SACE ONE - AUSTRALIAN CURRICULUM

BIOLOGY

WORKBOOK
THIRD EDITION

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Essentials education

ADELAIDE TUITION CENTRE

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All of the authors trust that these materials will assist and even inspire, in some small ways, the next generation of biology students and biologists.

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Extra resources (online version only)

Essentials concepts videos
Science as a Human Endeavour
Capabilities
Science Inquiry Skills
Laboratory notes

Topic 1 Cells and microorganisms

Chapter 1.1 Living things consist of cells

Science Understanding

Living things are distinguishable from non-living things.

The cell theory unifies all living things.

Living things are made up of one or more cells.

Cells:

- are the structural and functional units of life
- come from pre-existing cells
- contain hereditary material.

The cell is the smallest independent unit of life.

The cell membrane defines a cell; it separates the cell from its surroundings.

The cell theory

The invention of the microscope enabled the discovery of the microscopic structures that make up organisms. These microscopic structures were named "cells" by Robert Hooke because the cork cells he viewed under the microscope reminded him of the cells (rooms) in monasteries. The discovery of cells led to the formation of the original cell theory, which was proposed by Theodore Schwann in the 19th century. The original cell theory is a set of principles that explains how all living things are made up of cells and can be used to distinguish between living and non-living things.

The original cell theory states that:

- all organisms are made of cells
- cells are the basic units of life
- cells come from pre-existing cells that have multiplied.

There have been many scientific advancements since the development of the original cell theory in the 19th century. These advancements have led to a greater understanding of cells and some subsequent additions to the original cell theory. The three modern additions state that:

- DNA is passed between cells during cell division
- the cells of all organisms within a similar species are mostly the same, both structurally and chemically
- energy flow occurs within cells.

Helpful online resources

Scio-ology: Cell Theory | Cell Biology

https://www.youtube.com/watch?v=ogQyN4_ruUA

MinuteEarth: An Egg Is Just One Cell

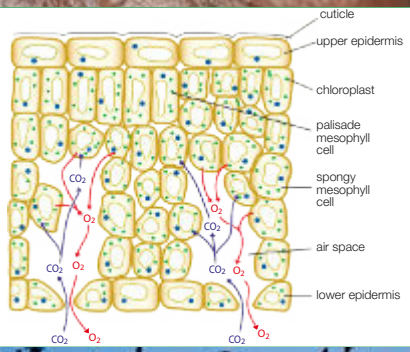
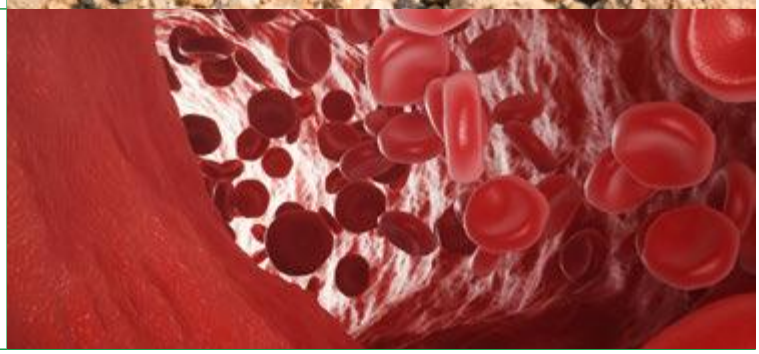
https://www.youtube.com/watch?v=bfGJw-t706o

Living things

The Earth is the only place known to sustain life. The term 'life' refers to the vast diversity of living things that inhabit the planet. The scientific study of living things is called biology and scientists who study living things are called biologists. But what exactly is a living thing?

One way to define living things is to ask what makes living things alive. To most biologists, something is alive if it carries out fundamental processes associated with life called **life processes** (see Table 1.1.1). All living things carry out these same fundamental life processes. Conversely, the organelles within cells cannot carry out these fundamental life processes independently and are therefore considered non-living.

Table 1.1.1: The main life processes and some specific examples.

Life process	Example	Image
Maintaining a stable internal environment	Humans sweating on a hot day	
Controlled exchange of materials	Plants absorbing carbon dioxide and releasing oxygen in daylight hours	
Response to stimuli	Birds migrating for winter	
Obtaining energy and chemical elements	Reptiles catching, killing and consuming prey	
Transport of materials	Blood carrying oxygen to muscle cells	

Life process	Example	Image
Removal of waste	Human kidneys producing urine	
Cell division	A fertilised ovum dividing many times to form an embryo	
Growth and development	The metamorphosis of a caterpillar into a butterfly	
Independent movement	A turtle swimming	
Reproduction	A bacterium dividing by binary fission	

An organism is the name given to a living thing. Organisms can be **unicellular** (made up of one cell) **or multicellular** (made up of many cells), sometimes many billions, even trillions of cells. It has been estimated that there are about 35 trillion cells in an adult human being.

The cell is the fundamental or basic unit of life. It is often stated that the cell is the unit of structure and function of organisms. As such, **the cell is the smallest independent unit of life that can carry out life's processes.**

Cells

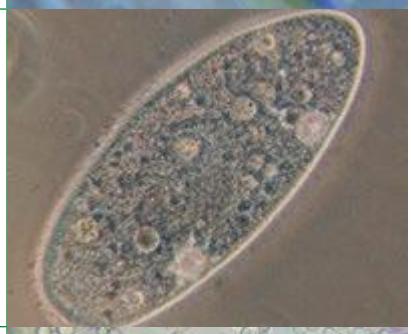
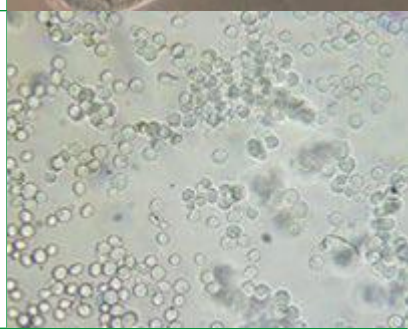
There are two major types of cells: prokaryotic and eukaryotic. **Prokaryotic cells**, such as bacteria, are less specialised than eukaryotic cells such as plant and animal cells. All cells consist of a volume of fluid (cytoplasm) enclosed by a cell membrane. The cytoplasm is mostly made up of water in which substances are dissolved and some insoluble proteins. **Eukaryotic cells** also have structures called membrane-bound organelles that reside in the cytoplasm. Each organelle has a specific function; for example, a nucleus stores DNA and controls the overall function of the cell. These cell types, organelles and their functions are discussed in further detail in Chapter 1.2.

Unicellular organisms

All life in earth has evolved from a single cell over millions of years. Living things that consist of one cell are known as unicellular organisms. They are also called microorganisms because they generally cannot be seen with the naked eye.

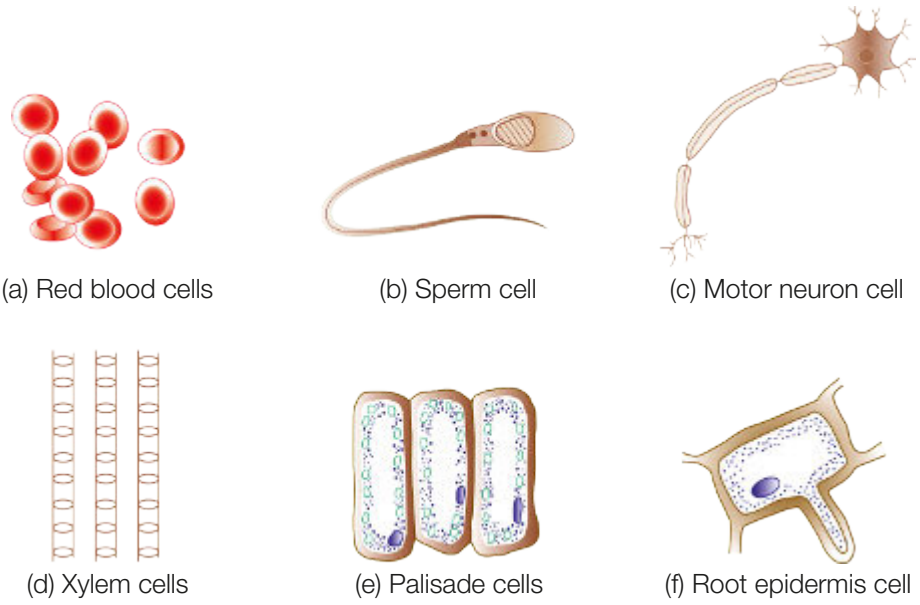
Unicellular organisms can be prokaryotes or eukaryotes and can be found in almost all habitats including thermal vents, caves and even deep underground. They usually reproduce asexually and obtain their nutrients through a process called diffusion. Some examples are highlighted in Table 1.1.2.

Table 1.1.2: Some examples of unicellular organisms.

Unicellular organism	Kingdom	Type of cell	Image
Escherichia coli	Bacteria	Prokaryotic	
Euglena	Protista	Eukaryotic	
Paramecium	Protista	Eukaryotic	
Baker's yeast (*Saccharomyces cerevisiae*)	Fungi	Eukaryotic	

Multicellular organisms

Living things that consist of more than one cell are called multicellular organisms. They are eukaryotes and some examples include mushrooms, animals and plants. Multicellular organisms are more complex than unicellular organisms. They generally consist of large numbers of different types of cells. The different cells within multicellular organisms are specialised cells with different structures and functions (see Figure 1.1.1). They are produced through a process called differentiation, which involves stem cells. As the different cells have different functions, coordination is required between cells to carry out the life processes. As a result, they generally have organs and organ systems to help control and facilitate these life processes. This is explored further in Topic 3: Multicellular organisms.



(a) Red blood cells (b) Sperm cell (c) Motor neuron cell

(d) Xylem cells (e) Palisade cells (f) Root epidermis cell

Figure 1.1.1: Some examples of specialised animal cells (a),(b),(c) and some specialised plant cells (d),(e),(f)

Hereditary material in cells

Heredity is defined as the passing on of characteristics genetically from one generation to the next. All cells contain hereditary material known as **DNA** (deoxyribonucleic acid). DNA is essential to life as it enables cells to synthesise important molecules like proteins for cellular function and divide to produce new cells.

DNA molecules consist of **two complementary** strands. Each strand consists of a phosphate backbone and a specific sequence of DNA bases. There are 4 bases: adenine (A), thymine (T), cytosine (C) and guanine (G), but A only pairs with T and C only pairs with G (see Figure 1.1.2). The complementary nature of the two DNA strands allows it to be replicated prior to cellular division so the genetic information can be passed from parents to their offspring.

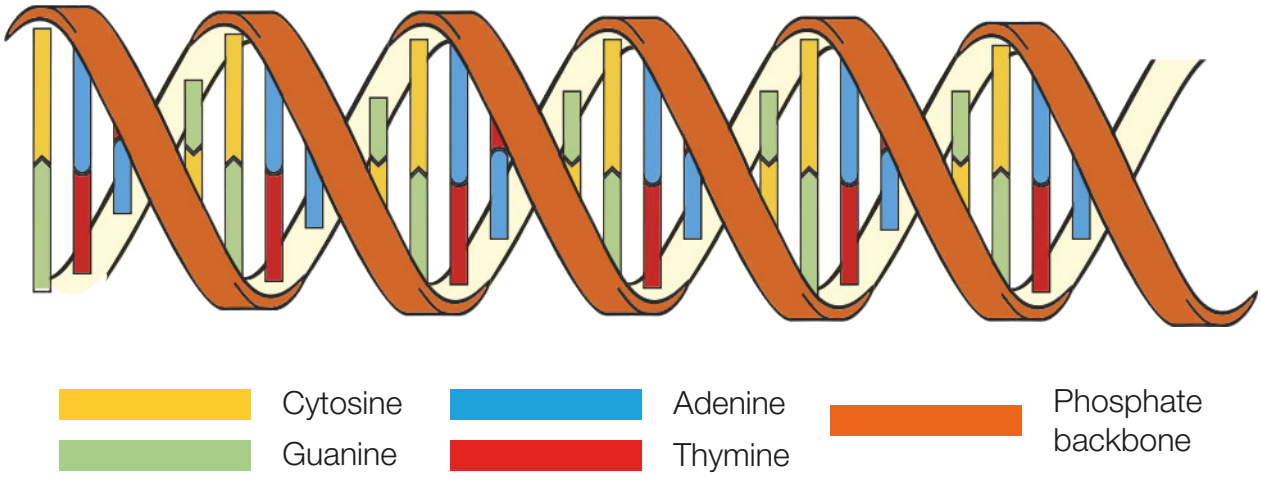


Figure 1.1.2: The basic structure of a DNA molecule showing the two complementary strands and double helix shape.

DNA molecules are generally very long; for example, human cells contain approximately 2 metres of DNA. It is remarkable that this amount of DNA can fit into a single microscopic cell, but it does so by being packed into structures called chromosomes. **Chromosomes** are the structural unit of information in cells and consist of a DNA molecule wrapped around proteins (see Figure 1.1.3). This packaging structure condenses the DNA molecule significantly and helps to protect the genetic code from mutations.

The number of chromosomes, their shape and location in a cell differs between prokaryotes and eukaryotes. This is explored further in Chapter 1.2.

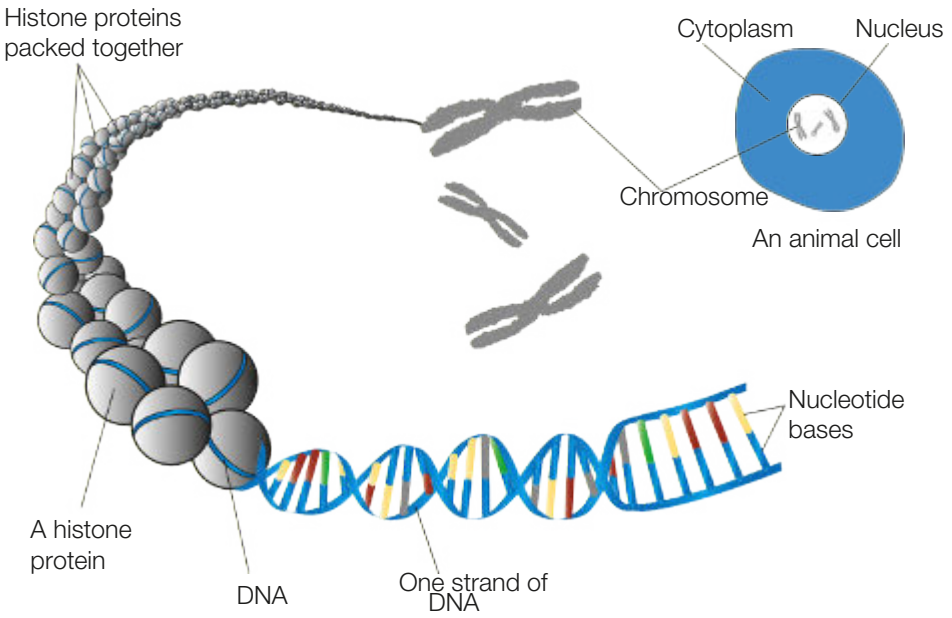


Figure 1.1.3: Chromosomes consist of a DNA molecule wrapped around histone proteins allowing the long DNA molecule to fit inside microscopic cells.

The cell membrane

The cell membrane is a structure found in all cells. It defines a cell and separates the intracellular environment from its extracellular environment (see Figure 1.1.4). The cell membrane is a thin layer (0.01µm) consisting of two layers of phospholipid molecules with a range of different proteins embedded in it. As the boundary between the intracellular and extracellular environments, the cell membrane controls the entry and exit of materials to and from the cell. This will be discussed further in Chapter 1.5.

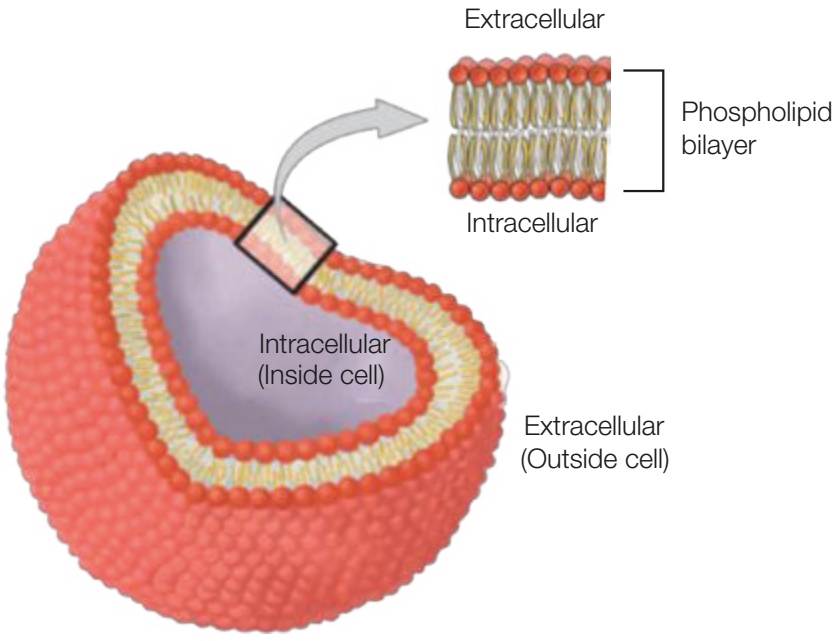


Figure 1.1.4: A model of a cell membrane highlighting that it is the boundary of the cell that separates the cell from its surroundings.

Microscopes

As cells are microscopic and cannot be seen with the naked eye, a microscope is required to view them. There are two major types of microscopes: light and electron microscopes. These two types of microscopes have different applications as they vary in magnification power, resolution and portability.

The light microscope

Light microscopes use visible light to illuminate specimens and lenses to magnify an image (see Figure 1.1.5). Light microscopes are therefore essential tools in scientific research, offering a window into the microscopic world. Scientists use light microscopes across various fields like biology, medicine and more, to study cells, tissues, microorganisms, and other small structures. They're valued for their versatility, ease of use, and ability to provide real-time imaging of living samples.

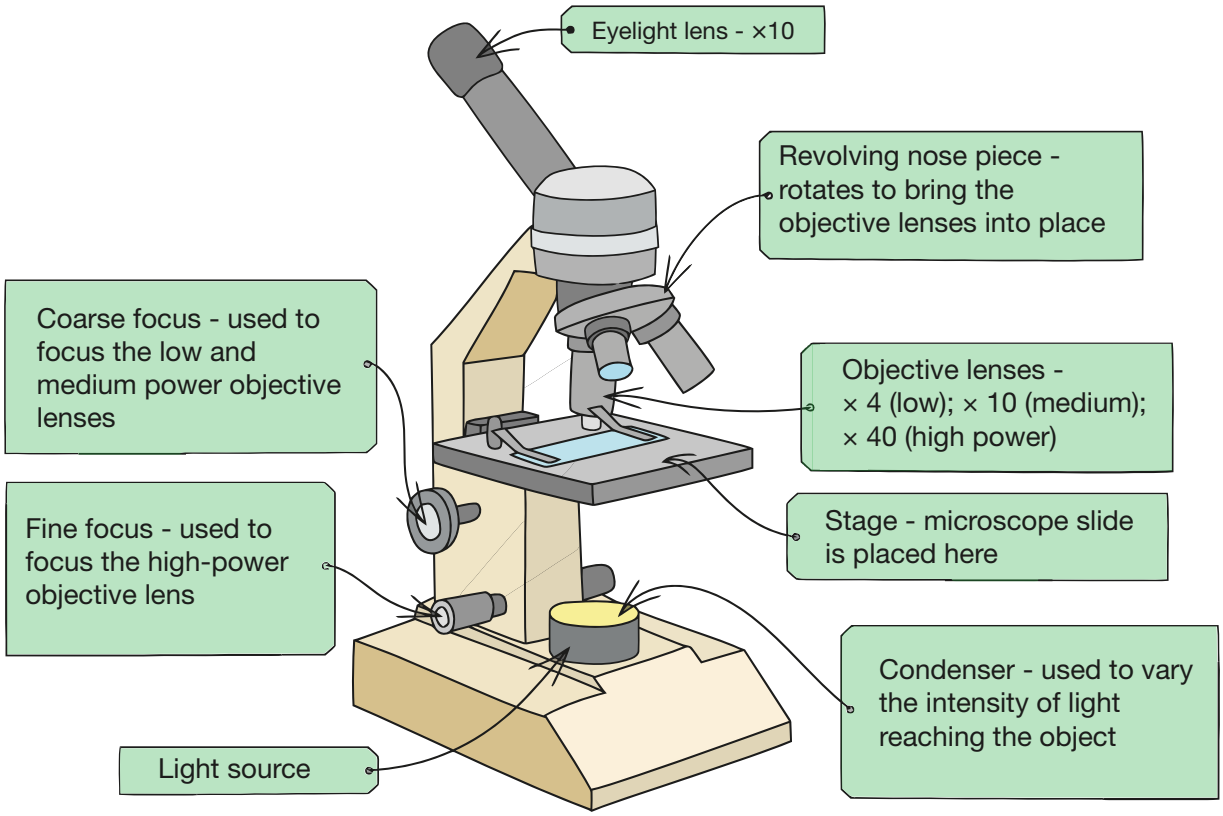
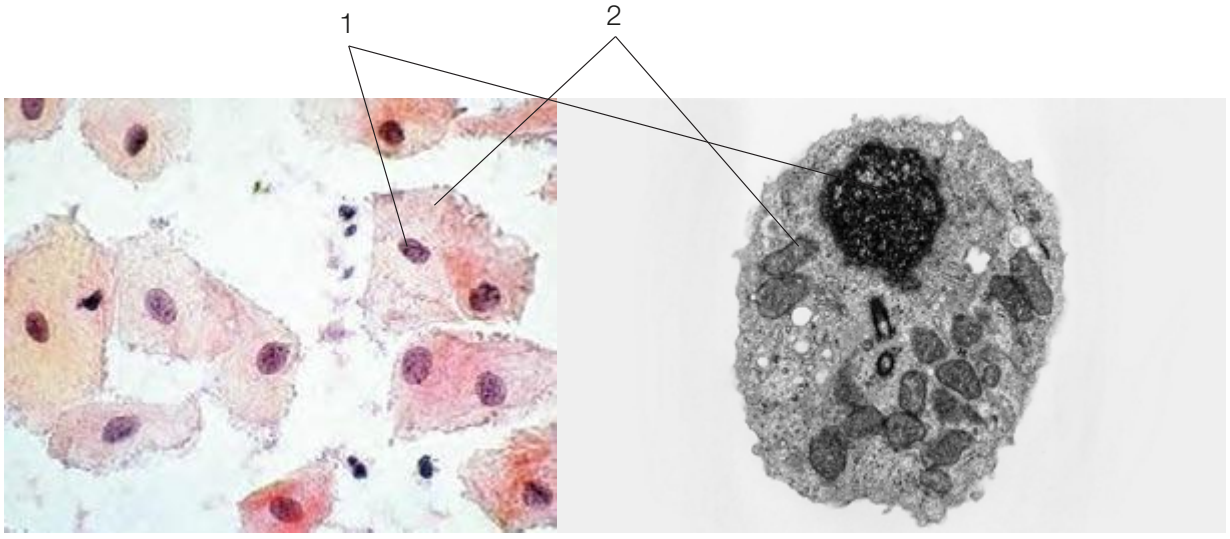


Figure 1.1.5: A summary of the main components of a light microscope and their functions.



Light microscope vs Electron microscope

Figure 1.1.6: A comparison of the magnification of the nucleus (1) and mitochondria (2) of some animal cells when viewed under a light microscope and electron microscope.

Table 1.1.3: A comparison of some features of light and electron microscopes.

Light microscope	Electron microscope
Small, compact and portable	Big, bulky and requires permanent installation
Light energy used to illuminate specimens	Beams of electrons used to illuminate specimens
Generally ×400 magnification but most powerful magnification is approximately ×2000	Generally ×500,000 but most powerful magnification is approximately ×2,000,000
Low resolution (200 nm)	High resolution (0.5 nm)
Living and non-living specimens can be viewed (must be thin to allow light through)	Only non-living (dead) specimens can be viewed
Affordable and low maintenance required	Expensive and requires high maintenance

Helpful online resources

Insider Science: Award-Winning Footage Of The Microsopic World Around Us

https://www.youtube.com/watch?v=ZyXrtODhJEA

The electron microscope

Electron microscopes are powerful instruments used in scientific research to study objects at an extremely high resolution. Unlike light microscopes, which use visible light, electron microscopes use a beam of electrons to illuminate specimens. This allows for much higher magnification and resolution, revealing details at the nanoscale level (see Figure 1.1.6). Electron microscopes are commonly used by scientists in laboratories where detailed imaging of the components of cells are required. There are two main types of electron microscopes: Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM). SEMs produce detailed 3D images of the surface of specimens, while TEMs create high-resolution images by passing electrons through thin sections of specimens, offering insights into internal structures. Refer to Table 1.1.3 for a comparison of some features of light and electron microscopes.

Magnification calculations

To calculate the actual size of a cell using the image size and magnification of a light microscope lens, you can use the formula:

π Formula

Actual size = Image size ÷ Magnification

First, measure the size of the cell in the microscope's field of view (image size). Then, divide this measurement by the magnification of the microscope lens being used. This calculation provides an estimation of the actual size of the cell being observed.

This formula can be rearranged to find the magnification and image size when required.

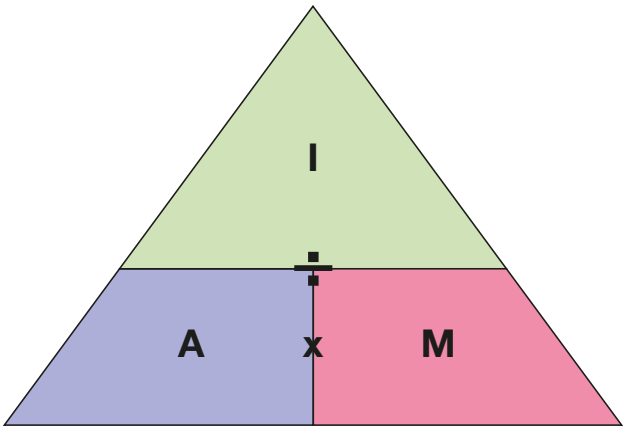
π Formula

Magnification = Image size ÷ Actual size

Image size = Actual size × Magnification

Note: magnification does not have any units and is just written as '×10' or '×5000'

An easy way to complete microscopy calculations is to use the 'I AM' triangle method (see Figure 1.1.7). To use this method, you must first determine what you are trying to find and then place your finger over it in the triangle (e.g. if you are trying to find the actual size, you would put your finger over the 'A'). This will leave two other variables that will be multiplied or divided depending on their position in the triangle. You may also need to convert units where appropriate (see Figure 1.1.8). Refer to the example calculation on page 10 for further information.



I - Image size | A - Actual size | M - Magnification

Figure 1.1.7: The 'I AM' triangle method, where the horizontal line below 'I' represents a division symbol (÷) and the vertical line between the 'A' and 'M' represents a multiplication symbol (x).

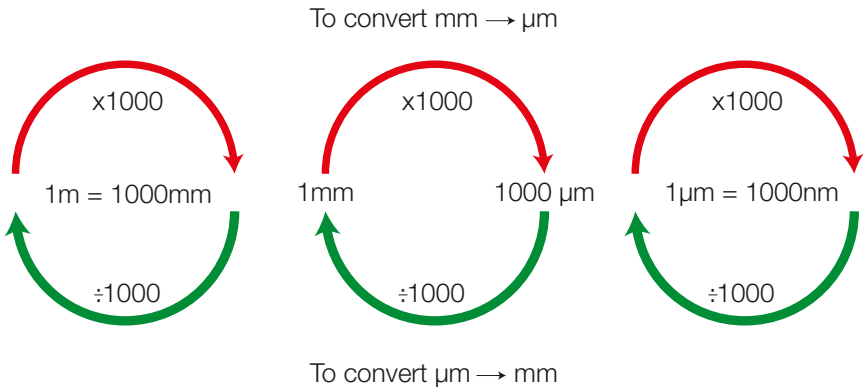
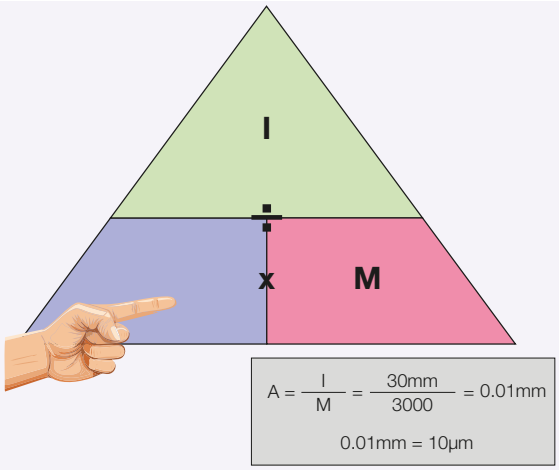


Figure 1.1.8: A length conversion chart

Example calculation

An **image** of an animal cell is 30 mm in size and it has been **magnified** by a factor of ×3000. Determine the **actual** size of the cell.

To find the **actual** size of the cell:



1.1 Review questions

Multiple choice questions

1. *Refer to the diagrams in the table below to answer the following question.*

A	B	C	D
			

Identify the non-living thing in the table above.

J A
K B
L C
M D

2. Which of the following options is **not** a unicellular organism?

J Sea urchin
K Streptococcus
L Escherichia coli
M Paramecium

3. Unicellular organisms

J do not adhere to every principle of the cell theory.
K cannot be seen with the naked eye.
L do not respond to stimuli.
M are only found living on other organisms.

4. Which of the following options is the least likely to be considered as a fundamental life process to classify an organism as living?

J Independent cell division.
K Ability to reproduce.
L Ability of sight.
M Move independently.

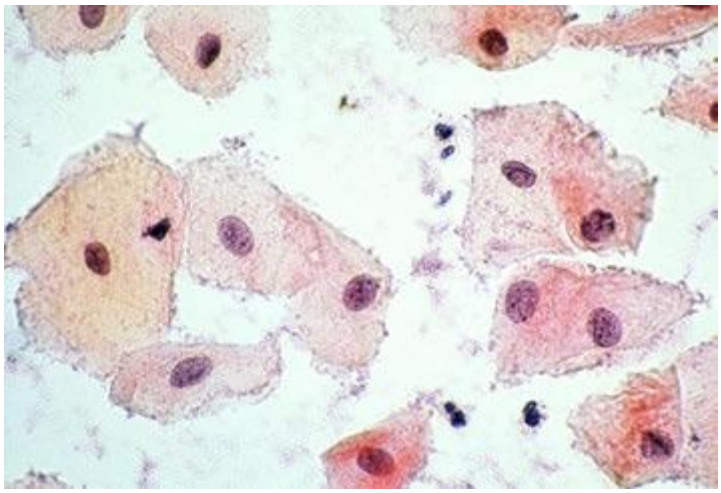
5. Which of the following is **not** a principle of the cell theory?

J All living organisms are multicellular.
K Cells contain genetic information.
L All cells arise from pre-existing cells.
M All living organisms are made up of one or more cells.

6. Which of the following options best explains why all cells contain hereditary material?

J Because containing hereditary material is a principle of the cell theory.
K Hereditary material is required for cells to make proteins and to reproduce.
L Hereditary material is required to divide and produce new cells, but it is not required for anything else.
M Having hereditary material is a fundamental life process required to be classified as a living cell.

Refer to the image below to answer question 7.



7. The image of some human cheek cells above is likely to have been magnified using

   J a light microscope.
   K a magnifying glass.
   L a transmission electron microscope.
   M a scanning electron microscope.

8. The cell membrane defines a cell. This means that

   J the cell membrane is the boundary between the intracellular and extracellular environments.
   K only the cells that make up multicellular organisms have cell membranes.
   L something is classified as a cell if it has a membrane.
   M the cell membrane is where the DNA is located.

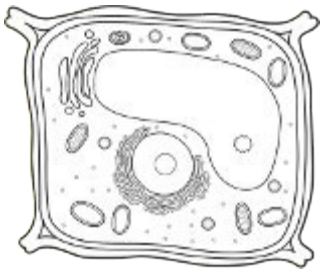
9. The human endocrine system consists of glands that communicate through the secretion of hormones into the blood. These hormones have specific shapes and only bind to specific receptors that have a complementary shape.

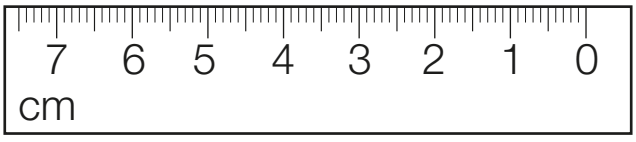
   The most correct reason why humans require an endocrine system, but bacteria do not is because

   J bacteria only respond to antibiotics.
   K living things require hormones to exhibit every fundamental life process.
   L humans are multicellular.
   M if humans did not have an endocrine system, they would not be classified as living in accordance with the cell theory.

10. A plant cell with an actual size of 80µm was viewed under a light microscope. Use the image below to determine the magnification of this plant cell.

    J ×400
    K ×500
    L ×1500
    M ×3200





Free response questions

1. State **three** life processes performed by all forms of life.

2. Using examples, explain the difference between a unicellular and multicellular organism.

3. State the **three** features of the original cell theory.

4. Cells vary in size. State **one** example of:
   a) very small cell in a human
   b) a large cell in a human
5. Explain why the cell theory was not formulated until after the invention of the light microscope.

6. State **two** functions of the cell membrane.

7. State why specimens observed using a light microscope must be very thin.

8. State **two** properties of the molecule DNA that explain why it is found in virtually all forms of life.

9. Explain why the cell is described as the unit of structure and function in a multicellular organism.

10. A student found a scaly leafy type structure growing on a rock surface. Describe **two** pieces of evidence they could collect or observe to enable them to determine if this was a living organism.

11. Explain **one** likely reason why all the leaves of an indoor plant have grown towards the window it faces.

12. A student was examining two sets of photographs one taken with a light microscope and the other with an electron microscope. Explain the evidence to the student that would enable them to determine which one was which.

13. *Refer to the table below of some typical sizes of cells to answer the questions that follow*:

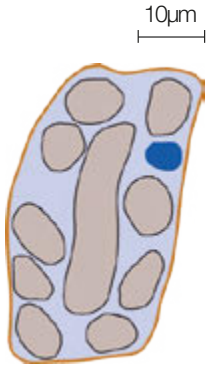
Cell	Human skin cell	Bacteria	Human ovum	Amoeba
Approximate size	50 µm	2 µm	0.12 mm	50 µm

a) Use data from the table above to determine if a human ovum or an amoeba is bigger.

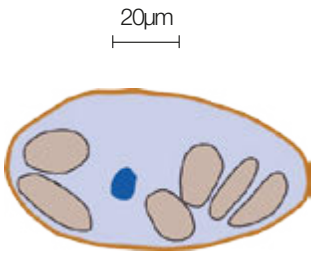
b) Determine how many times bigger an ovum is than a skin cell.

c) Approximately how many *E. coli* bacteria would fit across a human skin cell?

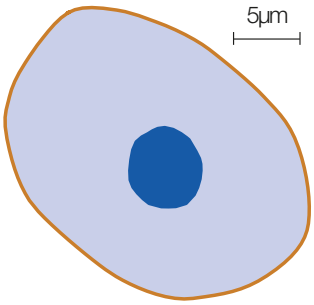
14. The diagrams below show three types of cells. Use the scale bars to select the longest cell **and** explain your reasoning.



Moss cell



Banana cell

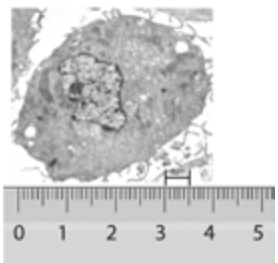


Liver cell

15. Use the scale bars on the diagram to the right to determine:

a) the actual size of this animal cell.

b) the magnification used to view this animal cell.



Chapter 1.2 Two major types of cells

Science Understanding

The major cell types are:

- prokaryotic
- eukaryotic.

Prokaryotic and eukaryotic cells have many features in common (a reflection of their common evolutionary past). These features include:

- cell membrane
- nucleic acids
- proteins
- ribosomes.

Prokaryotic cells lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotic cells, and usually have a single circular chromosome.

- Compare the structure of prokaryotes and eukaryotes.

The two major types of cells

The two major types of cells are prokaryotic cells and eukaryotic cells. Prokaryotic cells are smaller, simpler and less specialised than eukaryotic cells. Prokaryotic cells do not have a true nucleus and do not contain membrane-bound organelles, whereas the more complex eukaryotic cells do. Prokaryotes have the ability to adapt to a vast range of habitats and their collective mass is considered to be many times that of all of the eukaryotes.

Prokaryotic cells have existed for millions of years and are known to be the first organisms to inhabit the earth. There is strong evidence that supports that eukaryotes evolved from prokaryotes. Some examples of evidence supporting this are:

- prokaryotic cells and eukaryotic cells do share some common features such as cell membranes, nucleic acids (DNA and RNA), ribosomes and proteins, and
- fossil records show that the oldest prokaryotes discovered are 3.5 billion years old whereas the oldest unicellular eukaryotes are 2 billion years old.

Prokaryotic cells

Prokaryotic cells are unicellular and are generally very small (approximately 0.1-5µm). They may be rod-shaped, spherical or spiral. They **do not contain a nucleus**, so the single circular chromosome resides in the cytoplasm in a region called the nucleoid. The two examples of prokaryotic cells are **bacteria** and **archaea**. Even though prokaryotic cells are small and relatively unspecialised, they are well organised and possess all the necessary chemicals and processes that enable them to carry out all of life's processes (see Figure 1.2.1).

Prokaryotic cells usually:

- exist as single cells
- have a **cell wall** that surrounds the **cell membrane**
- contain a **single circular chromosome** located in the **nucleoid region** of the cytoplasm
- contain **ribosomes** that are free floating in the cytoplasm.

Some prokaryotes have structures in addition to those mentioned above. These may include:

- A layer of sticky material that covers the cell wall called a **capsule**
- Hair-like structures that project from the cell wall called **pili** (singular pilus)
- Filaments attached to the cell wall called **flagella** (singular flagellum)
- Small loops of DNA in the cytoplasm that are separate from the chromosome called **plasmids**.

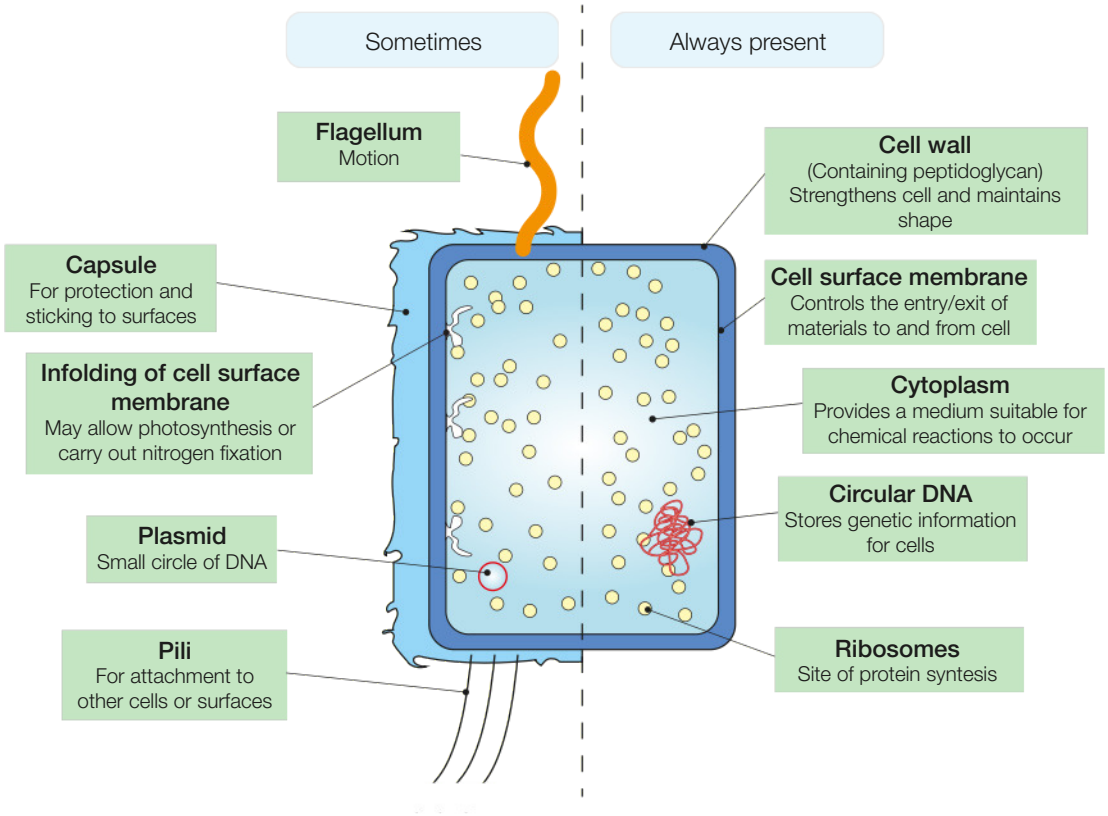


Figure 1.2.1: The structure and functions of different parts of a generalised prokaryotic cell.

Eukaryotic cells

Eukaryotic cells tend to be larger (approximately 10-100 µm) and more complex than prokaryotic cells. They contain many **membrane-bound organelles** including a nucleus, which have specific structures that suit their particular function in the cell. The compartmentalised nature of eukaryotic cells means that they can maintain different environments within a single cell, enabling them to conduct numerous metabolic reactions simultaneously. As a result, eukaryotic cells can grow much larger than prokaryotic cells. Eukaryotic cells are predominantly found in multicellular organisms, but not exclusively. **Protists, fungi, plants and animals** are all consist of eukaryotic cells.

Eukaryotic cells usually:

- **store DNA in a nucleus as pairs of linear chromosomes** (see Figure 1.2.2).
- contain a variety of membrane-bound organelles (see Table 1.2.1 for the main organelles and their functions).
- exist with large numbers of similar cells (e.g. in animals/plants) but may exist as single cells (e.g. protists).
- are significantly larger than prokaryotic cells.

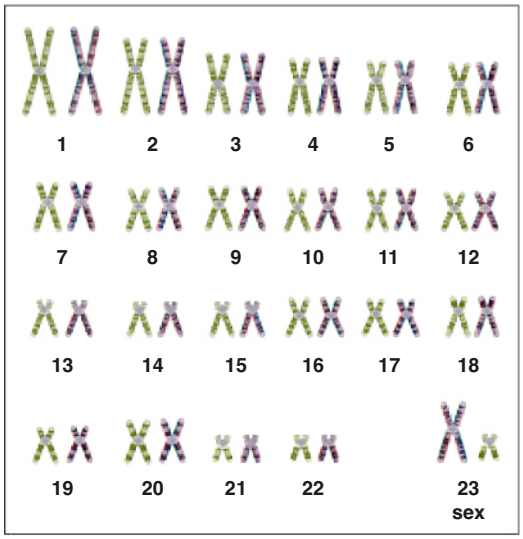


Figure 1.2.2: A human karyotype which highlights the 23 pairs of linear chromosomes that exist in the nucleus of human cells (eukaryotic cells).

Although animal and plant cells are both eukaryotic cells, their structure differs in several ways (see Figure 1.2.3). The main differences are:

- **plant cells** have a **cell wall (composed of cellulose)**; animal cells do not.
- **plant cells** have a **large central vacuole**; animal cells do not.
- **plant cells** may have **chloroplasts**; animal cells do not.

To determine if a cell is a plant cell, it is best to look for the presence of these features mentioned above. **Chloroplasts are only found in plant cells** and therefore any cell containing them is a plant cell. Be careful not to mix up chloroplasts with mitochondria though. They both have a similar shape and size, but they have different structures and functions (see Table 1.2.2 for more information).

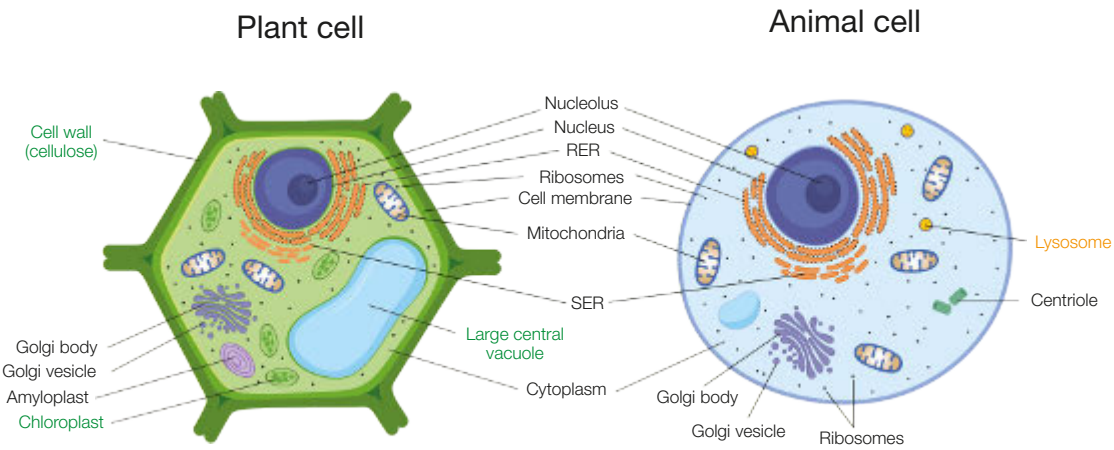
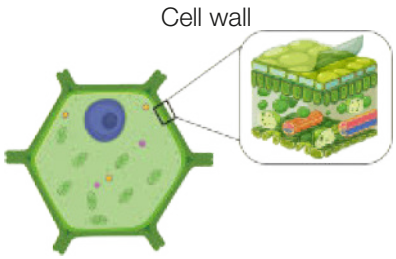
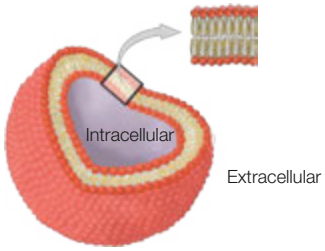
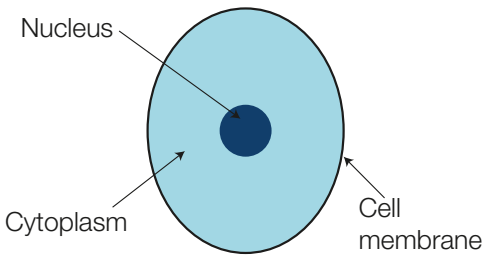
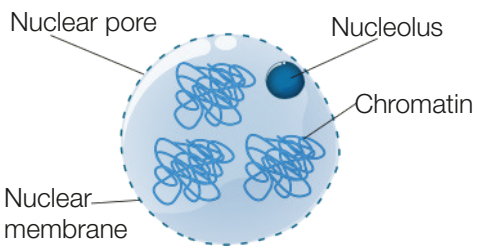
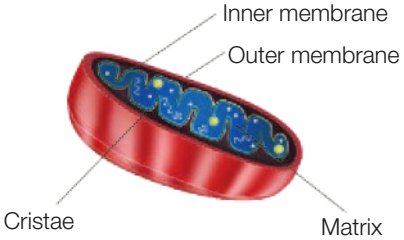
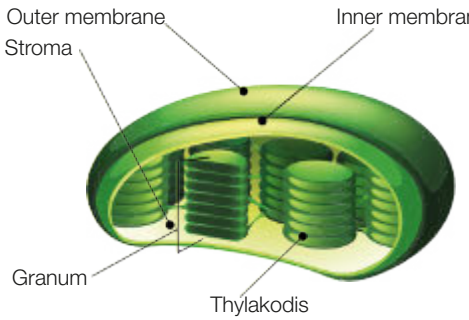
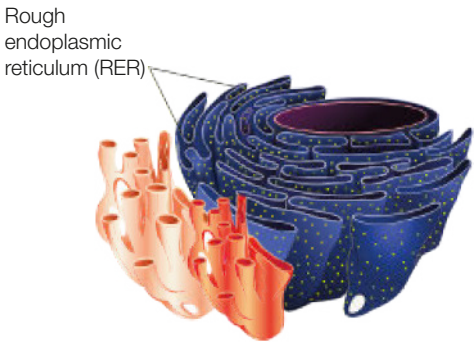
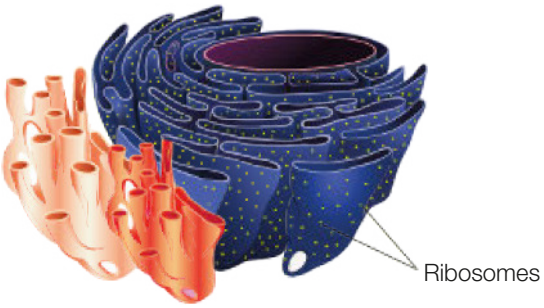
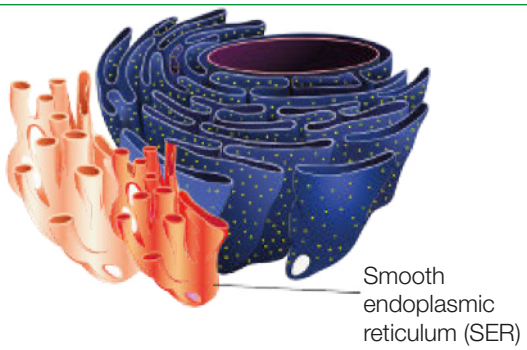
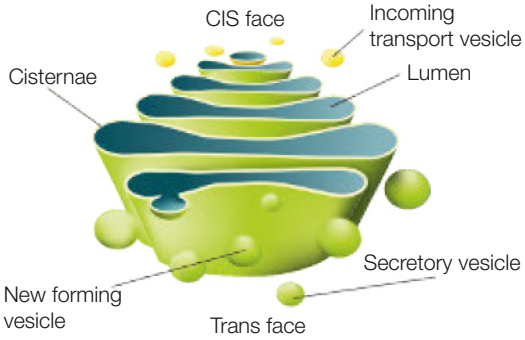


Figure 1.2.3: The structural differences of a typical plant and animal cell.

Table 1.2.1: A summary of some eukaryotic structures and their respective functions.

Cell structure	Image	Function(s)
Cell wall Note: they are not found in animal cells. Note: it is not an internal membrane-bound organelle.		To strengthen the cell and to help maintain its shape.
Cell membrane Note: it is not an internal membrane-bound organelle.		To control the exchange of materials between the cell and its external environment and to facilitate communication between cells.
Cytoplasm Note: it is not considered an organelle, but it is the space inside the cell membrane where internal organelles reside.		To contain the **cytosol**, which is the fluid in the cytoplasm, and provide a medium suitable for biochemical reactions to take place.
Nucleus Note: the plural of nucleus is nuclei.		To store and protect the genetic information (DNA), and to coordinate the overall functions of a cell.
Mitochondrion Note: the plural of mitochondrion is mitochondria.		To carry out aerobic respiration to produce an energy-carrying molecule called ATP which cells use for energy-requiring processes.

Cell structure	Image	Function(s)
Chloroplast Note: they are only found in some types of plant cells.		To carry out photosynthesis to produce organic molecules (glucose) using simple inorganic ones (carbon dioxide and water).
Rough endoplasmic reticulum (RER)		To package proteins made by ribosomes into small vacuoles for transport to a Golgi body.
Ribosomes		To synthesise proteins for the cell or for secretion from the cell.
Smooth endoplasmic reticulum (SER)		To synthesise lipids (e.g. phospholipids and cholesterol) and metabolise carbohydrates.
Golgi body Note: They are also called golgi apparatus.		Modification, processing and packaging of proteins into vesicles for storage within the cell or movement out of the cell by exocytosis.

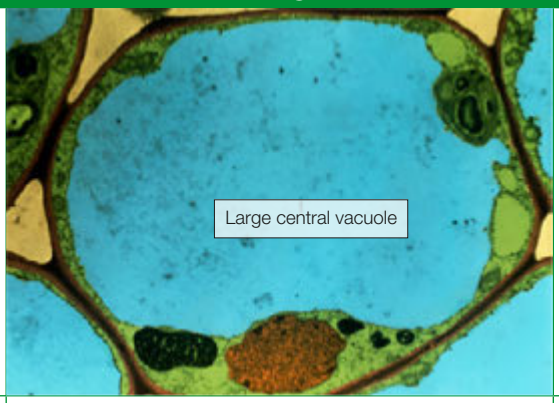
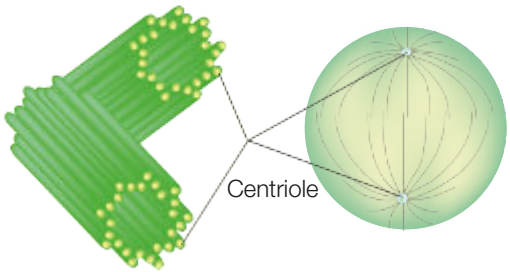
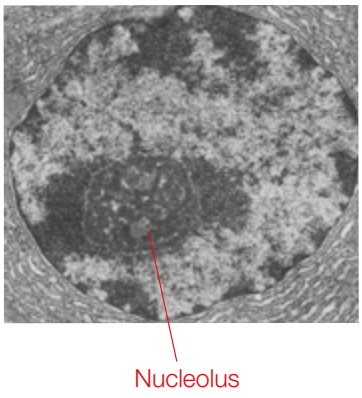
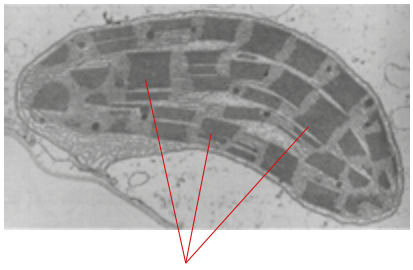
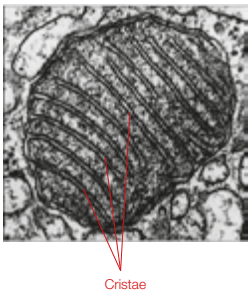
Cell structure	Image	Function(s)
Large central vacuole Note: they are only found in some types of plant cells Note: vacuoles can be found in animal cells but they are much smaller and are not large central vacuoles.		Many functions including: • storage of water in plant cells • provides structural support and regulates plant cell shape • nutrient storage • storage and disposal of waste products
Centrioles Note: they are only found in animal cells.		Required for development of the spindle apparatus and the separation of sister chromatids during cellular division (see Chapter 1.3 for more information).

Table 1.2.2: A comparison of the nucleus, chloroplast and mitochondrion structures viewed as an electron micrograph. Note: these micrographs are not to the same scale.

Nucleus	Chloroplast	Mitochondrion
		
The nucleus is the biggest organelle in the cell (apart from the vacuole in plant cells) and contains a nucleolus inside it which can generally be seen easily and can help identify it.	The grana (stacks of membrane containing chlorophyll) can clearly be seen in the chloroplast above and can help identify it.	The folded inner membrane extensions (called cristae) can clearly be seen extending across the mitochondrion. These 'lines' can clearly be contrasted to the 'stacks' of chloroplasts.

Comparing the structure of prokaryotic and eukaryotic cells

Whilst there are a number of differences between prokaryotic and eukaryotic cells there are also a number of structural and functional similarities, a fact that supports and is a reflection of their common evolutionary past. Refer to Table 1.2.2 for a comparison of prokaryotic and eukaryotic cells.

Table 1.2.2: A comparison of the structural features between prokaryotic and eukaryotic cells.

Structural features	Prokaryotic cells (e.g. bacteria, archaea)	Eukaryotic cells (e.g. protists, fungi, plants and animals)
Size	Generally smaller (most bacteria 0.1-5μm)	Generally larger (most animal & plant cells 10-100μm)
Cell type	Unicellular	Unicellular or multicellular
Chromosome shape	One circular chromosome	Many linear chromosomes (generally in pairs)
Location of chromosome(s)	In cytoplasm	In nucleus
Membrane-bound organelles	None	Many different types
Ribosomes	Smaller ribosomes are present and free floating in the cytoplasm	Larger ribosomes are present and generally attached to a rough endoplasmic reticulum (can also be free floating in the cytoplasm)
Cell division	Binary fission	Mitotic division
Cell wall	Present but consists of a different carbohydrate to eukaryotic cell walls (peptidoglycan)	Only present in plant (cellulose) and fungi (chitin) cells but both consist of a different carbohydrate to prokaryotic cell walls
Cell membrane and cytoplasm	Present	Present

Helpful online resources

RicochetScience: Prokaryotic Vs. Eukaryotic Cells

<https://www.youtube.com/watch?v=RQ-SMCmWB1s>

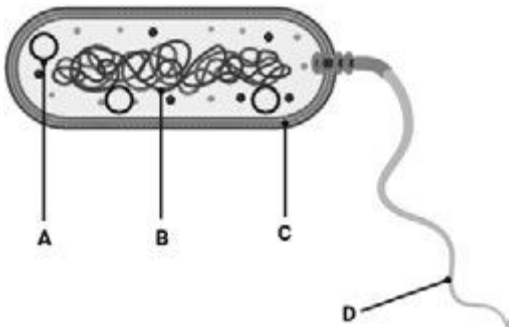
1.2 Review questions

Multiple choice questions

1. Which of the following statements is true for prokaryotic cells.

   J They are generally about 10-100µm in size.
   K They contain a single circular chromosome in the nucleus.
   L Bacteria and archaea are examples of prokaryotic cells.
   M They contain membrane-bound organelles.

2. *Refer to the diagram below to answer the following question.*



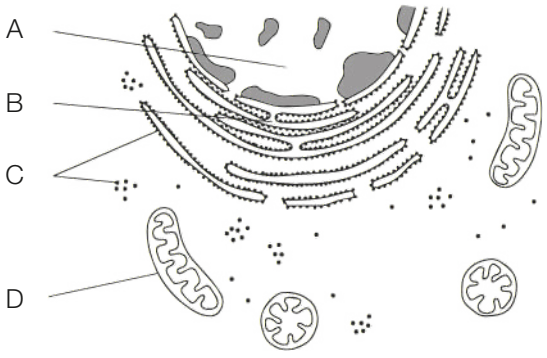
Identify the four structures in the diagram above labelled A, B, C and D.

	A	B	C	D
J	Ribosome	Circular chromosome	Cell Wall	Pili
K	Plasmid	Circular chromosome	Cell wall	Flagellum
L	Plasmid	Cytoplasm	Cell Wall	Flagellum
M	Ribosome	Cytoplasm	Flagellum	Pili

3. Which of the following options would be the most useful when trying to identify whether a cell is prokaryotic or eukaryotic?

   J The presence of a cell wall surrounding the cell membrane.
   K The presence of linear chromosomes.
   L Determining that the cell is unicellular.
   M The presence of ribosomes in the cell.

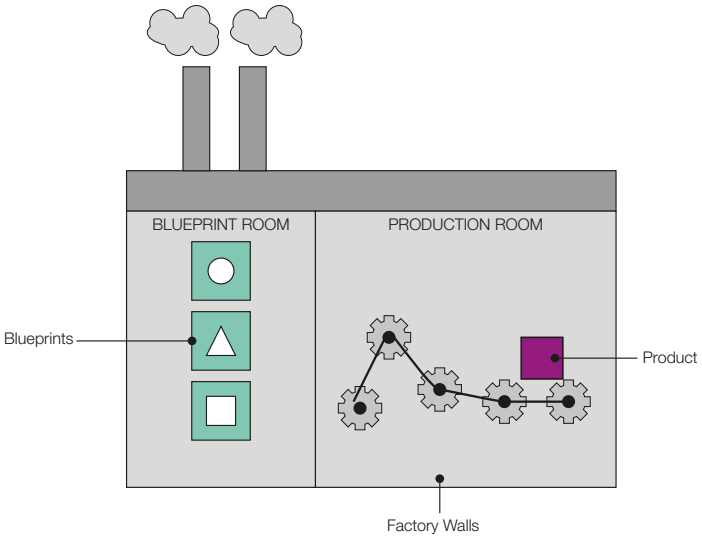
4. *Refer to the diagram below to answer the following question.*



Identify the four organelles labelled A, B, C and D in the diagram above.

	A	B	C	D
J	Nucleus	Golgi body	Vacuole	Chloroplast
K	SER	RER	Vacuole	Chloroplast
L	SER	Golgi body	Ribosomes	Mitochondrion
M	Nucleus	RER	Ribosomes	Mitochondrion

Refer to the text and image below to answer questions 5 to 7.



A cell is often compared to a factory where the blueprint (DNA) is translated into a product (protein) using the factory's (cells) machinery.

5. Use the image and the information provided above to determine the organelle that best represents the '*Production Room*' in this analogy.

   J ribosome
   K cytoplasm
   L smooth endoplasmic reticulum
   M nucleus

6. The '*Factory Walls'* have doors that require a security pass, which helps to control the movement of people in and out of the factory.

   Use the image and information provided above to determine the organelle that best represents the '*Factory Walls*' in this analogy.

   J cell wall
   K cytoplasm
   L capsule
   M cell membrane

7. The image above does not show the '*Powerplant Room'* of the factory that supplies the factory with electricity.

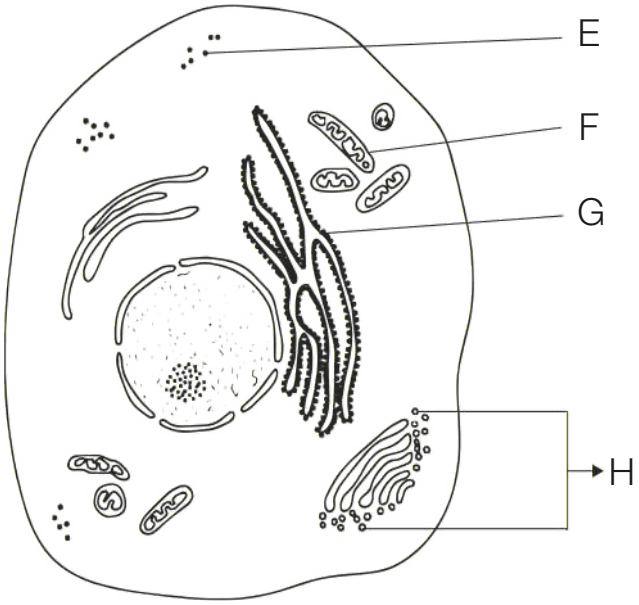
   Using the image and information provided above, determine the organelle that best represents the '*Powerplant Room'* in this analogy.

   J nucleus
   K chloroplast
   L mitochondrion
   M ribosome

8. Which of the following options is **not** evidence that prokaryotic and eukaryotic cells share a common evolutionary past and eukaryotic cells likely evolved from prokaryotic cells?

   J Prokaryotic cells and eukaryotic cells share some common features such as cell membranes and ribosomes.
   K Eukaryotic cells are more primitive and less specialised than prokaryotic cells.
   L Fossil records show that the oldest prokaryotes discovered are 1.5 billion years older than the oldest eukaryotic cells discovered.
   M Both prokaryotic and eukaryotic cells contain the same genetic code – DNA.

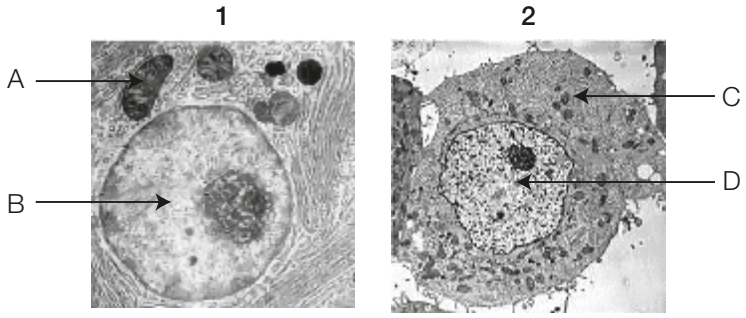
9. *Refer to the image below to answer the following question.*



Identify the type of cell and the structures labelled E, F, G and H.

	Type of Cell	E	F	G	H
J	Animal cell	Ribosomes	Mitochondrion	RER	Golgi body
K	Plant cell	Ribosomes	Chloroplast	SER	Golgi body
L	Animal cell	Ribosomes	Chloroplasts	RER	SER
M	Plant cell	Proteins	Mitochondrion	Golgi body	SER

10. *Refer to the two electron micrographs (1 and 2) below to answer to following question. Note that they are not viewed at the same magnification.*



Determine the four organelles (A, B, C and D) and the likely magnification of electron micrographs 1 and 2.

