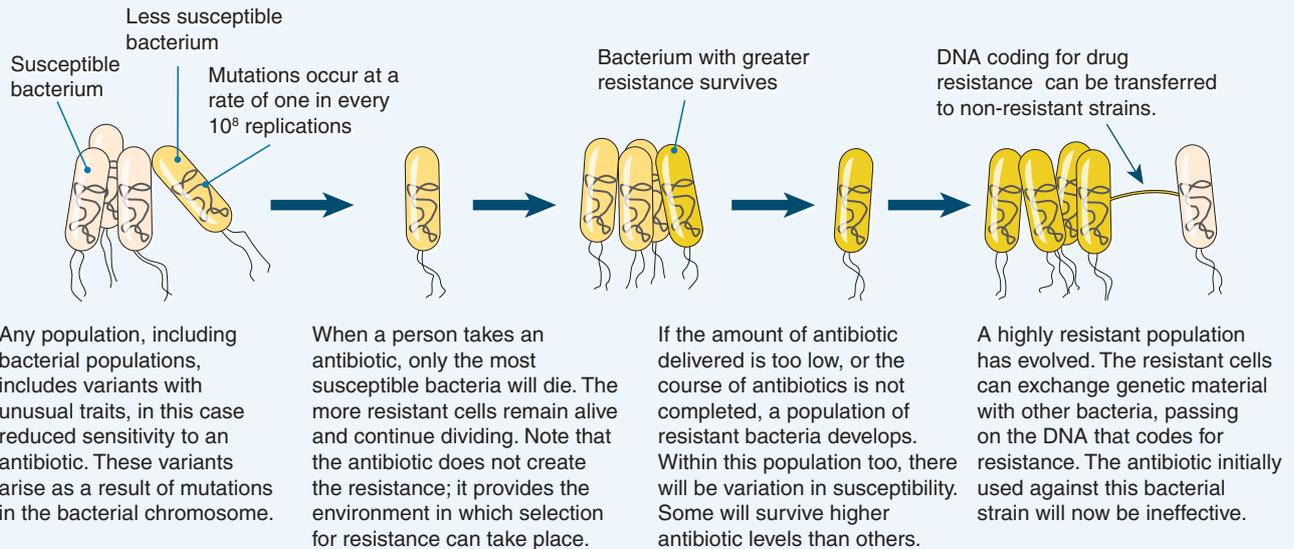
**Key Idea:** The overuse of antimicrobial drugs has driven the evolution of drug resistant microbes.

Resistance to antibiotics and other antimicrobial drugs is becoming increasingly common. Antimicrobial drugs create an environment that selects for resistance, which can arise and spread when chemical control agents do not remove

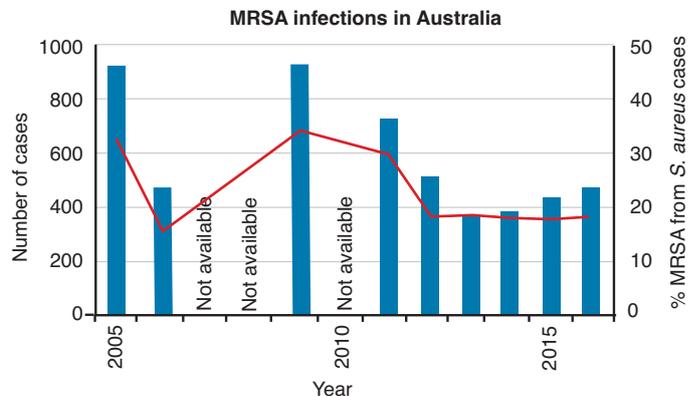
all the targeted organisms. Those that survive as a result of their particular suite of heritable characteristics are able to pass these on so resistance becomes more common in subsequent generations (i.e. natural selection). Resistance to antibiotics in bacteria and to antimalarial drugs in *Plasmodium* pose serious threats to current and future human health.

## The evolution of antibiotic resistance in bacteria

Antibiotic resistance arises when genetic changes allow bacteria to tolerate levels of antibiotic that would normally inhibit growth. Resistance may arise spontaneously through mutation (changes to the DNA) or by transfer of DNA between microbes. Analyses of DNA from 30,000 year old permafrost sediments show that the DNA coding for antibiotic resistance predates modern antibiotic use. In the current selective environment of widespread antibiotic use, having antibiotic resistance is beneficial and so antibiotic resistance has spread. For example, methicillin resistant strains of *Staphylococcus aureus* (MRSA) have acquired resistance to all penicillins. Such strains are called superbugs.



*Staphylococcus aureus* is a common bacterium responsible for several minor skin infections in humans. MRSA is a strain that has evolved resistance to penicillin and related antibiotics. MRSA is troublesome in hospital-associated infections because patients with open wounds, invasive devices (e.g. catheters), or poor immunity are at greater risk for infection than the general public.



In Australia MRSA cases have remained relatively steady since 2012. Greater reporting measures and strict hygiene standards have reduced the number of cases since the early 2000s.

1. Analysis of ancient bacterial DNA indicates that the DNA coding for antibiotic resistance is ancient:

(a) Explain how the DNA for antibiotic resistance could have arisen: \_\_\_\_\_

(b) Explain why antibiotic resistance is proliferating now: \_\_\_\_\_

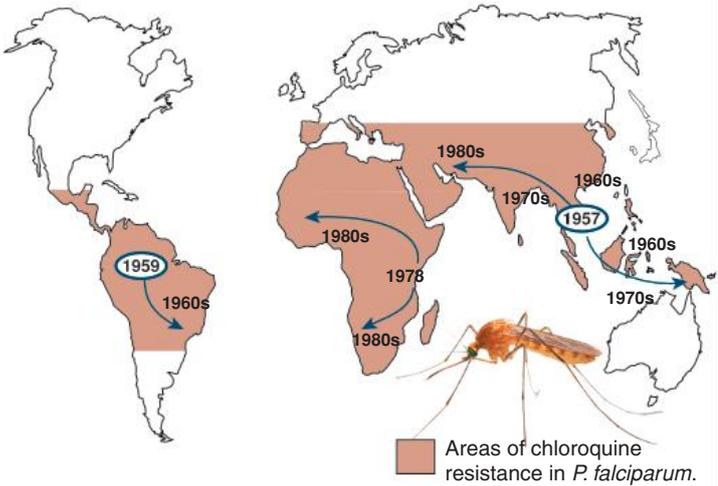
2. Explain how failing to complete a course of antibiotics can lead to antibiotic resistance, such as seen in MRSA:

\_\_\_\_\_

**Chloroquine resistance**

- ▶ Mutations in some strains of the protozoa that cause malaria allowed them to become more resistant to some antimalarial drugs. **Chloroquine** is an antimalarial drug discovered in 1934. It was first used clinically to prevent malaria in 1946. Chloroquine was widely used because it was cheap to produce, safe, and very effective.
- ▶ Chloroquine resistance in *Plasmodium falciparum* first appeared in the late 1950s, and the subsequent spread of resistance has significantly decreased chloroquine's effectiveness. However, chloroquine is still effective at preventing malaria in Central American countries (chloroquine resistance has not yet arisen there), with a 2014 study in Haiti showing no treatment failure. In 30 other countries, chloroquine failure rates ranged between 20 and 100%. In some regions, chloroquine used in combination with other anti-malarial drugs is still an effective treatment.

**Global spread of chloroquine resistance**



Malaria in humans is caused by various species of *Plasmodium*, a protozoan parasite transmitted by *Anopheles* mosquitoes. The inexpensive anti-malarial drug **chloroquine** was used successfully to treat malaria for many years, but its effectiveness has declined since resistance to the drug was first recorded in the 1950s.

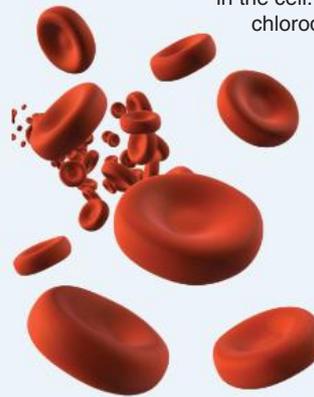
Chloroquine resistance has spread steadily (above) and now two of the four *Plasmodium* species, *P. falciparum* and *P. vivax*, are chloroquine-resistant. *P. falciparum* alone accounts for 80% of all human malarial infections and 90% of the deaths, so this rise in resistance is of global concern.

New anti-malarial drugs have been developed, but are expensive and often have undesirable side effects. Resistance to even these newer drugs is already evident, especially in *P. falciparum*, although this species is currently still susceptible to artemisinin, a derivative of the medicinal herb *Artemisia annua*.

DNA can be divided into basic units of inheritance called **genes**. Genes are involved in the production of proteins and regulating cellular function. Studies have demonstrated a link between mutations in the chloroquine resistance transporter (PfCRT) gene and resistance to chloroquine in *P. falciparum*. PfCRT is a membrane protein involved in drug and metabolite transport.



A mutation in the DNA of the PfCRT gene produces resistance to chloroquine. Parasites with the mutation are better able to release the chloroquine from the vesicles in which it normally accumulates in the cell. Therefore, they accumulate less chloroquine than susceptible parasites.



Chloroquine is a suppressive drug. It is only effective at killing the malarial parasite once the parasite has entered the blood-borne stage of its life cycle.

The use of chloroquine in many African countries was stopped during the 1990s because of resistance to the drug in *P. falciparum*. Recent studies in Malawi and Kenya have revealed a significant decrease in chloroquine resistance since the drug was withdrawn. There may be a significant fitness cost to the PfCRT mutants in the absence of anti-malarial drugs, leading to their decline in frequency once the selection pressure of the drugs is removed. This raises the possibility of re-introducing chloroquine as an anti-malarial treatment in the future.

3. Describe the benefits of using chloroquine to prevent malaria: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. With reference to *Plasmodium falciparum*, explain how chloroquine resistance arises: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

5. Describe two strategies to reduce the spread of chloroquine resistance while still treating malaria:

(a) \_\_\_\_\_

\_\_\_\_\_

(b) \_\_\_\_\_

\_\_\_\_\_

# 164 Changes in Cane Toads

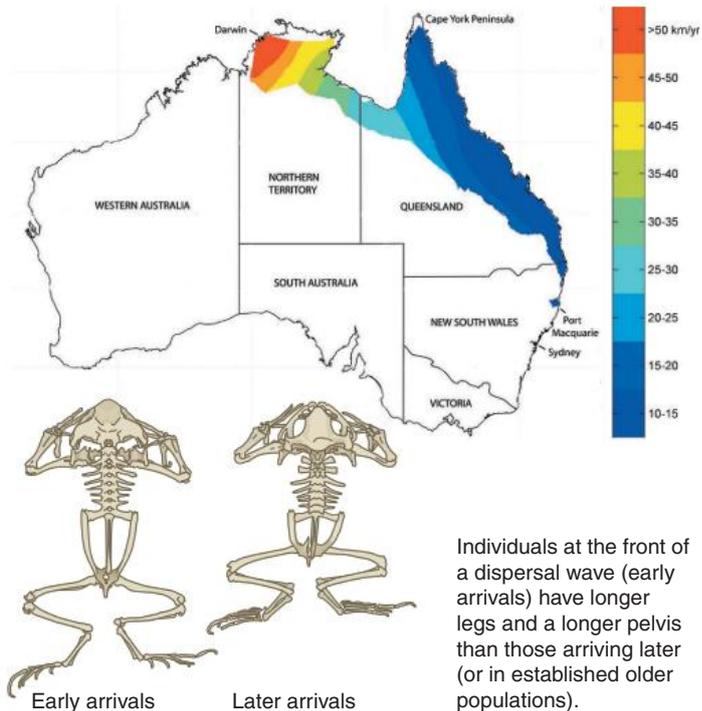
**Key Idea:** Cane toads have evolved to be faster travellers since their introduction to Australia.

Since their introduction in 1935, cane toads have spread across the northeastern part of Queensland. Interestingly

scientists have found their spread seems to be accelerating. Investigations into this phenomenon suggest toads at the invasion front tend to travel in straight lines and have longer legs than toads in more established populations.

## Cane toads on the move

- ▶ Shortly after their introduction into Queensland, cane toads began moving into other states. A lack of predators, an abundance of food, favourable environmental conditions, and the ability to lay up to 30,000 eggs a time, allowed them to successfully breed in large numbers and expand their range.
- ▶ Between the 1940s-1960s cane toads expanded their range by about 10 km/year. In more recent times radio tracking shows they are now moving at a rate of over 50 km/year (diagram, right).
- ▶ Evidence suggests there has been a genetic change in the Australian cane toads to favour individuals who can arrive first at a new destination. Individuals who arrive first have fewer competitors, have access to more resources, and are more successful in breeding than those arriving later.
- ▶ Researchers discovered the cane toads which arrived first into a new area had longer legs and more endurance than those that arrived later.
- ▶ Researchers also collected data from two populations of cane toads to see if there were any difference in back leg length and travel speed. The data for the two populations (recent arrivals in Western Australia and an established population in Queensland) are shown below.



Individuals at the front of a dispersal wave (early arrivals) have longer legs and a longer pelvis than those arriving later (or in established older populations).

1. Explain why cane toads were able to establish so well in Australia: \_\_\_\_\_

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2. Why is it an advantage to reach a new area faster than other individuals? \_\_\_\_\_

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3. Study the graph right.

(a) How does the back leg length compare between the two populations?

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(b) How does the travel time compare between the two populations?

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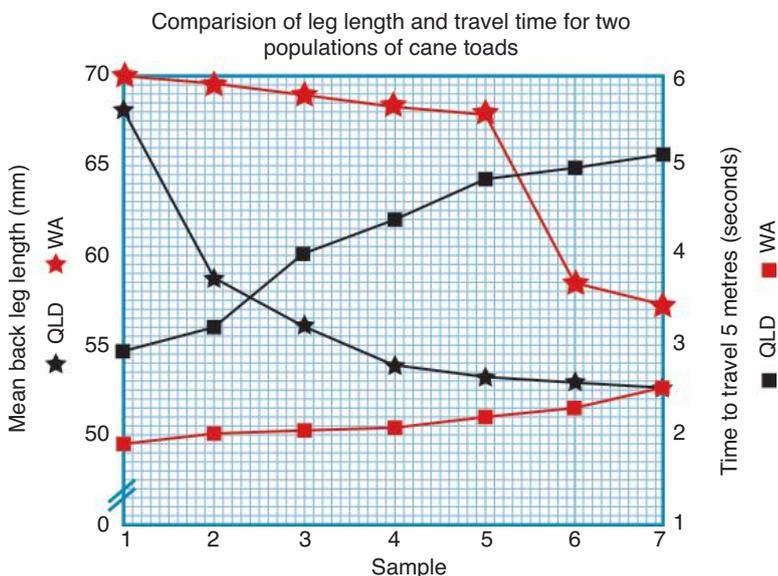


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(c) The data suggests travel time is decreased / increased for individuals with longer legs (circle the correct answer).



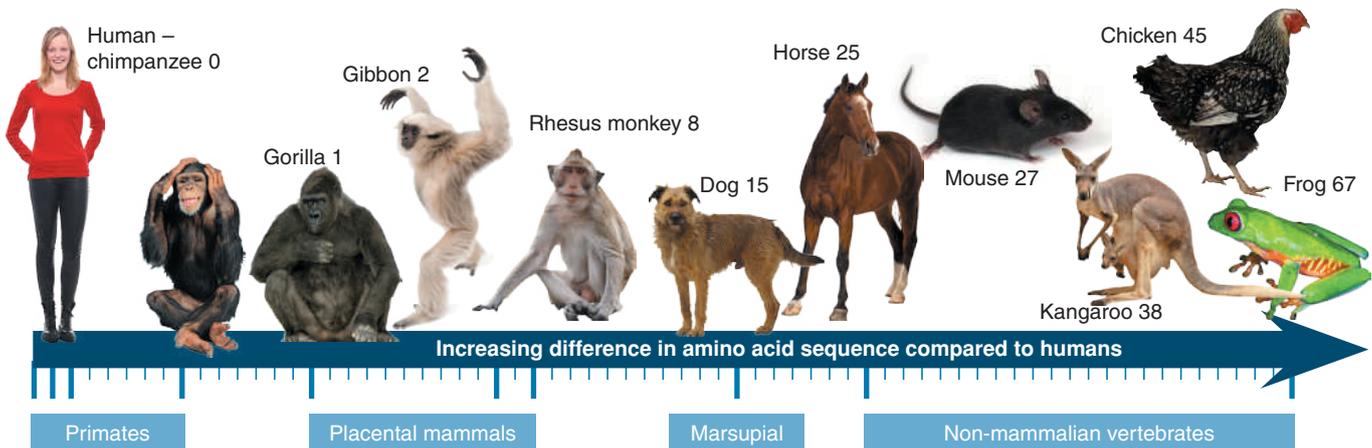
# 165 Determining Relatedness Using Proteins

**Key Idea:** Proteins are the product of gene expression, so an analysis of the differences between the same protein in different taxa gives an indication of species relatedness.

Traditionally, phylogenies were based largely on anatomical traits, and biologists attempted to determine the relationships between taxa based on similarity or by tracing the appearance of key characteristics. With the advent of new molecular techniques, homologies (similarities arising from shared ancestry) could be studied at the molecular level as well

and the results compared to phylogenies established using other methods. Protein sequencing provides an excellent tool for establishing homologies. Proteins are made of **amino acids** arranged in a specific order. Because DNA contains the instructions for the manufacture of proteins by cellular machinery, any differences in the sequence reflect changes in the DNA sequence. Commonly studied proteins include blood proteins, such as haemoglobin, and the respiratory protein cytochrome c.

## Haemoglobin homology



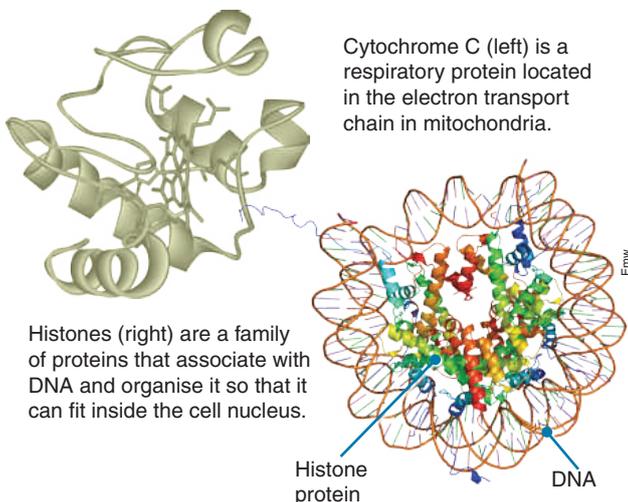
Haemoglobin is the oxygen-transporting blood protein found in most vertebrates. The beta chain haemoglobin sequences from different organisms can be compared to determine evolutionary relationships.

As genetic relatedness decreases, the number of amino acid differences between the haemoglobin beta chains of different vertebrates increases (above). For example, there are no amino acid differences between humans and chimpanzees, indicating they recently shared a common ancestor. Humans and frogs have 67 amino acid differences, indicating they had a common ancestor a very long time ago.

## Highly conserved proteins

Some proteins are common in many different species. These proteins are called highly conserved proteins, meaning they change (mutate) very little over time. This is because they have critical roles in the organism (e.g. in cellular respiration) and mutations are likely to be lethal.

Evidence indicates that highly conserved proteins are homologous and have been derived from a common ancestor. Because they are highly conserved, changes in the amino acid sequence are likely to represent major divergences between groups during the course of evolution.



## The Pax-6 protein provides evidence for evolution

- ▶ The Pax-6 gene belongs to a family of master genes that regulate the formation of a number of organs, including the eye, during embryonic development.
- ▶ The Pax-6 gene produces the Pax-6 protein, which controls the expression of other genes.
- ▶ Scientists know the role of Pax-6 in eye development because they created a knockout model in mice where the Pax-6 gene is not expressed. The knockout model is eyeless or has very underdeveloped eyes.
- ▶ The Pax-6 gene is so highly conserved that the gene from one species can be inserted into another species, and still produce a normal eye.
- ▶ This suggests the Pax-6 proteins are homologous, and the gene has been inherited from a common ancestor.

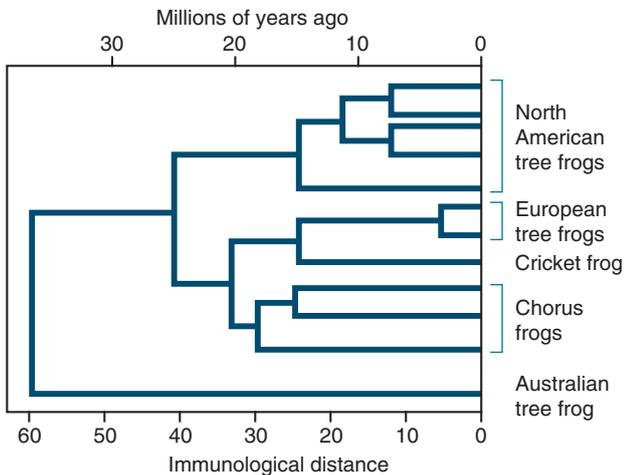
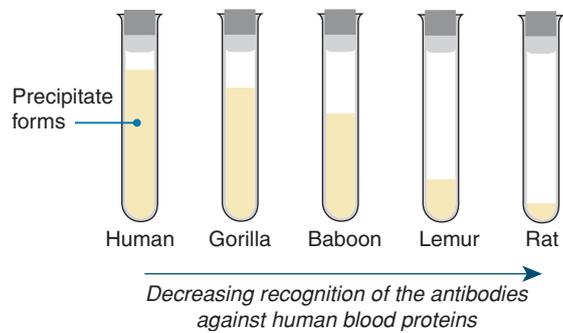
An experiment inserted mouse Pax-6 gene into fly DNA and turned it on in a fly's legs. The fly developed morphologically normal eyes on its legs!



A-1

### Using immunology to determine phylogeny

The immune system of one species will recognise the blood proteins of another species as foreign and form antibodies against them. This property can be used to determine the extent of relatedness between species. Blood proteins, such as albumins, are used to prepare **antiserum** in rabbits, a distantly related species. The antiserum contains antibodies against the test blood proteins (e.g. human) and will react to those proteins in any blood sample they are mixed with. The extent of the reaction indicates how similar the proteins are; the greater the reaction, the more similar the proteins. This principle is illustrated (right) for antiserum produced to human blood and its reaction with the blood of other primates and a rat.



The relationships among tree frogs have been established by immunological studies based on blood proteins such as immunoglobulins and albumins. The **immunological distance** is a measure of the number of amino acid substitutions between two groups. This, in turn, has been calibrated to provide a time scale showing when the various related groups diverged.

1. Compare the differences in the haemoglobin sequence of humans, rhesus monkeys, and horses. What do these tell you about the relative relatedness of these organisms?

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2. (a) What is a highly conserved protein? \_\_\_\_\_

---

(b) What type of proteins tend to be highly conserved? \_\_\_\_\_

---

(c) Why are the proteins named in (b) highly conserved? \_\_\_\_\_

---

(d) Why are highly conserved proteins good for constructing phylogenies? \_\_\_\_\_

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3. (a) Describe the role of the Pax-6 gene: \_\_\_\_\_

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(b) What evidence is there that the Pax-6 protein is highly conserved? \_\_\_\_\_

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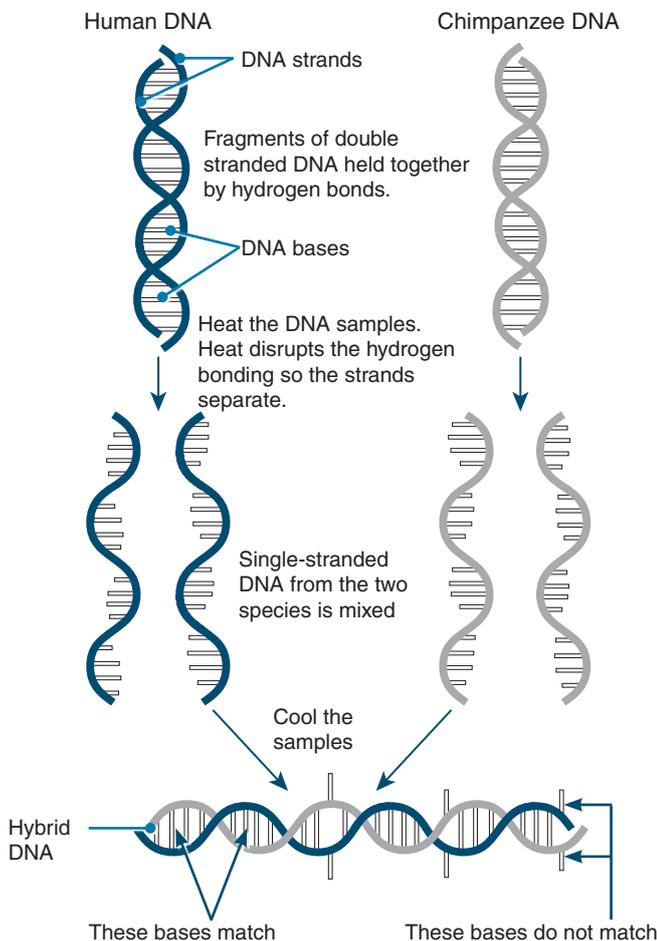
# 166 Determining Relatedness Using DNA

**Key Idea:** DNA hybridisation compares DNA similarity between species and can be used to measure relatedness. DNA hybridisation is a technique used to quantify the DNA similarity between species. More closely related species have fewer genetic differences than more distantly related species. The method provides information only about how much of

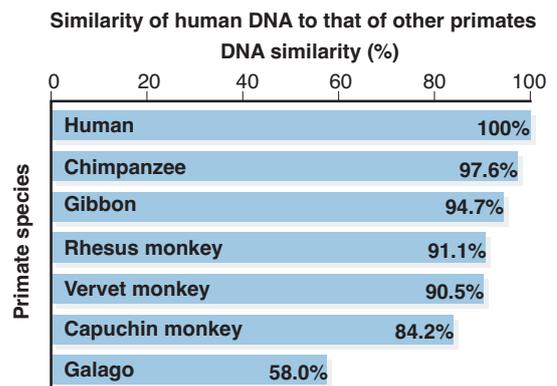
the DNA is the same and cannot provide specific information about what the similarities or differences are. Although it has largely been replaced by DNA sequence analysis, DNA hybridisation is still used in microbial studies and has been used to determine the date of human divergence from apes, which has been estimated at 10 and 5 million years ago.

## DNA hybridisation technique

1. DNA from the two species to be compared is extracted, purified and cut into short fragments.
2. The mixture is heated so the DNA separates. The DNA from the two species is mixed together.
3. As it cools, bonds form between compatible nucleotides. Hybrid double-stranded DNA forms.
4. If species share low similarity, the hybrid DNA will have few bonds (and the strands will be weakly held together). The number of bonds (and therefore the strength of the hybrid DNA) increases with increasing similarity.
5. The similarity is measured by heating the hybrid DNA to force it to form single strands. The greater the similarity, the more heat that is required to break the hybrid DNA apart.



1. How can DNA hybridisation give a measure of genetic relatedness between species?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. Why do the double strands of DNA break when they are heated?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. What is responsible for the hybridisation between the DNA strands?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
4. The graph below shows the results of a DNA hybridisation between humans and other primates.



- (a) Which primate is most closely related to humans?  
 \_\_\_\_\_
  - (b) Which primate is most distantly related to humans?  
 \_\_\_\_\_
5. Hybrid DNA from species A and B comes apart at a lower temperature that of species A and C. Which species is A most closely related to?  
 \_\_\_\_\_

# 167 Comparing DNA Sequences

**Key Idea:** Comparing nucleotide sequences from different organisms provides information about their relatedness.

A nucleotide is the basic building block of DNA. A DNA molecule may be made up of millions of nucleotides. Each nucleotide contains one of the molecular bases A, T, C, or G. DNA sequencing can identify the precise order of nucleotides in a DNA molecule. Analysing the information with computers

allows researchers to compare sequences between species in much more detail than is possible with DNA hybridisation. Not only can areas of difference be identified, but the variation between the nucleotides at a certain position can be determined. This information allows researchers to accurately determine the relatedness between species, even between those with very minor differences.

## Comparing DNA sequences

Improved DNA sequencing techniques and powerful computing software have allowed researchers to accurately and quickly sequence and compare entire genomes (all an organism's genetic material) within and between species.

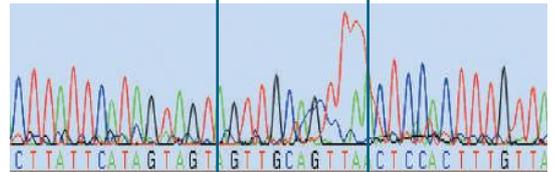
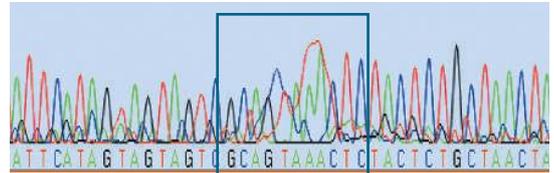
Once DNA sequences have been determined, they are aligned and compared to see where the differences occur (right). DNA sequencing generates large volumes of data and the rise in computing power has been central to modern sequence analyses. The technological advances have been behind the new field of bioinformatics, which uses computer science, statistics, mathematics, and engineering to analyse and interpret biological data.



DNA: Species 1



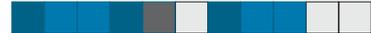
DNA: Species 2



Species 1



Species 2



## What type of sequences are compared?

Highly conserved sequences are often used for comparative genomic analysis because they are found in many organisms. The changes (mutations) of the sequences over time can be used to determine evolutionary relationships. As with other forms of molecular analysis, species with fewer nucleotide differences are more closely related than those with many.

Whole genome (all the DNA in an organism) analysis has been important in classifying the primates. Historical views attributed special status to humans which often confused primate classification schemes. DNA evidence provides impartial quantitative evidence and modern classification schemes have been based on this data.



Based on DNA evidence, chimpanzees are more closely related to humans than they are to gorillas and there is no taxon called "great apes".

1. (a) What advantages does DNA sequence comparison have over DNA hybridisation? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) How is this an advantage in determining evolutionary relationships? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. Below are three short nucleotide sequences from three different species. Recall that a nucleotide can be labelled A, T, C, or G. The more similar the nucleotide sequence, the more closely related the species.

Species 1    ATGGCCCCAACATTCGAAAATCGCACCCCTGCTCAAATTATCAAC

Species 2    ATGGCACCTAACATCCCCAACTCCACCGTGTACTCAAATCATCAAG

Species 3    ATGGCACCCAATATCCGCAAATCACACCCCTGTTAAAACAATCAAC

Based on the number of differences in the DNA sequences:

(a) Identify the two species most closely related: \_\_\_\_\_

(b) Identify the two species that are least closely related: \_\_\_\_\_





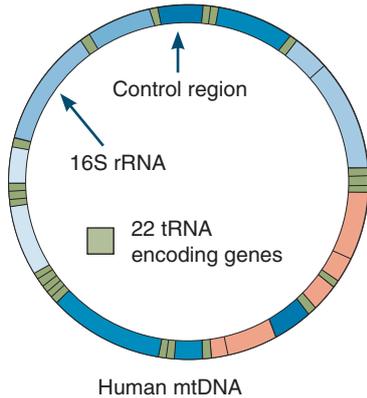
# 169 Using Mitochondrial DNA

**Key Idea:** Mitochondrial DNA (mtDNA) can be used to determine relationships between closely related species.

Mitochondrial DNA (mtDNA) is a single circular piece of DNA found in the mitochondria of eukaryotic organisms. mtDNA mutates at a much higher rate than nuclear DNA and it is inherited only from the mother (except in extremely rare

occurrences). Thus mtDNA mutations are passed on 100% of the time from mother to all her offspring. These two features make mtDNA useful for determining relationships between closely related species or individuals within a species, and for following maternal lineages through time.

The length of the mtDNA can vary between eukaryotes. The human mitochondrial genome contains about 16 kilobases. It encodes 37 genes, 22 of them being for mitochondrial tRNA. Genes that are commonly compared are the 16S rRNA gene and the control region of the mtDNA.



## Identifying species using mtDNA

Transatlantic mangrove oysters of the genus *Crassostrea* are important commercial oysters on the Atlantic shores of South America and Africa. mtDNA studies have found that the division of this genus into distinct South American and African species (the African *C. gasar* and the South American *C. rhizophorae*) may be incorrect. A study sequenced a 570 base-pair length of mtDNA from the 16S rRNA gene of 18 individuals from nine locations along the African and South American coastline. The study found two distinct DNA sequences. Bases 1 - 60 are shown below:

**A** TTGATTTT TAGTAGTACCTGCCAGTGCG-TATTATCTTGTTAACGGCCGCCTT  
**B** ..... C ..... A ..... AG.C . . C . . . . .

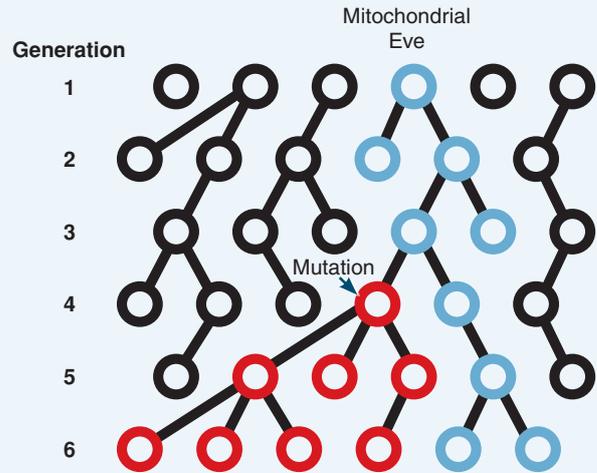
In was presumed that the mangrove oyster *C. gasar* was found only on the African side of the Atlantic while *C. rhizophorae* was found only in South America. All samples from the African coastline had the same sequence as A above. However the South American sample was found to have both A and B DNA sequences, showing that *C. gasar* is also present in South America.



## Using mtDNA to trace human ancestry

Because mtDNA is only passed through the maternal line it can be used to trace maternal lineage. Barring new mutations, the mtDNA of any one person is the same as their direct maternal ancestor back many generations.

In humans, this concept has been used to trace the most-recent common mitochondrial ancestor of all humans, a single female from Africa (dubbed Mitochondrial Eve or ME). The ME represents that woman whose mitochondrial DNA (with mutations) exists in all humans alive today. Mutations to the mtDNA provide the molecular clock that allows us to determine how much time has elapsed since the ME lived. The existence of a ME does not mean that no other women have left descendents. At some point, these other females must have produced no daughters themselves and so broke the mitochondrial line (right).



- (a) How does mtDNA differ from nuclear DNA? \_\_\_\_\_

\_\_\_\_\_

(b) Why is mtDNA useful for following maternal lineages? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- Why is mtDNA useful for determining relationships between closely related species: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 170 Chapter Review: Did You Get It?

1. Test your vocabulary by matching each term to its correct definition, as identified by its preceding letter code.

- common ancestor .....
- DNA hybridisation .....
- molecular clock .....
- mtDNA .....
- phylogeny .....

- A** A technique in molecular evolution that uses molecular change to deduce the time in geological history when two species or other taxa diverged. Can be used to establish phylogenies.
- B** The evolutionary history or genealogy of a group of organisms.
- C** DNA located in mitochondria.
- D** A technique used to determine the percentage similarity between the DNA of two organisms.
- E** The individual from which all organisms in a taxon are directly descended.

2. Compare and contrast DNA hybridisation and DNA sequence comparison as methods for generating phylogenies:

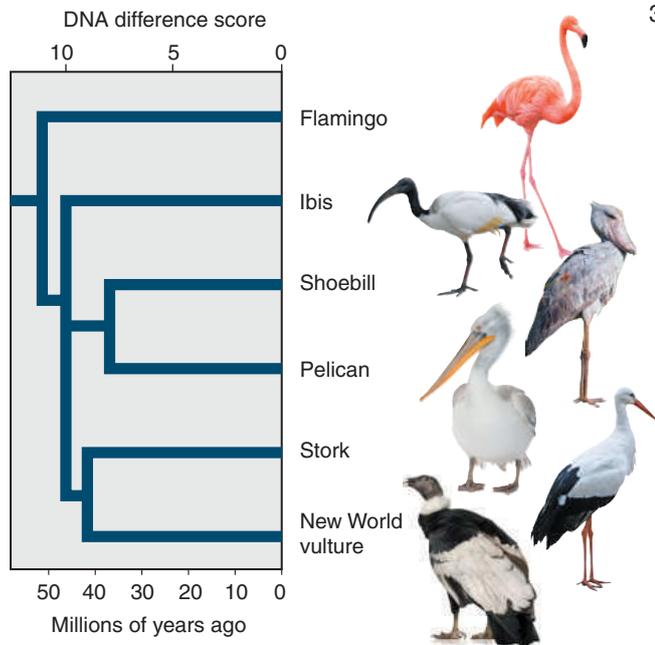
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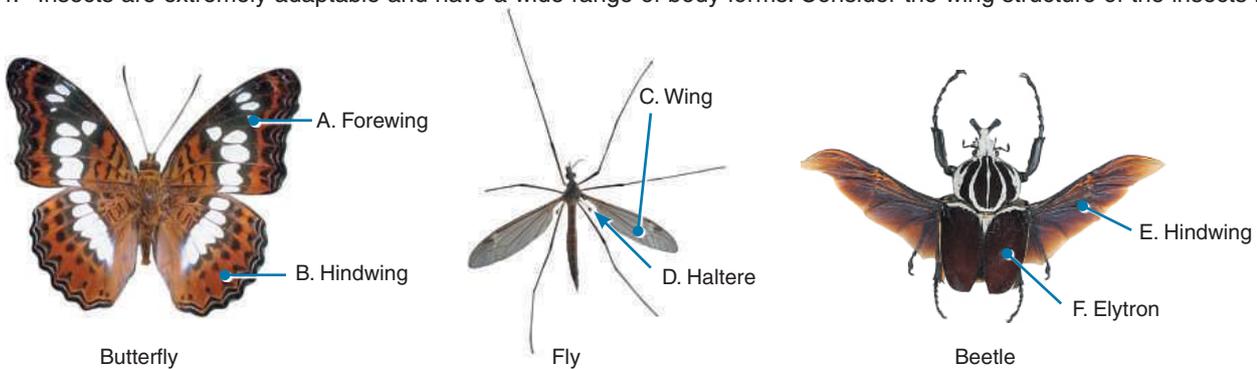
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3. The diagram (left) shows the evolutionary relationship of a group of birds based on DNA similarities:

- (a) Place an X to the last common ancestor of all the birds: \_\_\_\_\_
- (b) How many years ago did storks diverge from vultures?  
\_\_\_\_\_
- (c) What are the most closely related birds? \_\_\_\_\_
- (d) What is the difference in DNA (score) between:
  - i: Storks and vultures: \_\_\_\_\_
  - ii: Ibises and shoebills: \_\_\_\_\_
- (e) Which of the birds is the least related to vultures?  
\_\_\_\_\_

4. Insects are extremely adaptable and have a wide range of body forms. Consider the wing structure of the insects below:



- (a) Use the letters to identify the wing structures that are homologous on the images above: \_\_\_\_\_
- (b) What does the homology of these structures indicate? \_\_\_\_\_

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# 171 Synoptic Assessment: Module 3



Sugar glider



Flying squirrel (rodent)

1. Sugar gliders and flying squirrels (left) are an example of unrelated organisms that have both evolved gliding abilities. Explain the advantage of this adaptation to both these animals and why might it have evolved?