	A	B	C	D	Magnification of Image 1	Magnification of Image 2
J	Mitochondrion	Nucleus	Mitochondrion	Nucleus	Lower	Higher
K	Chloroplast	Nucleus	Chloroplast	Nucleus	Lower	Higher
L	Mitochondrion	Nucleus	Mitochondrion	Nucleus	Higher	Lower
M	Chloroplast	Nucleus	Chloroplast	Nucleus	Higher	Lower

Free response questions

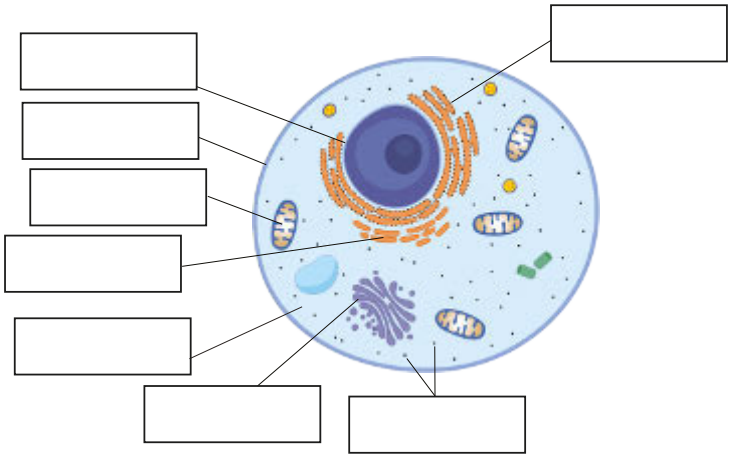
1. Complete the following table for some of the organelles found in bacterial, plant and animal cells.

Organelle	Present in bacterial, plant and/or animal cells	Structural features	Special functions
Cell wall			
Nucleus			
Nucleoid			
Mitochondria			
Chloroplasts			
Ribosomes			
Smooth endoplasmic reticulum			

2. State **three** features that eukaryotic and prokaryotic cells have in common.

3. Describe **two** differences between prokaryotic and eukaryotic cells.

4. a) Identify **and** label the highlighted structures of the following eukaryotic cell:



b) Identify the structures of the eukaryotic cell in the diagram above that are not considered internal membrane-bound organelles.

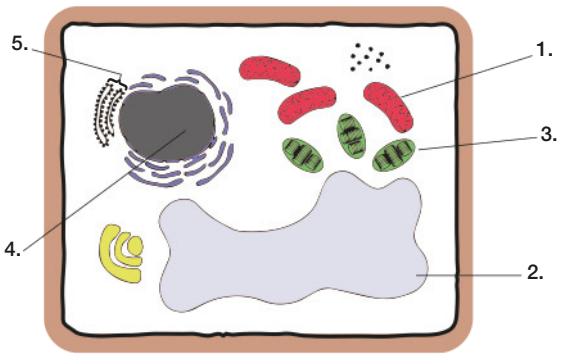
5. Prokaryotic cells do not contain membrane-bound organelles. Discuss how is it possible for them to grow, divide and make energy available.

6. A human consists of approximately 230 different types of cells. As each type of human cell has different structures and functions, they often contain differing numbers of each organelle. Suggest **one** type of human cell where large numbers of the following organelles would be found:

   a) Mitochondria

   b) Golgi bodies

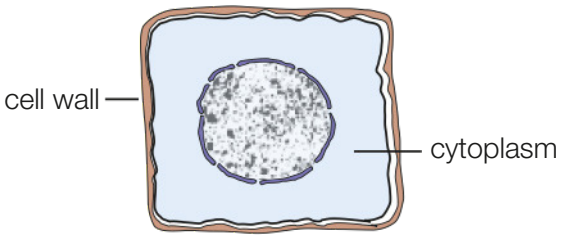
7. Refer to the adjacent diagram, which shows the structure of a eukaryotic plant cell and some of its organelles to answer the following questions.



   a) State **two** functions of organelle 2.

   b) Determine if this plant cell is likely to be found in leaves **and** justify your answer using evidence from the diagram.

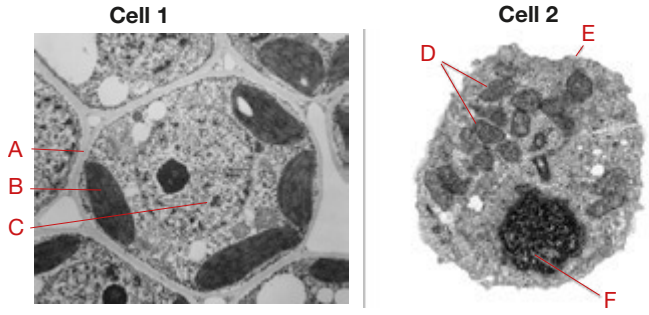
8. The adjacent diagram shows a student's partly labelled drawing of a cell.



   a) Based only on the information shown in the diagram, determine if the cell is prokaryotic or eukaryotic.

   b) Justify your answer.

9. *Refer to the electron micrographs of 'Cell 1' and 'Cell 2' below to answer to following questions.*



   a) Identify what type of cell '*Cell 1*' is **and** use evidence to justify your answer.

   b) Identify what type of cell '*Cell 2*' is **and** use evidence to justify your answer.

c) Identify the organelles labelled A, B, D and E **and** state their functions.

(i) Name of organelle A:

Function of organelle A:

(ii) Name of organelle B:

Function of organelle B:

(iii) Name of organelle D:

Function of organelle D:

(iv) Name of organelle E:

Function of organelle E:

d) Compare the structure and function of the two organelles labelled C and F.

Chapter 1.3 Cell division

Science Understanding

In order to reproduce, cells need to copy their genetic material, and then divide to form two new (daughter) cells.

- Describe and represent binary fission in prokaryotic cells.
- Describe and represent mitosis.
- Compare binary fission with mitotic cell division in eukaryotic cells.

The purpose of cell division

New cells are formed by a process called cell division. The division of cells is fundamental to the **continuity of life** of all living things. This is because cell division:

- Permits genetic information (encoded in DNA) to be transmitted from generation to generation.
- Provides a way for multicellular organisms to **grow** and develop from a fertilised ovum.
- Makes new cells available in multicellular organisms to **replace** dead or **repair** damaged cells.
- Allows some organisms to **reproduce** asexually.

It is important to recognise that only binary fission in prokaryotic cells and mitotic division in eukaryotic cells is discussed in Chapter 1.3. Many multicellular eukaryotic organisms reproduce sexually. This involves another type of cell division called meiotic division, which occurs in germline cells to produce gametes (e.g. sperm and ova in animals). **Meiotic division is covered in the Stage 2 Biology course**. Therefore, in Chapter 1.3, mitotic division for the purpose of reproduction, is only referring to eukaryotic organisms that can reproduce asexually. Some examples include:

- unicellular amoeba
- multicellular hydra
- multicellular sea stars
- multicellular strawberry plants

Transferring DNA between generations of cells

A dividing cell, called a parent cell, must pass on an **identical copy of its DNA** to each of the two new daughter cells formed. It is therefore essential for the doubling of DNA to occur through a process called **DNA replication, prior to cell division** (see Figure 1.3.1). If DNA replication does not occur prior to cell division, it is not possible for a parent cell to supply an identical copy of its DNA to its two potential daughter cells. It is important to note that the process of DNA replication is covered in the Stage 2 Biology course, but the general understanding of the purpose of this process is required when discussing cell division in Stage 1 Biology.

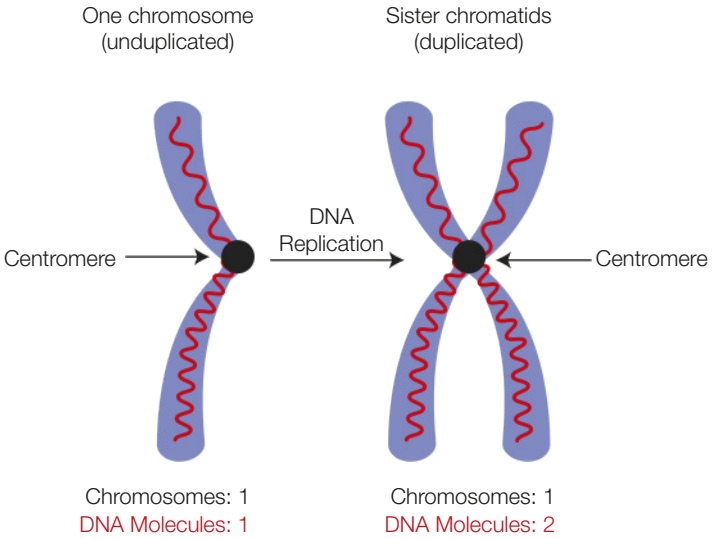


Figure 1.3.1: Prior to mitotic division, a eukaryotic cell has one copy of each chromosome, but following a process called DNA replication, a cell has two identical copies of each chromosome (called sister chromatids) that are joined together at the centromere.

The transfer of identical copies of DNA from parent cells to daughter cells involves a few events:

1. The doubling of DNA through DNA replication, prior to cell division.
2. The two copies of the DNA need to be moved to opposite ends of the parent cell (to ensure each daughter cell gets one copy each).
3. The cytoplasm of the parent cell must be divided to form the two new daughter cells.

The three events mentioned above are required for both binary fission and mitotic division to occur. There are differences in how the three events occur in prokaryotic and eukaryotic cells and this is discussed further in the specific sections on binary fission and mitotic division in this Chapter 1.3. Additionally, Figure 1.3.2 highlights these three steps occurring in a unicellular eukaryotic amoeba cell.

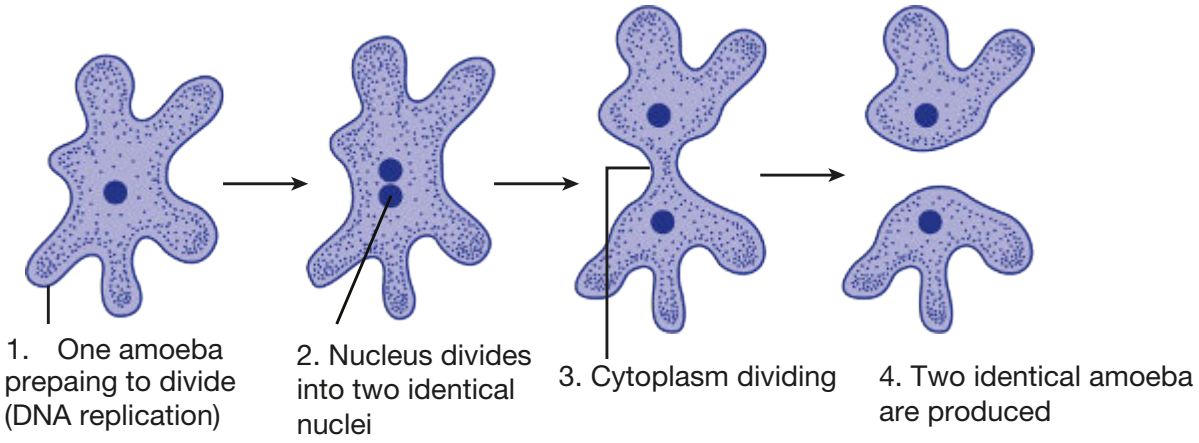


Figure 1.3.2: Cellular division can allow unicellular organisms such as an amoeba to reproduce asexually, resulting in two identical and fully functional amoeba.

Binary fission

Most unicellular prokaryotic organisms, such as bacteria and archaea, reproduce by a type of cell division called binary fission. As prokaryotic cells are simple cells and their DNA is located in the cytoplasm rather than a nucleus, the process of binary fission is also a relatively simple one.

Prior to binary fission, **the cell's contents doubles**. This includes the synthesis of more ribosomes, plasmids and doubling of DNA. The parent cell's **circular chromosome is replicated to produce two identical copies** to ensure that each eventual daughter cell has a copy of its own upon the division of its cytoplasm. Refer to Table 1.3.1 and Figure 1.3.3 for an outline of the main steps in the process of binary fission.

Table 1.3.1: The main steps in the process of binary fission in prokaryotic cells.

	Prokaryotic binary fission process
1.	The cell's circular chromosome attaches to the inside of the cell membrane.
2.	DNA replication occurs, resulting in two identical circular chromosomes that are attached to the cell membrane.
3.	The size of the cell increases length-ways (elongates), which separates the two chromosomes.
4.	The separated chromosomes are moved to the opposite ends of the original (parent) cell as the cell elongates.
5.	A new cell wall and cell membrane form (known as the cross wall) through the centre of the cell.
6.	The cell divides into two daughter cells, each one with one identical circular chromosome.

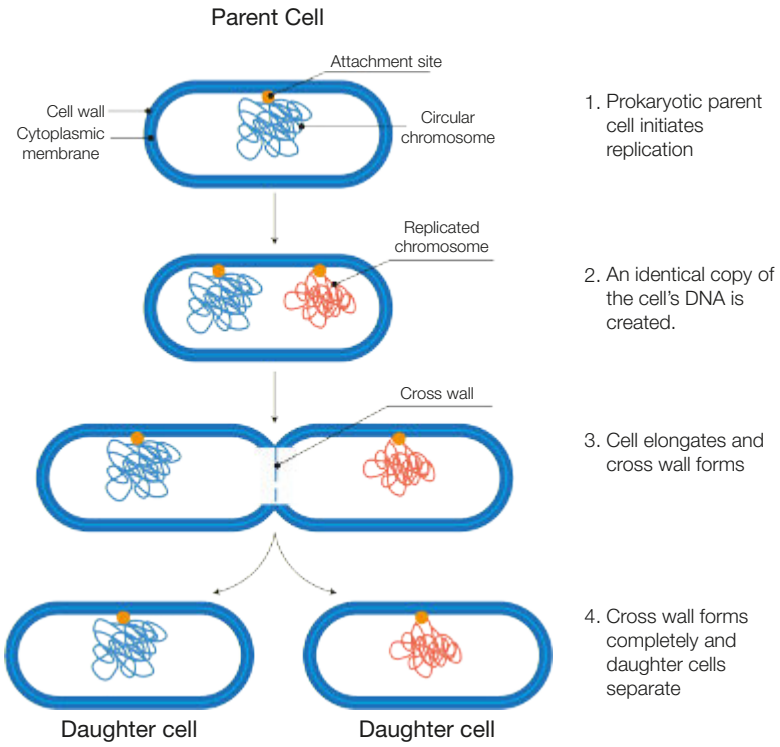


Figure 1.3.3: A visual representation of the major steps involved in the process of binary fission.

Helpful online resources

Cognito: Binary Fission - How Do Bacteria Divide?

<https://www.youtube.com/watch?v=kKiz8Wzcfc8>

Mitotic division

As eukaryotic cells are more complex and have their DNA stored in a nucleus, a more complex division is required. Both the contents of the nucleus and the cytoplasm need to be divided. Most eukaryotic cells divide by a type of cell division called mitotic division.

Prior to mitotic division, the DNA is in a decondensed (or uncoiled) structure called **chromatin**. This decondensed structure of chromatin makes it easier for the DNA molecules to be replicated. Each linear DNA molecule in the nucleus is replicated to produce **two identical sister chromatids joined at the centromere** within the cell's nucleus (see Figure 1.3.1).

Before mitotic division can begin, the **chromatin must condense** (coil tightly around the histone proteins) **to form chromosomes** (see Figure 1.3.4). This condensation allows the DNA to be moved around the cell easily during mitosis and helps to protect the long DNA molecules from getting tangled during the division of the nucleus. For example, there are 46 duplicated chromosomes in human cell ready to divide by mitotic division. This equates to approximately 4 metres of DNA if stretched out end-on-end. The condensation of this roughly 4 metres of DNA into tightly packed chromosomes, helps to ensure the **protection of the genetic code** and also makes the **individual chromosomes visible under a light microscope** (see Figure 1.3.5).

Once the cell is fully prepared to divide, mitotic division can begin. Mitotic division involves two processes:

- Mitosis (division of the nucleus), and
- Cytokinesis (division of the cytoplasm)

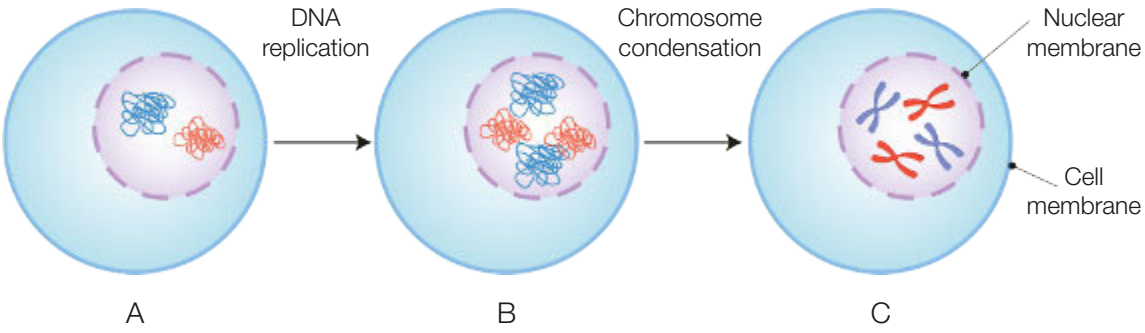


Figure 1.3.4: Prior to mitotic division the genetic information is decondensed and is called chromatin (A). This makes it easier for the cell machinery to access the genetic code in the process of DNA replication, resulting in a duplicated set of DNA that is still in chromatin form (B). Following DNA replication, the chromatin must condense to form chromosomes seen at (C).

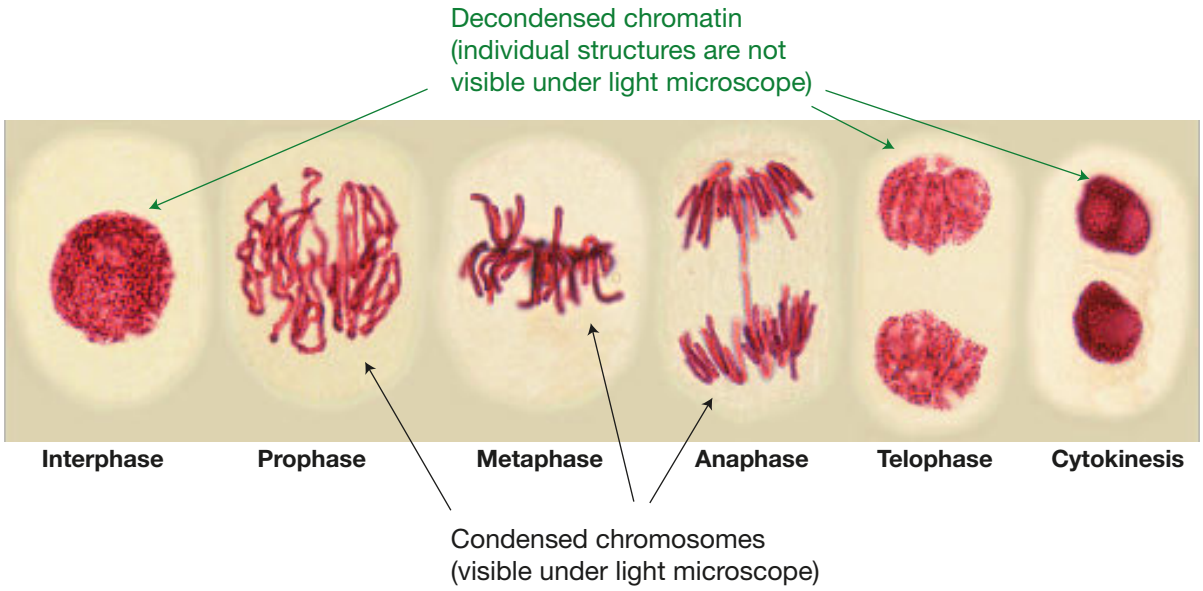


Figure 1.3.5: A photo micrograph of the stages of mitotic division and the distinguishment between chromatin and chromosomes.

Mitosis

Mitosis refers to the **division of the nucleus** and is a continuous process. During mitosis the nucleus of the parent cell divides to give rise to two identical daughter nuclei. There are four phases in this process where recognisable changes occur to the visibility and location of chromosomes in cells undergoing mitosis.

The four phases of mitosis are:

- **P**rophase
- **M**etaphase
- **A**naphase
- **T**elophase

A detailed look at each phase of mitosis is highlighted in Figures 1.3.6 to 1.3.9.

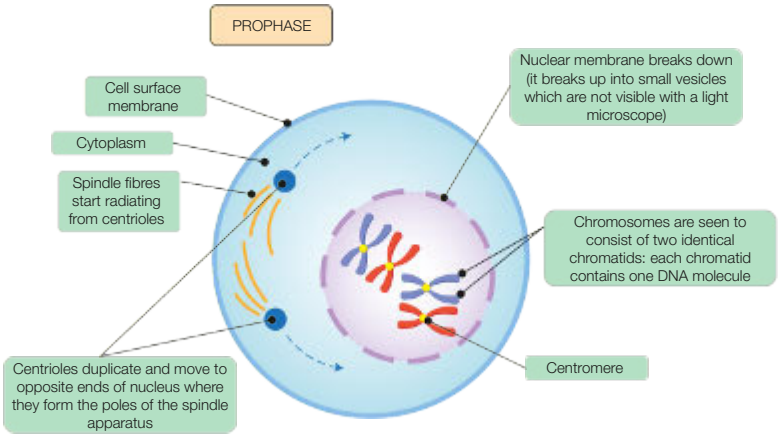


Figure 1.3.6: A summary of the main events that occur in prophase in a dividing animal cell.

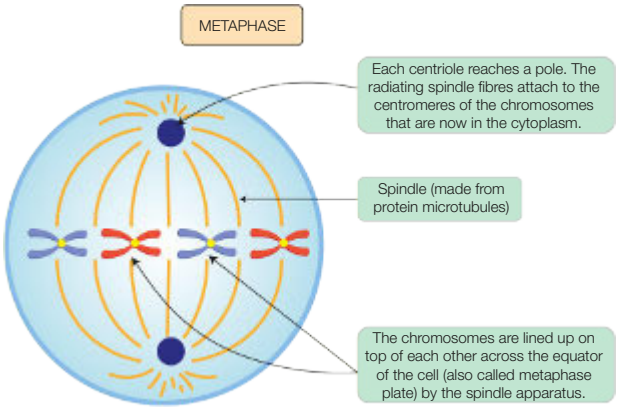


Figure 1.3.7: A summary of the main events that occur in metaphase in a dividing animal cell.

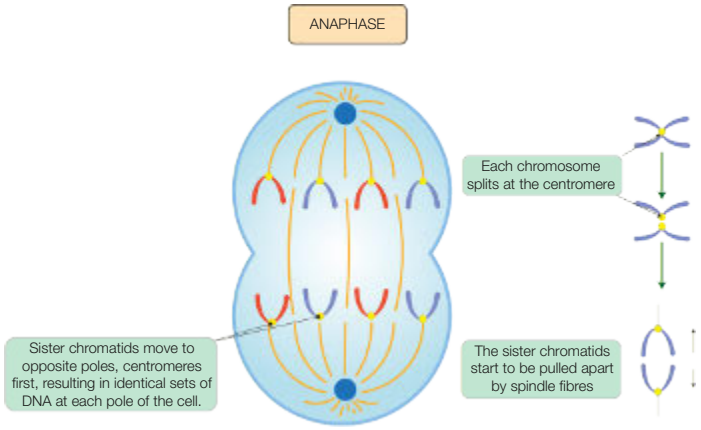


Figure 1.3.8: A summary of the main events that occur in anaphase in a dividing animal cell.

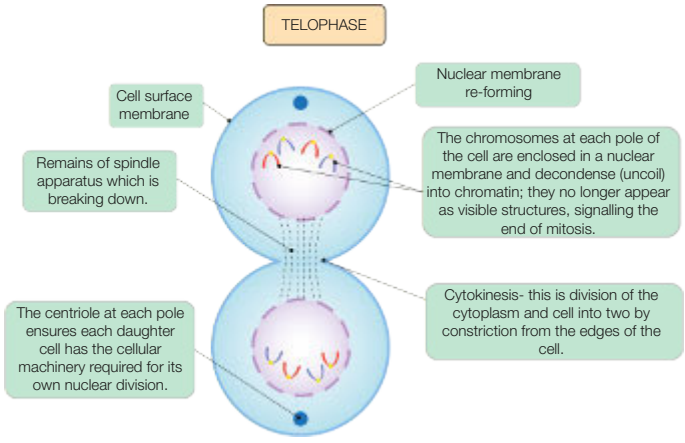


Figure 1.3.9: A summary of the main events that occur in telophase in a dividing animal cell.

Cytokinesis

Cytokinesis is considered separate to mitosis and is the **division of the cytoplasm** (not the nucleus). Cytokinesis starts in either anaphase or telophase (depending on the type of cell) and finishes after telophase. In animal cells, protein fibres (microfilaments) constrict the cell membrane to form an infolding called a cleavage furrow. Eventually, the constriction results in two separate genetically identical daughter cells (see Figure 1.3.10).

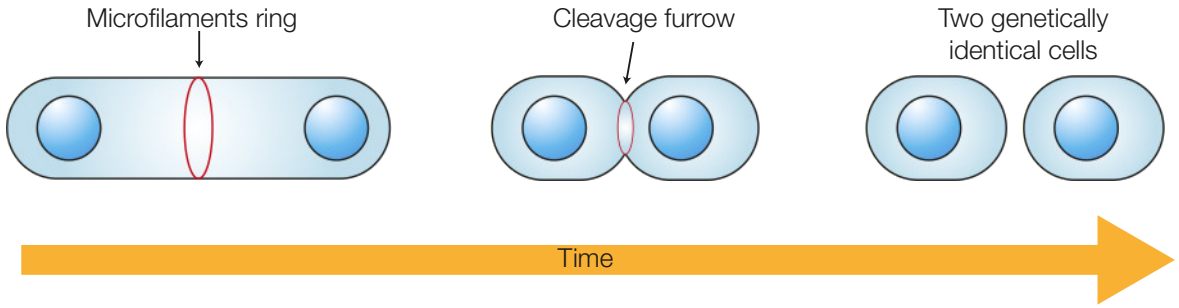


Figure 1.3.10: Cytokinesis is the division of the cytoplasm into two cells by constriction from the edges of the cell.

Helpful online resources

Amoeba Sisters: Mitosis: The Amazing Cell Process that Uses Division to Multiply! (Updated)

<https://www.youtube.com/watch?v=f-IdPgEfAHI>

Cancer

In the bodies of multicellular organisms there is a constant cycle of cells undergoing mitotic division to form new cells. For example, every epithelial cell in the lining of the intestines are replaced every 2-5 days. **It is important that mitotic division is highly regulated**. This is because the loss of control could lead to **uncontrolled cell division** and the formation of a mass of cells known as **a tumour or cancer** (see Figure 1.3.11). There are several factors that can increase the likelihood of uncontrolled cell division occurring such as exposure to ionising radiation, cigarette smoke, asbestos and even some viruses. The cell cycle that controls cell division is covered in more detail in Stage 2 Biology.

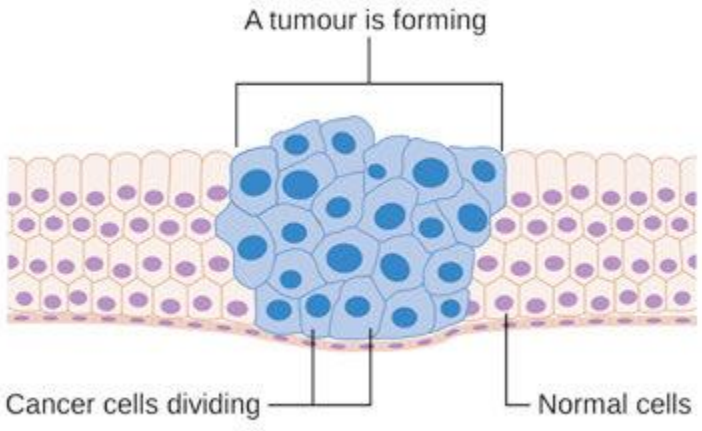


Figure 1.3.11: If one cell loses its control over one or more of the mechanisms controlling cell division, it can lead to uncontrolled cell division and formation of a tumour.

Comparing binary fission and mitotic division

Both binary fission and mitotic division allow prokaryotic cells and eukaryotic cells respectively to divide into two new genetically identical cells. There are some similarities and differences between these two processes. Refer to Table 1.3.2 for more details.

Table 1.3.2: A comparison of some features of binary fission and mitotic division.

Area of comparison	Binary fission	Mitotic division
Type of cell	Prokaryotic	Eukaryotic
Replication prior to division	Yes	Yes
Nuclear division	No	Yes
Type of chromosome(s)	Single, circular	Many, linear
Number of cells produced	Two	Two
Daughter cells	Clones of parent cell	Clones of parent cell
Spindle fibres involved	No	Yes
Growth if no restrictions	Exponential	Exponential

1.3 Review questions

Multiple choice questions

1. *Refer to the image to the right to answer the following question.*

   Identify the process shown in this image.

   J Mitosis
   K Chromatin condensing
   L Asexual budding
   M Binary fission

2. Which of the following options is **not** a phase of mitosis?

   J Prophase
   K Metaphase
   L Anaphase
   M Cytokinesis

3. Which of the following options is **not** a purpose of mitosis for all eukaryotic organisms?

   J Reproduction
   K Repair
   L Growth
   M Cell replacement

4. Sister chromatids are:

   J formed during mitosis.
   K attached by a centriole.
   L genetically identical.
   M separated during metaphase.

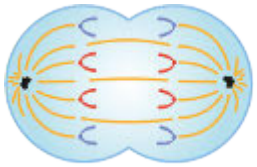
5. Outlined below are some various events that occur in the process of binary fission in no particular order:

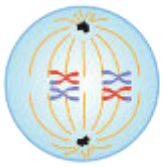
A	New cell wall forms between the two circular chromosomes.
B	Circular chromosomes are separated due to cell elongation.
C	DNA replication results in two identical circular chromosomes.
D	Daughter cells separate.
E	DNA replication is switched on when cell reaches a certain size.

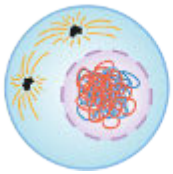
Select the correct order of these events of binary fission in the table below.

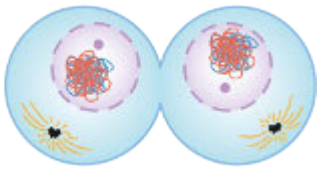
	1st	2nd	3rd	4th	5th
J	C	B	A	D	E
K	C	E	B	A	D
L	E	C	B	A	D
M	E	C	A	B	D

6. Which of the following is **not** a phase of mitosis?

J 

K 

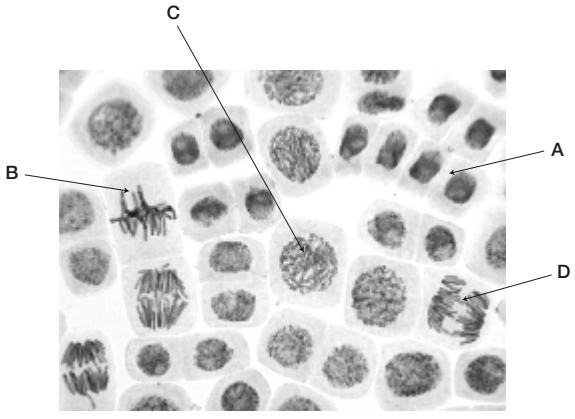
L 

M 

7. Identify the statement below that is **not** true of spindle fibres in mitotic division.

J They help align chromosomes along the metaphase plate.
K They radiate from centromeres.
L The break down during telophase.
M Are composed of protein microtubules.

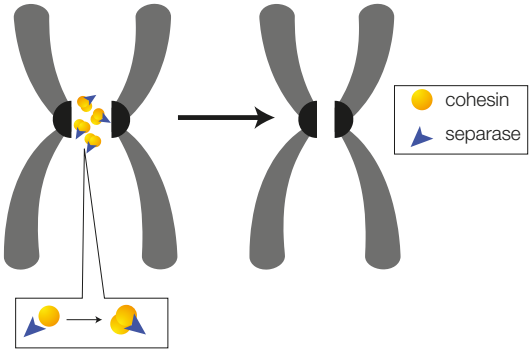
8. *Refer to the image below which shows some cells at various stages of mitotic division.*



Identify the correct order of the 4 phases of the process of mitosis.

	1st	2nd	3rd	4th
J	C	B	D	A
K	A	C	B	D
L	B	D	A	C
M	D	B	C	A

9. *Refer to the image below which shows an enzyme called separase breaking down a protein called cohesin during mitosis.*

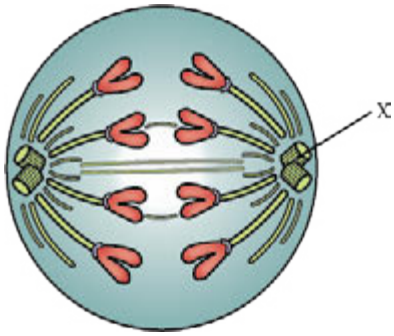


Cohesin is a protein that helps hold the two structures shown in the image together.

Identify the most likely phase of mitosis that separase breaks down cohesin.

J Prophase
K Metaphase
L Anaphase
M Cytokinesis

10. *Refer to the image to the right to answer the following question.*



Identify the structure labelled 'X' in this image.

J Centromere
K Chromatid
L Chromosome
M Centriole

Free response questions

1. Explain why the daughter cells produced by binary fission and mitosis are identical to the parent cell.

2. Outline **two** key events that occurs at each of the four phases of mitosis.

   a) Prophase

   b) Metaphase

   c) Anaphase

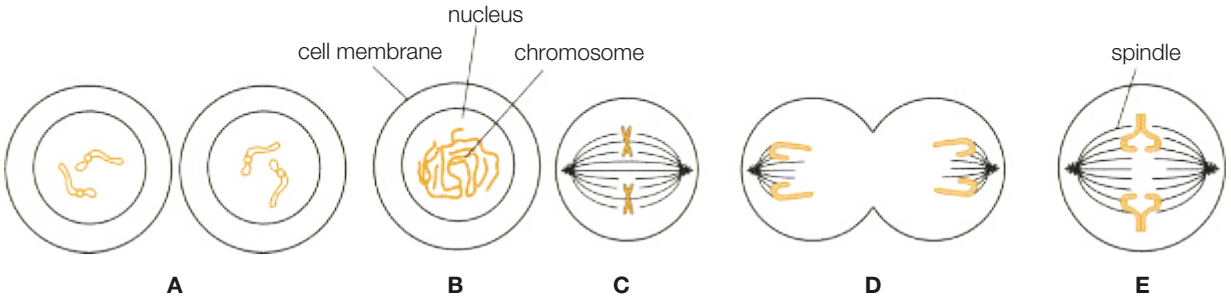
   d) Telophase

3. Distinguish between mitosis and cytokinesis.

4. Complete the table below comparing binary fission with mitosis.

Type of division	Type of organism	Type of chromosome	Number of cells formed	Spindle fibres involved?	DNA replication involved?
Binary fission					
Mitotic division					

5. The diagram below shows events that occur in mitosis.



a) Identify how many chromatids can be seen at C.

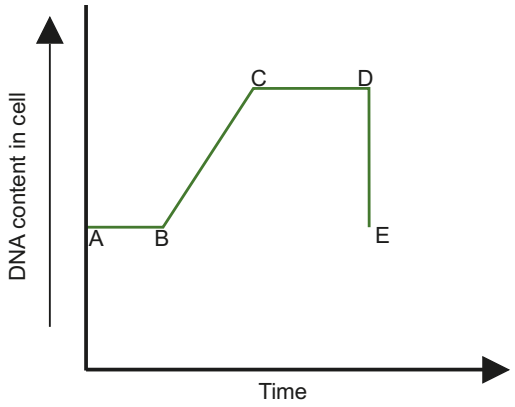
b) Determine the correct sequence of the events.

6. A student wrote the following to compare mitotic division with binary fission:

"*Binary fission is how all prokaryotic organisms reproduce and mitotic division is how all eukaryotic organisms reproduce.*"

Analyse the accuracy of the student's statement.

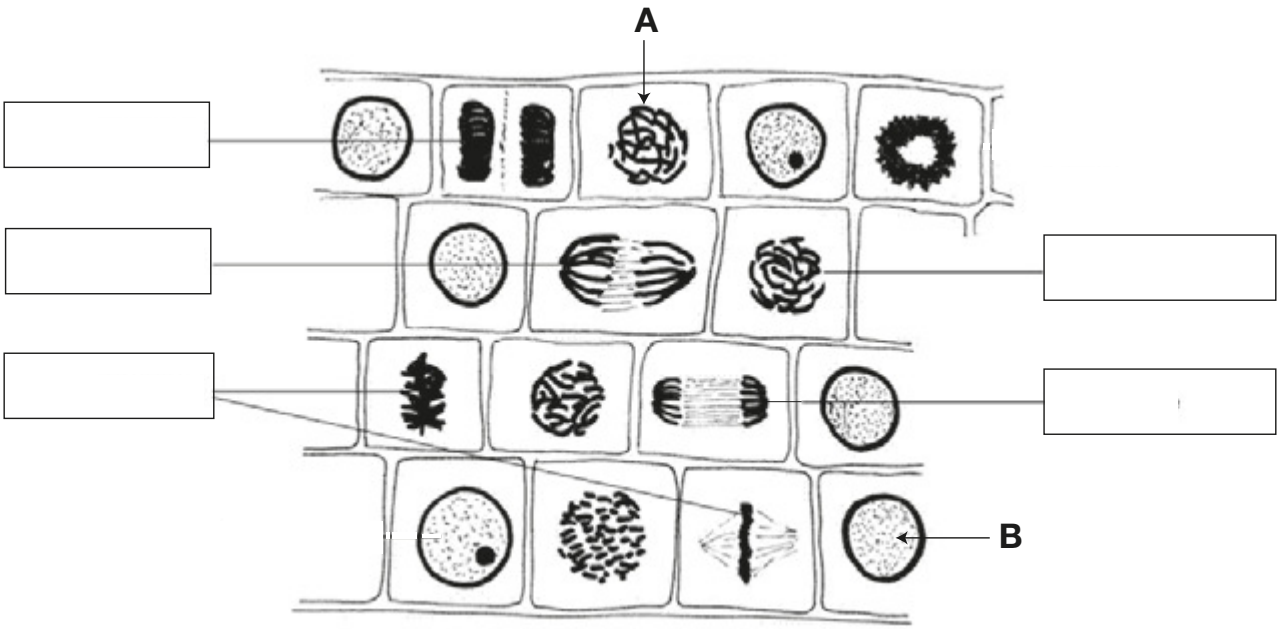
7. Refer to the graph below to answer the following questions.



a) Explain what is happening in the cell between stages B and C.

b) Explain what is happening in between the stages D and E.

8. *Refer to the image below which shows some plant cells viewed under a light microscope to answer the following questions.*



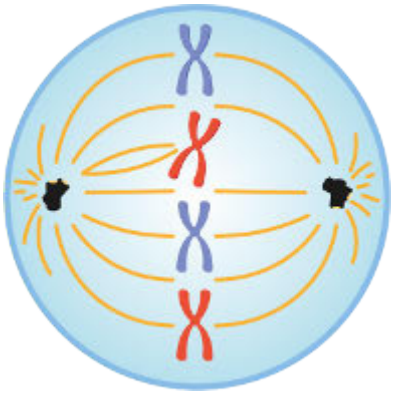
a) Identify the highlighted phases of mitosis represented in the image above.

b) Cells A and B on the image display the genetic information in two different forms. Determine the form of the genetic information in each cell **and** justify your answer.

c) Explain why the genetic information in cells must condense prior to cell division.

9. a) Explain why mitotic division is highly regulated in multicellular organisms.

The image below shows a eukaryotic cell undergoing mitosis.



b) Identify the error being made in mitosis by this cell **and** explain the likely consequences for the cell.

Chapter 1.4 Cell requirements

Science Understanding

Cells require energy.

The source(s) of energy are light (most autotrophs) and chemical (heterotrophs). Photosynthesis, respiration, and fermentation are important energy processes for cells.

- Write word equations for photosynthesis, respiration, and fermentation (in plant and animal cells).

Cells require materials and the removal of wastes:

- Compare the sources of materials for autotrophs and heterotrophs.
- Explain the need for removal of wastes.

Cells require energy

All organisms are composed of cells. These cells are constantly performing many processes such as movement, synthesis of materials and maintaining a stable internal environment (see Table 1.4.1). All cells therefore require constant inputs of suitable forms of energy.

The main source of energy for life on Earth is **the sun**. Energy is radiated from the sun as **physical light and heat energy**. Light energy can be used by **photosynthetic organisms** to convert inorganic materials into **potential chemical energy** (glucose). Heat energy that reaches the Earth ensures surface temperatures remain suitable for life.

In all living cells there is a continual transformation of energy from one type into another. The chemical energy stored in glucose molecules can be converted into a usable form of energy to do work within the cell. This occurs through the process of **respiration** where glucose is converted into a usable form of energy (through the synthesis of ATP). **ATP** (adenosine triphosphate) is the cell's **immediate source of energy** and is used for almost every energy-requiring reaction or process that occur in cells. The source of ATP's power is its triphosphate tail (see Figure 1.4.1). To release the usable energy for the cell to do work, the bond between the second and third phosphate group is broken forming **ADP** (adenosine diphosphate) **and a free phosphate group** (see Figure 1.4.1). ATP is therefore termed 'the energy currency of the cell.'

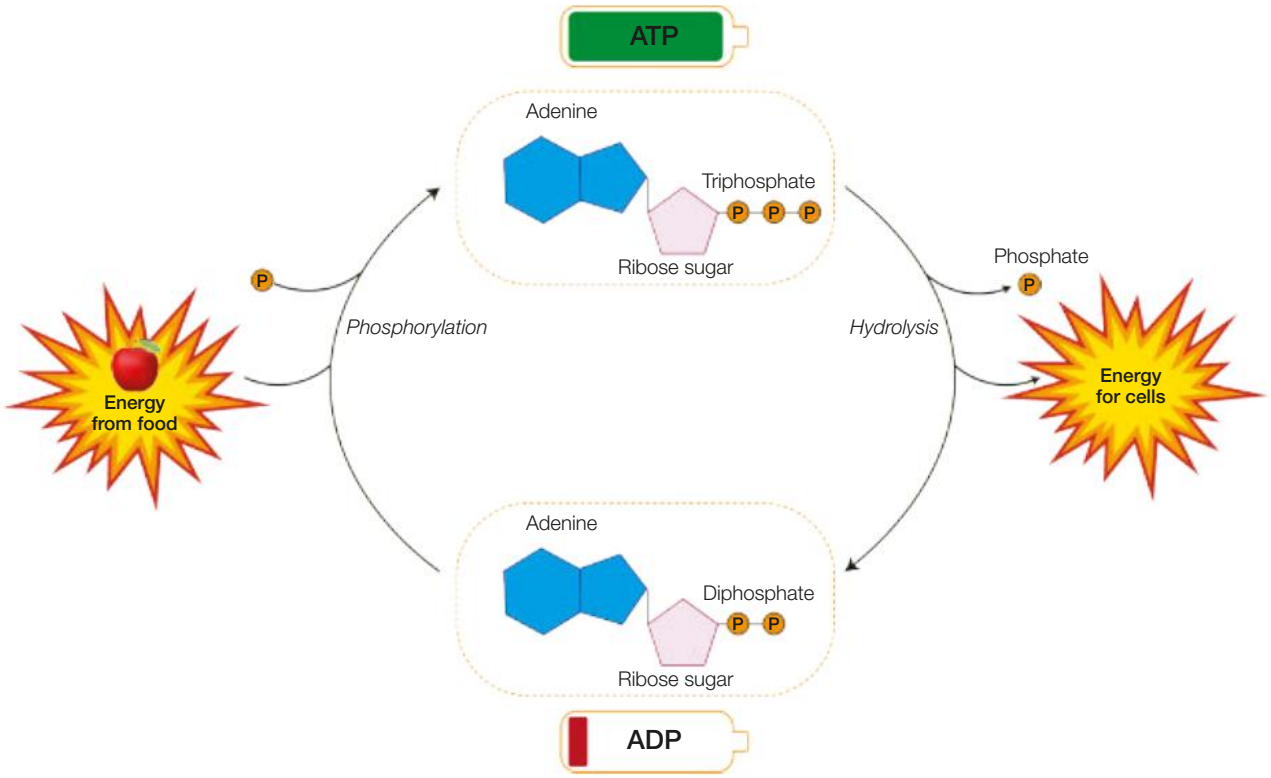


Figure 1.4.1: ATP captures the chemical energy obtained from digested food molecules (e.g. glucose) which can be released to supply usable energy for different cellular processes.

Table 1.4.1: Some examples of essential processes that occur within cells and organisms to maintain life.

Type of process	Examples
Movement	• the contraction of muscle cells • the spinning movement of sperm flagella (tails) to propel forward • the movement of chromosomes within the cell by spindles fibres during cell division
Synthesis of materials	• the synthesis of DNA molecules during DNA replication • the synthesis of proteins at ribosomes • the synthesis of glucose through photosynthesis
Maintaining a stable internal environment	• actively regulating the concentration of various substances in the cell (e.g. ions and waste products) • maintaining a constant internal blood temperature • maintaining a suitable pH • maintaining suitable blood glucose levels

Autotrophs and heterotrophs

An **autotroph** is an organism that **can synthesise its own organic energy-rich molecules** (e.g. glucose) from simple **inorganic molecules** (e.g. carbon dioxide and water). As autotrophs can synthesise their own food, they are also called **producers** as ecosystems depend on them to produce energy-rich molecules. There are two main types of autotrophs:

1. Photosynthetic autotrophs
2. Chemosynthetic autotrophs

Most organisms on Earth depend on photosynthetic organisms converting light energy from the sun into glucose that they can eventually consume (see Figure 1.4.2). However, there are some ecosystems on Earth where light cannot penetrate, yet life still exists. It is here that life generally depends on chemosynthetic organisms to produce energy-rich molecules to fuel the ecosystem. One example is the sulfur bacteria that live near deep-ocean hydrothermal vents. These hydrothermal vents release molecules such as hydrogen sulfide (H_2S) from the Earth's interior, which are used by the sulfur bacteria as a chemical energy source to synthesise carbohydrates (food).

Table 1.4.2: A comparison of photo-autotrophs and chemo-autotrophs.

Type of autotroph	Energy source used	Chlorophyll required?	By-product(s) formed	Examples
Photosynthetic	Light	Yes	Oxygen	Plants, algae, cyanobacteria.
Chemosynthetic	Chemical	No	Depends on the type of chemosynthesis	Sulfur bacteria, nitrogen-fixing bacteria.

A **heterotroph** is an organism that **cannot synthesis its own organic energy-rich molecules** (e.g. glucose). Heterotrophs must therefore obtain their organic molecules by **consuming** other organisms or parts of them (see Figure 1.4.2). Heterotrophs rely on autotrophs to produce a continuous supply of organic energy-rich molecules. They can directly consume autotrophs or consume other heterotrophs that have already consumed autotrophs to obtain their energy needs. As a result, heterotrophs are also referred to as **consumers**.

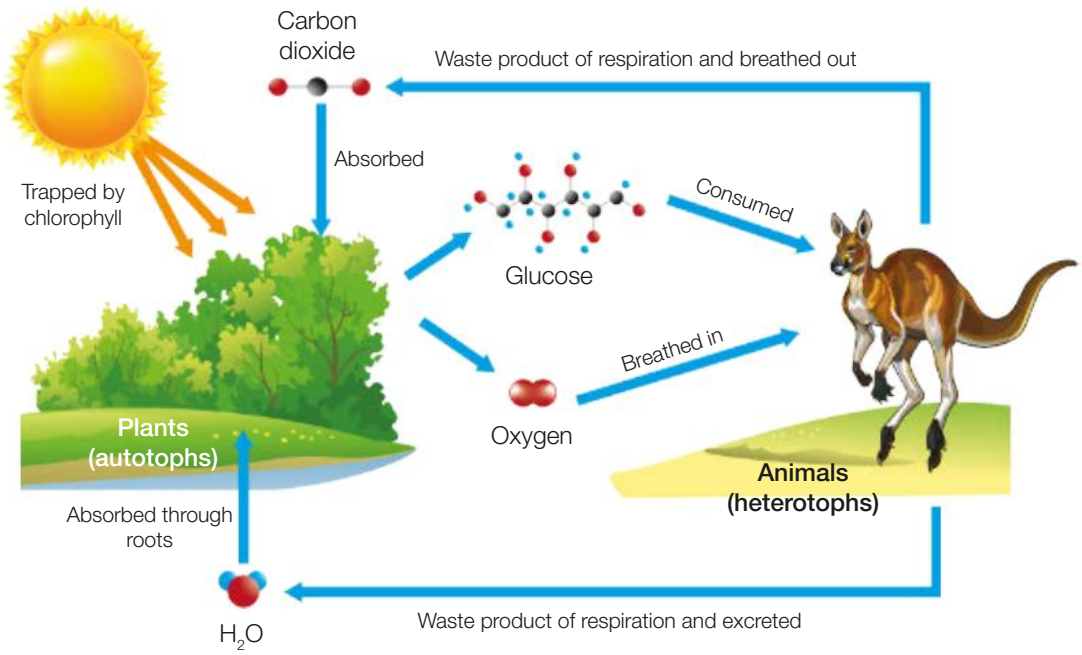


Figure 1.4.2: A flow diagram showing some of the interactions between autotrophs and heterotrophs and how heterotrophs must consume their energy-rich compounds (glucose).

Helpful online resource

Amoeba Sisters: Autotrophs and Heterotrophs

<https://www.youtube.com/watch?v=f8G7lulYxiA>

Photosynthesis

Photosynthesis is an important process that occurs in photosynthetic autotrophs. These organisms can use the light energy emitted by the sun to convert inorganic molecules into organic energy-rich molecules (glucose). In this process, light energy is trapped by the green pigment **chlorophyll** and is used to break the bonds between the atoms of the reactants so they can be rearranged to form a glucose molecule and six oxygen atoms (see Figure 1.4.3 below).

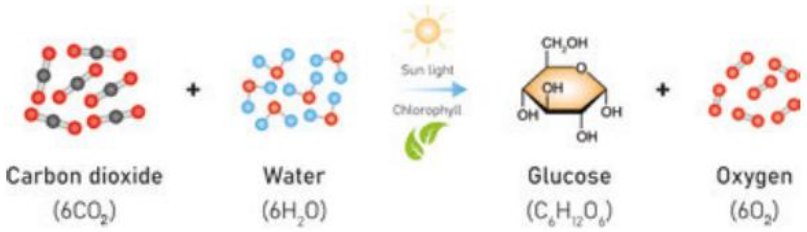


Figure 1.4.3: The word and chemical equations for photosynthesis.

Factors that affect photosynthesis

Photosynthesis is the process that occurs in producers to synthesise glucose. If the rate of photosynthesis is high in a producer, it is likely to have an abundance of energy-rich molecules to fuel its growth, and hence grow faster.

Humans are consumers that rely on photosynthetic organisms to feed us directly (e.g. fruits and vegetables) or to feed animals that we consume (e.g. cattle feedstock). Humans therefore have a strong interest in understanding the factors that affect photosynthesis so that they can be manipulated with the aim to producing higher yield crops. Factors that prevent photosynthesis occurring at its maximum rate are called **limiting factors**. Some examples include:

- Light intensity (see Figure 1.4.4)
- Carbon dioxide concentration (see Figure 1.4.4)
- Wavelength/colour of light (see Figure 1.4.5)

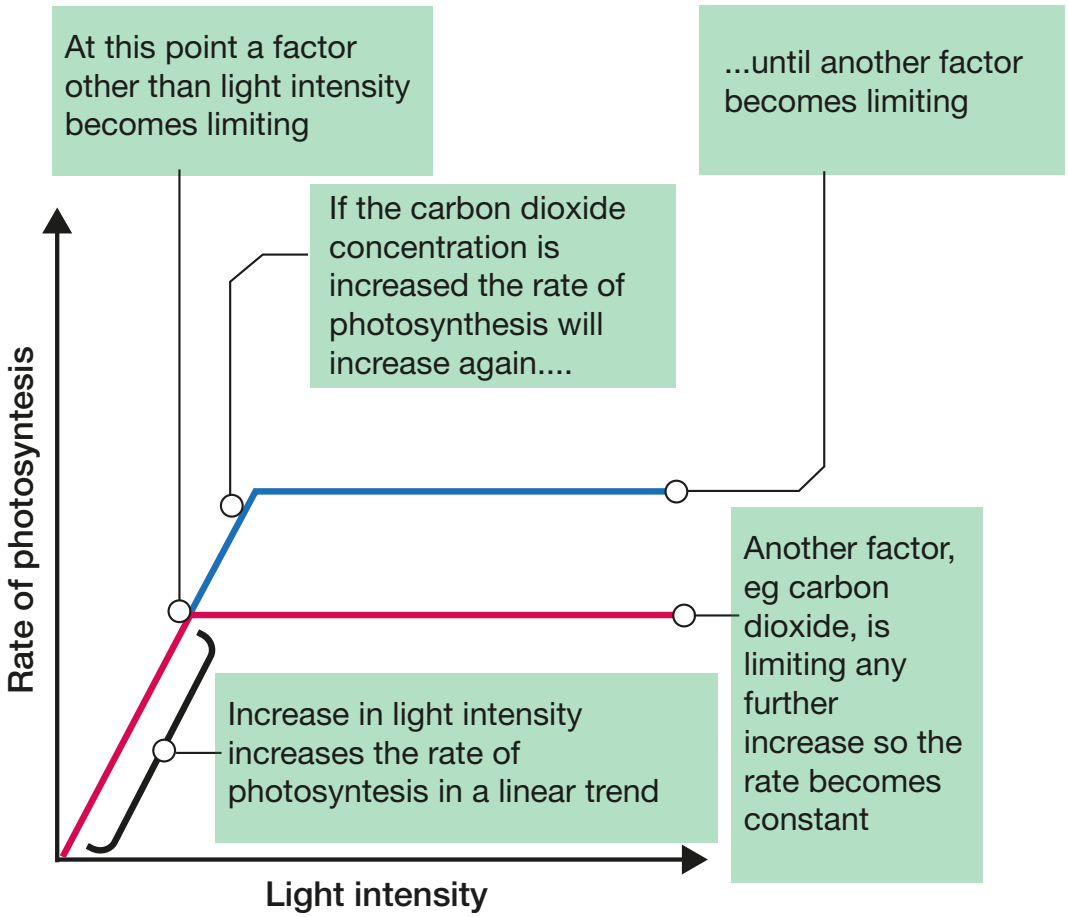


Figure 1.4.4: The effect of light intensity and carbon dioxide concentration (%) on the rate of photosynthesis

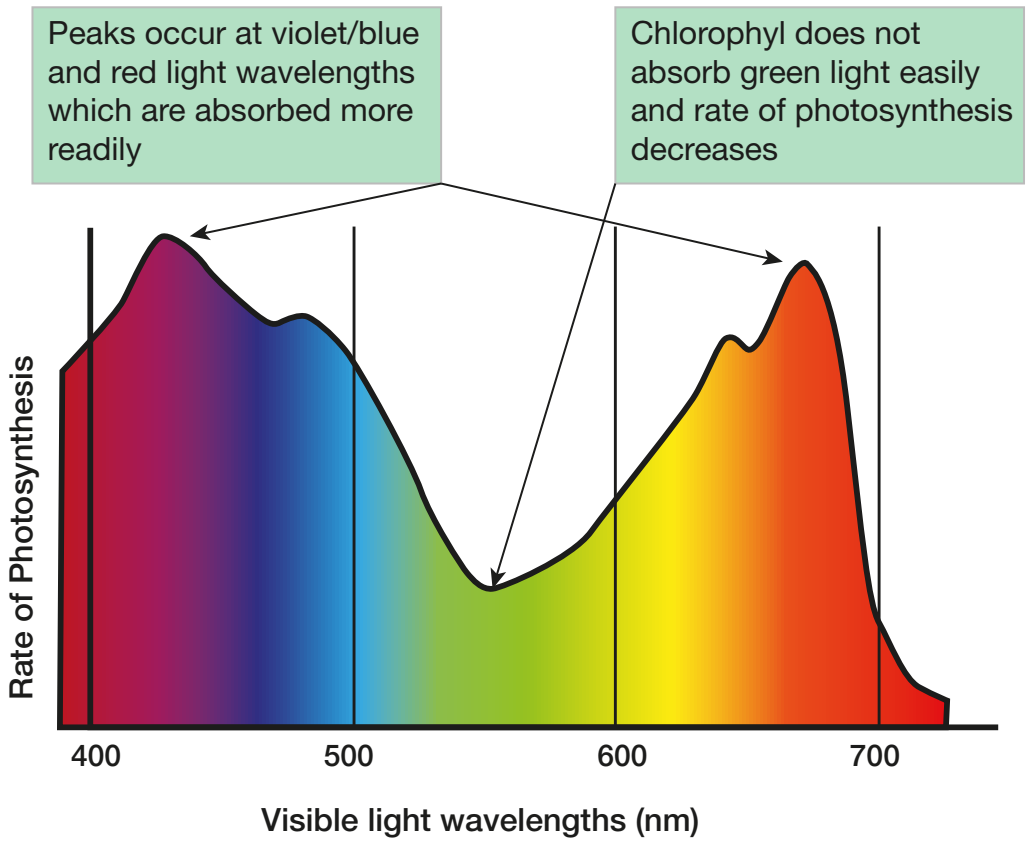


Figure 1.4.5: The effect of light wavelength on the rate of photosynthesis.

Helpful online resources

Cognito: GCSE Biology–Photosynthesis

<https://www.youtube.com/watch?v=X81OIkeuHJw>

Cognito: GCSE Biology–Factors Affecting the Rate of Photosynthesis

<https://www.youtube.com/watch?v=J0KxRX3fyoI>

Respiration

Cellular respiration is a metabolic pathway that uses glucose to produce ATP, which the body can use to power cellular processes. There are **two types of respiration**, aerobic and anaerobic. Aerobic respiration occurs in the presence of sufficient oxygen and involves mitochondria. Anaerobic respiration, also called fermentation, occurs in the cytoplasm of cells when there is not sufficient oxygen available.

Aerobic respiration

Aerobic respiration is a process that occurs in cells where glucose is converted into cellular energy (ATP) in the **presence of sufficient oxygen**. This process produces a **large amount of cellular energy** (36 ATPs) as the presence of oxygen allows for **a more complete breakdown of glucose**. The by-products of this process are carbon dioxide and water (see Figure 1.4.6).

Aerobic respiration consists of three main stages. The first stage (glycolysis) occurs in the cytoplasm of the cell and produces two ATPs. The second and third stages (Krebs cycle and electron transport chain respectively) both occur in the **mitochondria of cells** and produce a further 34 ATPs in the **presence of oxygen** (see Figure 1.4.7).

Figure 1.4.6: The word and chemical equations for aerobic respiration.

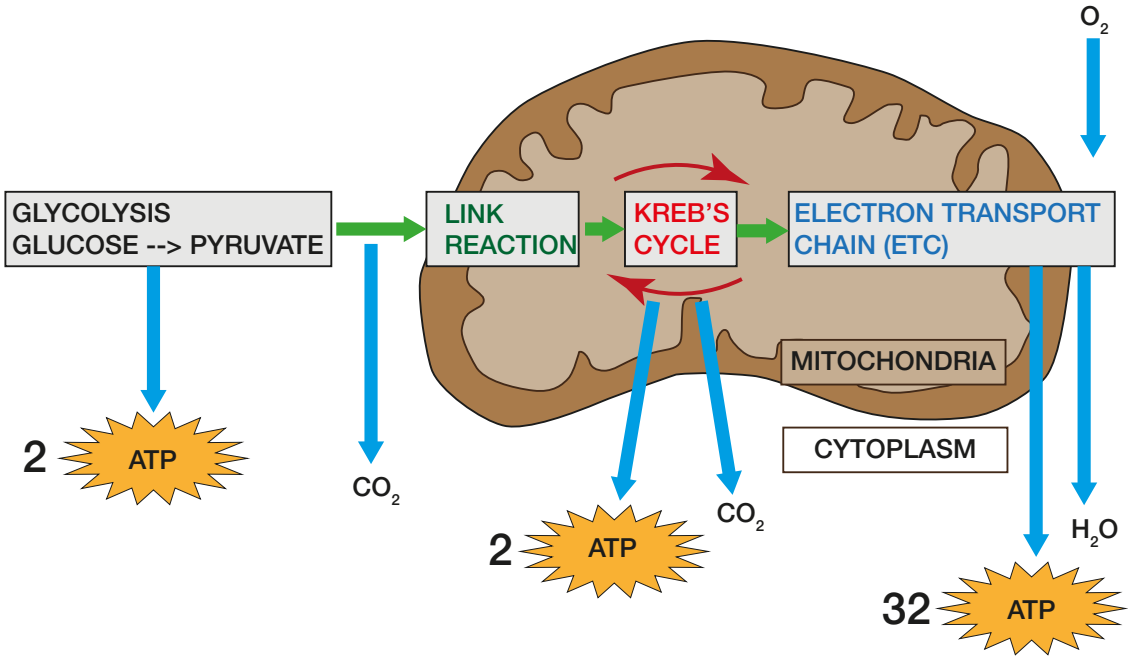


Figure 1.4.7: Aerobic respiration consists of three main stages and requires the presence of oxygen and mitochondria to produce large amounts of cellular energy (36 ATP) through a more complete breakdown of glucose.

Helpful online resource

Cognito: GCSE Biology–Respiration

<https://www.youtube.com/watch?v=U4WwWuVZSe4>

Anaerobic respiration (fermentation)

It is important for cells to have an alternative energy producing pathway to aerobic respiration in case sufficient oxygen is unavailable. An example of this is when humans exercise vigorously and our muscles require greater amounts of energy. If the circulatory system cannot deliver enough oxygen for the muscle cells to respire aerobically, an anaerobic alternative is required.

Anaerobic respiration occurs **only in the cytoplasm** of cells and in the **absence of oxygen**. This process produces much **smaller amounts of cellular energy** (2 ATPs) than aerobic respiration (36 ATPs) due to the **incomplete breakdown of glucose** in the absence of oxygen. Like aerobic cell respiration, anaerobic respiration begins with a process called glycolysis in the cytoplasm. An anaerobic process of fermentation then follows.

There are two kinds of fermentation:

- ethanol (alcohol) fermentation, which occurs in plants and yeast, and
- lactic acid fermentation, which occurs in animals and some bacteria.

Formula

Ethanol fermentation equation

glucose → ethanol + carbon dioxide

$C_6H_{12}O_6 \rightarrow C_2H_5OH + 2CO_2$

Lactic acid fermentation equation

glucose → lactic acid

$C_6H_{12}O_6 \rightarrow C_3H_6O_3$

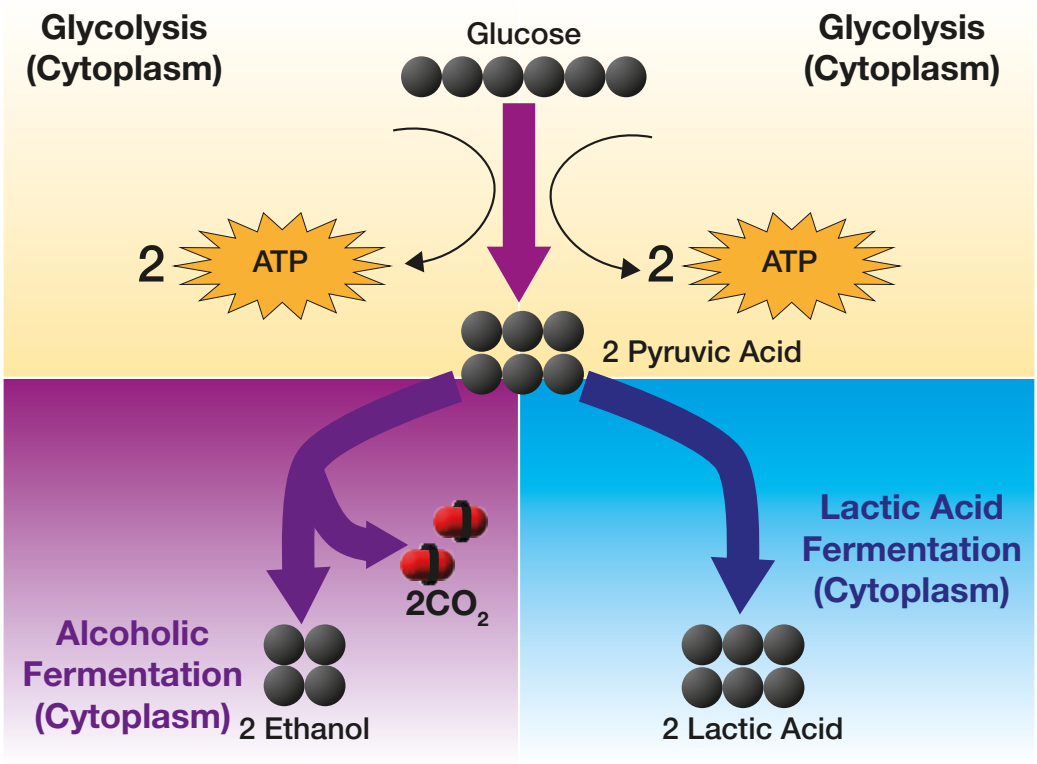


Figure 1.4.8: A comparison of ethanol and lactic acid fermentation. Note that each black circle represents a carbon atom and that both processes start and finish with 6 carbon atoms in their reactants and products.