(a) Identify the pattern of evolution in the sugar glider and flying squirrel

\_\_\_\_\_

(b) Suggest why gliding between trees has evolved in these mammals:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Identify two other species that show that same evolutionary pattern as the sugar glider and flying squirrel and explain why they show this pattern:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. The endemic Hawaiian silverswords form a diverse group of around 30 distinct species derived from a single ancestor 5.2 ± 0.8 million years ago. The species are phenotypically very different and occupy different niches. Describe the pattern of their evolution and justify your answer:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



Haleakala silversword

3. The half life of carbon-14 is 5730 years. A bone from a cave is radiocarbon dated and it is found to have about 12% of the carbon 14 it would have if in a living specimen. Approximately how old is the bone?

\_\_\_\_\_

\_\_\_\_\_

4. What is the difference between allopatric speciation and sympatric speciation? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

5. Using the example of a kangaroo, distinguish between physical, behavioural, and physiological adaptations:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

- ▶ Parasites may adapt and radiate among host species in the same way that free-living species adapt when isolated on islands. Feather lice are host-specific parasites of birds that feed on the feathers, skin, and blood of birds, reducing fitness through energetic stress. Feather lice depend on feathers to move around and most dispersal is from parent to offspring in the nest.
- ▶ Birds reduce lice infestations by removing them during preening. Lice are thought to escape preening through camouflage because light-coloured bird species have light-coloured lice, and dark-coloured species have dark-coloured lice. Researchers carried out a multi-year experiment to investigate adaptive divergence in feather lice in response to host preening. The experiment tracked ~60 louse generations. At time 0, lice were transferred from wild caught grey feral rock pigeons to white, black, or grey rock pigeons that could either preen normally, or were stopped from preening with a harmless device on the beak. The luminosity (brightness) of the lice was quantified every 6 months through colour-matching to colour standards. The results were normalised to the control (gray) birds (as zero) to gain a relative luminosity. The results after 42 months are tabulated below.



Dr. Josef Fleischig cc BY-SA 3.0

Feather louse (*Columba columbae*) used in this study.

	White pigeons		Grey (control) pigeons		Black pigeons	
	n	Relative luminosity mean ± 95% CI	n	Relative luminosity mean ± 95% CI	n	Relative luminosity mean ± 95% CI
Normal preening	71	23.39 ± 4.30	91	8.25 ± 1.5	75	4.47 ± 1.56
Impaired preening	193	9.26 ± 1.02	189	8.39 ± 1.18	184	9.17 ± 1.36

Adapted from data in Bush et al. (2019). See credits for full citation.

6. (a) Describe what is meant by selection pressure: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Explain how selection pressure can result in phenotypic change over generations: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. Plot an appropriate labeled graph of the data tabulated above.

8. Describe the results: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

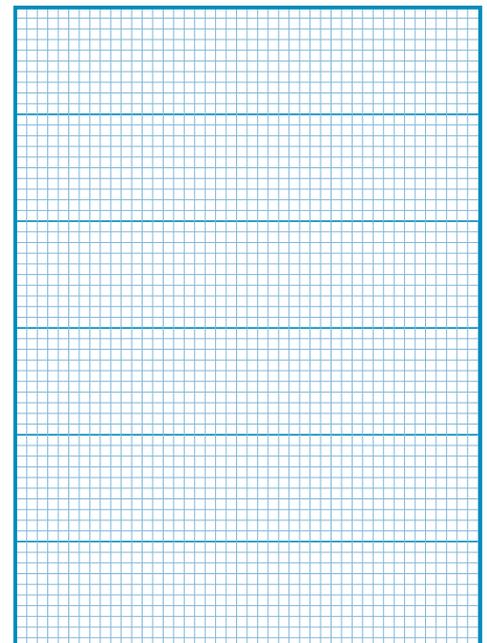
\_\_\_\_\_

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\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



9. Predict the likely consequences to the luminosity of subsequent generations of feather lice if they were transferred from the white pigeons back to gray pigeons. Justify your prediction:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

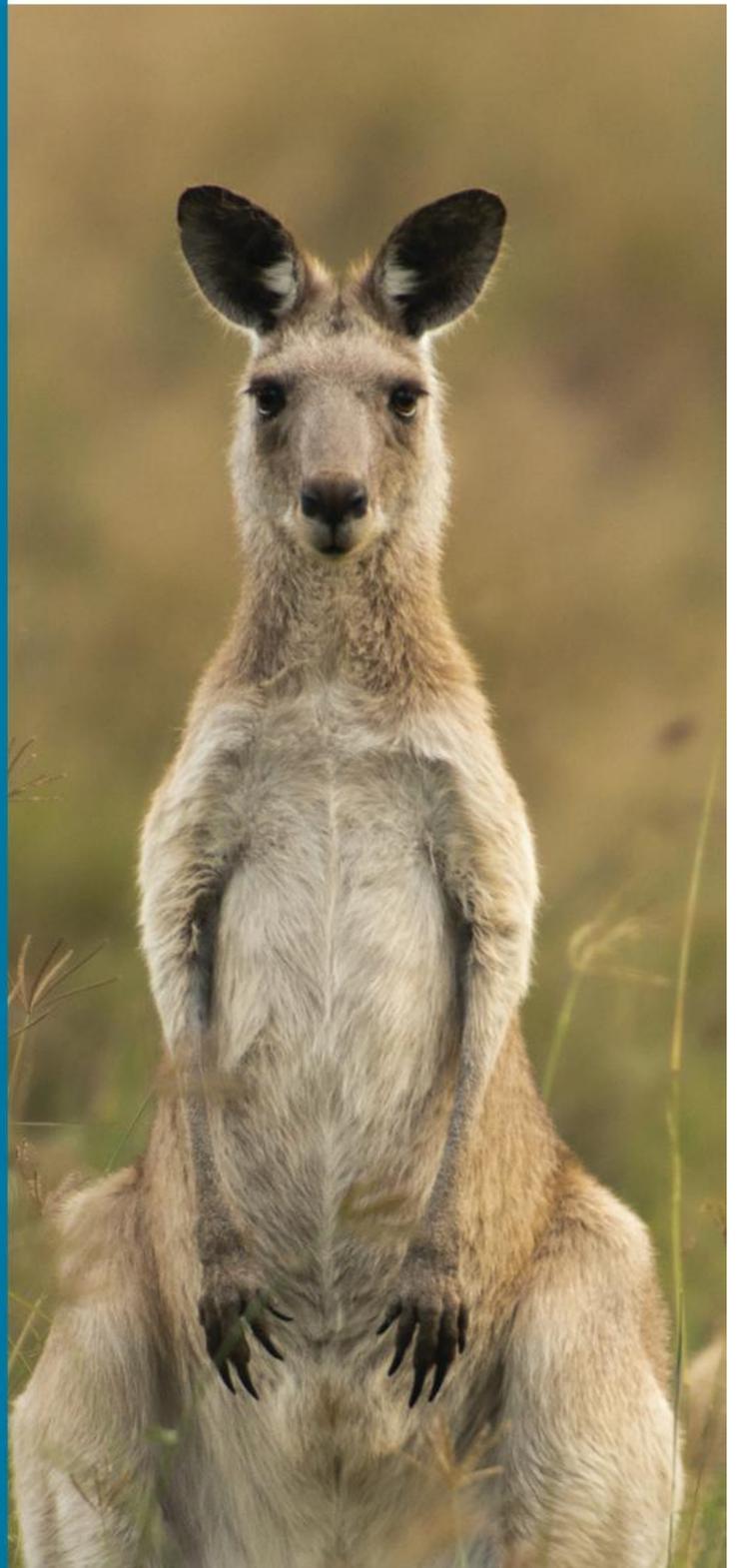
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## MODULE

# 04

### Ecosystem dynamics



#### Student outcomes:

- ▶ Conduct and evaluate investigations in order to obtain primary and secondary data and information
- ▶ Select and process qualitative and quantitative data and information using a range of appropriate media
- ▶ Analyse and evaluate primary and secondary data and information
- ▶ Analyse ecosystem dynamics and the interrelationships of organisms within an ecosystem

# Population Dynamics

Activity  
number

## Key terms

abiotic (physical) factor  
biodiversity  
biotic factor  
birth rate  
carrying capacity  
competition  
competitive exclusion principle  
death rate  
density  
density dependent factor  
density independent factor  
distribution  
ecosystem  
ecological niche  
emigration  
exponential growth  
immigration  
interspecific competition  
keystone species  
limiting factor  
Lincoln index  
logistic growth  
parasitism  
population  
predation  
quadrat  
transect

**Inquiry question:** *What effect can one species have on the other species in a community?*

## Factors affecting populations

### Key skills and knowledge

- |                          |   |                        |
|--------------------------|---|------------------------|
| <input type="checkbox"/> | 1 Identify the components of an ecological community, including biotic and abiotic factors. Explain that ecosystems are composed of varied habitats that range in conditions. Understand that each species has an optimum range in which it is best able to survive.  | <b>172 173</b>         |
| <input type="checkbox"/> | 2 Describe factors limiting population size, including biotic and abiotic factors. Discuss how changes in limiting factors can alter carrying capacity over time. Describe how population size changes. Calculate population growth rate and change.  | <b>174 75</b>          |
| <input type="checkbox"/> | 3 Describe, using examples, how biotic factors e.g. predator-prey relationships, and abiotic factors e.g. rainfall, can regulate population growth and size. Describe the effect of disease on population growth.   | <b>176 177<br/>181</b> |
| <input type="checkbox"/> | 4 Use the Lincoln Index ( $N = M \times n \div m$ ) to estimate population size from primary and/or secondary data.   | <b>178</b>             |
| <input type="checkbox"/> | 5 Distinguish between exponential and logistic growth and describe the characteristic features of each. Analyse population growth data to determine the growth pattern exhibited (J shaped exponential or S shaped logistic). Use a computer simulation to model continuous density-independent (exponential) and density-dependent (logistic) population growth.           | <b>179-180</b>         |
| <input type="checkbox"/> | 6 Define ecological niche. Distinguish between the fundamental and realised niche.  | <b>182</b>             |
| <input type="checkbox"/> | 7 Describe how species within ecosystems can interact in ways that are harmful, neutral, or beneficial to one or both parties. Define and describe examples of amensalism, commensalism, mutualism, predation, parasitism, and competition. Identify which of these relationships is classified as an exploitation. Predict the consequences of competition on populations. | <b>183</b>             |
| <input type="checkbox"/> | 8 Analyse data to identify species occupying an ecological niche. Explain how species with similar resource requirements avoid direct competition through niche partitioning (e.g. in eucalypt woodland and coral reefs).   | <b>184-186</b>         |



## Identifying relationships in populations

### Key skills and knowledge

- |                          |   |                |
|--------------------------|---|----------------|
| <input type="checkbox"/> | 9 Investigate biodiversity in an ecosystem. Discuss what factors might influence the biodiversity of an ecosystem.  | <b>187</b>     |
| <input type="checkbox"/> | 10 Explain the role of keystone species in the stability of community structure and function. Analyse data from an Australian ecosystem to identify a keystone species and predict the outcomes of removing the species from an ecosystem.  | <b>188 189</b> |
| <input type="checkbox"/> | 11 Describe the process of stratified sampling in terms of: <ul style="list-style-type: none"> <li>• purpose (what can sampling tell us?)</li> <li>• site selection (how do we choose where to sample?)</li> <li>• sampling technique (quadrats or transects?)</li> <li>• minimising bias (size and number of samples, random sampling, counting criteria)</li> <li>• methods of data presentation and analysis (tables, graphs, descriptive statistics)</li> </ul> | <b>190-195</b> |
| <input type="checkbox"/> | 12 Identify a recent Australian extinction and the reasons for it. Identify reasons for the continued decline of Australian animal populations.   | <b>196</b>     |

# 172 Components of an Ecosystem

**Key Idea:** An ecosystem consists of all the organisms living in a particular area and their physical environment. An **ecosystem** is a community of living organisms and the physical (non-living) components of their environment. The community (living component of the ecosystem) is in turn

made up of a number of **populations**, these being organisms of the same species living in the same geographical area. The structure and function of an ecosystem is determined by the physical (abiotic) and the living (biotic) factors, which determine species distribution and survival.

**PHYSICAL ENVIRONMENT: Abiotic factors**

**Atmosphere**

- Wind speed and direction
- Light intensity and quality
- Precipitation and humidity
- Air temperature

**What is the biosphere?**

The biosphere is a narrow belt around the Earth containing all the Earth's living organisms. It extends from the bottom of the oceans to the upper atmosphere. Broad scale life-zones or **biomes** within the biosphere are characterized according to the predominant vegetation. Within these biomes, ecosystems form natural units comprising the non-living, physical environment (the atmosphere, water, and soil) and the community.

**Species**

A biological species is a group of organisms that can potentially interbreed to produce fertile offspring. Species are reproductively isolated, meaning they cannot successfully interbreed with other species.

**Soil**

- Nutrient availability
- Soil moisture and pH
- Composition
- Temperature

**Water**

- Dissolved nutrients
- pH and salinity
- Dissolved oxygen
- Temperature

**COMMUNITY: Biotic factors**

- Producers
- Consumers
- Detritivores
- Decomposers

**Interact in the community as:**  
Competitors, parasites, pathogens, symbionts, predators, herbivores

1. Distinguish clearly between a community and an ecosystem: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Distinguish between biotic and abiotic factors: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Use one or more of the following terms to describe each of the features of a beech community listed below:  
**Terms:** *population, community, ecosystem, physical factor.*

(a) All the beech trees present: \_\_\_\_\_ (c) All the organisms present: \_\_\_\_\_  
 (b) The entire forest: \_\_\_\_\_ (d) The humidity: \_\_\_\_\_

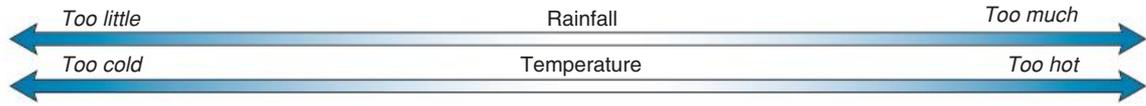
# 173 Habitat

**Key Idea:** The environment in which an organism lives is its habitat. The habitat may not be homogeneous in its quality. The environment in which an organism (or species) lives (including all the physical and biotic factors) is its **habitat**. Within any habitat, each species has a range of tolerance to variations in its environment. Within the population, individuals will have slightly different tolerance ranges based on small differences in genetic make-up, age, and health. The

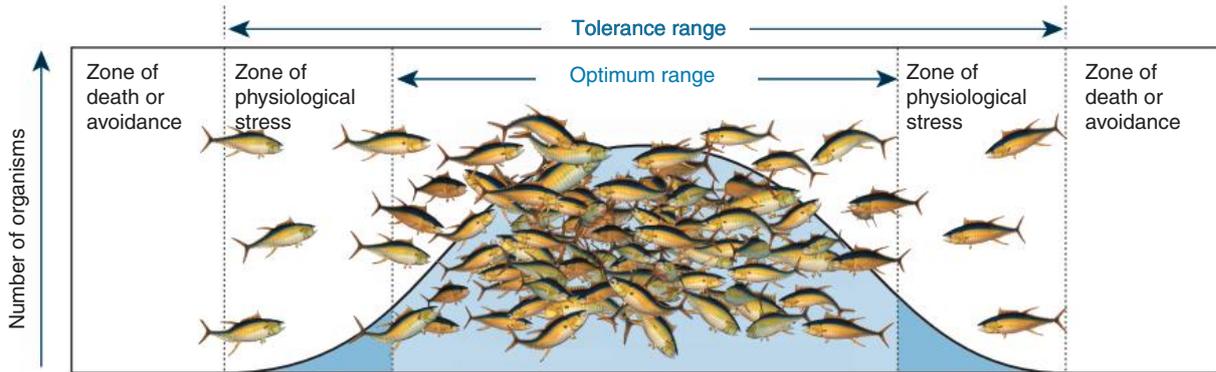
wider an organism's tolerance range for any one factor (e.g. temperature) the more likely it is that the organism will survive variations in that factor. For the same reasons, species with a wider tolerance range are likely to be more widely distributed. Organisms have a narrower **optimum range** within which they function best. This may vary seasonally or during development. Organisms are usually most abundant where the abiotic factors are closest to the optimum range.

## Habitat occupation and tolerance range

Examples of abiotic factors affecting habitat range and niche breadth:



The law of tolerances states that *for each abiotic factor, a species population (or organism) has a tolerance range within which it can survive. Toward the extremes of this range, that abiotic factor tends to limit the organism's ability to survive.*



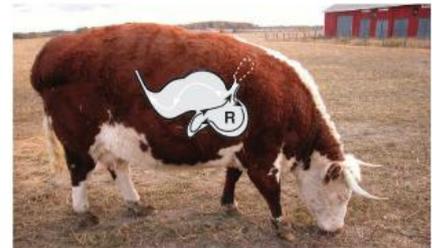
## The scale of available habitats



A habitat may be vast and relatively homogeneous for the most part, as is the open ocean. Barracuda (above) occur around reefs and in the open ocean where they are aggressive predators.



For non-motile organisms, such as the fungus pictured above, a suitable habitat may be defined by the particular environment in a relatively small area, such as on this decaying log.



For microbial organisms, such as the bacteria and protozoans of the ruminant gut, the habitat is defined by the chemical environment within the rumen (R) of the host animal, in this case, a cow.

1. What is the relationship between an organism's tolerance range and the habitat it occupies? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. (a) In the diagram above, in which range is most of the population found? Explain your answer: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 (b) What are the greatest constraints on an organism's growth and reproduction within this range? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. How would having a wide tolerance range affect a species survival in changing conditions?  
 \_\_\_\_\_  
 \_\_\_\_\_



# 174 Factors Affecting Population Size

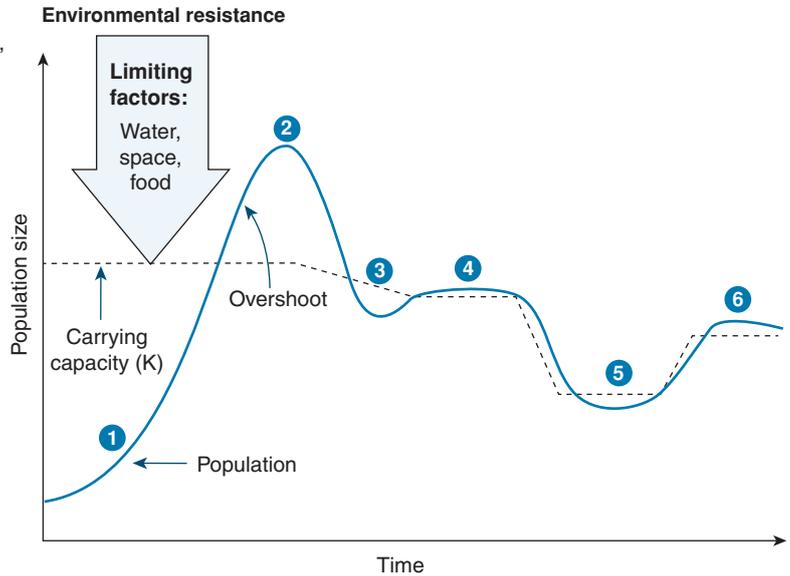
**Key Idea:** Carrying capacity is the maximum number of organisms a particular environment can support indefinitely. An ecosystem's **carrying capacity**, i.e. the size of population that the available resources can sustain indefinitely, is limited by the ecosystem's resources. Factors affecting carrying capacity (population limiting factors) can be biotic (e.g. food supply) or abiotic (e.g. water, climate, and available

space). The carrying capacity is determined by the most **limiting factor** and can change over time (e.g. as a result of environmental changes). Below carrying capacity, population size increases because resources are not limiting. As the population approaches its carrying capacity (or exceeds it) resources become limiting and environmental resistance increases, decreasing population growth.

## Limiting factors

Limiting factors are factors limiting the growth, abundance, or distribution of an organism or a population. The effect of limiting factors and the type of factor that is limiting may change over time. The graph, right, shows how the carrying capacity of a forest environment varies based on changes to the biotic and abiotic limiting factors:

- 1 A population moves into the forest and rapidly increases in numbers due to abundant resources.
- 2 The population overshoots the carrying capacity.
- 3 Large numbers damage the environment and food becomes limiting. The carrying capacity falls.
- 4 The population becomes stable at the new carrying capacity.
- 5 The forest experiences a drought and the carrying capacity is reduced as a result.
- 6 The drought breaks and the carrying capacity rises but is less than before because of habitat damage during the drought.



## Limitations to population growth are either density-dependent or density-independent

<p><b>Density dependent factors</b> The effect of these on population size is influenced by population density. They are most important at high population densities.</p> <ul style="list-style-type: none"> <li>▶ Tend to be biotic factors.</li> <li>▶ They generally regulate population size by decreasing birth rates and increasing death rates. Usually self regulating (negative feedback).</li> </ul> <p>Examples: Biotic interactions such as:</p> <ul style="list-style-type: none"> <li>▶ Competition and predation</li> <li>▶ Parasitism and disease</li> </ul>		<p><b>Density independent factors</b> The effect of these on population size does not depend on population density. Their action is independent of population density.</p> <ul style="list-style-type: none"> <li>▶ Tend to be abiotic factors.</li> <li>▶ They generally regulate population size by increasing death rates and can lead to sudden changes in population size.</li> </ul> <p>Examples: Natural disasters such as:</p> <ul style="list-style-type: none"> <li>▶ Bushfires, droughts, floods</li> <li>▶ Volcanic eruptions, earthquakes</li> </ul>
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1. What is carrying capacity? \_\_\_\_\_
2. How can changes in limiting factors alter carrying capacity? \_\_\_\_\_
3. What limiting factors have changed at points 3, 5, and 6 in the graph above, and how have they changed?
  - (a) 3: \_\_\_\_\_
  - (b) 5: \_\_\_\_\_
  - (c) 6: \_\_\_\_\_

# 175 Calculating Change in Population Size

**Key Idea:** Population size increases through births or immigration and decreases through deaths and emigration.

Populations are dynamic and the number of individuals in a population may fluctuate considerably over time. Populations gain individuals through births or immigration, and lose

individuals through deaths and emigration. For a population in equilibrium, these factors balance out and there is no net change in the population abundance. When losses exceed gains, the population declines. When gains exceed losses, the population increases.

Births, deaths, immigration (movements into the population) and emigration (movements out of the population) are events that determine the population size. Population growth depends on the number of individuals added to the population from births and immigration, minus the number lost through deaths and emigration. This is expressed as:

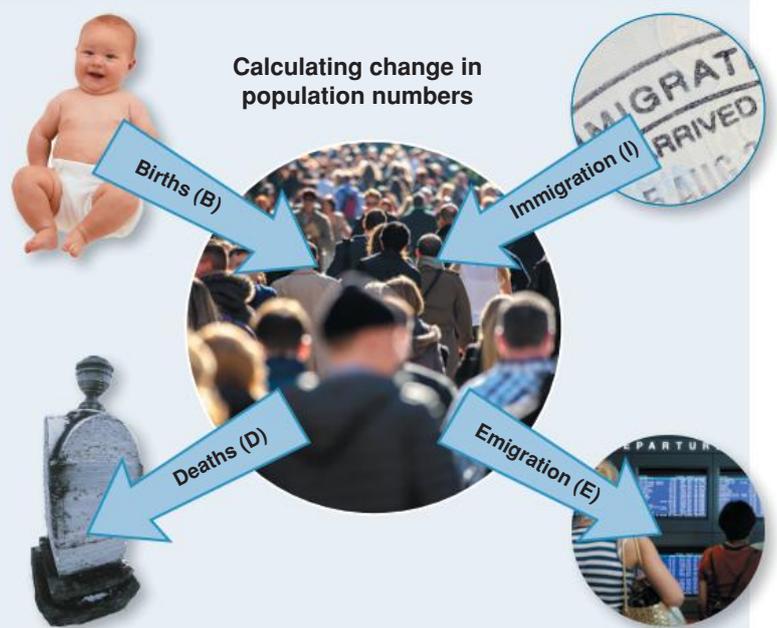
$$\text{Population growth} = \text{Births (B)} - \text{Deaths (D)} + \text{Immigration (I)} - \text{Emigration (E)}$$

The difference between immigration and emigration gives net migration. Ecologists usually measure the **rate** of these events. These rates are influenced by environmental factors (see below) and by the characteristics of the organisms themselves. Rates in population studies are commonly expressed in one of two ways:

- **Numbers per unit time**, e.g. 20,150 live births per year. The birth rate is termed the natality, whereas the death rate is the mortality.
- **Per capita rate** (number per head of population), e.g. 122 live births per 1000 individuals per year (12.2%).

## Limiting factors

Limiting factors affect population growth and abundance. Availability of food, predation pressure, or available habitat are all population limiting factors operating to different degrees at different times.



The human population is estimated to peak at around 10 billion by 2050 as a result of multiple factors, including falling birth rates. Humans have the technology and production efficiency to solve many resource problems and so might appear exempt from limiting factors, but declining availability of water and land for food production is likely to constrain population growth, at least regionally.

- Define the following terms used to describe changes in population numbers:
  - Death rate (mortality): \_\_\_\_\_
  - Birth rate (natality): \_\_\_\_\_
  - Net migration rate: \_\_\_\_\_
- Explain how the concept of limiting factors applies to population biology: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Using the terms, B, D, I, and E (above), construct equations to express the following:
  - A population in equilibrium: \_\_\_\_\_
  - A declining population: \_\_\_\_\_
  - An increasing population: \_\_\_\_\_
- A population started with a total number of 100 individuals. Over the following year, population data were collected. Calculate birth rates, death rates, net migration rate, and rate of population change for the data below (as percentages):
  - Births = 14: Birth rate = \_\_\_\_\_
  - Deaths = 20: Death rate = \_\_\_\_\_
  - Net migration = +2: Net migration rate = \_\_\_\_\_
  - Rate of population change = \_\_\_\_\_
  - State whether the population is increasing or declining: \_\_\_\_\_

**Key Idea:** Predator and prey populations frequently show regular population cycles. The predator cycle is often based on the intrinsic population cycle of the prey species. It was once thought that predators regulated the population numbers of their prey. However, we now know that this is

not usually the case. Prey species are more likely to be regulated by other factors such as the availability of food. However, predator population cycles are often regulated by the availability of prey, especially when there is little opportunity for switching to alternative prey species.

### A case study in predator-prey numbers

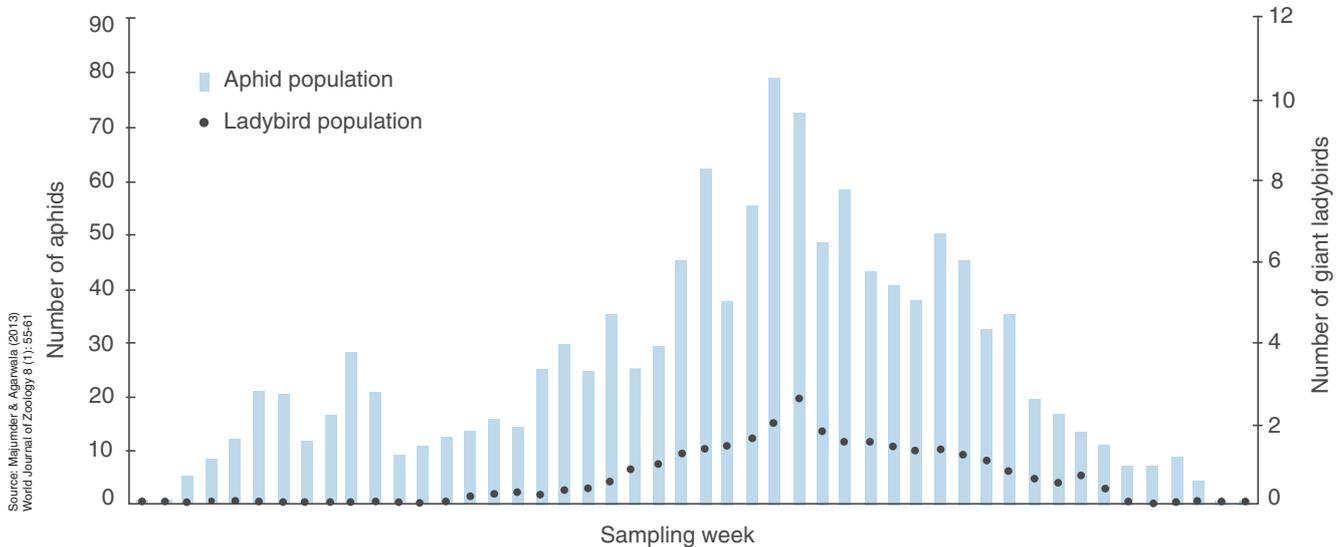
In some areas of Northeast India, a number of woolly aphid species colonise and feed off bamboo plants. The aphids can damage the bamboo so much that it can no longer be used by the local people for construction and the production of textiles.

Giant ladybird beetles feed exclusively on the woolly aphids of bamboo plants. There is some interest in using them as biological control agents to reduce woolly aphid numbers, and limit the damage woolly aphids do to bamboo plants.

The graph below shows the relationship between the giant ladybird beetle and the woolly aphid when grown in controlled laboratory conditions.

Bamboo plants are home to many insect species, including ladybirds and aphids.

Aphids feed off the bamboo sap, and the ladybirds are predators of the aphids (below).



- (a) On the graph above, mark (using different coloured pens) where the peak numbers of woolly aphids and giant ladybirds occurs:

(b) Do the peak numbers for both species occur at the same time? \_\_\_\_\_

(c) Why do you think this is? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- (a) What is the response of the ladybird population when their prey decline? \_\_\_\_\_

\_\_\_\_\_

(b) What feature of the ladybird's response to prey suggests it would be a good choice to control woolly aphids? \_\_\_\_\_

\_\_\_\_\_

(c) Can you think of any other factors that could affect the numbers of ladybirds and aphids? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



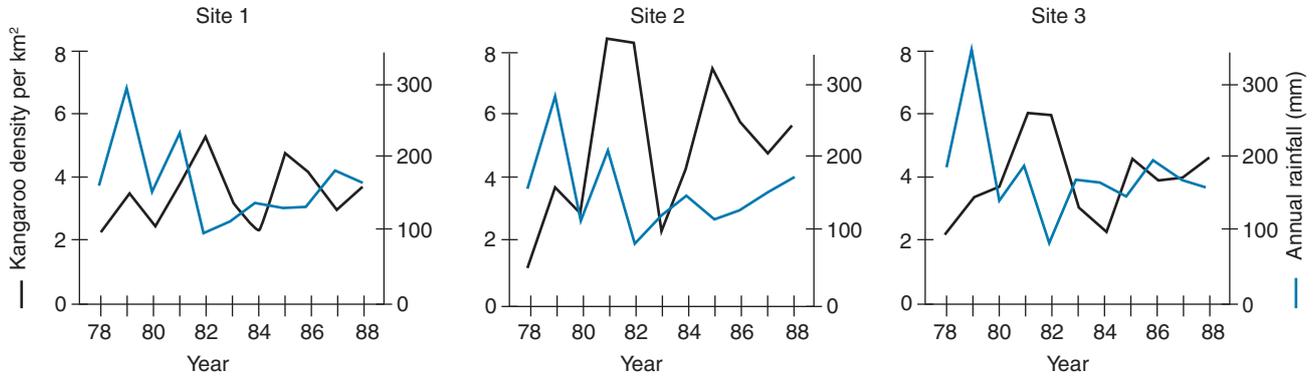
# 177 Abiotic Factors and Population Size

**Key Idea:** Abiotic factors can affect population size.

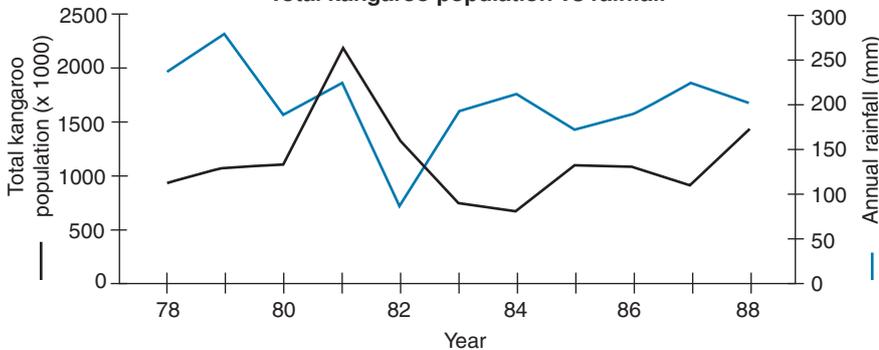
Abiotic factors such as rainfall and temperature can play an important role in the size of population an area can support. For example, rainfall is needed for plant growth and so to support grazers of that plant material. Low rainfall reduces

plant growth and biomass and available water for animals, so it would be expected that it would also reduce animal population sizes. The study below was conducted from 1978 to 1988 on the relationship between population sizes of red kangaroos and rainfall in South Australian pastoral zones.

**Kangaroo population density and rainfall**



**Total kangaroo population vs rainfall**



Aerial surveys (1978-1988) were made of red kangaroo populations in South Australia. Rainfall was also recorded. The plots show the results of three of the areas surveyed.

1. How might rainfall affect the size of an population of:

(a) Animal grazers? Explain: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) Predators dependent on those grazers? Explain: \_\_\_\_\_  
 \_\_\_\_\_

2. (a) Would you expect the effect of reduced rainfall to be seen immediately? \_\_\_\_\_

(b) Explain why: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Why do you think the survey above used kangaroo density instead of population numbers in each site?

\_\_\_\_\_

4. Is there any pattern in the way kangaroo density and total kangaroo population fluctuate over the time of the survey?

\_\_\_\_\_

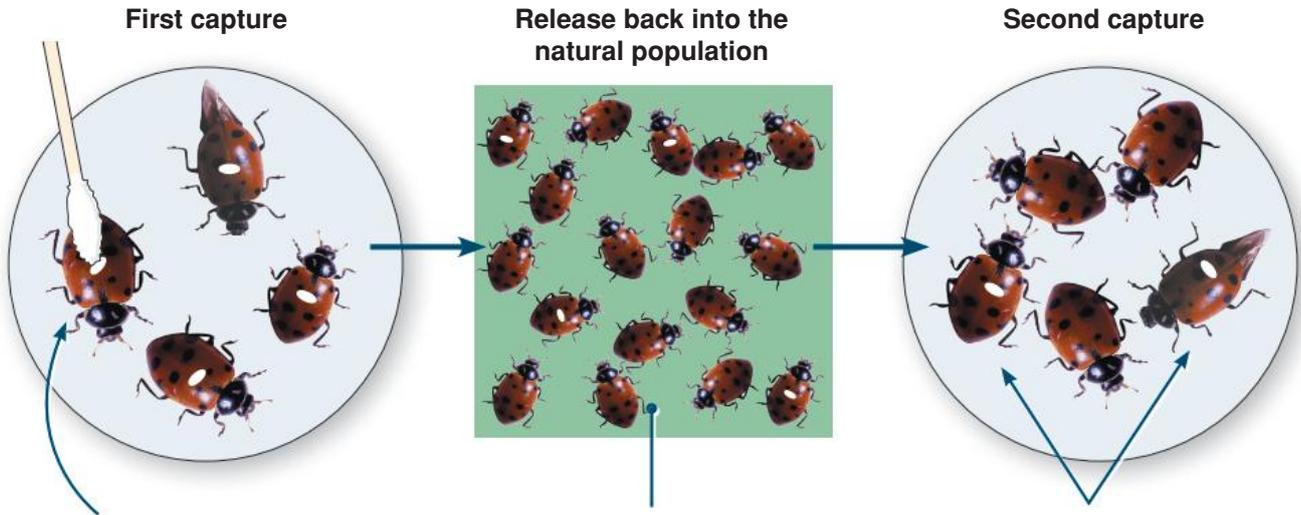


# 178 Estimating Population Size

**Key Idea:** Mark and recapture sampling enables estimates of the population size of highly mobile organisms.

The mark and recapture method of estimating population size is used in the study of animal populations in which the

individuals are highly mobile. It is of no value where animals do not move or move very little. The number of animals caught in each sample must be large enough to be valid. The technique is outlined in the diagram below.



In the first capture, a random sample of animals from the population is selected. Each selected animal is marked in a distinctive way.

The marked animals from the first capture are released back into the natural population and left for a period of time to mix with the unmarked individuals.

Only a proportion of the second capture sample will have animals that were marked in the previous capture.

### The Lincoln Index

$$\text{Total population } (N) = \frac{\text{Number in 1st sample (all marked) } (M) \times \text{Number in 2nd sample } (n)}{\text{Number of marked individuals recaptured in 2nd sample } (m)}$$

Steps in the mark and recapture technique:

1. Sample the population by capturing as many individuals as possible and practical. Capture technique will depend on the animal.
2. Mark the captured animals to distinguish them from unmarked animals.
3. Return the marked animals to their habitat and leave them for an extended period to allow them to redistribute themselves in the population.
4. Sample the population again (the sample must be large enough to provide valid data but the sample size can be different to the first).
5. Determine the numbers of marked to unmarked animals in the second sample. Use the equation above to estimate the population size.



Animals may be marked or tagged

USFWS

1. For this exercise you will need several boxes of matches and a pen. Work in a group of 2-3 students to 'sample' the population of matches in the full box by using the mark and recapture method. Each match will represent one animal.
  - (a) Take out 10 matches from the box and mark them on 4 sides with a pen so that you will be able to recognise them from the other unmarked matches later.
  - (b) Return the marked matches to the box and shake the box to mix the matches.
  - (c) Take a sample of 20 matches from the same box and record the number of marked matches and unmarked matches.
  - (d) Determine the total population size by using the equation above.
  - (e) Repeat the sampling 4 more times (steps b–d above) and record your results:

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Estimated population					

(f) Count the actual number of matches in the matchbox: \_\_\_\_\_

(g) Compare the actual number to your estimates and state by how much it differs: \_\_\_\_\_



Researchers at New Zealand's University of Waikato used mark and recapture to obtain estimates of population number and biomass of four fish species and one hybrid in one of the campus lakes. Fish were sampled using electrofishing (right), which temporarily stuns the fish so that they can be netted. Biomass estimates for each species were calculated from mean mass of all fish sampled in the recapture.

Fish were marked with a fin clip (tagging carries a higher risk of infection at the tagging site). Resampling period was 7 weeks (22 January 2014-14 March 2014). The purpose of recapture was to remove pest species (all species except shortfin eels).

Each of the campus lakes is isolated with no inflow or outflow.

Results are presented in the table below:



Electrofishing, campus lakes, University of Waikato NZ

BH

Species	Number originally marked (M)	Number caught in recapture (n)	Number of marked recaptures (m)	Population estimate (N = M x n / m)	Mean fish mass (g)	Biomass (kg)	Lake area (ha)	Biomass by area (kg per ha)
Goldfish	32	104	14		365		0.69	
Koi carp-goldfish hybrids	6	9	3		1020		0.69	
Koi carp	9	35	2		114		0.69	
Catfish	7	33	2		303		0.69	
Shortfin eels	45	12	1		189		0.69	

Data provided by Prof. Brendan Hicks, University of Waikato

2. (a) Complete the columns in the table above for population estimate, biomass, and biomass by area (kg per hectare).

(b) What is the significance of the lake being isolated in terms of the reliability of the mark-recapture estimates?

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(c) Why is it useful to make biomass estimates for the fish in this lake, especially when the pest fish are being removed:

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3. Describe some of the problems with the mark and recapture method if the second sampling is:

(a) Left too long a time before being repeated: \_\_\_\_\_

---



---

(b) Too soon after the first sampling: \_\_\_\_\_

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4. Describe two important assumptions in this method of sampling that would cause the method to fail if they were not true:

(a) \_\_\_\_\_

---



---

(b) \_\_\_\_\_

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5. Some types of animal would be unsuitable for this method of population estimation (i.e. would not work).

(a) Name an animal for which this method of sampling would not be effective: \_\_\_\_\_

(b) Explain your answer above: \_\_\_\_\_

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# 179 Patterns of Population Growth

**Key Idea:** Populations typically show either exponential or logistic growth. The maximum sustainable population size is limited by the environment's carrying capacity.

Population growth is the change in a population's numbers over time ( $dN/dt$  or  $\Delta N/\Delta t$ ). It is regulated by the carrying capacity ( $K$ ), which is the maximum number the environment can sustain. Population growth falls into two main types:

exponential or logistic. Both can be defined mathematically. In these mathematical models, the per capita (or intrinsic) growth rate is denoted by a lower case  $r$ , determined by the per capita births minus deaths, i.e.  $(B-D)/N$ . **Exponential growth** occurs when resources are essentially unlimited. **Logistic growth** begins exponentially, but slows as the population approaches environmental carrying capacity.

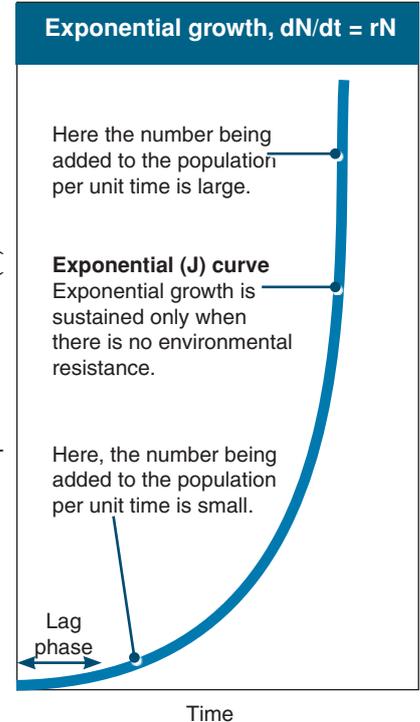
Exponential growth occurs when the population growth rate is not affected by the population size,  $N$ . In this case, the population growth rate is simply  $r$  (the maximum per capita rate of increase) multiplied by  $N$  so that  $dN/dt = rN$ . On a graph, exponential growth is characterized by a J shaped curve. A lag phase occurs early in population growth due to low population numbers.

In nature, exponential growth is observed in two circumstances: (1) a few individuals begin a new population in a new habitat with plenty of resources, (2) a natural disaster reduces the population to a few survivors, and the population recovers from a low base.

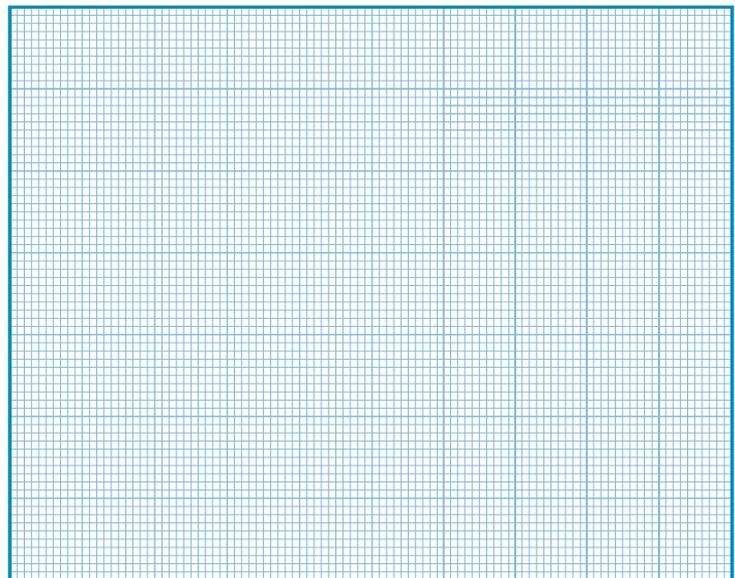
The human population is currently in an exponential phase of growth. In ancient times, the human population remained relatively stable, but low. It was not until the end of the Middle Ages and the beginning of the Renaissance that the population began to grow. The Industrial Revolution increased living standards and population with it. Antibiotics and the Green Revolution sparked the current rapid increase in the human population.



The kangaroo population in Australia (all kangaroos) fluctuates wildly over cycles lasting many years. In 1984, the total kangaroo population was estimated at 16 million. In 2015, it reached over 50 million. Droughts cause rapid collapse of the population, but it can recover almost as quickly afterwards. The data below shows the population increase after the last collapse of the population in 2003-2004.



Total kangaroo population (millions)	
Year	Population
2006	23.6
2007	24.0
2008	25.8
2009	27.0
2010	25.0
2011	34.3
2012	40.0
2013	53.0
2014	50.0

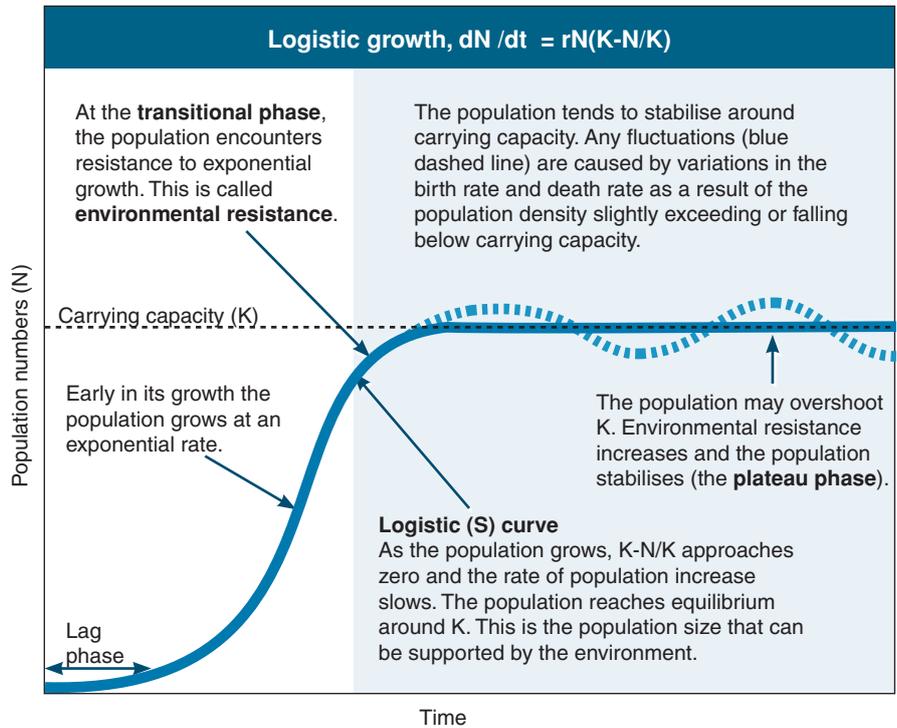


1. Produce a line graph of the kangaroo population on the grid above:
2. Around which year(s) did explosive exponential growth begin in the kangaroo population? \_\_\_\_\_
3. Use the data to calculate the approximate doubling time of the kangaroo population: \_\_\_\_\_
4. Why did the human population only begin its rapid increase after the Renaissance? \_\_\_\_\_

In nature, the population growth of most organisms follows a **logistic growth curve**. When entering a new environment, a founding population will enter a period of exponential growth. The maximum size of population that the environment can support is called the carrying capacity (K). As the population nears K and the resources become limiting, population growth slows.

Under the logistic growth model,  $dN/dt = rN$  is multiplied by the proportion of K that is left unfilled or unused. As the population increases, the proportion of K available decreases and individuals find it difficult to find or utilise space and resources. The rate of population increase therefore slows as population size approaches carrying capacity.

Occasionally a population's growth rate may not slow as it approaches K. This usually occurs in rapidly breeding organisms when there is a time lag between the depression in resources and the population response. In this case, the population overshoots K and then declines again as it responds to low resource availability. In time, populations usually stabilise around K.



**Logistic growth curve on a spreadsheet.**

Plotting a logistic growth curve on a spreadsheet can help in understanding the effect of population size on the population growth rate and how the logistic equation describes this. For a hypothetical population of 2, r is 0.15 and K 100. The following formulae can be entered into the spreadsheet:

	A	B	C	D	E	F	G
1	r	t (period)	N	K	K-N/K	dN/dt	
2	0.15	0	2	100	=(D5-D2)/D\$2	=\$A\$2*C2*E2	
3		=B2+1	=C2+F2				
4							
5							
6							
7							
8							

Population at  $t_1$  = population at  $t_0$  +  $dN/dt$  (the amount of population change over 1 time period)

The cells can then be filled down. The first three steps have been filled here. Fill the cells down to about 60 time periods, then plot t vs N.

	A	B	C	D	E	F	G
1	r	t (period)	N	K	K-N/K	dN/dt	
2	0.15	0	2.00	100	0.98	0.29	
3		1	2.29		0.98	0.34	
4		2	2.63		0.97	0.38	
5		3	3.01				
6							
7							

- Why don't populations continue to increase exponentially in an environment? \_\_\_\_\_
- How does carrying capacity act to slow the rate of population growth? \_\_\_\_\_
- Describe and explain the phases of the logistic growth curve: \_\_\_\_\_
- (a) Around which time period does the curve on the spreadsheet above begin to flatten out? \_\_\_\_\_  
 (b) Describe how  $dN/dt$  changes over time: \_\_\_\_\_  
 (c) What is the general shape of the logistic curve: \_\_\_\_\_

# 180 Modelling Population Growth

**Key Idea:** Computer programs can be used to model population growth. This activity uses Populus 6.0. Population growth can be simulated using spreadsheets or computer programs. This activity uses Populus 6.0, a Javascript program, which will run on Mac or Windows platforms. It models continuous and discrete population growth as well as the effects of competition. In this activity you will model continuous density-independent (exponential)

and density-dependent (logistic) growth. Using Populus, you can also model discrete growth, which uses  $\lambda$  instead of  $r$ , where  $\lambda$  is the discrete-time per capita growth rate. Discrete models are used for organisms with a discrete breeding season (e.g. annual plants and insects that breed once a year) because population growth occurs in 'steps' only within a discrete time period (not continuously) and there is no population growth outside those times.

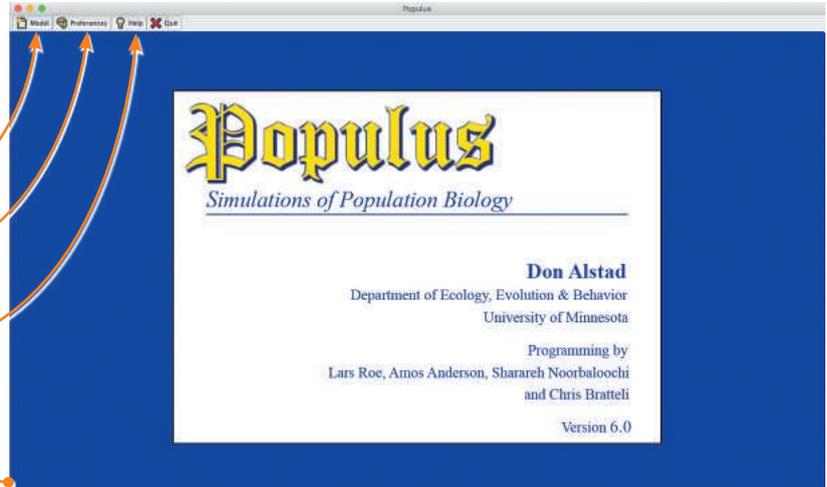
Populus is shareware. Download it free from <https://cbs.umn.edu/populus/overview>

(you can also download via Weblinks)

The opening screen looks like this.

- ▶ **Model** allows you to choose which type of simulation you want to run.
- ▶ **Preferences** lets you to load saved files and save new ones.
- ▶ **Help** loads a comprehensive PDF file covering all aspects of the program.

If it fills the entire screen grab the lower corner and resize it with the mouse.

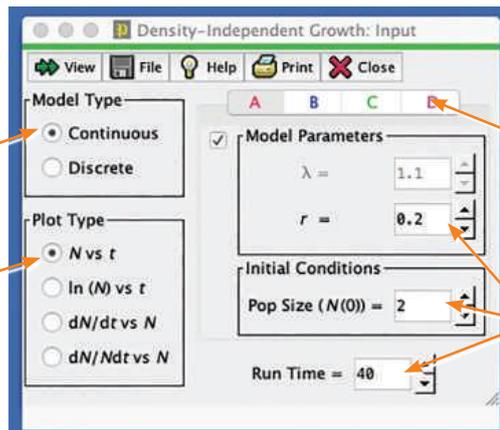


## Density independent growth

- ▶ Click on the Model in the menu bar
- ▶ Select Single-Species Dynamics
- ▶ Then choose **Density-Independent** Growth

Set the model type to continuous (as in continuous growth). This produces a single line in the output window. Discrete produces a series of points (as in discrete bursts of growth).

Set plot type to N vs t. This models population vs time.



Up to four populations can be displayed on the one graph, using A, B, C, and D. Make sure the check box is ticked.

Set r to 0.2 and population size N to 2. Set run time 40. Click View to see the graph.

Questions 1-4 refer to density independent growth

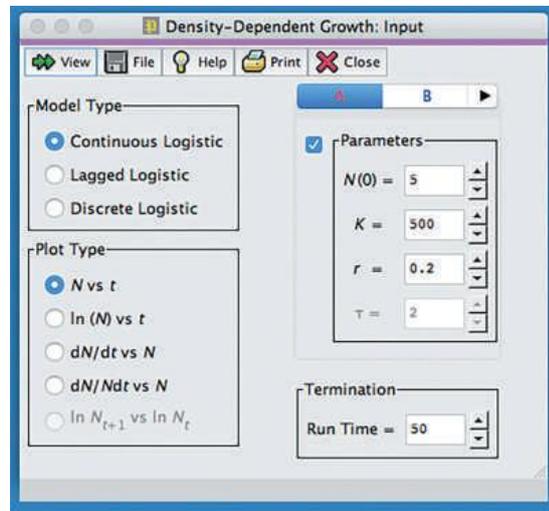
1. What is the shape of the graph produced? \_\_\_\_\_
2. Describe what happens to the shape of the graph when:
  - (a)  $r$  is increased to 0.4: \_\_\_\_\_
  - (b) Population size is increased to 20: \_\_\_\_\_
  - (c) Population size is increased to 20 but  $r$  is reduced to -0.2: \_\_\_\_\_
3. Set the parameters back to  $N = 2$  and  $r = 0.2$ . Set the plot type to  $dN/dt$  vs  $N$  and view the plot. Describe the shape of the graph and explain what it means: \_\_\_\_\_
4. What is the value of  $r$  if the population doubles over one time period? \_\_\_\_\_

**SAVE AND PRINT ALL YOUR SIMULATIONS AND ATTACH THEM TO THIS PAGE**



## Density dependent growth

- ▶ Click on the Model in the menu bar
- ▶ Then select Single-Species Dynamics
- ▶ Then select **Density-Dependent Growth**
- ▶ As before set the model type to continuous.
- ▶ Produce a plot for  $N = 5$ ,  $K = 500$ ,  $r = 0.2$ , and  $t$  to 50.



Questions 5-9 refer to density dependent growth

5. Describe what happens to the shape of the graph when:

(a)  $r$  is increased to 0.4: \_\_\_\_\_

\_\_\_\_\_

(b) Population size is increased to 50: \_\_\_\_\_

\_\_\_\_\_

(c) Reset the parameters and plot a graph of  $dN/dt$  vs  $N$ . Describe the shape of this graph and explain what it means:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

6. The standard logistic growth curve assumes the effect of the population size immediately affects the population growth rate. Now set the graph type to Lagged Logistic. This introduces a time lag between the population size and its effect on growth rate. Set the parameters to  $N = 5$ ,  $K = 500$ ,  $r = 0.2$ , and  $t$  to 50. Set the time lag  $T$  to 4 and view the graph. What is the effect of the time lag on population growth?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. (a) Now set  $r$  to 0.5 and  $t$  to 150. Describe the shape of the graph: \_\_\_\_\_

\_\_\_\_\_

(b) What kind of species ( $r$ -selected or  $K$ -selected) would show this type of growth? \_\_\_\_\_

8. (a) Keep  $T$  at 4 and set  $r$  to 0.2 view the graph. Describe the shape of the graph now: \_\_\_\_\_

\_\_\_\_\_

(b) What kind of species ( $r$ -selected or  $K$ -selected) would show this type of growth? \_\_\_\_\_

9. Keeping  $r$  at 0.2, vary  $T$  between 1 and 10. How does increasing the lag affect how the population oscillates around  $K$ ?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**SAVE AND PRINT ALL YOUR SIMULATIONS AND ATTACH THEM TO THIS PAGE**

# 181 The Impact of Disease

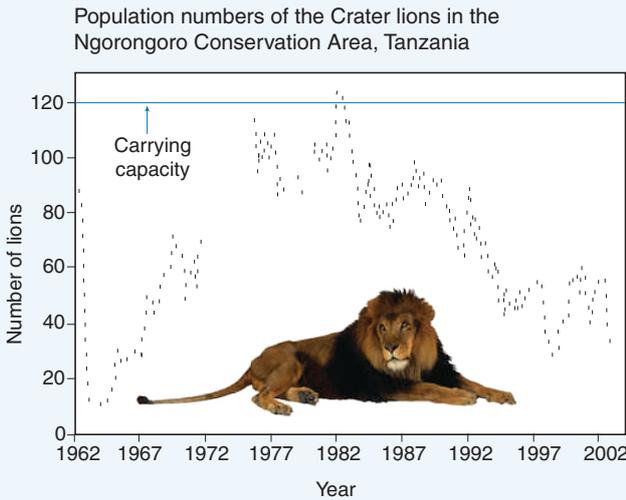
**Key Idea:** Disease regulates population numbers by increasing the death rate within a population.

Disease is a limiting factor on population size. Disease regulates population size by increasing death rates within a

population. Infectious disease is a density dependent factor and has more impact when population density is high and the disease can be spread more easily between individuals. In small populations, disease can be the cause of extinction.

### Case study: the lions of the Ngorongoro Crater

The Ngorongoro Conservation Area in Tanzania is home to a large number of savanna species, including the Crater lion prides. The area is rich in resources, including prey species for the lions, and has the capacity to sustain about 120 lions. All members of the Crater lion population are descended from 15 founders, and the population has a low genetic diversity relative to lions in the nearby Serengeti. In recent times, the population size has been around 60, well below the carrying capacity of the area.



Food and water have always been in plentiful supply to the crater lions, and their cubs have high survival rates. Researchers believe disease is the main factor regulating the size of the crater lion population. In 1962, an outbreak of blood-sucking stable flies resulted in the crater lion population crashing from near carrying capacity to 12. The flies fed off the lions and caused extensive skin infections that prevented the lions from hunting, and many died of starvation. Although lion numbers recovered well in the 1970s, a series of canine distemper virus outbreaks (transferred from hyaenas) have kept the lion population low.

### Devil facial tumour disease in the Tasmanian devil



Tasmanian devils are highly susceptible to catching a type of infectious cancer called devil facial tumour disease (DFTD). Unlike most cancers, DFTD is contagious and it is easily spread between devils when they bite each other. The disease causes larger tumours to grow on the face and mouth. These prevent the animal from eating and it usually starves to death.

Researchers estimate that 60% of animals in the wild have been killed by the disease since 1996, although in high density populations there may be up to 100% mortality in 12-18 months. This has reduced the genetic diversity (the variety of genes) of the devil population markedly. Low diversity in the immune genes in particular means that the devils are unable to fight the disease. Currently, at least 80% of the devil population is infected although the disease is concentrated in the eastern part of Tasmania. It was previously thought that DFTD might drive Tasmanian devils to extinction. However, research done in 2020 suggests that infections are slowing and that Tasmanian devils may be evolving to resist the tumour disease. In some cases tumours have been seen to shrink and even disappear.

- (a) What is the main factor regulating population size of the crater lions? \_\_\_\_\_

(b) What evidence is there to support this? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- (a) What effect is disease having on the population numbers of Tasmanian devils? \_\_\_\_\_

\_\_\_\_\_

(b) How does population density contribute to the impact of the disease in local populations? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Why is the risk Tasmanian devils becoming extinct probably decreasing? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



# 182 Ecological Niche

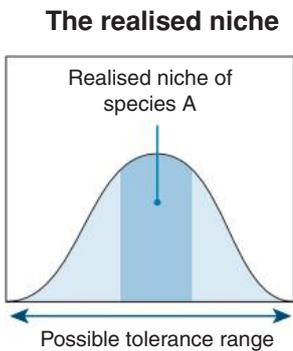
**Key Idea:** An organism's niche describes its functional role within its environment.

The **ecological niche** describes the functional role of an organism in an ecosystem, including its habitat and all its interactions with the environment. It includes how the species responds to the distribution of resources and how it alters those resources for other species. The full range of environmental conditions under which an organism can exist

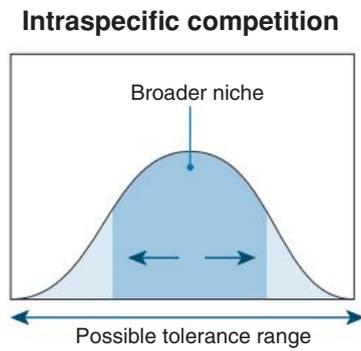
describes its fundamental niche. As a result of interactions with other organisms, species usually occupy a realised niche that is narrower than this. Central to the niche concept is the idea that two species with exactly the same niche cannot coexist, because they would compete for the same resources and one would exclude the other. This is **Gause's competitive exclusion principle**. More often, species compete for only some of the same resources.

The physical conditions influence the habitat. A factor may be well suited to the organism, or present it with problems to be overcome.

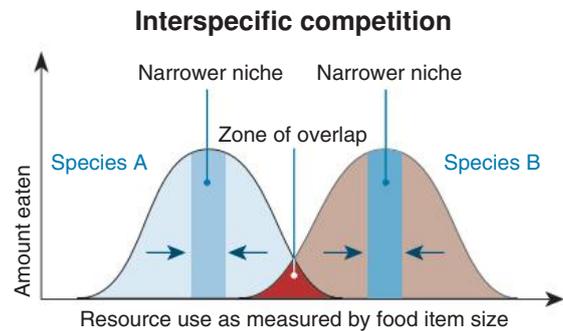
Adaptations enable the organism to exploit the resources of the habitat. The adaptations take the form of structural, physiological and behavioural features of the organism.



The tolerance range represents the **fundamental niche** of a species. The **realised niche** of a species is narrower than this because of competition with other species.



Individuals of the same species exploit the same resources so competition is intense. Individuals must use resources at the extremes of their tolerance range and the realised niche expands.



When two (or more) species compete for some of the same resources, their resource use curves will overlap and competition will be intense in this zone. Selection will favour niche specialisation so that one or both species occupy a narrower niche.

- (a) In what way could the realised niche be regarded as flexible? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) What factors might further constrain the extent of the realised niche? \_\_\_\_\_

\_\_\_\_\_

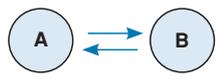
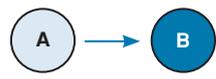
\_\_\_\_\_
- Contrast the effects of interspecific competition and intraspecific competition on niche breadth: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Key Idea:** Every species interacts with others. The interactions usually, but not always, benefit at least one of the species. Species interact with other species. The nature and outcome of these interactions structures communities and leads to interdependence. Interactions range from those that are beneficial to all parties, to those where only one species

benefits. In a relationship involving exploitation, one party benefits at the expense of another. Sometimes, neither party benefits from the interaction. Such interactions include amensalism (below) or competition, a relationship in which two parties (which may be the same or different species) directly or indirectly contest the same resource, e.g. food.

Type of interaction between species				
Mutualism	Commensalism	Amensalism	Exploitation	
			Predation	Parasitism
 <p>Benefits      Benefits</p>	 <p>Benefits      Unharmed</p>	 <p>Unaffected      Harmed</p>	 <p>Benefits      Harmed</p>	 <p>Benefits      Harmed</p>
<p>Both species benefit from the association.</p> <p><b>Examples:</b> Tick bird on zebra removes parasites and alerts zebra to danger, while tick bird gains access to food.</p> <p>Flowering plants and their insect pollinators have a mutualistic relationship. Flowers are pollinated and the insect gains food (below).</p>	<p>One species benefits and the other is unaffected by the association.</p> <p><b>Examples:</b> Remora are fish with special sucker organs to attach to other marine animals such as sharks or turtles. The remora saves energy by hitching a ride on the other animal, and the shark or turtle is unharmed.</p>	<p>One species incidentally harms the second species but does not obtain any benefit from the interaction.</p> <p><b>Examples:</b> Algal blooms can lead to the death of fish and other aquatic organisms by depleting the water of oxygen or producing toxins. However, the algae do not benefit from the deaths of the fish.</p>	<p>Predator kills the prey outright and eats it.</p> <p><b>Examples:</b> Lion preying on wildebeest or praying mantis (below) consuming insect prey. The adaptations of predators and prey are the result of their close ecological relationship throughout their evolution: predators have adaptations to capture prey and prey have adaptations to avoid capture.</p>	<p>The parasite lives in or on the host, taking (usually all) its nutrition from it. The host is harmed but usually not killed.</p> <p><b>Examples:</b> Pork tapeworm in a pig's gut. Some plants (e.g. mistletoes) are semi-parasitic (hemi-parasites). They photosynthesise but rob the host plant of nutrients and water.</p>
				

- Summarise your knowledge of species interactions by completing the following, entering a (+), (-), or (0) for each species, and writing a brief description of each relationship.  
Codes: (+): species benefits, (-): species is harmed, (0): species is unaffected.

Interaction	Species		Description of relationship
	A	B	
(a) Mutualism			
(b) Commensalism			
(c) Amensalism			
(d) Parasitism			
(e) Predation			
(f) Competition			



Examples of interactions between different species are illustrated below. For each example, identify the type of interaction, and explain how each species in the relationship is affected.



J.J. Harrison cc 3.0

2. The honeyeaters are a diverse family of small to medium-sized nectar-feeding birds common in Australia. Many Australian plant species, including proteas and myrtles, are pollinated by honeyeaters.

(a) Identify this type of interaction: \_\_\_\_\_

(b) Describe how each species is affected (benefits/harmed/no effect):

\_\_\_\_\_

\_\_\_\_\_



3. The squat anemone shrimp, also known as the sexy shrimp, lives among the tentacles of sea anemones, where it gains protection and scavenges scraps of food from the anemone. The anemone is apparently neither harmed nor benefitted by the shrimp's presence.

(a) Identify this type of interaction: \_\_\_\_\_

(b) Describe how each species is affected (benefits/harmed/no effect):

\_\_\_\_\_

\_\_\_\_\_



Marc Tardock cc 2.0

4. Dingoes will kill and scavenge a range of species. In groups of two or more, they can attack and kill large animals, such as kangaroos, but will also scavenge carrion, such as this dingo with a fish on Fraser Island.

(a) Identify this type of interaction: \_\_\_\_\_

(b) Describe how each species is affected (benefits/harmed/no effect):

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



5. The Australian paralysis tick (*Ixodes holocyclus*) lives attached to the skin of mammalian hosts, commonly bandicoots, koalas, possums, and kangaroos, where it sucks body fluids and causes irritation. Most native species are immune to the tick's toxins but it can cause paralysis in susceptible species.

(a) Identify this type of interaction: \_\_\_\_\_

(b) Describe how each species is affected (benefits/harmed/no effect):

\_\_\_\_\_

\_\_\_\_\_



6. Large herbivores expose insects in the vegetation as they graze. The cattle egret, which is widespread in tropical and subtropical regions, follows the herbivores as they graze, feeding on the disturbed insects when the herbivore moves away.

(a) Identify this type of interaction: \_\_\_\_\_

(b) Describe how each species is affected (benefits/harmed/no effect):

\_\_\_\_\_

\_\_\_\_\_

7. Explain the similarities and differences between a predator and a parasite:

\_\_\_\_\_

\_\_\_\_\_

# 184 The Influence of Competition

**Key Idea:** Species interact with other living organisms in their environment. Competition occurs within and between species when they utilise the same limited resources.

**Competition** occurs when two or more organisms compete

for the same limited resource (e.g. food or space). Competition harms both competitors. It can occur between members of the same species (**intraspecific competition**) or between members of different species (**interspecific competition**).



Competition occurring between members of the same species is called intraspecific competition. Male kangaroos (above) fight each other to mate with a female or for access to limited resources such as water.



Competition harms both competitors. The negative effects of competition limit population numbers because resources are limited and growth, reproduction, and survival are affected.



A complex system of interactions occurs between the different species living on the Great Barrier Reef. Population numbers will be limited by competition for resources, such as food and space on the reef.

Richard Ling CC 2.5

## Examples of limited resources



Brocken Inaglory cc3.0

**Space can be a limited resource**  
These sea anemones are competing for space in a tidal pool. Some species defend areas, called territories, which contain the resources they need.



**Suitable mates can be hard to find**  
Within a species, individuals may compete for a mate. These male whitetail deer are fighting to determine which one will mate with the females.



**Food is usually a limited resource**  
In most natural systems, there is competition for food between individuals of the same species, and between different species with similar diets.

- (a) What is competition? \_\_\_\_\_

\_\_\_\_\_

(b) Why does competition occur? \_\_\_\_\_

\_\_\_\_\_

(c) Why does competition have a negative effect on both competitors? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- Explain the difference between intraspecific and interspecific competition and give an example of each: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



# 185 Interspecific Competition

**Key Idea:** Interspecific competition is competition between individuals of different species. It can affect species distribution.

**Competition** occurs when two or more organisms attempt to access the same limited resource, e.g. food or space. 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. However, when a foreign species is introduced to the range of a native species with very similar ecological requirements, one (usually the native) may be outcompeted and decline in numbers (the competitive exclusion principle).

## 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. 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 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 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
<b>Historical data</b>		
Sugar glider	77%	23%
Squirrel glider	17%	83%
<b>Recent data</b>		
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
<b>Historical data</b>					
Sugar glider	77%	0%	23%	70%	100%
Squirrel glider	85%	12%	3%	14%	33%
<b>Recent data</b>					
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>

1. Study table 1. What do you notice about the type of forest each species is found in? \_\_\_\_\_

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2. The majority of both species are found below 80 m (Table 2). How do you think they avoid competition with each other? \_\_\_\_\_

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3. Suggest why the niche of the sugar glider is more restricted when both species inhabit the same area: \_\_\_\_\_

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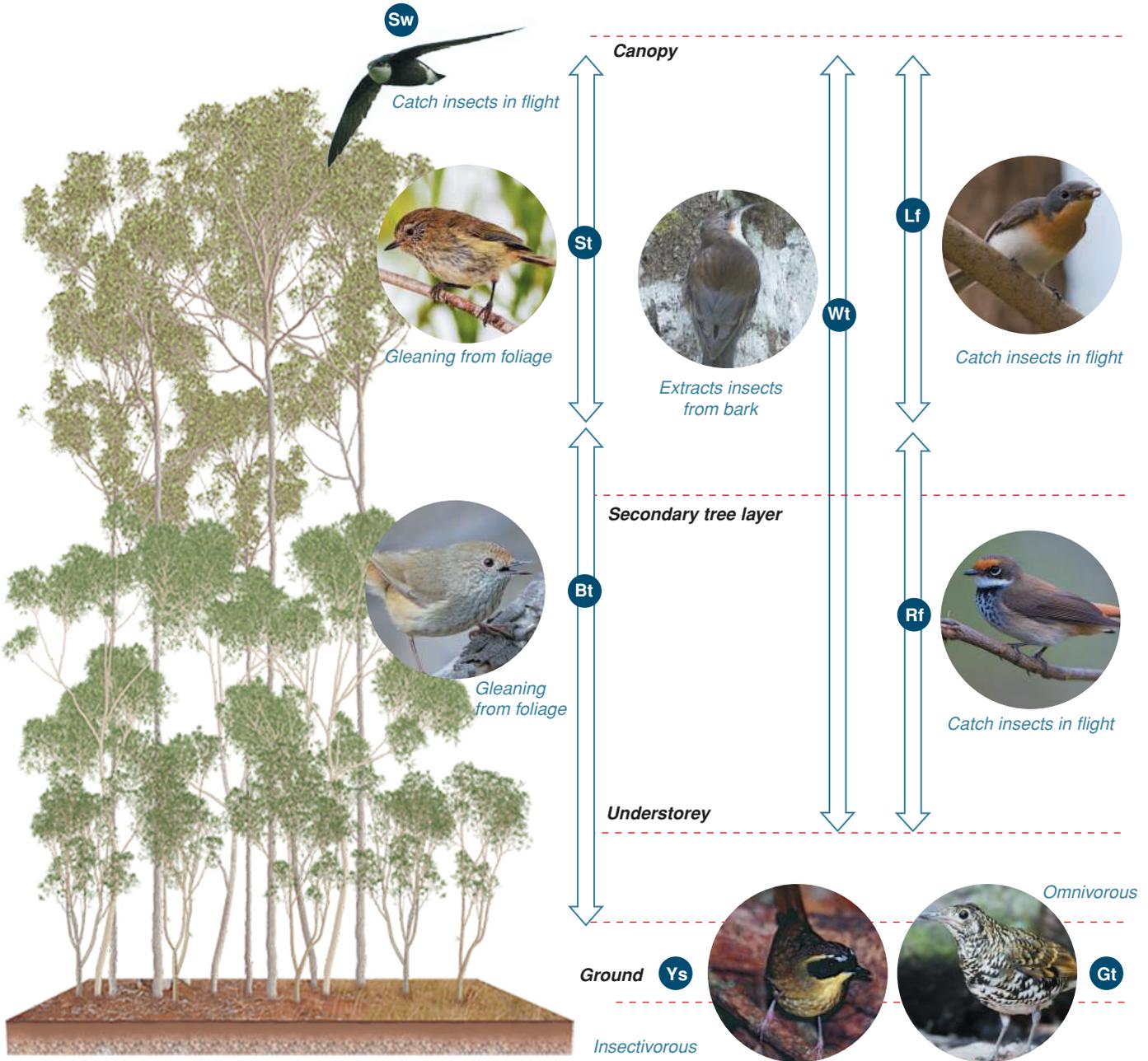
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# 186 Competition and Species Distribution

**Key Idea:** Interspecific competition is reduced when different species exploit slightly different resources. Competition is most intense between members of the same species because their habitat and resource requirements are identical. Interspecific competition is usually less

intense, although many species exploit at least some of the same resources. Different species with similar ecological requirements may reduce direct competition by exploiting the resources within different microhabitats or by exploiting the same resources at different times of the day or year.