Comparison of aerobic and anaerobic respiration

Aerobic respiration produces more energy (34 ATPs more) than anaerobic respiration (fermentation) due to a more complete breakdown of glucose in the presence of oxygen. The products produced by aerobic respiration are always the same, however the products of fermentation differ depending on the type of organism it is occurring in. Refer to Table 1.4.3 for more information and a comparison of a Bunsen burner to respiration in terms of energy output.

Table 1.4.3: Comparing the energy output of a Bunsen burner to aerobic respiration and fermentation.

	Image	Fuel	Reaction	Oxygen supply	Products	Energy Output
Bunsen burner		Methane	Combustion	High (collar open)	CO_2 and water	High (blue flame)
A cell		Glucose	Aerobic respiration	High (aerobic)	CO_2 and water	High (36ATPs)
Bunsen burner		Methane	Combustion	Low (collar closed)	Carbon, carbon monoxide	Low (yellow flame)
Animal cell		Glucose	Lactic acid fermentation	Low (anaerobic)	Lactic acid	Low (2ATPs)
Plant cell		Glucose	Ethanol fermentation	Low (anaerobic)	CO_2 and ethanol	Low (2ATPs)

Material requirements and waste production of cells

As well as energy requirements, cells also need very specific nutrients and materials for their survival. Generally, organisms need a supply of **water, macronutrients (carbohydrates, protein and lipids) and essential micronutrients (vitamins and minerals)** for their growth and development. Organisms may also need a supply of **nucleic acids (DNA and RNA)** if they cannot synthesis their own. Due to the diverse nature of life on Earth, different species have evolved different mechanisms to obtain essential nutrients and deliver them to their cells. Additionally, different species can produce different waste products that must be removed from cells, to maintain a suitable internal cellular environment for chemical reactions to occur.

Sources of materials for autotrophs

Autotrophs can convert inorganic materials into organic energy-rich molecules through the process of photosynthesis or chemosynthesis. Photosynthetic autotrophs need to source carbon dioxide from the air, water from the soil or a waterbody, and light from the sun (see Figure 1.4.9). Whereas chemosynthetic autotrophs need to source their inorganic materials such as hydrogen sulfide, methane, carbon dioxide from their environment (e.g. hydrothermal vents in oceans), often by diffusion.

Autotrophs also require a range of additional inorganic nutrients. In the case of plants, they require at least 14 mineral nutrients, which are dissolved in water and **absorbed by their roots from the soil** (see Figure 1.4.9). Two vital minerals are **nitrogen and phosphorus** because they are required in large amounts to synthesise important molecules for life (see Table 1.4.4 for further information). The nitrogen and phosphorus cycles are discussed further in Topic 4: Biodiversity and ecosystem dynamics.

Table 1.4.4: Nitrogen and phosphorus are two mineral nutrients that are essential for plants to absorb in large amounts as they are required in the synthesis of some very important molecules required for life. When heterotrophs consume plant-based products, they also consume the minerals incorporated into molecules that the plant(s) have synthesised.

Mineral	Is this mineral vital to these essential life processes?				
	Photosynthesis	DNA/RNA synthesis	Protein synthesis	ATP synthesis (energy)	Membrane synthesis
Nitrogen	Yes	Yes	Yes	Yes	No
	Is a key component of chlorophyll pigments	Is a key component of the nitrogenous bases that form nucleic acids	Is a key component of amino acids (the building blocks of proteins)	Is a key component of the adenosine base in ATP	
Phosphorus	No	Yes	No	Yes	Yes
		Is a key component of the sugar-phosphate backbone of nucleic acids		Three phosphate groups make up the triphosphate tail of ATP	It is a key component of the phospholipids that make up cell membranes

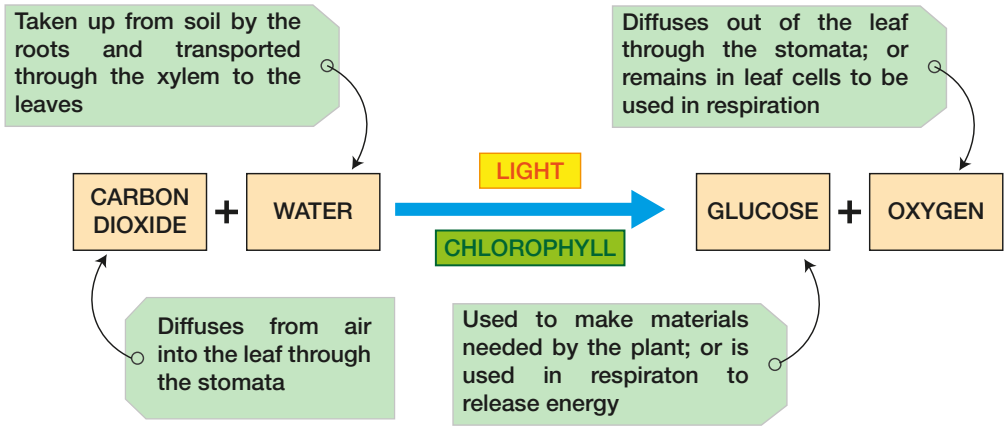


Figure 1.4.9: An example of how plants source their materials for the essential process of photosynthesis and how the products formed can be used as a source for other processes, such as respiration.

Sources of materials for heterotrophs

Heterotrophs must obtain their essential nutrients through **consumption**. Essential macronutrients, micronutrients and nucleic acids are consumed by eating a wide range of animal and plant-based products. Many of these foods also provide some water to heterotrophs but drinking water separately is also required to obtain their daily needs. The carbohydrates, protein, lipids and nucleic acids consumed are broken down into their building blocks (simple sugars, amino acids, fatty acids/glycerol and nucleotides respectively) in the digestive system so they can be absorbed across the small intestinal lining. The circulatory and lymphatic systems then transport these nutrients to cells to be used for specific processes (see Figure 1.4.10). This is explored further in Topic 3: Multicellular organisms.

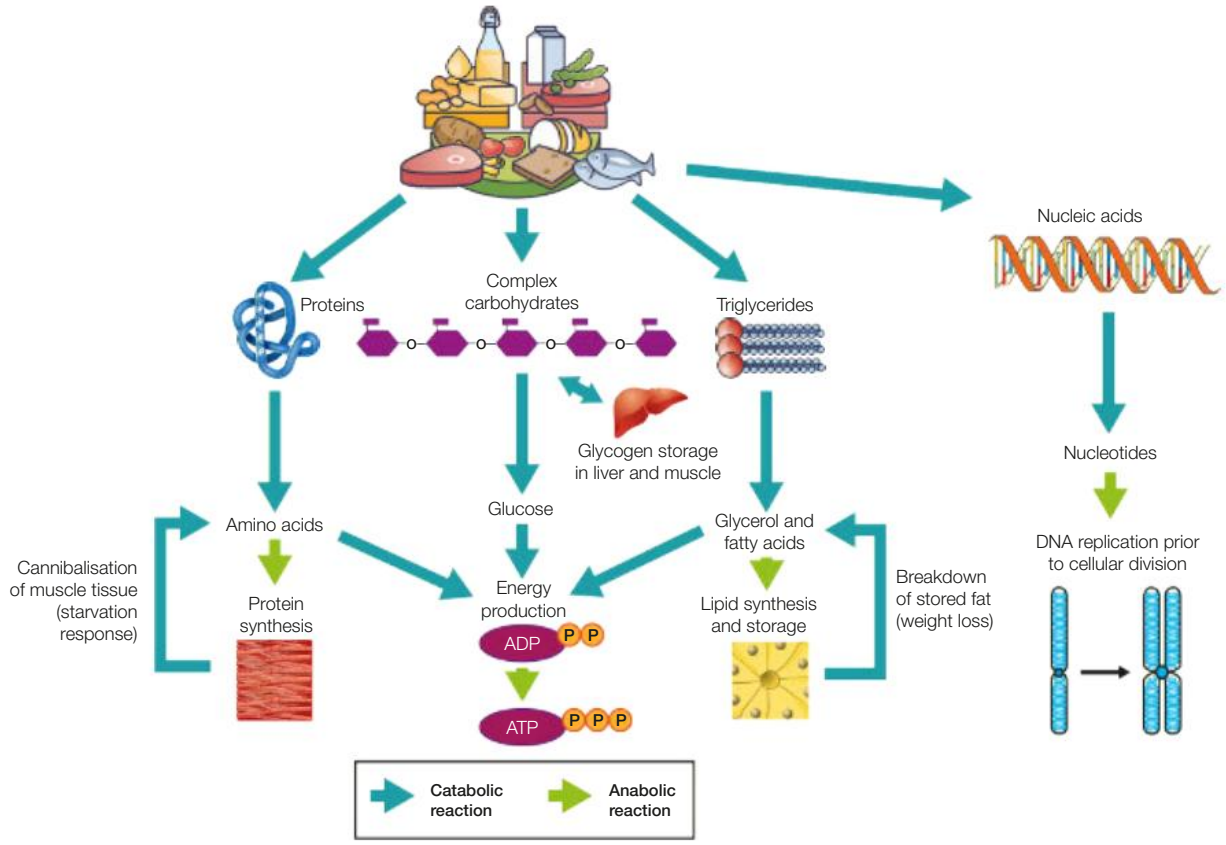


Figure 1.4.10: Consuming animal and plant-based products (food) provides heterotrophs with the three macronutrients and nucleic acids that can be digested and transported to cells to perform specific functions. It also provides water and the micronutrients (vitamins and minerals), but this is not shown in this flow diagram.

Waste production and removal

Some metabolic reactions in cells produce waste products that can be toxic, especially if they build up to high concentrations. These waste products therefore need to be **excreted from cells**, and eventually the body of multicellular organisms.

Carbon dioxide

Carbon dioxide is produced by all cells in aerobic respiration. It is also produced by plant and yeast cells when they perform ethanol fermentation. In animals, carbon dioxide is excreted into the blood and is transported to the respiratory system. The carbon dioxide diffuses from the blood into the lungs and is then removed from the body in exhaled air. In plants, the carbon dioxide can be transported to leaf cells and used as a reactant in photosynthesis.

Urea

Urea is a by-product of the metabolism of protein, which occurs in the liver cells of animals. Urea is excreted into the blood and is transported to the excretory system. The kidneys filter the blood and excrete urea and other waste products forming urine, which is removed from the body though urination. Urea is a molecule that contains nitrogen, which is an important element for plant growth. Many plants can metabolise urea and use the nitrogen it provides to produce essential molecules for cells as outlined in Table 1.4.4. Some plants can absorb urea directly from the soil, whereas others require bacteria to convert it to a usable form first.

Ethanol and lactic acid

Ethanol and lactic acid are by-products of ethanol and lactic acid fermentation respectively. Ethanol and lactic acid are toxic to cells. If they accumulate to high levels, they can denature proteins and eventually cause cell death. Additionally, the production of high levels of lactic acid during very strenuous exercise, can contribute to muscle fatigue and soreness. As lactic acid increases acidity inside cells that produce it (lowers pH), it must be excreted into the blood. It is transported to the liver where it is metabolised in the presence of oxygen to release additional energy. Energy is also available to cells from ethanol, which is involved in further metabolic pathways in plant and yeast cells to make it available for cellular use.

1.4 Review questions

Multiple choice questions

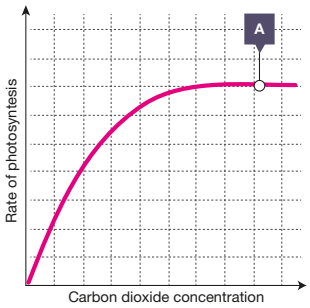
1. All autotrophs:

   J require light for photosynthesis.
   K convert inorganic materials into potential chemical energy.
   L are bacteria.
   M require hydrogen sulfide as a chemical energy source.

2. The amount of energy (ATP) produced by respiration in the presence of oxygen when compared to the absence of oxygen is

   J slightly less.
   K slightly more.
   L significantly less.
   M significantly more.

3. *Refer to the graph to the right to answer the following question.*



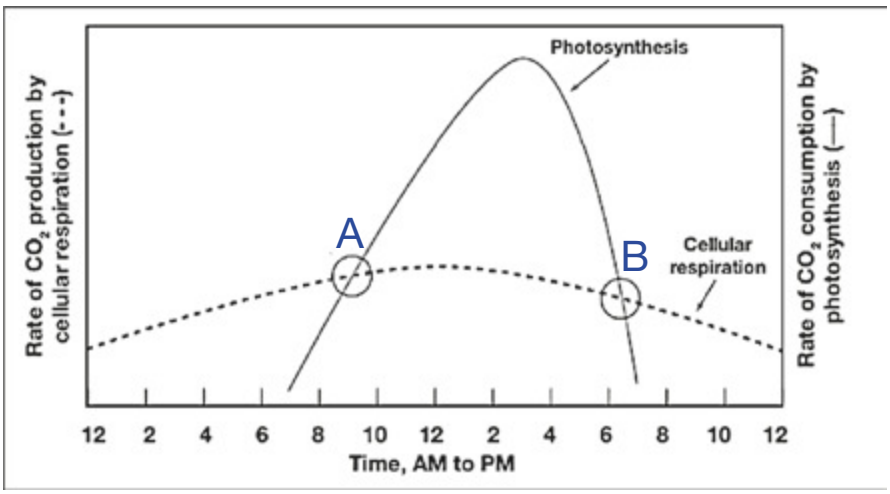
   Which of the following answers correctly explains the significance of the plateau in the graph highlighted at 'A'?

   J Photosynthesis is not occurring at all due to a limiting factor.
   K The rate of photosynthesis is occurring at the maximum possible rate for the conditions provided.
   L Carbon dioxide concentration is a limiting factor at this point.
   M The mitochondria are performing photosynthesis at a constant rate.

4. Which of the following options most correctly describes how plants obtain the nucleotides that make up their DNA.

   J They synthesise them from nutrients obtained from their environment.
   K They consume them.
   L Their roots absorb them from the soil.
   M They are a product of photosynthesis.

5. *Refer to the graph below to answer the following question.*



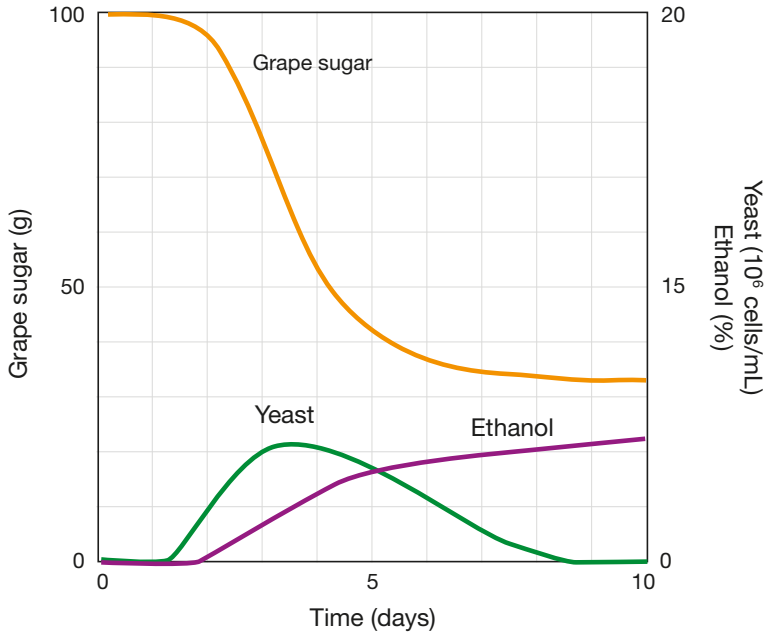
   The points on the graph where the two lines intercept (A and B) represent:

   J the times at which the sun rises and sets.
   K the peak rate of cellular respiration.
   L the optimum rates of cellular respiration and photosynthesis for all plants.
   M when the rate of cellular respiration and photosynthesis are the same.

6. Which of the following options correctly matches an organism with an energy producing reaction that occurs in that organism, the location this reaction occurs in its cell(s) and the products produced?

	Organism	Energy producing reaction	Location this reaction occurs in cells	Products
J.	Animal	Aerobic respiration	Cytoplasm	Carbon dioxide and water
K.	Animal	Fermentation	Cytoplasm	Carbon dioxide and lactic acid
L.	Yeast	Aerobic respiration	Mitochondria	Carbon dioxide and lactic acid
M.	Yeast	Fermentation	Cytoplasm	Carbon dioxide and ethanol

Refer to the graph below to answer questions 7, 8 and 9.

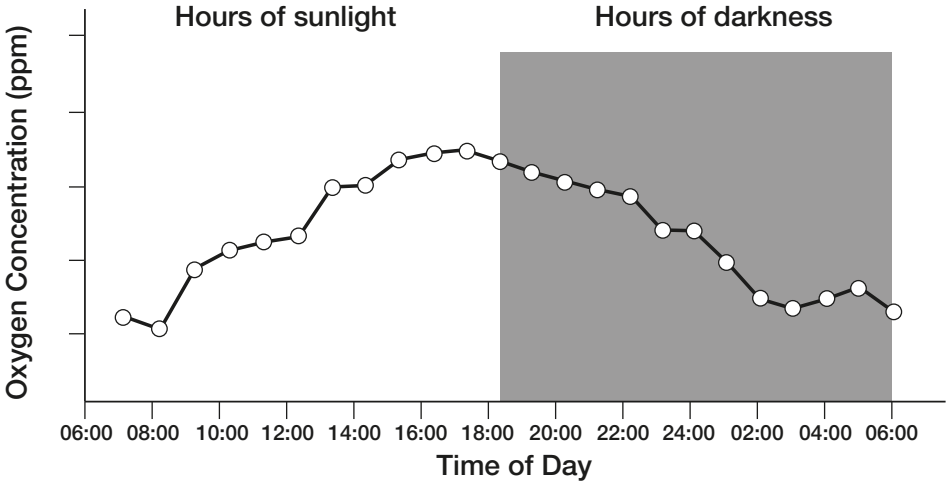


7. The process occurring in the yeast cells that the graph highlights is:
   - J fermentation.
   - K aerobic respiration.
   - L chemosynthesis.
   - M wine making.

8. The best explanation for the decrease in yeast cells shown in the graph is:
   - J there is not enough grape sugar left to support all yeast and some start to die off.
   - K yeast only live for about 3 days.
   - L yeast cells can only respire aerobically and without available oxygen cannot produce energy.
   - M the yeast cells are dying due to the increase in ethanol production.

9. Identify the mistake made by the individual who constructed this graph.
   - J There is no legend supplied in the graph.
   - K The scales are not constant.
   - L It doesn't show the rate of carbon dioxide production.
   - M The x-axis label is incorrect.

10. *Refer to the graph below which shows the oxygen concentration in the water of a lake containing both autotrophic and heterotrophic organisms to answer the following question.*



Which of the following options provides a correct explanation to a trend shown in the graph above?

J More organisms in the lake respire at night than during the day.

K Autotrophs are unable to photosynthesise and respire during the hours of darkness.

L More oxygen is produced by autotrophs than is consumed by organisms in the lake during the hours of sunlight.

M Oxygen is absorbed by the lake during the hours of sunlight and released back into the atmosphere during the hours of darkness.

Free response questions

1. Outline **three** processes that occur in cells that require energy.

a)

b)

c)

2. Complete the table below comparing two different organisms and their sources of nutrition.

Organism	Type of nutrition	Process by which carbon is obtained	Initial energy input
A fern			
A human			

3. Write **word** equations for each of the following processes:

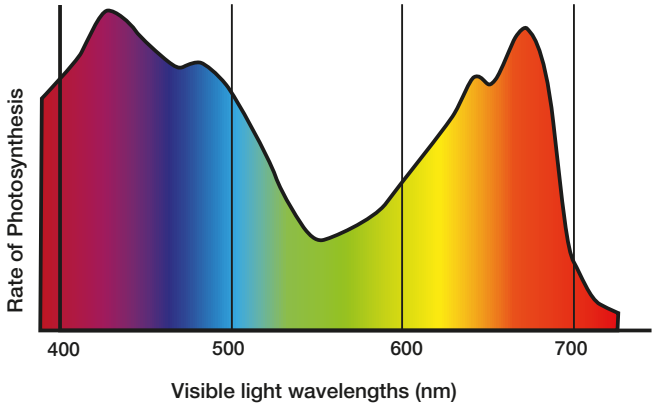
a) Photosynthesis
b) Aerobic respiration
c) Lactic acid fermentation
d) Ethanol fermentation

4. Name **two** metabolic waste products produced by cells.

5. Explain why carbon dioxide (CO_2) can be considered a metabolic waste product from human cells but not from plant cells.

6. Visible light is part of a continuum of radiations with different wavelengths called the electromagnetic spectrum. These wavelengths are measured in nanometres (nm).

   Refer to the graph below that shows how the wavelength (colour) of light affects the rate of photosynthesis for a typical flowering plant.



   a) Identify **and** explain which wavelength(s), and colours, are most likely to increase the growth rate of a typical flowering plant.

   b) Use information in the graph to explain why leaves tend to be green.

7. State **and** explain **three** factors that may alter the rate of photosynthesis, other than the wavelength (colour) of light.

8. Plants can convert inorganic materials into organic materials through the process of photosynthesis. The chemical equation for photosynthesis is:

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

   a) Use the chemical equation to complete the number of atoms of carbon, oxygen and hydrogen for the reactants and products of photosynthesis:

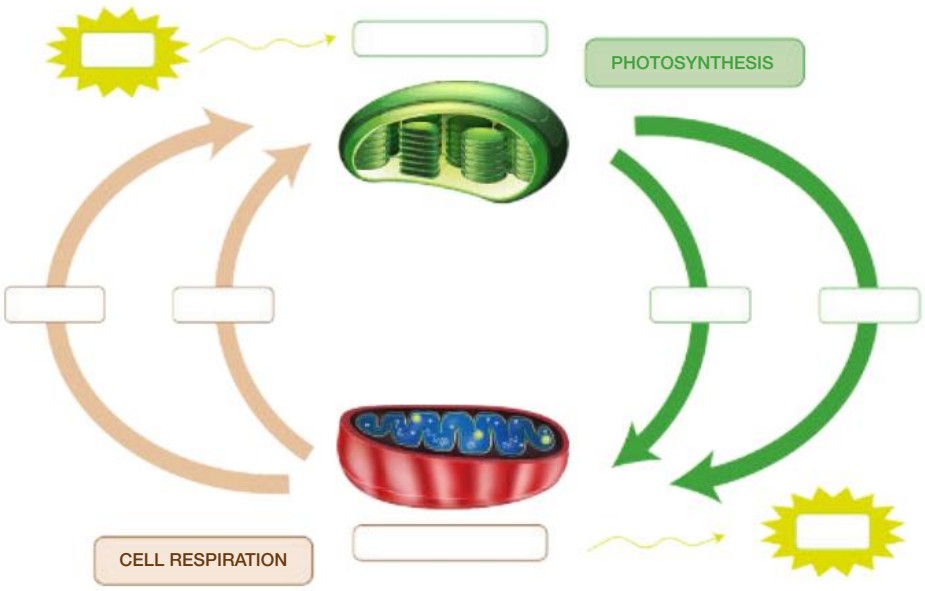
Element	Number of atoms	
	Reactants	Products
Carbon		
Oxygen		
Hydrogen		

b) (i) Compare the number of atoms for the reactants and products of photosynthesis.

(ii) Identify the inorganic source of carbon for plants **and** state the main way that plants obtain it.

Plants can also respire aerobically.

c) Use your understanding of aerobic respiration and photosynthesis to label the following diagram.



d) Explain why plants need to be able to perform both photosynthesis and aerobic respiration.

9. *Refer to the Figure 1 below, which shows the setup of a basic respirometer measuring the respiration rate of a small animal called a woodlouse, to answer the following questions.*

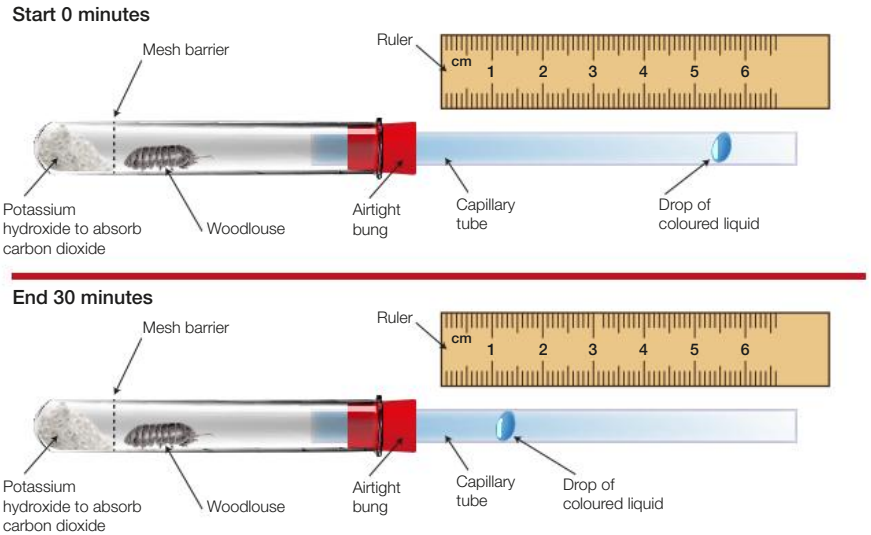


Figure 1

At the start of this respiration experiment (0 minutes), the position of a coloured drop of liquid in a capillary tube is recorded. The coloured droplet in the capillary moves as the woodlouse respires. The position of the coloured droplet is recorded again at the end of the elapsed time (30 minutes).

a) Calculate the total distance (in mm) the coloured droplet has moved in the capillary tube during the elapsed time.

b) Calculate the rate of movement (in mm per minute) of the coloured droplet in the capillary tube during the elapsed time.

The rate of movement of the coloured drop of liquid along the respirometer can be used as an estimate of the rate of respiration.

c) Explain why the coloured droplet moved in the capillary tube as the woodlouse respired.

In a separate experiment, some students used the same respirometer setup (*Figure 1*) and procedure mentioned above to estimate the respiration rate of four different animals. The students completed 3 trials for each of the four species (A to D). Refer to Table 1 below to see the results.

Table 1

Animal	Estimated respiration rate (mm/min)			
	Trial 1	Trial 2	Trial 3	Average (mean)
A	1.4	1.6	1.5	
B	0.5	0.9	0.9	
C	1.7	2.3	2.0	
D	1.3	1.1	1.4	

d) Calculate the average estimated respiration rate for each of the four animals (A, B, C and D) and add your answers to Table 1. Note: some working out space is provided below.

e) (i) Identify which set of data in Table 1 (animal A, B, C or D) is the least precise.

(ii) Use data from Table 1 to explain why the identified set of data from part (e)(i) is the least precise.

f) Identify **and** explain **one** limitation of this experiment with regard to comparing the respiration rate of the four animal species.

Chapter 1.5 The cell membrane

Science Understanding

. Material requirements move in and wastes and some cell products move out of cells. The cell membrane separates cellular activity from the external environment.

- Describe the structure of the semi-permeable cell membrane.

The selectively permeable nature of the cell membrane maintains relatively constant internal conditions.

- Explain how the cell membrane controls the exchange of materials between the cell and its environment.
- Describe how some substances move passively across the cell membrane with the concentration gradient (i.e. by diffusion and osmosis).
- Compare active and passive transport with regard to:
  - concentration gradient
  - energy requirement

The surface area-to-volume ratio of cells is critical to their survival.

The cell membrane

All living cells consist of a cell membrane (also known as the plasma membrane). The cell membrane physically separates the internal environment of the cell from its surroundings and controls the movement of materials in and out of the cell. It is often called **semi-permeable** because some molecules can pass through it, but not all. This is based on factors such as the size, charge and water solubility of molecules and will be explored further in this chapter.

Structure of the cell membrane

The cell membrane mostly consists of **phospholipids** and membrane **proteins**, but it also consists of **carbohydrates** and another lipid called **cholesterol** (see Figure 1.5.1).

Cell membranes consist of:

- a phospholipid bilayer (two layers of phospholipid molecules)
- a range of membrane proteins that either span the width of the membrane or sit in the bilayer
- glycoproteins which are carbohydrate chains attached to membrane proteins
- glycolipids which are carbohydrate chains attached to phospholipids
- cholesterol (a type of lipid) which is embedded within the phospholipids.

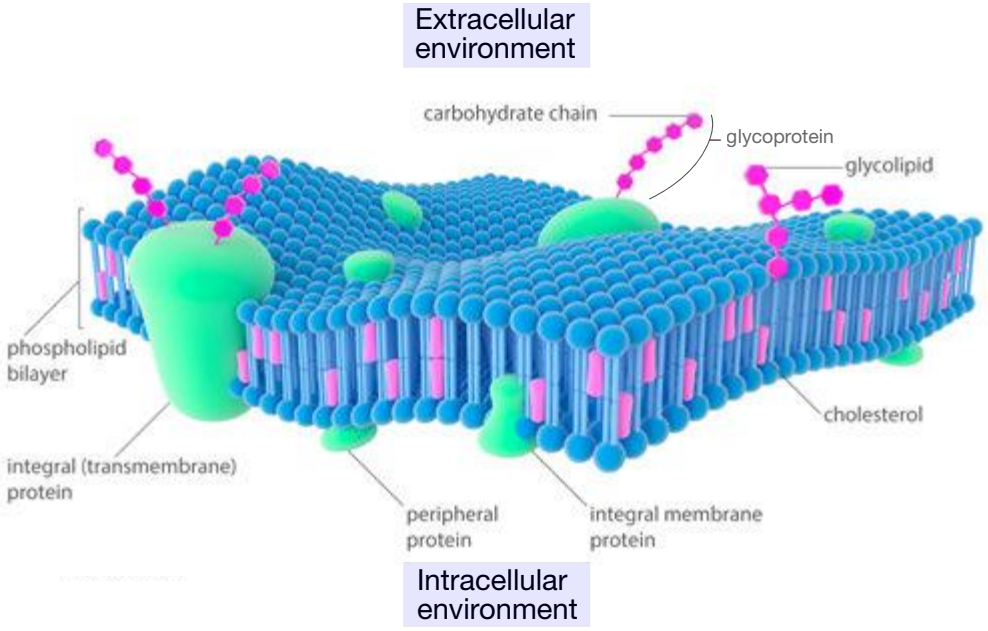


Figure 1.5.1: The basic structure of a cell membrane.

Phospholipids

The structure of the phospholipid bilayer is a result of the physical properties of the phospholipid molecules. A phospholipid molecule consists of a phosphate head and two fatty acid chains (see Figure 1.5.2). The **phosphate heads are hydrophilic** (water-loving) and therefore orientate towards the aqueous environments of the cytoplasm and extracellular fluid. Conversely, the **fatty acid tails** do not interact well with water and are **hydrophobic** (water-fearing). The fatty acid tails therefore project inwards towards each other and away from the aqueous environments (see Figure 1.5.2).

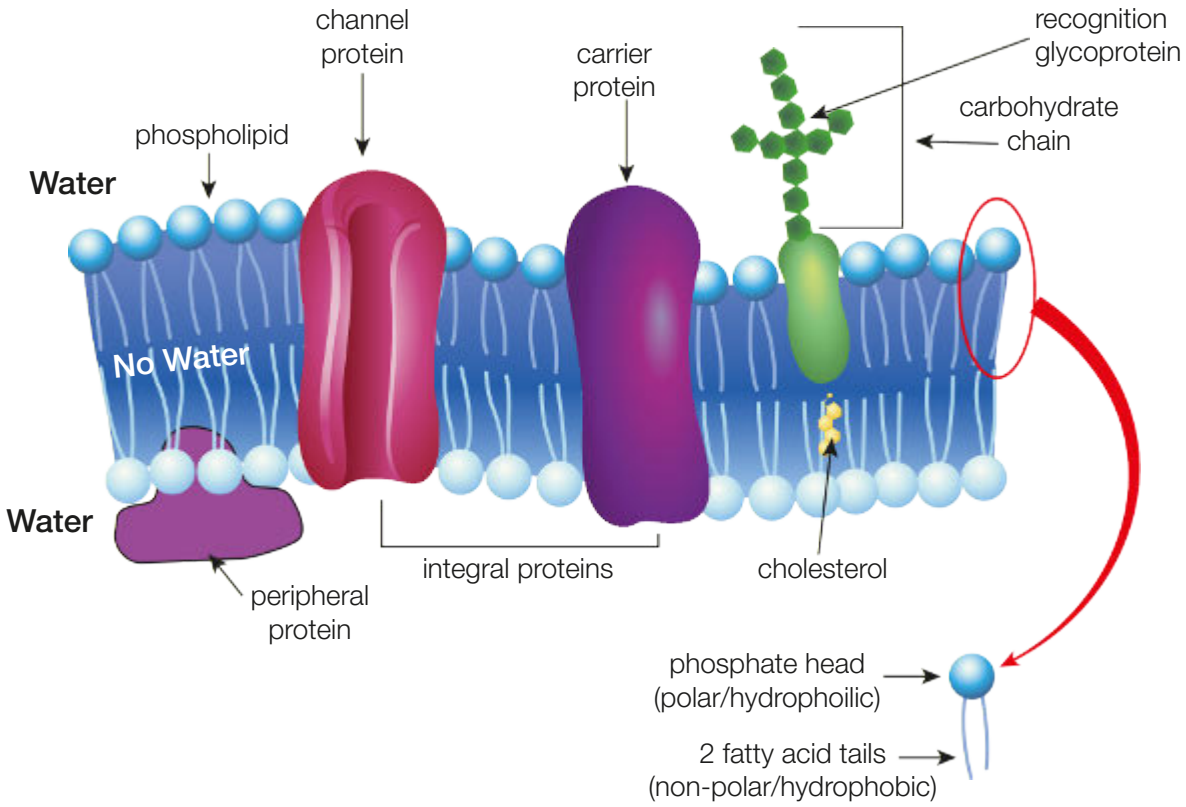


Figure 1.5.2: A cross-section view of the structure of the cell membrane and a close-up look at the structure of a single phospholipid.

Proteins

There are two main types of proteins that the cell membrane consists of: integral proteins and peripheral proteins. Integral proteins are integrated in the phospholipid bilayer, whereas peripheral proteins attach to internal or external surfaces of the bilayer (see Figure 1.5.1 and 1.5.2). There are a variety of integral and peripheral proteins within the cell membrane that perform essential functions for the cell. These proteins include transport proteins, enzymes, receptor proteins, recognition (or cell identity) proteins and adhesion proteins (see Figure 1.5.3).

Functions of the cell membrane

The cell membrane is the physical barrier between the intracellular and extracellular environments and therefore has many important cellular functions (see Figure 1.5.3). Some of the important functions include:

- Protecting the intracellular environment.
- Providing support and helping to maintain cell shape through **adhesion proteins** that can stick out and bind to specific protein molecules on adjacent cells.
- Selectively controls the exchange of molecules between the cell and its external environment through **transport proteins**.
- Allows **communication** through **receptor proteins** and complementary hormones.
- Involved in **cell recognition** through **glycoproteins and glycolipids** that act as cell identity markers and allow the immune system to distinguish between the organism's 'self' cells and foreign 'non-self' cells (e.g. bacteria).

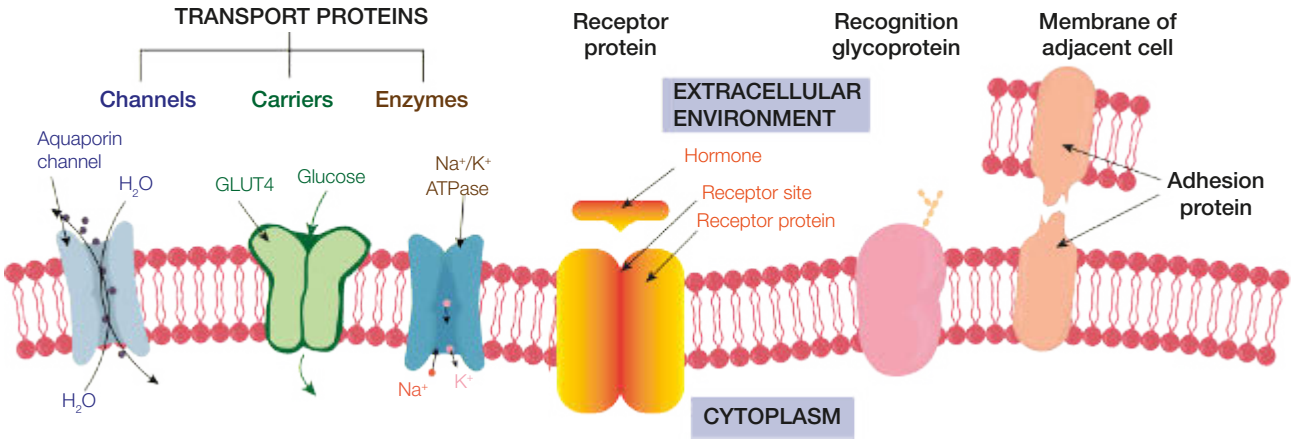


Figure 1.5.3: The cell membrane has a range of different proteins within it that perform a variety of functions.

The fluid-mosaic model

Like many other structures or processes too small to see, or to comprehend, scientists have constructed a 'model' to visualise, and thus better understand cell membrane structure. This is called the 'fluid mosaic model' (named by S.J. Singer and G.L. Nicholson who proposed it in 1972).

The word '**fluid**' in the name of the model refers to the ability of both lipids and proteins to continually move in the membrane. This characteristic is critical for membrane **permeability**, or ease of movement of molecules across the membrane.

The term '**mosaic**' refers to the pattern formed by the **variety of proteins** embedded within the phospholipid bilayer. These proteins are fundamental to the function of the cell membrane.

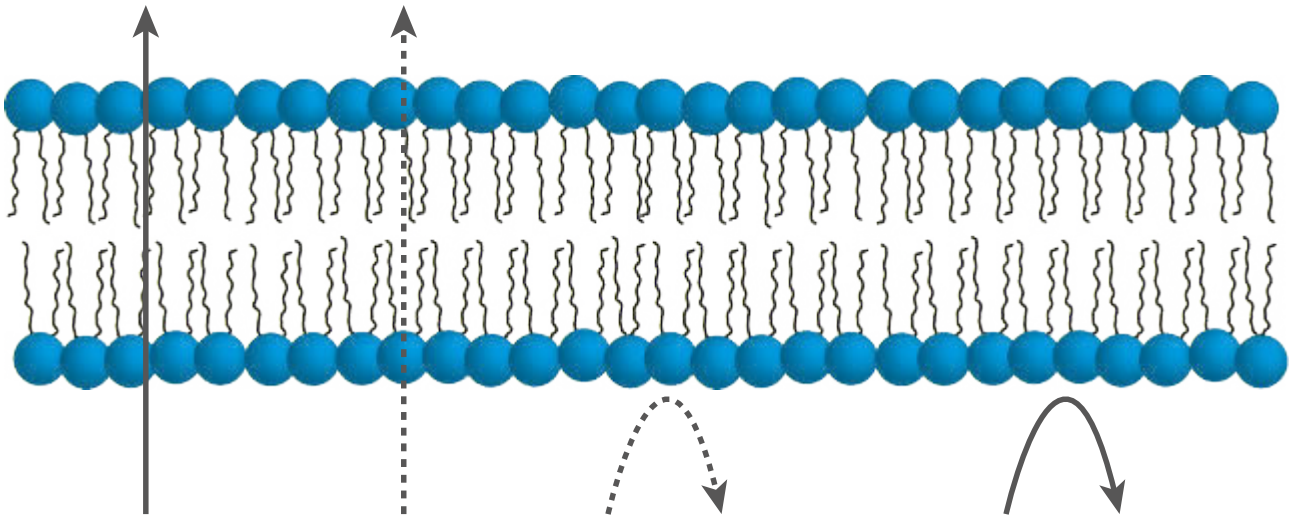
Helpful online resource

TED-Ed: Cell membranes are way more complicated than you think–Nazzy Pakpour

<https://www.youtube.com/watch?v=nsklF1w4eok>

Selective permeability of the cell membrane

Some molecules can pass through the phospholipid bilayers of the cell membrane easily, but others cannot (see Figure 1.5.4). This is why it is called semi-permeable. However, some of the molecules that cannot pass through the bilayer easily can be important for cell survival, such as amino acids and nucleic acids. These molecules rely on transport proteins to be transported across the cell membrane. The transport proteins for these molecules are specific and therefore **selective for the molecules that can move across them** (see Figure 1.5.5). The cell membrane therefore controls which molecules move into and out of the cell, which is important as **cells need to maintain a narrow range of conditions to function normally**. Collectively, the semi-permeable nature of the cell membrane and the selective transport proteins allow the cell to dispose of waste products and accrue important nutrients in higher concentrations internally than its external environment.



High permeability	Moderate permeability	Low permeability	Very low permeability
some gases CO_2, O_2	water	polar organic molecules glucose	ions sodium, potassium
very small uncharged polar molecules ethanol	urea		charged polar molecules and macromolecules amino acids ATP proteins polysaccharides nucleic acids

Figure 1.5.4: The relative membrane permeability of some example molecules.

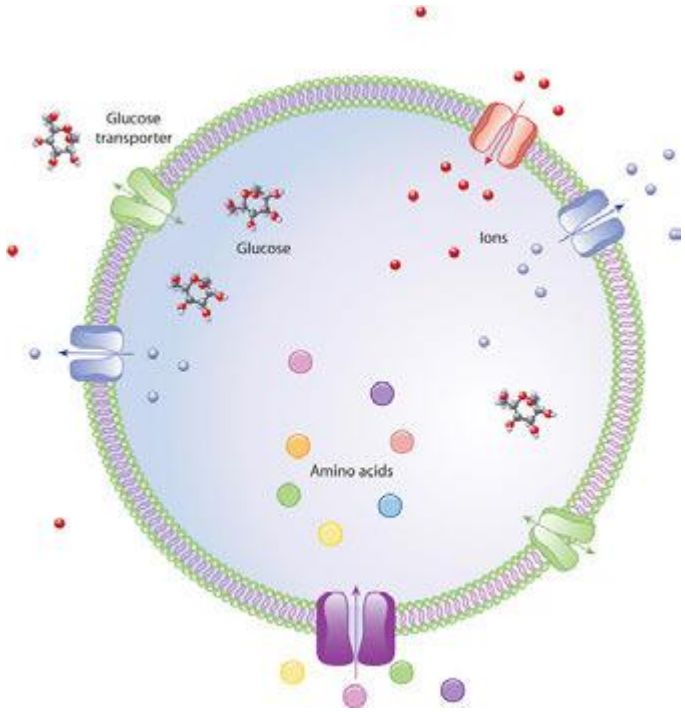


Figure 1.5.5: The cell membrane has a range of different transport proteins that facilitate its ability to select which molecules can enter and leave the cell.

Passive transport across the cell membrane

According to the kinetic model for matter, atoms and molecules are in a state of constant, random motion. In gases and liquids, this causes them to collide so often that there is a gradual net movement away from where the atoms or molecules are most concentrated to where they are least concentrated. The movement of atoms and molecules in this way is called passive transport because it **does not involve the expenditure of energy**. Simple diffusion, facilitated diffusion and osmosis are passive transport processes across the cell membrane.

Simple diffusion

Simple diffusion is the movement of molecules from a region of high concentration to a region of lower concentration until an overall even concentration is reached. The steeper the gradient, the greater the rate of diffusion. Small, uncharged molecules such as oxygen and carbon dioxide are free to cross membranes by diffusing between the phospholipids (see Figure 1.5.6).

Helpful online resource

Cognito: What is Diffusion? How Does it Work? What Factors Affect it?

<https://www.youtube.com/watch?v=lxHMJaXOzP4>

Facilitated diffusion

Some important molecules that cells require are unable to move directly into cells through simple diffusion due to the properties of the phospholipid bilayer. Instead, the movement of some of these molecules can be **facilitated through transport proteins embedded in the phospholipid bilayer** (see Figure 1.5.6). This process is called facilitated diffusion and it is still a passive process because molecules still move down the concentration gradient and requires no energy. Substances that enter cells by facilitated diffusion include:

- hydrophilic molecules such as glucose and amino acids, and
- ions (charged particles) such as sodium and potassium ions.

Osmosis

Osmosis is the name for the diffusion of water from an area of **high water concentration to an area of low water concentration**. The movement of water differs to diffusion and facilitated diffusion because the **movement of water is also affected by the concentration of solutes**. This is because solute molecules attract and bind to water, reducing the number of 'free' water molecules within the solution. The greater the concentration of solutes, the lower the number of free water molecules. Water molecules will therefore move from a low solute concentration (high water concentration) to a high solute concentration (low water concentration) through a semi-permeable membrane. Water molecules can move directly through the phospholipid bi-layer or through specific channel proteins called aquaporins (see Figure 1.5.6). Aquaporins help regulate the movement of water into and out of cells.

It is important to note that this process is passive and only water molecules move by osmosis (see Figure 1.5.7). Osmosis continues until the same solute concentration is attained on both sides of the membrane, also known as isotonic solutions.

Isotonic solutions

When two solutions have the same solute concentration on either side of a membrane, they are said to be isotonic. Water molecules will move across the membrane in both directions but there will be no net movement of water molecules. This is also known as a state of **dynamic equilibrium**.

Hypotonic and hypertonic solutions

If two solutions are separated by a membrane their solute concentrations may not be equal. The solution that has a **lower solute concentration** is called **hypotonic**. The hypotonic solution has more free water molecules than the other solution and these water molecules will move by osmosis into the other solution. The other solution in this case is a **hypertonic solution** as it has a **higher solute concentration** and less free water molecules than the hypotonic solution (see Figure 1.5.7).

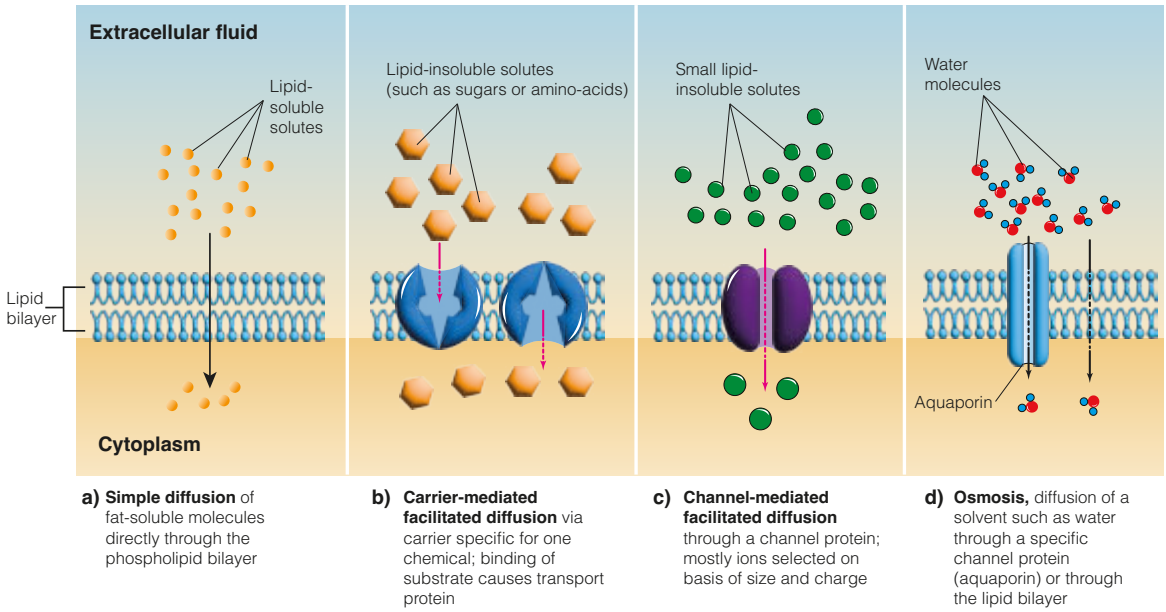


Figure 1.5.6: Passive transport can occur directly across the phospholipid membrane for some molecules, whereas others require a transport protein to facilitate its movement across the membrane. Water can move directly through the membrane, but the presence of aquaporins can increase the movement of water across the membrane. In all cases, the molecules move from an area of high concentration to an area of low concentration and therefore no energy is required to facilitate the movement.

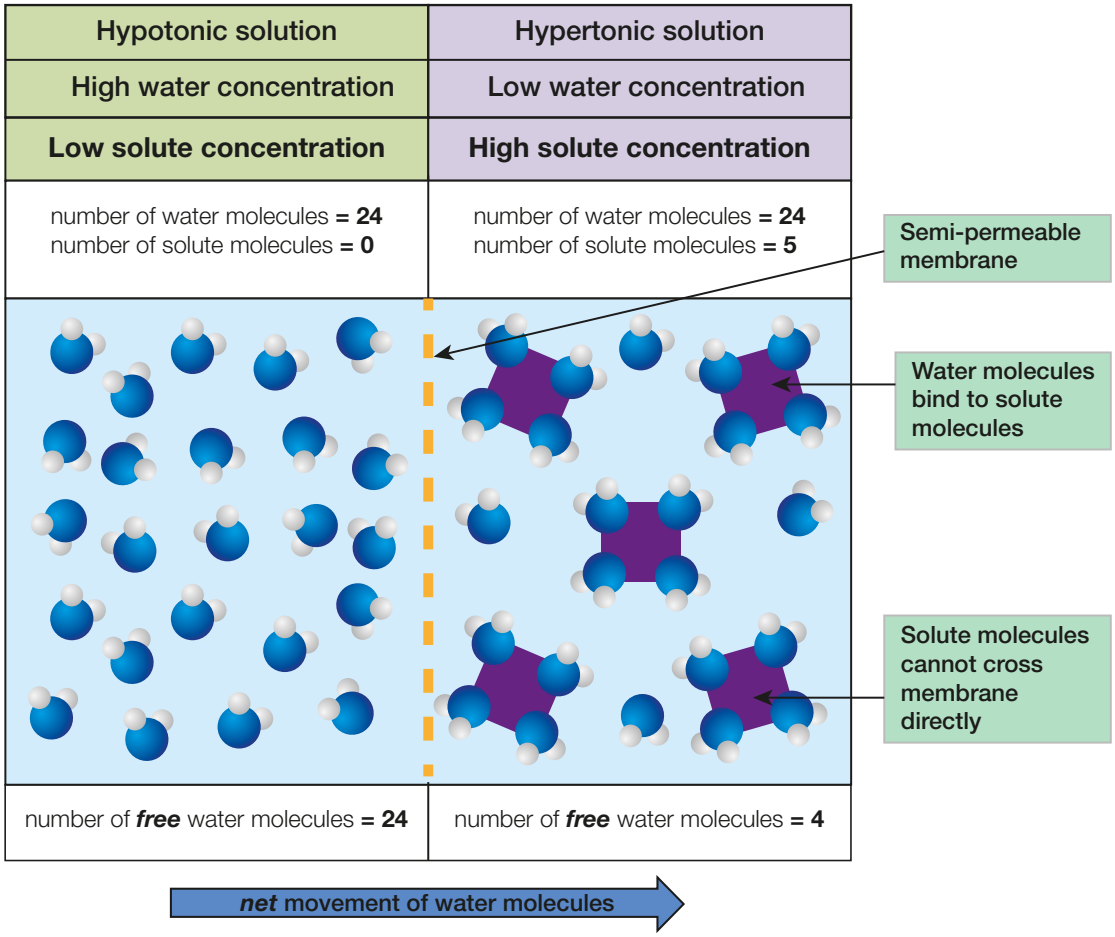


Figure 1.5.7: Solute molecules bind to water molecules reducing the number of free moving water molecules. Even though the two solutions above both have 24 water molecules, only 4 water molecules in the hypertonic solution (right) are 'free.' Therefore, water molecules from the hypotonic solution (left) move by osmosis to the hypertonic solution in an effort to even up the number of 'free' water molecules.

The effects of osmosis on plant and animal cells

Osmosis generally has a greater impact on animal cells as they do not contain a cell wall like plant cells. **The typical solute concentration of animal and plant cells is approximately 0.9%**. When exposed to a **hypotonic** environment (less than 0.9% solute concentration), water moves into cells and osmotic pressure can build up inside cells placing pressure against the cell membrane. In animal cells, the pressure can become too great for the membrane **causing the cell to burst** (called cell lysis). In plant cells however, the cell wall helps to maintain the water balance. Water moves into plant cells until it **becomes turgid (firm)** in hypotonic environments (see Figure 1.5.8). The tough cell wall stops any further entry of water into plant cells and prevents them from bursting. On the other hand, when exposed to **hypertonic** environments (greater than 0.9% solute concentration), water moves out of both animal and plant cells, **dehydrating them**. This causes animal cells to **shrivel** and can result in cell death. Plant cells also shrivel, but as they contain a cell wall, the cell membrane pulls away from it. This is called **plasmolysis** (see Figure 1.5.8).

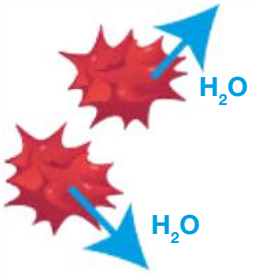
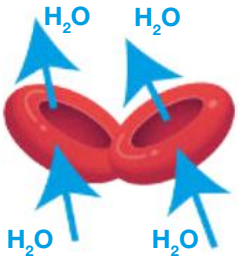
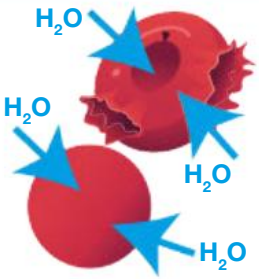
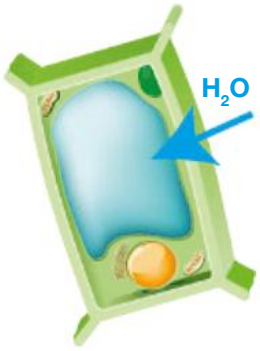
	Hypertonic Solution (net movement of water out)	Isotonic Solution (no net movement of water)	Hypotonic Solution (net movement of water in)
Human Red Blood Cells	 10% solute	 0.9% solute	 0% solute
	Shriveled cells	Normal cells	Cells swell and eventually burst
Plant Cells	 10% solute	 0.9% solute	 0% solute
	Cell body shrinks, large central vacuole shrinks, and membrane pulls away from cell wall	Normal cells	Large central vacuole expands and the cell swells and becomes turgid

Figure 1.5.8: The varying effects of different solute concentrations on animal and plant cells, which have a general internal solute concentration of 0.9%.

Helpful online resource

Cognito: GCSE Biology–What is Osmosis?

<https://www.youtube.com/watch?v=vCJVXYmXkzM>

Active transport across the cell membrane

Some molecules cannot be transported across the cell membrane passively and may require an input of energy to be transported into or out of the cell. This could be a waste product that needs to be excreted by a cell or it could be a useful product that the cell requires. In these cases, the cell will expend energy to transport these molecules through active transport or endocytosis/exocytosis.

Active transport

Active transport is a process in which solutes are moved **against the concentration gradient** from an area of low concentration to an area of high concentration. This process **requires energy** as the molecules need to be transported in the opposite direction that they would normally move by diffusion (see Figure 1.5.9).

The absorption of glucose in the human small intestine is a good example of where active transport is utilised. Glucose from digested carbohydrates is absorbed by facilitated diffusion and active transport. Glucose moves from the small intestine into the epithelial cells of the villi by facilitated diffusion, but when the concentration of glucose is lower in the small intestine, active transport is used to absorb glucose.

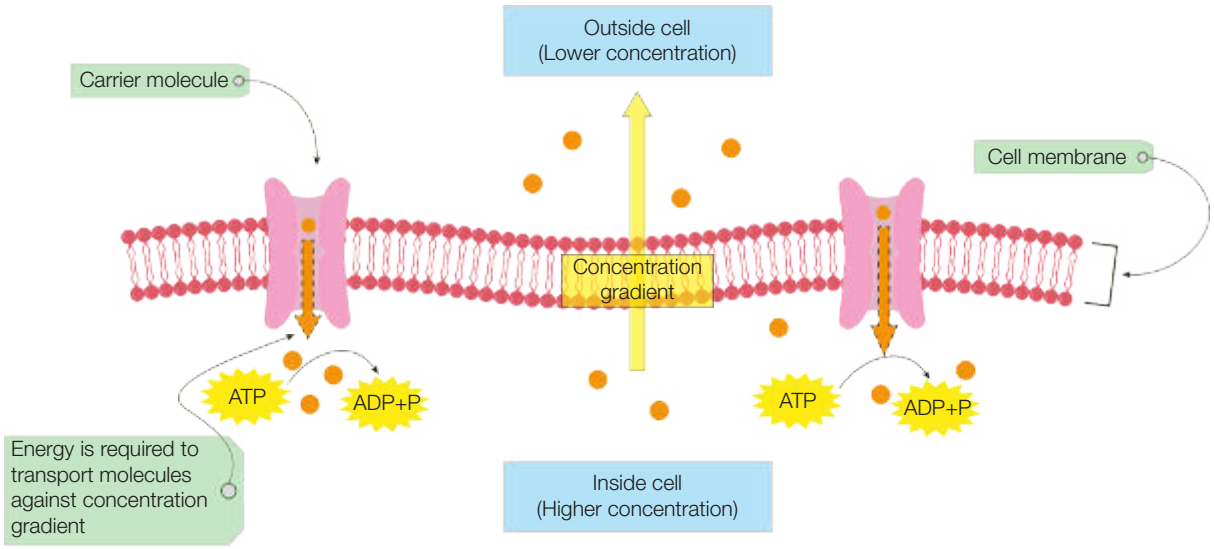


Figure 1.5.9: Active transport requires energy in the form of ATP to transport molecules against the concentration gradient.

Helpful online resource

Cognito: GCSE Biology–Active Transport

<https://www.youtube.com/watch?v=tM0bGaaQ2jY>

Endocytosis and exocytosis

Some materials are too big to pass through the phospholipid bilayer and transport proteins. To move these molecules into or out of cells, endocytosis or exocytosis is used. These two processes are active transport processes as they both involve the movement of the cell membrane which requires energy expenditure.

Endocytosis

Endocytosis is the process in which large molecules (or particles in bulk) outside the cell are engulfed by the cell membrane and moved **into the cell**. This involves the cell membrane folding inwards around the large molecule(s) and **pinching off to form a vesicle** inside the cell containing the large molecule(s) (see Figure 1.5.10).

Exocytosis

Exocytosis is the process in which large molecules (or particles in bulk) inside the cell are **secreted out of the cell**. Molecules are packaged inside vesicles, for example by a golgi body, which are then transported to the cell membrane. These vesicles then **fuse with the cell membrane** releasing the molecules to the extracellular environment (see Figure 1.5.10).

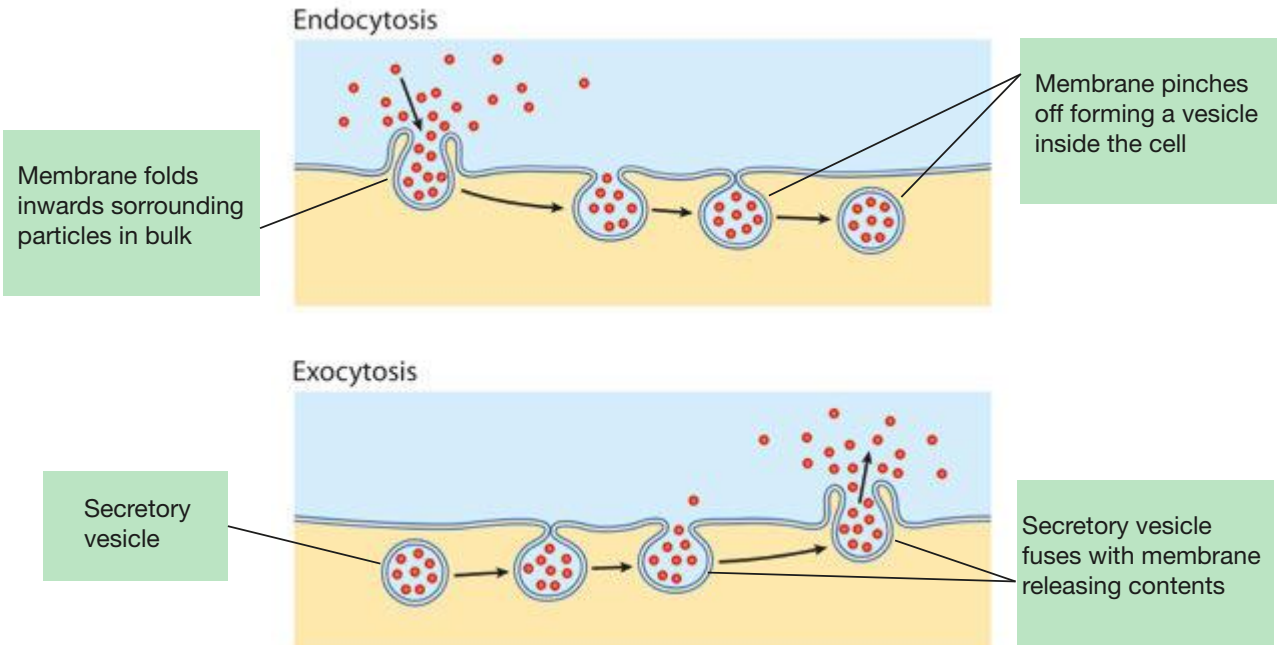


Figure 1.5.10: Endocytosis and exocytosis are complementary processes that require energy to move materials across the cell membrane.

Helpful online resource

Osmosis: Endocytosis and Exocytosis

<https://www.youtube.com/watch?v=HMbNAKUX3i4>

Richochet Science: Active, Passive, and Bulk Cell Transport

<https://www.youtube.com/watch?v=BGeSDI03aaw>

Factors that affect the rate of exchange of materials across the cell membrane

How quickly materials are exchanged across the cell membrane depends on factors including the:

- nature of the material being exchanged,
- concentration gradient (or, in the case of water, the solute concentration gradient), and
- surface area to volume ratio of the cell.

It is important to note that there are other factors that can also affect the rate of exchange of materials across the cell membrane. One example being temperature, which is explored further in Stage 2 Biology.

Nature of the materials being exchanged

Both the physical (size in particular) and the chemical nature of molecules, influence their ability to move across the cell membrane. Factors that influence whether a substance will pass across the cell membrane or not include its size, water solubility and charge (see Table 1.5.1). Two characteristics of the membrane that are largely responsible for the selective nature of the exchange are

- the lipid nature of the membrane, and
- the proteins embedded in the lipid bilayer.

Table 1.5.1: The nature of materials can affect the movement of materials across the cell membrane.

Factor	Explanation
Size	Only very small molecules are freely exchanged, such as gases like oxygen and carbon dioxide. Larger molecules, like many proteins, are too big and not exchanged freely. They may require other transport methods such as endocytosis and exocytosis.
Solubility in water	Molecules that are highly soluble in water (hydrophilic molecules) can only be exchanged if specific membrane transport proteins are used as well. This is because molecules that are water soluble do not interact easily with the lipid molecules that the bilayer is made up of. Conversely, molecules that interact easily with lipids (lipophilic molecules), such as steroid hormones, can move through the lipid bilayer more easily.
Charge	Ions (charged particles) are highly soluble in water and can only be exchanged if specific transport membrane proteins are present.

Concentration gradient

A concentration gradient exists when there is a difference in the concentration of molecules in two regions. The greater the difference in concentration of the molecules between the two regions, the greater the rate of diffusion (see Figure 1.5.11).