Adapted from: Recher et al., 1986. A Natural Legacy: Ecology in Australia. Maxwell Macmillan Publishing Australia.

## Reducing competition in a eucalypt forest

The diagram above illustrates how a layered forest structure provides the opportunities and resources for species with similar foraging niches to coexist. Different layers of the forest allow insectivorous birds to specialise in foraging at different heights and in different ways. The similar sized striated and brown thornbills feed at different heights, as do the leaden flycatcher and the rufous fantail. Adaptations reflect their feeding specialisations. The ground-dwelling yellow-throated scrubwren and the larger ground thrush have robust legs and feet, while the white-throated treecreeper has long toes and large curved claws, specialising in removing insects from the bark. The swifts are extremely agile fliers capable of catching insects on the wing.

## Key to bird species

<b>Rf</b> Rufous fantail <small>PHOTO: Greg Miles cc 2.0</small>	<b>Lf</b> Leaden flycatcher <small>PHOTO: Jim Bendon cc 2.0</small>
<b>Bt</b> Brown thornbill <small>PHOTO: JJ Harrison cc 3.0</small>	<b>Gt</b> Ground thrush <small>PHOTO: JJ Harrison cc 3.0</small>
<b>Sw</b> Spine-tailed swift <small>PHOTO: Ron Knight cc 2.0</small>	<b>Wt</b> White-throated treecreeper <small>PHOTO: Lip Kee cc 2.0</small>
<b>St</b> Striated thornbill <small>PHOTO: JJ Harrison cc 3.0</small>	<b>Ys</b> Yellow-throated scrubwren <small>PHOTO: Bernard Dupont cc 2.0</small>



1. Describe two ways in which species can avoid directly competing for the same resources in their habitat:

- (a) \_\_\_\_\_  
\_\_\_\_\_
- (b) \_\_\_\_\_  
\_\_\_\_\_

2. How do the insectivorous birds in the secondary tree layer of the forest avoid direct competition for the same resources?

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

3. The yellow-throated scrubwren (Ys) and ground thrush (Gt) are both ground feeders. Explain why both species are able to inhabit the ground layer in eucalypt forest:

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

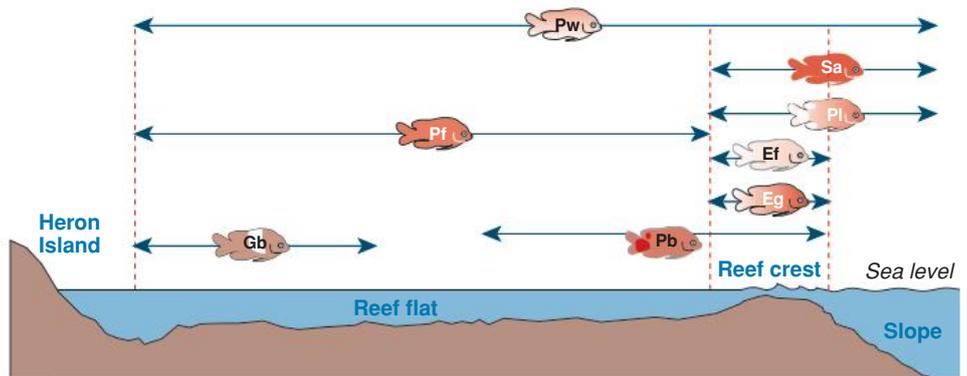
4. In forests where shrubs are absent or sparse, only the striated thornbill (St) is present. In shrub habitats with few trees there are few striated thornbills and the brown thornbills (Bt) are common. Suggest why this is the case:

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

5. The diagram below shows the distribution of ecologically similar damselfish over a coral reef at Heron Island, Queensland, Australia. The habitat and resource requirements of these species overlap considerably.

**Key to damselfish species**

- Pw** *Pomacentrus wardi*
- Pf** *Pomacentrus flavicauda*
- Pb** *Pomacentrus bankanensis*
- Sa** *Stegastes apicalis*
- Pl** *Plectroglyphidodon lacrymatus*
- Ef** *Eupomacentrus fasciolatus*
- Eg** *Eupomacentrus gascoynei*
- Gb** *Glyphidodontops biocellatus*



How might the damselfish on the reef at Heron Island (above) reduce competition? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

# 187 Identifying Species in a Eucalypt Forest

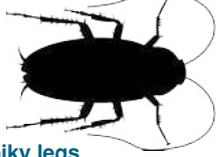
**Key Idea:** Leaf litter communities can be used to assess biodiversity. Many different species are found in leaf litter, but some are more common than others.

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
 <p><b>Hard wing covers</b> 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.</p>	 <p><b>Membranous wings</b> 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.</p>	 <p><b>Narrow waist</b> 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).</p>	 <p><b>Tail nippers</b> 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.</p>	 <p><b>Spiky legs</b> 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.</p>
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
 <p><b>4-10 false legs</b> 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.</p>	 <p><b>Very small and slender</b> 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.</p>	 <p><b>Often long wings</b> 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.</p>	 <p><b>Have a folded tail-like furcula for jumping</b> 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.</p>	 <p><b>Obvious fangs</b> 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.</p>
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
 <p><b>Small size, simple unsegmented body</b> 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.</p>	 <p><b>Flat pear-shaped body</b> 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).</p>	 <p><b>Body segmented</b> 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.</p>	 <p><b>Body flattened</b> 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.</p>	 <p><b>Body rounded</b> 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.</p>

 Insect hexapods

 Non-insect hexapods

 Arachnids

 Crustaceans

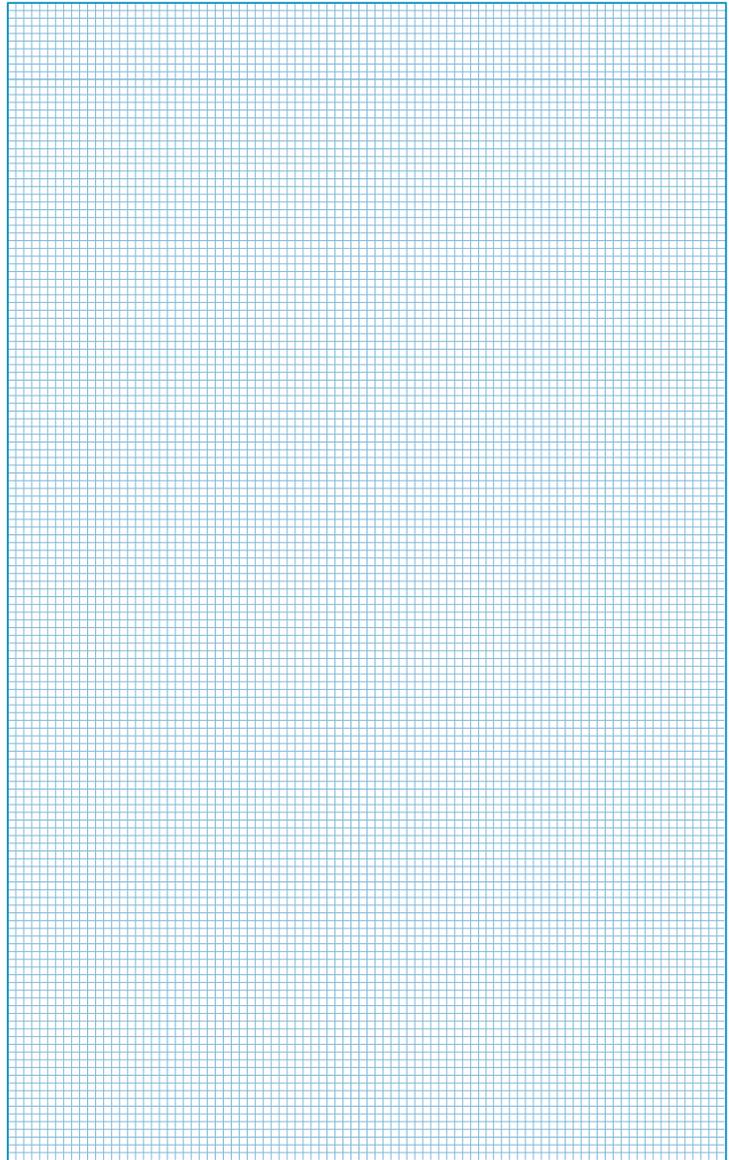
 Myriapods



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 <sup>2</sup> )
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
<b>TOTAL</b>	<b>296</b>

Data: Hurditch, W.J. (1981). From Recher, H.E. ed. (1992) A Natural Legacy Ecology in Australia.



- Graph the species abundance on the grid above. Use the letter codes provided in the table to identify each organism:
- Identify the most abundant species found: \_\_\_\_\_
  - What percentage of the total organisms does it make up? \_\_\_\_\_
  - Describe their importance in this habitat: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- One measure of environmental stress is lack of soil moisture. What litter invertebrates would be useful indicators of environmental stress and why?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Identify an organism that you might not find easily if you sample during day time: \_\_\_\_\_
  - Could this affect your biodiversity assessment? Explain? \_\_\_\_\_  
 \_\_\_\_\_

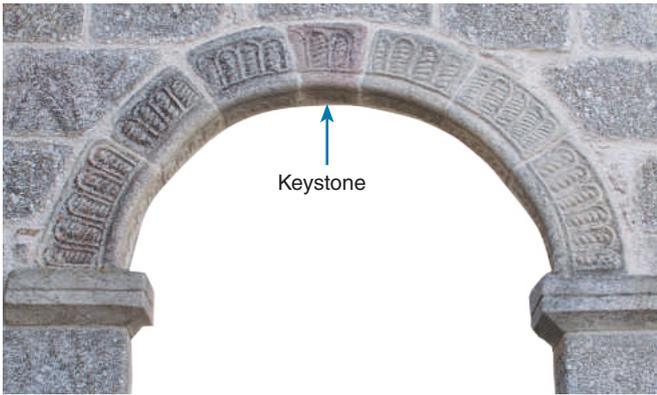
# 188 Keystone Species

**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

## 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.

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.



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.



Keystone: predator

Tierro 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.



Keystone: seed dispersal

istockphotos.com

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.



Keystone: critical food source

Gnanagarra cc 2.5

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.

1. Why are keystone species so important to ecosystem function? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

### Australian keystone species



Albert Kotr, cc3.0

**Tiger shark**



Marjorie Lundgren, cc3.0

**Cockatoo grass**



Andrew Mercer, cc 4.0

**Grey-headed flying fox**

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 are hunted for their flesh, fins, and skin. Finning, although largely banned in Australian waters, still continues illegally.

Cockatoo grass (*Alloteropsis semialata*) is found throughout 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 of 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.

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) Acorn banksia: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) Southern cassowary: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) Humphead wrasse: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(d) Tiger shark: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(e) Cockatoo grass: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(f) Grey-headed flying fox: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Key Idea:** When mulgara were excluded from a fenced area, the number of smaller dasyurid species present reduced.

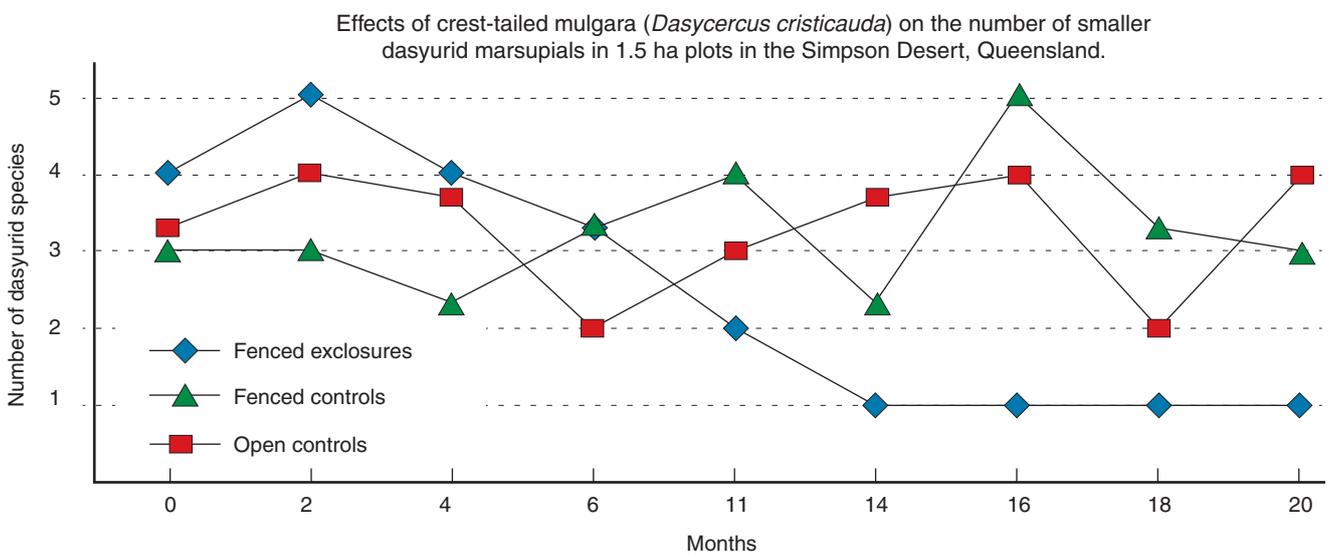
Two species of mulgara (*Dasyercus* genus) are found in Australia, the brush-tailed mulgara and the crest-tailed mulgara. Mulgara are nocturnal marsupials belonging to the family Dasyuridae, which includes the Tasmanian devil and the quolls. Both mulgara species are small (30 cm long from head to tail) 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.



Bobby Tamayo CC 4.0

The effect of the crest-tailed mulgara (*Dasyercus 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.



Data source: Dickman in Attwill, P. and Wilson, B. (2003) Ecology: An Australian Perspective.

- Describe what happens to species numbers after the fences were established (at 10 months) for each of the following:
  - Fenced exclosures: \_\_\_\_\_
  - Fenced controls: \_\_\_\_\_
  - Open controls: \_\_\_\_\_
- Describe the difference in species numbers between the fenced exclosure and the:
  - Fenced control: \_\_\_\_\_
  - Open control: \_\_\_\_\_
- Based on the data presented above, do you think the crest-tailed mulgara acts as a keystone species? \_\_\_\_\_
  - Explain your answer: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- Why do you think the researchers included a fenced control and open control? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



# 190 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 Ianfleck 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.



BH

### 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.



High diversity ecosystem

Richard Ling CC 2.5

### 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.



Northern hairy-nosed wombat

Eva Hegda cc2.0

### 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?

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2. Why must scientists sample an ecosystem or population instead of studying it in its entirety?

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# 191 How Do We Sample Ecosystems?

**Key Idea:** Sampling should provide data that are 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.

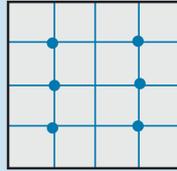
## Sampling designs and techniques

### Point sampling

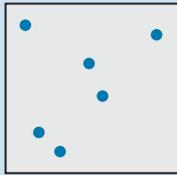
Individual points are chosen using a grid reference or random numbers applied to a map grid. The organisms at each point are recorded. Point sampling is often used to collect data about vegetation distribution.

**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.



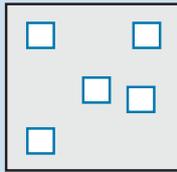
Systematic (grid)



Random

### Area sampling using quadrats

A quadrat provides a known unit area of sample (e.g. 1 m<sup>2</sup>). 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.



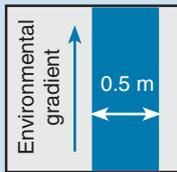
### Line and belt transects

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.



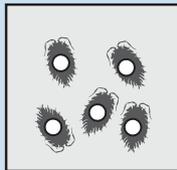
In a **belt transect**, quadrats are used to sample the plants and/or animals at regular intervals along a measured strip.

**Pros:** Provide a lot of information on abundance and distribution as well as presence/absence. **Cons:** Can be time consuming to carry out properly.



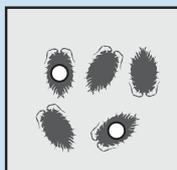
### Mark and recapture sampling

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

## 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:

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(b) Change in community composition from low to high altitude on a mountain:

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(c) Association of plant species with particular soil types in a nature reserve:

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(d) Determining the population size of a fish in a lake:

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2. What are the benefits of collecting information about the physical environment when sampling populations?

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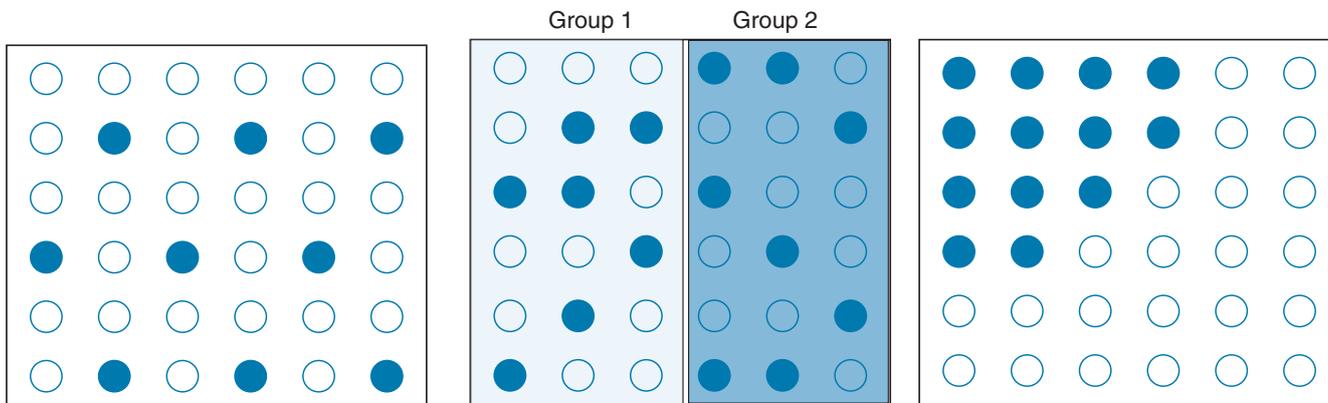
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### Sampling strategies

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.

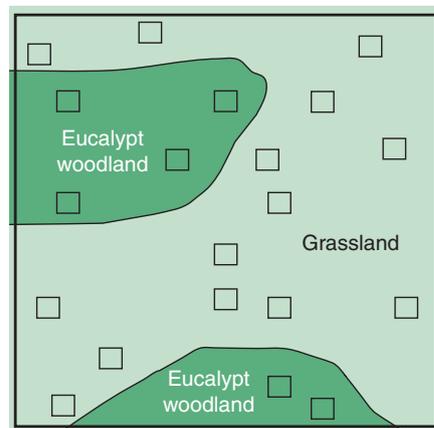
#### Opportunistic sampling

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: \_\_\_\_\_

\_\_\_\_\_

**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.

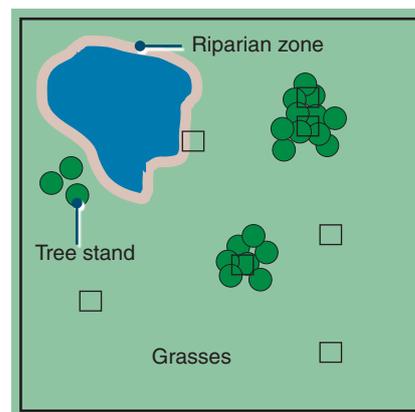


Fritz Geller-Grimm CC3.0

Quadrats are excellent for collecting data on plants but 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 very slow moving animals, and some very fast moving animals (e.g. ants).



(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:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

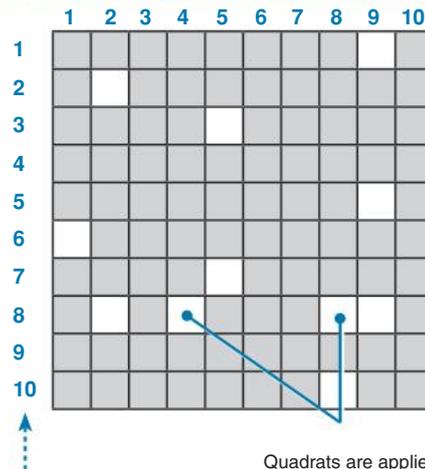
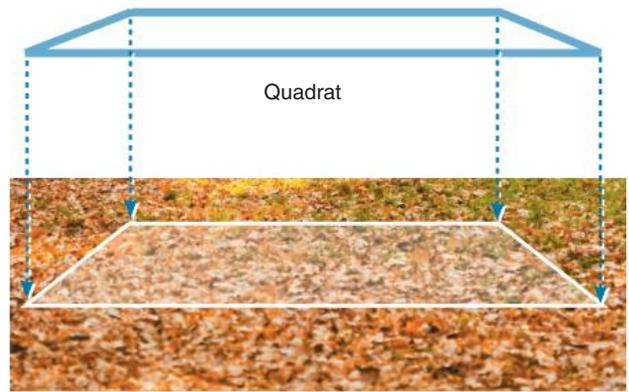
(c) Suggest a technique they could use to collect information on mobile species: \_\_\_\_\_

# 192 Quadrat Sampling

**Key Idea:** Quadrat sampling involves a series of random placements of a frame of known size over an area of habitat to assess the abundance or diversity of organisms.

**Quadrat sampling** is a method by which organisms in a certain proportion (sample) of the habitat are counted directly. It is used when the organisms are too numerous to count in total. It can be used to estimate population **abundance** (number), **density**, **frequency of occurrence**, and **distribution**. Quadrats may be used without a transect when studying a relatively uniform habitat. In this case, the quadrat positions are chosen randomly using a random number table.

The general procedure is to count all the individuals (or estimate their percentage cover) in a number of quadrats of known size and to use this information to work out the abundance or percentage cover value for the whole area.



The area to be sampled is divided up into a grid pattern with indexed coordinates

Quadrats are applied to the predetermined grid on a random basis. This can be achieved by using a random number table.

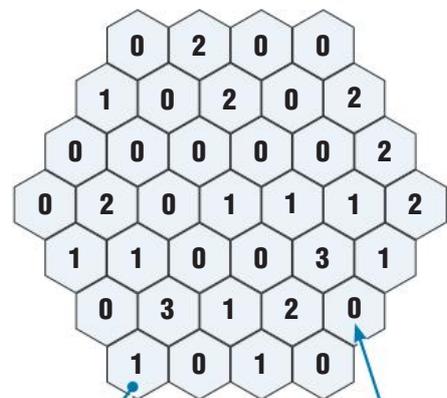
$$\text{Estimated average density} = \frac{\text{Total number of individuals counted}}{\text{Number of quadrats} \times \text{area of each quadrat}}$$

### Guidelines for quadrat use:

1. The **area of each quadrat** must be known. Quadrats should be the same shape, but not necessarily square.
2. **Enough quadrat samples** must be taken to provide results that are representative of the total population.
3. The **population of each quadrat** must be known. Species must be distinguishable from each other, even if they have to be identified at a later date. It has to be decided beforehand what the count procedure will be and how organisms over the quadrat boundary will be counted.
4. The size of the quadrat should be appropriate to the organisms and habitat, e.g. a large size quadrat for trees.
5. The quadrats must be **representative of the whole area**. This is usually achieved by **random sampling** (right).

### Sampling a centipede population

A researcher by the name of Lloyd (1967) sampled centipedes in Wytham Woods, near Oxford in England. A total of 37 hexagon-shaped quadrats were used, each with a diameter of 30 cm (see diagram on right). These were arranged in a pattern so that they were all touching each other. Use the data in the diagram to answer the following questions.



Each quadrat was a hexagon with a diameter of 30 cm and an area of 0.08 square meters.

The number in each hexagon indicates how many centipedes were caught in that quadrat.



1. Determine the average number of centipedes captured per quadrat:  
\_\_\_\_\_
2. Calculate the estimated average density of centipedes per square metre (remember that each quadrat is 0.08 square metres in area):  
\_\_\_\_\_
3. Looking at the data for individual quadrats, describe in general terms the distribution of the centipedes in the sample area:  
\_\_\_\_\_  
\_\_\_\_\_
4. Describe one factor that might account for the distribution pattern:  
\_\_\_\_\_  
\_\_\_\_\_



# 193 Quadrat-Based Estimates

**Key Idea:** The size and number of quadrats used to sample a community must be sufficient to be representative of that community without taking an excessively long time to use. The simplest description of a community is a list of the species present. This does not provide information about

the relative abundance of the species, although this can be estimated using abundance scales (e.g. ACFOR). Quadrats can provide quantitative information about a community. The size of the quadrat and the number of samples taken must represent the community as fairly as possible.

## What size quadrat?

Quadrats are usually square, and cover 0.25 m<sup>2</sup> (0.5 m x 0.5 m) or 1 m<sup>2</sup>, but they can be of any size or shape, even a single point. The quadrats used to sample plant communities are often 0.25 m<sup>2</sup>. This size is ideal for low-growing vegetation, but quadrat size needs to be adjusted to habitat type. The quadrat must be large enough to be representative of the community, but not so large as to take a very long time to use.



A quadrat covering an area of 0.25 m<sup>2</sup> is suitable for most low growing plant communities, such as this alpine meadow, fields, and grasslands.



Very large quadrats (e.g. 10 x 10 m) may be marked out for communities with taller vegetation. For densely forested environments, transects are often better.



Small quadrats (0.01 m<sup>2</sup> or 100 mm x 100 mm) are appropriate for lichens and mosses on rock faces and tree trunks.

## How many quadrats?

As well as deciding on a suitable quadrat size, the other consideration is how many quadrats to take (the sample size). In species-poor or very homogeneous habitats, a small number of quadrats will be sufficient. In species-rich or heterogeneous habitats, more quadrats will be needed to ensure that all species are represented adequately.

### Determining the number of quadrats needed

- Plot the cumulative number of species recorded (on the y axis) against the number of quadrats already taken (on the x axis).
- The point at which the curve levels off indicates the suitable number of quadrats required.



Fewer quadrats are needed in species-poor or relatively uniform habitats, such as this woodland.

## Describing vegetation

Density (number of individuals per unit area) is a useful measure of abundance for animal populations, but can be problematic in plant communities where it can be difficult to determine where one plant ends and another begins. For this reason, plant abundance is often assessed using **percentage cover**. Here, the percentage of each quadrat covered by each species is recorded, either as a numerical value or using an abundance scale such as the ACFOR scale.

### The ACFOR abundance scale

- A** = Abundant (30% +)
- C** = Common (20-29%)
- F** = Frequent (10-19%)
- O** = Occasional (5-9%)
- R** = Rare (1-4%)

The ACFOR scale could be used to assess the abundance of species in this wildflower meadow. Abundance scales are subjective, but it is not difficult to determine which abundance category each species falls into.



1. Describe one difference between the methods used to assess species abundance in plant and in animal communities:

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2. What is the main consideration when determining appropriate quadrat size? \_\_\_\_\_

3. What is the main consideration when determining number of quadrats? \_\_\_\_\_

4. Why are plant communities often sampled using percentage cover? \_\_\_\_\_

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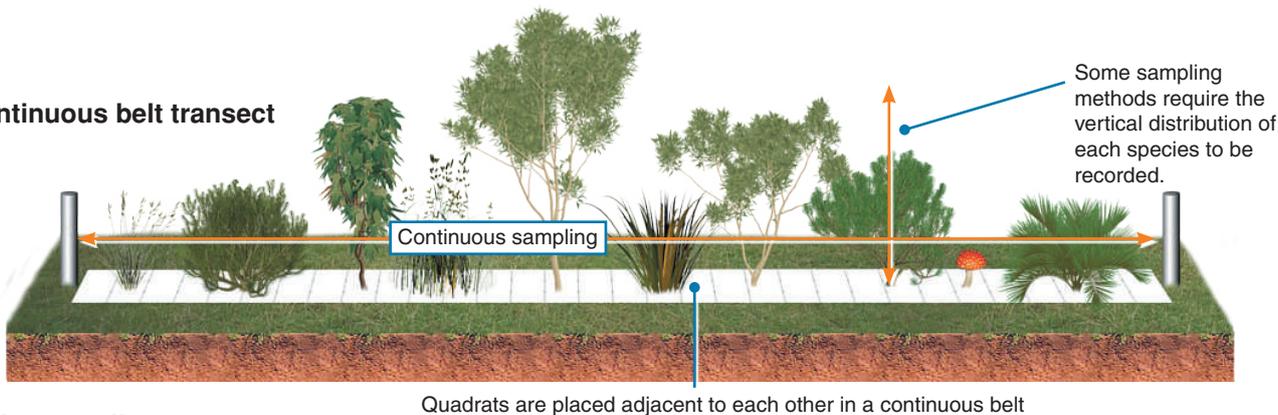
# 194 Transect Sampling

**Key Idea:** Transect sampling is useful for providing information about species distribution along an environmental gradient.

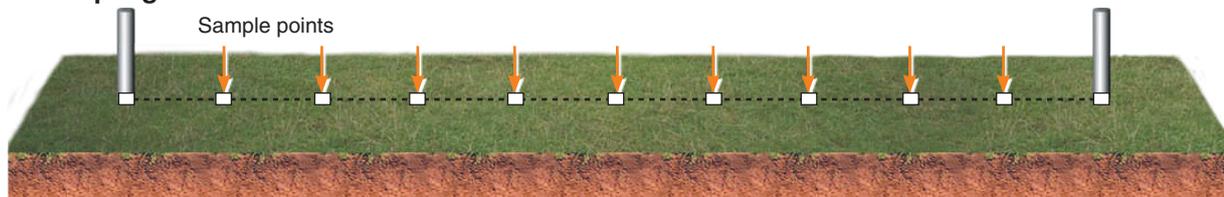
A **transect** is a line placed across a community of organisms. Transects provide information on the distribution of species in the community. They are particularly valuable when the transect records community composition along an **environmental gradient** (e.g. up a mountain or across a seashore). The usual practice for small transects is to stretch a string between two markers. The string is marked off in

measured distance intervals and the species at each marked point are noted. The sampling points along the transect may also be used for the siting of quadrats, so that changes in density and community composition can be recorded. Belt transects are essentially a form of continuous quadrat sampling. They provide more information on community composition but can be difficult to carry out. Some transects provide information on the vertical, as well as horizontal, distribution of species (e.g. tree canopies in a forest).

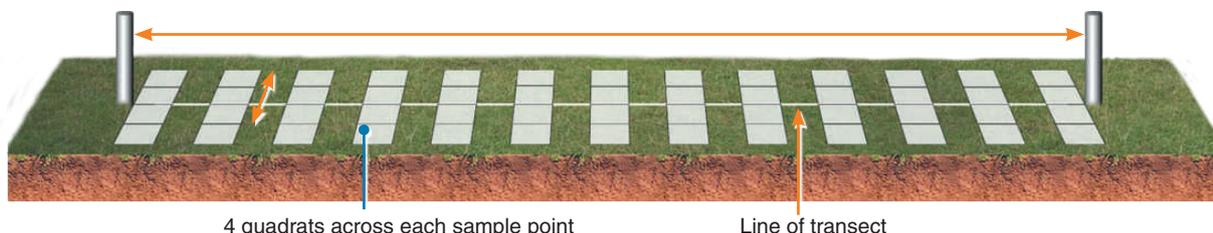
## Continuous belt transect



## Point sampling



## Interrupted belt transect



1. Belt transect sampling uses quadrats placed along a line at marked intervals. In contrast, point sampling transects record only the species that are touched or covered by the line at the marked points.

- (a) Describe one disadvantage of belt transects: \_\_\_\_\_
- \_\_\_\_\_
- (b) Why might line transects give an unrealistic sample of the community in question? \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- (c) How do belt transects overcome this problem? \_\_\_\_\_
- \_\_\_\_\_
- (d) When would it not be appropriate to use transects to sample a community? \_\_\_\_\_
- \_\_\_\_\_

2. How could you test whether or not a transect sampling interval was sufficient to accurately sample a community?  
 \_\_\_\_\_  
 \_\_\_\_\_



A **kite graph** is a good way to show the distribution of organisms sampled using a belt transect. Data may be expressed as abundance or percentage cover along an environmental gradient. Several species can be shown together on the same plot so that the distributions can be easily compared.



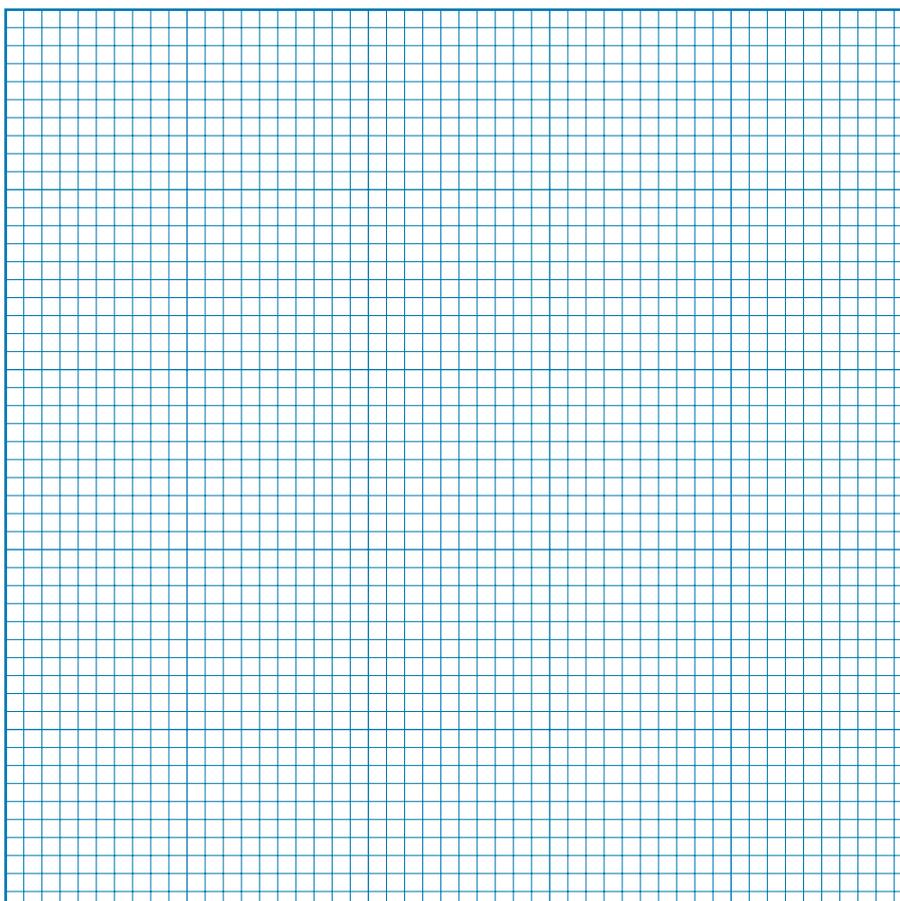
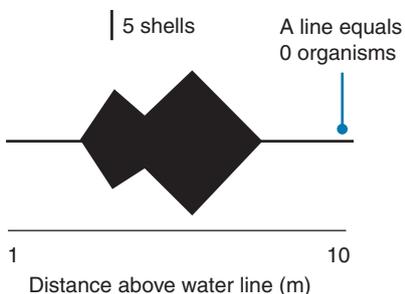
- The data on the right were collected from a rocky shore field trip. Four common species of barnacle were sampled in a continuous belt transect from the low water mark, to a height of 10 m above that level. The number of each of the four species in a 1 m<sup>2</sup> quadrat was recorded.

Plot a **kite graph** of the data for all four species below. Be sure to choose a scale that takes account of the maximum number found at any one point and allows you to include all the species on the one plot. Include the scale on the diagram so that the number at each point on the kite can be calculated.

Distribution of 4 common barnacle species on a rocky shore

Height above low water (m)	Barnacle species			
	Plicate barnacle	Columnar barnacle	Brown barnacle	Sheet barnacle
0	0	0	0	65
1	10	0	0	12
2	32	0	0	0
3	55	0	0	0
4	100	18	0	0
5	50	124	0	0
6	30	69	2	0
7	0	40	11	0
8	0	0	47	0
9	0	0	59	0
10	0	0	65	0

**An example of a kite graph**

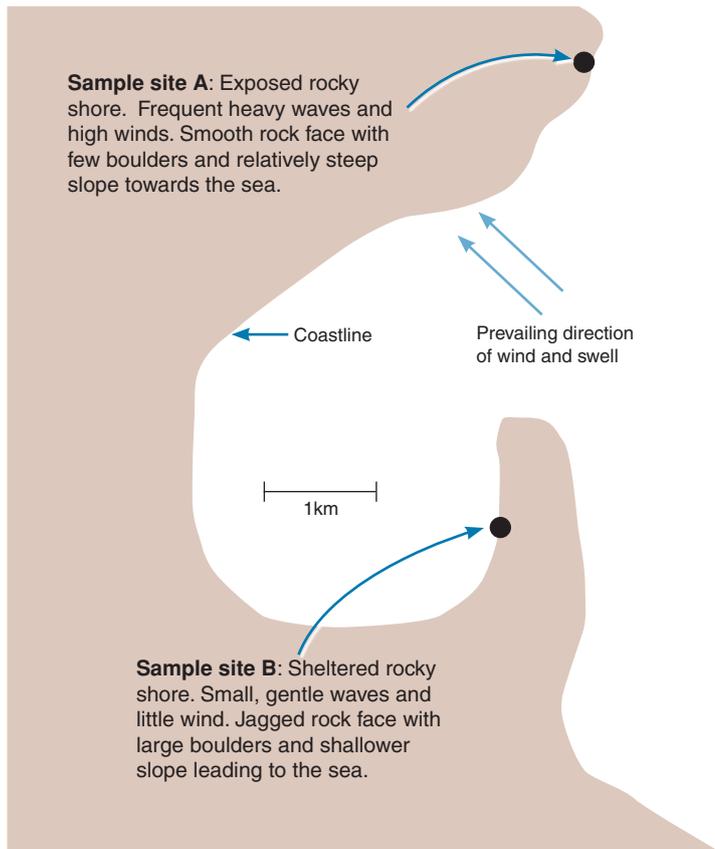


# 195 Field Study of a Rocky Shore

**Key Idea:** Stratified sampling of a rocky shore ecosystem can highlight differences between different regions.

Stratified sampling can be used to investigate the physical and biotic differences between regions within the same

ecosystem. In a rocky shore ecosystem, the type of organisms found and their distribution can vary depending on the physical attributes of the shoreline and the amount of wave exposure received. These differences can be quantified.



## The aim

To investigate the differences in the abundance of intertidal animals on an exposed rocky shore and a sheltered rocky shore.

## Background

The composition of rocky shore communities is strongly influenced by the shore's physical environment. Animals that cling to rocks must keep their hold on the substrate while being subjected to intense wave action and currents. However, the constant wave action brings high levels of nutrients and oxygen. Communities on sheltered rocky shores, although encountering less physical stress, may face lower nutrient and oxygen levels.

To investigate differences in the abundance of intertidal animals, students laid out eight 1 m<sup>2</sup> quadrats at regular intervals along one tidal zone at each of two separate but nearby sites of roughly the same area: 1) a rocky shore exposed to wind and heavy wave action and 2) a rocky shore with very little heavy wave action. The animals were counted and their numbers in each quadrat recorded.

## Rocky shore animals



The oyster borer is carnivorous and preys on barnacles such as the brown barnacle and the plicate barnacle. Numbers of oyster borers may be lower when there are fewer barnacles as prey.

The columnar barnacle is found around the high to mid tide level but can extend lower in suitable areas. It is uncommon on soft substrates and prefers moderately exposed shorelines.



The plicate and brown barnacles can be found together on exposed rocky shores. On more sheltered shores, the columnar barnacle is more prevalent.

The rock oyster often grows on steeply sloped or vertical surfaces and tends to flourish in harbours, as settlement on rocks is inhibited by even moderate wave action.



Limpets are found throughout rocky shores, although the ornate limpet has a slight preference to exposed shores.

The black nerite (snail) is widespread on rocky shores and extends across most tidal zones. It is more common on exposed sites.



1. During the field study, students counted the number of animals in each quadrat and recorded them in a logbook (below). Complete the table below the raw data with the total number of each species at each site, the mean number of animals per quadrat, and the median and mode for each set of samples per species. Remember, in this case, there can be no 'part animals' so you will need to round your values to the nearest whole number:

Field data logbook  
Count per quadrat. Quadrats 1 m<sup>2</sup>

Site A	1	2	3	4	5	6	7	8
Brown barnacle	39	38	37	21	40	56	36	41
Oyster borer	6	7	4	3	7	8	9	2
Columnar barnacle	6	8	14	10	9	12	8	11
Plicate barnacle	50	52	46	45	56	15	68	54
Ornate limpet	9	7	8	10	6	7	6	10
Radiate limpet	5	6	4	8	6	7	5	6
Black nerite	7	7	6	8	4	6	8	9
Site B	1	2	3	4	5	6	7	8
Brown barnacle	7	6	7	5	8	5	7	7
Oyster borer	2	3	1	3	2	2	1	1
Columnar barnacle	56	57	58	55	60	47	58	36
Plicate barnacle	11	11	13	10	14	9	9	8
Rock oyster	7	8	8	6	2	4	8	6
Ornate limpet	7	8	5	6	5	7	9	3
Radiate limpet	13	14	11	10	14	12	9	13
Black nerite	6	5	3	1	4	5	2	3

		Brown barnacle	Oyster borer	Columnar barnacle	Plicate barnacle	Rock oyster	Ornate limpet	Radiate limpet	Black nerite
Site A	Total number of animals								
	Mean number of animals per m <sup>2</sup>								
	Median value								
	Modal value								
Site B	Total number of animals								
	Mean number of animals per m <sup>2</sup>								
	Median value								
	Modal value								

2. Why was a stratified sampling design chosen to investigate the animal diversity of this rocky shore ecosystem?

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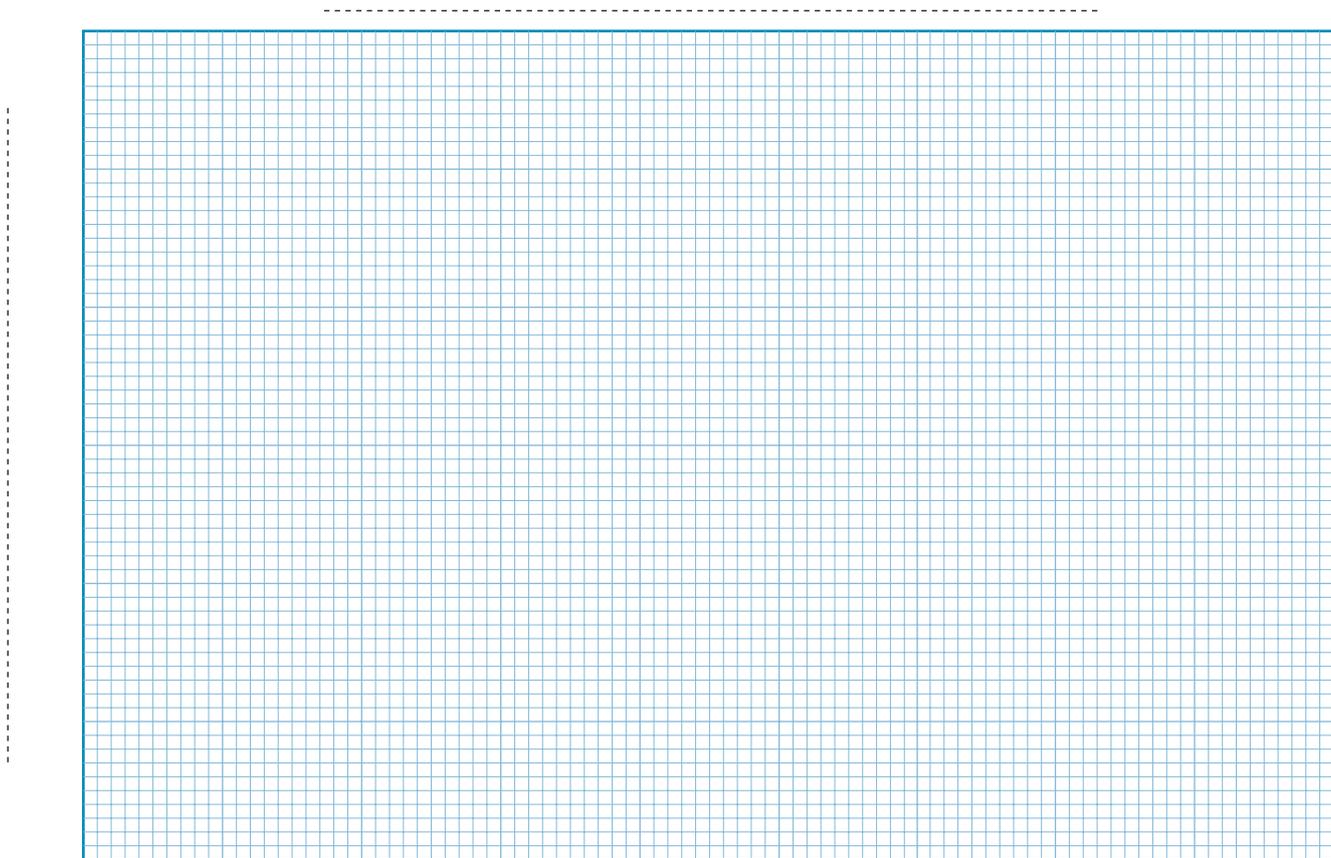


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3. Use the grid below to draw a column graph of the mean number of species per 1 m<sup>2</sup> at each sample site. Remember to include a title, correctly labelled axes, and a key.



4. (a) Compare the mean, median, and modal values at each site: \_\_\_\_\_

(b) What does this tell you about the distribution of the data: \_\_\_\_\_

5. (a) Which species was entirely absent from site A? \_\_\_\_\_

(b) Suggest why this might be the case: \_\_\_\_\_

\_\_\_\_\_

6. (a) Explain why more brown barnacles and plicate barnacles were found at site A: \_\_\_\_\_

\_\_\_\_\_

(b) Explain why more oyster borers were found at site A: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. (a) Comment on the numbers of limpets at each site: \_\_\_\_\_

\_\_\_\_\_

(b) What does this suggest to you about their biology: \_\_\_\_\_

\_\_\_\_\_

8. Did stratified sampling provide more information about this ecosystem than if only one area had been sampled? Explain:

\_\_\_\_\_

\_\_\_\_\_

# 196 The Sixth Extinction

**Key Question:** Is there any evidence that the Earth is experiencing a sixth mass extinction event?

Human activity dominates Earth. Humans can be found almost everywhere on the globe, even at the South Pole. As humans have spread across the planet, from Africa into Europe and Asia, and across into the Americas and beyond, they have changed the environment around them to suit their needs. How these changes have occurred has varied according to the technology available and the general social environment and attitudes at the time. Human-associated change has had a profound impact on the globe's physical

and biological systems. Only in the past century have we begun to fully evaluate the impact of human activity on the Earth. Humans have caused the deliberate or accidental extinction of numerous species and brought many more to the brink. So many species have been lost as a direct or indirect result of human activity that this period in history has been termed the **Sixth Extinction**. There is debate over when this extinction began, its extent, and the degree of human involvement. However, it is clear that many species are being lost and many that existed before humans appeared in their domains, no longer do.

## What is the Sixth Extinction?

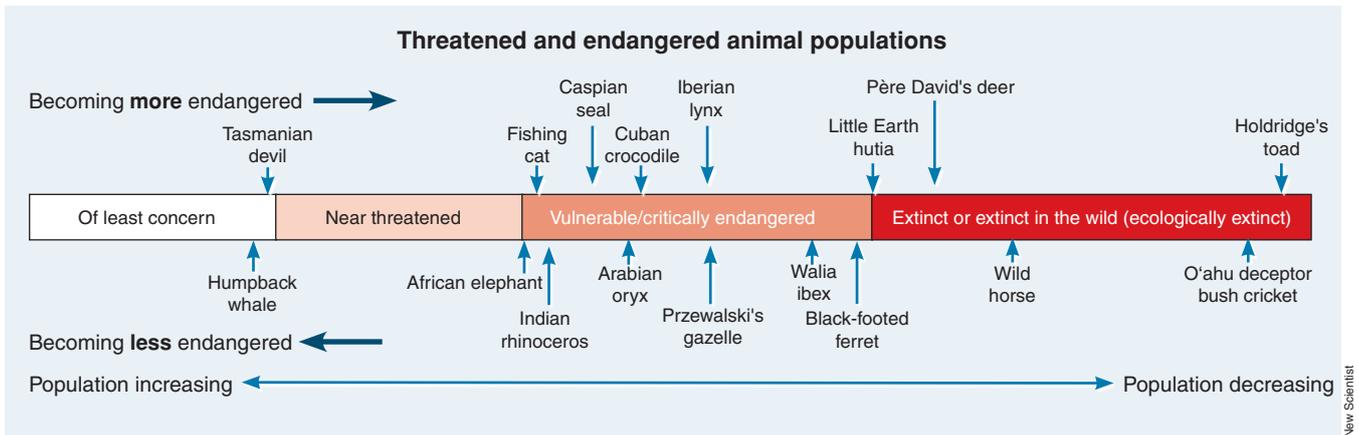
There have been five previous major mass extinctions. The last, 65 mya, saw the end of the dinosaurs and most marine reptiles. The Sixth Extinction refers to the apparent human-induced loss of much of the Earth's biodiversity. Twenty years ago, Harvard biologist E.O. Wilson estimated that as many as 30,000 species a year were being lost – one every 20 minutes. The extinction dates for some examples are given right.



Golden toad (Costa Rica) 1989



Bramble Cay mosaic-tailed rat (Australia) 2019



1. Define the **Sixth Extinction**: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. Humans are frequently not directly responsible for the extinction of a species, yet recently extinct species have often become so after humans arrive in their habitat. Discuss the reasons for these extinctions:  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. Identify a species, other than one mentioned earlier, that has recently become extinct. Identify the date and possible reasons for its extinction:  
 \_\_\_\_\_  
 \_\_\_\_\_

### The extinction of the thylacine

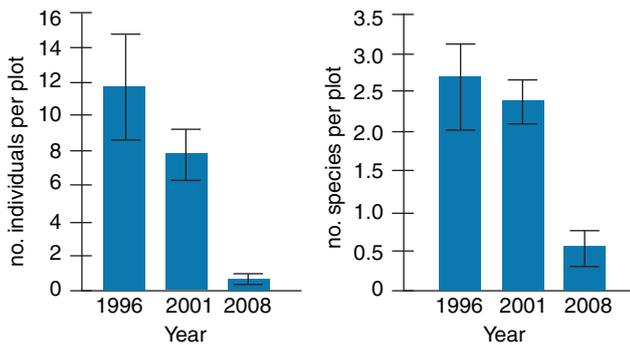
- ▶ The black and white photo of the last thylacine in a zoo in Hobart, Tasmania, (right) is an iconic image of an Australian mammal. But unfortunately for the wrong reasons. It shows how vulnerable many animals are to changes in their habitat, and the carelessness of humans.
- ▶ Fossils show the thylacine was once found throughout Australia and Papua New Guinea. Its decline in pre-European times is thought to be linked to the spread of the dingo, starting about 5000 years ago. By about 2000 years ago the thylacine was restricted to Tasmania. Its population at the time of European arrival is thought to have been about 5000.
- ▶ The Thylacine's wolf-like appearance was probably a major reason for its final downfall. European farmers found it an easy scapegoat on which to blame stock losses, and so bounties were placed on it.
- ▶ Around 3500 thylacine were killed by hunting between 1830 and 1920. The rest of the population declined under the effects of competition from wild dogs, habitat destruction, and disease.
- ▶ The last thylacine, named Benjamin, died from exposure at the Beaumaris Zoo in Hobart in 1936.



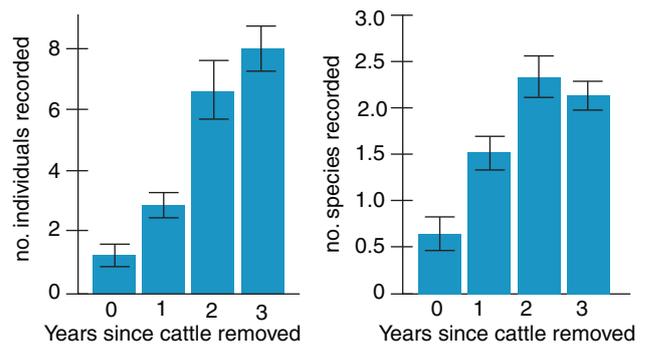
### Driving factors in the decline of Australia's native mammalian species

- ▶ Long term monitoring of plots in the Kakadu National Park show a significant decline in both the number of mammalian species and individuals detected (below left).
- ▶ One of the most important factors in the reduction of small mammal populations in Australia is habitat loss, especially to agriculture, which takes up large tracts of land. The introduction of large mammalian grazers e.g. cattle, have a major effect on small mammals, by removing important food sources and disturbing territory (below right).

Mean number of mammalian species and individuals recorded in monitoring plots in Kakadu National Park



Response of native mammals to the removal of cattle from monitoring plots in the Kimberly



Into Oblivion? The disappearing native mammals of northern Australia

4. Large appealing animals, e.g. pandas, are known as charismatic megafauna. Research shows these kinds of animals receive far more money and time for conservation efforts than less appealing organisms such as snakes, spiders and plants. Suggest why this might be the case and explain how this could affect the conservation of biodiversity:

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5. (a) What is the % decline in individual mammals recorded per plot in the Kakadu National park from 1996 to 2008?

---

(b) What is the % decline in mammalian species recorded per plot in the Kakadu National park 1996 to 2008?

---

6. What is the effect on native mammalian species of removing cattle from a particular habitat?

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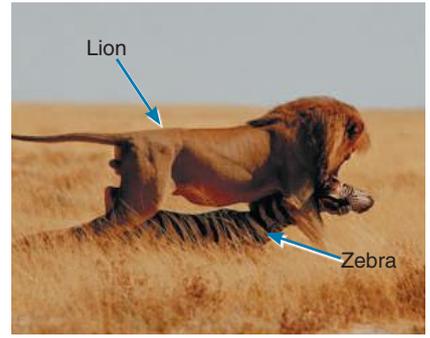
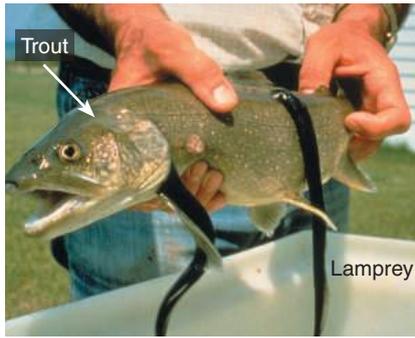
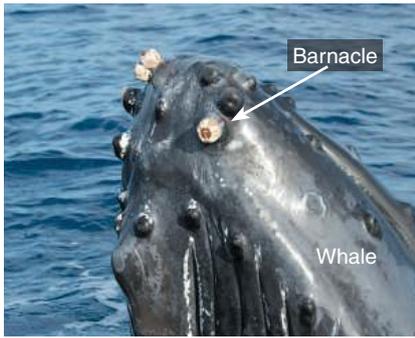
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# 197 Chapter Review: Did You Get It?

1. Describe the species interactions below as mutualism, commensalism, amensalism, predation, or parasitism, and note which species benefits and which is harmed (if any).



(a) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(b) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(c) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Study the graph of population growth for a hypothetical population below and answer the following questions:

(a) Estimate the carrying capacity of the environment:

\_\_\_\_\_

(b) What happened at point A? \_\_\_\_\_

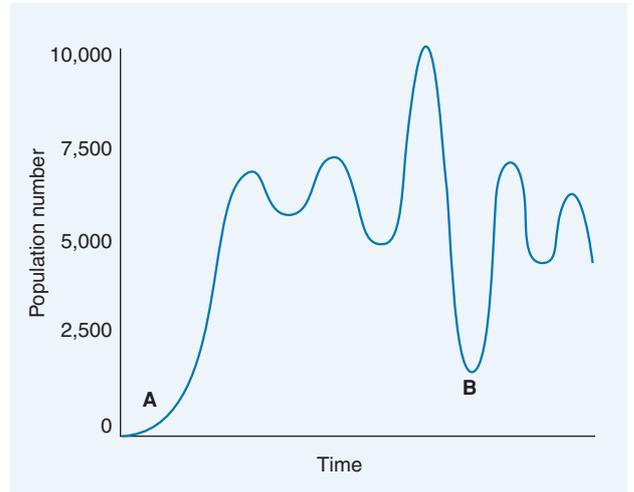
\_\_\_\_\_  
 \_\_\_\_\_

(c) What happened at point B? \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_

(d) What factors may have caused this?

\_\_\_\_\_  
 \_\_\_\_\_



3. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code

<p><u>abiotic factor</u> .....</p> <p><u>carrying capacity</u> .....</p> <p><u>competition</u> .....</p> <p><u>keystone species</u> .....</p> <p><u>mutualism</u> .....</p> <p><u>parasitism</u> .....</p> <p><u>quadrat</u> .....</p>	<p><b>A</b> A measured and marked region used to isolate a sample area.</p> <p><b>B</b> A species that has a disproportionate effect on ecosystem stability and function because of their pivotal role in some aspect of ecosystem functioning such as nutrient cycling</p> <p><b>C</b> The maximum number of organisms of a species an environment can support indefinitely.</p> <p><b>D</b> Interaction in which a resource is contested.</p> <p><b>E</b> Exploitation involving an organism and its host. The host is detrimentally affected by the relationship but is not usually killed.</p> <p><b>F</b> A term for any non-living part of the environment, e.g. rainfall or temperature.</p> <p><b>G</b> A mutually beneficial interaction between individuals of different species</p>
--	--

# Past Ecosystems

Activity  
number

## Key terms

biota  
 coevolution  
 continental drift  
 Gondwana  
 Great Oxidation Event  
 ice core  
 isotope  
 megafauna  
 palaeontology  
 radiometric dating  
 rock art  
 rock strata  
 sclerophyll  
 stromatolite  
 zircon

*Inquiry question: How do selection pressures within an ecosystem influence evolutionary change?*

## Analysing evidence for past ecosystem change

### Key skills and knowledge

- |                          |   |                        |
|--------------------------|---|------------------------|
| <input type="checkbox"/> | 1 Use palaeontological and geological evidence, including rock strata, to describe past environments. Compare fossils with living representatives to describe past environmental conditions and the changes that have taken place over time. Understand the significance of banded iron formations. | <b>155 198</b>         |
| <input type="checkbox"/> | 2 Analyse data from ice cores to infer past climates based on concentrations of particular gases or isotopes.   | <b>156 198<br/>199</b> |
| <input type="checkbox"/> | 3 Use ancient rock art as evidence of past ecosystems and environments.   | <b>198</b>             |
| <input type="checkbox"/> | 4 Investigate the use of radiometric dating. Use isotope data to calculate the age of rocks. Understand the importance of producing accurate dates for rock samples.  | <b>199</b>             |



NASA Goddard Space Flight Center/Ludovic Brucker

## Analysing evidence for past biological change

### Key skills and knowledge

- |                          |  |            |
|--------------------------|--|------------|
| <input type="checkbox"/> | 5 Use a range of secondary sources to investigate the origin of Australian flora and fauna. Identify important fossil sites that illustrate particular periods in the evolution of Australian flora and fauna. | <b>200</b> |
| <input type="checkbox"/> | 6 Evaluate the evidence for changes in Australia's characteristic fauna, including the extinction of the marsupial megafauna.  | <b>200</b> |
| <input type="checkbox"/> | 7 Use pollen records to investigate and determine changes in the dominant flora over time. Compare with records of carbonisation (fire history) and climate changes to determine reasons for the changes.      | <b>200</b> |

## Reasons for past ecosystem change

### Key skills and knowledge

- |                          |  |            |
|--------------------------|--|------------|
| <input type="checkbox"/> | 8 Investigate the coevolution of life and the environment as a reason for major ecosystem changes over time.               | <b>201</b> |
| <input type="checkbox"/> | 9 Explain how continental drift has affected the Australian continent and its environment over the past 250 million years. | <b>201</b> |
| <input type="checkbox"/> | 10 Evaluate the effect of humans on Australia's characteristic flora and fauna, including the use of firestick farming.    | <b>201</b> |

# 198 Analysing Evidence for Ecosystem Change

**Key Idea:** Palaeontological and geological data provides importance evidence of past environmental changes. Evidence for past biological and environmental change comes from many sources. Some may be relatively simple

to see e.g. different coloured layers in a rock profile (strata). Others may require much more in-depth research and knowledge to apply, such as analysing gases trapped in ice cores, or radiometrically dating a rock sample.

## Comparing living organisms with fossils

- Fossils can provide valuable information about the organisms present and their past environment. The fossils can be compared to similar organisms alive today to give us clues about the past environment. For example, stromatolites are layered rocky structures formed in shallow water by the accumulation of sediment by microbial mats (particularly cyanobacteria). Stromatolites are found today at Shark Bay in Western Australia in shallow highly saline water. Stromatolite fossils have been found in many places around Australia indicating warm shallow seas were present over the early Australian continent. Stromatolites have been dated to 3.5 billion years old.

### Locations of Australian stromatolite fossils



Rygel, M.C. CC 3.0 via wikipedia

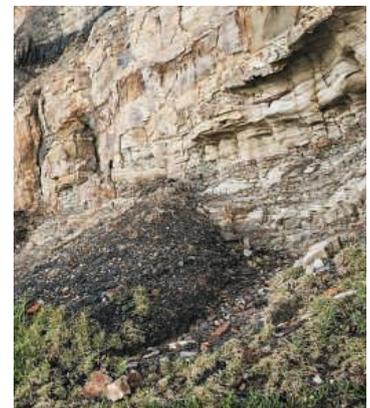
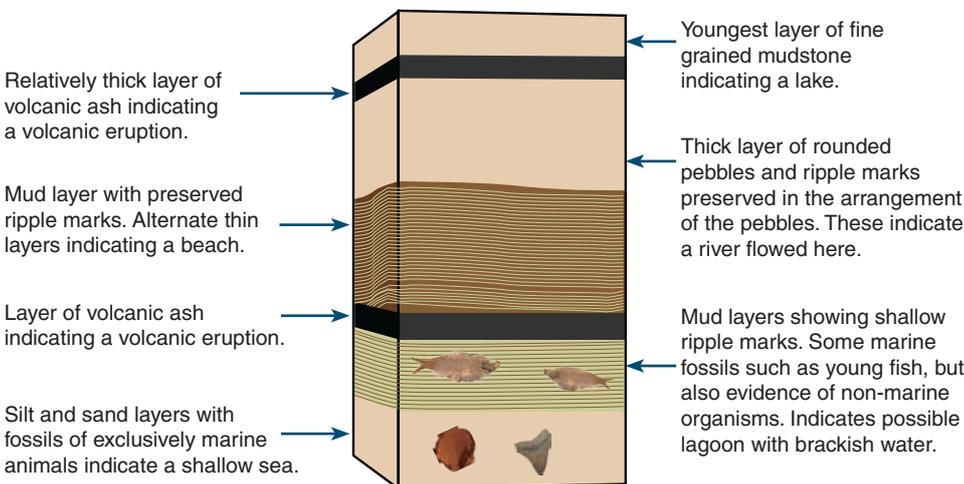


Graeme Churchard CC 2.0

- Cyanobacteria flourished in shallow waters throughout the world until ~1 bya after which their abundance and diversity declined. They were among the first bacteria to split water to produce oxygen during photosynthesis. The newly abundant oxygen reacted with iron ions dissolved in the seawater to form iron oxides that formed sediments on the sea floor producing **banded iron** formations. These are mostly dated between 2.4 and 1.9 billion years old and provide evidence for the rise in Earth's oxygen concentration called the Great Oxidation Event.

## Interpreting rock strata

- We have already seen that fossils provide evidence of change over time. Relatively simple fossils are found in deeper rock layers, whereas shallower layers have more complex fossils. While fossils can tell us much about the life and environment at certain times, the rock layers themselves can provide information about the environment. The composition of the rock strata hold clues that can be interpreted to provide information about past environments. The rock strata below illustrate how strata might change over time in a coastal area.



Sedimentary strata, New South Wales

1. How do we know warm shallow seas must have covered much of Australia in the distant past? \_\_\_\_\_

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2. Investigate the Great Oxidation Event using an internet or literature search. Write a short paragraph on what caused it and its significance.

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3. Write an interpretation of the history of the area around the strata shown at the bottom of the previous page. Justify your interpretation with evidence in the rocks:

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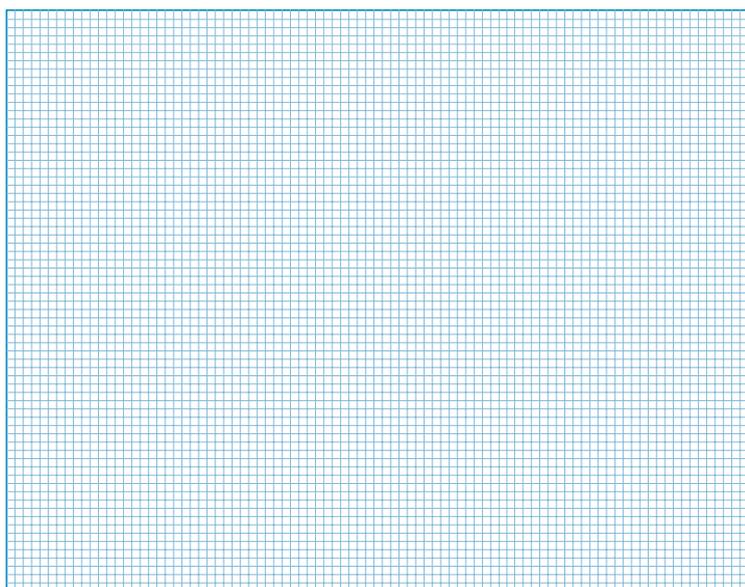


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**Analysing ice cores**

- ▶ In the same way that rock strata shows detail about the environment when the sediments were laid down, so ice cores show detail about the environment when the snow and ice was laid down. In places like Greenland and the Antarctic, ice has been present for hundreds of thousands to millions of years. By drilling down into the ice and extracting cores (long cylindrical blocks of ice) we can reveal and study the ice from the distant past.
- ▶ Not only does the ice hold dust, ash, or pollen, from when the ice layers were laid down, but it also contains bubbles of gas, atmosphere that was trapped when snow fell and turned to ice. The amount of carbon dioxide and methane (CH<sub>4</sub>) in the gas at different layers in the ice can be analysed, and this provides information about past climates.
- ▶ The data below shows the concentration of methane in parts per billion (ppb) in ice cores from Queen Maud Land in Antarctica.

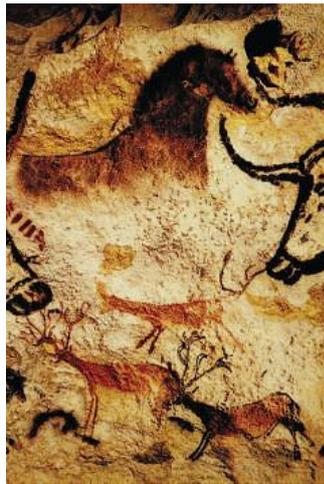
Depth (m)	Years BP	CH <sub>4</sub> (ppb)
717.02	11599	609.35
829.64	14543	529.66
1070.95	23231	383.60
1154.20	27748	392.50
1173.61	28810	419.31
1233.17	32339	435.59
1260.48	33728	456.60
1286.47	35417	467.63
1337.80	38258	488.11
1365.07	39433	423.15
1403.97	41378	443.35
1489.88	46719	469.20
1601.65	53264	491.10
1680.64	58176	538.28
1760.37	63448	468.08
1860.22	71706	470.32
1949.26	78706	480.43
2065.88	89241	493.35



4. (a) To what depth did the ice core drill? \_\_\_\_\_
- (b) Plot the change of methane over time on the grid on the previous page:
- (c) Describe how atmospheric methane has changed over time: \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- (d) What effect might these changes have had on the climate? \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

**Rock art**

- ▶ Rock art (images and designs drawn on rock overhangs and in caves, often dating to prehistoric times) is found throughout the world and can provide us with useful information about past environments. The people who drew the images often included the types of animals that lived in the area. This gives us a clue to the diversity of animals and the environment at the time.
- ▶ For example, paintings on the walls of caves in Lascaux, France, dated to around 17,000 years old, show a diversity of horses, cattle, and deer (right).
- ▶ Rock art can be found in many places in Australia. The oldest reliably dated rock art in Australia is found at Gabarnmung cave, a large rock shelter in south-western Arnhem Land, at the top of Australia's Northern Territory. The fragment of a rock painting is dated to around 28,000 years old, although human habitation there is dated to at least 44,000 years ago.
- ▶ The oldest reliably dated **intact** rock art in Australia is found in the Kimberly region. It is a painting of a kangaroo (far right), dated at 17,500 years old. The painting was dated by radiometrically dating the fossilised nests of mud wasps that had been constructed over parts of the painting.
- ▶ Other paintings include images of kangaroos, dingoes, emus, turtles, fish, and many other kinds of animals.
- ▶ In the Sahara desert, rock art has been found that shows a range of animals, including hippopotamus, buffalo, and elephant, that no longer live there. The art is dated from about 12,000 years ago. This suggests that the climate of the Sahara was much wetter at the time and that the desert has since expanded.



17,500 year kangaroo painting. Redrawn from Pauline Heaney



Giraffe painting, Tassili n'Ajjer, Sahara Desert

5. Why are ancient rock paintings important tools for studying past environments? \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
6. Using an internet search or other investigative methods find out about aboriginal rock paintings or carvings in New South Wales. Identify their locations, what kinds of organisms are depicted, and the dates they were drawn. Are there any organisms depicted that are no longer in the area?
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

# 199 Techniques for Analysing Environmental Change

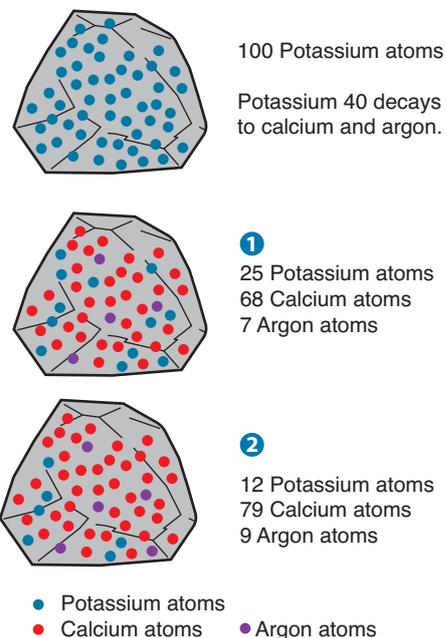
**Key Idea:** Radiometric dating and isotope analysis can provide both dates for events and information on past climates and environments.

Although rock profiles, ice cores, and paintings can tell us much about what a past environment might have been like, they can generally provide approximate or relative dates for

when the events occurred. Radiometric dating uses the rate at which the isotopes decay and is able to provide dates for events by measuring the proportions of isotopes in the material being tested. Ice cores, much like tree rings, can have annual freeze and thaw events counted, but the gas content in them requires more technical analysis.

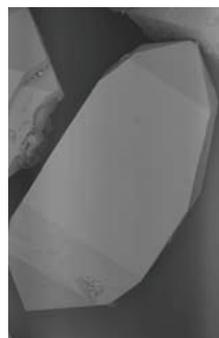
## Radiometric dating

- ▶ We have already seen that radiometric dating can provide dates based on the half-lives of radioactive isotopes.
- ▶ Working out the age of a rock is simple if the radioisotopes have undergone a whole number of half-lives. For example, if radioactivity is 50% of what is expected then one half-life has past. But what if the ratios in the sample don't correspond to full half-lives (e.g. 0.5, 0.25 etc)? How do we calculate the number of half-lives passed if 80% of the radioactivity remains for example?
- ▶ Important for radiometric dating is the ratio of parent isotopes (the original element) left in the sample to the daughter isotope (produced by decay).
- ▶ For any number of half-lives (t) the proportion of radioactive atoms left is equal to  $0.5^t$ , i.e.  $r = 0.5^t$ .
  - Therefore the proportion of radioactive atoms left gives us the half-lives that have passed:  $t = -\ln(r) \div -0.6931$ .  $\ln$  refers to natural logarithms.
- ▶ **Example:** A sample contained a ratio of 2:3 parent isotopes to daughter isotopes.
  - The proportion of parent isotope is therefore 0.4, since 2 out of every 5 atoms is a parent atom.  $2 \div 5 = 0.4$
  - A proportion of 0.4 means that 40% of the original sample is left. Therefore  $t = \ln(0.4) \div -0.6931 = 1.32$  half-lives.
  - If the isotope being studied is carbon-14 then  $5730 \times 1.32 = 7560$  years have passed.

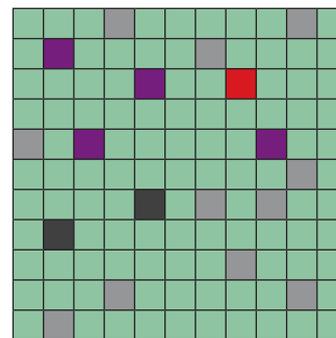


## Zircons- the oldest crystals found

- ▶ Particularly stable areas of continents can be dated radiometrically because the rocks are not recycled back into the mantle. The oldest rocks in New South Wales, found in Broken Hill, are about 1.7 billion years old. The oldest material in Australia are zircons, found in Jack Hills, Western Australia, dated to 4.375 billion years old.
- ▶ Zircons are crystals containing the elements zirconium, silicon and oxygen, with the formula  $ZrSiO_4$ . They form when molten rock cools. Zircons also contain traces of uranium when they form and so can be dated radiometrically. Uranium has a similar electron structure to zirconium and so sometime gets incorporated into the zircon crystal structure, but lead does not. The uranium decays over time to lead. Therefore the ratio of U-238 to Pb-206 and U-235 to Pb-207 can tell us how long ago the crystal formed (far right).



SEM image of a zircon crystal



U-235 ■ Pb-207 ■ Zr ■  
U-238 ■ Pb-206 ■

1. Fossils don't form in volcanic rocks, radiometrically dating volcanic rocks can often give us a good idea of the age of fossils found nearby. Explain why:

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2. Potassium-40 decays to calcium-40 89% of the time and to argon-40 11% of the time (top right). It has a half-life of 1.28 billion years. Use the information in the diagram top right to calculate the age of the rock at times 1 and 2.

---



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3. The green square above right represents a zircon crystal with incorporated uranium atoms. U-235 has a half life of 703.8 million years. U-238 has a half-life of 4.5 billion years. Calculate the age of the zircon crystal.