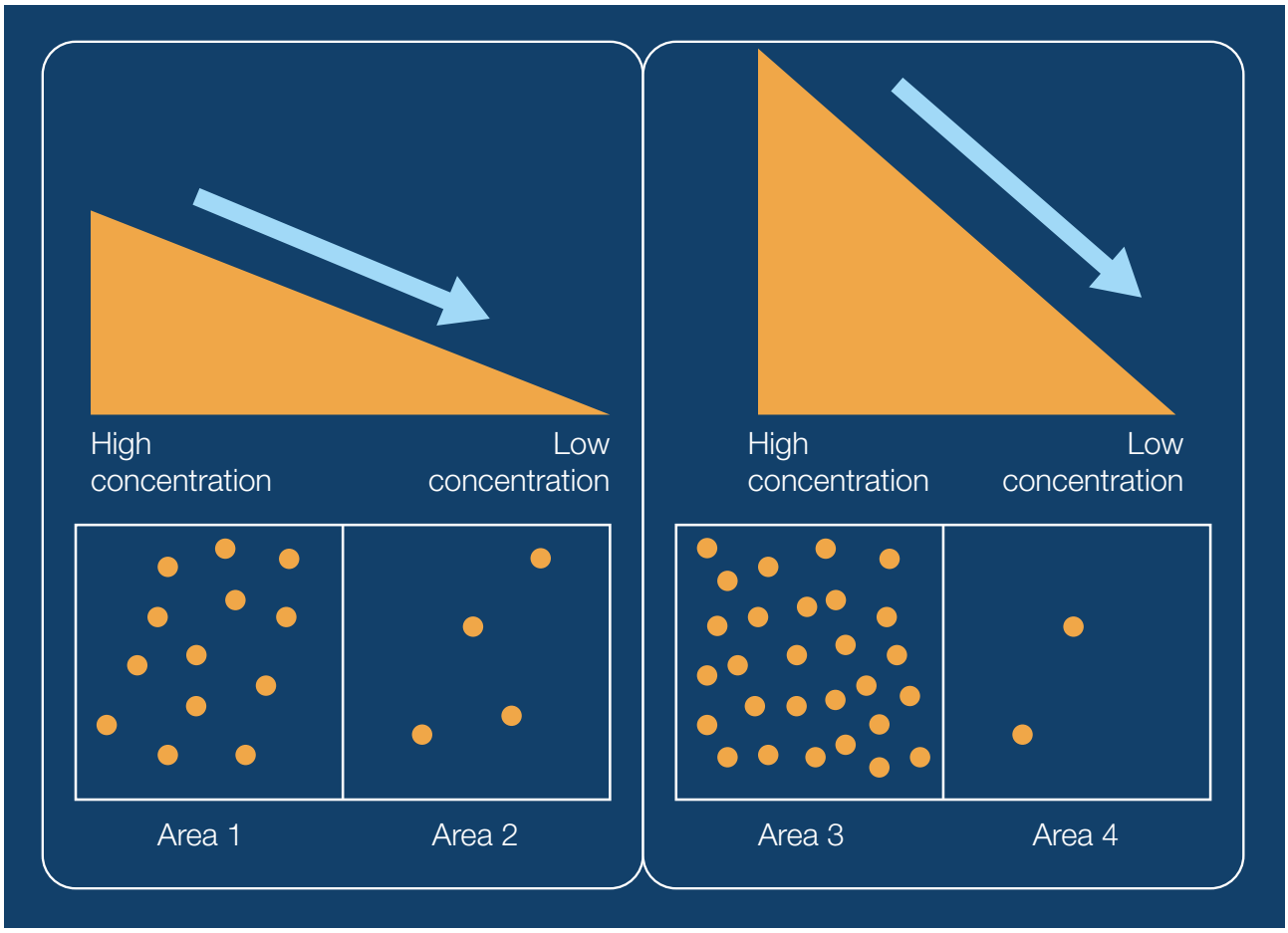


Figure 1.5.11: The greater the difference in concentration gradient between two areas, the greater the rate of diffusion.

Surface area to volume ratio

The surface area to volume ratio (SA:V) is an important concept for cells in explaining the efficiency of the exchange of materials between the external and internal environments. The ratio is a numerical value that represents the relationship between the amount of external surface area of the cell membrane and the volume of the cytoplasm. Virtually all cells are microscopic for a reason. By being incredibly small they have a very large surface area to volume ratio. This is critical to their survival because it means they can exchange materials with the external environment very efficiently.

No cells are the size of a seed, let alone a tennis ball because to be that large would mean having a very small surface area to volume ratio. Cells that big could not survive because the efficiency of exchange of materials with the external environment would be far too low to carry out life processes. As a cell grows larger it will have relatively less membrane area compared to its volume and this can be a stimulus for the cell to divide.

To summarise, as a cell grows:

- its surface area increases,
- its volume increases, but
- its surface area to volume ratio (SA:V) **decreases**

This is because as cells grow their **volume increases more than its surface area** (Figure 1.5.12).

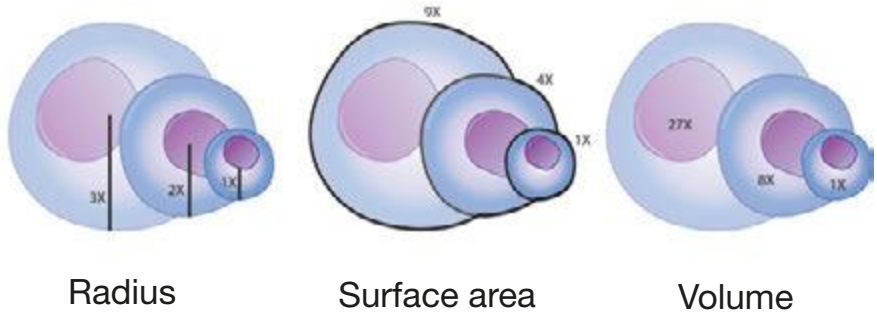


Figure 1.5.12: As the radius of the cell increases from 1x to 3x the surface area does not increase as much as the volume. The surface area only increases to 9x whereas the volume increases to 27x. The SA:V therefore decreases as the size of the cell increases.

Helpful online resource

Cognito: GCSE Biology–Surface Area to Volume Ratio

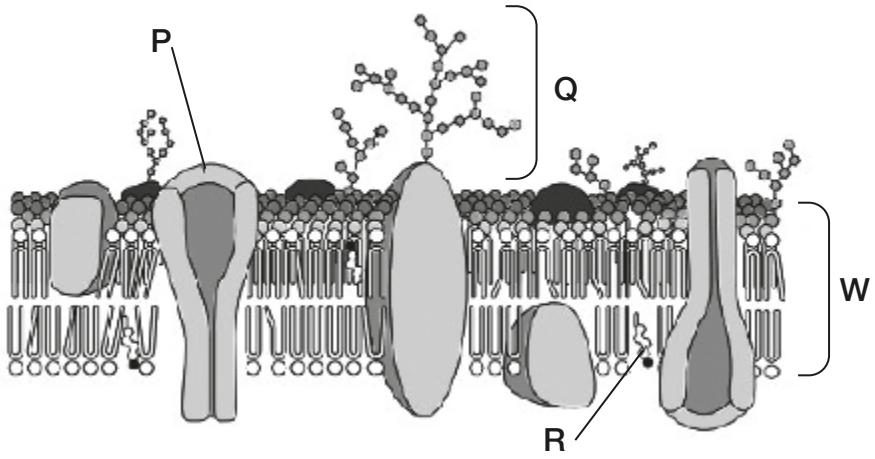
<https://www.youtube.com/watch?v=HMbNAKUX3i4>

1.5 Review questions

Multiple choice questions

1. Which of the following molecules is **not** part of the cell membrane structure?
   - J Carbohydrates
   - K Cellulose
   - L Lipids
   - M Protein
2. Cholesterol
   - J contributes to the fluid nature of the phospholipid membrane.
   - K is not a component of the cell membrane.
   - L is hydrophilic and is located in aqueous parts of cells.
   - M is embedded in the phospholipid membrane and is responsible for its mosaic nature.

3. *Refer to the diagram of a cell membrane below to answer the following question.*



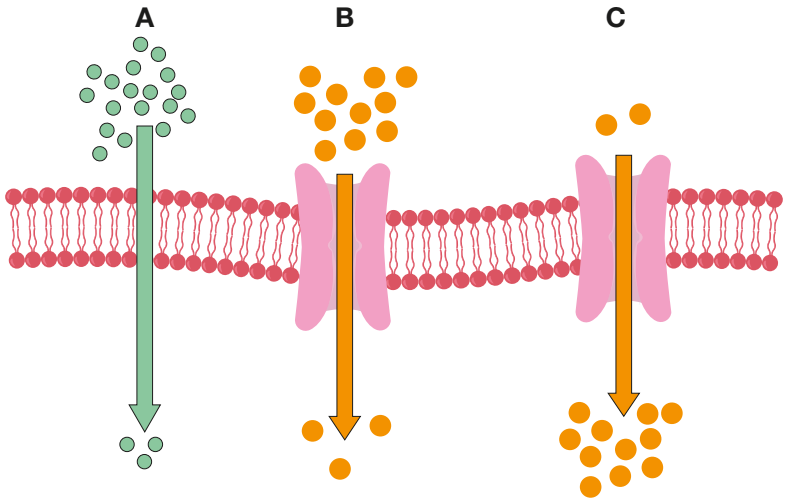
Select the option in the table below that correctly matches a part of the cell membrane with its structure and primary function.

	Label of membrane structure	Structure	Function
J	P	Protein	Anchorage
K	Q	Carbohydrate	Communication
L	R	Protein	Transport
M	W	Lipid	Energy

4. Endocytosis

J is a passive process.
K allows molecules to be transported out of the cell.
L is an active process involving a vesicle merging with the cell membrane.
M allows molecules to enter a cell without having to pass through the membrane directly.

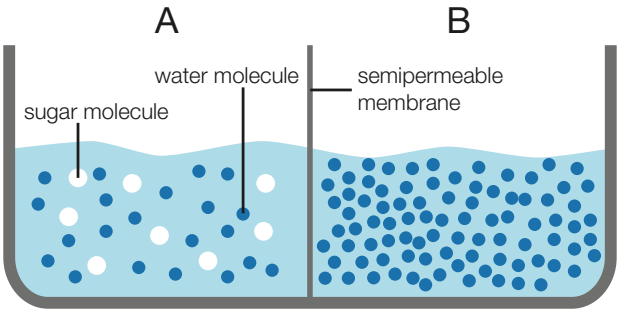
5. *Refer to the diagram below which shows the movement of molecules across a cell membrane to answer the following question.*



Which one of the transport mechanisms shown above best represents active transport?

J A
K B
L C
M None of the above

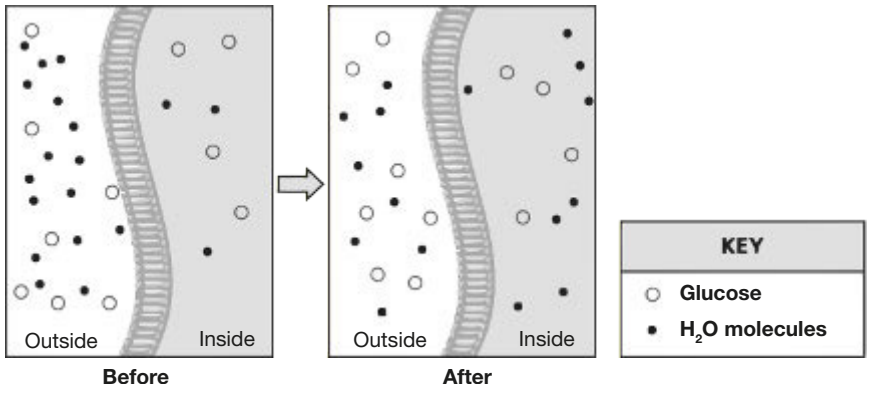
6. *Refer to the diagram below which shows two solutions (A and B) separated by a semipermeable membrane to answer the following question.*



After 10 minutes, the most likely outcome observed would be that…

J the volume of solution A increased.
K the volume of solution B increased.
L the volume of solution A decreased.
M no net change occurred in the volume of solutions A or B.

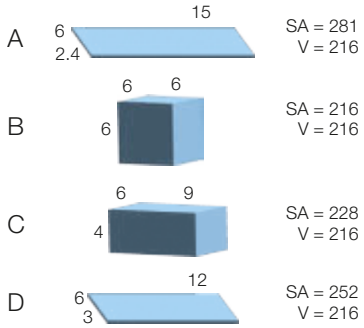
7. *Refer to the diagram below which shows the movement of molecules across a cell membrane to answer the following question.*



By referring only to the diagram above, it can be concluded that

J water and glucose molecules both move into the cell by passive transport.
K water and glucose molecules both move into the cell by active transport.
L water moves into the cell by passive transport and glucose moves into the cell by active transport.
M only water molecules move into the cell by passive transport.

8. *Refer to the diagram below which shows four 3D shapes and their respective total surface areas (SA) and volumes (V) to answer the following question.*



Which of the above 3D shapes has the greatest SA:V?

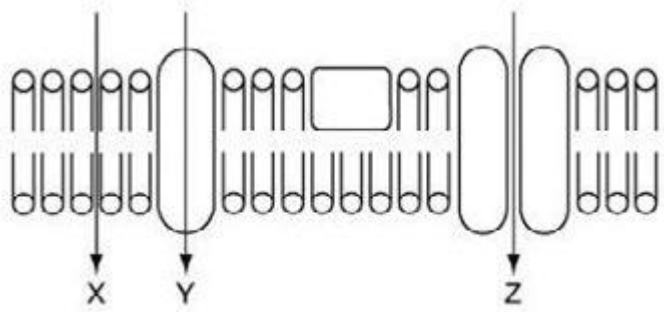
J A
K B
L C
M D

9. *Refer to the diagram to the right which shows the effect of solution X on a plant cell to answer the following question*.

By referring only to the adjacent diagram, identify the concentration of solution X in comparison to the plant cell's intracellular concentration.

J Hypotonic
K Hypertonic
L Isotonic
M Dynamic equilibrium

10. *Refer to the diagram below which shows a section of a cell membrane and three transport routes for molecules into the cell to answer the following question.*



Cells require essential vitamins for cellular processes. Some vitamins are water soluble whereas others are lipid soluble.

Identify the most likely transport routes of vitamin C (water soluble) and vitamin D (lipid soluble) across the cell membrane.

	Vitamin C	Vitamin D
J	X	X
K	Y	Z
L	Z	X
M	X	Y

Free response questions

1. Name the **three** macromolecules that the cell membrane consists of.

2. Name **three** useful substances that move into a cell from the external environment **and** state why each substance is required by the cell.

3. Describe the general structure of the cell membrane.

4. State **three** functions of the cell membrane.

5. Explain why the 'fluid mosaic model' is a suitable model for describing the cell membrane.

6. Explain why the cell membrane is described as semi-permeable.

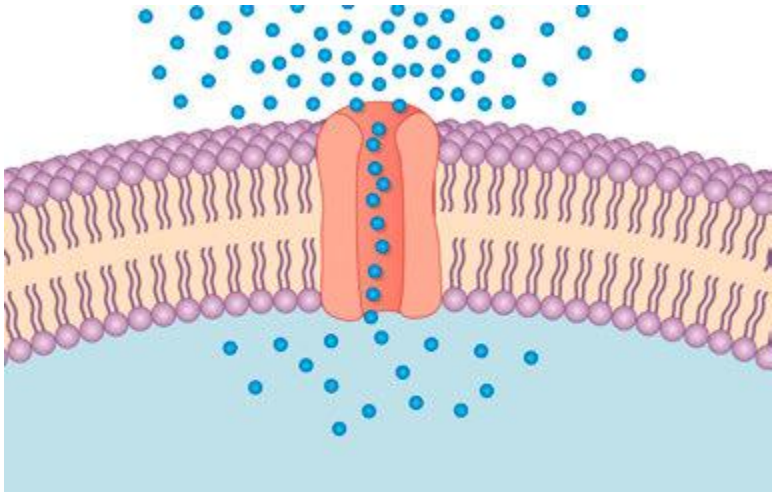
7. Glucose is highly soluble in water. Explain why glucose has a low cell membrane permeability.

8. Describe why the cell membrane is also described as selectively permeable.

9. Compare and contrast the different types of passive and active transport processes by completing the table below:

Transport process	Are proteins in the lipid bilayer required?	What is the concentration gradient?	Is an energy input required?
Simple diffusion			
Facilitated diffusion			
Active transport			
Osmosis			

10. *Refer to the diagram below to answer the following questions.*



a) Identify the process shown in the diagram above.

b) Justify your answer to 10(a).

11. State the likely method used to transport each material in the following examples:
    a) Water moves from wet soil into the roots of a plant
    b) Low concentrated mineral ions move from the soil into the roots of a plant
    c) Epithelial cells in the small intestine absorbing small droplets of lipid from the intestinal lumen
    d) A white blood cell engulfing a bacterium
    e) Oxygen gas moving from an animals' lungs into the blood

12. Surface area to volume ratio (SA:V) of cells is one factor that affects the rate of exchange of materials across the cell membrane. Cubes are often used to model the effect of increasing cell size on SA:V.
    a) Complete the following table to calculate the SA:V of the different sized cubes. One row has already been completed to provide an example.

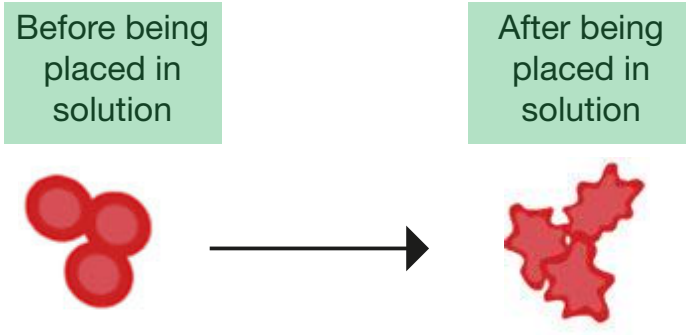
Edge length (cm)	Total surface area SA = l × w × 6 (cm^2)	Volume V= l × w × h (cm^3)	SA:V	SA:V (simplified to compare more easily)
1				
2				
3				
4	4 × 4 × 6 = 96	4 × 4 × 4 = 64	96 : 64	1.5 : 1
5				
6				

    b) Use data from the table to describe the trend observed as the cube size increases.

    c) Explain why the trend observed in part (b) occurs as the cube size increases.

    d) Using the trend observed in part (b), discuss the effect of increasing cell size on a cells ability to exchange materials with its environment.

13. *Refer to the diagram below which shows some human red blood cells before and after being placed in an unknown solution to answer the following questions.*



    a) State whether the external solution the red blood cells were exposed to is isotonic, hypotonic or hypertonic, when compared to the internal solute concentration of the red blood cells.

b) Using evidence from the diagram above, describe the effect(s) that exposing the red blood cells to this solution had.

c) Name the process that is responsible for the change seen in the diagram above **and** explain why this change occurred.

d) Explain why it is important for cells to maintain a relatively constant internal environment.

14. Endocytosis and exocytosis are essential transport processes to cells.

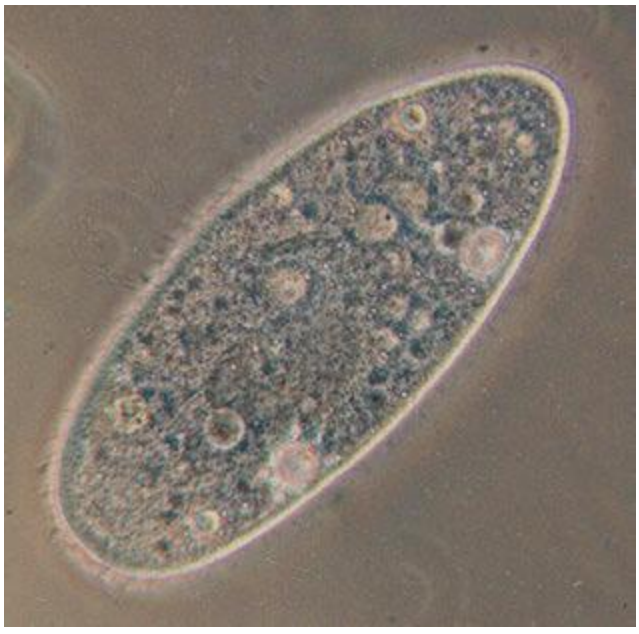
a) Explain why endocytosis and exocytosis are considered active transport processes.

b) Draw a simple labelled diagram to show the process of endocytosis.

15. *Refer to the diagram to the right which shows a photomicrograph of a paramecium at 400x and the information that follows to answer Question 15.*

Paramecium is a unicellular organism that lives in fresh-water and possesses a structure known as a contractile vacuole. This vacuole fills with fresh water and periodically contracts to expel water from the cell. Paramecium have a cell membrane but lack cell walls.

A researcher conducted an investigation to observe the effect of changing the external solute concentration on the rate of contraction of these vacuoles in a paramecium. The results from this investigation are shown in the following Table.



External solute concentration (arbitrary units)	Number of contractions per minute
0.00	7.1
0.02	7.0
0.04	5.3
0.06	5.2
1.00	4.9

a) Using the data in the table, draw a graph showing the number of contractions per minute against the external solute concentration.

b) Describe the relationship between the external solute concentration and the number of contractions per minute.

c) Identify **and** explain the likely effect on a paramecium of being exposed to a 0% solute concentration environment if it didn't have contractile vacuoles.

d) Using the data, explain **one** likely reason why the number of contractions changes as the solute concentration changes.

e) Outline **two** possible limitations to any conclusions made from this investigation.

Chapter 1.6 The importance of microorganisms

Science Understanding

Microorganisms are important living things. Microorganisms include bacteria, fungi and protists. In ideal conditions bacteria grow exponentially.

Different bacteria require specific conditions for growth.

- Discuss the effects of factors such as:
  - temperature
  - nutrient availability
  - moisture
  - pH
  - the removal of wastes.

Microorganisms act as decomposers, which enables recycling of essential nutrients. Bacteria reproduce by binary fission (asexual).

Microorganisms are important to humans.

- Discuss the role of microorganisms in:
  - the digestive system
  - oxygen production by phytoplankton
  - recycling nutrients through the non-living environment by decomposing dead and waste materials
  - recombinant DNA technology.
- Humans have cultured and used microorganisms for about 10,000 years.

Types of microorganisms

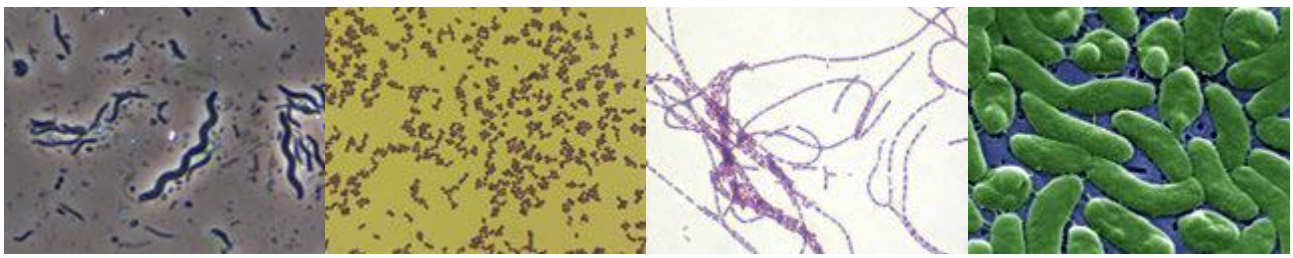
Microorganisms (or microbes) are living organisms that are too small to be seen with the naked eye. They are a diverse group, consisting of both unicellular and multicellular organisms. The five major types of microorganisms are **bacteria, archaea, fungi, protists and viruses.**

Microorganisms exist in virtually all environments on Earth making up approximately 60% of all living matter. Some perform crucial roles such as nutrient recycling and producing oxygen. Many microbes are beneficial to life, but others can be harmful and cause disease.

Bacteria

Bacteria are unicellular and consist of a prokaryotic cell that lacks a nucleus and other membrane-bound organelles. They contain cell walls consisting of peptidoglycan and reproduce through the process of **binary fission** (see Chapter 1.3 for more information). Some bacteria can produce spores, which allow them to survive environmental stresses, such as extreme temperatures. Bacteria exist in different shapes including bacillus (rod shaped), coccus (spherical shape), spirilla (spiral shape) and vibrio (curved shape).

Bacteria can be classified as **aerobes** (requires oxygen for life), **anaerobes** (do not require oxygen for life) or **facultative anaerobes** (can live in environments with or without oxygen). Some bacteria use autotrophic nutrition and others are heterotrophic (see Chapter 1.4 to review these concepts). Bacteria that obtain their organic molecules by consuming decaying or dead matter are termed **decomposers** (or saprophytes).



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

Figure 1.6.1: Photomicrographs of four bacterial species (at different magnifications) highlighting the four major bacterial shapes (a) Bacilli, (b) Cocci, (c) Spirilli and (d) Vibrio.

Archaea

Archaea were initially classified as bacteria because they are **unicellular prokaryotic organisms** (do not contain a nucleus) and have a similar structure to bacteria. The structure of their cell wall differs from bacterial cell walls however and is not composed of peiptidoglycan. Acrhaean cell walls are chemically distinct and contains unique lipids that allow them to **survive in extreme environmental conditions**. Some types of archaea include:

- methanogens (methane-producing archaea),
- halophiles (archaeans that live in salty environments),
- thermophiles (archaeans that live at extremely hot temperatures), and
- psychrophiles (archaeans that live in extremely cold temperatures).

When previously classified as bacteria, they were originally named archaebacteria. They are now classified as their own domain (Archaea) though due to their unique properties that separate them from the other two domains (bacteria and eukarya).

Archaea are part of the microbiomes of all organisms and perform essential roles such as assisting in the digestion process in animals. Some archaeans use organic molecules as an energy source, whereas others use inorganic molecules such as ammonia, hydrogen gas or metal ions to obtain energy rich molecules through chemosynthesis. Archaeans can reproduce asexually by **binary fission**, fragmentation, or budding. Currently, no known species of Archaea form spores like bacteria can.

Fungi

Fungi are comprised of eukaryotic cells that contain a nucleus and other membrane-bound organelles. Fungi cells also contain a cell wall, but it is composed of **chitin**, which is a different carbohydrate to bacterial cell walls (peptidoglycan) and plant cell walls (cellulose). Some fungi are unicellular (yeast), but most are multicellular (moulds and mushrooms). Mushrooms are not microscopic, but there are multicellular microscopic fungi such as some moulds and mildews.

Fungi are heterotrophic and obtain their nutrients through absorption. Many fungi form branching networks of hyphae (collectively known as mycelium) that absorb nutrients (see Figure 1.6.2). Decomposers obtain their nutrients from decaying and dead matter, symbionts obtain their nutrients through symbiotic relationships with plants, and parasites obtain theirs through harmful relationships with host organisms. Fungi reproduce by releasing **spores** which are then able to grow into new organisms in suitable environments.

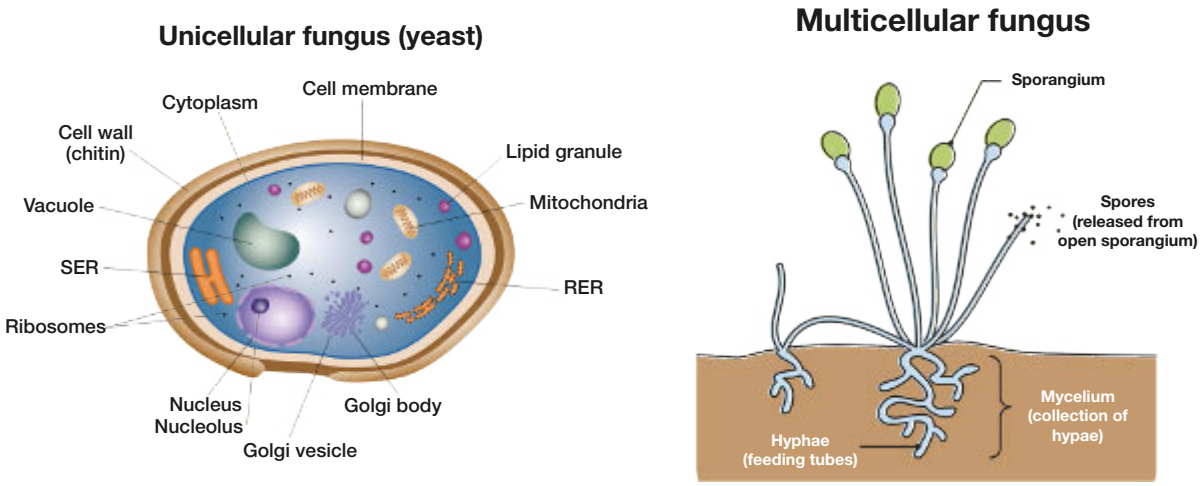


Figure 1.6.2: The general structures of unicellular and multicellular fungi.

Protists

Protists are a diverse group of **eukaryotic organisms** consisting of all eukaryotes not classified as fungi, plants or animals. They are mostly unicellular, but some are multicellular. Protists are consequently the largest group of organisms on Earth in terms of numbers (over 100,000 living species), biomass and diversity. Protists exhibit a diverse range of characteristics. Some are autotrophic, whereas others are heterotrophic. Some protists reproduce through asexual processes (including binary fission and budding), some protists reproduce sexually, and others can reproduce using a mixture of both reproduction strategies. Protists are generally classified into three main groups based in their similarities to other kingdoms of life:

1. Protozoa (animal-like protists)
2. Algae (plant-like protists)
3. Slime moulds and water moulds (fungus-like protists)

Protozoa (animal-like protists)

Protozoa are single-celled eukaryotic organisms that exhibit animal-like behaviors, such as movement and predation. They are **heterotrophic** and obtain nutrients by ingesting other microorganisms or organic matter through **endocytosis**. Their ability to move is facilitated by structures like cilia, flagella, or pseudopodia (see Figure 1.6.3). Protozoa are much simpler than animals and are thought to have been the ancestors of animals.

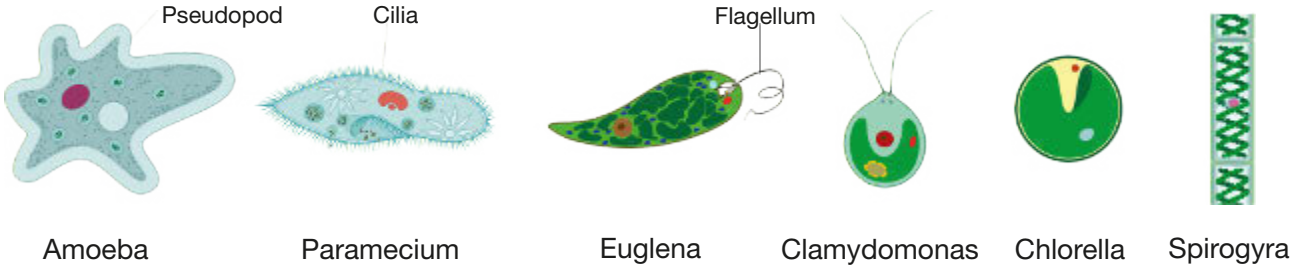


Figure 1.6.3: Some examples of animal-like protists (amoeba and paramecium) and plant-like protists (euglena, clamydomonas, chlorella and spirogyra).

Algae (plant-like protists)

Algae (also known as cyanobacteria or blue-green algae) are **autotrophic** organisms that obtain their energy-rich molecules through the process of **photosynthesis**. They tend to lack many of the structures associated with typical plants and can vary in size from unicellular and microscopic (see Figure 1.6.3), to the extremely large multicellular kelps and seaweeds.

Algae are important contributors to life on Earth. They are producers in aquatic food webs, trapping the sun's energy for other organisms in both marine and freshwater environments. They also produce a significant portion of the Earth's oxygen (an estimated 50%) through photosynthesis.

The classification of these organisms is not universally agreed amongst scientists as not all algae are closely related in an evolutionary sense. In fact, some groups of algae are more closely related to fungi and protozoa than other algae.

Slime moulds and water moulds (fungus-like protists)

Fungus-like protists share some similarities with fungi, such as their filamentous growth (see Figure 1.6.4), heterotrophic mode of nutrition and reproducing through spore production. They are not classified as fungi though because there are some clear differences, such as their cell walls being composed of different carbohydrates. Fungi contain cell wall composed of chitin, whereas the cell walls of fungus-like protists are composed of cellulose.

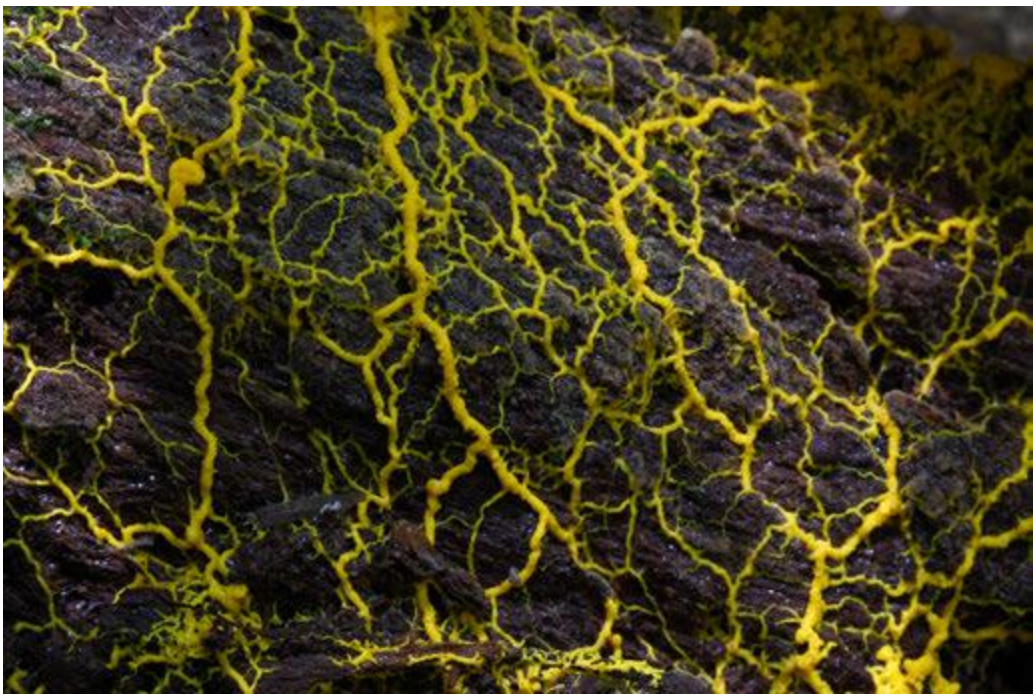


Figure 1.6.4: A clear example of the filamentous growth of slime mould in search of food on a decaying log.

Viruses

Viruses are classified as microorganisms, but they are not considered living organisms because they cannot carry out life's processes, as discussed in Chapter 1.1. They are non-cellular entities containing nucleic acids (DNA or RNA), lipids and proteins (see Figure 1.6.5). They can only reproduce inside the cell of a host organism (animals, humans, plants and bacteria) and often cause disease as a result.

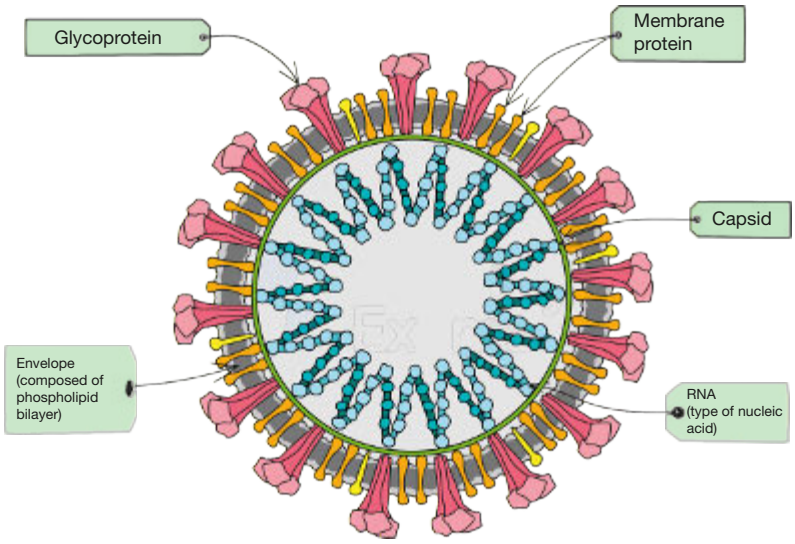


Figure 1.6.5: The basic structure of a virus.

Conditions for the growth of bacteria

Under optimum conditions a single bacterium can multiply into approximately two million bacteria within 7 hours and more than 68 billion in 12 hours (see Figure 1.6.6). The number of bacteria doubles through the process of **binary fission**, resulting in this **exponential growth**. As many bacterial species have a short generation time of approximately 20 minutes, this exponential growth can occur in a relatively short period of time. Fortunately, such exponential growth rarely occurs because resources are a limiting factor and waste production is toxic.

Different bacterial species require different sets of conditions for optimal growth including:

- a supply of specific nutrients
- oxygen availability
- available free water (moisture)
- a suitable temperature
- a suitable pH
- ability to remove waste products efficiently.

Time	Number of Cells	
0 min	1	$= 2^0$
20 min	2	$= 2^1$
40 min	4	$= 2^2$
60 min	8	$= 2^3$
80 min	16	$= 2^4$
100 min	32	$= 2^5$
120 (2hr)	64	$= 2^6$
⋮	⋮	⋮
4 hr	4,096	$=2^{12}$
⋮	⋮	⋮
12 hr	68,719,476,736 = 2^{36}	

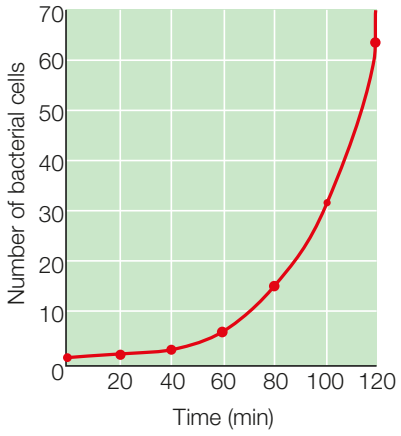


Figure 1.6.6: An example of the exponential growth of bacteria that divide every 20 minutes.

Nutrients

Bacteria need essential matter to provide them with the required elements such as carbon, nitrogen, sulphur, and phosphorus. As has been explained in Chapter 1.4, there are two distinct types of nutrition, heterotrophic and autotrophic. **Autotrophic** bacteria require inorganic nutrients that they can convert into organic nutrients (such as glucose), whereas **heterotrophic** bacteria cannot synthesise their own energy rich organic molecules and therefore must be supplied. Other bacteria use decaying life as a source of energy and are called **saprophytes**.

Oxygen

Aerobic bacteria (aerobes) require oxygen for life whereas anaerobic bacteria (anaerobes) do not. **Aerobes require oxygen to respire and produce energy** for cellular activity and division. If oxygen availability is reduced, aerobes cannot grow and divide as efficiently. An example of an aerobe is *Escherichia coli* (*E. coli*) bacteria. Conversely, **anaerobes do not need oxygen to produce energy** and can survive in environments very low in oxygen. An example of an anaerobe is *Clostridium botulinum*, which can survive in the very low oxygen environment of tinned cans.

Moisture

All bacteria need moisture to survive. **Bacteria require water to perform many chemical reactions** and they obtain this from their environment. However, **water molecules can be bound to salts (such as Na^+ and Cl^-),** soil or cell structures and be unavailable for microorganisms to use for chemical reactions. The **amount of free water** that is available to support bacterial growth is known as **water activity (a_w)**. Water activity is measured on a scale of 0.0 (no free water) to 1.0 (pure free water). Most pathogenic bacteria require a water activity above 0.9 and bacterial growth is inhibited below a water activity of 0.75 (see Figure 1.6.7 for some specific examples). However, some yeasts and moulds can still grow below a water activity of 0.75. Environments that have a water activity below 0.6 prevent all growth of microorganisms.

Product	a_w
water	1
meat	0.97 – 0.99
milk	0.97
juice	0.97
cheeses	0.93 – 0.96
bacon	<0.85
jams	0.82 – 0.94
saturated solution of NaCl	0.75
room air	0.5 – 0.7
honey	0.5 – 0.7
dry fruits	0.5 – 0.6
crackers	0.3
infant formula	<0.2

Microorganism	a_w
Clostridium botulinum	0.97
Pseudomonas fluorescens	0.97
Escherichia coli	0.95
Clostridium perfringens	0.95
Salmonella	0.95
Vibrio cholerae	0.95
Clostridium botulinum A, B	0.97
Bacillus cereus	0.93
Listeria monocytogenes	0.92
Bacillus subtilis	0.91
Staphylococcus aureus	0.87
Most of the moulds (fungi)	0.70
No development	0.60

Figure 1.6.7: Some examples of the water activity in various foods and the minimum water activity various microorganisms can survive at.

Temperature

As bacteria are such a diverse group they can live in a vast range of temperatures, from very cold (beneath ice) to extremely hot (in hot springs). Bacteria that live in very cold temperatures are called **psychrophiles** and those that live in high temperature environments are called **thermophiles**. Nonetheless many disease-causing bacteria flourish from about 30°C to 40°C.

Many bacteria tend to grow and divide readily in temperature's ranging from 5°C to 60°C. This temperature range is often referred to as the **temperature danger zone**, especially in the context of food safety (see Figure 1.6.8).

Bacteria that prefer the danger zone temperature range do not multiply quickly at temperatures below 5°C. For example, at 1°C, some bacteria double approximately every 6 hours and at -10°C some bacteria can double every 60 hours. At temperatures **below -18°C, bacteria become dormant** (no growth and division at all). At these temperatures, the water in the food needed for chemical reactions by bacteria to grow and divide is **frozen**. Therefore, there is no free water for bacteria to use (water activity is 0.0).

Most bacteria cannot grow above 60°C so this slows their growth. If bacteria are exposed to high temperatures for long enough, they die. For example, salmonella die at 71°C. With the exclusion of thermophiles and hyperthermophiles, **most bacteria die at temperatures above 75°C.** Some bacteria are able to form **dormant spores** that are very resistant to environmental stresses, such as extremely high temperatures, to ensure its survival. Once the environmental stress passes and conditions return to normal, the spores are able to reactivate, and the bacterial growth can continue. **Exposure to extremely high temperatures does not destroy dormant spores or the toxins already released by bacteria**.

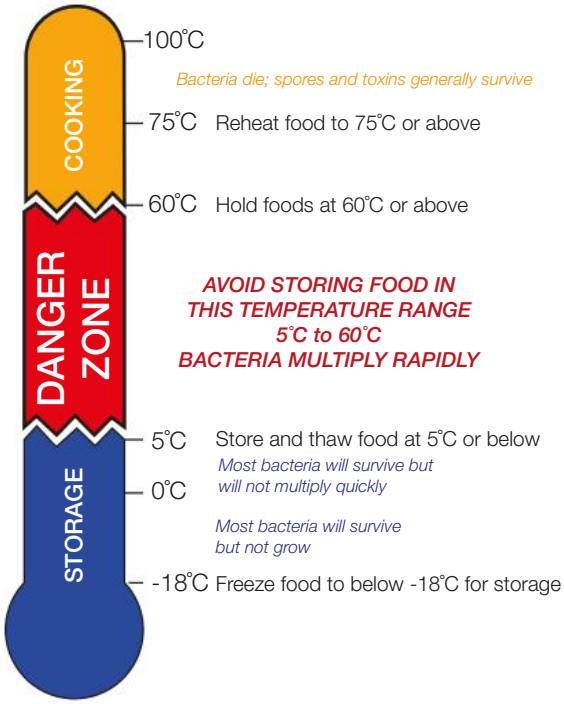


Figure 1.6.8: A summary of the storage, cooking and danger zone temperatures to reduce the risk of contracting food poisoning.

pH

pH is a measure of how acidic or alkaline an environment is. The pH scale ranges from 0 to 14. At a pH of 7, the environment is neutral. As the pH decreases towards 0, it becomes progressively more acidic; as pH increases towards 14, it becomes progressively more alkaline (see Figure 1.6.9). The majority of bacteria prefer a pH closer to neutral in the range 6.6 to 7.5 for optimal growth, however some bacteria prefer acidic environments and others prefer alkaline environments.

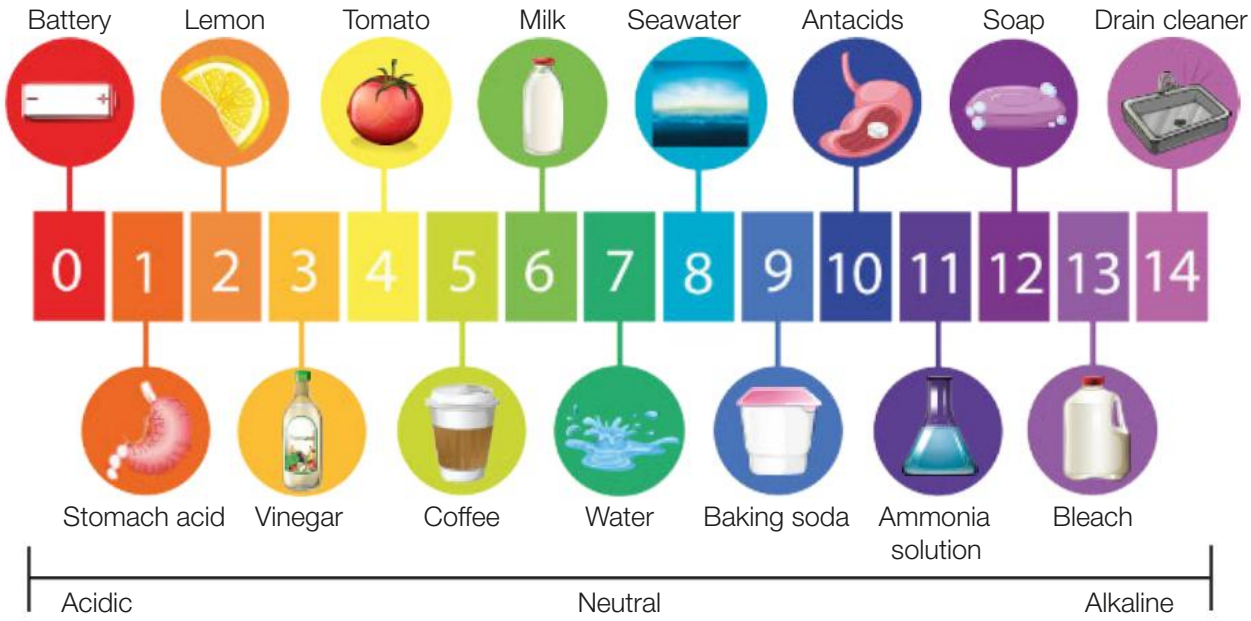


Figure 1.6.9: The pH scale and some examples of substances at the various levels of the pH scale.

Importance of microorganisms to humans

Microbiome

The human **microbiome is the collection of microorganisms** such as bacteria, fungi, protozoans and viruses that inhabit the human body. It is estimated that there are 100 trillion microorganisms living on or within the body. In fact, current research estimates there are approximately the same number of microbial cells on or within a human as there are human cells. Every individual has a unique community of microorganisms with some studies suggesting that only 10% to 20% of the bacteria an individual has is shared with others.

Recent research is highlighting the important role our unique microbiome has on our health. This is because we have a **symbiotic relationship** with most of the microorganisms that live on or within us. Most of these relationships are mutualistic, where we provide them with a home and nutrition, and they benefit us in various ways such as extracting energy and vitamins from our food for us to absorb. However, humans can experience health issues if the wrong type(s) of species are introduced or if the balance of populations is disrupted.

The human microbiome is **possibly the most diverse ecosystem on earth**. Each area of our body is a different 'habitat' that has its own unique community of microorganisms, which develop and change throughout our lives. The species in these habitats are very specific, for example, there are certain bacteria that will only be found on the front of your teeth and not the back (and vice versa). See Figure 1.6.10 which shows the percentages of some 'divisions' of bacteria at different habitats of the body.

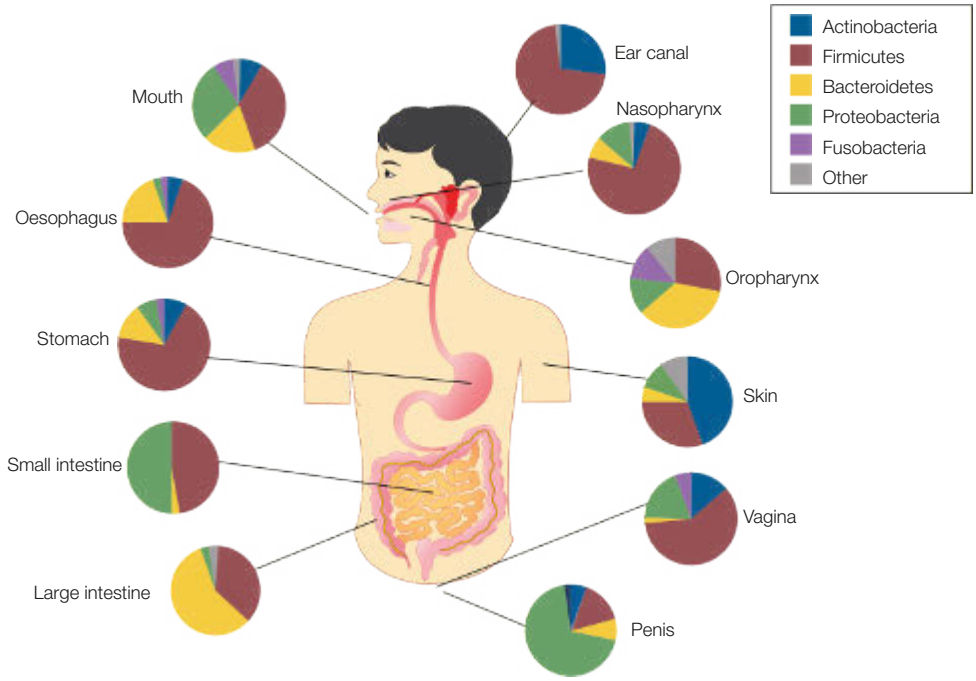


Figure 1.6.10: The general compositions of bacterial communities at various sites on or within the body.

Helpful online resource

Kurzgesagt: How Bacteria Rule Over Your Body – The Microbiome

<https://www.youtube.com/watch?v=VzPD009qTN4>

The gut microbiome

Although there are trillions of microorganisms on and within our bodies, **the majority of them live in our gastrointestinal tract.** Collectively, the gut microbiome weighs about 1.5kg. It is currently estimated that there are up to 1,000 different species of microorganisms within our guts. Only a small percentage of these species reside in the stomach because of its acidic nature. Many more species reside in the small intestine but **most of them live in the large intestine.** The majority of the gut microbiome is made up of bacteria. There are currently 55 recognised 'divisions' of bacteria, of which eight have been found residing in the guts to date. Three of these bacterial divisions are common in the gut. *Bacteroidetes* and *Firmicutes* make up two thirds of the microbes in the guts. The third common division is *Proteobacteria*.

It is now known that **the more diverse an individual's microbiome is, the less likely they are to develop adverse health outcomes** (see Figure 1.6.11). One reason for this is that the more diverse an individual's microbiome is, the more resilient it is. **A resilient microbiome can recover more easily from disturbances, such as infections and antibiotics.** This concept is also seen elsewhere in nature, such as stable ecosystems throughout the world. Each species in an ecosystem has a specific role(s) and removing one species can start a chain reaction of adverse effects and destabilise it. Healthy ecosystems with a large biodiversity exhibit greater resilience to the removal of a species than ecosystems with reduced biodiversity. This is generally because there is a greater number of species available to fill the role(s) of the missing species (see Topic 4: Biodiversity and Ecosystem Dynamics for more information).

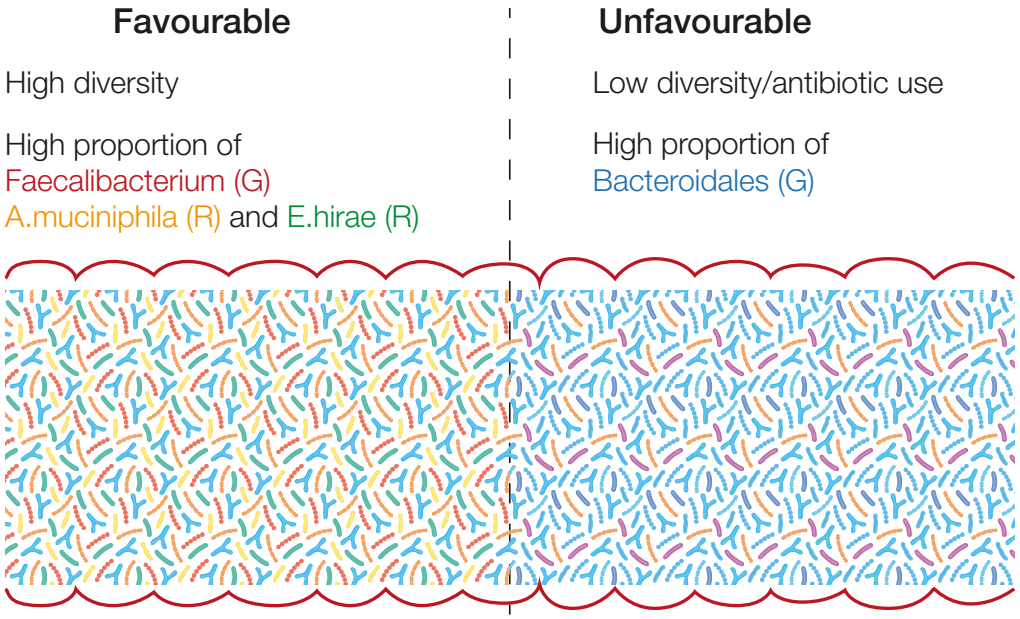


Figure 1.6.11: A microbiome with high diversity is generally associated with more favourable health outcomes than a microbiome with low diversity.

The roles of gut microbiome in the digestive system

The gut microbiome plays many important roles in the digestion of food. There are many we know about and there are also many that are yet to be determined.

Bacteria in the intestines **increase energy availability from our food by helping with the digestion of carbohydrates**, especially those we cannot digest (such as fibre and resistant starch). The bacteria use some of this energy, but the remainder is made available to us. In fact, the bacteria in our guts can produce up to 30% of our daily energy. *Bacteroides thetaiotaomicron* is one species of bacteria that lives in our guts and it has over 460 different enzymes that can extract energy from carbohydrates. That is approximately 360 more enzymes involved for carbohydrate digestion than our bodies possess. These additional enzymes allow the bacteria to digest some fibre and extract energy and other nutrients from it. As every individual's microbiome is unique, the amount of nutrients extracted from the carbohydrates we cannot digest varies from person to person. **A microbiome that can extract more energy from indigestible carbohydrates could increase the risk of the host being overweight/obese**. However, all of us rely on our microbiome to extract the energy required for our daily needs.

Gut bacteria also release **short chain fatty acids (SCFAs)** as a result of fermenting our dietary fibre. Short chain fatty acids, such as butyrate, nourish our intestinal lining and **protect against inflammation of the gut**. Ultimately, this also **protects us against intestinal cancer** and other adverse health conditions (see Figure 1.6.12). Additionally, bacteria also release vitamins from our food increasing their bioavailability. **An important vitamin produced by the microbiome is vitamin K.** Infants have severely underdeveloped microbiomes and therefore cannot synthesise vitamin K efficiently. As a result, they are generally given a vitamin K supplement injection to last until the microbiome develops and they can become more self-sufficient at producing it. The gut microbiome can produce additional vitamins, but not enough for our body to rely on. Furthermore, as everyone's microbiome and diet are unique, the production of these vitamins will differ from person to person.

Some intestinal bacteria **produce lactic acid** as a byproduct when fermenting carbohydrates. This helps to lower the pH of the gut (increases acidity) and **make the environment less suitable for pathogenic microorganisms to grow.** They are also known to produce a variety of substances that can inhibit or destroy potentially dangerous or pathogenic bacteria. Some strains can also produce enzymes capable of destroying bacterial toxins. Microorganisms in our intestines are an important component of a robust, balanced immune system.

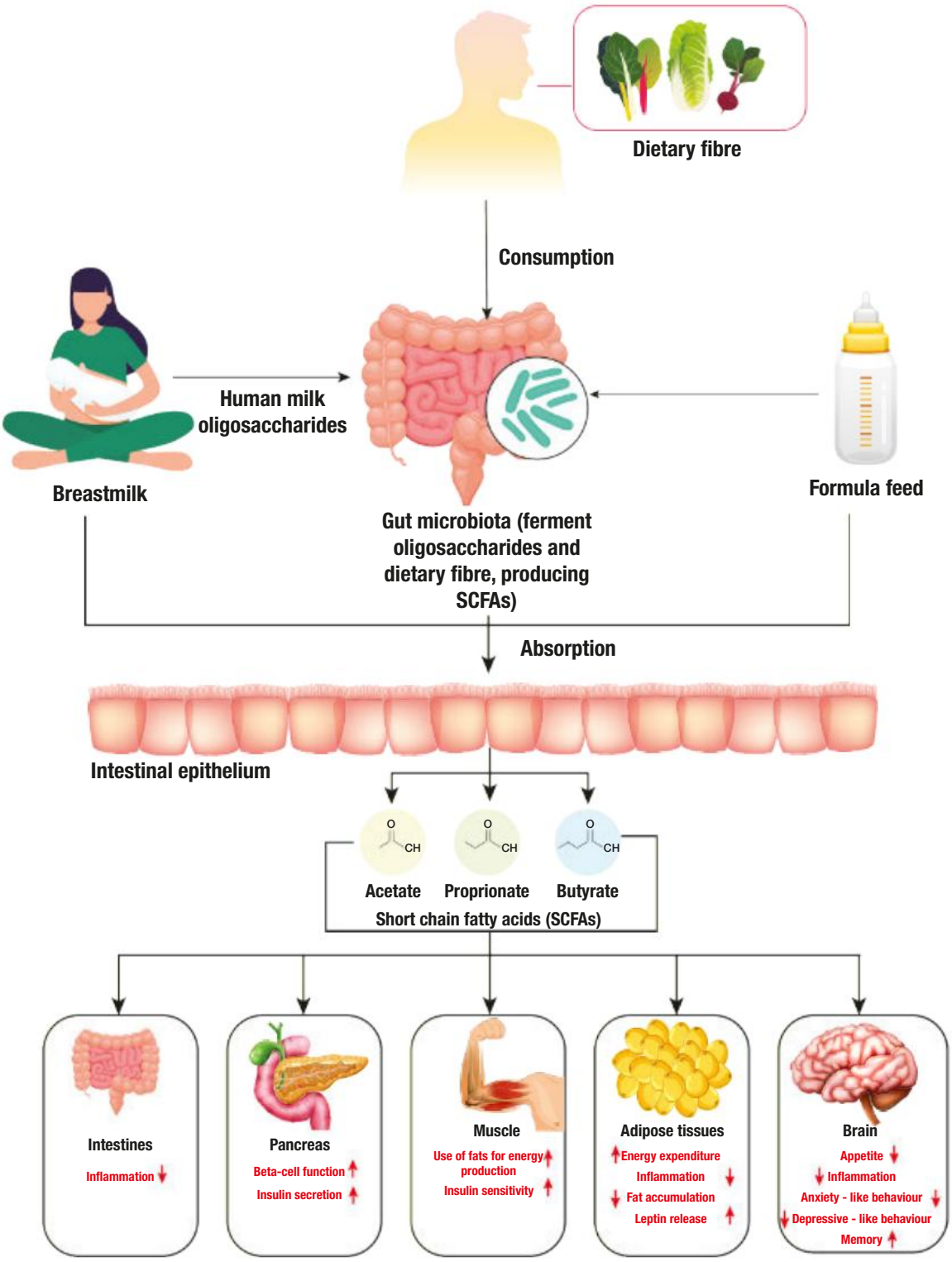


Figure 1.6.12: The gut microbiome ferments oligosaccharides and dietary fibre to produce short chain fatty acids (SCFAs). The three major types of SCFAs are acetate, proprionate and butyrate, which play multiple roles within the body including reducing inflammation (and disorders associated with it), anti-obesity roles (e.g. decreasing fat accumulation) and anti-diabetic roles (e.g. increasing insulin sensitivity). Please note that the arrows pointing upwards indicate an increase, and arrows pointing downwards indicate a decrease.

Helpful online resource

FuseSchool – Global Education: Bacteria in Digestion

<https://www.youtube.com/watch?v=laUPud5PVhU>

Oxygen production

The ocean has a relatively high solute concentration and is low in nutrients. As a result, not all organisms can survive the limiting environmental conditions of the oceans. Phytoplankton (also known as microalgae) thrive in these conditions though. These plant-like protists are **autotrophic** and contain chlorophyll to capture sunlight which is used in the process of **photosynthesis**. It has been estimated that approximately 50% of the Earth's oxygen production comes from the ocean's phytoplankton. In fact, the smallest known phytoplankton – *Prochlorococcus*– produces up to 20% of this, which is more than all tropical rainforests on land produce collectively.

It is important for ocean ecosystems to remain balanced because phytoplankton not only provide food for a wide range of organisms, but they also produce the majority of oxygen that both land and aquatic organisms require for respiration and survival (see Figure 1.6.13).

Recycling of essential nutrients

All organisms need energy and matter to build up their tissues. The main elements that make up living tissue are carbon, oxygen, nitrogen, sulfur, phosphorous, potassium and calcium. Large animals, in fact, require around 40 essential nutrients to sustain life processes. **Matter is neither created nor destroyed, it is recycled**. If matter was not recycled, dead organic matter would pile up everywhere and nutrient enrichment of soil would not occur.

Living microorganisms are important role players in the recycling of these nutrients back into the physical (abiotic) environment. **Decomposers, such as bacteria and fungi, feed on dead and decaying organic matter.** The metabolic action of decomposers breaks down the organic material (carbohydrates, proteins, nucleic acids and lipids) back into inorganic substances, returning them to the environment (such as the soil or oceans). Producers can then absorb them and incorporate into new cellular materials. When heterotrophic consumers feed on these producers (or other animals that have already fed on these producers) the nutrients are passed on to them, and the cycle continues.

A specific example of this is the aforementioned oceanic phytoplankton. They are primary producers and the foundation of oceanic food webs. Phytoplankton require inorganic nutrients such as nitrates, phosphates, and sulfur which they absorb from the ocean and convert into proteins, fats, and carbohydrates. They are fed on by a wide range of consumers such as microscopic zooplankton, small fish, and whales. When phytoplankton die, they are decomposed returning the nutrients to the ocean (see Figure 1.6.13).

Microorganisms play important roles in the carbon, nitrogen, and phosphorus biogeochemical cycles. These cycles are covered in detail in Topic 4: Biodiversity and Ecosystem Dynamics.

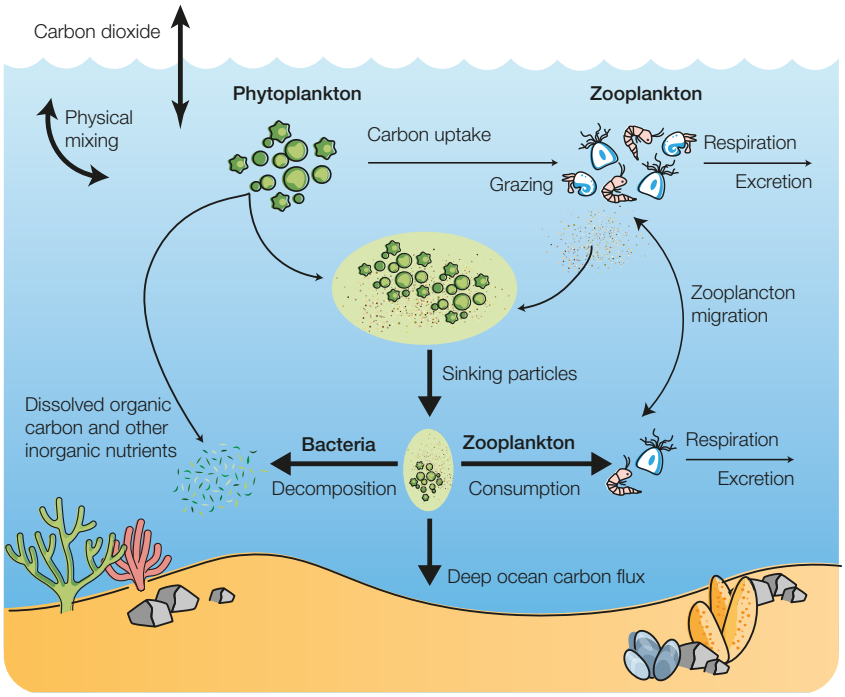


Figure 1.6.13: Phytoplankton are microorganisms that transfer carbon dioxide from the atmosphere to the ocean. Carbon dioxide is consumed during photosynthesis producing glucose and oxygen. Most of the carbon and other inorganic nutrients are returned to near-surface waters when phytoplankton are consumed or decomposed by other microorganisms.

Recombinant DNA technology (genetic engineering)

Recombinant DNA technology is used to produce artificial DNA by recombining DNA from two or more different sources. It is also known as **genetic engineering.** Microorganisms such as bacteria, viruses, and fungi, are frequently used in genetic engineering. Features such as a short generation time, small size, simple DNA and less ethical concerns make microorganisms (especially bacteria) ideal to use in this technology.