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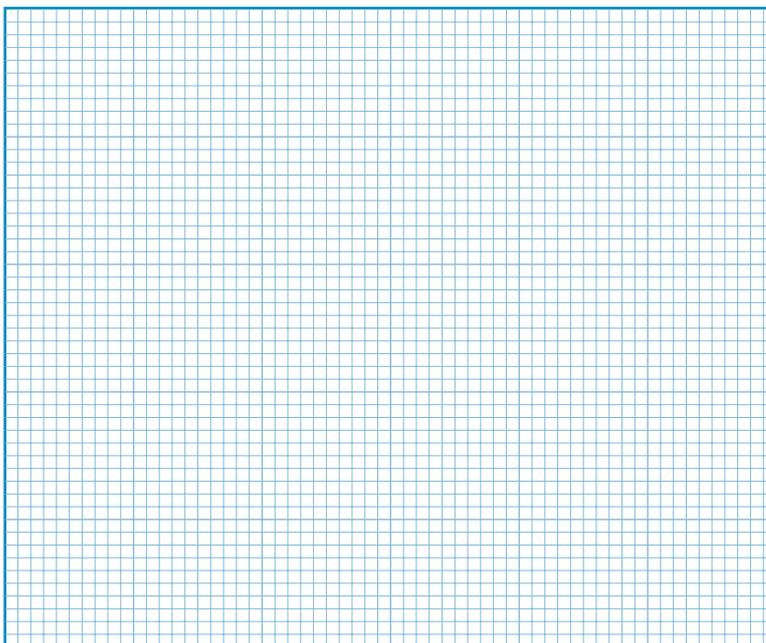
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### Analysing oxygen isotopes in ice cores

- Oxygen comes in two common isotopes oxygen-16 ( $^{16}\text{O}$ ) (light) and oxygen-18 ( $^{18}\text{O}$ ) (heavy). In water, this causes water molecules with  $^{18}\text{O}$  to be heavier than water containing  $^{16}\text{O}$ . Heavy water evaporates less than light water. Therefore there is less  $^{18}\text{O}$  in the atmosphere and in rain than in seawater. Temperature affects the amount of  $^{18}\text{O}$  in the atmosphere. The data below measures the difference in  $^{18}\text{O}$  in rainwater compared to the ocean at different temperatures.

4. Plot the isotope data on the grid below. Temperature is on the x axis:

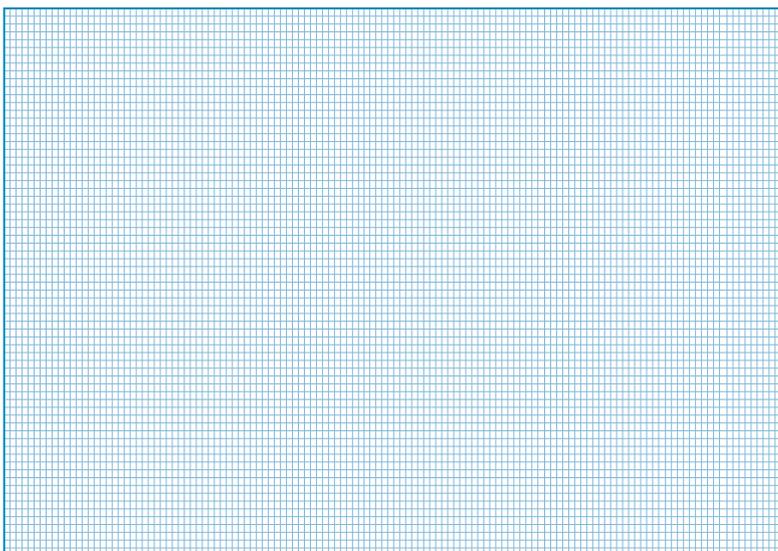
Difference $^{18}\text{O}$ (%) in rainwater compared to seawater	Temp $^{\circ}\text{C}$
-4.2	-36
-3.8	-34
-2.8	-27
-3.5	-19
-2.7	-19
-1.6	-10
-1.5	0
-1.9	4
-1.2	1
-0.6	5
-1.0	8
-0.6	11
-0.5	20



5. (a) Once a reference has been established (as above) it is then possible to measure oxygen isotopes in ice cores and determine what the temperature must have been at the time the ice was laid down. The data below is taken from ice cores on the Gomez Plateau in Antarctica. Use the data below and above to complete the table and work out how the temperature of the Gomez Plateau has changed over time.

- (b) Plot a graph of temperature change over time for the Gomez Plateau. Draw a line of best fit through the points:

Year	Difference $^{18}\text{O}$ (%) in rainwater compared to seawater	Temp $^{\circ}\text{C}$
2005	-2.10	
1995	-2.30	
1985	-2.28	
1975	-2.25	
1965	-2.30	
1955	-2.03	
1945	-2.06	
1935	-2.26	
1925	-2.19	
1915	-2.31	
1905	-2.23	
1895	-2.27	
1885	-2.24	
1875	-2.16	



- (c) Describe the trend in temperature over time on the Gomez Plateau: \_\_\_\_\_

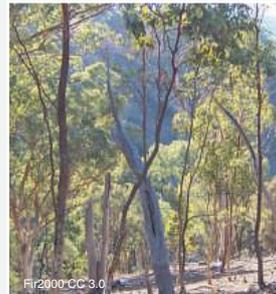
# 200 Analysing The Evidence for Biological Change

**Key Idea:** Australia's biota is diverse in origin, but much of it is unique, the species having undergone adaptive radiation at a time when Australia was isolated from other land masses. By analysing fossils and comparing living specimens it is possible to establish the evolutionary origins of much of Australia's biota. Evidence shows that many of Australia's unique species are Gondwanan in origin, and close relatives of these species can be found on other continents originating

from Gondwana. Australia separated from the rest of Gondwana about 60 million years ago and for much the time since has been isolated from the rest of the world. However during glacial periods land-bridges formed between Australia and Asia allowing some species to arrive as a result of the sea level dropping. Australia's unique biota is a result of species undergoing adaptive radiation at a time when Australia was geographically isolated.

## Origin of Australia's biota

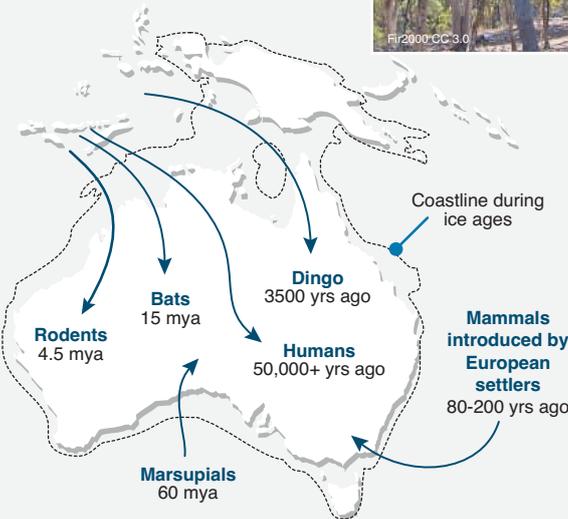
The origin of monotremes (right) is unknown. The only surviving monotremes are indigenous to Australia and New Guinea. The oldest monotreme fossils are dated at 120 mya.



Eucalyptus pollen first appeared in Australia about 34 mya, but the Myrtaceae family to which it belongs was present about 64 mya. Today, eucalypts (left) are a predominant Australian plant.

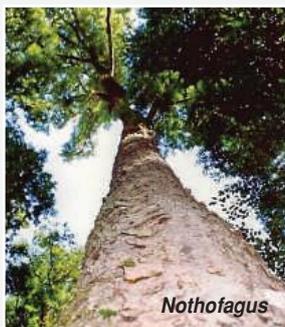


Australia has about 117 species of endemic marsupials (above). Marsupials are also found in New Guinea and South and Central America. Ancestral marsupials probably originated about 60 mya in South America.



The emu (above) evolved from an ancestral Gondwanan ratite population into its current form when Australia was isolated from other land masses.

## Dispersal of some mammalian fauna



The Southern (or Antarctic) beeches (*Nothofagus* species) evolved when Australia was still part of Gondwana. While once widespread through ancient Australia, *Nothofagus* is now limited to the south-east. They are also found in temperate regions of New Zealand, New Guinea, New Caledonia, and southern South America.



Andrew Mercer (www.baldwhiteguy.co.nz) CC 4.0

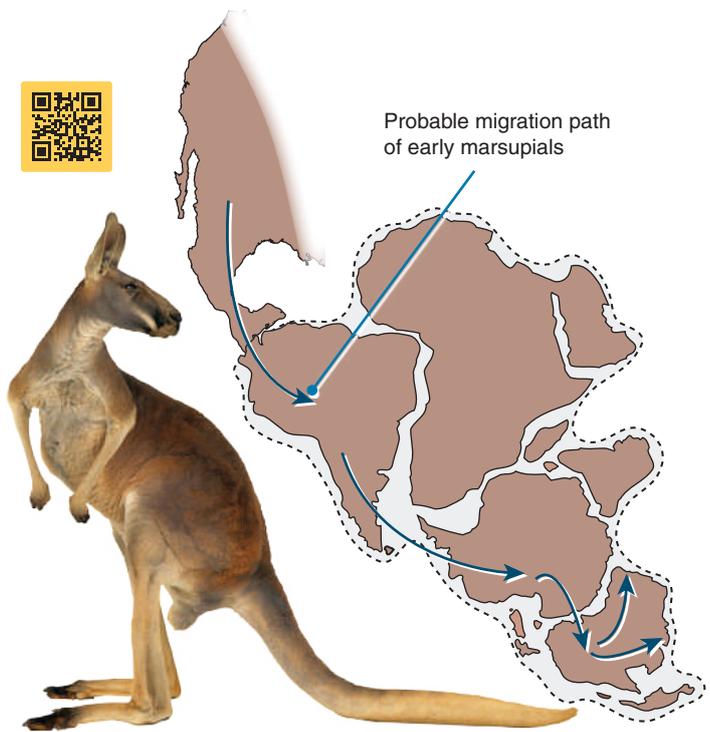
Bats and rodents are relatively recent arrivals to Australia. Most Australian bats (both fruit bats and micro-bats) are related to Asian groups. Their ancestors almost certainly flew to Australia across narrowing marine straits.

1. What role did the landbridge between Australia and Asia have on Australia's biota? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

## Investigating the evolution of Australian animals

### Arrival of the marsupials

- ▶ About 70% of marsupials are found in Australia, the rest are found in South and Central America. One species is found in North America. Australia is about 12,000 km from South America. This is far further than any marsupial could swim or fly (there are no truly flying or marine marsupials anyway!). There are no known land bridges between Australia and South America, indeed the ocean depth between the two continents is an average of at least 3000 m. How then, did the marsupials arrive in Australia?
- ▶ The first true marsupials appeared in North America about 60-80 million years ago. They then spread to South America before Gondwana split from Laurasia. The fossil record shows marsupials were in Antarctica by at least 40 million years ago, although they likely arrived much earlier as fossil evidence shows marsupials reached Australia by 55 million years ago, about the time Australia split from Gondwana. Although there is some evidence to show placental mammals did reach Australia about the same time, for some reason they never dominated and quickly disappeared. Because Australia then drifted away from the rest of the continents, marsupials became the dominant mammalian group.



- Using information from this activity, earlier in this book, internet, and literacy searches complete the timeline of Australia's biological history. Include significant events and evidence, such as fossils and locations. Researching the following fossil locations may be useful: Murgon, Riversleigh, Lightning Ridge, Bluff Downs, and Naracotte.

	Geological period	Significant biological and geological developments	Evidence
Present			
Millions of years ago	Holocene		
0.01			
2			
5.2			
23.2			
35.4			
56.5			
65			
	Cretaceous		
145.6			

**Australian megafauna**

- ▶ **Megafauna** are large animals such as elephants, giraffes, whales, and dinosaurs. Many continents and islands once had their own megafauna, including Australia, but today Africa is the only continent that still has a significant mammalian megafauna. The timing and causes of megafaunal extinctions is the subject of much debate. Some researchers claim that the extinction patterns on each continent or island closely follow the current chronology of human expansion around the world.
- ▶ At the end of the last ice age, Australia’s climate shifted from cold-dry to warm-dry. This resulted in surface water becoming scarce, with most inland lakes becoming completely dry, at least seasonally. Most of the large, predominantly browsing animals lost their habitat and retreated to a narrow band in eastern Australia where there was permanent water and more palatable vegetation. While some of Australia’s megafauna became extinct soon after the assumed arrival date of humans, some 60,000 - 50,000 years ago, at least one, *Diprotodon*, may have survived until about 7000 years ago. If this is so, megafauna may have coexisted with humans for 20,000 to 40,000 years.

Modern common wombat



**Giant wombat**

(*Phascolonus gigas*)  
The giant wombat was the largest wombat of all, about the size of a half-grown cow. Its fossils are reasonably common in Pleistocene deposits in lakes and rivers in central Australia.

Modern eastern grey kangaroo



**Short-faced giant kangaroo**

(*Procoptodon goliath*)  
This was the largest kangaroo ever, and had a shortened flat face and forward looking eyes. It was a very big, heavy animal, thought to have been 2 metres tall, with a short, blunt face, long arms, and a single functional toe on the hindfoot.



**Diprotodontids**

(e.g. *Diprotodon optatum*)  
The diprotodontids were the largest marsupials ever known. They ranged in size from sheep- to cow-sized adults and were probably browsers. They had an extensive geographic range; fossils have been found in New Guinea, New Caledonia, as well as throughout Australia.

**Other strange megafauna**

**Marsupial tapir** (*Palorchestes azeal*)  
Probably a solitary animal the size of a bull, it possessed a short trunk to strip bark from trees and eat roots.

**Marsupial lion** (*Thylacoleo carnifex*)  
This animal was about as heavy as a modern lion (130-260 kg). A particularly fearsome predator, it possessed powerful carnassial teeth used for shearing bones.

**Giant goanna** (*Megalania prisca*)  
Weighing an astounding 620 kg and measuring 7 metres in length, this savage, dragon-like predator could kill and eat very large prey.

**Powerful-toothed giant-rat kangaroo** (*Ekaltadeta ima*)  
While other species in this group weighed up to 60 kg, this 20 kg animal was still a ferocious predator. While its canines were small, it had evolved daggerlike incisors.

**Big bird** (*Dromornis stirtoni*)  
This giant flightless bird was perhaps 3 metres tall and weighed more than 500 kg. Their skeletons suggest they were herbivores.

**Giant constrictor snake** (*Wonambi*)  
The 5-6 metre Wonambi from South Australia (50 000 years ago) was the last surviving madtsoiid snake. It was slow moving and patterned for camouflage.

3. Explain what you understand by the term **megafauna**: \_\_\_\_\_

4. There is debate over the cause of the megafaunal extinctions in Australia (and indeed, elsewhere in the world). Briefly describe the two contrasting hypotheses about how environmental change accounts for their demise:

(a) Cause: \_\_\_\_\_

Evidence: \_\_\_\_\_

\_\_\_\_\_

(b) Cause: \_\_\_\_\_

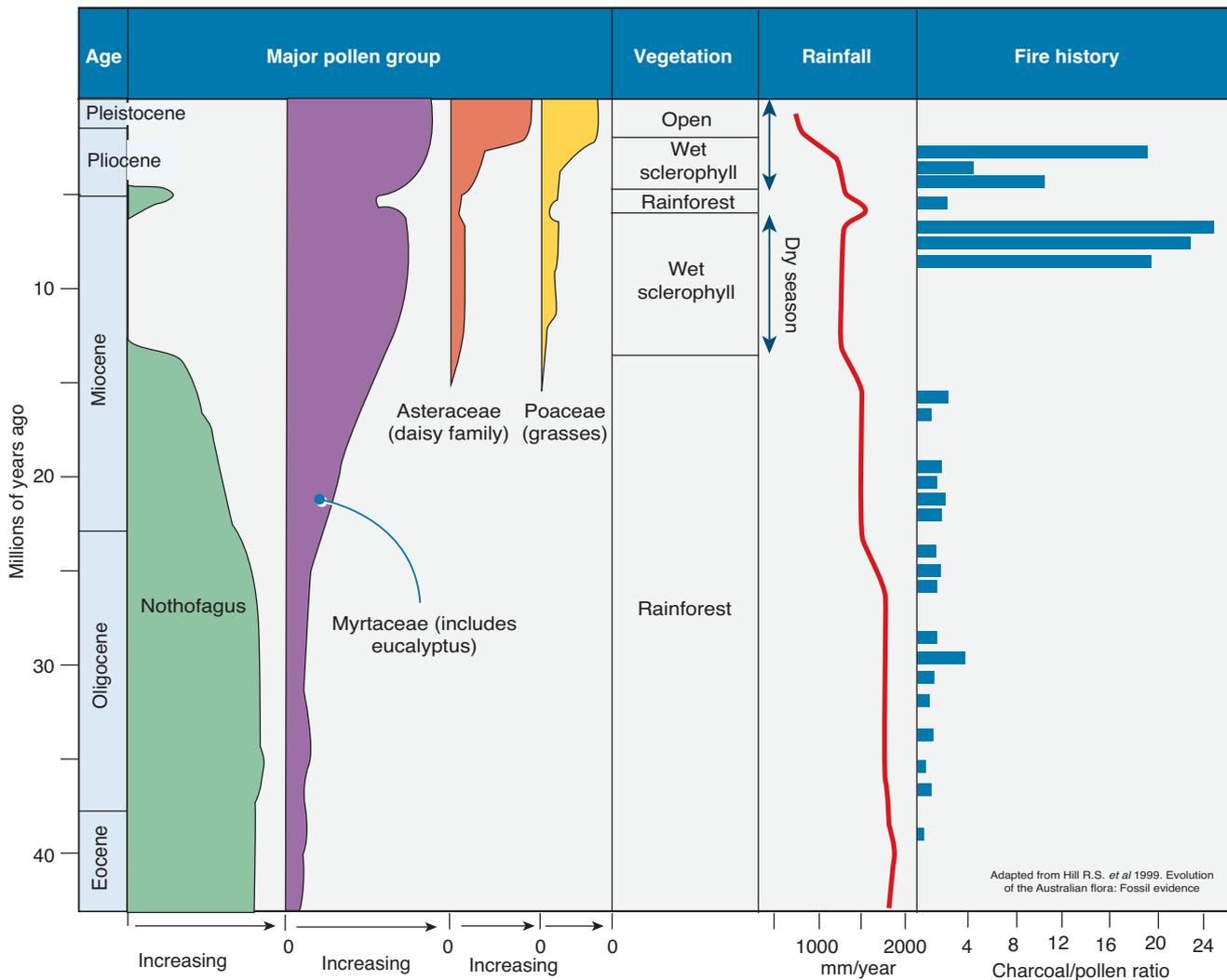
Evidence: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

### Changes in Australian climate and vegetation

- ▶ Australia separated from Gondwana about 60 million years ago and has remained isolated apart from links with New Guinea during the ice ages. Many of Australia’s plant species are unique; some 80% of the flowering plants occur nowhere else in the world. Apart from the tropical and temperate rainforests, two species of flowering plants, the **eucalypts** and the **acacias**, form the dominant flowering plants over much of Australia. A distinctive feature of many Australian flowering plants is the presence of hard and often small leaves. This is thought to be a response to the nutrient-poor, ancient soils. These plants are called **sclerophylls** (‘hard leaf’). With the increase in the incidence of fire, those woody, fire adapted sclerophyll species became more common.
- ▶ The diagrams below show changes in vegetation and fire incidence in New South Wales based on pollen records. Pollen’s extremely durable coat makes it a particularly useful microfossil. Pollen morphology can be easily matched to different species so the presence of different types of pollen in soil cores and sediments indicates the presence of particular types of plants. Carbonised (burnt) particles and pollen in samples indicate the presence of fire.



5. Describe the change in the major plant groups in New South Wales over the last 40 million years and what kind of environment they represent:

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6. Describe the fire history over the last 40 million years. Are there correlations with the change in plant life?

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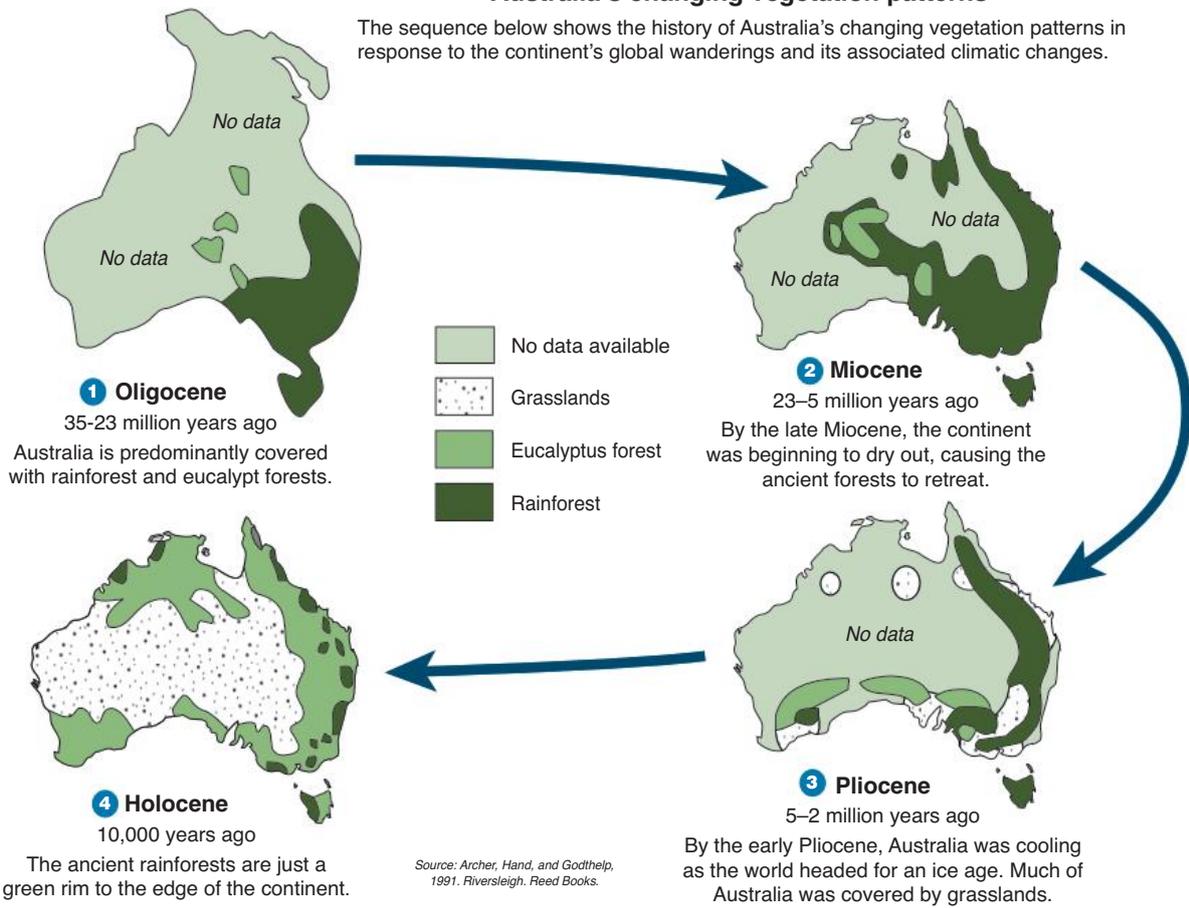
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7. Why might these patterns have occurred?

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### Australia's changing vegetation patterns

The sequence below shows the history of Australia's changing vegetation patterns in response to the continent's global wanderings and its associated climatic changes.



8. Describe the change in rainfall over the last 40 million years: \_\_\_\_\_

9. Why has there been a general decline in rainforest abundance? \_\_\_\_\_

10. The grasslands have gradually expanded their range and become more abundant.

(a) Approximately when did this expansion begin? \_\_\_\_\_

(b) What was the likely cause? \_\_\_\_\_

11. The abundance of fire-tolerant woody sclerophyll forest increased 20-15 million years ago. What physical factor was probably responsible for this increase?

12. Research the globe's climatic zones. How do these help explain Australia's current vegetation? \_\_\_\_\_

# 201 Reasons for Past Environmental Change

**Key Idea:** The environment changes on short and long term time scales. Some changes may have significant effect on the evolution of life.

The environment is not static. Change is continual. Some changes, such as tides and seasons are short term, predictable, and cyclical. However, long term, large scale changes tend to be least predicable and although slow, produce significant change over time. These may occur through the movement of

continents, changes in the planet's orbit or rotation, variation in the energy output from the Sun, or even changes in the type of life on Earth. These large scale changes affect life on Earth, and often the direction of the evolution of life on Earth has been forever changed by such an event. Examples include the Great Oxidation Event, the extinction of the dinosaurs triggered by the Chicxulub impactor, or the drying of Africa, which may have played a significant role in human evolution.

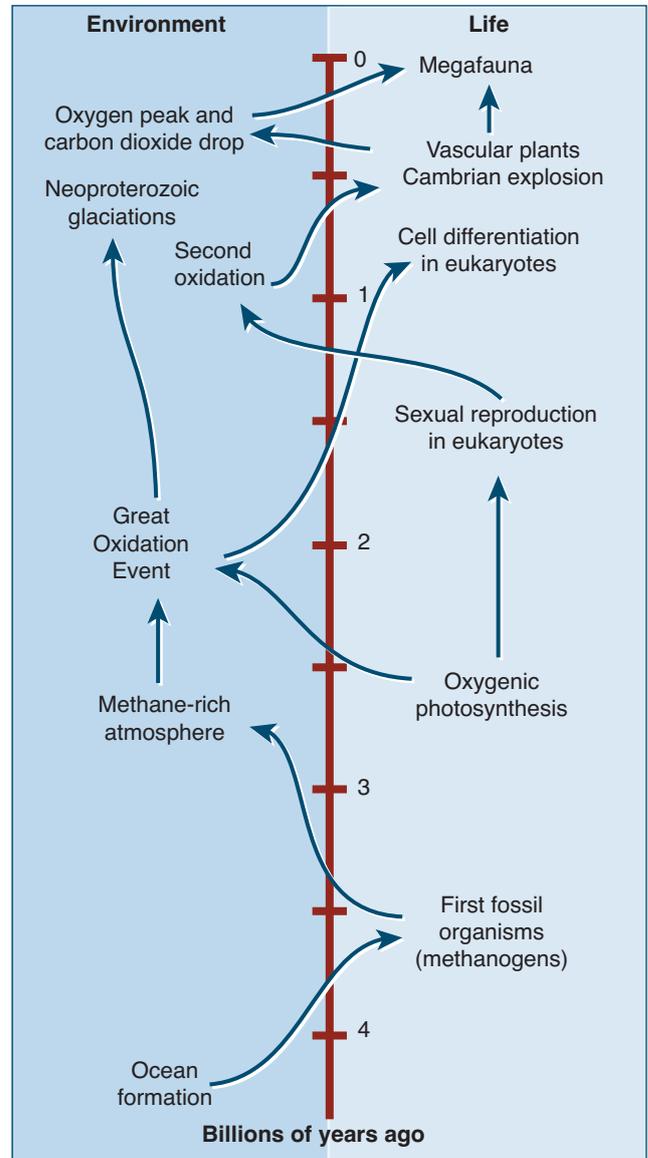
- ▶ Life began on Earth about 3.8 billion years ago. Life takes resources from its surroundings, modifies them, and then uses them to replicate itself. In doing this, life modifies the environment, either by modifying chemicals and structures in the environment directly or by adding chemicals from waste or through decay after death.
- ▶ The modification of the environment produces new conditions for the evolution of life and as life evolves so does the environment, forcing more change upon life.
- ▶ This reciprocal influence is termed **coevolution** and it can be observed between the biosphere and Earth's other systems. For example, Earth's current atmosphere is the result of activity by early photosynthetic organisms, which produced oxygen as a waste product of oxygenic photosynthesis. The presence of oxygen caused the extinction of many anaerobic bacteria but eventually led to the rise of multicellular life forms.
- ▶ The diagram (right) illustrates key stages of the coevolution of life and Earth's other systems showing how changes in one influenced changes in the other.



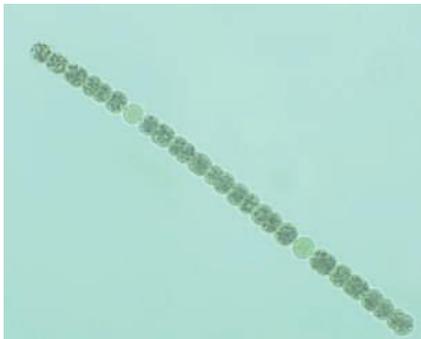
KF

Mangroves have evolved to inhabit estuarine environments. They modify the estuary by collecting sediment and thus the environment evolves from primarily marine to primarily terrestrial.

- ▶ The rise of free oxygen in the atmosphere had a profound effect on life. A 2009 study led by paleobiologist Jonathan L. Payne found that there were correlations between the evolution of eukaryotes and multicellular life, increase in body size, and the rise of oxygen in the atmosphere. The body size of organisms increased in two sharp jumps: at the evolution of eukaryotes and the evolution of multicellular organisms. Both these events correlate with sharp increases in the amount of available oxygen.



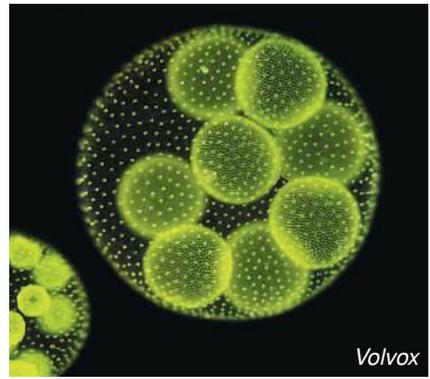
1. What is coevolution? \_\_\_\_\_
2. Describe the effect of mangroves on estuaries: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
3. Climate change is expected to raise sea levels. How might this affect the mangrove/estuary relationship?  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



BH

Anabaena, a cyanobacterium

▶ Multicellularity (being made of many cells) has evolved independently in eukaryotes at least 46 times and also in some prokaryotes such as cyanobacteria (left). One hypothesis for its origin is that it was a result of unicellular organisms failing to separate after dividing. Some cells can then take on different tasks, e.g. nitrogen fixation or reproduction, to the benefit of the colony as a whole. This mechanism has been observed in modern prokaryotes, such as the filamentous cyanobacteria, and in 16 different protistan phyla (e.g. Volvox, right), providing support for the hypothesis.



Volvox



Herpin

Very high oxygen levels during the Carboniferous allowed invertebrates, including giant dragonflies and millipedes, to easily obtain the oxygen they needed to support a very large size.



The impact of a giant asteroid 65 mya produced a nuclear winter that marked the Cretaceous-Paleogene extinction event that ended the age of the dinosaurs. In their place, mammals diversified.



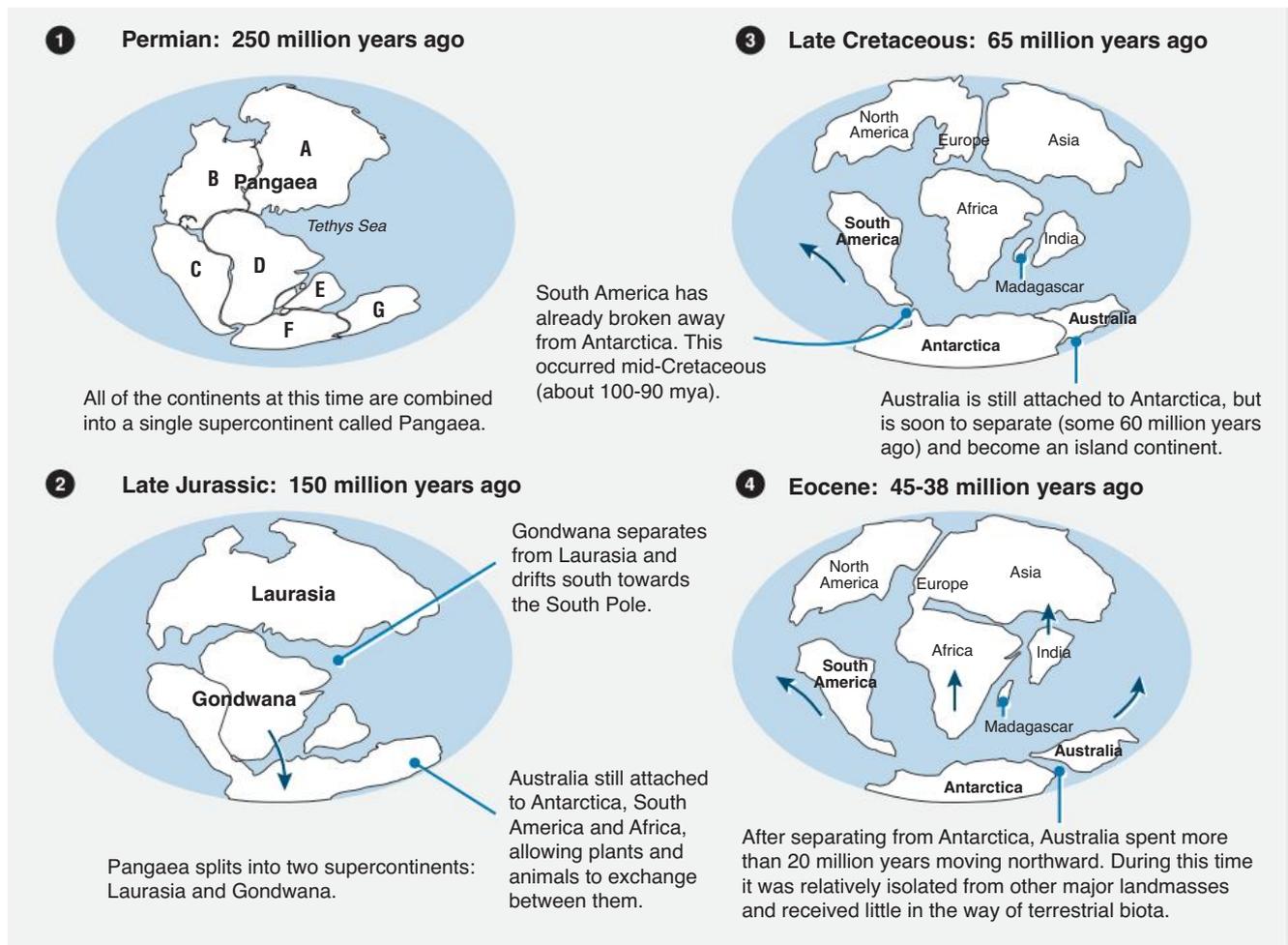
Australia's separation from Gondwana around 60 million years ago isolated the animal population there. Marsupials became the dominant mammals. Reptiles also became an important part of the biota.

4. Using the evidence in this and earlier activities, including photosynthesis and respiration, and your own research, present a discussion on the coevolution of the environment and living systems on Earth.

Lined area for student response.

### The effect of continental drift on Australia

- ▶ Continental drift has had an important effect on the geology and biodiversity of Australia. Australia began its existence as part of the super-continent Gondwana. Over a billion years ago the rocks forming the western half of Australia were forced together. During its existence Australia has drifted between the tropics and the polar regions. 470 million years ago, Australia was situated on the equator. 280 million years ago it was situated near the South Pole.
- ▶ Gondwana began to break up during the Cretaceous period 145-65 million years ago (mya), but Australia remained attached to Antarctica until about 60 mya. It then began to drift north, leaving Antarctica. Australia remained isolated for more than 20 million years.
- ▶ Although it continues to drift north at the rate of 6 cm per year, it still has no direct connection with Asia and only in the last 15 million years has it been close enough to Asia to allow a major exchange of organisms. It is not surprising then that much of Australia's characteristic biota is Gondwanan in origin (e.g. marsupials, ratites, eucalypts, acacia, and *Protea*).



5. Identify the continental landmasses labelled A to G in the diagram above (top, left: Permian, 250 mya):
  - A. \_\_\_\_\_ B. \_\_\_\_\_ C. \_\_\_\_\_ D. \_\_\_\_\_
  - E. \_\_\_\_\_ F. \_\_\_\_\_ G. \_\_\_\_\_
6. What has been the role of continental drift in shaping Australia's biota? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
7. When did the following continents separate from each other (period, or years if known)?
  - (a) South America from Antarctica: \_\_\_\_\_
  - (b) Australia from Antarctica: \_\_\_\_\_
8. Gondwana contained the ancestral populations of much of Australia's modern biota.
  - (a) Name an example of an Australian plant group that has a Gondwanan origin: \_\_\_\_\_
  - (b) Name an example of an Australian animal group that has a Gondwanan origin: \_\_\_\_\_

**Human effects on Australia**

- ▶ Aboriginal Australians arrived in Australia around 60,000 years ago. One of the most debated questions of this original human settlement in Australia is the effect it had on the Australian flora and fauna. The extent to which hunting and deliberately set fires had on wildlife is a key part of this debate.
- ▶ Evidence from modern hunting of feral cattle and other large animals in the Australian bush shows that even with modern technology (e.g. helicopters and rifles) exterminating large wild animals is extremely difficult. Some researchers therefore believe that events such as the extinction of the Australian megafauna can not have been caused by human hunting, especially when populations reached very low density. Habitat modification by use of fire has therefore been suggested as at least part of the reason for the decline of the megafauna.
- ▶ However, a study by S.D. Mooney *et al* in 2010, using 223 sediment sites around the country, found that the incidence of fires in Australia over the last 70,000 years followed climatic records and there is no distinct change in the fire regime after the arrival of humans.
- ▶ Supporting this, a study by R. B. Bird *et al* in 2008 showed that although fire-stick farming was (and still is) used as a tool for shaping plant communities (and so the animals that feed on them) human populations in Australia would not have been large enough for widespread change. Additionally they found that although landscapes generated by firestick farming (deliberately setting fire to specific area of bush) differ from natural ones in scale, they did not differ in kind. This supports the idea that human generated fire was protective of diversity.
- ▶ Firestick farming ensured that the grass, trees, and scrub grew in a balance that encouraged the kinds of plants and animals humans found useful to flourish. It also made predicting the locations of these plants and animals simpler and reduced the incidence of wildfires. Today, controlled burns are still used to remove undergrowth and prevent major wildfires.
- ▶ The arrival of Europeans caused more changes to the environment including clearing land for agriculture, mining large tracts of lands and introducing new species such as rabbits, foxes, cats, and cane toads. These large scale changes have caused significant declines in many native flora and fauna.