Genetic engineering refers to the techniques and processes used to directly manipulate the genomics of organisms. Genetic engineering allows scientists to **transfer specific genes from one species to another**, providing the target organism with the new desired physical trait(s). The products of genetic engineering are generally called **genetically modified organisms (GMOs).** Very specific trait(s) can be transferred, and it is possible because **DNA is universal across all organisms**. It is also possible to 'knockout' unwanted genes, removing the limiting effect, or undesired trait, of that gene on an organism.

Genetic engineering can also be used to produce proteins using microorganisms such as bacteria and yeast. This is often referred to as **protein engineering**, and it is a reliable process to help manufacture large quantities of proteins like:

- insulin for diabetics,
- some antibiotics
- anti-blood clotting factors for the treatment of haemophilia,
- human growth hormone (HGH), and
- antigens for use in some vaccines.

Synthesising recombinant DNA and gene cloning

Recombinant DNA is **DNA composed of genetic material taken from two or more sources**. To synthesise recombinant DNA, plasmids from bacteria and DNA from the target cell must first be extracted. A specific restriction enzyme is then used to cut the target DNA and bacterial plasmid. Bacterial plasmids are loops of DNA that when cut once with a restriction enzyme, allows the insertion of a sequence of DNA or gene (see Figure 1.6.14). The two sources of DNA are then recombined using another enzyme called DNA ligase, forming recombinant DNA. The **recombinant DNA plasmid** can then be transferred back into bacteria through a process called transformation and is then **cultured**. As the bacteria are provided with optimum conditions, they divide by **binary fission** quickly, growing in number exponentially. As the plasmid can replicate independently, more copies of the gene of interest are produced with each division, **cloning the gene**. This method is quicker and cheaper than the artificial synthesis of DNA, known as gene synthesis.

If the goal is to produce and harvest proteins (protein engineering), the ribosomes in the transformed bacteria can synthesise the desired protein that the gene of interest codes for (such as insulin). The desired protein can then be harvested and processed for human use. However, if the goal is to transfer the genes of interest into another organism through **transgenesis** (genetic engineering), then they need to be isolated from the recombinant plasmids using restriction enzymes. Many copies of the gene of interest are required in transgenesis to increase the chance of it being incorporated into the genome of the desired organism.

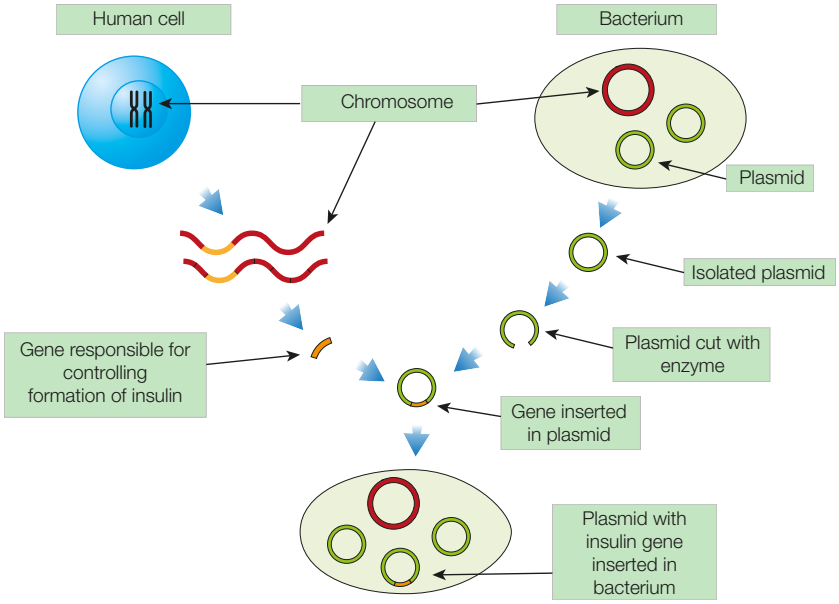


Figure 1.6.14: An overview of the formation of a recombinant DNA plasmid containing a gene of interest and its transformation of the recombinant plasmid back into the bacterium.

Helpful online resource

FuseSchool – Global Education: Genetic engineering

<https://www.youtube.com/watch?v=DIM38NIkWEo>

Transgenesis

Gene transfer involves techniques in which genetic material is transferred from one organism to another. The process is called transgenesis and organisms formed in this manner are called **transgenic organisms.** Prior to transgenesis, the gene(s) of interest are cloned. They are then isolated using restriction enzymes and can then be transferred into the cells of desired species. **The gene of interest must be transferred into the 'first' cell of the transgenic organism, so that the recombinant DNA is present in all cells in the organism.** Multiple copies of genes are needed to increase the chance of the gene of interest incorporating into the new organism's genome and being expressed in the correct cells. Gene transfer can be achieved chemically, physically or by using vectors, such as viruses or bacterial plasmids. Some examples of transgenic organisms are summarised in Table 1.6.1.

Table 1.6.1: Some examples of transgenic organisms produced through the manipulation of microorganisms and DNA recombinant technology to benefit humans.

Transgenic organism	Purpose of its genetic modification
Golden rice and golden bananas	To increase the vitamin A content in staple foods of Asia and Africa, reducing the number of disorders and deaths associated with vitamin A deficiency (VAD).
Herbicide resistant crops	To increase yields by creating crops that can be sprayed with herbicides and remain unaffected. Only weeds are affected by the herbicides resulting in less competition for resources for crops.
Pest resistant crops	To produce crops that can secrete their own insecticides and protect themselves from insects. This results in increased yield due to less damage by insects, and less chemical pollution by reducing the need for insecticide spaying.
Disease resistant crops	To save some crops from extinction and increase yields by providing immunity to certain diseases An example is GM potato crops that are resistant to the PVY virus.
Nitrogen fixing crops	To produce crops that can synthesise their own nitrates from N_2 gas in the atmosphere. This would reduce fertiliser use and risk of fertiliser runoff that cause eutrophication and algae blooms.
Plastic eating bacteria	To genetically engineer plastic digesting bacteria to break down multiple types of plastic at a much faster rate. These GM bacteria could be applied to oceans and landfill to breakdown plastic that can kill animals and even microplastics that enter human food chains.
Fast growing Atlantic salmon	To cut the time it takes for salmon to grow to full size from 4 years to 2 years. GM salmon supplies food to the growing population faster and helps to reduce strain on wild salmon populations and the environment.

Helpful online resource

FuseSchool – Global Education: GM Crops

<https://www.youtube.com/watch?v=kZIYkYNpnP0>

Uses of microorganisms by humans

Humans have cultured microorganisms such as bacteria and yeast for about 10,000 years to make products that are useful including alcoholic beverages, bread and dairy products, such as yoghurt and cheese. Please refer to Table 1.6.2 and Figure 1.6.15 for more information on the types and uses of microorganisms that are beneficial to humans.

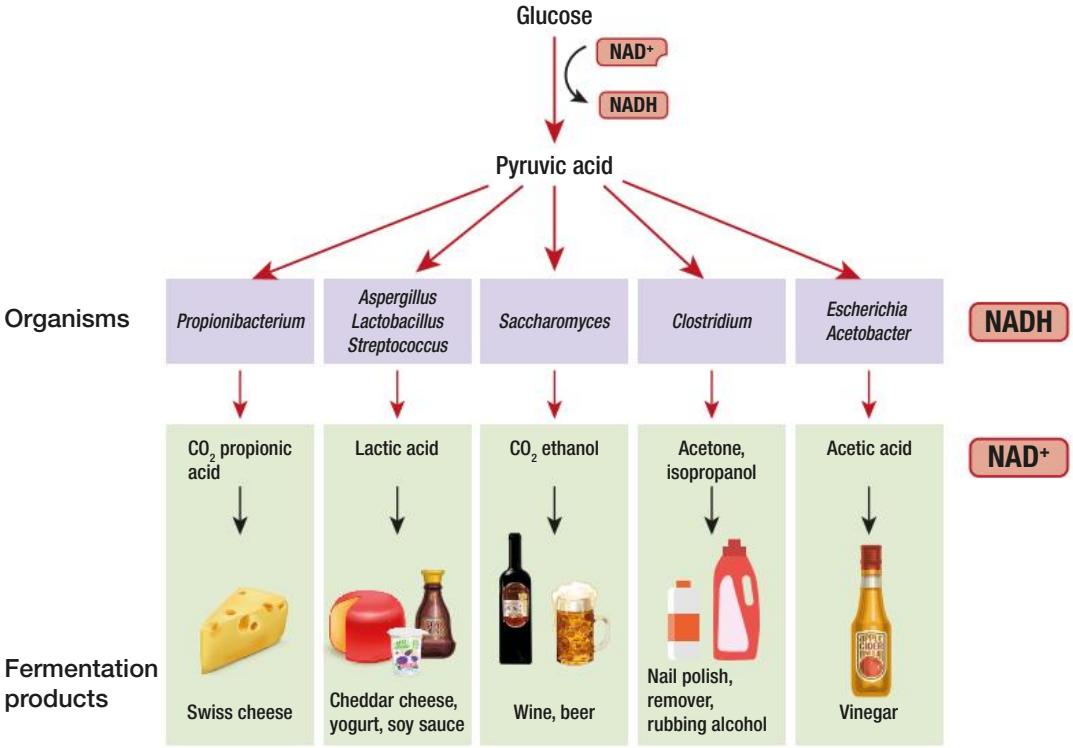


Figure 1.6.15: A flow diagram highlighting some different microbes that humans have cultured to generate some beneficial products.

Table 1.6.2: Some examples of beneficial products produced through humans culturing microorganisms.

Product produced	Description of process
Bread	See Figure 1.6.16 for a brief description of the bread making process.
Wine	Yeast is added to grape juice, which converts the sugar glucose it contains into the gas carbon dioxide and an alcohol called ethanol. Wine is one alcoholic beverage that the ethanol fermentation of yeast is used to produce but there are many more including beer and spirits.
Yoghurt	Lactic acid bacteria ferment the lactose sugars in milk producing lactic acid which decreases the pH and results in the milk clotting. This results in the soft gel mouthfeel associated with yoghurt and the sour taste (before more sugar is added to give it additional flavour).
Swiss cheese	When added to milk, bacteria such as *Lactobacilli* convert the sugar lactose it contains into an acid called lactic acid. This process is an example of lactic acid fermentation. Propionic bacteria are then added to the cheese vat which ferments the lactic acid, producing propionic acid, acetic acid and carbon dioxide. The carbon dioxide produced causes the holes in the swiss cheese to form.
Blue cheese	Just like with the production of swiss cheese, lactic acid bacteria are added to milk to ferment the sugars and produce lactic acid. However, the fungus (mould) ***Penicillium roqueforti*** is also added resulting in the distinct blue veins and distinctive taste.
Penicillin (antibiotic)	A fungus called ***Penecillium chrysogenum*** is added to a commercial fermenter with the nutrients it requires such as oxygen and lactose. The fungal cells are also constantly subjected to stress, which is required for penicillin production. The antibiotic, penicillin, is extracted from the medium and purified.

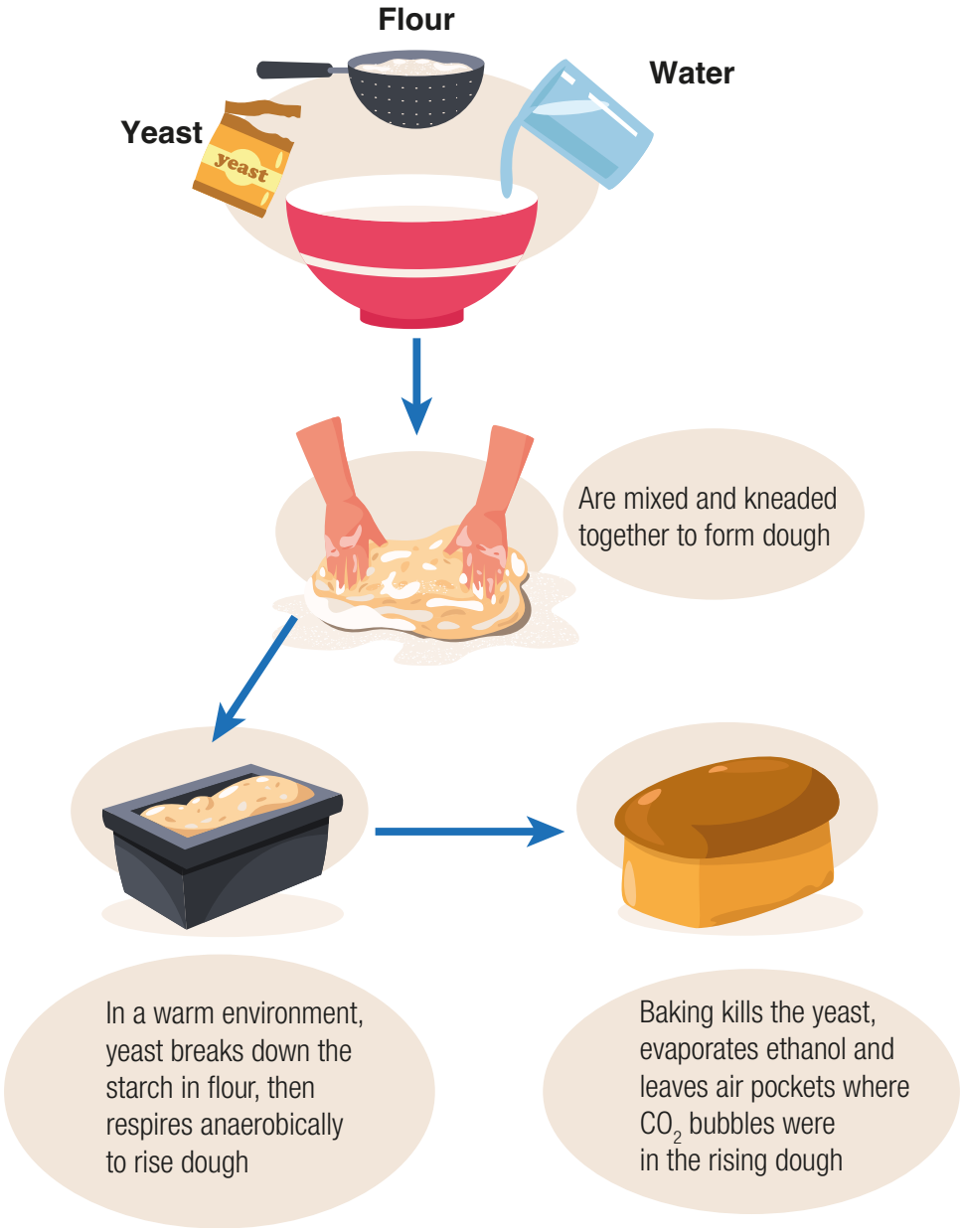


Figure 1.6.16: The basic process of making bread and how yeast is involved in making the dough rise.

Helpful online resource

The beneficial bacteria that make delicious food – Erez Garty

<https://www.youtube.com/watch?v=eksagPy5tmQ>

1.6 Review questions

Multiple choice questions

1. *Refer to the diagram below to answer the following question.*

Identify the product above that involves the use of both bacteria and fungi.

N A
O B
P C
Q D

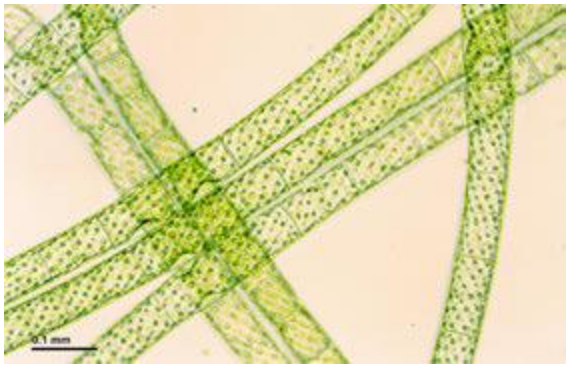
2. Which of the following best describes the human gut microbiome?

J The community of fatty acids found within the digestive tract.
K The total sum of all microorganisms within the body.
L The community of microorganisms that reside in the gastrointestinal tract.
M The total sum of all yeast and other living organisms in the human abdomen.

3. If the optimum conditions for bacterial growth are met, they can generally double in number in approximately

J 20 seconds
K 20 minutes
L 2.0 hours
M 20 hours

4. *Refer to the image below which shows an organism classified as a protist to answer the following question.*



The type of protist shown in the image above is most likely to be

J a protozoan.
K an alga.
L a slime mould.
M another type of protist.

5. Which of the following is **not** an example of microorganisms being beneficial to humans?

   J Pseudomonas breaking down strawberries at refrigerated temperatures.
   K Phytoplankton performing photosynthesis.
   L Fermenting microorganisms producing sauerkraut.
   M Bacteria reproducing exponentially to clone genes to be used in gene therapy.

6. Which of the following is true regarding water activity?

   J The water activity of a food increases when salt is added to it.
   K A raw beef steak has a lower water activity than beef jerky.
   L The amount of available water for microbial growth increases as water activity decreases.
   M Water activity decreases when foods are frozen.

7. Decomposing microorganisms are important because

   J without them, dead organic matter would be destroyed.
   K they prevent carbon from being trapped in organic matter.
   L plants would not be able to obtain carbon dioxide for photosynthesis.
   M otherwise, the carbon cycle would stop immediately.

8. A microbiologist placed a small sample of bacteria in a culture dish and cultured them in optimal conditions. The number of bacteria present was recorded every 30 minutes beginning at 1:00 PM, but the 2:00pm recording was missed. Refer to the table below to observe the results.

Time	Number of bacteria present
1:00pm	2400
1:30pm	9600
2:30pm	153,600

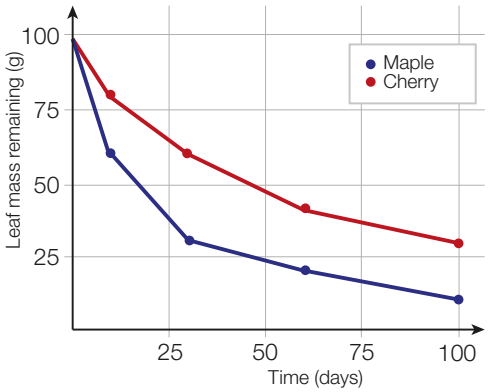
   The bacteria in this culture dish are doubling every

   J 15 minutes.
   K 20 minutes.
   L 30 minutes.
   M 45 minutes.

9. The technique used to transfer foreign DNA into a host organisms' DNA using a plasmid vector is called

   J gene cloning.
   K protein engineering.
   L transgenesis.
   M recombinant DNA technology.

10. Some scientists conducted an experiment to compare the decomposition rates of dead leaves from two types of trees. The scientists measured 100g of each type of leaf (maple leaves and cherry leaves) and placed them in separate bags. The leaves were removed from living trees at the same time and the two bags of leaves were exposed to the same environmental conditions. The scientists measured the mass of leaves remaining at several time points across 100 days. The results of the experiment are presented in the graph to the right.



   Which of the following options is **not** correct based only on the information provided and the results of the experiment shown in the graph?

   J The purpose of using 100g of each type of leaf is to control this variable and increase the validity of the investigation's results.
   K After 100 days, there is approximately 20% difference in the leaf mass remaining between the two types of leaves.
   L Maple leaves decomposed at a faster rate than cherry leaves because there was a greater number of decomposers in the maple leaves bag than the cherry leaves bag.
   M Even though the leaves were picked from the two types of trees at the same time, there will be some variation in the time each leaf was picked, and this is a possible source of random error in this investigation.

Free response questions

1. Name the five major types of microorganisms.

2. a) Name the process that bacteria use to reproduce **and** describe how bacterial populations can grow exponentially.

   b) State **two** reasons why an exponential growth rate cannot be sustained for long periods.

3. a) Compare the different cell wall structures of bacteria and archaea.

   b) State the important function of the archaean cell wall.

4. Fungi are heterotrophic eukaryotes. Describe the **three** main ways that fungal species obtain their nutrients.

5. Describe the role of decomposers in the recycling of carbon.

6. a) Identify the microorganism(s) involved in the production of bread **and** describe its role in the bread making process.

   b) Identify the microorganism(s) involved in the production of yoghurt **and** describe its role in the yoghurt making process.

7. a) Explain why protists are the most diverse group of eukaryotic organisms.

b) Discuss why algae are important to humans.

8. State **three** features of bacteria that make them highly suitable to use in genetic engineering.

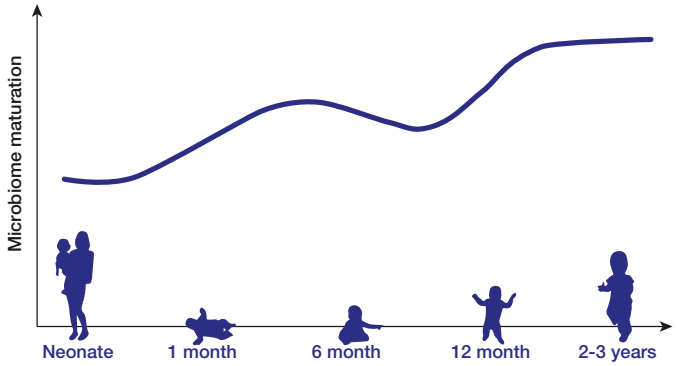
9. *Phytophthora infestans* is a water mould (fungus-like protist) that is responsible for the 'late blight' disease responsible for the great potato famine in Ireland in the 1840s. The potato famine resulted in Ireland losing a quarter of its population killing 1 million people and resulting in another 1 million people emigrating from Ireland.

a) State **one** piece of evidence scientists use to classify *Phytophthora infestans* as a protist and not a fungus.

b) Explain how potato crops could be genetically engineered to be resistant to 'late blight' disease.

10. a) Define the gut microbiome.

Refer to the graph below which shows the general development of the gut microbiome for an individual to answer part (b).



b) Identify **and** explain **one** likely reason for the dip in this individual's microbiome maturation between 6 and 12 months.

Some gut bacteria help with the extraction of energy from carbohydrates in our diet. This results in the production of lactic acid as a by-product.

c) Explain why lactic acid production by bacteria in the gut can be beneficial to the host organism.

11. *Refer to the tables below showing some bacterial water activity (aw) growth limits and the water activity levels of some foods to answer the following questions.*

a_w Bacteria Growth Limits	
E. coli	0.96
C. botulinum	0.93
L. monocytogenes	0.91
S. aureus	0.86
Yeast and molds	0.65-0.7

Food	Typical Water Activity (a_w)
Fresh fruits	0.97-0.99
Most cheese varieties	0.93-0.96
Dried meat	0.80-0.90
Marmalade, jams, and jellies	0.75-0.80
Wheat flour	0.72
Dried fruits	0.60-0.065
Honey	0.50-0.65
Pasta	0.50
Milk Powder	0.20
Potato crisp	0.08

a) Identify which microorganism(s) can grow well in dried meat.

b) Explain why a lower water activity is less favourable for bacterial growth.

Chapter 1.7 Microorganisms and food

Science Understanding

Microorganisms can cause food spoilage and by controlling the growth of microorganisms, food can be preserved.

- Describe the causes of food spoilage, and explain the importance of hygienic practices.
- Describe techniques for preserving food, including the use of heat/cold, the addition of acids, sugars, or salt, and the removal of water. Relate each technique to growth requirements of microorganisms and/or diffusion.

Food spoilage

Food spoilage is defined as any undesirable change to a food. It can result from physical, chemical or microbiological changes. Most food spoilage occurs due to microbiological activity, which results in the production of certain chemicals that can change the colour, texture and odour of foods. **These sensory cues can indicate that the food may be unsafe to eat** and can therefore be detected by humans, preventing them from consuming it. It is important to note that food spoilt by microbes should not be consumed because it could cause illness, such as vomiting, and it is a lot less nutritious than its fresh counterpart. **Microbiological spoilage** can result from different microorganisms, such as fungi and bacteria. Spoilage by fungi includes the growth of moulds on breads, cheese, fruits and vegetables (see Figure 1.7.1). If food spoilt by fungi is consumed it could cause food poisoning, but it is a lot less common and dangerous than food poisoning by bacteria. The majority of microorganisms that cause food spoilage are non-pathogenic (not disease causing) to humans. Food can also become spoilt through **physical factors, such as damage to the food** causing bruising and openings incurred during processing or transport. This can reduce its appeal and **increase the surface area for microorganisms to grow**, further reducing its shelf life.

Figure 1.7.1: An example of microbial spoilage of a mandarin by fungi (left) and an example of how physical damage to an apple can increase its spoilage by increasing the surface area for bacteria to grow (right).

Food spoilage is not to be confused with food poisoning. Food poisoning occurs when **pathogenic** (disease causing) microorganisms spread to food and are consumed. When pathogenic organisms contaminate food, they can multiply exponentially, especially in optimum conditions, and **release toxins** that can be harmful to humans when consumed. Food poisoning is generally associated with symptoms such as fatigue, vomiting, diarrhoea and dehydration. **Most bacteria that cause food poisoning and the toxins they release have no smell or taste**. Microbial contamination that causes food poisoning can therefore commonly go **unnoticed before the food is consumed** due to its lack of sensory indicators. It is also important to note that **cooking foods to temperatures above 75°C will kill most pathogenic bacteria, but the toxins they produce remain in the food** (please refer to back to Figure 1.6.8 for more information on the temperature danger zone).

Helpful online resource

What if?: What happens if you eat mould?

<https://www.youtube.com/watch?v=6vIogSJ7kTo>

Hygienic practices

It is essential to always apply safe food handling and the use of proper hygiene techniques. This requires proper cleaning and sanitising of surfaces involved in food preparation and cooking, including all utensils. Safe food handling is required by businesses to ensure their food is safe to eat but it is also required when preparing food at home. All consumers need to know how to handle, prepare and store food optimally to reduce the risk of contamination and contracting foodborne illnesses. According to OzFoodNet, there are 5.4 million cases of foodborne illness in Australia every year, which costs the economy approximately $1.2 billion. Many of these cases could be prevented if greater food safety measures were applied.

Personal hygiene

Prior to handling food, hands should always be washed and dried properly. Hands should be washed rigorously with soap for 20 seconds and then rinsed. This is an effective technique to destroy many different microorganisms that contain a cell membrane. **The cell membrane is made of lipids that soap molecules bind to ripping the cells apart, destroying them** (see Figure 1.7.2). Rubbing hands against each other rigorously creates greater friction, destroying and removing more microorganisms from hands. It is also important to wash hands after handling certain foods that could cross contaminate other foods or cooking equipment, such as raw and processed meats. Some additional personal hygiene tips when handing food are:

- wash hands frequently, especially after touching digital devices, changing a nappy, etc.
- avoid coughing or sneezing over food or the area where it is being prepared
- wear clean protective clothing, such as an apron
- tie back long hair and wear hair nets
- completely cover all cuts and wounds with a band-aid or wear gloves to cover them
- if an individual has diarrhoea and/or vomiting they should not prepare food for others and should arrange for someone else to do it.

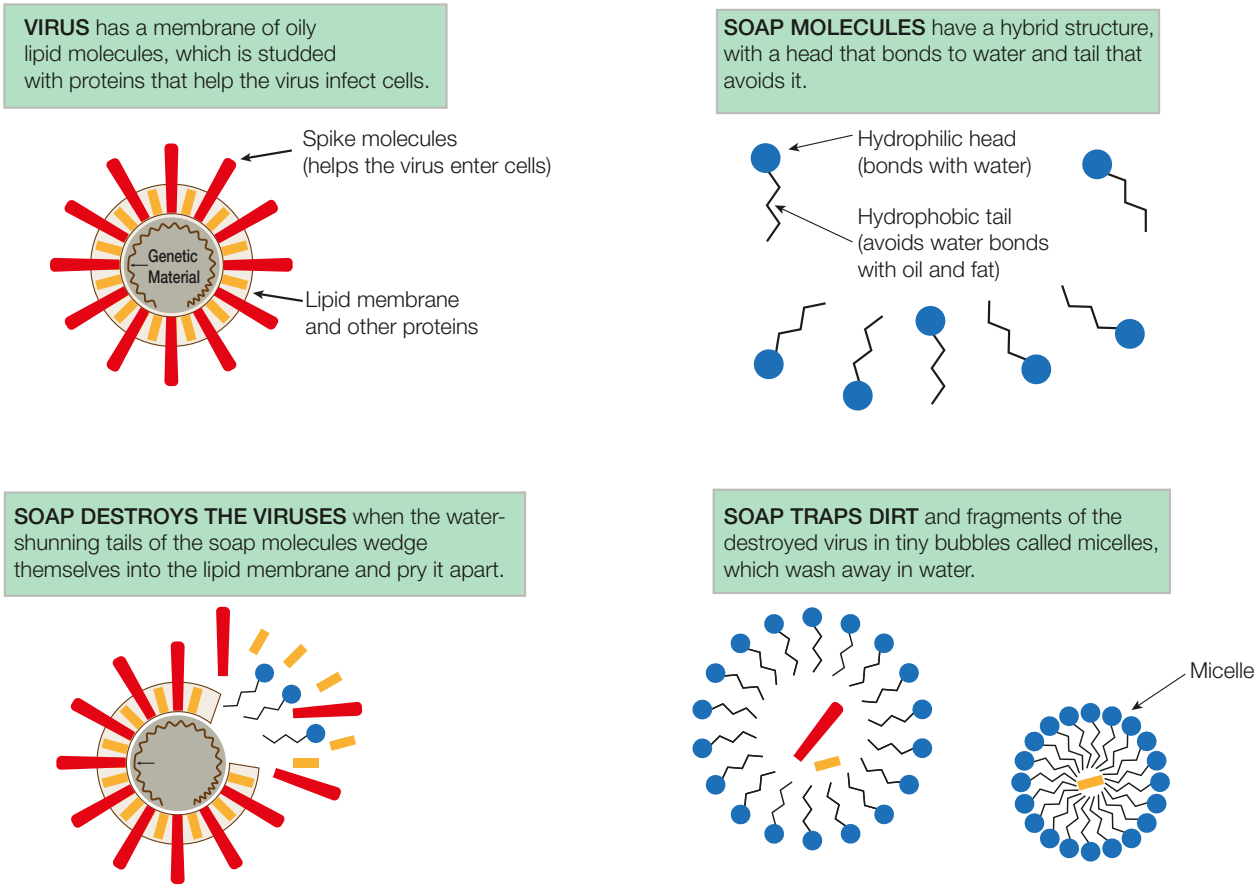


Figure 1.7.2: How soap and water work to destroy and dislodge microorganisms from hands.

Food preparation

Before foods can be prepared, they need to be purchased. When purchasing foods, the **packaging should be checked for any damage or tampering**. For example, **swollen cans** should not be purchased as they indicate microbial growth within the can. Also, supermarket employees can accidentally cut through food packaging when opening boxes. Any **slits in the packaging** can allow oxygen to enter, promoting microbial life and increasing the rate of food spoilage. **The use by date of foods should also be checked** prior to purchasing to ensure it can be used before the use by date and that it has not already passed. When packing purchased foods for transport, cold foods should be placed in insulated bags to help maintain their low temperature. **Hot foods should also be kept separate from cold foods** to prevent the transfer of heat between them, making the temperature of both foods more suitable for microbial growth.

Some preparation techniques that should be applied to reduce the risk of microbial contamination include proper defrosting, eliminating cross contamination and cooking foods to the optimum temperature.

Defrosting

If food requires defrosting prior to preparation, it should be **defrosted in a fridge and not on a bench**. This is because when defrosted on a bench at room temperature, the food is in the 'danger zone' and this can promote increased microbial growth and division.

Cross contamination

Meats and vegetables should be prepared using separate cutting boards and utensils, and cooked foods should never touch equipment used to process raw meats. Raw foods such as meat and other animal products contain living microorganisms, which can easily be transferred between surfaces. The transfer of microorganisms from a food, surface or utensil to another food is known as cross contamination. Pathogenic microorganisms can be transferred through cross contamination increasing the risk of food poisoning.

Cooking and re-heating food

Cooking foods properly kills the microorganisms on and within it, making it significantly safer to consume. When cooking or reheating food, it needs to be **heated to 75°C or above** to ensure that enough microorganisms have been killed. This can be tested using a food thermometer.

Some foods contain higher levels of microorganisms than others and are considered high-risk. Raw chicken is an example of a high-risk food. Unlike beef, chicken needs to be cooked all the way through (well done) and should not be consumed if any part of it is uncooked.

Food storage

All foods need to be stored appropriately to maximise their shelf life and reduce the risk of food poisoning. Consumers should adhere to the instructions provided on the individual food product's packaging. The instructions generally give the storage location and how many days the item can be used after opening.

Some foods are at risk of **contamination by pests**. Large bags of grains or grain products should not be stored on the floor. Doing so allows easy access for pests, such as cockroaches, mice and rats. These pests can damage the packaging allowing microorganisms to enter and **promoting conditions for food spoilage.** Another pest that can contaminate dry foods is pantry moths, which generally enter the pantry through larvae in contaminated dry foods. They can quickly spread and can chew through cardboard and soft plastic packaging, spreading to other dry foods. To prevent infestation from pantry moths and promote the shelf life of dry foods, they should be stored in **airtight containers** in the pantry.

Cooked foods also need to be stored appropriately. It is important that cooked food is **not left on the bench in the danger zone for more than four hours**, otherwise it should be discarded. Instead, the cooked food should be 'cooled rapidly' to 5°C (usually in the refrigerator) and stored in a refrigerator or freezer. 'Cooled rapidly' is defined as foods being cooled to 21°C within 2 hours and then 5°C within a further 4 hours. Large casseroles or pots of soup that have just been cooked can take approximately 24 hours for the entire meal to cool to 5°C in a refrigerator. This means the **centre of the meal is within the temperature danger zone for a long period of time**, providing a suitable environment for microbial growth and increases the risk of food poisoning. To ensure safe food storage, the casserole or soup should be stored in **multiple shallow airtight containers** instead. If stored in the fridge, it should be consumed within a couple of days.

The placement of food products in the refrigerator is also important. For example, **high-risk foods**, such as meats and expressed breastmilk **should be stored at the back of the fridge, where it is the coldest**, to reduce microbial growth and not in the fridge door. Furthermore, **raw meats should always be stored below cooked meats in the fridge**. This storage technique alleviates the risk of fluid leaking from the raw meat packaging onto cooked meats on a shelf below, contaminating them. In addition, vegetables should not be washed prior to

entering the fridge as this **can provide moisture for microorganisms to grow**. They should also be stored in the salad drawer, which regulates airflow and maintains the humidity surrounding your vegetables, keeping them fresher for longer (see Figure 1.7.3).

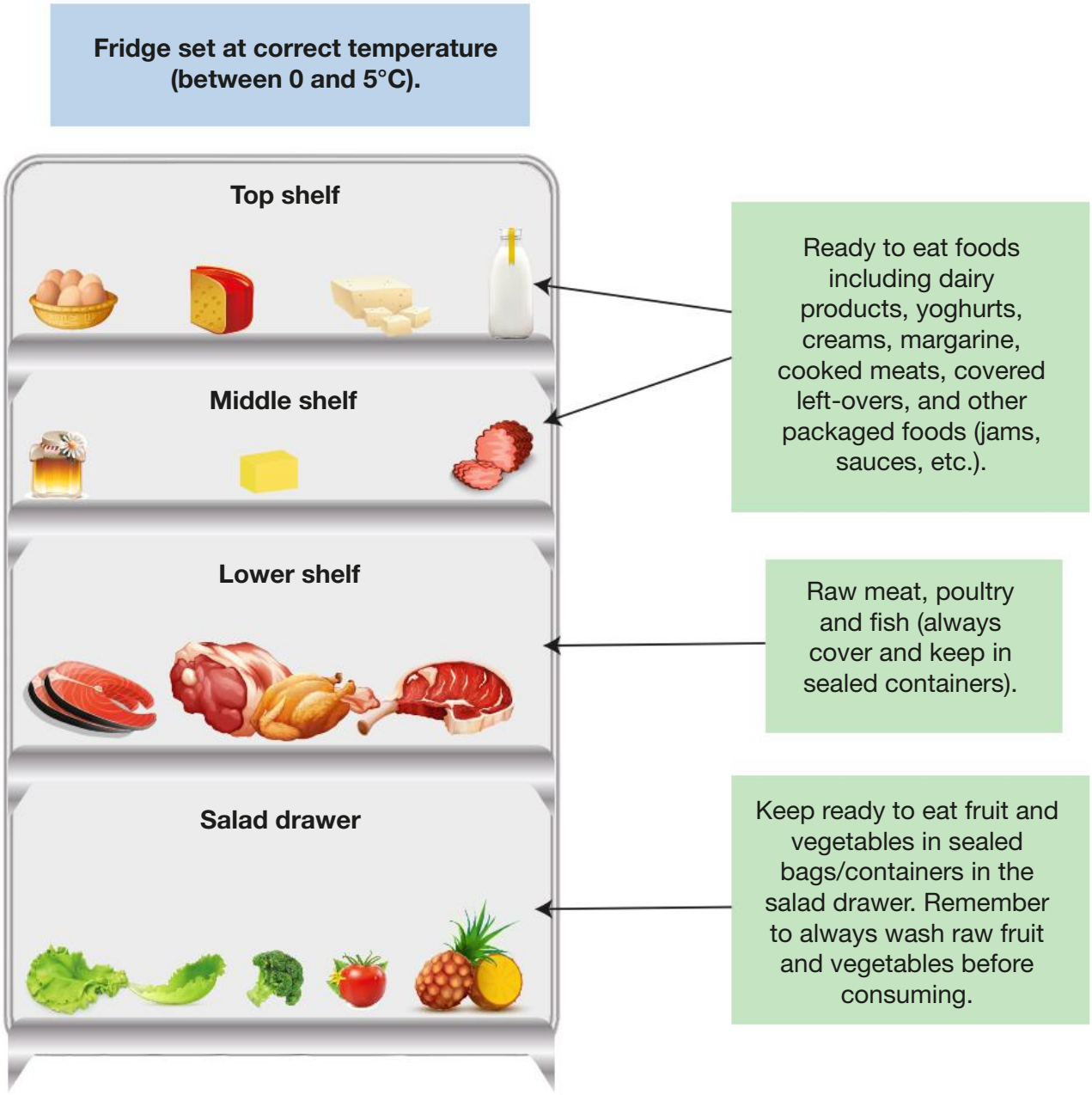


Figure 1.7.3: The recommended storage technique of foods in a fridge.

Food preservation

Foods are processed and preserved to decrease the rate of food spoilage and reduce the risk of food poisoning occurring. Food preservation aims to eliminate microorganisms already residing on food, deactivate enzymes involved in food spoilage and prevent future contamination by microorganisms by sealing the food. Food preservation is essential to modern society because it ensures a safe, continuous and plentiful supply of food by reducing nutrient loss and increasing shelf life. Food preservation also increases the convenience of certain foods by allowing some foods to be available all year round, saving time preparing foods and potentially reducing costs. Without food preservation techniques, we would have less food options and would have to shop more frequently to purchase foods that are safe to eat.

Examples of preservation techniques include heat treatments, reducing temperature, controlling water activity, changing the pH, oxygen reduction and irradiation**.** Sometimes more than one method of preservation is used; for example, preserving fruit (see Figure 1.7.4).

Figure 1.7.4: A summary of the many food processing stages involved in producing cans of pears. Multiple preservation techniques are evident here including cold storage, washing, blanching (heating), addition of syrup (dehydration), canning sterilisation and vacuum sealing.

Throughout time many discoveries about food preservation were probably uncovered by chance. Today we understand how these preservation methods disrupt the essential conditions required for the optimal growth of microbes (see Table 1.7.1 for more information).

Table 1.7.1: A brief overview of some food preservation methods and some explanations of how each method reduces microbial growth and food spoilage.

Food preservation method	Technique description and explanation of how it preserves food
Heating techniques	
Kills microorganisms and deactivates enzymes involved in food spoilage.	
Cooking	Cooking foods above the temperature danger zone for a certain period can eliminate microorganisms. It is recommended that foods are cooked above 75°C. There are many cooking methods including frying, baking, boiling, steaming, blanching and microwaving.
Canning sterilisation	This involves placing foods into cans, jars or similar containers and heating them to temperatures above 100°C (above danger zone). The canning process also drives oxygen out and is vacuum sealed preventing air exposure and microorganisms from entering (see Figure 1.7.4).
Pasteurisation	The standard heat treatment for pasteurising milk is heating it for 15 to 20 seconds at 72°C. As pasteurised products are not sterile, they also require refrigeration to preserve their shelf life.
Ultra-high temperature (UHT) pasteurisation	UHT pasteurisation involves heating the product to 138°C for 2 seconds. If the product is placed in an aseptic container (see Figure 1.7.5) after UHT processing, it can last for 6 to 12 months at room temperature.
Reducing temperature techniques	
Slows microbial growth by exposing them to temperatures below the 'danger zone'.	
Refrigeration (cold storage)	Refrigerators are generally set at 3°C and should be set between 0°C and 5°C. This keeps food out of the temperature danger zone, providing a less suitable environment for microbial growth and multiplication. Refrigerated food can last for days to weeks, depending on the product.

Food preservation method	Technique description and explanation of how it preserves food
Reducing water activity (a_w) techniques	
Slows microbial growth by reducing available water required for chemical reactions and growth. Reducing water activity does not kill microbes, it prevents them from reproducing.	
Food dehydration (including smoking)	Foods can be dehydrated by air drying, using commercial food dehydrators, freezing, or smoking. Dehydration removes moisture from microbes and the food itself. This slows microbial growth, and they can become dormant (enter resting phase).
Deep freezing	Freezing food exposes microorganisms to temperatures below -18°C, which converts the water in foods to ice, reducing available free water molecules and hence, water activity. Freezing food below -18°C also significantly reduces the activity of enzymes involved in food spoilage, slowing microbial growth considerably.
Salt and sugar additives	Salts and sugars are added to foods like cured meats and jams respectively, where they bind to free water molecules, reducing water availability for microorganisms. This increases the extracellular solute concentration, which can result in water moving by osmosis from microbes to the extracellular environment further dehydrating them.
Reducing pH techniques	
Exposes microorganisms to lower pH (more acidic) environment which can kill them by deactivating enzymes essential for survival. The majority of microorganisms (and their spores) that are subjected to a pH lower than 4.5, cannot survive.	
Pickling with acetic acid (vinegar)	Acetic acid has a pH of approximately 2.4, therefore foods placed in acetic acid do not have to be sterile prior to being immersed because the acidic environment will kill most microorganisms.
Pickling using saltwater solution and lactic acid fermenting bacteria	Saltwater solutions dehydrate the food and promotes anaerobic bacteria to ferment, producing **lactic acid** as a by-product. Lactic acid has a pH of approximately 3.5; therefore, its production by bacteria progressively lowers the pH making it unsuitable for microorganisms to survive.
Oxygen reduction techniques	
Aerobic microorganisms require oxygen to produce energy, therefore less oxygen reduces their growth and ability to divide efficiently. Reducing oxygen does not kill bacteria, it makes them dormant. Oxygen also increases food spoilage through oxidation, so reducing oxygen exposure helps to increase the shelf life of food.	
Vacuum sealing (including canning and bottling)	Vacuum packaging removes the atmospheric gases from the product and is sealed tightly to reduce the amount of oxygen in the packaging (see Figure 1.7.5).
Oxygen absorbers	Oxygen absorbers are little packets of chemicals inserted into certain products, such as pita wraps (see Figure 1.7.5). The chemicals in the packet absorb oxygen, reducing the availability of oxygen that can react with the food and for aerobic microorganisms to use.
Modified atmosphere packaging (MAP)	Modified atmosphere packaging extends the shelf life of foods by removing the atmospheric gas and replacing it with a specific mixture of gases (see Figure 1.7.5). Each product has a specific mixture of gases based on its physical and chemical qualities to optimise its shelf life. One example is processed meats, such as salami, which contain packaging with 30% carbon dioxide and 70% nitrogen.
Additional techniques	
Food irradiation	Certain foods can be exposed to ionising radiation in the form of gamma rays, x-rays or high energy electron beams to increase preservation. The high energy ionising radiation passes through the food, destroying organisms involved in food spoilage such as insects, parasites, bacteria and other microorganisms. Food irradiation is an alternative to heating and chemical preservation methods and generally has comparably less effect on the appearance, flavour and texture.
Chemical preservatives	Some chemical preservatives are intentionally added to foods to prevent microbial growth and decrease food spoilage. These additives include sodium benzoate, sodium nitrate and sulfur dioxide. These three preservatives are weak acids that lower the pH of the food, making the environment less suitable for microbial growth and disrupt their normal cellular metabolism.

a b c d

Figure 1.7.5: Examples of long life UHT milk in aseptic containers (a), vacuum packaged steak (b), oxygen absorbers (c) and modified atmosphere packaged lean mince (d).

Helpful online resource

Are food preservatives bad for you? – Eleanor Nelsen

<https://www.youtube.com/watch?v=ZJU34yTJL4M>

1.7 Review questions

Multiple choice questions

1. Which of the following options best describes food spoilage?
   - J Changes that occur to foods that make them toxic.
   - K Changes that occur to foods that make them more palatable.
   - L Changes that occur to foods that make them unpleasant to see, smell, touch or taste.
   - M Undesirable changes to food that are only caused by microorganisms.
2. Which of the following options is **not** a likely sign of food spoilage?
   - J Firmness of fruits.
   - K Bulging in cartons or cans.
   - L Rancid smells in oils.
   - M A discolouration.
3. With regard to food safety, touching hair whilst preparing food for other people is advised against because
   - J it is considered rude.
   - K doing so could introduce bacteria to the hands.
   - L hairnets get in the way.
   - M hair is in the temperature danger zone.
4. With regard to food safety, chicken breasts should **not** be defrosted on a kitchen bench because
   - J the chicken juices could spread on the kitchen bench when defrosting.
   - K it takes less time to defrost than in a refrigerator.
   - L the kitchen bench is in the danger zone.
   - M it takes up space on the kitchen bench that could otherwise be used.
5. An individual was preparing a ham, cheese and salad sandwich at home. After adding the ham to the bread, the phone rang, and the individual answered the phone immediately.

   This is an example of
   - J good hygienic practice.
   - K food poisoning.
   - L food spoilage.
   - M cross contamination.

6. Which of the following is **not** an outcome of food preservation.

   J Decreased shelf life of foods.
   K Reduced food waste.
   L Decreased rate of food spoilage.
   M Increased convenience for consumers.

7. Refrigerating foods

   J kills bacteria.
   K decreases pH, making conditions less favourable for microbial growth.
   L deactivates enzymes involved in food spoilage.
   M slows microbial growth.

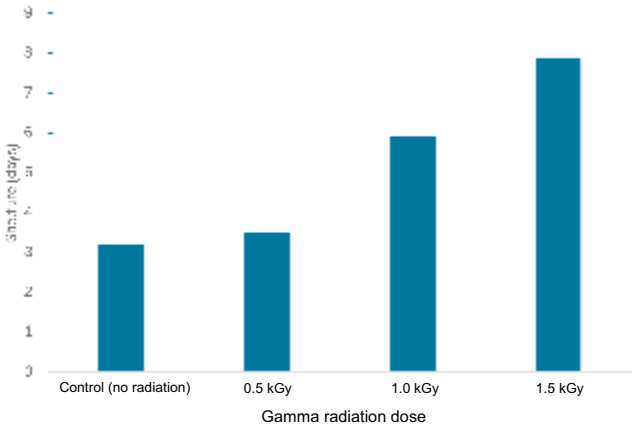
8. Salt can be used to preserve foods because

   J it kills bacteria.
   K salt causes cardiovascular disease in microorganisms.
   L it reduces water activity.
   M it lowers acidity.

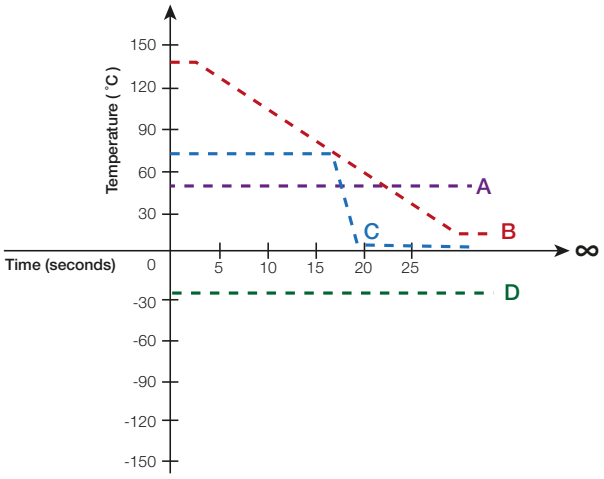
9. *Refer to the adjacent graph which shows the effect of gamma radiation on the shelf life of strawberries stored at room temperature.*

   Which of the following options is a valid conclusion based on the data presented in the graph?

   J As shelf life increases so does the amount of radiation.
   K As gamma radiation decreases, so does the shelf life of strawberries.
   L The greater the gamma radiation, the greater the loss of nutrients in the strawberries.
   M As gamma radiation increases so does the shelf life of strawberries as more organisms involved in food spoilage were destroyed.



10. *Refer to the graph below which shows three methods of food preservation (P, Q and R) that each work on the principle that at a particular temperature(s) the growth of food spoiling microbes is adversely affected.*



   With reference to the above information and graph, which of the following options is **the least** correct?

   J A is cooking which eliminates microbes if temperature is maintained.
   K B is UHT in which food is heat sterilised and then stored in microbe-free container.
   L C is pasteurisation which preserves food for few days if stored in a cool place.
   M D is deep freeze preservation which preserves food for longer when it is kept frozen.

Free response questions

1. Define food spoilage.

2. Explain how food spoilage is different to food poisoning.

3. State **three** personal hygiene guidelines that should be followed when preparing food.

4. State **three** effects of food preservation.

5. *Refer to the table below showing a list of a few common foods generally found in supermarkets.*

   Complete this table by identifying the most likely method(s) of food preservation used to extend its shelf life **and** briefly describing how.

Food	Method(s) of preservation	Description of preservation method(s)
		
		
		
		
		
		

6. Explain how washing hands with soap kills microorganisms and reduces the risk of food poisoning.

7. With regard to risk of food poisoning, explain why hot and cold foods should be packed in separate shopping bags.

8. Explain why cooked chicken should not be placed back on the cutting board it was previously prepared on.

9. Explain why deep-freezing food preserves food for longer than refrigerating foods.

10. Explain how adding salt to foods can increase their shelf life.

11. An individual cooked spaghetti bolognaise for dinner using minced beef that was 5 days past the use-by-date. The following day, the individual began experiencing food poisoning symptoms even though the minced beef was cooked all the way through and above 75°C.

    Explain why this individual still contracted food poisoning.

Topic 1 Review Test: Cells as the Basis of Life

It is recommended that 85 minutes is allocated to complete this test. Indicate your choice for each multiple choice question (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks allocated for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (10 marks)

1. A prokaryotic cell can be distinguished from a eukaryotic cell by the:

   J presence of a cell membrane.
   K absence of chloroplasts.
   L absence of a nucleus.
   M presence of a cell wall.

2. In mitosis, a parent cell usually produces:

   J two daughter cells, each of which has the same number of chromosomes as the parent cell.
   K four daughter cells, each of which has the same number of chromosomes as the parent cell.
   L two daughter cells, each of which has half the number of chromosomes as the parent cell.
   M four daughter cells each of which has half the number of chromosomes as the parent cell.

3. If liver cells growing in a solution with required nutrients had the oxygen removed from the solution, they would most likely:

   J produce alcohol.
   K produce lactic acid.
   L fail to break down glucose.
   M die from a lack of energy for cellular requirements.

4. Autotrophs can be distinguished from heterotrophs by:

   J their ability to carry out photosynthesis.
   K the presence of chloroplasts in their cells.
   L the ability to make organic molecules from simple inorganic ones.
   M their ability to carry out the process of fermentation.

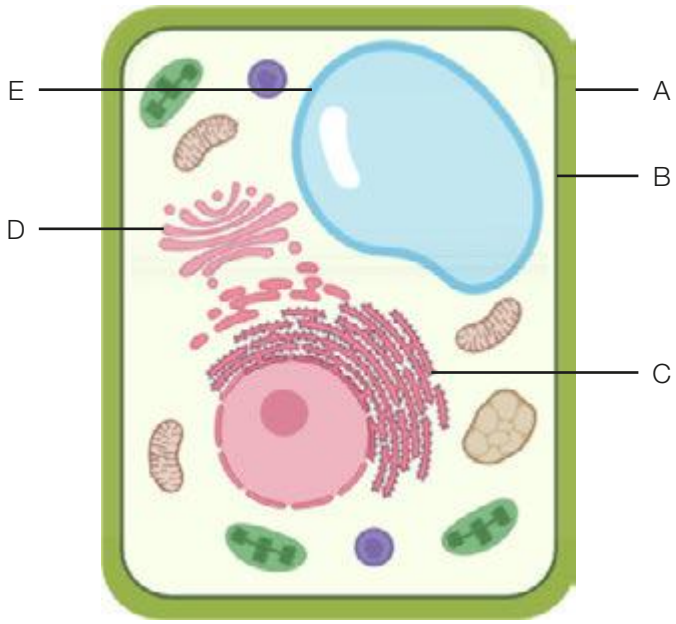
5. Which of the following statements is correct regarding the surface area of cells?

   J Cells need to have a small surface area to help speed up the rate of diffusion.
   K Cells need to have a small surface area to volume ratio to maximise their exchange of materials.
   L Cells need to have a large surface area to volume ratio and therefore tend to grow as large as possible.
   M Cells need to remain small to maximise their exchange of materials.

6. Which of the following statements is **not** correct regarding the structure of the cell membrane?

   J The cell membrane controls what substances enter and exit the cell.
   K The cell membrane consists of a bilayer of phospholipids.
   L Proteins are embedded in the cell membrane and can span the whole width.
   M Phospholipids have a fluid consistency.

7. Refer to the diagram below of a plant cell to answer the following question.



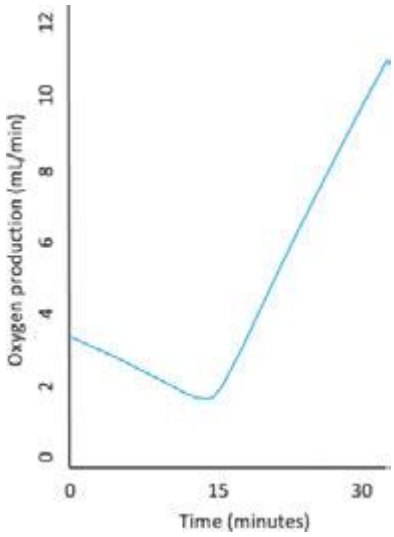
Select the answer that correctly identifies the labelled plant organelles.

	A	B	C	D	E
J	Cell wall	Cell membrane	Golgi body	Smooth endoplasmic reticulum	Cytoplasm
K	Cell membrane	Cell wall	Smooth endoplasmic reticulum	Rough endoplasmic reticulum	Golgi body
L	Cell wall	Cell membrane	Rough endoplasmic reticulum	Golgi body	Vacuole
M	Cell membrane	Cell wall	Vacuole	Cytoplasm	Smooth endoplasmic reticulum

8. Which of the following options is **not** an example of the use of microorganisms for the benefit of humans?

J The development of new pathogenic viruses infecting livestock.
K Bacteria decomposing human waste at sewerage plants.
L Consuming probiotics to aid the digestive system.
M Transferring genes to another organism using recombinant DNA technology.

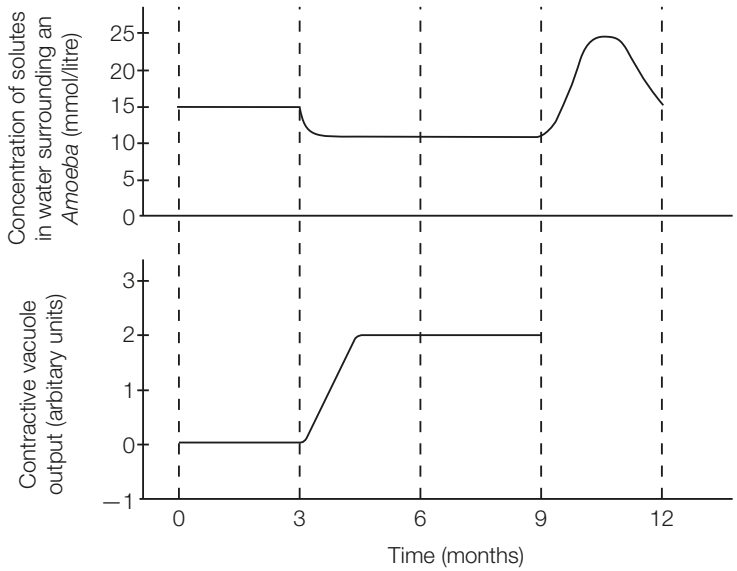
9. In an investigation into the effects of light on the rate of photosynthesis, a scientist enclosed a group of plants in the dark for a period of 15 minutes and then exposed them to light. The researcher continually measured and recorded the volume of oxygen production. The results of the investigation are shown in the graph to the right.



Based on the results of the investigation, which of the following statements is correct?

J During the first 15 minutes, no carbon dioxide was produced.
K During the second 15 minutes, oxygen production increased as the rate of photosynthesis increased, and no aerobic respiration occurred.
L During the first 15 minutes, the oxygen decreased due to anaerobic respiration occurring.
M During the second 15 minutes, the rate of photosynthesis was greater than the rate of aerobic respiration.

10. Amoeba, a single-cell freshwater organism lives in water where the solute concentration varies with the seasons. Amoeba have evolved an internal structure called a contractile vacuole which has the ability to expel water from the cell if too much water accumulates inside of the organism. Refer to the graph below which shows the solute concentration of the water in which the amoeba lives and its contractile vacuole activity at different times of the year.



Which one of the following changes in the Amoeba's environment is most likely to explain the increase in activity of the contractile vacuole between 3-4 months?

J An increase in the solute concentration.
K An increase in temperature.
L A decrease in temperature.
M An influx of fresh water.

Section 2: Free response questions (70 marks)

11. *Refer to the images below to answer the following questions.*

Cell A (~5000×)

Cell B (~250×)

Cell C (~500×)

a) Name **one** organelle that you would expect to find in the cytoplasm of all three types of cells.

(1 mark)

b) State **one** difference between cell A and cell B, regarding their DNA.

(1 mark)

c) State **two** differences between cells B and cell C.

(2 marks)

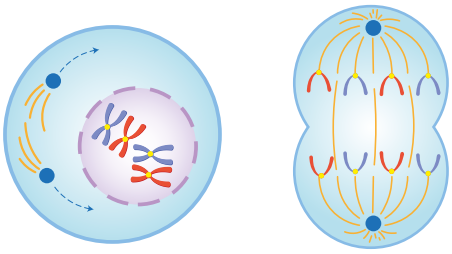
d) Explain why cells A, B and C are all considered cells according to the cell theory.

(2 marks)

e) Explain why cell A cannot be part of a tissue.

(2 marks)

12. *Refer to the two images below (A and B), which show two different stages in mitosis to answer the following questions.*



A B

a) Describe the events that occur in the stage of mitosis pictured at 'A'.

(2 marks)

b) Describe the events that occur in the stage of mitosis pictured at 'B'.

(2 marks)

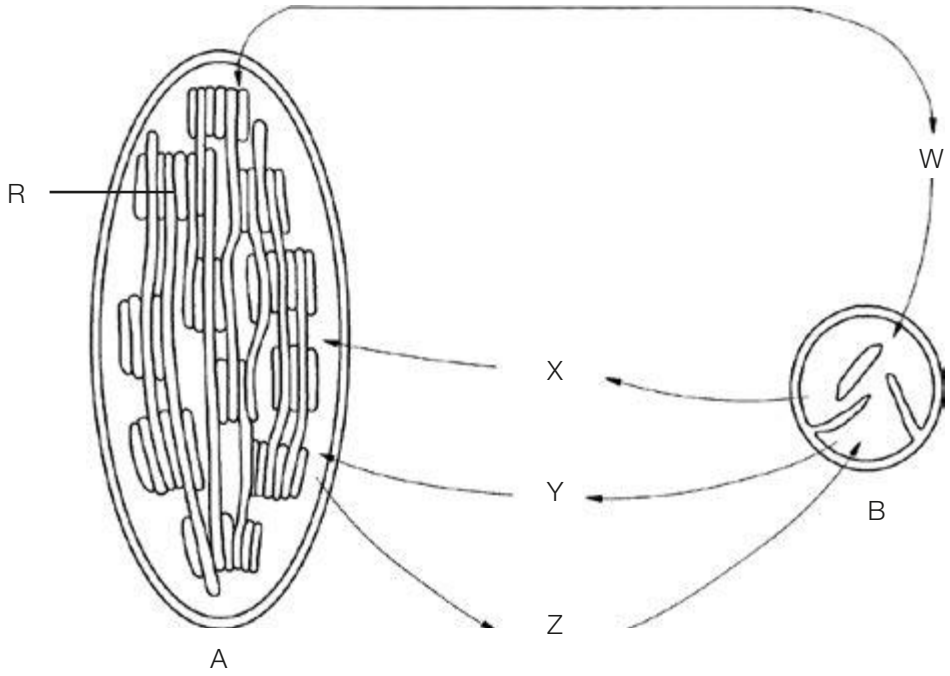
c) Identify **one** important process involving DNA that occurs prior to mitosis **and** explain why it is important.

(2 marks)

d) Compare mitotic division and binary fission.

(2 marks)

13. *Refer to the diagram below of some interactions between two organelles (A and B) in a eukaryotic cell to answer the following questions.*



a) Identify organelles A and B.

A:

B:

(2 marks)

The two pictured organelles play roles in two different cellular processes. Each cellular reaction produces molecules that can be used as reactants in the other.

b) Identify the four labelled products of these two cellular reactions.

W:

X:

Y:

Z:

(4 marks)

c) Identify the pigment inside the structure labelled 'R" **and** explain this pigment's role in organelle A.

(2 marks)

Both nitrogen and phosphorus are nutrients essential for life.

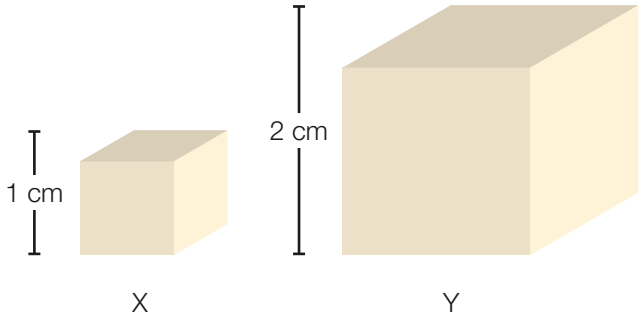
d) State how plants and animals obtain these nutrients **and** identify **two** molecules that they are essential for synthesising.

(3 marks)

e) Explain why cells must excrete waste products.

(2 marks)

14. *Refer to the diagram below of two potato cubes (X and Y) to answer the following questions.*



a) Calculate the surface area to volume ratio for each cube.

(2 marks)

As part of an investigation, the initial mass of the two potato cubes were measured and then placed in a 5% solution of glucose. After 20 minutes, the two cubes were removed from the glucose solution and the final mass was measured. The percentage change in mass was then calculated.

b) (i) State whether the two potato cubes would have gained mass or lost mass after 20 minutes in the glucose solution.

(1 mark)

(ii) Explain your answer to part (b)(i) above.

(4 marks)

(iii) Describe the effects of being in the 5% glucose solution for 20 minutes on the plant cells that the potato cubes consist of.

(2 marks)

c) Explain whether the percentage change in mass would have been greater for cube X or cube Y.

(2 marks)

15. Microorganisms are important living things and have uses to humans. One such example is the use of bacteria in making yoghurt.

a) Explain why bacteria are useful in the production of yoghurt.

(2 marks)

Bacteria can grow exponentially when they are exposed to optimum conditions.

b) Explain why sufficient oxygen is required for aerobic bacteria to grow exponentially.

(2 marks)

Microorganisms can cause food spoilage, but controlling their growth can help preserve foods.

c) Explain **two** ways that freezing foods help to control bacterial growth and therefore preserve food.

(4 marks)

Ethanol can be used in biofuel.

d) Identify **one** microorganism that would be useful in the production of biofuel and explain why.

(3 marks)

Microorganisms are also important to humans for DNA recombinant technology.

e) State the structure in bacterial cells that is useful for DNA recombinant technology.

(1 mark)

Some microorganisms have been discovered that can digest plastic waste. These microorganisms cannot digest all types of plastic though and are generally very slow at processing plastic. Scientists are genetically engineering these microorganisms to increase the types of plastic they can digest by inserting genes from other microorganisms that have adapted to do so. They are also genetically engineering microorganisms that can digest plastic to increase the speed at which they digest certain plastics.

f) Discuss how this example demonstrates one or more key concepts of Science as a Human Endeavour.

(4 marks)

16. Some students investigated the effect of varying the concentration of glucose on the rate of carbon dioxide production by yeast. To do this, the students measured the volume of carbon dioxide produced by yeast in 4 minutes.

The teacher asked students to practice the method prior to completing the whole practical. The students practiced the method three times using an unknown glucose solution and collected the results shown in Table 1 below.

Table 1

Trial	Volume (mL) of carbon dioxide produced in 4 minutes
1	10.9
2	11.5
3	10.3
Average	

a) (i) Calculate the average volume of carbon dioxide (mL) produced in 4 minutes for the three practice trials and add the answer to Table 1.

(1 mark)

(ii) Using your answer to part (a) above, calculate the average rate of carbon dioxide production per minute for the 3 practice trials.

(1 mark)

b) Explain the advantage of completing three trials and calculating the average when conducting an investigation.

(2 marks)

The students then performed the whole investigation. The results are shown in Table 2 below.

Table 2

Glucose concentration (%)	Average rate of carbon dioxide production (mL/minute)
0.5	1.1
1.0	2.3
1.5	3.4
2.0	4.0
2.5	4.5
3.0	4.5

c) Use the grid below and the data from Table 2 to construct a graph of the students' results.

(4 marks)

d) Use the graph constructed in part (c) and your answer to part (a)(ii) to determine the unknown glucose concentration the students used for the three practice trials prior to completing the whole investigation.

(1 mark)

It is very hard to ensure that each trial had the exact same number of yeast cells as they are microorganisms.

e) (i) State **one** method that the students could have used to keep this factor as controlled as possible.

(1 mark)

(ii) Explain the effect on the results if the number of yeast cells in each trial was not controlled and they differed significantly between trials.

(2 marks)

f) Write a possible conclusion for this investigation.

(2 marks)

Total: /60

Topic 2 Infectious Disease

Chapter 2.1 Different types of disease

Science Understanding

Infectious disease differs from other diseases.

- Distinguish between infectious and non-infectious disease.
- Determine the characteristics of a pathogen.

Disease

A disease is characterised by any change to an organism that negatively impacts on the functioning of that organism. Diseases can be categorised into two groups **infectious** and **non-infectious**. Infectious diseases are the direct result of **pathogens** and can be transmitted, whereas non-infectious diseases cannot be transmitted. A pathogen is a microorganism or infective agent that can cause disease in a host organism.

Infectious disease

Infectious diseases, also called communicable diseases, are illnesses **caused by pathogens that can be transmitted** from person to person. There are a variety of pathogens including bacteria, fungi, protists, viruses, parasites and prions, which can cause a range of diseases (see Figure 2.1.1). These pathogens can spread through different mechanisms such as airborne transmission, direct/indirect contact, or vectors. Once inside the **host's** body, a pathogen may cause disease by destroying cells, or by releasing chemicals called **toxins** that disrupt normal cell function.

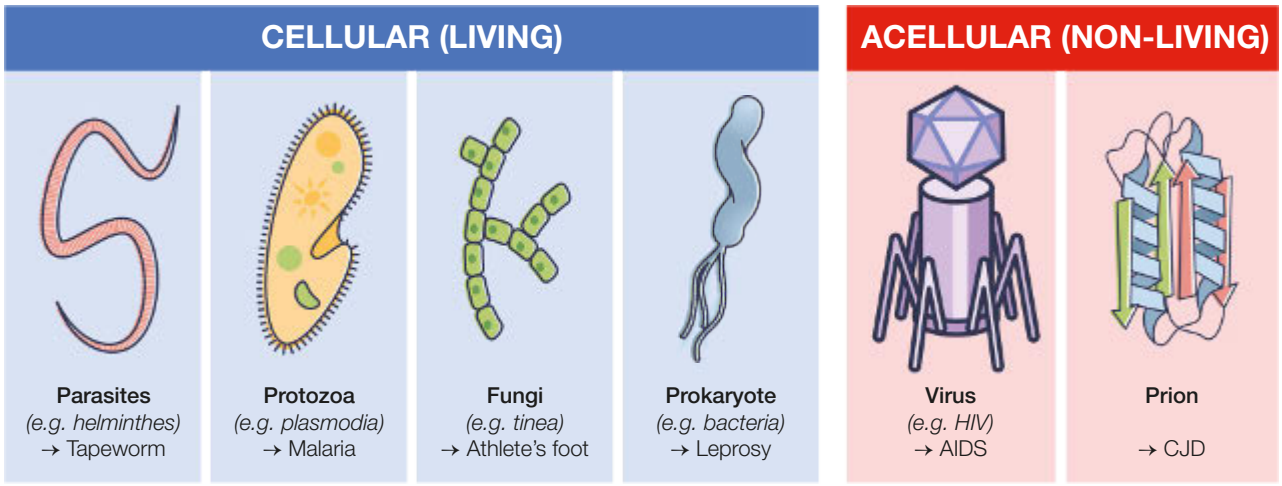


Figure 2.1.1: The six main types of pathogens that can spread infectious disease.

Non-infectious disease

Non-infectious diseases, also called non-communicable disease, are medical conditions that are **not caused by pathogens and are not transmitted** to other individuals. These diseases often result from environmental, lifestyle, and/or genetic factors (see Table 2.1.1). As the focus of this topic is on infectious disease, non-infectious disease is a point of comparison.

Table 2.1.1: Non-infectious diseases are caused by a wide variety of factors.

Cause of non-infectious disease	Description	Examples of non-infectious disease
Chemical carcinogens	Some chemicals, such as cigarette smoke and asbestos, can cause irreversible mutations to the genetic code (DNA) that can result in uncontrolled cell division and cancer.	Some types of cancer, such as lung and bowel cancer
Physical carcinogens	Exposure to high energy radiation, such as ultraviolet light and x-rays, can damage the genetic code (DNA) and can result in uncontrolled cell division and cancer.	Some types of cancer, such as skin cancer
Lifestyle choices	Unhealthy lifestyle choices, such as poor diet, lack of exercise, smoking and excessive alcohol consumption, can increase the risk of developing some non-infectious diseases.	Obesity, type 2 diabetes, cardiovascular disease and some types of cancer
Organ and tissue degeneration	Organ and tissue degeneration, often due to ageing or chronic wear and tear, can lead to or contribute to some types of non-infectious disease.	Arthritis, Alzheimer's disease, heart failure, kidney failure
Hypersensitivity	Hypersensitivity is an excessive immune response to substances that are normally harmless, such as pollen and dust mites.	Asthma, allergies, eczema, autoimmune diseases
Genetics	Diseases can be directly inherited from parents through genetic mutations passed on to their offspring.	Down syndrome, cystic fibrosis, sickle cell anaemia, Huntington's disease
	An increased likeliness to inherit some types of disease, called genetic predisposition, can also be inherited from parents.	Obesity, diabetes, cardiovascular disease and some types of cancer

Pathogens can cause some non-infectious diseases

As with many situations, things are not always black and white. Even though there are two main categories of disease, there can sometimes be a link between the two. Some pathogens can indirectly contribute to the development of non-infectious diseases by triggering immune responses or cellular changes that lead to chronic conditions. For example, some viruses can trigger autoimmune diseases. Refer to Table 2.1.2 for some specific examples.

Table 2.1.2: Some examples of pathogens that can spread and cause non-infectious diseases.

Disease	Pathogen	Description
Cervical cancer	Human papillomavirus (HPV)	HPV, which causes generally cause genital warts, can be spread through direct contact during sexual activity, and can also cause cellular mutations linked to cervical cancer.
Type 1 diabetes	Enteroviruses	Enteroviruses can spread directly from unwashed hands or indirectly through contaminated surfaces and are associated with triggering autoimmune reactions resulting in the development of type 1 diabetes.

Pathogenic organisms that cause disease

The human body contains around 10 trillion (10^{13}) human cells but also some 100 trillion (10^{14}) microbial cells such as bacteria, fungi and protozoa. Most of these microbes live in harmony with its host and form essential mutualistic relationships that benefit both species. Some, however, can be pathogenic (disease causing) and have developed characteristics that enable them to exploit the warm, nutrient rich and moist environments of their hosts.

To achieve this, pathogens must be able to:

- cross the protective barriers of the host.
- multiply inside the host.
- avoid the host's immune system attempts to destroy them.

Bacteria

Bacteria are unicellular and consist of a prokaryotic cell that lacks a nucleus and other membrane-bound organelles (see Figure 2.1.2). They contain cell walls consisting of peptidoglycan and reproduce through the process of **binary fission** (see Chapter 1.3 for more information). Bacteria exist in different shapes including bacillus (rod shaped), coccus (spherical shape), spirilla (spiral shape), and vibrio (curved shape).

Bacteria can be classified as **aerobes** (requires oxygen for life), **anaerobes** (do not require oxygen for life) or **facultative anaerobes** (can live in environments with or without oxygen). Some bacteria use autotrophic nutrition and others are heterotrophic (see Chapter 1.4 to review these concepts).

Bacteria can damage host tissues in a number of ways, including:

- producing toxins, poisonous chemicals, which may act by inhibiting protein synthesis, interfering with nerve function, or damaging membranes and hence the transport of materials in and out of cells
- invading organs and tissues inside of the host.

Some bacteria produce **spores** that can survive for long time periods and are highly resistant to tough environmental conditions. After the spores enter the host, they can germinate and replicate into new bacterial cells. After infecting a host through their method of transmission, bacteria can grow in number quickly leading to the symptoms associated with the disease. Refer to Table 2.1.3 and Figure 2.1.3 for some examples.

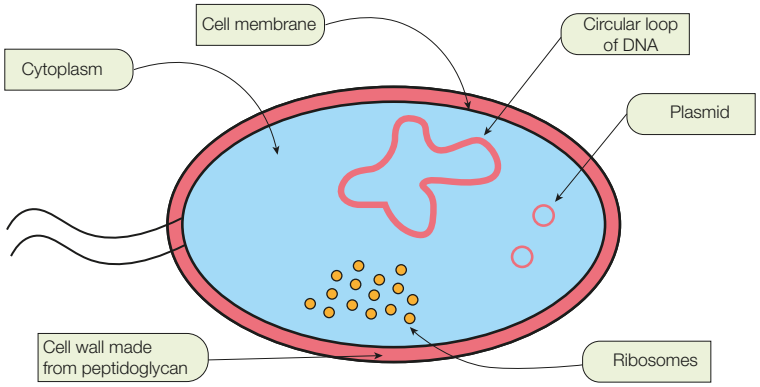


Figure 2.1.2: A typical bacterial cell.

Table 2.1.3: Some examples of infectious diseases caused by bacteria.

Disease	Symptoms	Examples of bacterial species that can cause this disease
Food poisoning	Nausea, vomiting, diarrhoea, dehydration	*E. Coli, Salmonella*
Syphilis	Sores around mouth and genitals, rash, fever	*Treponema pallidum*
Tuberculosis	Coughing blood, fatigue, weight loss	*Myobacterium tuberculosis*
Cholera	Vomiting, diarrhoea, severe dehydration	*Vibrio cholera*
Pneumonia	Chest pain, cough, fatigue, fever, shortness of breath, nausea	*Streptococcus pneumoniae*

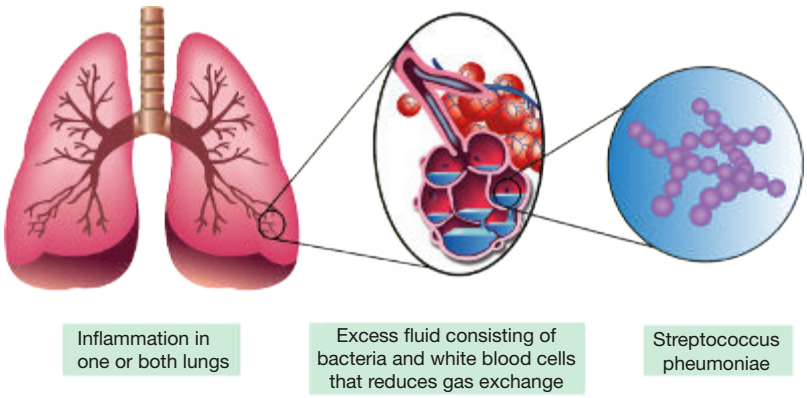


Figure 2.1.3: Pneumonia is caused by a bacterial infection that results in the inflammation of the air sacs (alveoli) in the lung(s).

Fungi

Fungi are comprised of eukaryotic cells that contain a nucleus and other membrane-bound organelles. Fungi cells also contain a cell wall, but it is composed of chitin, which is a different carbohydrate to bacterial cell walls (peptidoglycan) and plant cell walls (cellulose). Some fungi are unicellular (e.g. yeast), but most are multicellular (e.g. moulds).

Fungi are heterotrophic and obtain their nutrients through secreting enzymes that break down organic matter so the products can be absorbed. Parasitic fungi obtain their nutrients through harmful relationships with host organisms (see Table 2.1.4 for some examples). Fungi reproduce by releasing spores which spread remarkably easily, with numbers upwards of 100,000 per cubic metre recorded in the air.

Essentially, pathogenic fungi can be classified into four types depending on where they grow and reproduce:

1. On the surface of the host.
2. On the superficial layers of the host such as skin and nails.
3. In subcutaneous tissues, the inner layers of the skin.
4. Inside the host, by infecting inner tissues and organs.

Table 2.1.4: Some examples of infectious diseases caused by fungi.

Disease	Symptoms	Examples of fungal species that can cause this disease
Toenail infections	Discolouration and breakdown of nails	*Candida albicans* (yeast)
Ringworm	Red patches and blisters on the skin	*Microsporums, Dermatophytons and Trichophytons*
Aspergillosis	Fever, chest coughs, and pain	*Aspergillus fumigatas*

Figure 2.1.4: Ringworm, also called tinea, is a highly contagious fungal infection of the skin that generally presents as red circular patches. The fungus feeds on the keratin which is a protein found in skin.

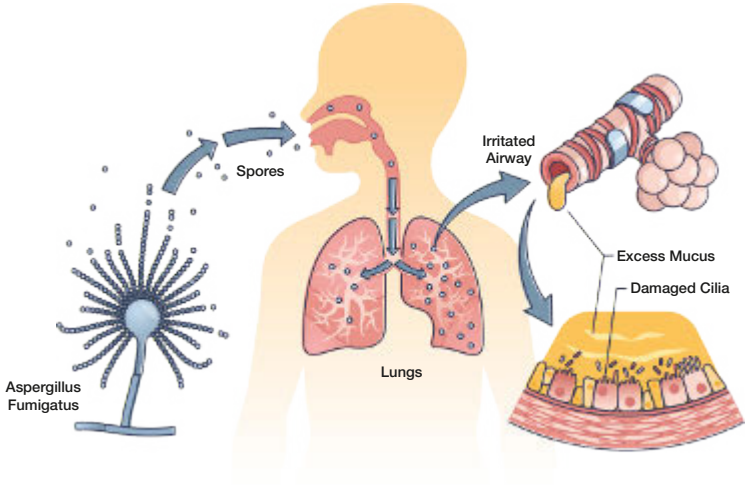


Figure 2.1.5: Aspergillosis is a group of diseases that generally affect the lungs caused by breathing in spores from a common mould (fungi) in the Aspergillus genus.

Protists

Protists are a diverse group of eukaryotic organisms consisting of all eukaryotes not classified as fungi, plants or animals. The animal-like protists are called **protozoa**. Some protozoa can produce **spores**, such as *Toxoplasma gondii*. Protists are mostly unicellular, but some are multicellular. Only a small number of this diverse group of protists are pathogenic, but some can cause severe diseases. They are heterotrophs, absorbing nutrients from their hosts (see Table 2.1.5 for some examples). These pathogenic protists often require a **vector**, such as mosquitoes, to transmit from one host to another. They can be classified into three groups according to their pathogenic nature and the site of infection:

- Intestinal
- Uro-genital
- Blood and tissue

Malaria is a very common protist disease infecting several hundred million people and killing over one million people per year. It is caused by members of the *Plasmodium* genus which is transmitted to humans via the bite of an infected *Anopheles* mosquito. The protozoa infect liver and blood cells which may rupture and release new parasites into the bloodstream causing a range of symptoms (see Figure 2.1.6). This type of transmission will be explored further in Chapter 2.2.

Table 2.1.5: Some examples of infectious diseases caused by protists.

Disease	Symptoms	Examples of bacterial species that can cause this disease
Giardia	Diarrhoea, nausea, cramps	*Giardia lamblia*
Uro-genital infection	Infection of the urinary tract or reproductive organs causing a foul-smelling discharge	*Trichomonas*
Malaria	Fever, chills, blood cells rupturing and often death	*Plasmodium*
Toxoplasmosis	Often no symptoms but some people will exhibit flu-like symptoms such as fever, headaches and muscle aches	*Toxoplasma gondii*

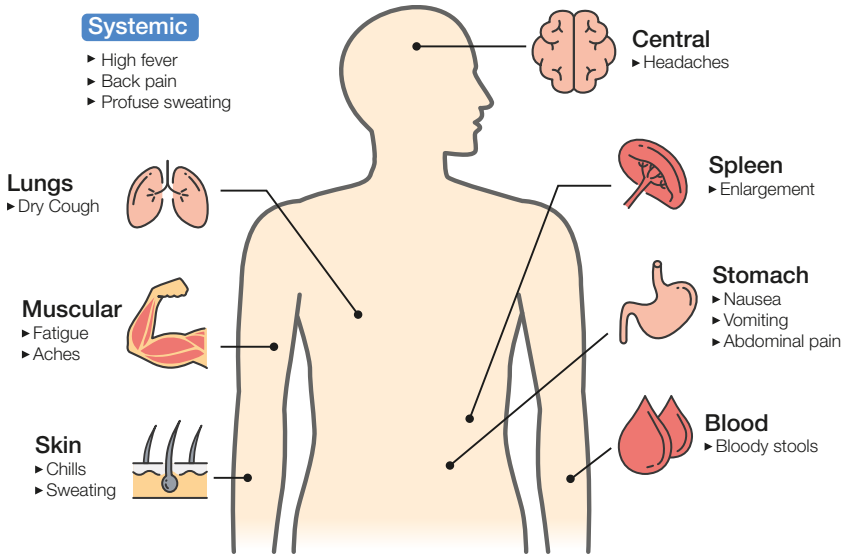


Figure 2.1.6: Some symptoms associated with malaria.

Viruses

Viruses are classified as microorganisms, but they are not considered living organisms because they cannot carry out life's processes, as discussed in Chapter 1.1. They are non-cellular entities, that are better described as **infective particles**. They can only reproduce inside the cell of a host organism (animals, humans, plants and bacteria) and often cause disease as a result.

Virus particles are extremely small and little more than a nucleic acid (RNA or DNA) packaged in a protein coat (see Figure 2.1.7). Either the entire virus enters the host cell it is infecting, or the virus attaches itself to the cell surface and injects its genetic material directly into the cell. The host cells machinery is then used to replicate hundreds or even thousands of new virus particles, which usually rupture the cell, discharging the new virus particles (see Figure 2.1.8).

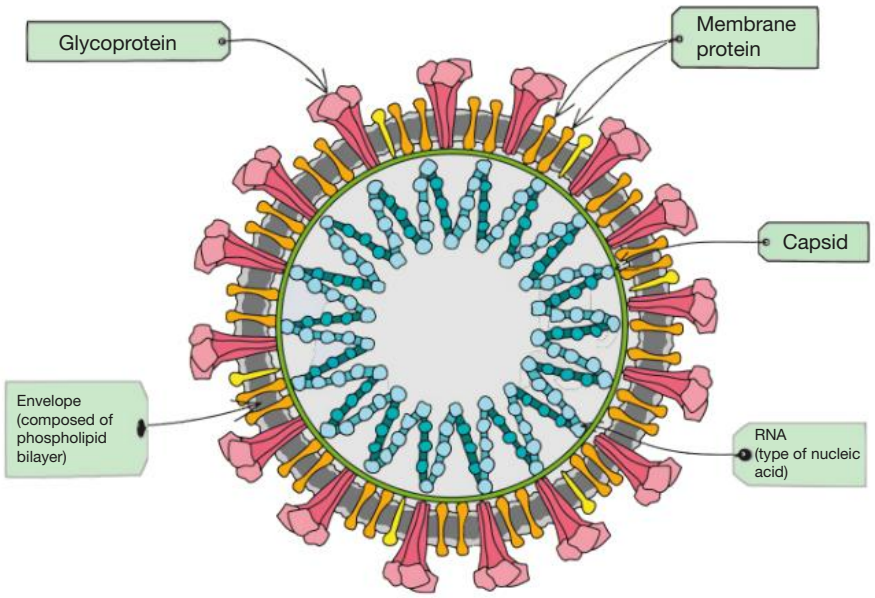


Figure 2.1.7: The basic structure of a virus.

Table 2.1.6: Some examples of infectious diseases caused by viruses.

Disease	Symptoms	Virus
Influenza (the flu)	Fever, cough, aches, chills etc.	Influenza viruses
Common cold	Stuffy nose, sore throat, headache	Over 200 different types of viral particles
AIDS	Fever, sore throat, vomiting, immune deficiency	Human immunodeficiency virus (HIV)

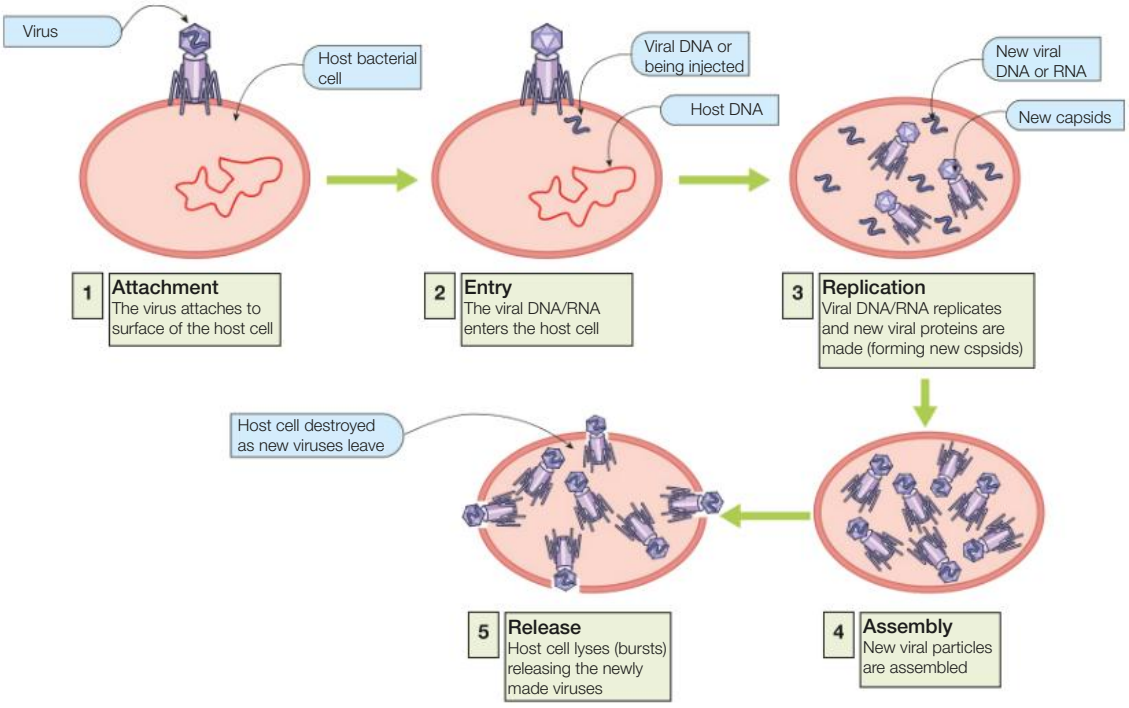


Figure 2.1.8: The virus life cycle.

Helpful online resources

FuseSchool – Global Education: Virus life cycle

https://www.youtube.com/watch?v=Qulwy6ow-Wc

Parasitic worms

Parasites are organisms that live on or within a host organism and generally relies on the host to complete their life cycle. They can be considered pathogenic if they cause disease. Parasitic worms, also called helminths, generally live inside their host organism, and feed on the food the host organism has consumed (see Figure 2.1.9). This generally takes place inside the host's intestines, which provides the parasitic worms with an adequate source of nutrients. Some of these parasites cause few, if any, symptoms in the host, whereas others weaken their hosts significantly.

Parasitic worms rely on their host organism to reproduce and are well adapted to their life cycles. They have highly developed reproductive systems, laying copious quantities of eggs, which are then passed out in the faeces to infect others.

Parasitic worms clearly cause infectious diseases as they spread easily between hosts. Thread worm is a typical parasite infecting the intestines of humans. When they mature, they lay hundreds of eggs which are released near the anus of an infected person giving rise to a condition sometimes called 'itchy bottom' (see Table 2.1.7).

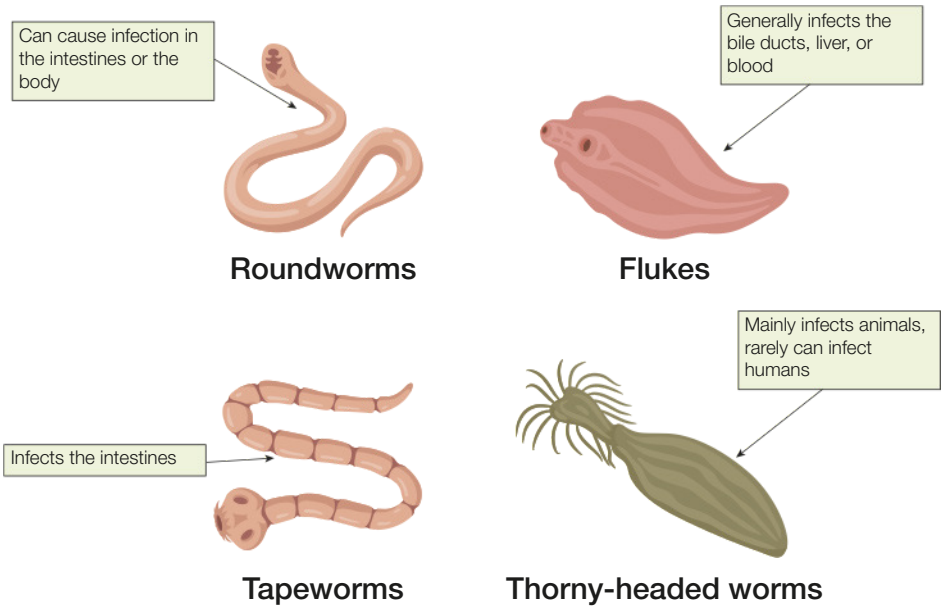


Figure 2.1.9: Some examples of parasitic worms.

Table 2.1.7: Some examples of infectious diseases caused by parasites.

Disease	Symptoms	Examples of bacterial species that can cause this disease
Thread worm	Itchy bottom, tiredness, irritability	Pin worm or thread worm
Tapeworm infection	Nausea, fatigue, weight loss	Tapeworm

Prions

Protein molecules are vital in all living organisms as they are involved in both structural and functional roles. These molecules are made up of chains of building blocks called amino acids which are folded into specific 3D shapes. It is this **specific shape** that is crucial for their function. One example of this is the specific shape of protein antibodies, that are secreted by some white blood cells, that bind to specific antigens on pathogens. This concept is explored further in Chapter 2.8.

A prion is a misfolded protein that can cause other normal proteins to misfold, leading to cellular death, brain damage and neurodegenerative diseases (see Figure 2.1.10). Unlike bacteria or viruses, prions are non-cellular and lack genetic material (DNA and RNA). These **infective agents** replicate by converting normal proteins into the abnormal, disease-causing form. This process leads to conditions like Creutzfeldt-Jakob disease in humans and mad cow disease in animals (see Table 2.1.8). Prions are considered pathogenic because they disrupt normal cellular functions and cause cell death, particularly in brain tissue. They are exceptionally hard to treat because they are resistant to heat, radiation, and conventional sterilisation, making them persist in both infected tissue and contaminated environments.

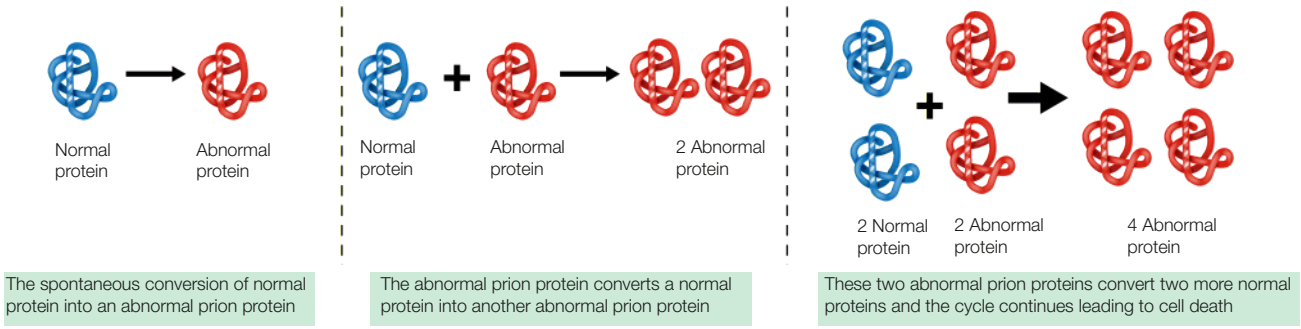


Figure 2.1.10: Prion disease is caused by a change to the 3D shape of a specific protein. This change can be spontaneous, which is rare, or through exposure to the infective particle from another contaminated source. This 'abnormal' prion protein causes a chain effect of conformational change, converting normal proteins to the 'abnormal' prion protein, resulting in cellular death and neurodegenerative diseases.

Table 2.1.8: Some examples of infectious diseases caused by prions.

Disease	Symptoms	Examples of bacterial species that can cause this disease
Scrapie	Fatal brain degeneration in animals	Scrapie prion
Mad-cow disease	Abnormal posture, aggressive temperament, loss of body weight	Bovine spongiform encephalopathy (BSE) prion
Creutzfeldt-Jakob Disease (CJD)	Failing memory, lack of coordination, total memory loss	Creutzfeldt-Jakob prion

2.1 Review questions

Multiple choice questions

1. Which of the following is not an example of an infectious disease?
   - J Anaemia
   - K Pneumonia
   - L Ringworm
   - M Influenza
2. Which of the following characteristics does not enable pathogens to exploit their hosts?
   - J Being able to enter a host.
   - K Being able to reproduce in a host.
   - L Being able to cause red rashes in a host.
   - M Being able to avoid a host's defences.
3. Select the option in the table that correctly identifies the roles of the mosquito and malarial parasite in the transmission of malaria.

	Mosquito	Malarial parasite
J	Host	Vector
K	Pathogen	Host
L	Vector	Pathogen
M	Pathogen	Vector

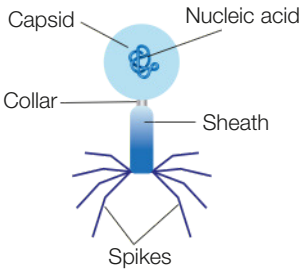
4. Which of the following pathogens do **not** produce spores?
   - J Bacteria
   - K Viruses
   - L Fungi
   - M Protists

5. *Refer to the diagrams below of three pathogens to answer the following question.*

Pathogen A

Pathogen B

Pathogen C



Select the option that correctly identifies the three pathogens.

	Pathogen A	Pathogen B	Pathogen C
J	Virus	Fungus	Protist
K	Fungus	Bacterium	Protist
L	Parasitic worm	Fungus	Virus
M	Prion	Bacterium	Virus

6. The symptoms of food poisoning are generally caused by

J spores left by pathogens.
K prions.
L toxins.
M protozoa.

7. Which of the following statements about prions is **not** correct?

J Prions lack genetic information.
K Prions consist of amino acids.
L Prions change the shape of DNA causing it to misfold and become abnormal.
M Prions are considered infective agents.

8. Select the option in the table below that correctly matches a type of pathogen with an example of a disease it causes and if consists of cells or not.

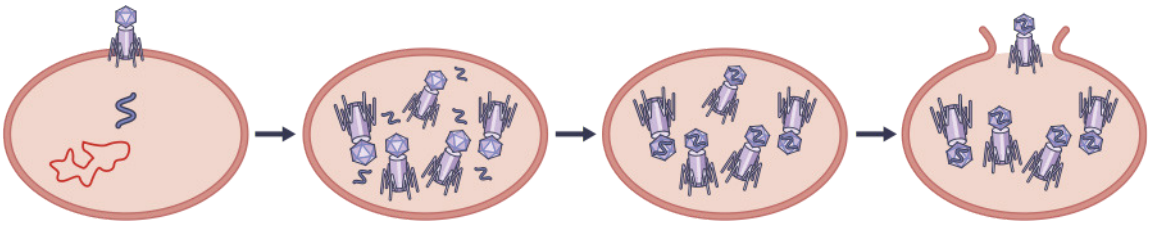
	Type of Pathogen	Cellular or non-cellular	Example of disease caused by pathogen
J	Parasitic worm	Cellular	Ringworm
K	Protist	Cellular	Tuberculosis
L	Prion	Non-cellular	Creutzfeldt-Jakob disease
M	Virus	Non-cellular	Cholera

9. Toxoplasmosis is a disease caused by the *Toxoplasma gondii* pathogen. This pathogen reproduces in the intestinal tract of cats and can infect humans who change an infected cat's contaminated litter box. If a pregnant woman is infected with this pathogen, the growing foetus can also be infected and can result in birth defects and miscarriage.

Based on the information above, which of the following statements is most correct?

J The cat is a direct vector for the *Toxoplasma gondii* pathogen to infect humans.
K The *Toxoplasma gondii* pathogen only infects pregnant women and their babies.
L *Toxoplasmosis* is a pathogen that infects cats and humans.
M The *Toxoplasma gondii* pathogen can also be considered a parasite.

10. *Refer to the image below which shows some steps involved in the viral life cycle to answer the following question.*



Which of the following options correctly matches a step in the diagram with a description of the events that occur during that step?

	Step	Description of event(s) occurring during this step
J	1	Host cell's DNA is injected into the cell
K	2	Host cell's machinery used to replicate viral genetic code
L	3	Viruses attach to the cell membrane of host cell
M	4	New viruses form

Free response questions

1. Explain the difference between infectious and non-infectious disease.

2. Describe the difference between a parasite and a pathogen **and** give an example of each to illustrate your answer.

3. The disease ring worm is not actually caused by a worm. Explain your understanding regarding this statement.

4. Spores, produced by microbes, can have two quite distinct functions:
   a) Name **two** pathogens that can produce spores.

   b) Discuss the advantages of producing spores to species that use them.

5. The human body contains about 100 trillion (10^{14}) cells of bacteria, fungi and protozoa yet remarkably remains mostly healthy with these microbes living on or inside of it. Explain how this is possible.

6. Complete the following table by providing an example of a typical disease caused by each pathogen, and describing how one characteristic it posesses assists their survival and/or transmission to other organisms.

Pathogen	Example of disease	Characteristic that assists survival and/or transmission
Bacteria		
Fungi		
Protozoa (Protist)		
Virus (HIV)		
Parasitic worm		
Prion		

7. Explain why prions are not considered to be alive.

8. a) Describe what a toxin is.

b) Explain why cooking and consuming a steak that has passed its use-by-date could result in food poisoning.

c) The table below lists some common diseases. Place a tick in the appropriate column(s) to indicate the type of pathogen(s) that is the causative agent.

Disease	Bacterium	Fungus	Virus	Protist	Worm	Prion
Common cold						
Diarrhoea						
Malaria						
Sinusitis						
Skin infections						
Pneumonia						
Mad cow disease						
Genital herpes						

d) *Refer to the table below showing recent global deaths from the most common infectious diseases according to the World Health Organisation from 2012 to 2015 to answer the following questions.*

Disease	Year	Number of deaths globally
Malaria	2013	584,000
Diarrhoea	2012	1.5 million
HIV/AIDS	2012	1.5 million
Tuberculosis	2012	900,000
Ebola	2013-2015	10,000

a) State where in the world most of these deaths are likely occurring.

b) Describe the likely reasons for these deaths in these parts of the world.

c) Discuss the reasoning behind the following statement: "Most people from developing countries die from infectious disease whereas people from developed countries die from non-infectious disease."

Chapter 2.2 Disease transmission

Science Understanding

Describe the methods by which pathogens may be transmitted between hosts, such as:

- air
- dust
- direct contact
- faeces
- food
- animals

Methods of disease transmission

Pathogens are transmitted from **host to host**, and **vector to host** through several pathways or mechanisms.

Helpful online resources

TED-Ed: How do germs spread (and why do they make us sick)? - Yannay Khaikin and Nicole Mideo

https://www.youtube.com/watch?v=yxonJTWhBJQ

Airborne and droplet transmission

When humans talk, breathe with their mouth open, cough or sneeze, small droplets are emitted from the mouth or upper respiratory passages. If a human is carrying an infection, then these droplets contain the pathogenic microorganisms and anyone who inhales these droplets can also become infected. It has been estimated that one cough or sneeze may release millions of microorganisms.

Airborne and droplet transmission are two ways infectious diseases can spread through the air, but they differ in how far the respiratory particles can travel and remain infectious (see Figure 2.2.1). **Airborne transmission** involves much smaller respiratory particles called **aerosols**, which can remain suspended in the air for longer periods and travel further distances. This makes airborne diseases, like **tuberculosis or measles**, more easily transmissible over larger spaces, even without direct contact. **Droplet transmission** however involves larger respiratory droplets, which are generally expelled when someone coughs or sneezes. These droplets are heavier and typically travel only a short distance, up to 1-2 meters, before falling to the ground or surfaces. Diseases like **influenza** often spread this way.

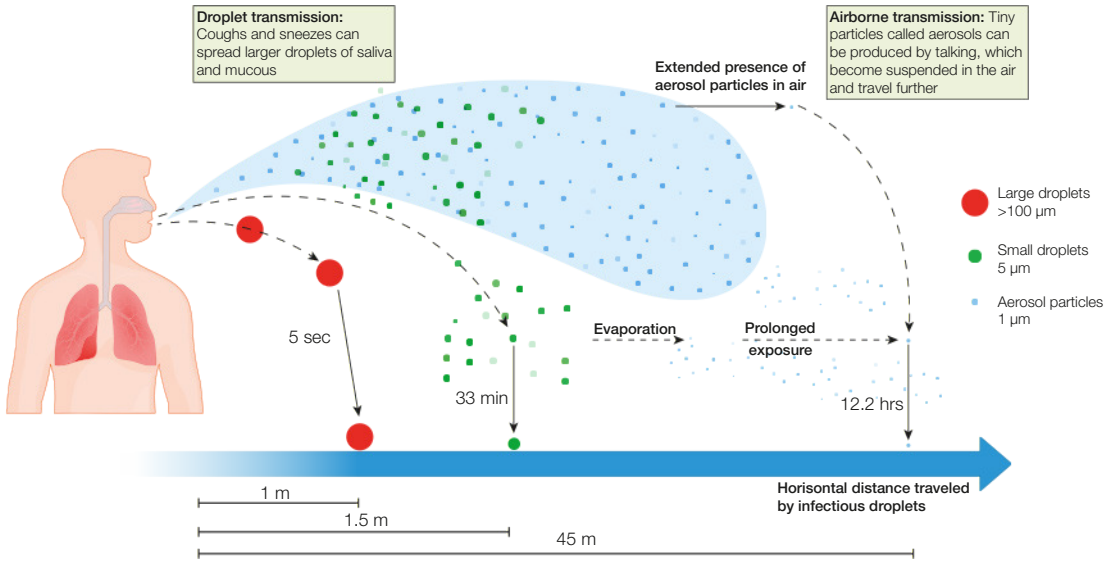


Figure 2.2.1: Smaller aerosol particles can travel much further in the air than the larger droplets, therefore droplet transmission is limited to closer contact compared to airborne transmission that can spread infections more broadly through the air.

Dust-borne transmission

Dust can also transmit infectious diseases through a process called dust-borne transmission. In this form of transmission, infectious agents like bacteria, viruses, or fungi **attach to tiny dust particles**, which can then be dispersed into the air. When these contaminated dust particles are inhaled, they can carry pathogens into the respiratory system, potentially causing infection. Dust-borne transmission is the primary mode of transmission of **hantavirus** to humans. This virus can be found in mouse saliva, faeces and urine, which can dehydrate and disintegrate into fine particles. When disturbed, these particles can become airborne and can potentially be inhaled. Dust-borne transmission is particularly relevant in environments where dust is disturbed, such as during cleaning, construction, or agricultural activities.

Indirect contact

If an infected person coughs, sneezes, or touches a surface, they can leave infectious particles behind. These infectious particles can linger on surfaces and can be spread to another person if they touch it. **Athlete's foot** is an example of a fungal disease that can be spread through indirect contact. If an infected individual walks barefoot, the fungus can be left on the surfaces walked on. When another barefoot individual walks on the same surface, they can then contract the Athlete's foot infection.

Direct contact

Infectious diseases can spread by direct contact when an uninfected person comes into immediate physical contact with an infected individual. This can happen through actions such as touching, kissing, or sexual contact, which allow pathogens to transfer from one person to another. Diseases like the **common cold, chickenpox, and genital herpes** are commonly transmitted through direct contact.

Faeces

Infectious diseases can also spread through contact with faeces. This is known as **vehicle transmission** and occurs when pathogens in the faeces of an infected person contaminate food, water, surfaces, or hands and are then ingested by another person. Poor sanitation, inadequate hand hygiene, and improper handling of food can increase the risk of faecal transmission. **Hepatitis A, cholera and giardia infections** are often spread this way. This is a significant cause of death in many developing countries as fresh, clean running water is not always readily available.

Contaminated food

When harmful pathogens such as bacteria, viruses, or parasites enter the food supply and are then ingested by people, foodborne illnesses can spread. Common foodborne illnesses, such as **salmonella, E. coli, and listeriosis**, occur when food is prepared or stored in unsanitary conditions, allowing pathogens to multiply. For example, raw or undercooked meat, unpasteurised dairy, and unwashed fruits and vegetables are frequent sources of contamination. Once consumed, these pathogens can cause symptoms like nausea, fever, cramps, vomiting, and diarrhoea. Refer to Chapters 1.6 and 1.7 for more information on microorganisms that can contaminate food and hygiene methods to prevent food contamination.

Animal vectors

Infectious diseases can sometimes spread from animals to humans. This transmission can occur through **direct contact** with animals, such as petting, bites, or scratches, **or through indirect contact** with their bodily fluids, faeces, or contaminated surfaces. These diseases are termed vector-borne diseases because the animal acts as a vector, or carrier, of the pathogen, in the transmission of the disease to humans. Dogs, cats, bats, monkeys, and insects such as **mosquitoes, ticks, or fleas** are some prime examples of animals that carry pathogens that can be transmitted to humans. Some examples of animals and the diseases they can transmit are outlined in Table 2.2.1. Some groups of people in society are more vulnerable to transmission of these diseases, including farmers, vets, abattoir workers and people working with exotic animals. Additionally, the spread of pathogens by mosquitoes are often more prominent in warm and humid tropical regions, where mosquito populations thrive.

Table 2.2.1: Some examples of animal vectors and the pathogens they can transmit to humans.

Animal vector	Disease	Type of pathogen	Method of transmission
Dogs, cats, bats, livestock	Rabies	Virus	Spread via saliva of infected animals, usually through biting. Can also be spread through scratches from infected animals after
Cats	Toxoplasmosis	Protozoan	Contact with cat faeces
Ticks	Lyme disease	Bacteria	Bite of some types of ticks
Mosquito	Malaria	Protozoan	Bite of some types of mosquito (see Figure 2.2.2)
Flying foxes and horses	Hendra virus infection	Virus	Exposure to infected horse tissue or bodily fluids (e.g. when sneezing, coughing)
Cats and dogs	Helminth (worm) infection	Parasitic worm	Oral contact and ingestion of cat or dog saliva, such as licking of hands or face. Can also be spread through contact with faeces or contaminated soil.

Helpful online resources

MinuteEarth: Why Do Bats Carry So Many Diseases? (like Coronavirus)

https://www.youtube.com/watch?v=Ao0dqJvH4a0

Kurzgesagt: The deadliest virus on Earth

https://www.youtube.com/watch?v=4u5I8GYB79Y

Examples of parasites that involve more than one animal host

Malaria

This disease is very serious, causing hundreds of thousands of human deaths around the world every year. It is caused by a few species of a pathogenic parasite called Plasmodium. The Plasmodium spends part of its life in humans and part of its life in the females of a species of mosquito (Anopheles) which acts as a vector in transmitting the disease (see Figure 2.2.2).

With some particularly **virulent** species, the symptoms can be very severe including fever, coma and convulsions, which can be fatal within a few days. As can be seen in Figure 2.2.2, the *Plasmodium* multiply inside human liver and red blood cells, bursting them open and releasing new *Plasmodium* cells.

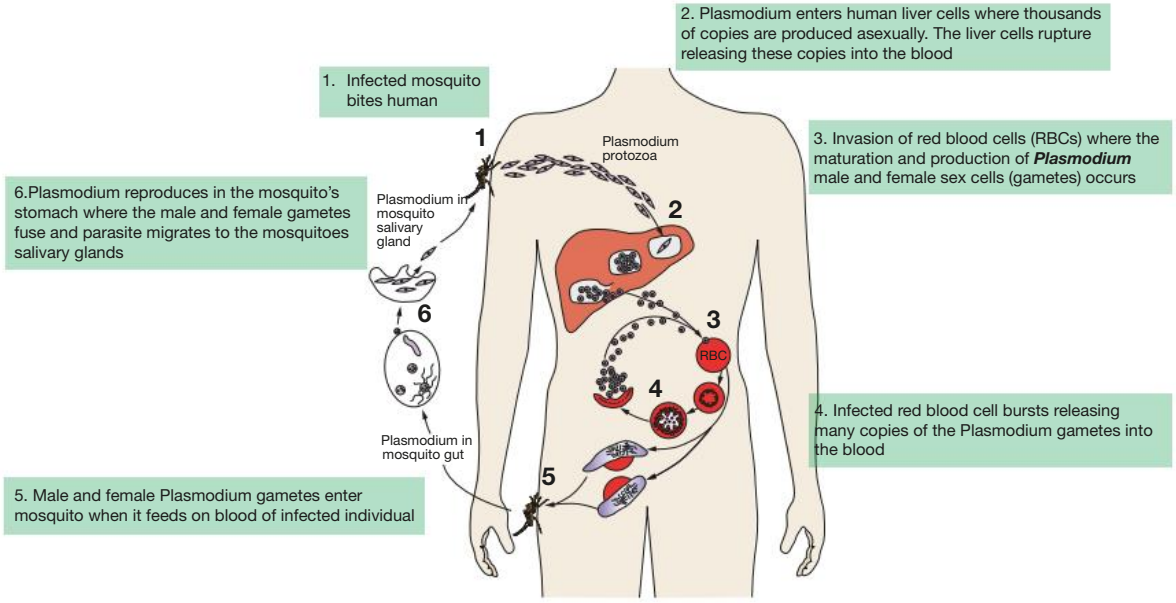


Figure 2.2.2: The life cycle of the protist Plasmodium that causes malaria and is spread through the bite of a mosquito vector.

Tapeworms

Another example of a parasite using multiple hosts is the tapeworm. The main host in this example is the household cat, and intermediate hosts include rats, mice and fleas depending on the species of tapeworm (see Figure 2.2.3 for example of a tapeworm lifecycle). A heavy infestation of tapeworms in a cat can lead to loss of condition, lethargy and poor fur condition. These worms can also infect humans, especially younger children.

The tapeworms are well adapted to their parasitic way of life with such features as suckers or muscular grooves on their head enabling them to attach to the cats' intestines. It is also noted that the tapeworms are hermaphroditic, that is, a single worm can contain both female ovaries and male testes.

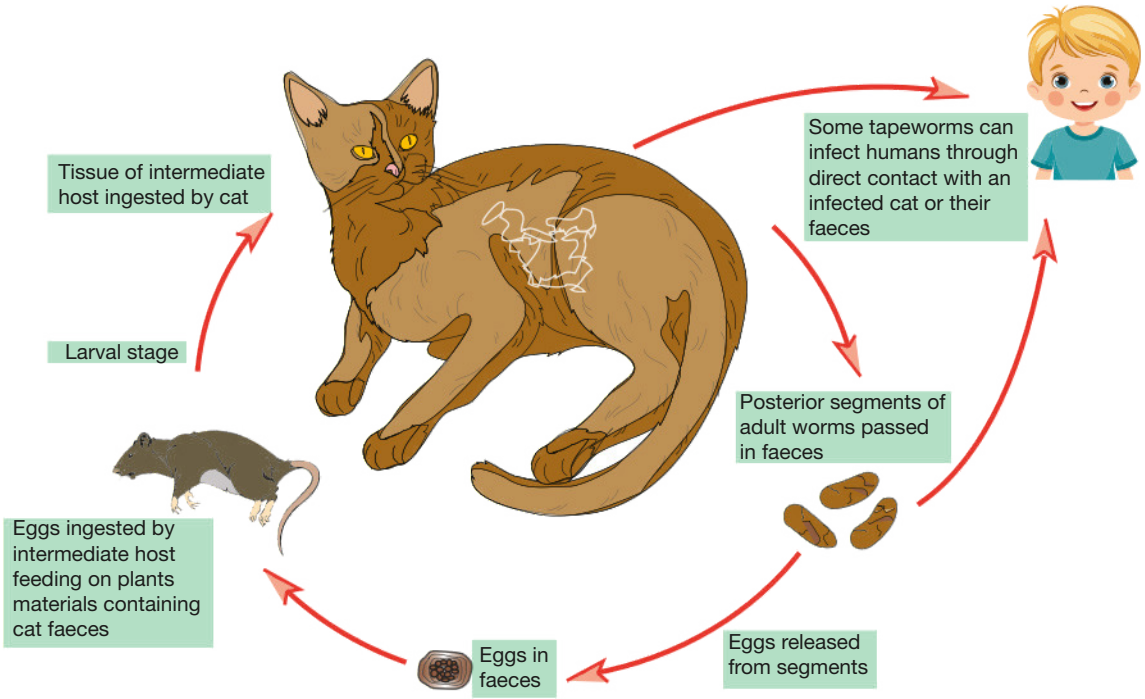


Figure 2.2.3: An example of the life cycle of a tapeworm that involves an intermediate host, a rat, transferring the parasite to a cat, and in turn, humans.

2.2 Review questions

Multiple choice questions

1. Which of the following options is **not** a method through which pathogens are transmitted?
   - J Water
   - K Dust
   - L Food
   - M Antibiotics
2. Which of the following options does **not** spread disease through the air?
   - J Direct contact transmission
   - K Droplet transmission
   - L Dust-borne transmission
   - M Airborne transmission
3. Which of the following options can spread disease the furthest through air?
   - J Large droplet
   - K Small droplet
   - L Aerosol
   - M Faeces

4. What type of transmission of disease is involved when two people share a drink bottle?

   J Direct contact transmission
   K Indirect contact transmission
   L Animal vector transmission
   M Airborne transmission

5. A mosquito bites a person who subsequently develops a fever and abdominal rash. This type of transmission is called

   J Direct contact transmission
   K Indirect contact transmission
   L Vehicle transmission
   M Vector transmission

6. Athlete's foot is a fungal infection mostly transmitted through

   J Direct contact transmission
   K Indirect contact transmission
   L Dust-borne transmission
   M Airborne transmission

7. An example of a disease that spreads through a vehicle such as water is

   J Cholera
   K Malaria
   L Chickenpox
   M Lyme disease

8. Salmonella can infect humans through the consumption of undercooked chicken. Another example of a foodborne disease is

   J Lyme disease
   K Listeriosis
   L Hendra virus infection
   M Tuberculosis

Refer to Figure 1 below which shows some information about the transmission of the Zika virus to answer questions 9 and 10.

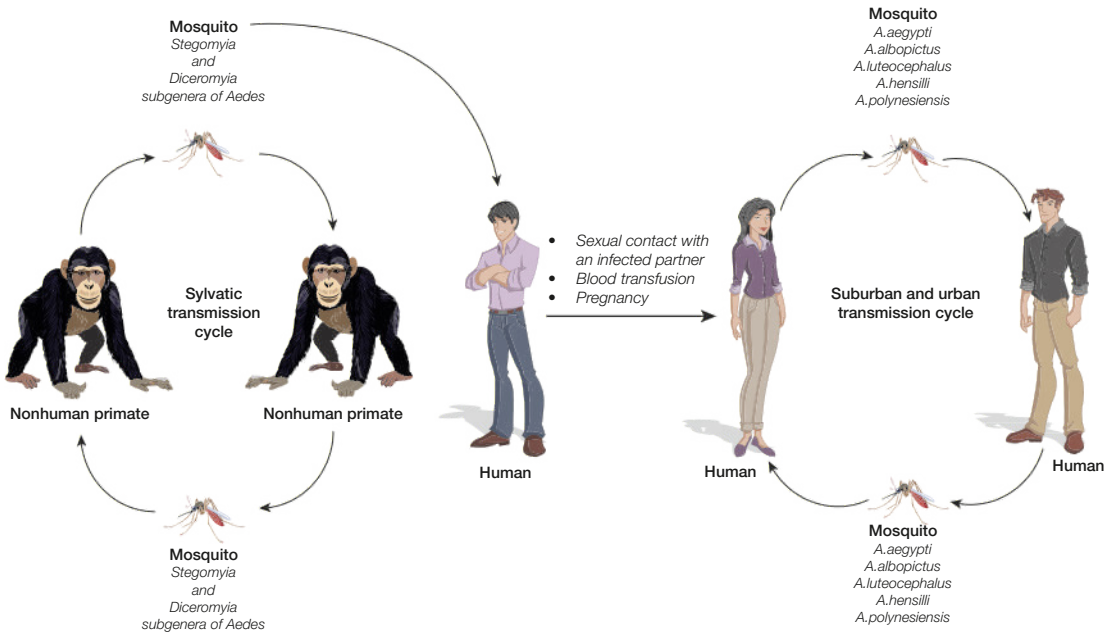


Figure 1: Zika virus is a re-emerging disease that can cause congenital abnormalities in newborns and is associated with Guillain–Barré syndrome in adults, where the immune system attacks the nerves and can lead to paralysis. The virus can be sexually transmitted and can persist in the male genital tract.

9. According to Figure 1, two major methods of transmission of the Zika virus are

   J direct contact transmission and vector transmission.
   K indirect contact transmission and vector transmission.
   L direct contact transmission and vehicle transmission.
   M indirect contact transmission and vehicle transmission.

10. With reference to Figure 1, which of the following statements is correct?

   J Only humans can be infected with the Zika virus.
   K Sexual activity with an infected male can only infect one female.
   L Only A. aegypti, A. albopictus, A. luteocephalus, A. hensilli and A. polynesiensis mosquitoes can infect humans with Zika.
   M The spread of the Zika virus to humans has been amplified through mosquitoes.

Free response questions

1. Complete the following table by naming four common methods by which pathogenic organisms can be transmitted to an individual, **and** list two pathogens for each method of transmission.

Method	Examples of pathogens

2. Describe why measles is considered more transmissible than influenza.

3. Describe **three** ways in which the HIV virus can be transmitted.

4. Some parasitic worms, including Helminths and tapeworms,can spread from dogs and cats to humans.

   a) Outline **two** methods by which a Helminth parasitic worm could spread from a domesticated pet dog to a child.

   b) Some tapeworms require an intermediate host before infecting cats.

   Name **one** example of an intermediate host **and** describe how it spreads tapeworm to cats.

5. *Salmonella* bacteria are a very common cause of food poisoning.

   Describe why chicken is considered a high-risk source for the transmission of this harmful bacteria.

6. Hikers and people camping in the outdoors are often susceptible to *Guardia* infections. Describe the most likely source of this disease **and** explain why.

7. Describe how rabies is transmitted.

8. Global warming is a consequence of human practices. It has been suggested that global warming may be a major factor in the increased spread of infectious diseases now, and in the coming decades, and that this may be linked to the vectors involved in the spread of disease. Explain likely reasons for this suggestion.

9. A vector is involved in the life-cycle of the pathogen that causes malaria.

   a) Name the vector **and** describe its role in the transmission of the malarial parasite.

   b) Describe how the actions of the malarial parasite could lead to human death.

   c) Explain how two organisms are required for the sexual reproduction of the malarial parasite.

   d) Suggest **one** way to reduce the spread of the disease malaria.

Chapter 2.3 Epidemics and other health issues

Science Understanding

Infectious diseases can cause widespread health issues for local, national, and/or global populations. Describe the interrelated factors that can determine the spread of infectious disease, including:

- persistence of the pathogen within hosts
- the transmission mechanism
- the proportion of the population that is immune or has been immunised
- mobility of individuals of the affected population.

Infectious diseases pose a significant threat to public health, with the potential to affect individuals and communities on local, national, and global scales. Caused by pathogens such as bacteria, viruses, fungi, and parasites, these diseases can spread rapidly through human contact, contaminated environments, or vectors like insects. On a local level, outbreaks can overwhelm healthcare systems and disrupt daily life, while nationally, they can strain resources, hinder economic productivity, and exacerbate social inequalities. Globally, infectious diseases can cross borders with ease, facilitated by international travel and trade, leading to pandemics that challenge global health systems and cooperation. Understanding and addressing the interrelated factors that can determine the spread of infectious disease, including the transmission mechanism and proportion of the population that is immunised against a pathogen, can help minimise the impact on health and society.

Epidemics and pandemics

The key difference between an epidemic and a pandemic lies in their scale and geographic spread. An **epidemic** refers to an active outbreak of an infectious disease that affects a large number of people **within a specific community, region, or country**, such as a localised outbreak of measles. A **pandemic**, on the other hand, is an epidemic that **extends across multiple countries or continents**, affecting a significant portion of the global population, as seen with COVID-19 or the 1918 influenza pandemic. While epidemics are confined to particular areas, pandemics require international coordination and pose a broader global health challenge.

Epidemics and pandemics can develop due to a number of factors including:

- the transmission of a pathogen to a group of humans that have not previously been exposed to it
- the transmission of a new pathogen from animals to humans that previously had not occurred, (i.e. crossing the species barrier)
- the development of a new strain of a pathogen, generally caused by random mutations or genetic changes in the pathogen
- low immunity or natural defence to the pathogen in the population (i.e. decreased herd immunity)

Historical background

Epidemics have been recorded in history since the beginning of human civilisation with populations giving up nomadic lifestyles and settling in villages and towns. The human population size was kept in check by such infectious diseases wiping out millions of people (see Figure 2.3.1). A range of factors contributed to such high mortality rates including poor sanitation, inadequate health systems and little or no understanding of the causative agents of these diseases.

The **Black Plague, or Black Death**, that occurred between 1347 and 1353 was one such disease. It has been estimated that 25 to 50 million people in Europe died of this disease, which is roughly roughly 30-60% of the continent's population at the time (see Figure 2.3.1). Globally, the death toll may have reached 75 to 200 million, considering its impact in Asia, the Middle East, and North Africa. This pandemic, caused by the bacterium *Yersinia pestis*, spread rapidly due to fleas carried by infected rats and humans, poor sanitation, and dense urban populations. It remains one of the deadliest pandemics in human history.

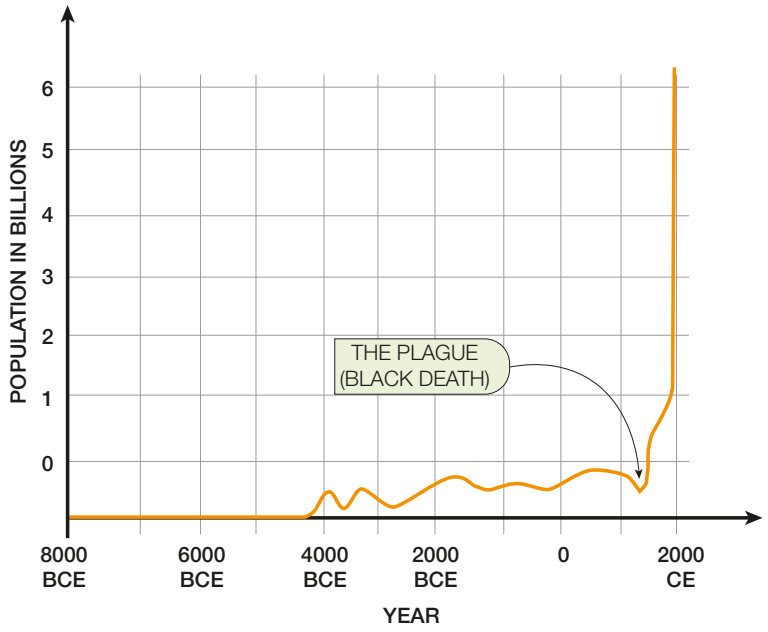


Figure 2.3.1: The Black Death was a pandemic in the 14th century that killed approximately one third of Europe's population at the time, significantly reducing the human population.

Helpful online resources

TED-Ed: The past, present and future of the bubonic plague–Sharon N. DeWitte

https://www.youtube.com/watch?v=ySCIB6-OH-Q

Throughout history, pandemics have been pivotal events, often leaving profound marks on the development of civilizations. These catastrophic outbreaks of disease, from the Plague of Justinian (the first major bubonic plague pandemic) in the years 541-542 to the global reach of the modern COVID-19 pandemic, have not only claimed millions of lives but also shaped the course of human history. The seven deadliest pandemics in human history are highlighted in Figure 2.3.2.

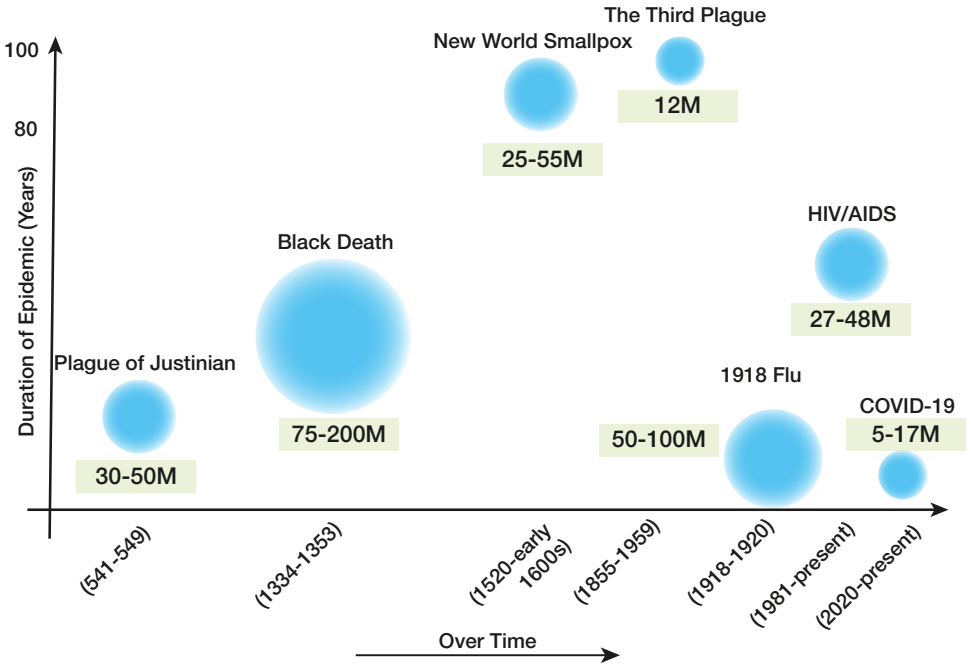


Figure 2.3.2: The seven deadliest pandemics in human history including the approximate number of deaths and their duration. Note: The size of the blue dot represents the number of deaths associated with the pandemic and the height of the blue dot on the graph indicates its duration (the higher it is, the longer the pandemic).

Factors influencing the spread of infectious disease

The spread of infectious diseases is influenced by a complex interplay of biological, social and environmental factors. One such factor is the increased human population. The human population has increased from approximately 1.6 billion in 1900 to 8.2 billion in 2024 and is predicted by the World Health Organisation to reach 10.4 billion by 2100. The increase in human population has increased the density of humans within cities and the number of different daily interactions with other humans. It has also contributed to increased migrations and mobility of populations through travel. As a result, this has also increased the ability of infectious diseases to spread locally and internationally (see Figure 2.3.3). Some additional factors are explored further in this Chapter.