Fire control Northern Queensland



Patchwork of fields captured by satellite, SA.

NASA

9. Using information in this and earlier activities, as well as your own research describe the abiotic and biotic changes in Australia since it split from Gondwana:

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10. Evaluate the following hypothesis using information in this and earlier activities, as well as your own research:

(a) Human activity is responsible for the characteristic Australian flora and fauna: \_\_\_\_\_

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(b) Bush fires should be put out as soon as possible: \_\_\_\_\_

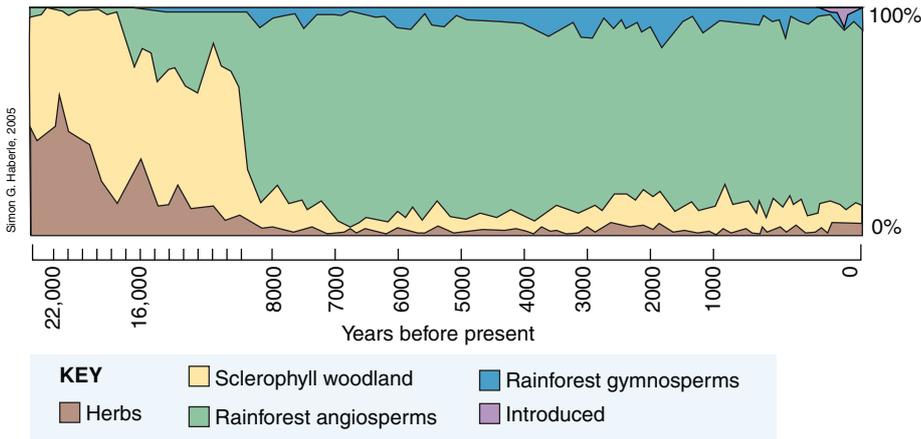
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# 202 Chapter Review: Did You Get It?

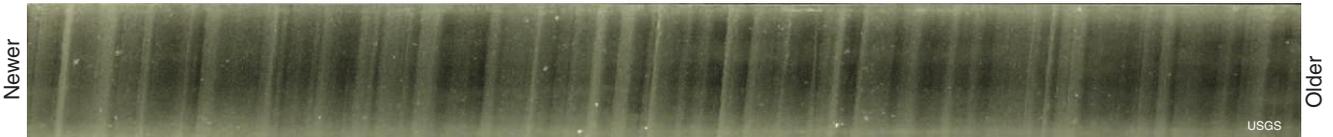
1. The diagram below shows the pollen records for lake Euramoo in Northern Queensland:



Lake Euramoo, Tablelands, north Qld

Describe how the ecosystem has changed over the last 22,000 years: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. The photograph below shows a section of a Greenland ice core. The section formed around 16,260 years ago. Approximately 38 years is represented in this ice core.



(a) What do the dark/light bands in the ice core represent? \_\_\_\_\_  
 (b) What caused these alternating bands? \_\_\_\_\_  
 \_\_\_\_\_  
 (c) Why are the bands of different thickness? What information might we gain from this? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. Test your vocabulary by matching each term to its correct definition, as identified by its preceding letter code.

- biota .....
- Great Oxygenation Event .....
- isotope .....
- megafauna .....
- strata .....
- stromatolite .....

- A** The large or giant animals of a particular habitat, region, or time. In Australia these are represented by large extinct marsupials.
- B** A series of layers of rock laid down over time.
- C** One of two or more forms of a chemical element that have the same atomic number (number of protons) but different atomic masses (protons + neutrons).
- D** Period of time in which the Earth's atmosphere and oceans experienced a rise in the amount of free molecular oxygen (O<sub>2</sub>) produce by cyanobacteria.
- E** Layered sedimentary formations created by trapping and binding sedimentary grains in biofilms created by cyanobacteria.
- F** The flora and fauna of a given habitat, region, or time.

# Future Ecosystems

Activity  
number

## Key terms

background extinction rate  
biological control  
conservation tillage  
extinct  
habitat fragmentation  
habitat loss  
introduced species  
mine rehabilitation  
salinisation  
soil degradation

*Inquiry question: How can human activity impact on an ecosystem?*

## Investigating future ecosystem changes

### Key skills and knowledge

- 1 Investigate reasons for the decline or extinction of Australian native species, including habitat loss and introduced species. **203**
- 2 Identify future pressures on native species that may cause their further decline or extinction, including increased incidence of bush fires, and climate change. **203**
- 3 Use models and data from past ecosystems to predict future impacts on Australian and global biodiversity. **204**



USDA

## Restoring ecosystems

### Key skills and knowledge

- 4 Identify best practice preparing and rehabilitating a mine. Investigate mine rehabilitation in New South Wales. **205**
- 5 Describe some negative effects of agriculture on ecosystems. Identify methods for more sustainable agriculture including conservation tillage and biological control. **205**
- 6 Identify reasons for soil loss in Australian agricultural systems. Describe methods that can reduce soil loss. **205**

# 203 The Role of Humans on the Future of Species

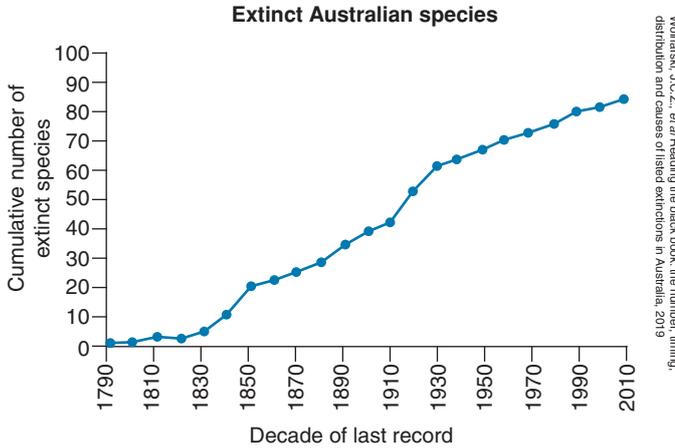
**Key Idea:** How has human activity affected the selection pressures facing plant and animal populations?

Human activities have had major effects on the Earth's plant and animal populations. Habitat loss, through clearing of land for farming or logging, has caused a decline in many plant

and animal populations. Rising global temperatures threaten the habitats of polar and alpine plants and animals and have prolonged fire seasons. Overuse of natural resources, (e.g. overfishing) not only removes the targeted species but affects wild species, such as sea birds that feed on those species.

## The effect of humans on Australia's native animal population

- ▶ The extent to which humans affected native populations of animals before Europeans arrived in Australia is difficult to know precisely. When Europeans arrived in Australia they made efforts to catalogue and classify the animal species they found.
- ▶ As a result it is possible to say with reasonable certainty the effect European settlement has had on Australia's native animal species. The graph below shows the cumulative number of extinct species since 1788.



Woinarski, J.C.Z. et al. *Heading the black book: the number, timing, distribution and causes of listed extinctions in Australia*, 2019



The last recorded sighting of the pig footed bandicoot (*Chaeropus*) was in the 1950s.

## Habitat loss

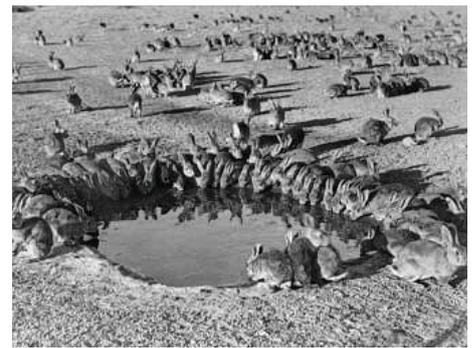
- ▶ Habitat loss and habitat fragmentation are important pressures facing native fauna. A reduction in habitat size, e.g. an area of forest, results in a reduction in the amount of wildlife it can support. As food sources or nesting sites dwindle, members of a population may leave the area, die, or fail to reproduce, reducing the breeding population. The reduced populations may suffer from inbreeding which will further reduce their viability. Habitat loss and fragmentation occurs when land is modified for human needs, such as agriculture or mining.

## Introduced species

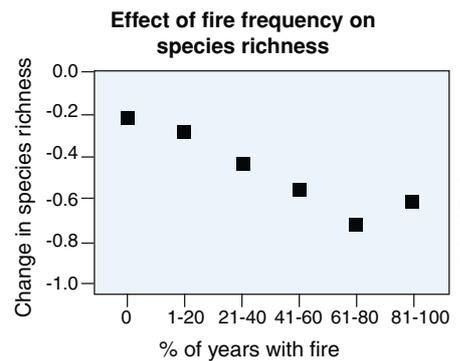
- ▶ Introduced species put pressure on native species via competition or predation. Often the introduced species has no natural predators and so can out-compete native animals, or it places a much greater predation or browse pressure on the animal or plant than occurs naturally. For example, introduced rabbits put pressure on an ecosystem by overgrazing native plants, especially grasses. This leaves less for native grazers and so can cause their decline.
- ▶ Another examples is feral cats. Cats are particularly adept hunters and will hunt native birds, lizards, and small mammals. It is estimated that feral cats kill 1.4 billion native Australian animals a year.

## Bush fires

- ▶ While Australia's forests and wildlife are adapted to deal with frequent bush fires, the severity and frequency of fires has increased in recent decades as the Earth's climate has warmed. Animals normally take refuge during fires in tree hollows, burrows, or escape to areas that are not affected. However, as fires become more severe and hotter these refuges no longer provide protection. As larger areas burn, animals such as kangaroos and wallabies are unable to escape to unaffected areas.



Rabbit plague, Wardang Island, 1938



Into Oblivion? The disappearing native mammals of northern Australia

1. How many Australian species have become extinct since 1788? \_\_\_\_\_
2. The table right shows the number of species from each taxonomic group that have become extinct in Australia since 1788:
  - (a) Which group has seen the most extinctions? \_\_\_\_\_
  - (b) How many mammals have become extinct? \_\_\_\_\_
  - (c) What percentage of total extinctions do the groups in (a) and (b) make up? \_\_\_\_\_

Taxonomic group	Total
Protists	1
Plants	38
Invertebrates	10
Fish	1
Frogs	4
Reptiles	3
Birds	9
Mammals	34
<b>Total</b>	<b>100</b>

Woinarski, J.C.Z. et al. 2019



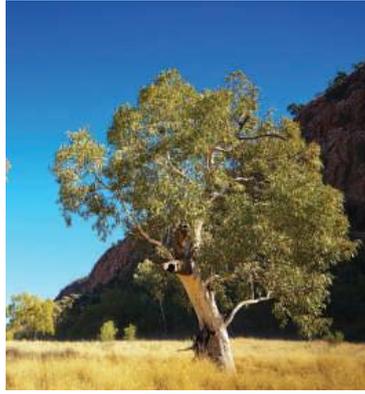
**Climate change**

▶ Since the Industrial Revolution (around the 1800s), the use of fossil fuels such as coal and oil has added large volumes of carbon dioxide to the atmosphere. The carbon dioxide traps heat in the atmosphere and so global surface temperatures have risen about 1°C on average since pre-industrial times. The rise in temperature is beginning to affect many animal and plant populations.



Photo: Bruce Marcot

Green ring-tail possums (*Pseudocheirus archeri*) in Queensland suffer dehydration if the ambient temperature rises above 30°C for 5 hours a day for 4 consecutive days. A large number died during a heat wave in 2002. Climate change could severely limit their habitat range.



Around 25% of eucalypts have a low tolerance to temperature change, with a less than 1°C difference in the mean annual temperature throughout their entire habitat range. If trends in global warming continue, this could lead to a reduction in many eucalypt tree populations.



Linda Broome

As global temperatures rise alpine habitats will be reduced in size. As temperatures increase, the snow line rises in altitude, reducing the range available to alpine species. In the Australian Alps the mountain pygmy possum faces reduction in its already tiny habitat range as the snow line rises. Early spring warming also puts it in danger of starvation, as it wakes from hibernation before its food supply, the bogong moth arrives.

3. Explain why each of the pressures identified below could drive Australian species to extinction:

(a) Habitat loss: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Introduced species: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Bush fires: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(d) Climate change: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. Research selection pressures facing Australian plants and animals. Identify any pressures that have not been discussed in this activity:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

# 204 Predicting Future Biodiversity

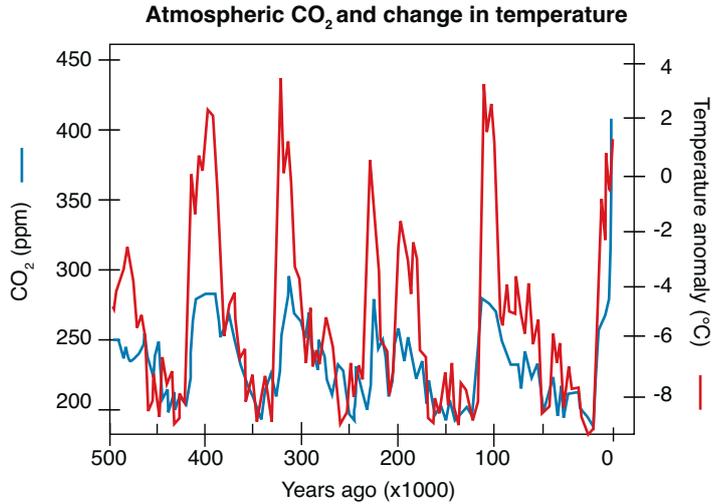
**Key Idea:** Evidence from the past can help inform us what the future might look like.

To predict what the Earth's biodiversity might be like in the future we can use data from the past, including ice core data

and changes in the fossil record. From this data it is possible to build computer models, construct equations, or plot graphs that can be used to predict future outcomes.

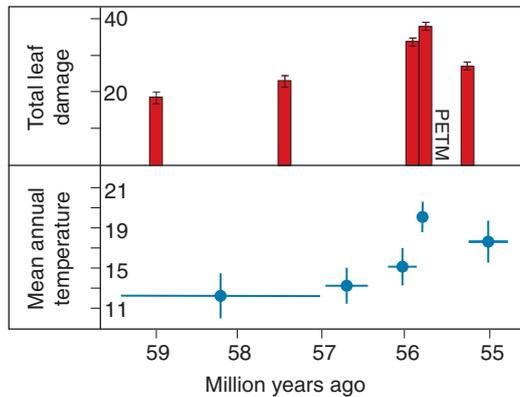
## Ice core data

- ▶ Recall that gases e.g. CO<sub>2</sub>, can be extracted from ice cores and that changes in their concentration over time can be investigated. Recall also that oxygen isotopes can be used to determine how temperature has changed over time. It is therefore possible to compare both changes in temperature and changes to atmospheric gases over time and determine if any patterns are present.
- ▶ Carbon dioxide traps heat in the atmosphere. By plotting carbon dioxide and temperature changes over time it is possible to see if there is a correlation between CO<sub>2</sub> concentration and temperature (right).
- ▶ Using data such as pollen records, past changes in temperature and climate can be matched to changes in past biodiversity. Computer models based on this data can be used to predict future temperature changes due to increases in CO<sub>2</sub>, and their effects on biodiversity.



## Using fossil data

- ▶ Fossil data can provide information about changes to past ecosystems. Combined with present data it is possible to predict changes that may occur to ecosystems in the future.
- ▶ At Lake Burrinjuck, New South Wales, and Windjana Gorge in Western Australia, 400 million year old fossil tropical reefs show they were centres of marine biodiversity. We can still see this today in tropical reefs around the world, so it is possible to say that tropical reefs have probably always been centres of biodiversity. Tropical reefs are currently in danger of being lost due to rising sea temperature and episodes of coral bleaching are becoming more frequent. It can therefore be predicted that if current trends in sea temperature continue there will be a dramatic drop in marine biodiversity.
- ▶ The fossil record shows that global temperatures rose sharply around 56 million years ago. Studies of fossil leaves with insect browse damage indicate that leaf damage peaked at the same time. This gives some historical evidence that insect abundance may be linked with temperature changes.



1. Is there a relationship between CO<sub>2</sub> concentration and the temperature? Is so, describe this relationship:

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2. How can fossil data help us predict changes in future ecosystems?

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3. Describe the use of ice cores in predicting future climates:

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### Estimating extinction rates

- ▶ Estimates of the rate of species loss can be made by using the **background extinction rate** as a reference. It is estimated that one species per million species per year becomes extinct. By totalling the number of extinctions known or suspected over a time period, we can compare the current rate of loss to the background extinction rate.
- ▶ Reptiles provide on a good example. There are about 10,000 living or recently extinct species of reptile. In the last 500 years an estimated 32 are known to have become extinct. From the background extinction rate we would expect one species to become extinct every 100 years ( $10,000/1,000,000 = 0.01$  extinctions per year = 1 extinction per 100 years). It then becomes apparent that  $32/500 = 0.064$  extinctions per year or 6.4 extinctions per century, 6.4 times greater than the background rate. The same can be calculated for most other groups of animals and plants.

Organism*	Total number of species (approx)*	Known extinctions (since ~1500)*	Known extinctions (since 1900)*
Mammals	5487	85	35
Birds	9975	159	57
Reptiles	10,000	32	8
Amphibians	6700	37	32
Plants	300,000	122	NA

https://www.iucnredlist.org/statistics

\*These numbers vastly underestimate the true numbers because so many species are undescribed.

4. Use the data in the table to calculate (1) the **rate of species extinction per century** since 1500 for each of the groups below and (2) how many times greater this is than the background extinction rate. Repeat the calculations for the rate of extinction since 1900.

(a) Mammals: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) Birds: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(c) Amphibians: \_\_\_\_\_

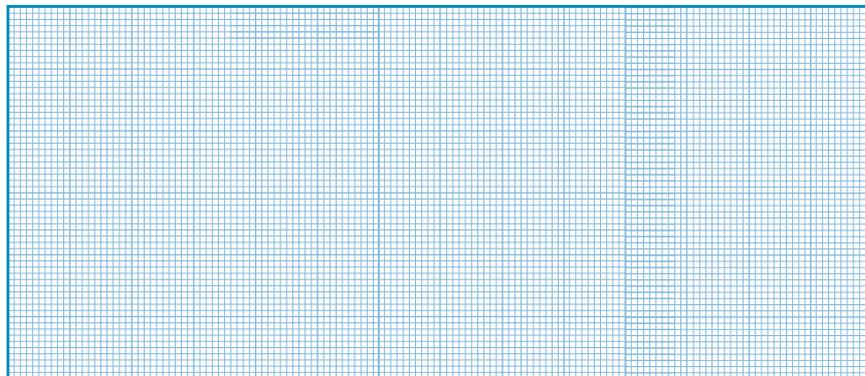
\_\_\_\_\_

\_\_\_\_\_

(d) Plants: \_\_\_\_\_

\_\_\_\_\_

5. (a) Plot a column graph how showing many times greater the extinction rate is for the four vertebrate groups compared to the background rate, for both 1500 and 1900:



(b) Are extinction rates increasing or decreasing? \_\_\_\_\_

(c) If extinctions continue at the rate you calculated from between 1900 to present day what can be predicted about biodiversity in a further 100 years?

\_\_\_\_\_

# 205 Restoring Damaged Ecosystems

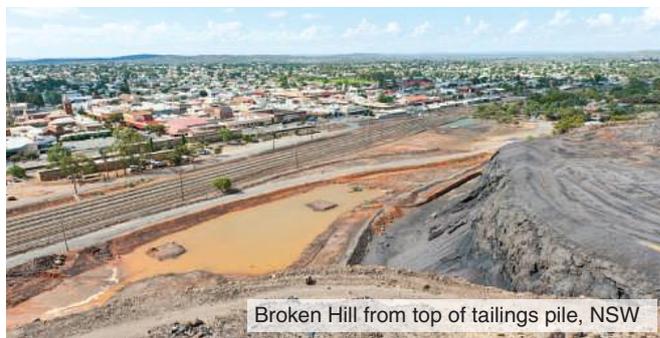
**Key Idea:** Careful management of resource extraction can reduce damage to the environment and make environmental restoration easier.

Land is often developed for various purposes such as mining or agriculture. This, of course, destroys the ecosystem that was originally present. In the case of agriculture the original ecosystem is replaced with a new one that is sustained by

the input of energy in the form of fertilisers, sprays, and mechanical means. Mining removes the ecosystem entirely in order to extract minerals from underground. However, it is possible, with careful management, that when the mining is completed the ecosystem can at least partially be restored. In both cases careful management of the land is needed to reduce the effect on the wider ecosystem.

## Mining in Australia

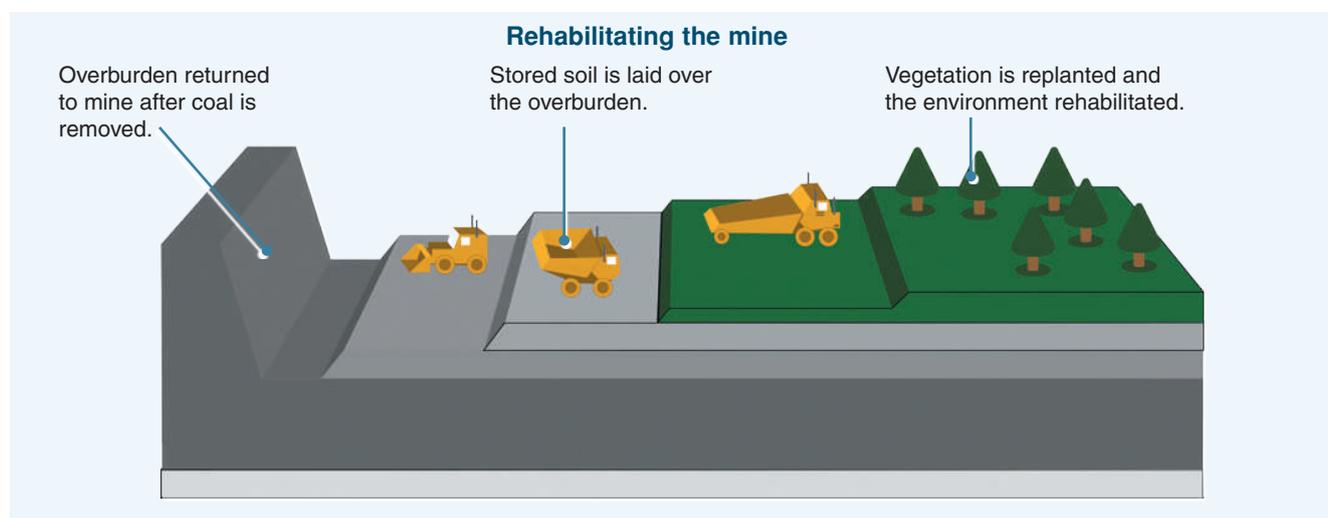
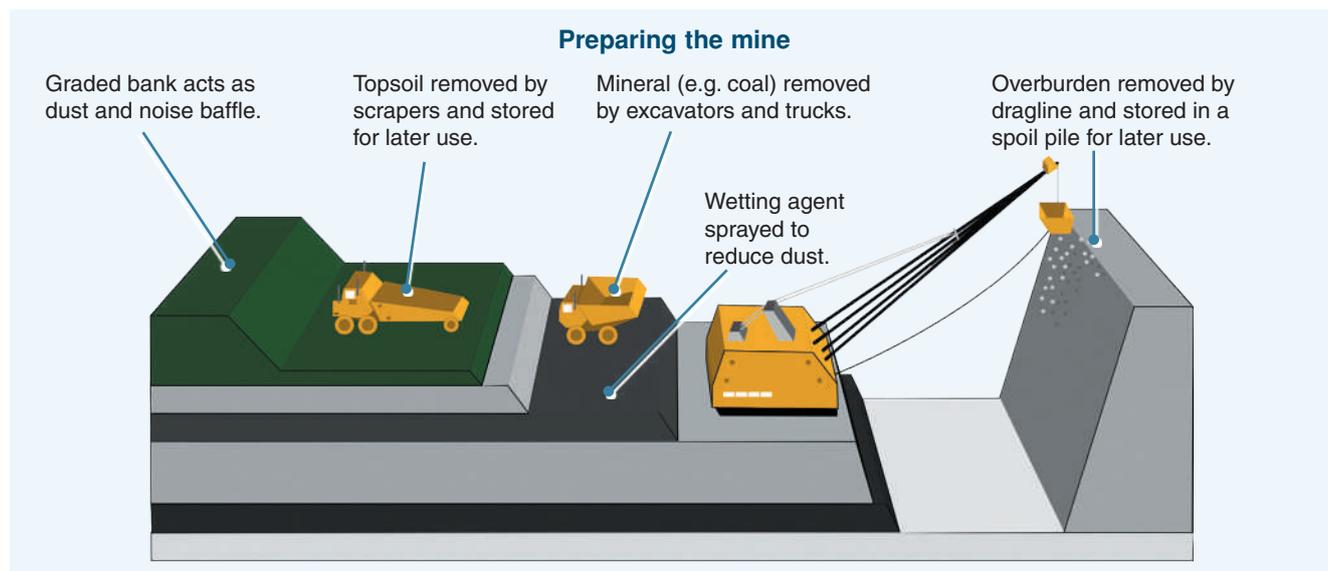
- ▶ There are over 350 mines operating in Australia. About one third of these are in Western Australia and one fifth in New South Wales. Iron and coal are the largest extraction industries, with coal being extracted mainly in Queensland and New South Wales. The majority of coal mines are open-cut mines.
- ▶ Careful planning and management needs to be carried out before and during mining to reduce the effects on the environment. Exposed tailings piles (waste rock) can leach various chemicals into waterways and soil if not placed correctly.



Jeremy Buckingham CC 2.0

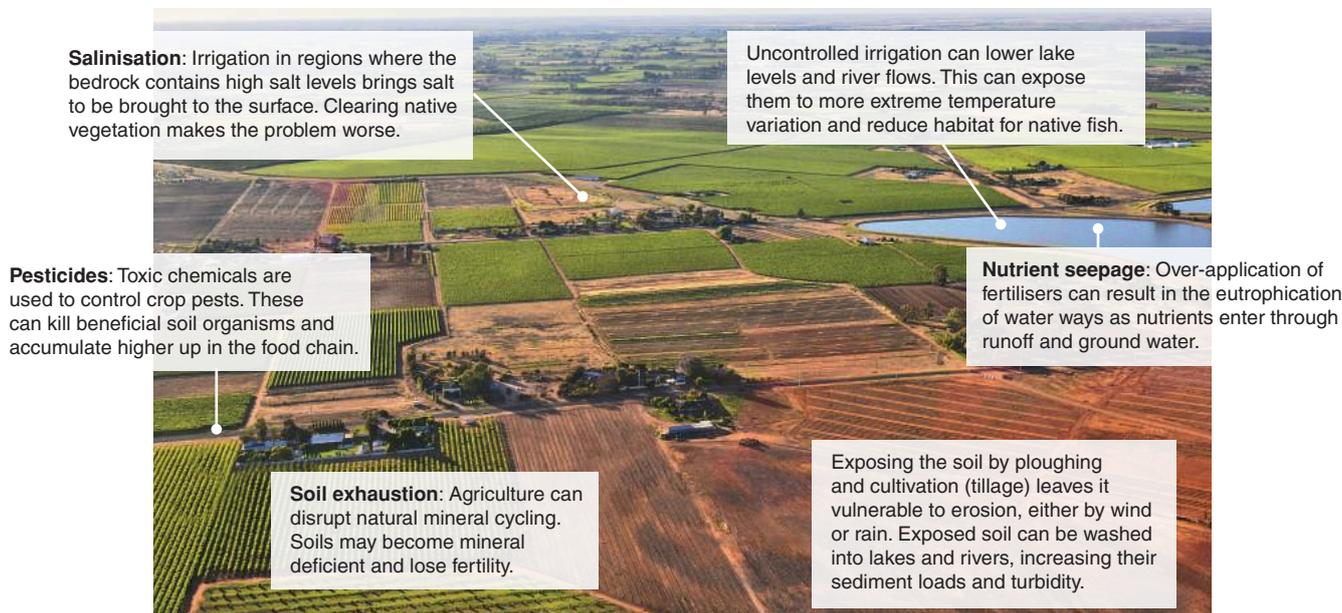
## Mineral extraction and mine rehabilitation

- ▶ When plans are put in place to open a mine, best practice dictates that economic, environmental, social, and even political costs and benefits are considered.
- ▶ It is preferable (and appropriate) that a mine's operators allocate some of the mine's revenue to pay for repairing environmental damage and restoring the original environment (if possible) when the mine closes. Large mines can cost tens to hundreds of millions of dollars to close and rehabilitate.



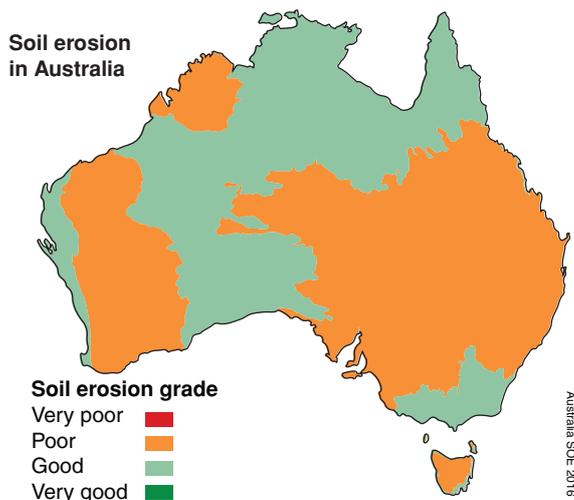
## Impacts of agriculture

- ▶ Intensive farming techniques are based on high-yielding hybrid cultivars and large inputs of inorganic fertilisers, chemical pesticides, and farm machinery. Intensive systems increased crop yields to up to four times those produced using the lower input methods before the 1960s.
- ▶ Large areas planted in monocultures (single crops) are typical. Irrigation and fertiliser programs are often extensive to allow for the planting of several crops per season. Given adequate irrigation and continued fertiliser inputs, yields from intensive farming are high. However intensive farming can damage the surrounding ecosystems by leaching chemicals, e.g. nitrates, into water ways, increasing pesticide resistance, and lowering river levels by drawing water for irrigation.



## Conserving soil

- ▶ Across Australia soil formation ranges from about 10mm per thousand years to 75mm per thousand years. This is much lower than the estimated global average. Across Australia soil loss is generally greater than its production. However, over the last twenty to thirty years soil loss has been reducing as more sustainable practices become more common.
- ▶ Changing the way soil is tilled (cultivated by machinery) can significantly reduce soil loss. In a no-tillage system the vegetation remaining after harvest is mowed, rolled, or sprayed to begin its breakdown. Seeds are planted into the ground with seed drills. Residue from the previous harvest helps to reduce loss of water and soil, and prevents weeds becoming established.
- ▶ Conservation tillage reduces disturbance and retains crop residues. Up to 50% of the crop residue is ploughed and buried but the soil is not inverted. Seed is planted into the soil beneath the residue. Conservation tillage reduces overall fuel use and labour costs, and increases carbon storage in the soil.



## Reducing the wider effects of agriculture



Integrated pest management is an approach to pest control that uses a combination of chemical, biological, and mechanical controls. Well designed IPM programs can reduce costs and pesticide use by 50-90%, reduce fertiliser use, and slow the development of pesticide resistance.



Biodiversity in agriculture is important for soil, plant, and animal health. Using many different agricultural crops (rotation) or grasses in a paddock decreases the risks of pests and diseases spreading in the soil and affecting crop yield. It also reduces the need for pesticides.



Windbreaks reduce soil erosion by reducing wind speed close to the ground. They also reduce water loss, and so lower irrigation demands. Windbreaks placed near drainage ditches help to reduce erosion because the tree roots stabilise soil at the edge of the ditch.

1. (a) Describe how the environmental effects of mining can be reduced while the mining continues:

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- (b) Describe how a mine can be rehabilitated after the mining has finished: \_\_\_\_\_

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2. (a) Describe the main difference between no-till and tillage farming methods: \_\_\_\_\_

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- (b) Why would no-till or conservation tillage reduce soil loss compared to an intensive tillage regime where soil is turned over and left exposed? When might each of these methods be advantageous?

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3. How does integrated pest management help reduce the wider ecological impacts of agriculture? \_\_\_\_\_

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4. (a) Explain how maintaining vegetative cover reduces soil erosion: \_\_\_\_\_

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- (b) Explain how windbreaks reduce soil erosion: \_\_\_\_\_

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5. Use an internet or literature search into a mining site in NSW. Identify the type of mine (e.g. open cut), what is mined there, details such as size, volume extracted etc, and what kind of rehabilitation plan there is for the mine. The links on [BIOZONE's Resource Hub](#), will help you get started.

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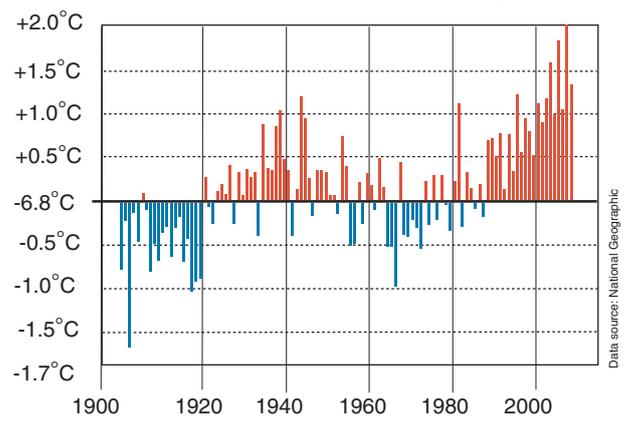
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# 206 Chapter Review: Did You Get It?

1. The graph on the right shows the annual Arctic air temperature deviation from the 1960-2000 average.

Arctic air temperature changes



(a) What is the temperature trend over the last 100 years?

\_\_\_\_\_

\_\_\_\_\_

(b) What is the likely cause of this trend?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. (a) One hundred known species have become extinct in Australia since 1788. The total global number of known species to have become extinct is 902. What percentage of extinct species come from Australia alone?

\_\_\_\_\_

(b) Globally, 85 mammal species have become extinct. In Australia, 34 mammal species have become extinct. What percentage of extinct mammal species is made up by Australian mammal species?

\_\_\_\_\_

(c) Identify some factors that may have caused these Australian extinctions: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

3. How can studying past changes in climate (e.g. through ice core analysis) help us predict future climate changes?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. The table on the right shows the average annual soil loss (in tonnes per hectare) and the percentage of rainwater run off for various crops.

Cropping system	Average annual soil loss (t/ha)	Percent rain runoff
Bare soil	41.0	30
Continuous corn	19.7	29
Continuous wheat	10.1	23
Rotation: corn, wheat, clover	2.7	14
Continuous grass	0.3	12

(a) Which crop produce the least soil loss and runoff?

\_\_\_\_\_

(b) Explain why this is so: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

5. Define the following in your own words:

(a) Extinct: \_\_\_\_\_

\_\_\_\_\_

(b) Mine rehabilitation: \_\_\_\_\_

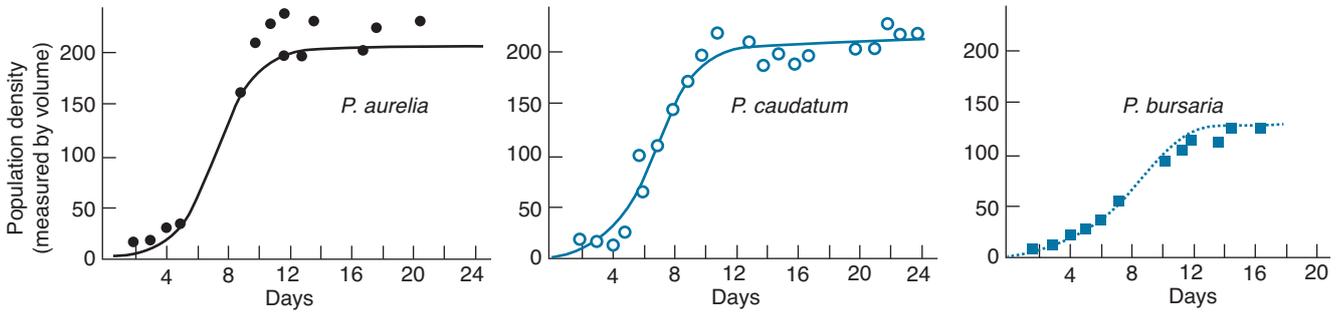
\_\_\_\_\_

(c) Conservation tillage: \_\_\_\_\_

\_\_\_\_\_

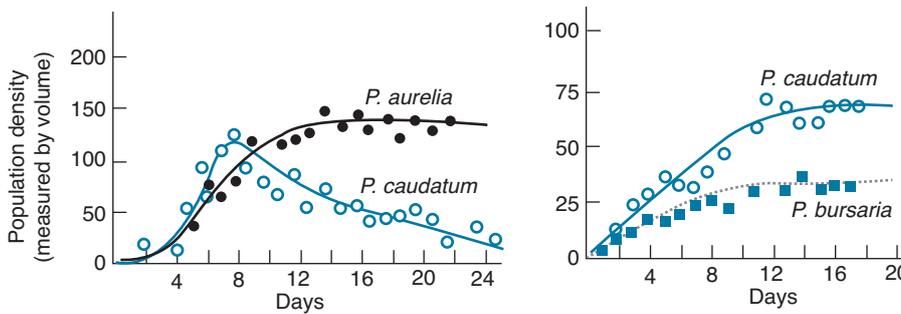
1. In 1934, Georgii Gause, a Russian biologist, carried out a series of experiments on *Paramecium*. The results led him to propose the **competitive exclusion principle**, a fundamental idea in ecology. In the first stage of the experiments, he grew three species of *Paramecium* in isolation in a nutritive medium containing their essential resource (bacterial food). Their growth curves are shown below:

**Paramecium grown in isolation**



In the second stage of the experiment, Gause grew *P. aurelia* and *P. caudatum* together. He found that *P. caudatum* was always out-competed and became extinct from the culture. Gause then grew *P. caudatum* with *P. bursaria*. He found they were able to exist together (but at lower numbers). Investigation found that *P. caudatum* occupied the oxygen rich top half of the culture tube, whereas *P. bursaria* retreated to the lower, poorly oxygenated region. *P. bursaria* contains symbiotic algae, which release oxygen in photosynthesis. This allows *P. bursaria* to remain in the anoxic zone.