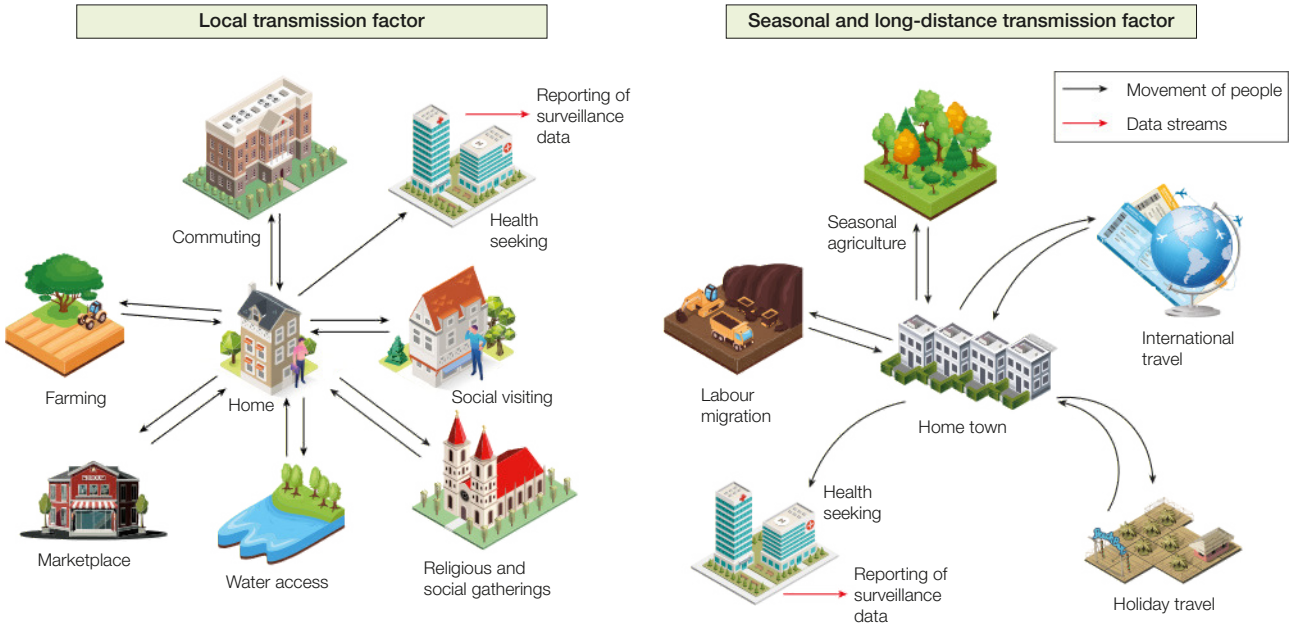


Figure 2.3.3: Some local and long-distance social factors that can influence the transmission of infectious diseases.

Persistence of pathogens within hosts

The persistence of a pathogen within hosts significantly impacts the spread of infectious disease by prolonging the period during which an infected individual can transmit the pathogen to others. Pathogens that remain active or latent in a host for extended periods, such as HIV or those causing tuberculosis, can **maintain a reservoir of infection within a population**, even in the absence of new exposures (see Figure 2.3.4). Persistent infections also provide opportunities for the pathogen to **adapt to the host's immune defenses**, potentially increasing its transmissibility or resistance to treatments.

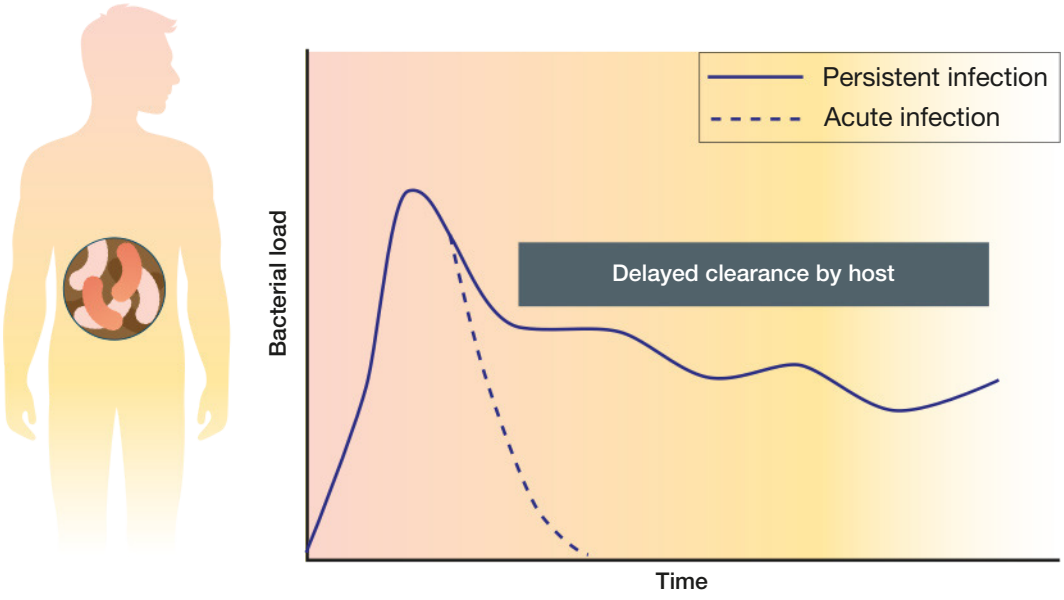


Figure 2.3.4: A comparison of the bacterial load in an individual during an acute infection compared with a persistent infection.

Human immunodeficiency virus (HIV)

HIV, which causes the disease AIDS, crossed the species barrier from non-human primates to humans in the 20th century. It is likely that this occurred through exposure to infected blood through hunting, somewhere in Central Africa. It was recognised as a global health crisis in the 1980s. HIV survives and spreads in humans by targeting the immune system, infecting a type of white blood cell that helps the body fight infections. Once inside these cells, HIV uses them to replicate, gradually destroying the immune system's ability to defend against other infections. This persistence allows the virus to remain in the body for life.

HIV infected hosts remain **asymptomatic** (no symptoms) in the early stages. The AIDS epidemic is therefore notoriously difficult to stop because many people who become infected do not know that they've contracted the disease for extended periods of time, increasing the chance that they unknowingly transmit the virus to others.

Helpful online resources

TED-Ed: Why it's so hard to cure HIV/AIDS–Janet Iwasa

https://www.youtube.com/watch?v=0TipTogQT3E

TED-Ed: How close are we to eradicating HIV?–Philip A. Chan

https://www.youtube.com/watch?v=5_78Fyk7mIE

Changes in genetic code and structure

Random **mutations** can occur to the genetic codes (DNA/RNA) of pathogens that can result in the **physical change of its structure** (see Figure 2.3.5). These random mutations can occur naturally due to the high reproduction rates of pathogens, and mistakes when replicating the genetic code.

Some mutations can result in changes to the pathogen that enable them to evade their hosts' immune system and allow them to **persist within the host for longer periods of time**. A physical change(s) to a pathogen's surface proteins can result in the pathogen infecting individuals that were once considered 'immune. This is because the host's immune system would not be able to recognise the changed shape of the pathogen's surface protein. This can increase a pathogen's **contagiousness**, or ability to spread, and can also result in the development of **new strains**. This can be seen with the many different strains of influenza virus and COVID-19 virus that are constantly evolving and infecting the global human population. Additionally, mutations could result in new physical structures in the pathogen that **increase the severity of symptoms** and/or death rate. This is known as an **increased virulence**. There is therefore a greater chance of a new or more virulent strain developing with a greater number of infected hosts.

The random mutations can also result in physical changes that allow **pathogenic bacteria** to develop resistance to antibiotics, which are medicines used to treat bacterial infections. Some pathogenic bacteria have developed resistance to multiple antibiotics and are known as superbugs. The development of **antibiotic resistance allows these pathogens to persist in hosts as antibiotic treatments no longer work**. The host is reliant on its immune system to combat these antibiotic resistant bacterial infections. These concepts will be explored further throughout Topic 2.

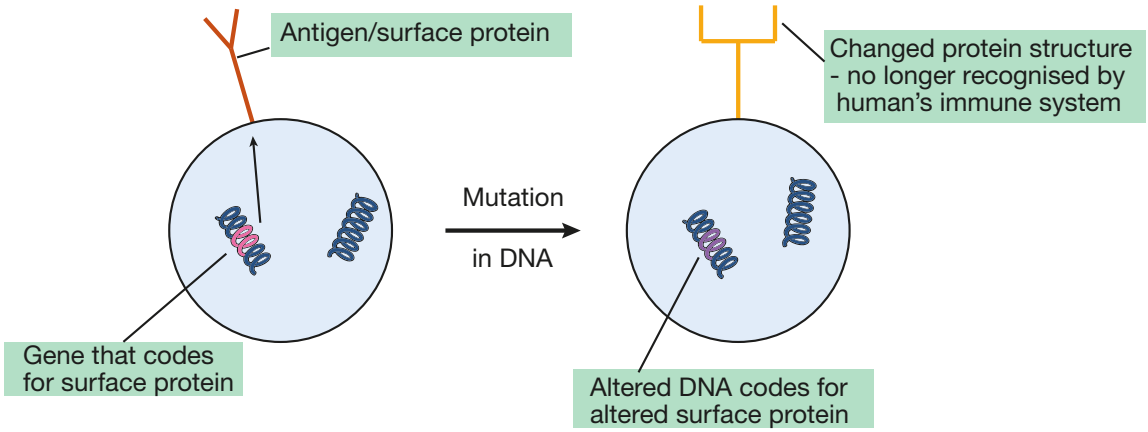


Figure 2.3.5: The accumulation of random genetic mutations can result in changes to the physical structure of pathogens and enable them to avoid the host's immune system as they are no longer recognised.

Transmission mechanisms

The contagiousness of pathogens varies significantly depending on their transmission mechanisms (see Chapter 2.2 for more information on transmission mechanisms). Understanding the transmission mechanism helps determine the appropriate control measures to reduce the spread of infectious diseases, which is explored in more detail in Chapter 2.4. A generalised order of highly contagious to less contagious methods of transmission are listed below:

1. Airborne transmission
2. Direct contact transmission
3. Droplet transmission
4. Faecal-oral transmission
5. Vector-borne transmission

The proportion of the population that is immune or has been immunised

The term "immunity" refers to the acquisition of body defences enabling the host to fight off invading pathogens and is covered in more detail in Chapter 2.8. When this term is applied to a population it is referred to as **herd immunity**, also known as herd protection or community immunity.

Herd immunity occurs when a significant portion of a population becomes immune to an infectious disease, **either through prior infection or vaccination**, reducing the likelihood of disease spread (see Figure 2.3.6). This protection is critical in safeguarding the community, as it limits the opportunities for the pathogen to find susceptible hosts, effectively controlling outbreaks. Herd immunity is particularly **important for protecting vulnerable individuals** who cannot be vaccinated or whose immune systems are compromised, such as:

- newborns
- the elderly
- individuals with autoimmune diseases
- cancer patients receiving chemotherapy
- pregnant women (due to temporary immune system suppression)
- individuals with HIV/AIDS

By breaking chains of transmission, herd immunity serves as a **collective defense**, ensuring the health and safety of the entire population.

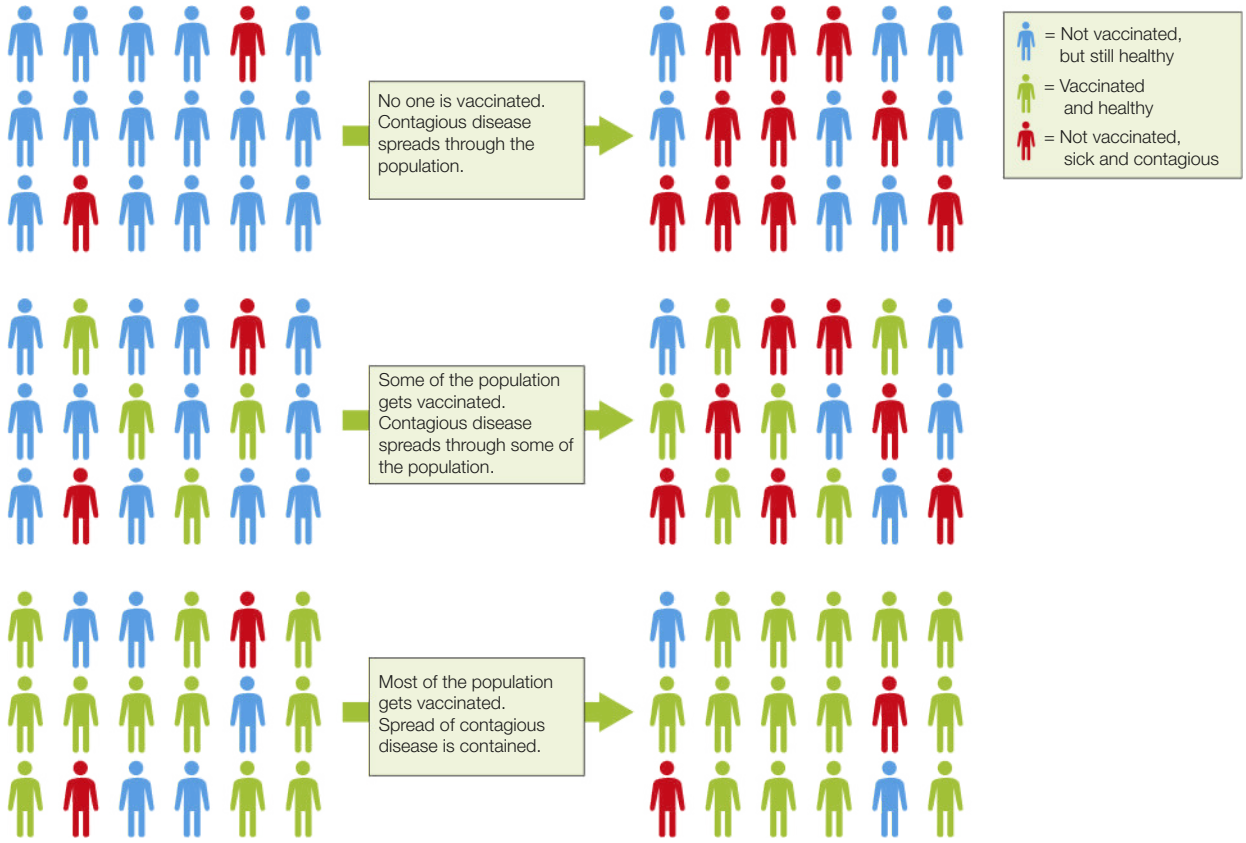


Figure 2.3.6: How herd immunity works to stop the spread of infectious diseases and protect communities.

Helpful online resources

Microbiology Society: What is Herd Immunity?

https://www.youtube.com/watch?v=cEn1PKyBUNc

Harvard Medical School: Herd Immunity Animation

https://www.health.harvard.edu/staying-healthy/herd-immunity-animation

Compulsory vaccination of children

The spread of infectious diseases in childcare settings is very common due to close physical contact among children, frequent sharing of toys, and underdeveloped hygiene practices among young children. These environments can therefore act as hotspots for transmission of infectious diseases. As a **vulnerable community**, vaccination of children is important to provide herd immunity and prevent unnecessary suffering, and developmental disorders associated with many pathogenic infections.

In Australia, the government enforces compulsory vaccination for children through policies that link vaccination to access to certain benefits and services. Under the "No Jab, No Pay" policy, parents who fail to vaccinate their children according to the National Immunisation Program schedule lose access to family tax benefits and childcare subsidies. Similarly, the "No Jab, No Play" policy, implemented in most states, restricts unvaccinated children from attending early childhood education unless they have a valid medical exemption. These measures aim to increase vaccination rates, protect public health, and **ensure herd immunity**, particularly to safeguard vulnerable populations, including young children, pregnant mothers and the elderly grandparents that may look after them.

Mobility of populations

Increased population mobility, through **international travel and migration** has significantly contributed to the spread of infectious diseases by enabling pathogens to quickly cross international borders, **often before symptoms appear in infected individuals**. Air travel has generally become cheaper and more accessible to humans, allowing for the rapid movement of people, facilitating the global spread of diseases such as COVID-19, influenza, and HIV/AIDS (see Figure 2.3.7). This increased mobility is making it harder to contain outbreaks and increases the potential for pandemics.

Furthermore, increased **urbanisation** contributes to the spread of infectious diseases by **creating densely populated environments** where close contact and poor sanitation can facilitate pathogen transmission. Overcrowded housing, inadequate waste management, and limited access to clean water in urban areas increase the risk of outbreaks, while **high mobility within cities further amplifies disease spread** (see Figure 2.3.3).

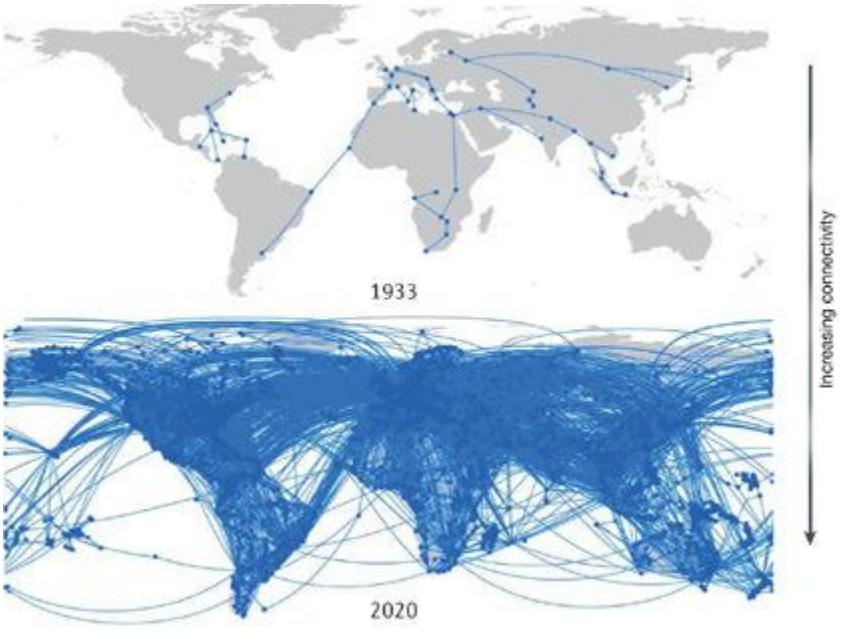


Figure 2.3.7: The global international air travel has increased significantly from 1933 to 2020 and with it, the spread of infectious diseases.

Intravenous drugs

The use of intravenous drugs, which are administered into veins, can increase the spread of some infectious diseases, mainly through the sharing of contaminated needles. This can facilitate the **transmission of bloodborne pathogens** like HIV and hepatitis B and C. Poor sterilisation practices and unsafe injection environments further exacerbate the risk. Additionally, the careless and irresponsible littering of used needles can spread infectious diseases to innocent individuals who encounter them through misfortune. For example, an individual walking barefoot at the beach who steps on a used needle.

Poor sanitation

Poor sanitation significantly increases the spread of infectious diseases by creating environments where pathogens can thrive and easily transmit. Contaminated water sources, improper waste disposal, and lack of hygiene facilities facilitate the **spread of waterborne diseases** like cholera and typhoid, as well as parasitic infections. **Poor sanitation also increases exposure to vectors**, such as flies and mosquitoes, which transmit diseases like malaria and dengue fever.

The spread of these diseases are more common in low income countries that do not have adequate access to fresh clean water. Wars, conflict and persecution of minority groups often create poor living conditions, such as refugee camps, and these poor sanitary conditions are ideal for the spread of infectious diseases.

Animal reservoirs

Animal reservoirs increase the spread of infectious diseases by serving as hosts for pathogens that can jump to humans in a process known as **zoonotic transmission**. Diseases like rabies, Ebola, and COVID-19 originate in animals and spread through direct contact, bites, or intermediate hosts. Poor management of wildlife, interactions with farming livestock, live animal markets and intensive wildlife farming amplify these risks. Additionally, urban expansion, that involves land clearance, can expose humans to new human-wildlife interactions which increases the opportunity for zoonotic transmission to occur (see Figure 2.3.8).

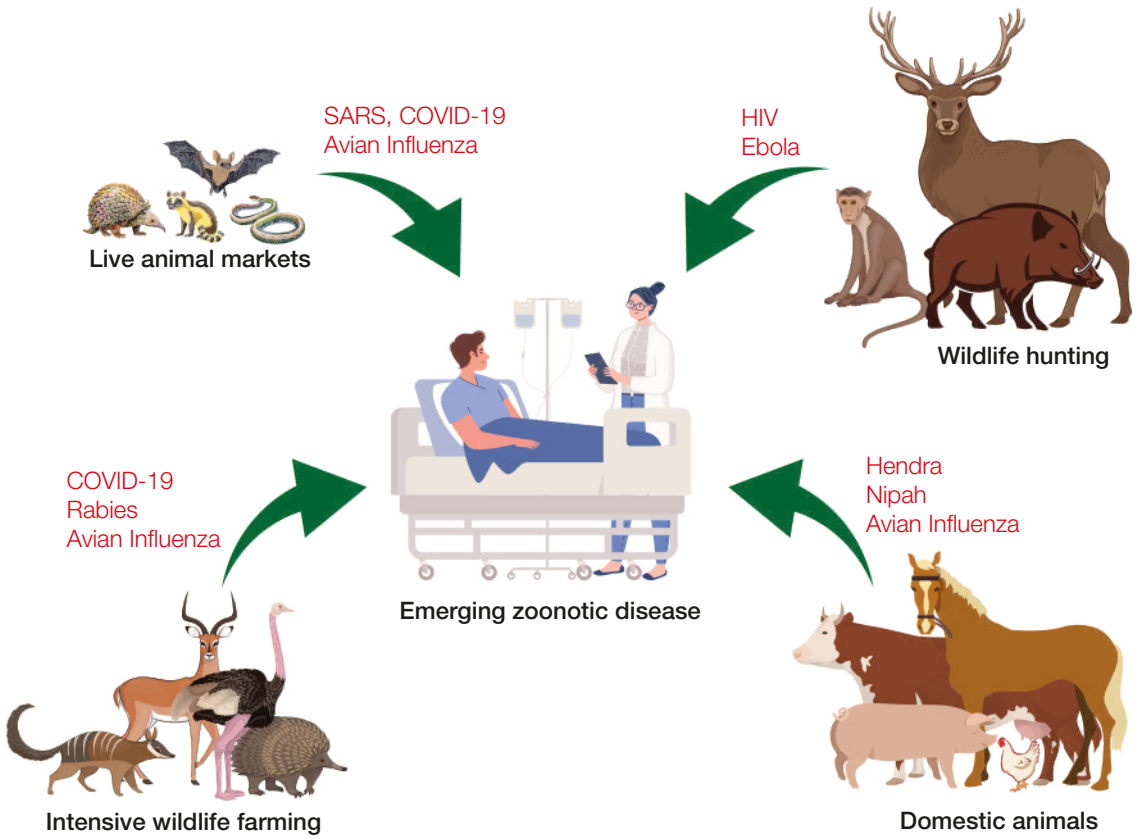


Figure 2.3.8: Some emerging zoonotic diseases and how humans are generally being exposed to them.

Flying foxes, also known as fruit bats, are an example of an animal reservoir for multiple pathogens that can spread to humans. Flying foxes can carry the rabies-like virus, Australian Bat Lyssavirus (ABLV) and Hendra Virus, both of which can be fatal to humans. In fact, **ABLV infections are almost always fatal in humans** with death occurring within 2 weeks of the onset of symptoms. These pathogens are generally spread through scratches and bites, and it is strongly advised against touching flying foxes, or any other type of bat, dead or alive, without being vaccinated and properly trained (see Figure 2.3.9).

Figure 2.3.9: The SA Health advice to prevent transmission of infectious diseases from bats and details of who to call if someone does see a bat on the ground so trained bat rescue teams can attend the site and remove it. The safe removal ensures other members of the public do not touch the bat and risk the spread of deadly infectious diseases.

2.3 Review questions

Multiple choice questions

1. An epidemic
   - J is when an infectious disease affects an extremely high proportion of the global population.
   - K is an outbreak of a disease that spreads rapidly affecting many individuals at the same time.
   - L is a disease that affects communities across multiple continents.
   - M generally requires a global response.
2. Which of the following options is the least likely to result in a new epidemic or pandemic occurring?
   - J The exposure of a pathogen to a community that previously has not been exposed.
   - K The reemergence of a pathogen in a community with low herd immunity to it.
   - L An exposure to wildlife containing a virus that cannot cross the species barrier.
   - M Mutations to an existing pathogen that result in a new strain that is more contagious.
3. The type of transmission that increases the spread of infectious disease the most is
   - J airborne transmission.
   - K vector borne transmission.
   - L indirect contact transmission.
   - M dust borne transmission.
4. Which of the following is **not** a vulnerable group to infectious diseases?
   - J cancer patients.
   - K pregnant women.
   - L the vaccinated.
   - M infants.
5. The persistence of a pathogen within a host
   - J maintains a reservoir of infection within a population.
   - K does not increase the chance of a pathogen to adapt to the host's immune system.
   - L reduces the chance of transmission occurring.
   - M always increases a pathogen's contagiousness.

6. Herd immunity is

   J a threshold that needs to be reached to increase the chance of an infectious disease being spread through a community.

   K when a sufficient proportion of individuals in a population are immune to a pathogen due to vaccination only.

   L the number of individuals naturally immune and unvaccinated in a population.

   M a point in time when it is hard for an infectious disease to spread through a community as enough individuals are immune to it.

7. Public transport within cities

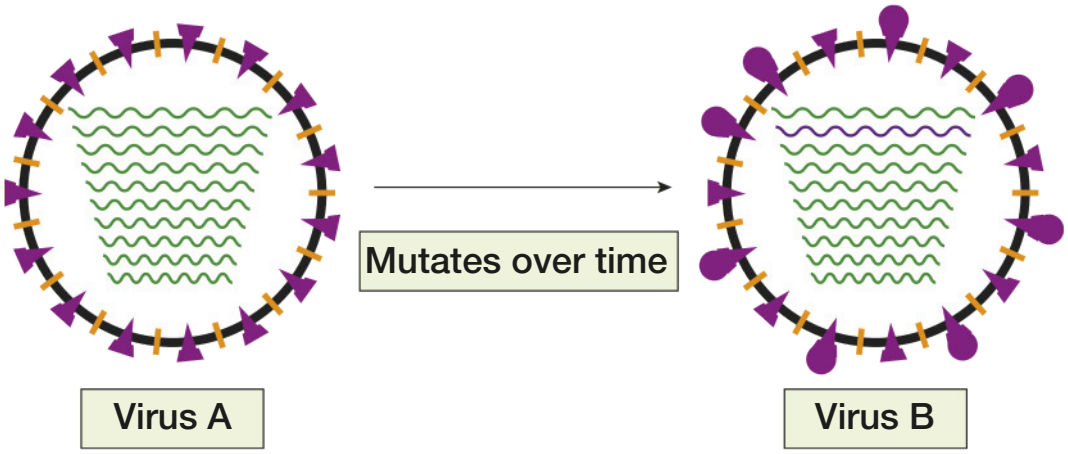
   J does not influence the spread of infectious disease.

   K can contribute to an increase in mobility and amplify the spread of disease.

   L increases the spread of disease between countries.

   M only influences the spread of disease if infected individuals are travelling and symptoms have not developed yet.

8. *Refer to the image below which shows the result of genetic mutations in a virus to answer the following question.*



   The mutations in this virus over time has

   J not resulted in any change to the virus.

   K resulted in the change in the shape of some surface proteins.

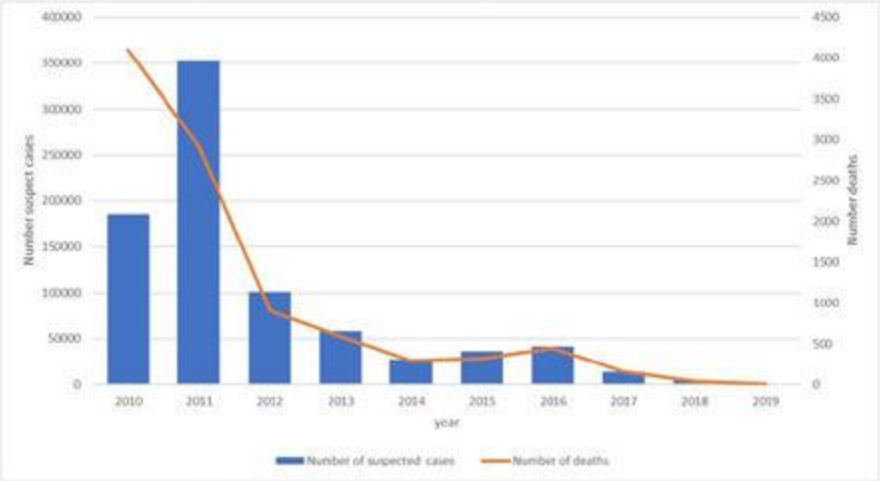
   L resulted in extra genetic code (DNA/RNA) in virus B.

   M only resulted in changes to the genetic code.

9. Which of the following options presents the interrelated factors that would have the highest chance of causing a new epidemic/pandemic.

	Type of transmission	Mutation rate of pathogen	Immunity of community	New or existing strain
J	Blood borne	High	Low	Existing
K	Airborne	Medium	High	Existing
L	Airborne	High	Low	New
M	Blood borne	Medium	High	New

10. *Refer to the graph below which shows the number of cholera cases and resultant deaths reported in Haiti between 2010 and 2019 to answer the following question.*



A conclusion based on the information in the graph is:

J Cholera is a waterborne disease.
K The number of suspected cases of cholera in Haiti continually decreased from 2010 to 2019.
L The number of deaths attributed to cholera decreased globally from 2010 to 2019.
M The highest number of suspected cases of cholera in Haiti occurred in 2011.

Free response questions

1. a) Describe the difference between an epidemic and a pandemic.

b) State **three** factors that could result in the development of an epidemic.

2. a) Outline **three** reasons why the Black Plague pandemic of the 14th century killed so many people.

b) Although there are occasional cases, explain why it is highly unlikely for another bubonic plague pandemic to occur this century.

3. Explain why diseases can spread more easily between continents today than they could in the early 1900s.

4. Cholera is a waterborne disease.

   a) State the most likely factor influencing the spread of cholera.

   b) Discuss why cholera is generally more of a concern for developing countries and not for most developed countries.

5. Discuss how urban expansion can result in pathogens crossing the species barrier.

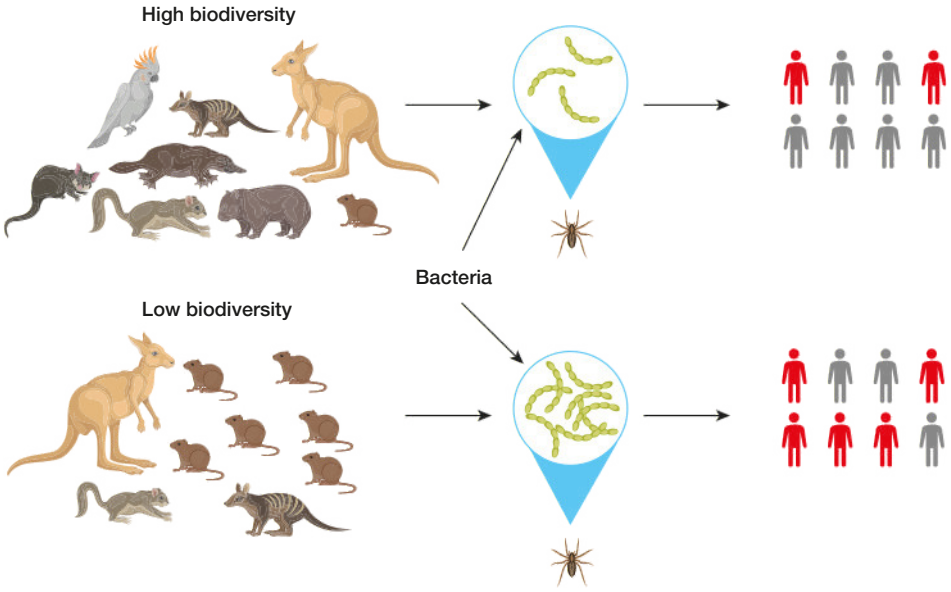
6. Discuss how genetic mutations can result in a pathogen becoming more contagious and/or more virulent.

7. *Refer to the image below which shows the spread of an infectious disease in two different populations (A and B) to answer the following question.*

   a) Identify **and** explain the factor that resulted in a decreased spread of this infectious disease in population B when compared to population A.

b) Other than a reduced spread of infectious disease, explain one other advantage the identified factor from part (a) can have for a community.

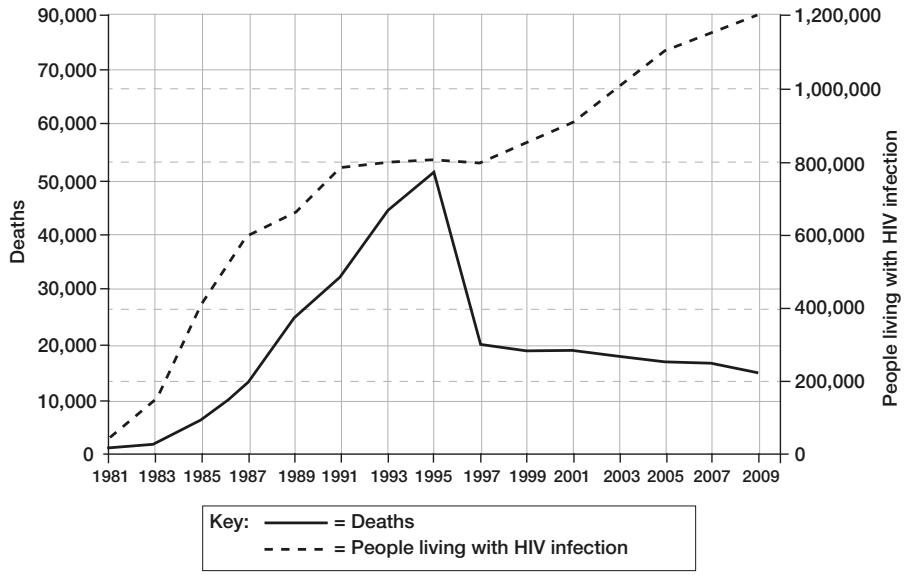
8. *Refer to the image below, which shows how biodiversity can influence the spread of infectious diseases to answer the following question.*



The bubonic plague can be spread by ticks that live on rodents such as rats.

Using the information in the diagram above, explain how the loss of biodiversity can impact the spread of this bacterial infectious disease to humans.

9. *Refer to the graph below which shows the number of people living with HIV and the number of deaths of individuals who are HIV positive between 1981 and 2009 to answer the following questions.*



a) State the main method of transmission of HIV.

b) Describe the shape of the two datasets presented in the graph.

c) Explain a likely reason for the observed trend in deaths of individuals who are HIV positive from 1995 onwards.

d) Explain a likely reason for the observed trend in the number of people living with HIV from 1995 onwards.

10. *Use your understanding of Science as A Human Endeavour and the information provided below to answer the following question.*

    Recently, we all experienced the COVID-19 pandemic. Unfortunately, there is always a threat of another pandemic occurring in the future.

    Discuss how the experience of the COVID-19 pandemic could influence society regarding future pandemics.

Chapter 2.4 Disease control

Science Understanding

Examples of disease control include:

- controlling the carriers (e.g. fleas, mosquitoes)
- killing the pathogen (e.g. antibiotics, antiseptics)
- quarantining carriers of the disease
- the immune response.

Controlling disease

Controlling infectious diseases requires a multifaceted approach that combines individual, community, and systemic measures to prevent or reduce their spread. **Vaccination programs**, such as those for measles and polio, play a vital role in building **herd immunity**. Proper hygiene practices, safe food and water handling, and public health interventions like **quarantine and contact tracing** are essential for managing outbreaks. For vector-borne diseases, such as malaria and dengue fever, control strategies include the use of insecticides, bed nets, and **environmental management to reduce breeding grounds for vectors like mosquitoes**. **Antibiotics** are critical in treating bacterial infections, while **antiseptics** help prevent infection by killing microorganisms on the skin and surfaces. The **Swiss Cheese Model** for infectious disease prevention illustrates how multiple layers of defence, each with its own limitations or "holes," work together to reduce the risk of outbreaks. These layers may include individual actions, such as wearing masks and maintaining social distance, alongside systemic measures like sustainable public health systems and effective communication (see Figure 2.4.1). **The core principle of this model is that all layers are important because no individual layer is perfect**. By integrating these diverse strategies, societies can effectively combat infectious diseases and limit their impact.

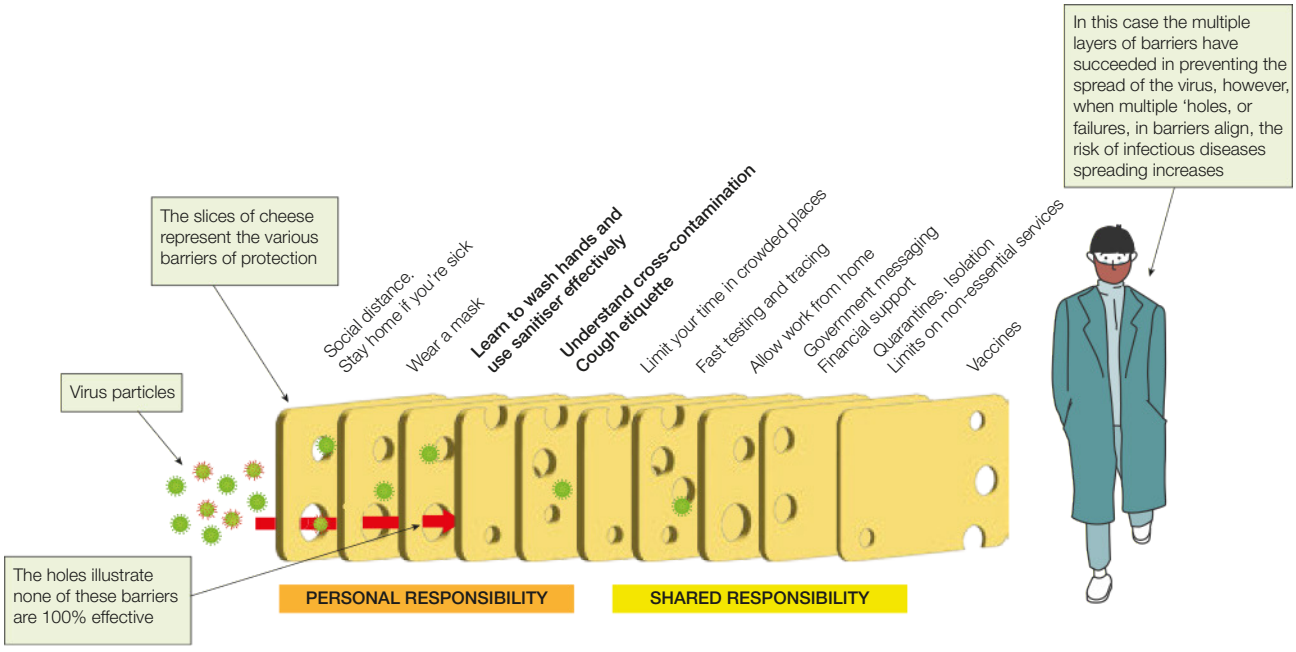


Figure 2.4.1: The Swiss Cheese Model for infectious disease shows that multiple layers, or barriers, work together to combat infectious diseases and limit their impact.

Examples of disease control

Controlling or killing vectors

Vector-borne infectious diseases can be controlled by targeting vectors, such as mosquitoes and fleas, that transmit pathogens to humans. Controlling or killing these vectors **disrupts the transmission cycle of diseases they spread**, such as malaria, dengue fever, Zika virus, and bubonic plague (see Table 2.4.1).

Table 2.4.1: Some examples of vector-borne diseases and their respective vectors.

Vector	Pathogen	Disease
Mosquito	Plasmodium protozoan (type of protist)	Malaria
Mosquito	Zika virus	Zika virus infection
Mosquito	Dengue virus	Dengue fever
Flea	*Yersinia pestis* (plague bacteria)	Bubonic plague
Monkey, fox or dog	Rabies virus	Rabies

There are a range of methods that can be used to control the number of vectors that transmit infectious diseases, including physical barriers, biological controls, chemical controls and environmental management strategies (see Table 2.4.2 for more information). By combining these methods, the spread of vector-borne diseases can be effectively reduced, improving public health and reducing the burden of these diseases on communities.

Table 2.4.2: Some methods that can control and/or kill vectors that carry infectious diseases.

Control method	Example	Description(s)
Environmental management	Removing breeding grounds	Eliminating stagnant water, such as in containers, drains, or tyres, prevents mosquito populations from multiplying (see Figure 2.4.2).
	Improved sanitation	Keeping environments clean and storing food properly reduces conditions favorable for rats, fleas and other pests.
Chemical control	Insecticides	Spraying insecticides, which are chemicals that kill insects, such as DDT, can kill adult mosquitoes or fleas.
	Insect repellant	These are generally available over the counter and contain chemicals like DEET that ward off vectors such as mosquitoes, fleas and ticks.
Physical barriers	Bed nets	Using insecticide-treated bed nets helps prevent mosquito bites while sleeping.
	Protective clothing	Wearing long sleeves and pants reduces skin exposure to bites.
	Traps	Manual rat traps can kill rats. Similarly, there are a range of mosquito traps available that can kill mosquitoes and other flying insects.
	Layer of paraffin oil or domestic kerosene	A water surface barrier, such as paraffin oil, can prevent mosquito larvae from being able to attach to the surface of the water and breathe. This can be applied to rainwater tanks if they become compromised as mosquitoes use them as breeding grounds.
Genetic control	Sterile Insect Technique (SIT)	Producing and releasing sterilised male mosquitoes reduces the reproduction rates and therefore mosquito population size (see Figure 2.4.3).
Biological control	Natural predators	Introducing fish or other organisms that feed on mosquito larvae.

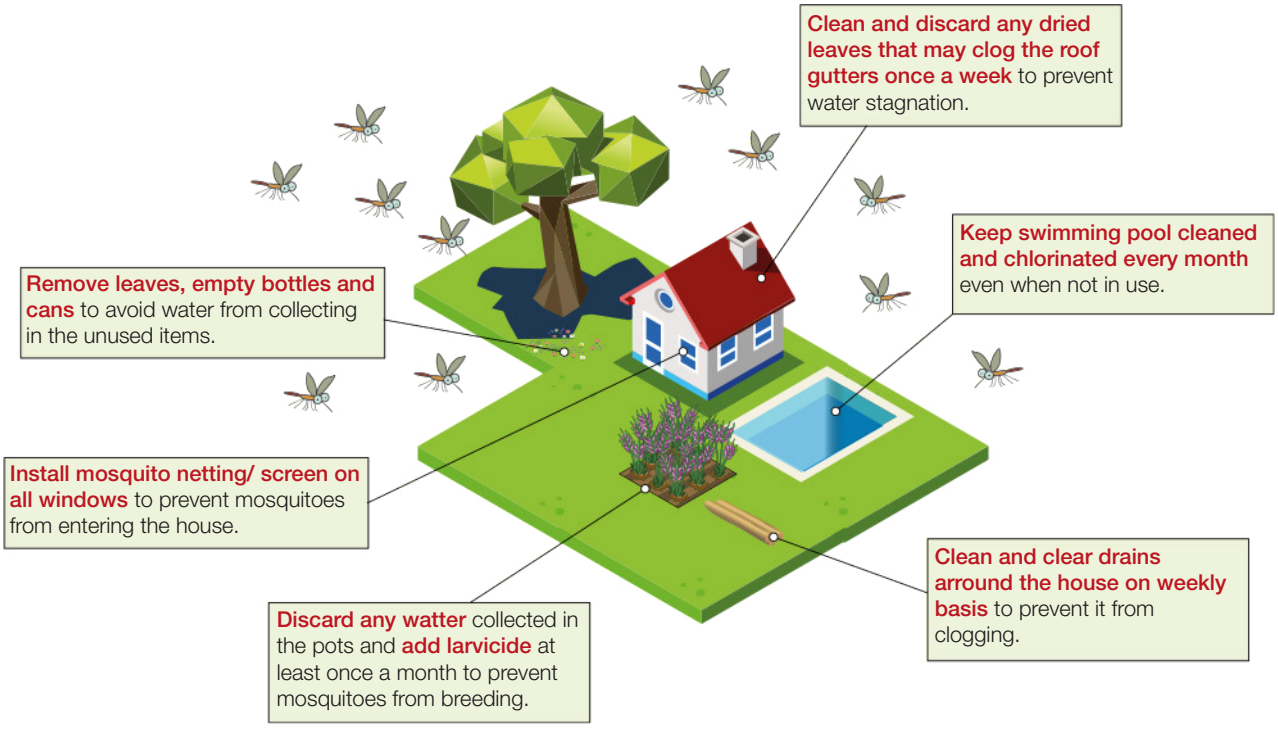


Figure 2.4.2: Some control methods that can be implemented at home to reduce the breeding grounds of mosquitoes.

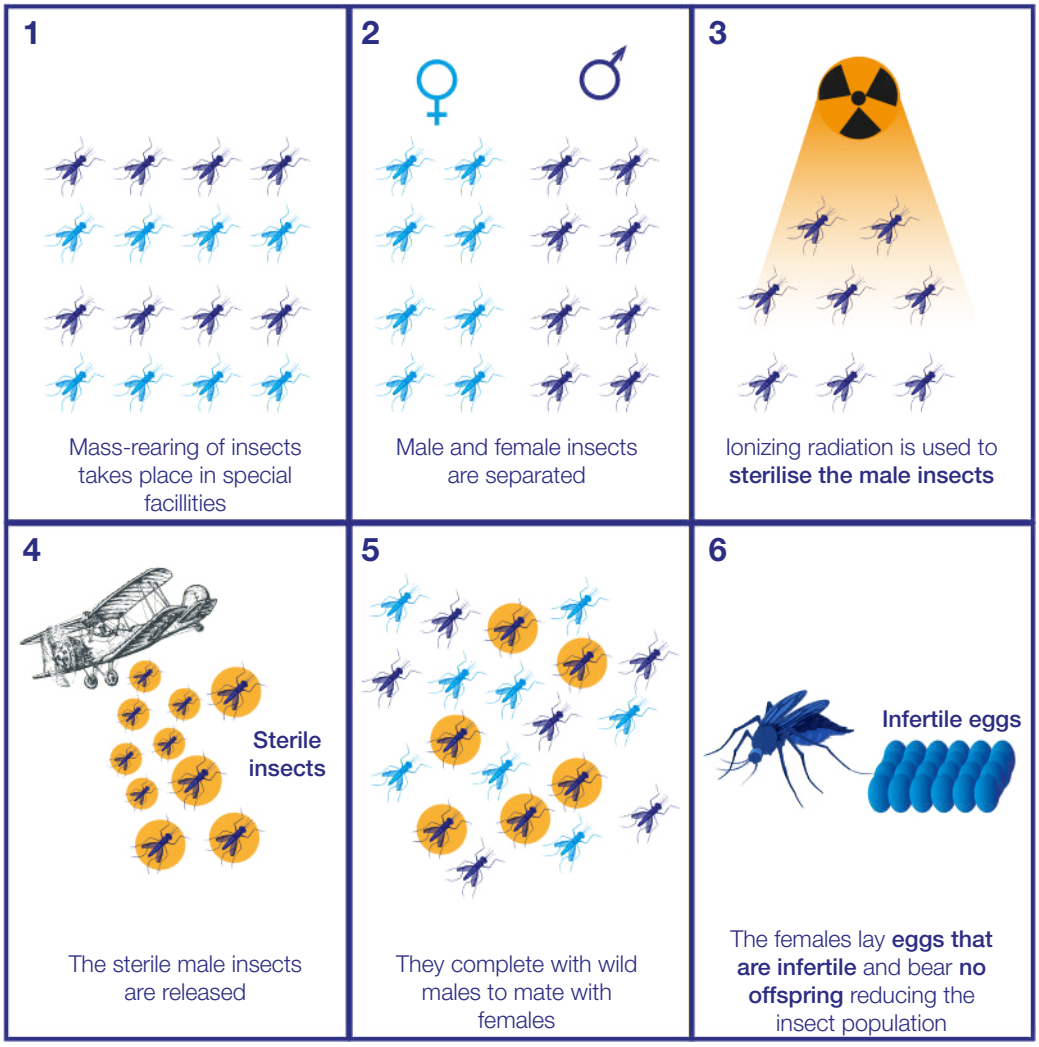


Figure 2.4.3: An overview of the Sterile Insect Technique (SIT) process.

Helpful online resources

Department of Health Victoria: Mosquito borne diseases and surveillance

https://www.youtube.com/watch?v=ecGoD2EUTO0

AsapSCIENCE: What If We Killed Every Mosquito On Earth?

https://www.youtube.com/watch?v=LIYEhcOn0a4

Killing pathogens

Antibiotics

Antibiotics are classified as chemicals produced by microorganisms, such as bacteria and fungi, that either **kill bacteria** (bactericidal) **or slow the growth and division of bacteria** (bacteriostatic), which allows the immune system to overcome the infection more easily. The first antibiotic, penicillin, was discovered by Alexander Fleming in 1928. This was a chance discovery made when Fleming noticed that some of the bacteria he was culturing were destroyed by a naturally occurring penicillium mould. This penicillium fungus produces the antibiotic penicillin as a means of competing with bacteria for resources. Penicillin acts by inhibiting the synthesis of bacterial cell walls (see Figure 2.4.4) allowing the fungus to outcompete bacteria.

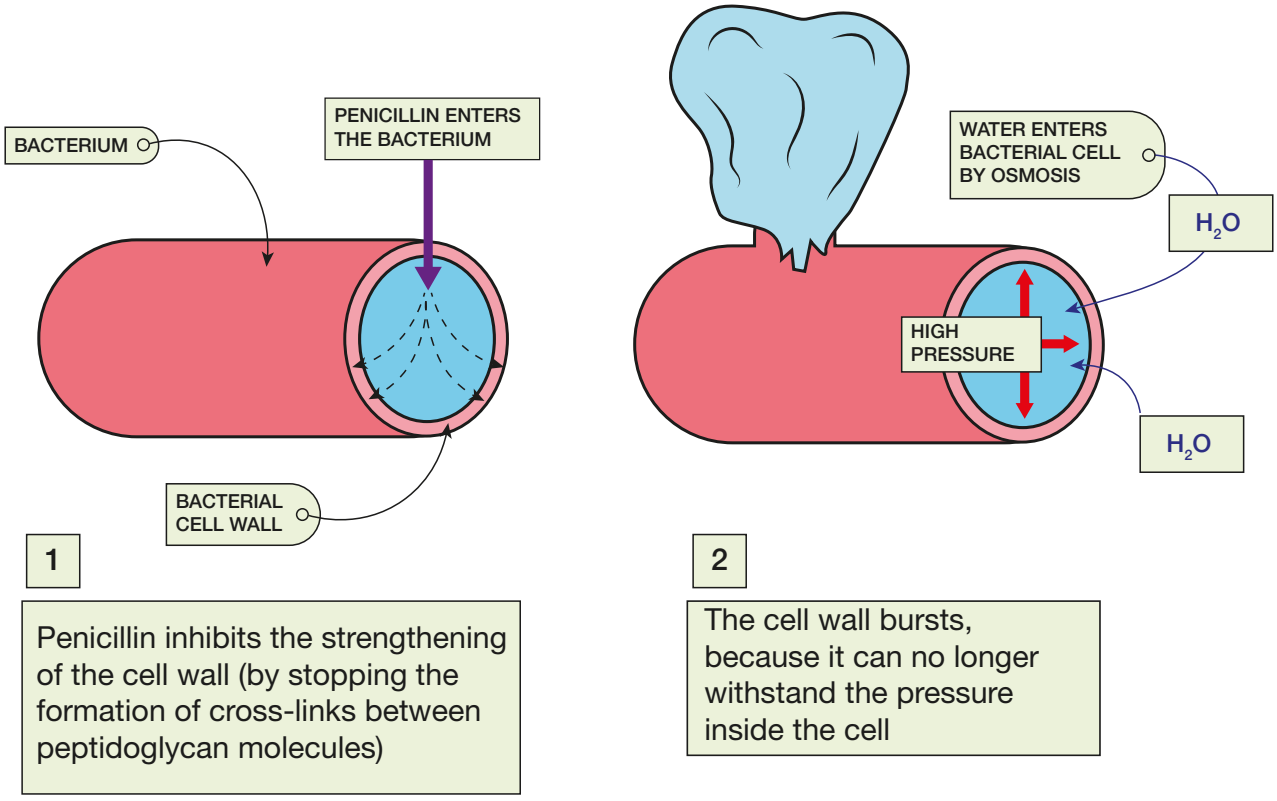


Figure 2.4.4: An overview of how penicillin kills susceptible bacteria.

Sulfonamides, also called **sulfa drugs**, were the first effective chemical treatments for a range of different bacterial infections. They are not considered antibiotics because they are synthetic (man-made) antibacterial agents and not produced by other microorganisms. They were first observed in 1932 and widely used during World War II, but as penicillin became more available through mass-production in the 1940s, sulfa drug use declined. This was because sulfa drugs commonly caused some side effects, whereas side effects from penicillin were much less common. In contrast to penicillin, which kills bacteria, sulfa drugs do not kill bacteria, but rather inhibit their growth and division. They act by interfering with the synthesis of **folate** (vitamin B9), which is **essential for the synthesis of DNA** and therefore cell division. Sulfa drugs and penicillin significantly reduced mortality rates from bacterial diseases (see Figure 2.4.5). The introduction of sulfonamides in the 1930s and penicillin in the 1940s marked pivotal moments in the history of medicine, revolutionising the treatment of bacterial infections.

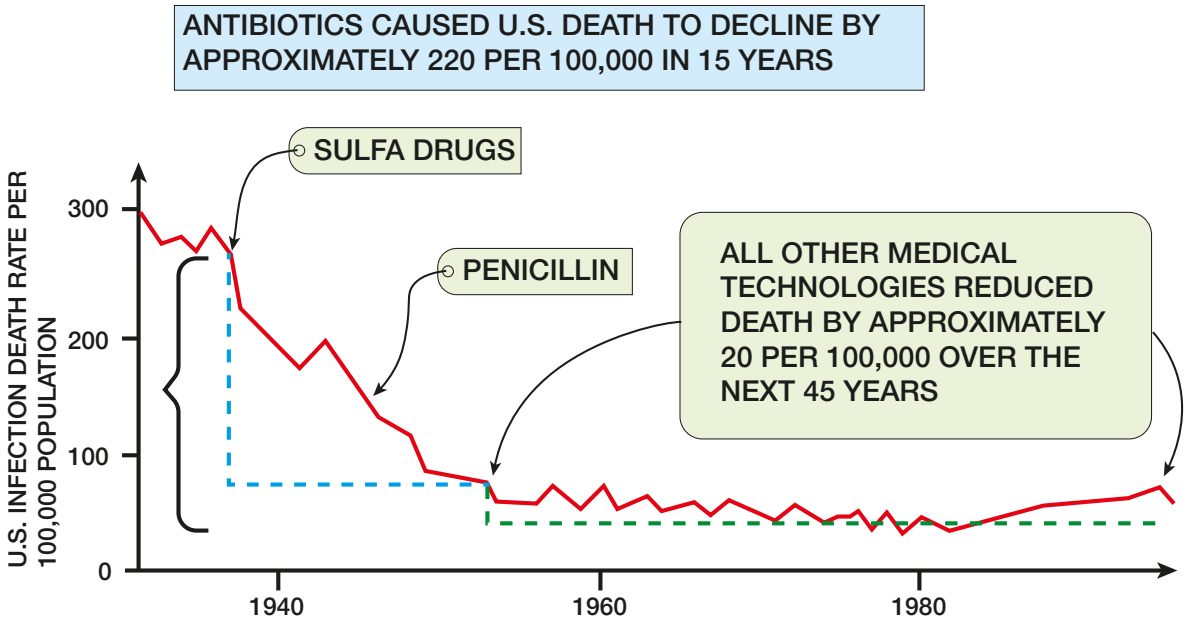


Figure 2.4.5: The introduction of sulfa drugs and antibiotics in the 1930s and 1940s has had one of the largest impacts on global health and the control of infectious disease, highlighted by this example in the USA.

Since the discovery of penicillin, many more antibiotics have been discovered and used to treat bacterial infections. There are generally five mechanisms of action by which antibiotics bring about their antibacterial effects (see Table 2.4.3 for more information).

Table 2.4.3: The five main antibiotic mechanisms of action.

Mechanism of action	Example(s) of antibiotic	Description
Inhibits synthesis of bacterial cell walls	Penicillin, vancomycin	Inhibit the strengthening of bacterial cell walls which results in their death through the cell bursting as it can no longer hold the contents of the cell (see Figure 2.4.4).
Inhibits bacterial protein synthesis	Tetracycline, chloramphenicol	Bacteria have smaller ribosomes to humans. These antibiotics inhibit the bacterial ribosomes from making proteins but do not interfere with human ribosomes.
Inhibits bacterial DNA synthesis	Quinolones	These antibiotics kill bacteria by inhibiting DNA synthesis resulting in DNA damage and bacterial death. They also inhibit the division of bacteria as DNA synthesis is required for binary fission.
Inhibits RNA synthesis	Rifampin	Bacteria require RNA molecules to produce proteins essential to their survival. This slows their growth, inhibits their ability to divide and results in their death.
Inhibits the synthesis of folate	Trimethoprim	Folate (vitamin B9) is essential for the synthesis of DNA and therefore cell division. These antibiotics do not kill bacteria but prevent them from dividing allowing the host's immune system to fight the infection more easily.

Helpful online resources

TED-Ed: The accident that changed the world–Allison Ramsey and Mary Staicu

https://www.youtube.com/watch?v=CNbnLgetqHs

Antibiotic resistance and superbugs

Bacteria's **rapid reproduction rates** allow them to quickly adapt to changing conditions, such as the selective pressure of antibiotics. In optimum conditions, bacteria can divide every 20 minutes, which results in more than 1 billion bacteria in 10 hours (2^{30} bacteria). As DNA must be synthesised prior to every division, there is an increased chance of **random mutations** (changes to the genetic code) occurring with such a high reproductive rate. This often occurs naturally through mistakes made in the synthesis of new DNA. The genetic mutation(s) can result in changes to physical structures (proteins) within bacteria, such as the shape of a recognition protein or enzyme being targeted by the antibiotic. In some cases, these mutations can **confer resistance to antibiotics**, allowing bacteria to resist their effects. These antibiotic resistant bacteria can then reproduce by binary fission spreading the resistance to their offspring, also known as vertical gene transfer (see Figure 2.4.6). Bacteria can also spread resistance to other bacteria through the process of conjugation (horizontal gene transfer) where a single strand of the genetic code containing the resistance gene(s) is donated (see Figure 2.4.6).

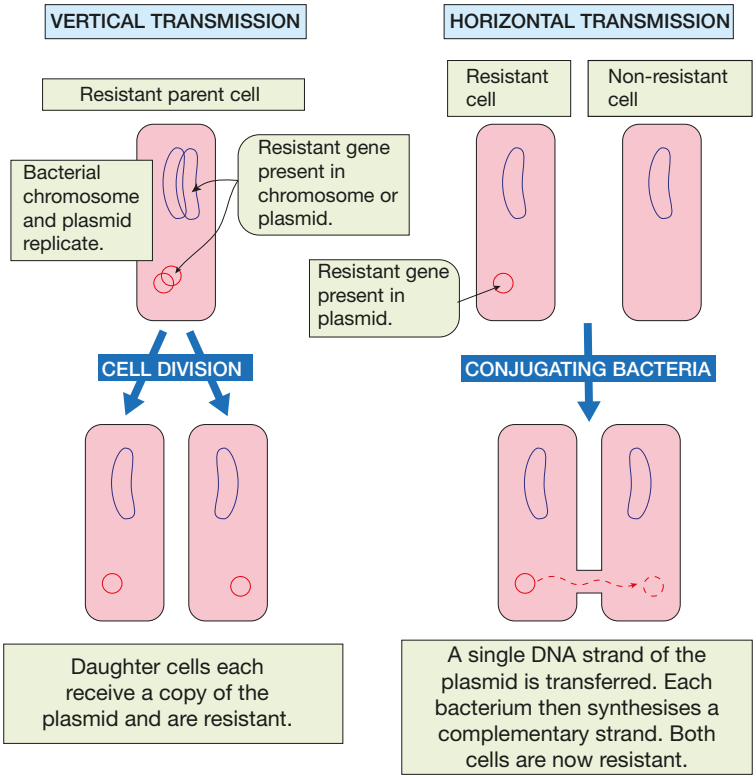


Figure 2.4.6: Bacteria containing antibiotic resistant genes can spread the resistance through vertical and horizontal transmission processes further accelerating the resistance.

Bacteria have adapted to the selection pressures of antibiotics through a range of adaptations such as altering targets of antibiotics, producing enzymes that deactivate the drugs, or improving mechanisms to expel the drugs from their cells (see Figure 2.4.7). Bacteria that develop resistance to several antibiotics are called **superbugs**, such as *Methicillin-resistant Staphylococcus aureus* (MRSA). Some bacterial strains have developed resistance to all typical antibiotic treatments, which are increasingly difficult to treat and pose a major threat to global health, such as super-gonorrhoea.

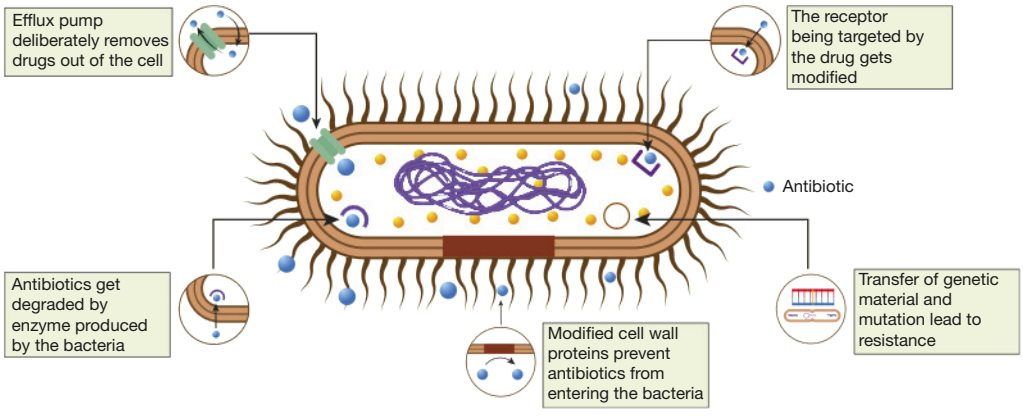


Figure 2.4.7: Some mechanisms that bacteria have developed to resist the effects of antibiotics.

The **misuse and overuse of antibiotics** have significantly contributed to the rise of antibiotic resistance and the emergence of superbugs. Over-prescription, inappropriate use (such as for viral infections), and the widespread use of antibiotics in agriculture create environments where bacteria are frequently exposed to these drugs. This selective pressure favours the survival of resistant strains, which then multiply and spread resistance. Additionally, the lack of education on antibiotic use and bacterial resistance further propagates the misuse and overuse of antibiotics. For example, a World Health Organisation study surveying over 10,000 individuals across 12 countries revealed that 64% of respondents believed antibiotics work effectively to treat common colds and influenza, both viral infections, even though **antibiotics have no effect on viruses**.

As multi-resistant bacterial infections, or superbugs, are becoming more common, typical antibiotic treatments that once used to combat these infections are no longer effective. When required, patients that contract these resistant and hard to treat infections can have samples taken and sent to laboratories to confirm what antibiotic, if any, is effective against it. This involves scientists culturing the bacteria from the sample and applying a range of different antibiotics to the culture (see Figure 2.4.8). Individuals may have to rely on their immune system to combat the infection until an effective antibiotic against the specific strain can be determined as the results can take a couple of days to be confirmed.