**Paramecium grown in competition**



- (a) What is meant by the "competitive exclusion principle"? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (b) What type of growth curve do the *Paramecium* species show when grown in isolation? \_\_\_\_\_  
 \_\_\_\_\_
- (c) Why could *P. caudatum* and *P. aurelia* not exist together but *P. caudatum* and *P. bursaria* could? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (d) Do the experiments support Gause's competitive exclusion principle? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
- (e) Why kind(s) of competition is occurring here? Explain: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_



# Depth Studies: Guidance and Ideas

## Depth study

### *Key skills and knowledge*

**Activity  
number**

- 1 Identify the type of investigation you plan to do, e.g. practical investigation (controlled experiment, field study), simulation or model, or secondary-sourced investigation. **208**
- 2 Describe the methods relevant to your investigation. For a practical investigation this will include the techniques you will use to generate primary data and its relevance to the investigation. For a secondary-sourced investigation how will you collate secondary data so that you can analyse and evaluate it more easily? **208**



## Science communication

### *Key skills and knowledge*

- 3 Use standard conventions of report writing to communicate the findings of your investigation. Whatever format you choose for your report (e.g. scientific poster, essay, practical report, or slideshow) you should use correct scientific terminology and representations, and standard abbreviations and units of measurement. **208**
- 4 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. **208**
- 5 Follow conventions for referencing and acknowledging sources of information. **208**

### Key terms

citation

practical investigation

primary data

secondary-sourced  
investigation

secondary data

# 208 Depth Studies: Guidance and Ideas

**Key Idea:** A depth study is an investigation or activity allowing further development of an idea covered during your course of study.

During the HSC course you will learn about many biological concepts involving biotechnologies, organisms and their adaptations for survival, and the environment. The depth

study will provide you with an opportunity to explore one or more of these ideas in detail. Your study may take the form of a practical investigation, a secondary source investigation, literary research, or fieldwork. In any case you will need to propose a question to investigate, plan and carry out your investigation and clearly communicate your findings.

## Ideas for depth studies include:

### Practical investigation:

This will take the form of a practical investigation. You will need to propose a question, construct a hypothesis, develop, carry out, and modify a method, analyse the results and produce a conclusion. You may wish to investigate a particular claim or how a device works and propose improvements.



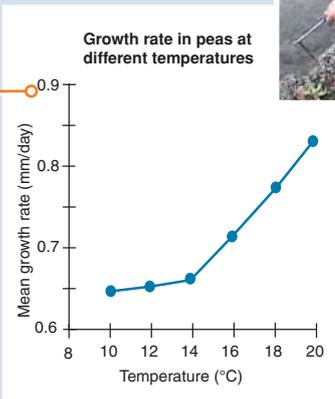
### Creating:

Modelling is an important part of science and biology. For your depth study you may wish to create a model of a particular biological concept. You could create a physical working model, produce a mathematical equation, or a computer simulation that explains the relationships between the parts of a biological system.

Time	Number of susceptible
1	100000
Antibiotic	$=(B2^*0.25)$
2	$=(B3^*2)$
Antibiotic	$=(B4^*0.25)$
3	$=(B5^*2)$
Antibiotic	$=(B6^*0.25)$
4	$=(B7^*2)$
Antibiotic	$=(B8^*0.25)$
5	$=(B9^*2)$
Antibiotic	$=(B10^*0.25)$
6	$=(B11^*2)$
Antibiotic	$=(B12^*0.25)$
7	$=(B13^*2)$
Antibiotic	$=(B14^*0.25)$
8	$=(B15^*2)$
Antibiotic	$=(B16^*0.25)$
9	$=(B17^*2)$
Antibiotic	$=(B18^*0.25)$
10	$=(B19^*2)$
Antibiotic	$=(B20^*0.25)$
11	$=(B21^*2)$
Antibiotic	$=(B22^*0.25)$
12	$=(B23^*2)$
Antibiotic	$=(B24^*0.25)$

### Data analysis:

You will need to organise and analyse the data you collect. This may take the form of data tables, graphs, or diagrams.



### Secondary-sourced investigation:

You will conduct research to answer a biological question or analyse a claim. This will require you to gather, analyse and critically evaluate data. This could include investigating any historical aspects of a concept or analysing works of fiction for scientific accuracy. You may communicate your findings by written or visual presentation, using your analysis to justify your conclusions.



### 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.



## Practical investigation or secondary source investigation?

### Practical investigation

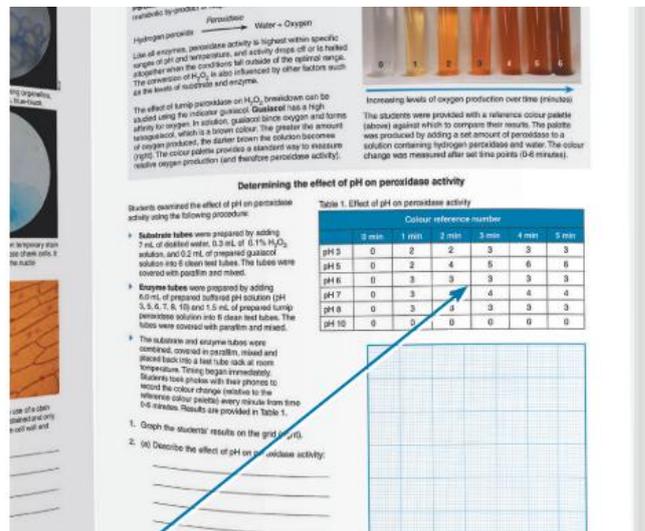
In a practical investigation you will directly collect data for analysis (primary data). For example, measuring the pH of water samples or recording how many students took the bus to school on a certain day. Primary data can be gathered through questionnaires and surveys, observations, interviews, and 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.

### Secondary-sourced investigation

In a secondary-sourced investigation you gather, analyse and evaluate other people's data to support or refute a claim. This may include data which has been gathered from studies, surveys, or experiments carried out by other people or gathering information from text books or articles. A secondary-sourced investigation may be appropriate when you do not have the equipment or resources to gather primary data yourself. It is also appropriate for gathering together a range of data relating to a specific concept, such as investigating the technical aspects of how a piece of technology works (e.g. a microscope).



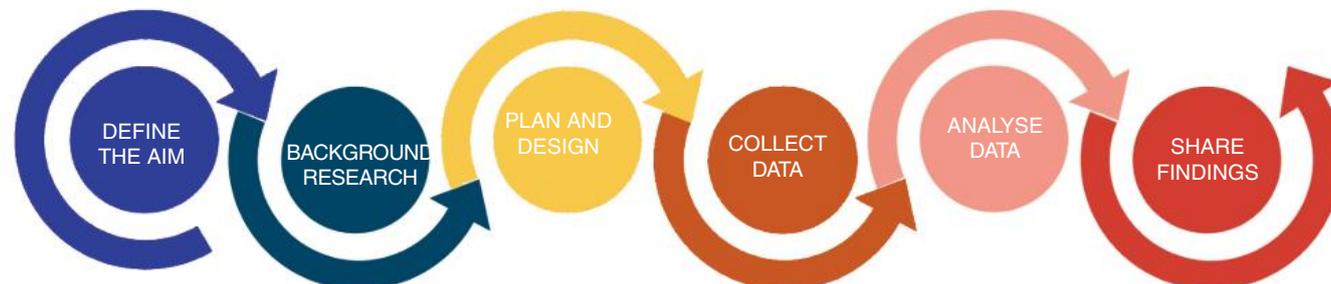
In this book second-hand data (the data is provided) is provided showing the effect of pH on enzyme activity.

## Planning your depth study

- Once you have decided on a topic for investigation and whether you will carry out a practical investigation or secondary-sourced investigation you need to decide what data is needed to support your investigation and how you will gather the appropriate data.
- Gathering evidence to test a hypothesis is central to a scientific investigation. For a practical investigation you need to ensure that the methods used to gather and analyse data are fair (i.e. without deliberate or unknowing bias) or the data may produce results 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 than 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.
- Similarly gathering secondary data from unreliable sources, such as online blog sites or tabloid magazines or newspapers, is likely to produce bias or flawed results.
- You need to plan how you will organise the data you gather. What statistical tests can be carried out? You may need to carry out preliminary investigations and modify your method based on the outcome. This can include a literary review to gather background information.
- A simple plan for your depth study is shown below:



How good was the investigation's design? Was it a fair test?

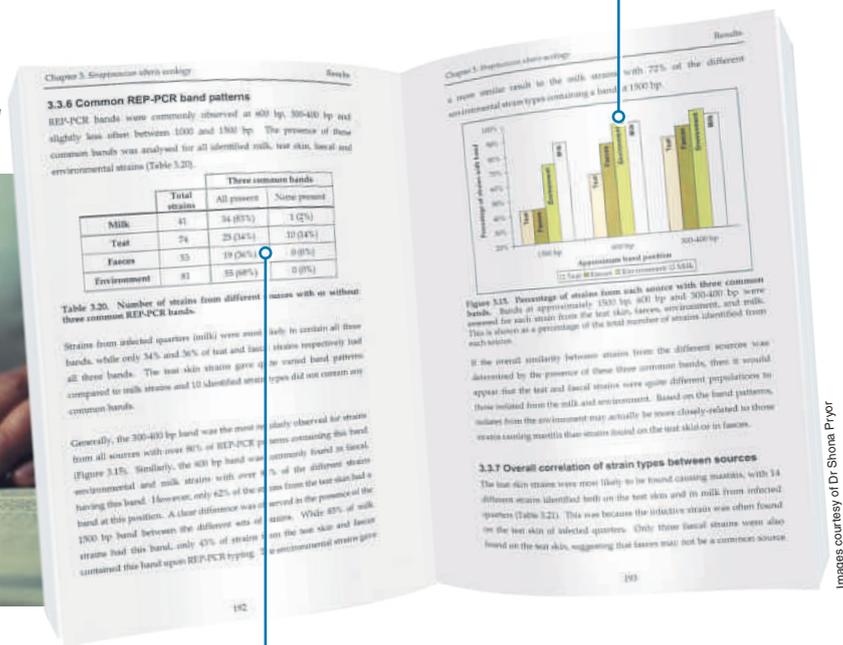


## Communicating your ideas

There are numerous ways to communicate your investigation's aims, methods, results, and conclusions. 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 depth study, providing background about the study, show your methods and results, and then provide 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.

### 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 to a wide range of audiences. Format will vary depending on whether the data is first or second hand.

Tables labelled sequentially through the report followed by a summary of results.

Including photos of experimental set ups or field site is useful.

Images courtesy of Dr Shona Pryor

**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.

**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

**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.

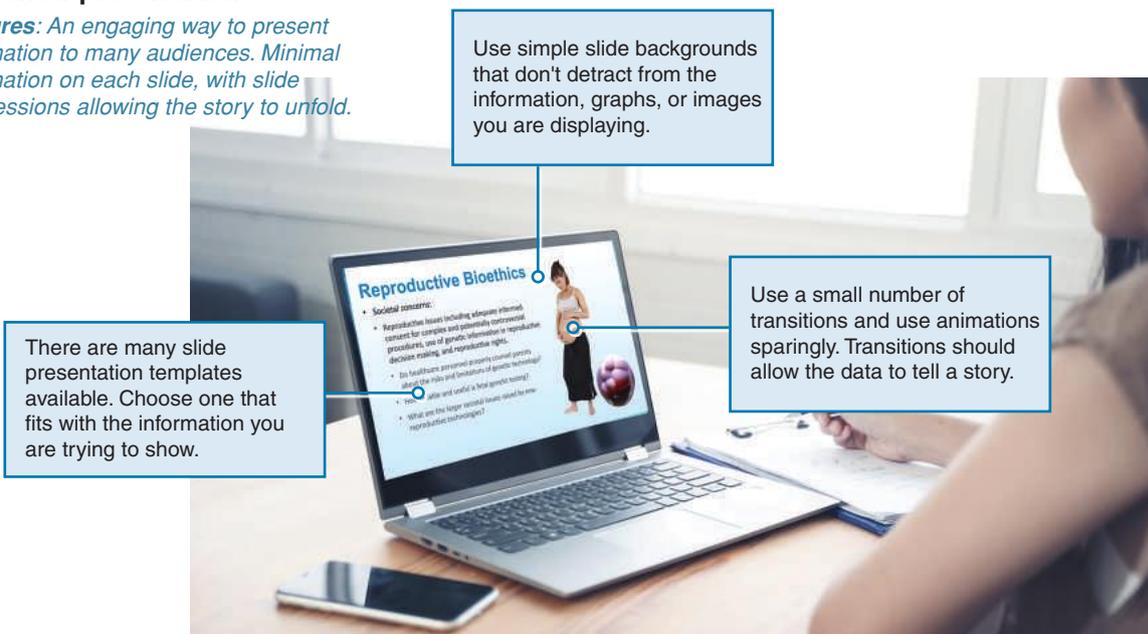
Photographs, diagrams, or schematics can be used to illustrate specific features of the research.

**REFERENCES**

Acknowledge sources of information and help, e.g. field or lab assistance.

## 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.



## Important points to communicate

- ▶ 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 investigation this may include background information, your aim and your hypothesis.
  2. **Methods:** How you carried out your depth study. What methods and equipment you used.
  3. **Results or analysis:** Results and discussion for practical investigation. An explanation of data or viewpoints for a secondary-source investigation.
  4. **Discussions or conclusions:** Discussion including analysis of the results. State your viewpoint and provide an evidence-based argument to support it.
  5. **Acknowledgements/references:** Include a section listing your sources of information. This helps validate your arguments.

## Citing and referencing correctly

- ▶ A reference list details all the sources of information used in your depth study. This will likely be longer for secondary-sourced investigation.
- ▶ Sources of information should be cited directly after the sourced information occurs in the text. For example: *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)...*
- ▶ Full details of the authors and the source of information are given in the reference list. The reference list can be listed alphabetically or numerically (in order of appearance in the text). Citations for an alphabetical reference list state the author(s) and year in brackets after each reference (as shown above). Numeric citations are given by a superscript numbers (<sup>1</sup>) after each new reference, and the numbers appear in order in the reference list.

## Examples of reference list entries

### Referencing peer reviewed journals

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 online articles

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 books

Last name, initials. (year). Title. Publication information.

Martin, R. A. (2004). *Missing Links in Evolutionary Concepts & Transitions Through Time*. Sudbury, MA Jones and Bartlett.

### Referencing social media

Last name, initials. (year, month day). *First 20 words of post* [description of multimedia aspects] [type of post]. Site name. URL

# A-1 Appendix 1: Glossary

## A

### abiotic factor

Non-living, physical features in an ecosystem, including temperature, humidity, and rainfall.

### absolute dating

A method of dating that uses a known measurement (e.g. the decay of unstable elements) to produce definitive times and dates for the age of an object.

### absorption

The process by which nutrients are taken up by the body (from intestine to blood).

### accuracy

The correctness of a measurement; how close a measured value is to the true value.

### acetyl coenzyme A, acetyl coA

A coenzyme that adds acetyl groups in biochemical reactions.

### activation energy

The minimum amount of energy needed to initiate a chemical reaction.

### active site

Region of an enzyme where the substrate binds and undergoes a chemical reaction.

### active transport

The movement of molecules or ions across a cell membrane against a concentration gradient, requiring an expenditure of energy.

### adaptation (*verb*)

The process by which populations become more suited to their environments.

### adaptive radiation

A process in which organisms diversify from an ancestral species into many species.

### aestivation

A prolonged dormancy in hot and dry conditions. Occurs in a variety of animals including land snails and lung fish.

### aim

A single statement describing the purpose or reason for conducting an experiment.

### allopatric speciation

Speciation that occurs when biological populations become geographically isolated.

### alveoli

Air sacs in the lungs through which carbon dioxide and oxygen are exchanged between the blood and the air.

### antibiotic resistance

The ability of bacteria to resist the effects of an antibiotic they were once sensitive to.

### argumentation

The scientific process of proposing, supporting, critiquing, and refining ideas.

### artery

Blood vessel that carries blood away from the heart. It has thick elastic walls which assist in moving blood along them.

### ATP

An organic compound that serves as an energy source for metabolic processes.

### ATP synthase

A protein that catalyses the formation of ATP from ADP and inorganic phosphate.

### assumption

A statement that is assumed to be true but is not (or cannot be) tested.

### autotroph

An organism that produces its own food using materials from inorganic sources.

## B

### background extinction rate

The number of species that would be expected to become extinct over a given period of time under normal (not man-made) environmental changes and conditions.

### behavioural adaptation

Actions of an organism that contribute to fitness (survival and reproduction).

### biological control

The control of a pest species using a natural predator.

### biodiversity

The amount of biological variation present in a region (includes genetic, species, and habitat diversity).

### biogeographical evidence

Evidence of evolution from the distribution of related species.

### biota

All the animal and plant life in a particular region, habitat, or time period.

### biotic factor

Relating to the living factors in an ecosystem, including distribution and abundance.

### birth rate

Number of individuals born per unit time. Usually given as live births per thousand of population per year.

### blood

The fluid transport medium of the cardiovascular system, composed of blood cells and plasma which distributes nutrients and respiratory gases to the cells of the body and transports metabolic wastes away from them.

### breathing

The process of moving air in and out of the lungs (by movement of the diaphragm and intercostal muscles) to facilitate gas exchange.

### bronchi

The large cartilaginous tubes that divide from the trachea and enter the each lung. They take air from the trachea to the lungs.

## C

### Calvin cycle

The light-independent phase of photosynthesis during which chemical reactions convert carbon dioxide into sugars.

### capillary

Thin blood vessel with walls only one cell thick. Capillaries make networks through organs and tissues to allow blood to flow close to all cells for exchange of materials.

### carrying capacity (K)

The maximum number of organisms that can be sustained by a specific environment.

### catalyst

A substance that modifies and increases the rate of a chemical reaction without being consumed in the process.

### cell wall

The rigid outermost cell layer found in plants and certain algae, bacteria, and fungi but absent from animal cells.

### cellular respiration

The series of metabolic reactions that oxidise organic molecules to produce ATP.

### chlorophyll

A green photosynthetic pigment found primarily in the chloroplasts of algae and plants, essential to photosynthesis.

### chloroplast

An organelle within the cells of plants and green algae that contains chlorophyll and is the site of photosynthesis.

### citation

A quotation of or explicit reference to a source for substantiation or evidence, as in a scholarly paper.

### closed circulatory system

A circulatory system in which the transport system remains inside vessels as it is transported around the body.

### cohesion-tension hypothesis

The hypothesis that explains how water is transported in plants to extreme heights against the force of gravity.

### conservation tillage

Tillage system that minimises the disturbance to the soil. Generally a minimum of 30% crop residue is left on the surface of the soil.

### crisetae

One of the inward projections or folds of the inner membrane of a mitochondrion.

### colonial

Two or more individuals of the same species living together in close association.

### coevolution

Evolution that occurs among interdependent species as a result of specific interactions.

### common ancestor

An ancestor that two or more descendant species have in common.

### competition

Interaction within or between species in which individuals attempt to access the same limited resource.

### competitive exclusion principle

The principle that two species with identical niches cannot coexist indefinitely.

### connective tissue

Tissue the supports, protects, or gives structure to other tissues and organs.

### continental drift

The gradual movement of the continents across the Earth's surface over geological time due to the movement of the Earth's mantle.

### convergent evolution

The independent evolution of similar traits or features in unrelated species.

### countercurrent exchange

Exchange system in which mediums close to each other travel in opposite directions and a property, such as gas or heat, is exchanged between them. The opposite flow of the medium maintains the concentration gradients of the mediums.

### cuticle

The waxy coating over the epidermis of a leaf.

### cytoplasm

The watery solution within 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.

### death rate

Number of individual deaths per unit time. Usually given as deaths per thousand of population per year.

### denaturation

The alteration of a protein shape resulting in a loss of function.

### density

The number of individuals per unit area or volume.

### density dependent factor

Any force that affects a population's size regardless of the density (number of individuals per unit area) of the population.

### density independent factor

Any force that affects a population's size in response to the density (number of individuals per unit area) of the population

### directional selection

A mode of natural selection in which an extreme phenotype is favoured over others, causing the allele frequency of a population to shift towards that phenotype.

### disruptive selection

A natural selection mechanism in which extreme values for a trait are favoured, creating trait variance that drives divergence.

### divergent evolution

The accumulation of differences between closely related populations within a species, resulting in the formation of new species.

### 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.

### distribution

The spatial arrangement of organisms.

### DNA (deoxyribonucleic acid)

A large molecule composed of two polynucleotide chains that carries the genetic code and enables cells to function.

### DNA hybridisation

The process of combining two complementary single-stranded DNA or RNA molecules to form a single double-stranded molecule through base pairing.

## E

### ectotherm

An animal that does not produce its own internal heat and so relies on external energy sources, such as the sun to help regulate its body temperature.

### ecological niche

The relationship of a species with all the biotic and abiotic factors affecting it. A species' functional role in an ecosystem.

## ecosystem

All the organisms in a given area as well as the abiotic factors with which they interact.

### electron transport chain

A series of protein complexes that transfer electrons from donors to acceptors across a membrane via redox reactions.

### egestion

The act of discharging undigested solid waste material from a cell or organism.

### emigration

The process of leaving one area or population for another.

### endotherm

Animal that is able to produce and maintain its own internal heat.

### enzyme

Globular proteins that act as biological catalysts for specific reactions.

### epidermis

In botany, the single layer of cells that cover the leaves, flowers, roots and stems.

### epidermal tissue

The tissues (in plants) that make up the outer layer of a plant organ e.g. the leaf.

### epithelial tissue

The tissues (in animals) that form the covering of all body surfaces.

### eukaryote

Organism whose bodies are made up of eukaryotic cells, such as plants, animals, protists, and fungi.

### excretion

The process by which organisms expel metabolised waste products and other toxic substances from their body.

### exponential growth

A pattern of population growth where the growth rate is proportional to the size of the population itself. (*cf. logistic growth*).

### extinct

There are no living members of a species left in the wild or captivity.

## F

### fauna

The animal life of a particular area or region.

### fermentation

An anaerobic metabolic process by which a carbohydrate, such as starch or a sugar, is converted into an alcohol or an acid.

### 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.

### flora

The plant life of a particular area or region.

### fossil

The remains or impression of an organism, preserved in rock.

### fossil record

The history of life as documented by fossils.

## G

### gene

A unit of hereditary information consisting of a specific nucleotide sequence in DNA.

### gene flow

The exchange of alleles between two or more populations.

## gene pool

The collective genetic information within a population of interbreeding organisms.

### geological time scale

The chronological framework relating different rock types and geological events to periods in time.

### glucose

A simple sugar that functions as the main source of metabolic energy in living things.

### glycolysis

The metabolic pathway that converts glucose into pyruvate.

### Gondwana

Ancient supercontinent that existed from about 550 mya to 180 mya. Included the modern continents of South America, India, Antarctica, Australia, and Africa.

### granum (*pl., grana*)

Stack of thylakoids found in the stroma of chloroplasts, where the light-dependent reactions of photosynthesis take place.

### Great Oxidation Event

Period of time in which the Earth's atmosphere and oceans experienced a rise in the amount of free molecular oxygen (O<sub>2</sub>) produced by cyanobacteria.

### ground tissue

Plant tissue other than the dermal or vascular tissues.

### guard cells

The two cells that flank the stomatal pore and regulate the pore's opening and closing.

## H

### habitat fragmentation

The process or result of the transformation of one large continuous habitat into many smaller separate discontinuous ones.

### heterotroph

An organism that feeds on producers (autotrophs), other heterotrophs (consumers), or on non-living material.

### hibernation

A state of minimal metabolic activity entered into to conserve energy, usually in colder months.

### homology

Similarity between two different species of organisms due to shared ancestry.

### hydrophyte

A plant that grows either partly or totally submerged in water.

### hypothesis

A tentative explanation, proposition, or set of propositions capable of being tested by scientific experimentation.

## IJ

### ice core

Cylinder of ice removed from ice sheets or glaciers. Used for dating geological events.

### introduced species

A non native (exotic) species that has arrived in a location (country) by means of human assistance.

### isotope

One of two or more forms of a chemical element that have the same atomic number (number of protons) but different atomic masses (protons + neutrons).

### immigration

The process of arriving into an area or

population from another.

### intestinal villi

Tiny finger-like projections that line the small intestine and increase surface area for absorption.

### interspecific competition

Competition for resources between different species.

## K

### Krebs cycle

A cycle of aerobic catalysed reactions in respiration occurring within mitochondria. Generates ATP and reducing power.

### 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, directly or indirectly.

## L

### large intestine

In vertebrates, the last part of the gastrointestinal tract and digestive system, comprising the caecum, colon, and rectum.

### leaf

The lateral appendage of the plant vascular system. The primary site of photosynthesis and gas exchange.

### light microscope

An optical instrument with lenses that refract visible light to magnify images of specimens.

### light dependent phase

The phase of photosynthesis during which light energy is converted into chemical energy through chemical reactions.

### light independent phase

See **Calvin cycle**.

### limiting factor

A resource or environmental condition which limits the growth, distribution or size of a population within an ecosystem.

### Lincoln index

In ecology a calculation that provides an estimate of the population based on the mark and recapture technique used to estimate the size of a population of mobile organisms.

### link reaction

The stage in respiration that converts pyruvate into acetyl CoA, linking glycolysis to the Krebs cycle.

### 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.

### logistic growth

A pattern of population growth in which growth rate declines as the population nears carrying capacity (*cf. exponential growth*).

### lungs

A pair of gas exchange organs located on either side of the chest cavity in mammals.

## M

### magnification

The amount or degree of visual enlargement of an observed object.

### mass flow hypothesis

A hypothesis that describes the movement of sap in plant phloem through diffusion gradients and hydrostatic pressure.

### matrix (of mitochondria)

The space within the inner membrane of a mitochondrion.

### 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.

### megafauna

The large or giant animals of a particular habitat, region, or time. In Australia these are represented by large extinct marsupials.

### mesophyll

Internal layer of tissue in leaves between the epidermal layers.

### metabolic pathway

A linked series of chemical reactions occurring within a cell.

### metabolism

The chemical processes occurring within a living cell/organism that sustain life.

### microevolution

The small changes in genetic information in a population over time.

### mine rehabilitation

The returning of a disused mining site to environmentally sound or sustainable conditions which will encourage plant and animal life to return.

### mitochondrion (pl., mitochondria)

An organelle in eukaryotic cells that serves as the site of cellular respiration.

### mode

The value that occurs most often in a data set.

### model

A conceptual, mathematical or physical representation of a real-world phenomenon.

### molecular clock

The mutation rate of DNA or amino acid sequences over time, from which the dates of taxonomic divergences can be deduced.

### multicellular

A organism comprising many specialised cells that cannot live independently of each other.

### muscle tissue

Tissue composed of muscle cells (fibres) specialised for contracting.

### mutation

A change in the nucleotide sequence of an organism's DNA (or RNA).

## N

### NAD/NADH

Electron carriers in cellular respiration (oxidised/reduced forms).

### NADP/NADPH

Electron carriers in photosynthesis (oxidised/reduced forms).

### natural selection

The differential survival and reproduction of favourable phenotypes.

### nervous tissue

Tissue composed of nerves cell. Specialised for conducting signals.

### nucleus

The organelle of a eukaryotic cell that contains the genetic material in the form of

chromosomes, made up of chromatin.

## O

### organelle

A subcellular structure with one or more specific jobs to perform in the cell.

### organ

A group of different tissues that perform a particular function.

### organ system

A group of interacting organs that carry out a particular body function.

### open circulatory system

A circulatory system in which the transport fluid leaves the vessels and enters cavities in the body and baths the organs before reentering the vessels.

### osmosis

The diffusion of free water across a selectively permeable membrane.

### oxygen-haemoglobin dissociation curve

Curve that plots the proportion of saturated haemoglobin (oxygen laden) against the oxygen pressure.

### oxidative phosphorylation

The process in which ATP is formed as a result of the step-wise transfer of electrons to a final acceptor, oxygen.

## P

### palaeontology

A branch of science that is concerned with the study of fossilised plants and animals.

### parasitism

Biological interaction in which one organism, the parasite, benefits at the expense of the other, the host.

### passive transport

The diffusion of a substance across a biological membrane with no expenditure of energy.

### 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.

### photosystem

Membrane-bound pigment complexes that capture light in photosynthesis.

### phyletic gradualism

Evolutionary model proposing that species arise through the gradual and continuous transformation of populations (*cf. punctuated equilibrium*).

### phospholipid

A lipid composed of glycerol joined to two fatty acids and a phosphate group. Phospholipids form bilayers that function as biological membranes.

### photosynthesis

A process used by green plants, algae, and some bacteria to convert light energy into chemical energy (carbohydrate).

### physiological adaptation

An internal or cellular process that regulates and maintains homeostasis for an organism, enabling to survive in its environment.

### phylogeny

The evolutionary history of a taxon.

**plasma membrane**

The membrane at the boundary of every cell that acts as a selective barrier, regulating the cell's chemical composition.

**population**

A group of interbreeding organisms of the same species, found in the same geographical area.

**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.

**prokaryote**

A unicellular organism consisting of a single prokaryotic cell. Prokaryotes lack membrane-bound organelles and a nucleus.

**punctuated equilibrium**

Evolutionary model proposing that evolution occurs primarily through short bursts of speciation followed by periods of stasis.

**pyruvate**

A versatile biological molecule that is the end product of glycolysis.

**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****radiometric dating**

A method for determining the age of an object based on the proportion of a particular radioactive isotope within it and the half-life of that isotope.

**random error**

An error in measurement caused by unknown and unpredictable changes in the experiment.

**relative dating**

A method of determining the age of an artefact, fossil, or stratigraphic layer relative to another. Does not give specific dates.

**reliability**

The degree of consistency of a measurement (see **precision**).

**respiratory gases**

Gas involved in respiration and gas exchange, oxygen and carbon dioxide.

**replication**

The process of duplicating and entire experimental design, at the same time, as a procedure in scientific experiments.

**resolution**

A microscope's ability to distinguish detail.

**rock art**

Human made markings on natural surfaces, including paintings and engravings. Are often found in caves or on rock overhangs protected from the elements.

**rock strata**

Stacked-up layers of sedimentary rock.

**root**

An organ in vascular plant that anchors the plant and enables it to absorb water and minerals from the soil.

**RuBisCo**

A plant enzyme involved in fixing atmospheric CO<sub>2</sub> during photosynthesis.

**S****sample size**

The number of units in a group or population to be studied.

**salinisation**

Increasing of salt content in soil or waterways.

**scientific evidence**

Empirical evidence gathered from research, which serves to either support or counter a scientific theory or hypothesis.

**sclerophyll**

Greek "hard leaf". A group of plants characterised by hard leathery evergreen foliage. Examples include *Eucalyptus*.

**secondary data**

Pre-existing data that has already been collected from first-hand sources.

**secondary sourced investigation**

Investigation using that analyses and evaluates secondary sourced information.

**selection pressure**

Any reason for organisms with certain phenotypes to have either a survival benefit or disadvantage.

**small intestine**

Part of the gastrointestinal tract where most of the absorption of nutrients occurs.

**soil degradation**

The process in which soil declines in quality due to a loss of organic matter, microbes, and soil structure.

**speciation**

The formation of new biological species through the process of evolution.

**specialised cell**

A cell that has developed the characteristics needed to perform particular functions.

**standard deviation**

A measure used to used to quantify the amount of variation in a set of data.

**stabilising selection**

A mode of natural selection that favours retention of the median phenotype.

**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.

**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.

**stromatolite**

Layered sedimentary formations created by trapping and binding sedimentary grains in biofilms created by cyanobacteria.

**structural adaptation**

A physical (morphological) feature of an organism that contributes to its fitness (survival and reproduction).

**substrate level phosphorylation**

The synthesis of ATP by the transfer of a phosphate from a substrate directly to ADP.

**sympatric speciation**

The evolution of a new species from an ancestral species while both continue to inhabit the same geographic region.

**systematic error**

An error in measurement that is predictable and either constant or proportional to the measurement.

**T****thermoregulation**

The maintenance of internal body temperature within a tolerable range.

**thylakoid discs**

Membrane-bound sacs containing chlorophyll; the site of the light-dependent reactions of photosynthesis.

**tissue**

An integrated group of cells with a common structure, function, or both.

**transect**

A line across a habitat or part of a habitat, used for sampling.

**torpor**

A state of reduced physiological activity in which the body temperature and metabolic activity lowers.

**transitional fossil**

A fossil that exhibits traits common to both an ancestral group and its derived descendants.

**translocation**

The transport of organic nutrients in the phloem of vascular plants.

**transpiration**

The evaporative loss of water from a plant.

**UVV****unicellular**

Made of one single living cell.

**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.

**vein**

Blood vessel that takes blood back to the heart. The walls are thin. Valves prevent backwards flow of blood

**XYZ****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.

**zircon**

Common mineral composed of zirconium, silicon, and oxygen in the formula ZrSiO<sub>4</sub>. Zircons can be used for radiometric dating.

# A-2 Appendix 2: Equipment List

The equipment list provides the material and equipment needed per student, pair, or group.

## 2: Cell Structure

### INVESTIGATION 2.1

#### Preparing an onion slide

Per student/pair  
Light microscope  
Onion/onion leaf  
Glass microscope slides  
Coverslips  
Scalpel or razor  
Iodine stain  
Filter paper/tissue paper

### INVESTIGATION 2.2a/b

#### Drawing onion peel cells using a microscope

Per student/pair  
Light microscope  
Onion/onion leaf  
Elodea or similar thin leafed plant  
Glass microscope slides  
Coverslips  
Scalpel or razor  
Iodine stain  
Filter paper/tissue paper

## 3: Cell Function

### INVESTIGATION 3.1

#### 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 3.2

#### 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

### INVESTIGATION 3.3

#### Measuring respiration in germinating seeds

Per group  
3 x boiling tubes  
Marker pen  
6 x cotton balls  
15% KOH solution  
2 x eye dropper or plastic pipette  
3 x gauze pieces  
Germinated bean seeds (enough to fill one quarter of the boiling tube)  
Ungerminated bean seeds (enough to fill one quarter of the boiling tube)  
Glass beads (enough to fill one quarter of the boiling tube)  
3 x 2-hole tube stoppers  
3 x bent glass tubes or pipettes  
3 x tubes (must be able to be clamped shut)  
3 x screw clips  
A few drops of colored liquid  
3 x syringes (must fit tube with screw clamp attached)  
3 x clamp stands or rack  
Water bath (25°C)  
Ruler  
Timer

### INVESTIGATION 3.4

#### Measuring fermentation in yeast

Per pair  
1 x 100 mL beaker  
10 g of active yeast  
50 mL tap water at 24°C  
25 g of substrate (glucose, maltose, sucrose, or lactose)  
1 x glass stirring rod  
1 x conical flask (to hold 275 mL)  
Parafilm  
Single hole stopper  
Tubing  
1 x 100 mL measuring cylinder  
1 x small basin to hold inverted cylinder  
Stopwatch

### INVESTIGATION 3.5

#### Investigating photosynthetic rate

Per pair/group  
1.0 g *Cabomba aquatica*  
Balance  
Scissors  
Water  
1 x large beaker (large enough to hold the glass funnel)  
1 x glass funnel  
0.2 mol/L sodium hydrogen carbonate solution (enough to cover the plant)  
1 x test tube  
1 x lamp with a 60W bulb  
Lux meter  
Timer  
1 x ruler or tape measure

### INVESTIGATION 3.6

#### Separating photosynthetic pigments

Per pair/group  
Leaves of silverbeet or spinach  
Toothpick  
Boiling tube or test tube  
Filter paper or chromatography paper  
Pencil  
Ethanol  
Clingwrap or parafilm  
Mortar and pestle  
Sand  
Scissors

### INVESTIGATION 3.7

#### Investigating peroxidase activity

Per pair/group  
13 x boiling tubes  
42 mL distilled water  
1.8 mL 0.1% H<sub>2</sub>O<sub>2</sub> solution  
1.2 mL prepared guaiacol solution  
Parafilm  
6 mL of each pH buffered solution (pH 3, 5, 6, 7, 8, 10)  
9 mL turnip peroxidase solution  
Test tube rack  
Timer

## 5: Nutrient and Gas Requirements

### 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)

### INVESTIGATION 5.2

#### Modelling lung ventilation

500 ml plastic bottle  
Scissors  
2 balloon  
Rubber band or tape

## 6: Investigating vascular tissue

### INVESTIGATION 6.1

#### Comparing stomatal density

Per student/pair  
 Light microscope  
 Dicot plants (e.g. buttercup sunflowers)  
 Monocot plant (e.g. maize or corn)  
 Glass microscope slides  
 Coverslips  
 Scalpel or razor  
 Access to a computer or device with internet connection

### INVESTIGATION 6.2

#### Investigating factors affecting transpiration

Per pair/group  
 250 mL conical flask with rubber bung  
 Petroleum jelly  
 1 cm<sup>3</sup> 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

## 8: Adaptations

### INVESTIGATION 8.1

#### Investigating body shape and temperature regulation

Per student/pair  
 Roll of aluminium foil  
 Thermometer  
 Lamp with 60 watt incandescent bulb or heat lamp

### INVESTIGATION 8.2

#### Exploring aquatic plant adaptations

Light microscope  
 Aquatic plant e.g. water lily Elodea (oxygen weed)  
 Elodea or similar thin leafed plant  
 Glass microscope slides  
 Coverslips  
 Scalpel or razor  
 Iodine stain  
 Filter paper/tissue paper



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