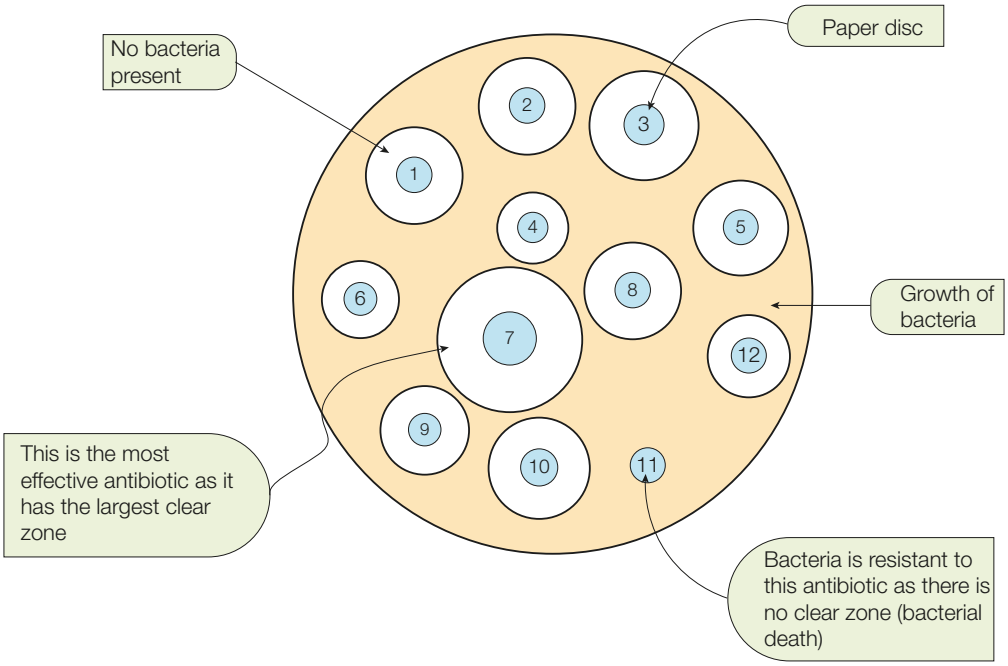


Figure 2.4.8: The effect of 12 different antibiotics on the growth of one bacterial strain on an agar plate. The bacteria are spread across the agar plate and then the discs coated with the different antibiotics are placed on top. After 24-48 hours of culturing, the discs that have the largest zones of inhibition are the most effective to use against this bacterial strain.

Helpful online resources

Kurzgesagt – In a Nutshell: The Antibiotic Apocalypse Explained

https://www.youtube.com/watch?v=xZbcwi7SfZE

Antiseptics

Antiseptics are **chemical agents applied to living tissues**, such as skin or mucous membranes, to kill or inhibit the growth of microorganisms and prevent infection. Unlike antibiotics, which are typically taken internally or applied locally to target infections within the body, **antiseptics are used externally and have a broad spectrum of activity against bacteria, viruses, and fungi**. They work by disrupting microbial membranes, denaturing proteins, or oxidising cellular components, thereby killing pathogens and preventing their reproduction. Antiseptics are essential for controlling the spread of infectious diseases by sterilising wounds and surgical sites and reducing pathogen transmission through products like hand sanitisers and iodine-based products such as Betadine.

Disinfectants

Disinfectants are **chemical agents used to kill or inactivate microorganisms on non-living surfaces**, such as floors, countertops, and medical equipment, to reduce the risk of infection. Unlike antiseptics, which are safe for application on living tissues, **disinfectants are harsher and designed solely for surfaces**. They work by disrupting microbial cell walls, denaturing proteins, or oxidising cellular components, effectively destroying bacteria, viruses, and fungi. Disinfectants play a critical role in controlling the spread of infectious diseases by sterilising contaminated surfaces, breaking transmission chains in healthcare settings, public spaces, and households.

Quarantine

Quarantining controls the spread of infectious diseases by **isolating individuals who are infected, exposed, or potentially exposed to a contagious pathogen**. This separation prevents the transmission of the disease to healthy individuals, particularly in the early stages of an outbreak when the risk of spread is highest. Quarantine measures can be applied at various levels, from isolating individuals in their homes to restricting movement in entire communities or regions. By limiting contact between infected and uninfected populations, quarantining reduces the rate of new infections, allowing healthcare systems to manage cases more effectively and giving public health officials time to implement broader containment strategies, such as contact tracing and vaccination campaigns.

Contact tracing

Contact tracing helps control the spread of infectious diseases by **identifying individuals who have been in close contact with an infected person** and taking steps to prevent further transmission (see Figure 2.4.9). This involves interviewing the infected individual to determine their recent contacts, notifying those contacts about their potential exposure, and advising them on appropriate actions, such as testing, monitoring for symptoms, or quarantining. By breaking the chain of transmission early, contact tracing reduces the spread of disease, particularly in outbreaks of highly contagious infections like COVID-19 or measles. It is an essential public health tool, often used alongside other measures like testing and isolation, to contain outbreaks and protect communities.

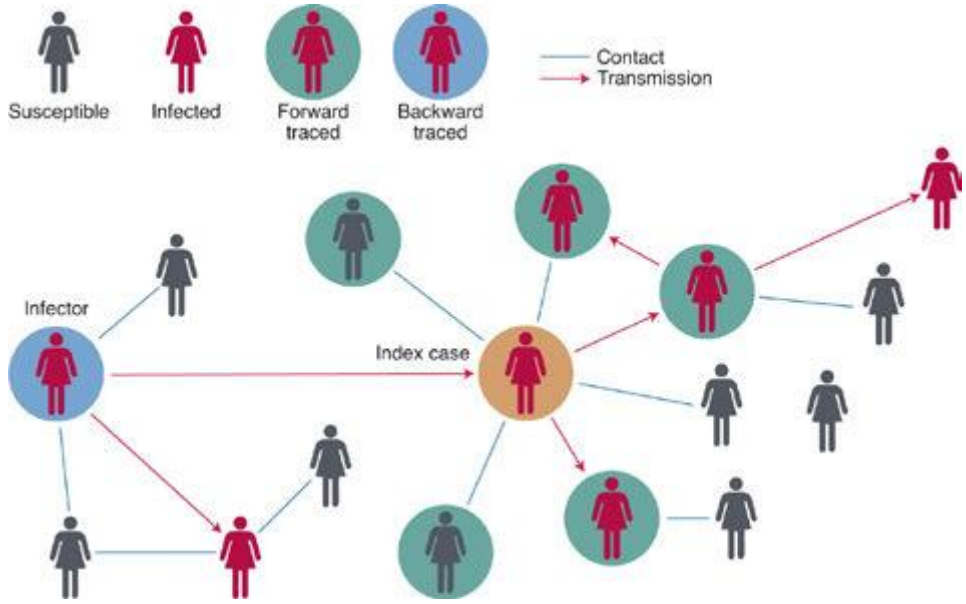


Figure 2.4.9: A simple model of how contact tracing works.

The immune response

The immune response is the body's natural defense mechanism against harmful pathogens like bacteria, viruses, and fungi. It involves recognising foreign invaders, neutralising them, and building a **memory** to respond more effectively if exposed again. **Vaccinations** harness this process by artificially introducing harmless components of a pathogen, prompting the immune system to develop immunity **without causing illness**. The innate and adaptive immune responses are covered in more detail in Chapters 2.6 to 2.8 but the concept of vaccinations is covered below as **widespread vaccination helps control the spread of infectious disease**.

Vaccinations

Vaccinations are medical interventions that induce **artificially acquired active immunity** by stimulating the immune system to recognise and fight specific infectious diseases without causing the illness. They work by introducing a harmless component of a pathogen, such as an inactivated virus, weakened bacteria, or a protein fragment, which triggers the body to **produce specific antibodies and memory cells**. These immune responses

prepare the body to quickly and effectively combat the actual pathogen if exposed in the future. Vaccinations control the spread of infectious diseases by reducing the number of susceptible individuals in a population, thereby achieving herd immunity, which protects even those who cannot be vaccinated. They have been instrumental in reducing and eradicating diseases like smallpox, polio, and measles globally.

Vaccination misconceptions

Misconceptions about vaccinations persist in some communities, often fuelled by misinformation and mistrust. One major contributor was Andrew Wakefield's **fraudulent 1998 study**, which falsely linked the MMR (measles, mumps, rubella) vaccine to autism. This study, published in *The Lancet*, was later discredited and retracted due to ethical violations, conflicts of interest, and manipulated data, leading to Wakefield losing his medical license. Furthermore, hundreds of different studies following the 1998 study have not found any credible link between the MMR vaccine and autism, wasting significant amounts of time, money and resources that could have been spent researching other medical issues. Despite being debunked, his claims sparked widespread fear and vaccine hesitancy, contributing to outbreaks of preventable diseases like measles and the needless suffering of many who caught preventable infectious diseases.

Other misconceptions include beliefs that vaccines weaken the immune system or contain harmful substances. Combating these myths requires clear communication from trusted health authorities and education about the safety and effectiveness of vaccines (see the Helpful online resources below for more information).

Helpful online resources

Kurzgesagt – In a Nutshell: The Side Effects of Vaccines – How High is the Risk?

https://www.youtube.com/watch?v=zBkVCpbNnkU

TED-Ed: How we conquered the deadly smallpox virus – Simona Zompi

https://www.youtube.com/watch?v=yqUFy-t4MIQ

Kurzgesagt – In a Nutshell: Measles Explained — Vaccinate or Not?

https://www.youtube.com/watch?v=y0opgc1WoS4

2.4 Review questions

Multiple choice questions

1. Which of the following options is **not** an effective control against the spread of infectious disease?

   J Vaccination programs
   K The use of disinfectants
   L Conferring antibiotic resistance
   M Quarantining infected individuals

2. Which of the following options is **not** a physical barrier that reduces the risk of infectious disease transmission through a vector?

   J Bed nets
   K Rat traps
   L Clothing
   M Insecticides

3. When managing the household environment to remove breeding grounds for mosquitos, leaves should regularly be removed from the gutters because

   J mosquito larvae require leaves as nutrition.
   K this is an effective example of chemically controlling mosquito populations.
   L it prevents water stagnation.
   M leaves inhibit the mosquito life cycle.

4. Disinfectants are

   J chemical agents used to kill pathogens on living tissues.
   K oral medications that can be consumed to treat bacterial infections but is not effective to treat other pathogenic infections.
   L chemical agents used to kill pathogens on non-living surfaces.
   M commonly used as a key ingredient in vaccinations.

5. Widespread vaccination

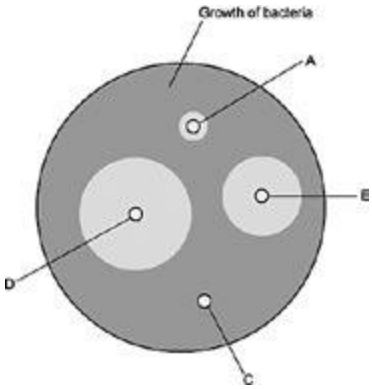
   J can kill bacteria by inhibiting protein synthesis.
   K can help control the spread of infectious disease.
   L always uses live pathogens to induce the immune response.
   M increases antibiotic resistance.

6. Select the option below that correctly identifies which pathogens can be effectively treated with antibiotics.

	Bubonic plague	Malaria	Staphylococcus aureus	Zika virus
J	No	No	Yes	Yes
K	Yes	Yes	No	Yes
L	Yes	No	Yes	No
M	No	Yes	No	No

7. *Refer to the image to the right showing the results of an antibiotic sensitivity test on bacteria isolated from a patients throat to answer the following question.*

   Which of the four antibiotics tested (A -D) should be used to treat this infection?



   J A
   K B
   L C
   M D

8. Quarantining

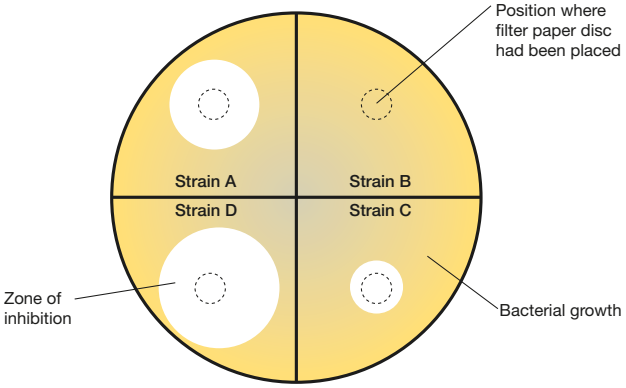
   J helps to identify individuals who have been in close contact with an infected individual.
   K isolates infected individuals with non-infected individuals.
   L helps to ease the burden on healthcare systems by reducing transmission.
   M is the use of aseptic techniques to ensure no microbial growth can occur on surfaces.

9. Penicillin is an antibiotic that was a typical treatment option for gonorrhoea infections worldwide, but it is now much less effective.

   Which of the following options is the most likely explanation for this?

   J The number of individuals infected with resistant strains has increased.
   K Antibiotics do not work on viruses.
   L Penicillin is resistant to gonorrhoea.
   M The rapid reproduction rate of penicillin fuels random mutations that can confer resistance to gonorrhoea.

10. *Refer to the image below which shows the results of an experiment aiming to test the effectiveness of an antibiotic on four bacterial strains (A to D) to answer the following question.*



An appropriate observation from the results of this experiment is

J strain A is the most resistant to this antibiotic due to the large zone of inhibition.
K strain B is the most sensitive to this antibiotic due to its lack of zone of inhibition.
L this antibiotic would not be recommended to treat strain C but would be recommended to treat strain D.
M strain D is the most sensitive to this antibiotic due to its lack of zone of inhibition.

Free response questions

1. Describe how the Swiss Cheese Model for infectious disease prevention works.

2. Outline **two** chemical control strategies that can reduce malaria transmission.

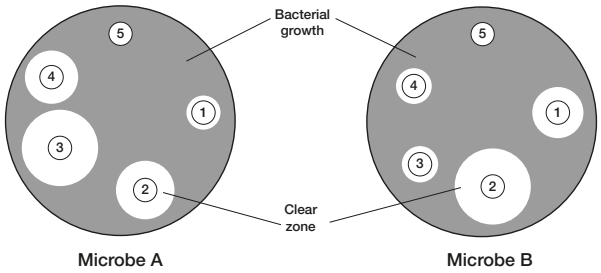
3. Describe how the Sterile Insect Technique (SIT) can control the spread of vector-borne infections.

4. Describe the difference between an antiseptic and a disinfectant **and** give an example of each.

5. Explain the difference between quarantining and contact tracing.

6. Explain why displaced populations are more vulnerable to infectious disease.

7. An investigation was conducted to determine to sensitivity of two species of a microorganism (A and B) to different types of antibiotics. After spreading the two microorganisms onto two different agar plates, five discs were applied to each plate. Discs 1 to 4 were coated with different antibiotics and disc 5 was coated in distilled water only. Both plates were then incubated at 37°C for 36 hours. The results are shown in the image below.



a) Describe what an antibiotic is.

b) (i) State the type of microorganism this investigation was conducted on.

(ii) Justify your answer using evidence from the results.

c) Identify which microorganism (A or B) would be the most concerning to the scientists **and** explain why.

d) Describe **two** different ways that antibiotics work to combat infections.

e) Explain why disc 5, which was soaked in water was used as part of this investigation.

f) (i) Identify **two** variables that were controlled in this investigation.

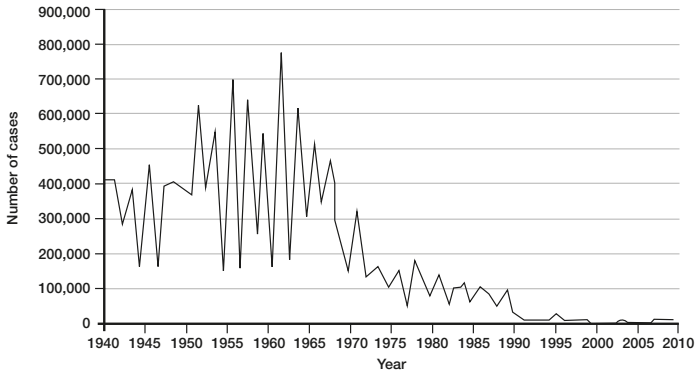
(ii) Explain why it was important to control the two variables identified in part (f)(i).

Use your understanding of Science as a Human Endeavour (SHE) to answer the following question.

Scientists have recently discovered that the use of antidepressants containing fluoxetine is contributing to antibiotic resistance. The reason for this is that fluoxetine can be excreted in the urine and pass into wastewater where it affects bacteria by causing oxidative stress, resulting in genetic mutations.

g) Using one or more concepts of SHE, discuss how this discovery highlights the interaction between science and society.

8. *Refer to the graph below which shows the number of measles cases in England and Wales between 1940 and 2010 to answer the following questions.*



a) Describe the trend observed between 1940 and 1968.

b) Describe the trend observed between 1968 and 2010.

The measles vaccine was introduced in 1968.

c) Explain how widespread vaccination helps to control the spread of infections like measles.

Unfortunately, measles has not been fully eradicated and outbreaks are becoming more common.

d) Discuss **two** reasons why measles has not been fully eradicated.

Chapter 2.5 Adaptations of pathogens

Science Understanding

Define the term 'antigen'.

Compare foreign antigens (non-self) with 'self' antigens.

Pathogens have adaptations that facilitate their entry into the cells and tissues of hosts.

- Describe how pathogens and host cells recognise each other.
- Explain that some pathogens enter cells to survive and reproduce.
- Describe the basic concept of molecular recognition (e.g. pathogens binding to cellular receptors).
- Explain that some pathogens must enter cells to ensure their survival, replication, and to evade the immune system.

To cause disease all pathogens must **colonise their specific host, avoid immune systems, multiply and then be able to spread** themselves to other hosts. The ability of a pathogen to do this can depend on the **adaptations** they have developed that impact its contagiousness, pathogenicity and/or virulence. **Contagiousness** refers to how easily a pathogen spreads, whereas pathogenicity and virulence both focus on a pathogen's ability to cause disease. **Pathogenicity is a qualitative measure** to determine if a microorganism can infect a host and cause disease (i.e. yes or no), whereas **virulence is a quantitative measure** of pathogenicity that indicates the degree of damage, or severity of symptoms, a pathogen can cause.

Some pathogens can be highly contagious and have a low virulence, such as the common cold viruses. As the host experiences few symptoms and can often continue with their daily life, the host can facilitate the spread of virus through airborne, droplet and direct/indirect contact transmission routes. Alternatively, some viruses are not very contagious but have a high virulence, such as some strains of the Ebola virus which has an average human fatality rate of 50%. Ebola is only transmitted through direct contact with body fluids of an infected individual or animal. Pathogens that are highly virulent and kill their hosts readily can reduce their ability to survive, reproduce and infect additional hosts.

Portals of entry

Humans are vulnerable to penetration and infection by pathogens through four main portals of entry: the skin, respiratory tract, gastrointestinal tract, and urogenital tract (see Table 2.5.1).

Table 2.5.1: Some general information about the four main portals of entry for pathogens.

Portal of entry	Description
Skin	The skin is generally a strong barrier, but some well adapted pathogens can enter through cuts, wounds, insect bites, or direct penetration.
Respiratory tract	Inhalation of airborne pathogens allows entry via the nose, throat, and lungs.
Gastrointestinal tract	Pathogens can enter through contaminated food or water, infecting the stomach and intestines.
Urogenital tract	Entry occurs through the urethra or genital openings, often during sexual contact or due to improper hygiene.

Molecular recognition

Molecular recognition is the process by which molecules, such as proteins, **interact and bind to specific target molecules with high precision**. This interaction relies on the **complementary shapes**, charges, and chemical properties of the molecules, much like a "lock and key " mechanism (see Figure 2.5.1). In biological systems, molecular recognition is crucial for many processes, including **immune responses**, enzyme activity, and cellular communication.

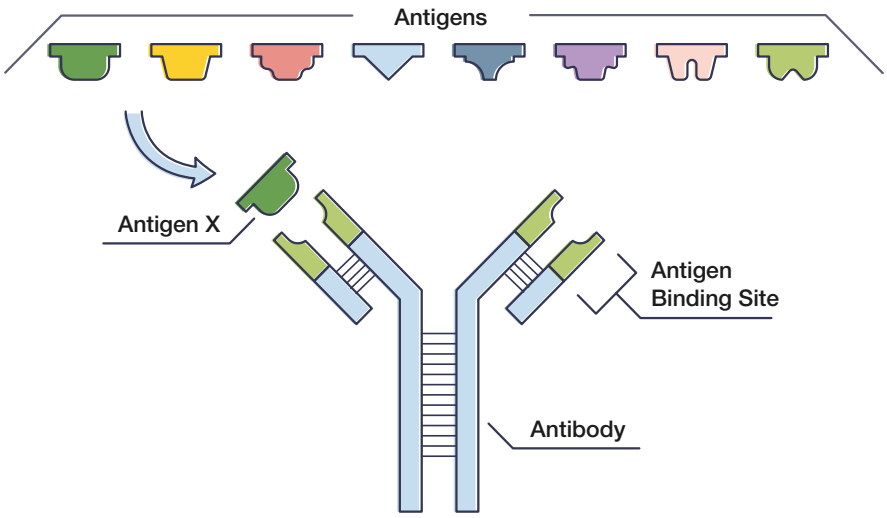


Figure 2.5.1: Antibodies are proteins secreted by cells in the third line of immune defence (the adaptive immune system) that perform their role through molecular recognition. They comprise antigen binding sites that have a specific complementary shape to specific antigens. The antigen labelled 'X' is recognised as 'non-self' and has a complementary shape to the displayed antibody. Antigen X is the only antigen this antibody can recognise and bind to given the specific complementary shape.

Self and non-self recognition

Self and non-self recognition is the immune system's ability to tell the difference between the body's own cells (self) and foreign substances (non-self). Non-self-substances, like bacteria and viruses, have unique protein or carbohydrate molecules on their surface called **antigens** (see Figure 2.5.1). Antigens are defined as a molecule **which can trigger an immune response** and is generally foreign to the host. Dust and pollen grains can also be recognised as non-self-antigens and can trigger and immune response, leading to allergies.

The human immune system recognises its own tissue and marker proteins as self-antigens and do not react to these. Failure to recognise self-antigens however can lead to several serious auto-immune diseases such as rheumatoid arthritis, Type 1 diabetes and multiple sclerosis (MS).

Recognition between host cells and pathogens

Recognition between host cells and pathogens is a key step in the immune response and involves molecular recognition interactions between pathogen molecules and host cell receptors. **Pathogens often express unique structures** called pathogen-associated molecular patterns (PAMPs), **which are not found in host cells**. Host cells, especially those of the immune system, have specialised receptors that recognise the unique pathogenic structures (PAMPs) as foreign, triggering immune responses.

In addition, some pathogens use specific molecules to recognise and bind to host cell receptors in a complementary manner, enabling them to attach, enter, and colonise the host. For example, viruses like influenza and SARS-CoV-2 (virus that causes COVID-19) use spike proteins to bind to a specific receptor on host cells, facilitating entry and infection. This recognition is therefore essential for both immune defence and pathogen invasion.

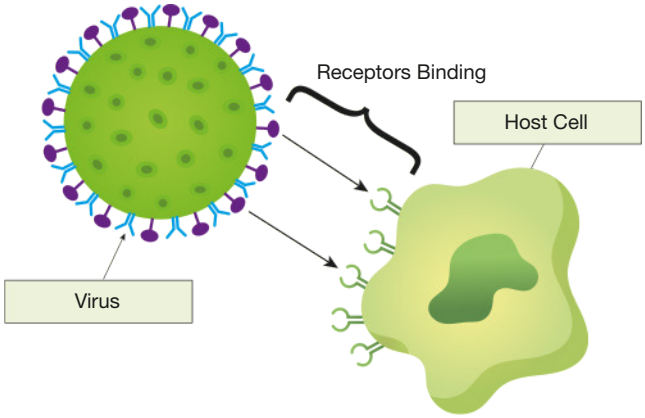


Figure 2.5.2: A representation of the molecular recognition through the complementary binding of virus surface structures and specialised host cell receptors.

Some pathogens enter cells to survive and reproduce

Some pathogens enter host cells to survive and reproduce because the intracellular environment provides **protection from external immune defences and access to nutrients necessary for their replication**. Viruses, for example, must enter host cells because they lack the machinery to replicate independently, relying on the host's cellular processes to produce new viral particles. Refer to Chapter 2.1 for more information on the life-cycle of a virus.

Bacteria and parasites, such as *Listeria monocytogenes* and the malaria-causing pathogen *Plasmodium*, may also invade host cells **to evade immune responses** like antibodies or complement proteins. Once inside, these pathogens exploit host resources to grow and spread, often causing damage to the host cell in the process.

The bacterium *Mycobacterium tuberculosis*, which causes tuberculosis, survives and reproduces by **infecting cells of immune system called macrophages**. These bacteria thrive within the protected environment of the macrophage and use the host cells nutrients to replicate. Additionally, the immune system attempts to contain *Mycobacterium tuberculosis* within a lesion (tubercules) in the lungs. Here the bacteria can enter a **dormant state**, where it can remain inactive but viable for decades. The thick, fibrous walls of the lesions (tubercules) **shield the bacteria from immune attacks and antibiotics**, allowing it to persist until conditions become favourable for reactivation.

Pathogen adaptations

Pathogens have developed various adaptations to enter hosts and evade their immune systems. For entry, some use specialised structures, like pili or adhesins, to attach to host cells, while others exploit wounds or inject proteins to penetrate tissues. To avoid immune detection, pathogens can hide inside host cells, produce capsules to resist phagocytosis, or mimic host molecules to appear less foreign. Additionally, some pathogens can disable or manipulate the host's immune response, allowing them to survive and spread within the host.

Bacterial adaptations

Bacteria have evolved various adaptations to assist their entry and survival in hosts. Refer to Table 2.5.2 for specific examples and Figures 2.5.3 and 2.5.4 for an overview of bacterial adaptations and their ability to form biofilms.

Table 2.5.2: Some adaptations bacteria have developed that help facilitate their entry, colonisation and reproduction within hosts.

Bacterial adaptation	Explanation of adaptation
Adhesins	Adhesins are specialised surface proteins on bacteria that allow them to attach firmly to host cells.
Pili and fimbriae	Pili and fimbriae are hair-like structures that help bacteria **adhere to host tissues**, such as the urinary tract, preventing them from being flushed out when the host urinates. Pili are longer than fimbriae but fewer in number.
Capsules	This protective layer that lies outside the cell wall can **shield bacteria from toxins and phagocytosis** by immune cells. The capsule covers the unique surface structures expressed by pathogens (PAMPs) preventing immune cells from recognising them.
Flagella	These tail-like structures assist the **movement of bacteria**, allowing them to swim and burrow into mucous membranes such as the stomach.
Biofilm formation	Most bacteria can form biofilms. Biofilms are communities of microorganisms, such as bacteria or fungi, that stick to surfaces (using adhesins, pili and fimbriae) and produce a protective slimy layer made of substances they secrete, like polysaccharides and proteins (see Figure 2.5.4). Biofilms **protect the microbes within from environmental stresses, and antibiotics and the immune system**, which often cannot penetrate the slime-like matrix. This makes the bacteria in biofilms harder to eliminate and are often associated with persistent infections (responsible for approximately 80% of chronic and recurrent microbial infections). Biofilms can form on many surfaces including the external and internal surfaces of human hosts. A prime example of a biofilm is **dental plaque** that forms on teeth and can increase the risk of dental caries. Not all biofilms are detrimental. Biofilm-forming bacteria on the gastrointestinal tract can protect the gut by preventing pathogens like *Clostridium difficile* from colonising and proliferating.

Bacterial adaptation	Explanation of adaptation
Enzymes	Bacteria can produce and secrete enzymes that **aid in their entry and survival within hosts**. Some bacteria can produce enzymes that assist them to break down the host's connective tissue, such as collagenase, which breaks down collagen. This can allow the bacteria to penetrate deeper tissues. Additionally, *Heliobacter pylori*, can survive in the harsh acidic conditions of the stomach due to its ability to produce and secrete urease, which is an enzyme that converts urea to ammonia assisting in neutralising the acidic environment.
Toxins	Toxins are molecules that **damage host cells and weaken defences**. Some bacteria can produce toxins that kill phagocytic cells enabling them to avoid being engulfed and destroyed by phagocytes. Additionally, the bacterium *Bordetella pertussis*, which causes whooping cough, produces toxins that destroy cells lining the respiratory tract reducing the infected person's chance of clearing the infection.
Antigen variation	Random mutations can occur to the genetic code (DNA) that can result in the physical change in the structure of its antigens. The change in the shape of these surface proteins can enable bacteria to **evade immune detection** as the immune system is unlikely to recognise their new shape.
Antibiotic resistance mechanisms	Random mutations can confer resistance to antibiotics, allowing bacteria to resist their effects, and transmit the resistance to offspring through binary fission and other bacteria through conjugation (see Chapter 2.4).
Iron acquisition systems	Some bacteria have developed compounds to capture iron from the host, which is essential for bacterial growth.
Intracellular survival	Some bacteria can invade and replicate within host cells, **avoiding external immune responses** like the aforementioned *Mycobacterium tuberculosis and Listeria monocytogenes.*
Host exit mechanisms	Bacteria can exit the host organism through a variety of mechanisms such as **inducing diarrhoea**, which can assist the host organism by flushing some bacteria from the intestines, but it also enables infections to spread via contaminated water (e.g. cholera).

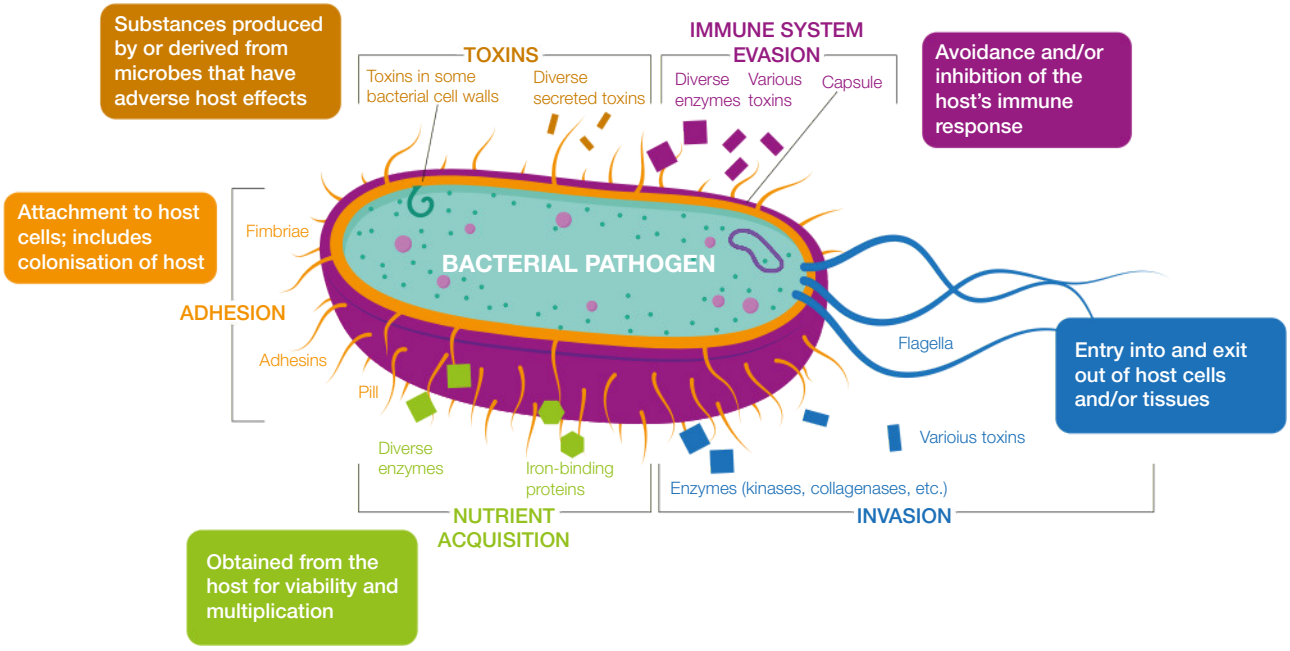


Figure 2.5.3: An overview of bacterial adaptations that can affect their pathogenicity and virulence.

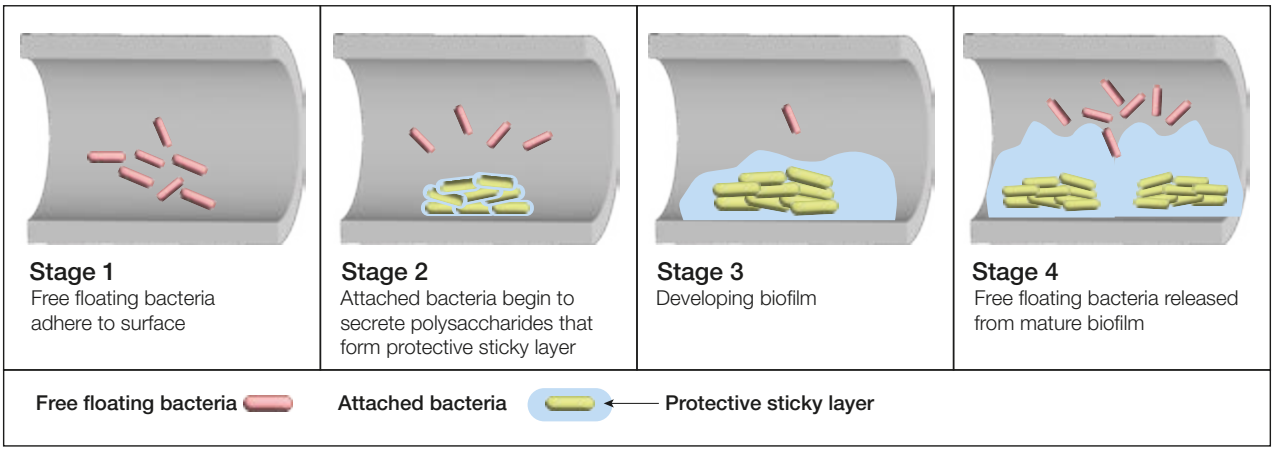


Figure 2.5.4: The stages of biofilm formation.

Viral adaptations

Viruses do not display many properties of other microbes, but they can enter a host cell and use its DNA and ribosomes to make new viral particles that can leave the cell and infect other cells. Viruses are specific in the cells they infect, and this is determined by the complementary binding between their surface antigens and host receptor molecules. Viruses have evolved a range of adaptations to facilitate their entry into hosts and ensure survival (see Table 2.5.3).

Table 2.5.3: Some adaptations viruses have developed that help facilitate their entry, colonisation and reproduction within hosts.

Virus adaptation	Explanation of adaptation
Hijacking host machinery	Viruses use the host's cellular machinery for replication and protein synthesis, avoiding the need for their own metabolic systems (see Figure 2.5.5).
Enveloped structures	During the virus lifecycle, the new viruses exit the host cells by **budding**, which results in the virus' envelope being derived from the hosts' lipid membrane (see Figure 2.5.5). This can help viruses **appear more like a host cell**, helping the virus to evade immune detection. Additionally, budding allows viruses to **exit the host cell undetected** by the immune system because the host cell is not destroyed (through cell lysis). If the cell bursts open (lyses), this triggers the host's immune system. Viruses that have adapted to exit host cells through **exocytosis**, also exit undetected and avoid triggering the host's immune system.
Rapid replication	Many viruses have high replication rates that can **overwhelm and exhaust the host's immune system** before an effective response can be mounted.
Antigenic drift	Viruses, like HIV, influenza and SARS-CoV-2, mutate rapidly and accumulate random mutations that can result in **changes in surface antigens and an increased ability to avoid immune recognition** (see Figure 2.5.6). This is known as antigenic drift and can sometimes result in individuals who were previously immune to a virus becoming susceptible to the antigenically different virus infection again. This is because the individual's antibodies cannot effectively recognise and neutralise the antigenically different virus. Antigenic drift is an important reason why people can be infected by viruses like influenza multiple times over the course of their lives. It is also the general reason for yearly influenza vaccinations.
Antigenic shift	In some cases, **two different viruses can combine inside a host cell** and create a new virus with different antigens (see Figure 2.5.6). This generally results in an abrupt major change to viruses that can create a new strain/subtype that most people have little or no immunity to.
Surface proteins	Specialised proteins, like spikes (e.g., hemagglutinin in influenza – see Figure 2.5.6), bind to specific host cell receptors, **facilitating entry** and infection.
Receptor mimicry	The accumulation of random mutations can result in proteins in the envelope changing shape and mimicking those of host molecules, enabling them to bind to host cell receptors and gain entry.

Virus adaptation	Explanation of adaptation
Genome integration	Some viruses, such as retroviruses like HIV, **integrate their genetic material into the host's DNA** enabling it to avoid immune detection. This provides a stable and long-term reservoir for viral replication **ensuring its persistence in the host**.
Immune evasion proteins	Some viruses can synthesise **proteins that can inhibit host immune responses**, such as preventing phagocytosis, binding to and preventing antibody recognition and even reducing inflammation.
Latency	Some viruses, such as herpes viruses, **remain dormant in host cells to evade immune detection** and reactivate later when the environment is more suitable to do so (e.g. immune system of host is suppressed).
Host exit mechanisms	Viruses can exit the host organism through a variety of mechanisms such as through **coughing or sneezing** which can remain in the air for an extended time and infect other individuals.

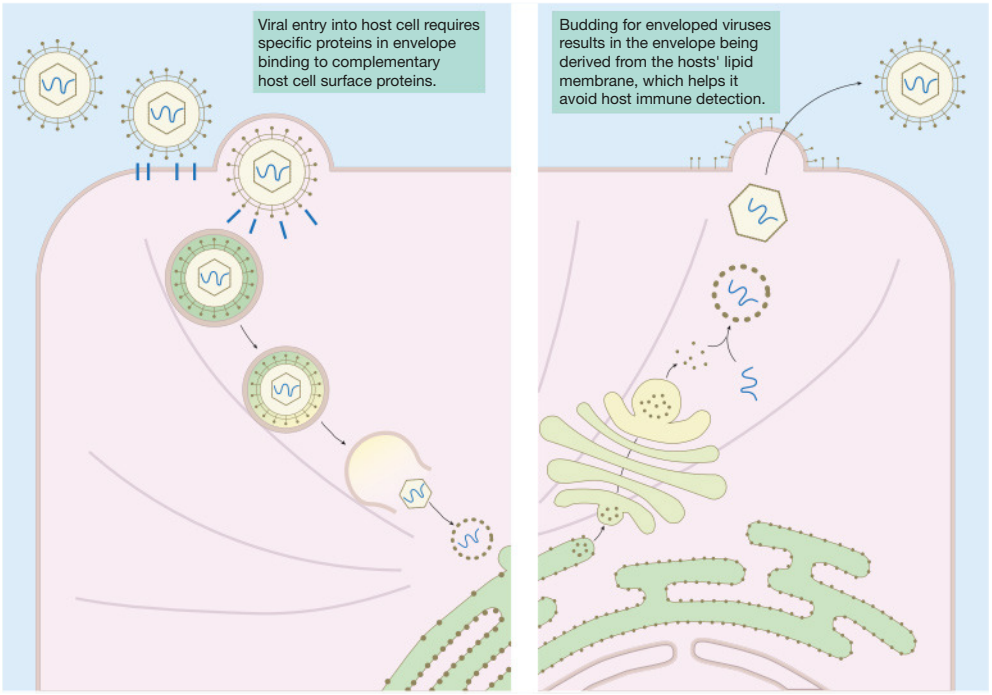


Figure 2.5.5: The virus life cycle involves molecular recognition for the entry of a virus into a host cell (left) and budding from the host cell for enveloped viruses (right).

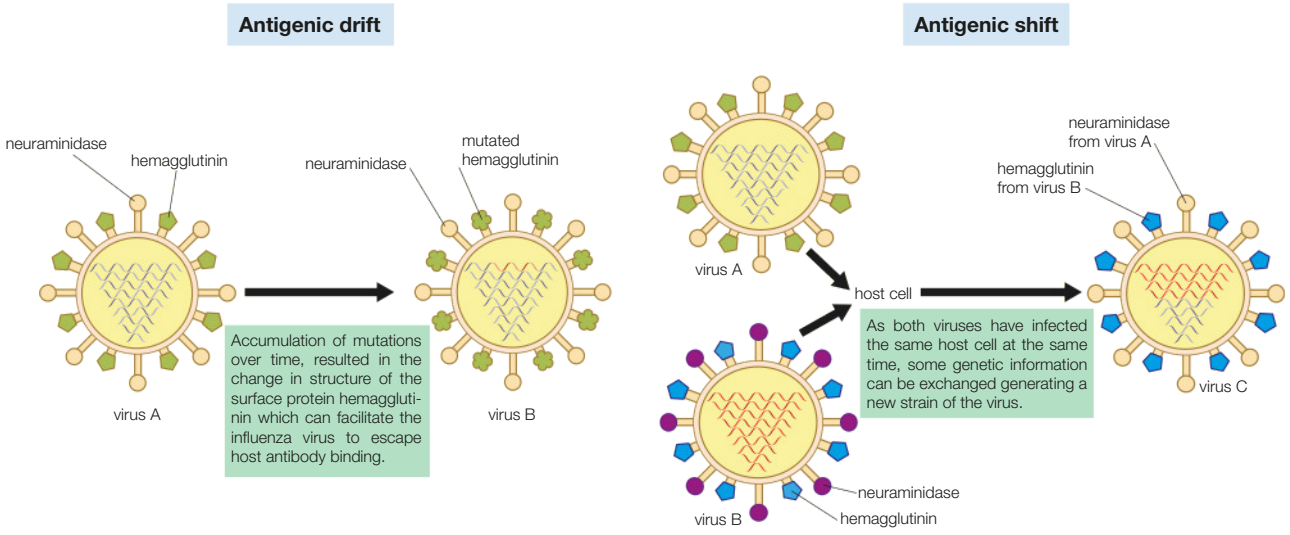


Figure 2.5.6: The difference between antigenic drift and antigenic shift using the influenza virus as an example.

Additional pathogen adaptations

Using a vector

Some pathogens manage to enter the host's bloodstream by using a vector. A rather large group of microbes, including examples from bacteria, viruses and protists, have adapted to survive in certain insects so they can be transferred to their hosts. The *Plasmodium* that causes malaria is well adapted to living in the females of a particular species of mosquito. Additionally, many viruses that infect plants are transmitted by insect vectors.

Spore production

Some bacteria, protists and fungi can produce dormant spores that allow them to persist in unfavourable conditions. Bacterial spores are not usually produced inside human hosts, but they can reactivate inside human hosts, where conditions are more favourable. Many fungi and fungus-like water moulds can produce spores as a survival mechanism that can lay dormant in soil for many years. These dormant spores can activate when conditions become favourable again and infect plants, causing disease. An example of this is the **fungus-like water mould** *Phytophthora cinnamomic*, which causes the **plant disease phytophthora root rot**, also called phytophthora dieback. This disease can kill a wide range of plants including native plants and many fruit bearing plants. It is a devastating plant pathogen and once established it cannot be eliminated.

2.5 Review questions

Multiple choice questions

1. Viruses like influenza facilitate entry into human host cells
   - J by producing enzymes to break cell walls.
   - K by binding to specific host cell receptors.
   - L by antigenic drift.
   - M by forming a biofilm.
2. Which of the following structures assists bacteria to adhere to host tissues?
   - J Pili
   - K Plasma membrane
   - L Biofilm
   - M Toxins
3. Some pathogens have adapted to enter host cells to survive and reproduce.

   Which of the following options is **not** a practical reason for this adaptation?
   - J To use the hosts machinery to make new pathogen structures.
   - K To access their nutrients.
   - L To avoid the hosts immune system.
   - M To kill the host cell.
4. Which of the following adaptations allow bacteria to resist antibiotics and immune responses?
   - J Flagella
   - K Fimbriae
   - L Enveloped structures
   - M Biofilm formation
5. Some bacteria have developed the ability to produce enzymes that can break down collagen in host tissues. This adaptation assists these bacteria to
   - J invade deeper tissues in the host.
   - K avoid immune detection more effectively.
   - L become more resistant to antibiotics.
   - M replicate more slowly in the host.

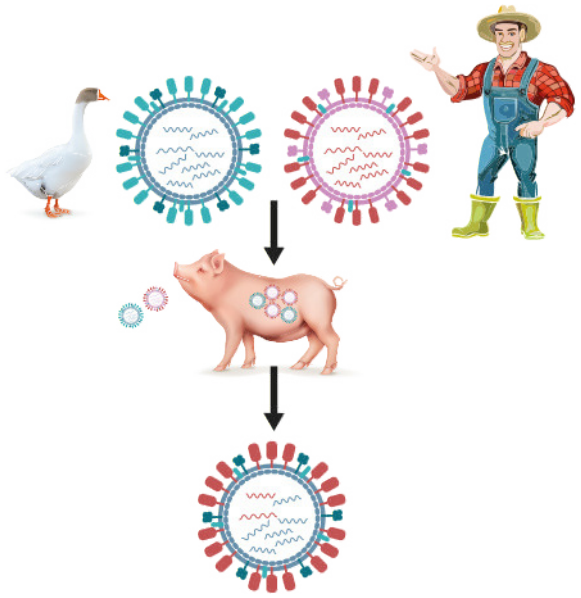
6. Why is antigenic drift more problematic for vaccine development compared to other pathogen adaptations?

   J It reduces the pathogen's susceptibility to antibiotics.
   K It continuously alters pathogen surface proteins, requiring frequent updates to vaccines.
   L It enhances the pathogen's replication rate.
   M It increases the pathogen's ability to survive in harsh environments.

7. Antigen variation can allow pathogens to avoid host immune systems because

   J the change in pathogen protein structure can still be recognised.
   K host immune cells can no longer bind in complementary fashion to pathogen.
   L the concept of molecular recognition is no longer applicable.
   M all mutations to the genetic code of pathogens are beneficial.

8. *Refer to the image below which shows an adaptation associated with a pathogen to answer the following question.*



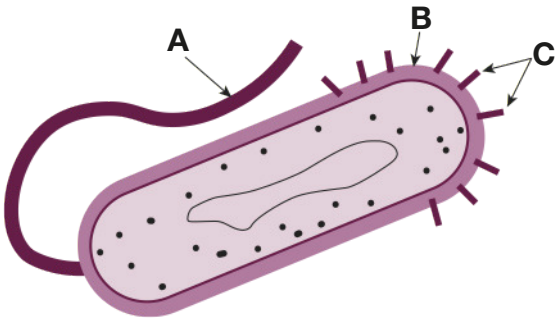
   The process illustrated above is

   J reassortment of bacterial DNA.
   K antigenic drift.
   L antigenic shift.
   M random mutations.

9. Which of the following options does **not** correctly match a type of pathogen with an adaptation that assists it to enter a human host through the identified portal?

	Portal of entry	Pathogen	Adaptation that assists pathogen entering a host through this portal
J	Urogenital tract	Bacterium	Fimbriae
K	Respiratory tract	Virus	Host exit mechanism of airborne transmission
L	Gastrointestinal tract	Bacterium	Biofilm formation
M	Breaking the skin barrier	Virus	Antibiotic resistance

10. *Refer to the image below which shows some structures associated with a pathogen to answer the following question.*



Select the answer that correctly identifies the three structures and their respective functions that aid them in infecting human hosts.

	Structure A	Function of A	Structure B	Function of B	Structure C	Function of C
J	Fimbriae	Allows movement and burrowing into host tissues	Capsule	Prevents cell lysis/ death	Pili	Facilitate entry to host cells
K	Fimbriae	Adherence to host cells	Cell wall	Prevents cell lysis/ death	Surface proteins	Facilitate entry to host cells
L	Flagellum	Allows movement and burrowing into host tissues	Capsule	Shields pathogen from immune system recognition	Pili	Adherence to host cells
M	Flagellum	Adherence to host cells	Cell wall	Shields pathogen from immune system recognition	Surface proteins	Adherence to host cells

Free response questions

1. State the **four** key portals of entry that pathogens can penetrate to infect a host.

2. a) Describe the difference between contagiousness, pathogenicity and virulence.

   b) Explain why high virulence can be seen as a disadvantage to the pathogen.

3. a) Describe how host cells recognise pathogens.

   b) Compare the importance of this recognition for hosts and pathogens like the influenza virus.

4. Viruses have developed many adaptations that facilitate their entry, colonisation and reproduction within hosts.

   a) Describe the advantage of a rapid replication rate to an invading virus.

   b) Describe the advantages of genome integration to the HIV virus.

   Herpes simplex virus (HSV) can exhibit latency.

   c) Describe how latency assists HSV to survive and reproduce.

   When HSV viruses exit a host cell, they do so without the host cell bursting.

   d) Explain why this adaptation is advantageous to the HSV virus.

5. Explain how an infection that causes diarrhoea in the host can be seen as an advantage for both the host and pathogen.

6. Panama disease is a fungal disease that infects banana plants. The tropical race 4 strain (TR4) can produce spores and survive in the soil for up to 30 years. It is also resistant to fungicides.

   a) Describe **one** way that spores provide a reproductive and/or survival advantage to the species that produce them.

   The previous strains of Panama disease (TR1 to TR3) could not infect Cavendish banana crops, but the new TR4 strain can and is threatening the global banana industry.

   b) Explain how the new strain of TR4 developed from the previous TR3 Panama disease strain.

Use your understanding of the interaction between science and society to answer part (c).

c) Discuss how communication and collaboration is required to combat the spread of Panama disease and to reduce the impact on the banana industry.

7. a) Describe the formation of a biofilm.

b) Explain why using dental floss is important to maintain good healthy teeth and gums.

The most common way antibiotic sensitivity tests are conducted on bacteria in laboratories is in their free-floating state, where they behave individually.

c) Discuss **one** limitation of conclusions for antibiotic sensitivity tests conducted in this manner.

Deep learning (AI) is being used to detect dental plaque by analysing images of teeth and identifying regions of plaque. This technology can provide rapid and consistent assessments that currently often matches or surpasses the accuracy of human experts in detecting plaque.

Use your understanding of the interaction between science and society to answer parts (d) and (e).

d) Discuss **one** way that this plaque detecting deep learning development could be applied.

e) Discuss **one** possible limitation of this plaque detecting deep learning technology.

Chapter 2.6 First line of defence

Science Understanding

The human immune system protects the body against disease by:

- physical barriers
- innate (non-specific) immune response
- the adaptive (acquired) immune response.

The different responses work together to neutralise or prevent the entry of pathogens:

- Describe the function of the various physical barriers that exist to prevent the entry of pathogens.

The immune system

The human immune system is a complex network of cells, tissues, and organs that protects the body against harmful pathogens. It has two main components:

- the innate immune system
- the adaptive immune system

Humans are born with their innate immune system, which provides immediate, **non-specific defence**, but the adaptive immune system develops over time as an individual's body is exposed to pathogens. The **adaptive immune system is a specific and targeted response** that develops memory to recognise pathogens in the future.

The immune system operates through **three lines of defence** (see Table 2.6.1). The first line includes physical, chemical and biological surface barriers, such as skin, stomach acid and the skin microbiome respectively, which prevent pathogens from entering the body. The second line involves internal innate responses like inflammation, fever, and the activity of phagocytic cells, which engulf invading pathogens. The third line is the adaptive immune response, which involves specialised white blood cells called lymphocytes (B-cells and T-cells) that produce antibodies and destroy infected cells, offering long-term immunity. Together, these systems ensure the body remains protected and healthy. The first, second and third lines of defence will be explored further in Chapters 2.6, 2.7 and 2.8 respectively.

Table 2.6.1: A summary of some key features of the innate and adaptive immune systems.

Innate immune system (non-specific defences)		Adaptive immune system (specific defences)
First line of defence	**Second line of defence**	**Third line of defence**
Physical barriers (skin, mucous membranes)	Inflammatory response	Lymphocytes (T-cells and B-cells)
Chemical barriers (tears, stomach acid)	Fever	Antibodies
Biological barriers (native microbiome)	Non-specific cellular responses (phagocytes)	Memory cells
	Complement system	

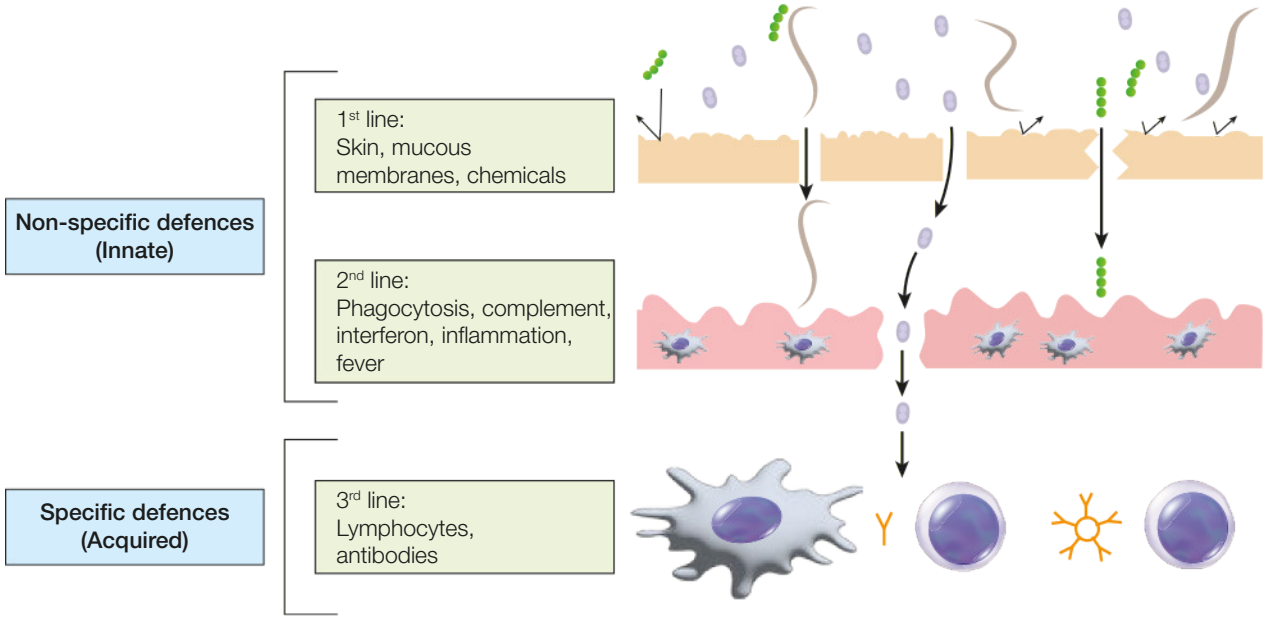


Figure 2.6.1: The three lines of immune defence work collectively to defend the body against constantly invading pathogens.

First line of defence

The first line of immune defence includes physical, chemical and biological barriers that **help prevent the entry of pathogens into the body**. The main portals of entry for pathogens are the skin, respiratory tract, gastrointestinal tract, and urogenital tract. Despite these barriers, **well-adapted pathogens have evolved mechanisms to bypass or exploit these entry points**, such as penetrating damaged skin or adhering to mucosal surfaces. The most effective defence against infection is preventing pathogen entry altogether, highlighting the importance of maintaining intact barriers and practicing good hygiene measures.

Physical barriers

The physical barriers of the first line of defence in the human immune system are the body's primary protection against pathogens. These include the **skin**, which forms a tough, waterproof barrier to block microorganisms, and **mucous membranes**, which line body openings such as the mouth, nose, and respiratory tract, trapping pathogens. In the respiratory tract, **cilia**, tiny hair-like structures, work to sweep trapped particles out of the airways. These physical structures act as a shield to prevent pathogens from entering the body and causing harm. Refer to Table 2.6.2 for more information on the physical barriers that comprise the first line of defence.

Table 2.6.2: Some physical barriers of the first line of defence in the human immune system and how they protect against pathogens.

Physical barrier	Explanation of protective action
Skin	The skin is the largest organ in the body and its structure makes it very hard for pathogens to penetrate. The tough outer layer of the epidermis (stratum corneum) consists of dead cells which are **constantly being shed, removing pathogens** that have adhered to it. The skin generally lacks moisture too, providing an **effective waterproof barrier** that is inhospitable to microbial growth as most pathogens require moisture to survive and reproduce (see Figure 2.6.2).
Mucous membrane (Note: Mucous is an adjective and mucus is a noun)	Mucous membranes protect the body physically by **trapping pathogens and foreign particles** in the sticky mucus they secrete, thereby preventing harmful microorganisms from entering body tissues. Additionally, the **movement of cilia on mucous membranes**, particularly in the respiratory tract, helps to transport mucus (along with trapped pathogens) out of the body, either by swallowing or expelling by coughing it up (see Figure 2.6.3).

Physical barrier	Explanation of protective action
Hair	Hair helps protect the body against pathogens by acting as a **physical barrier that prevents microorganisms, dust, and debris from entering** sensitive areas such as the eyes, nose, and ears. In the nostrils, nasal hair filters out larger particles and pathogens from the air, while eyelashes protect the eyes from foreign bodies. Additionally, body hair can help trap sweat and sebum, which have antimicrobial properties, further reducing the risk of infection.
Sneezing	Sneezing is a protective reflex that helps **expel pathogens and irritants** from the respiratory tract. When the body detects foreign particles, the brain triggers a rapid, forceful expulsion of air and pathogens from the lungs, through the nose and mouth. This action helps clear the nasal passages and prevent pathogens from traveling further into the respiratory system, reducing the risk of infection.
Eyes	Blinking and tears provide physical protection for the eyes by clearing out potential pathogens. **Blinking** helps remove debris and microorganisms from the surface of the eye by spreading a thin layer of tears across the eye. **Tears** continuously wash the eye, **physically flushing out foreign particles and pathogens**.
Urine	Urine provides physical protection against pathogens primarily through its **flushing action**. Regular urination helps expel microorganisms from the urinary tract, preventing their buildup and reducing the risk of infections.

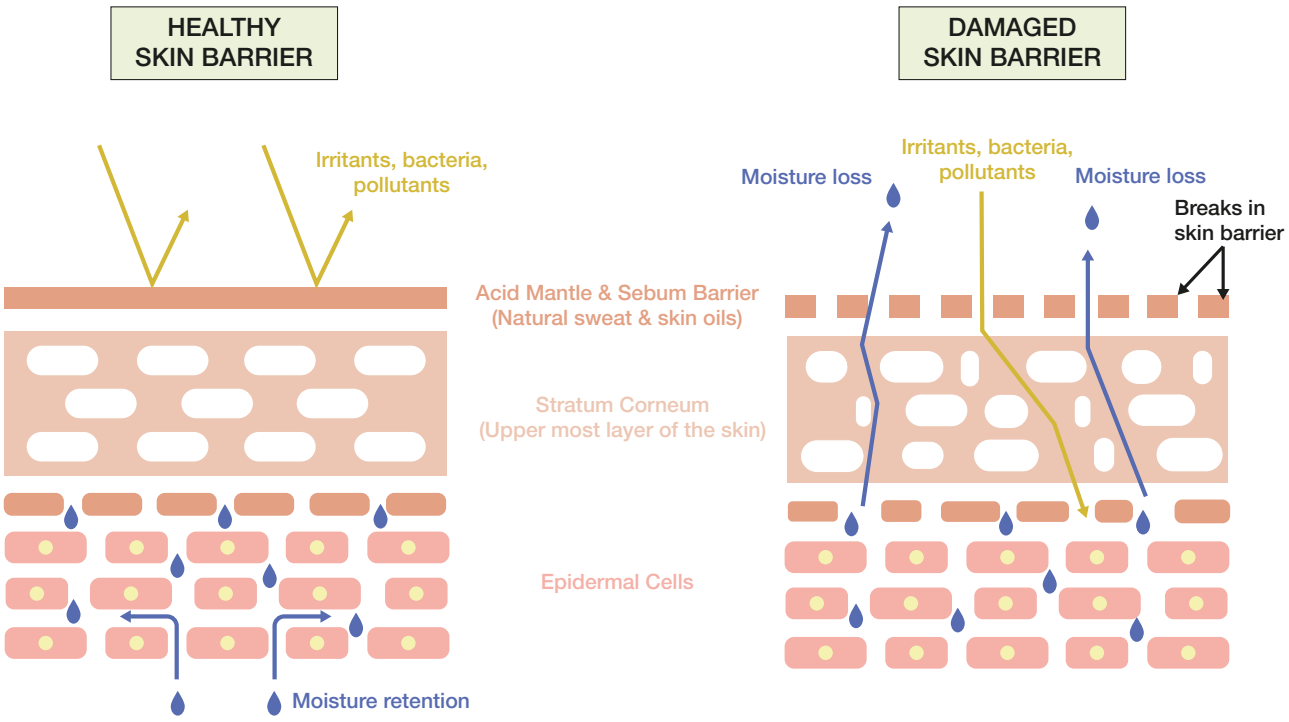


Figure 2.6.2: The skin acts as a continuous impassable barrier to potential pathogens however damaged or very dry skin can create gaps in this barrier enabling it to be penetrated by well adapted pathogens. This can also result in moisture loss from lower layers of the skin through evaporation.

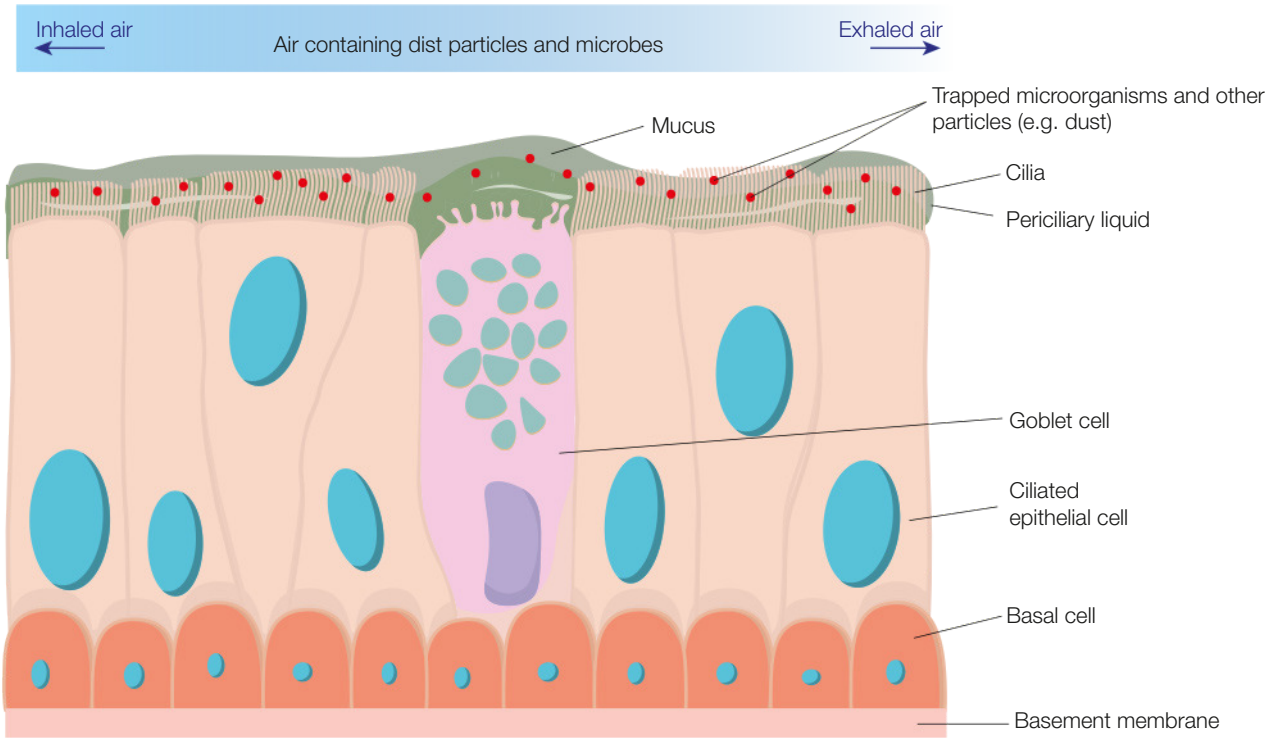


Figure 2.6.3: Mucous membranes secrete mucus which traps foreign particles and microorganisms in the inhaled air. The cilia move in a wave-like motion to transport the mucus and trapped particles to the throat where they can then be expelled from the body.

Chemical barriers

The chemical barriers of the first line of defence in the human immune system help protect the body by neutralising or destroying pathogens before they can cause harm. These include enzymes like **lysozyme**, found in tears, saliva, and mucous, which break down the cell walls of bacteria. The stomach produces **hydrochloric acid**, creating a highly acidic environment that kills most ingested pathogens. The skin secretes **sebum**, which contains acidic oils, and **sweat** that lower its pH and create an environment that inhibits the growth of harmful microorganisms. Additionally, **mucus** in the respiratory and digestive tracts contains antimicrobial substances that trap and neutralise pathogens. Together, these chemical barriers provide an essential layer of protection. Refer to Table 2.6.3 for more information on the chemical barriers that comprise the first line of defence.

Table 2.6.3: Some chemical barriers of the first line of defence in the human immune system and how they protect against pathogens.

Chemical barrier	Explanation of protective action
Lysozymes	Lysozymes are **antimicrobial enzymes** (proteins) that kill bacteria by digesting their cell walls. Lysozymes are secreted in tears, saliva, mucus, sweat and breast milk.
Mucus	Mucus is a sticky aqueous substance secreted by goblet cells in the epithelial lining that protects the body against pathogens by trapping microorganisms and preventing their attachment to epithelial surfaces. It also contains antimicrobial proteins, such as **lysozymes**, and **antibodies** which neutralise or destroy pathogens.
Stomach acid	The cells lining the stomach secrete **hydrochloric acid creating a highly acidic environment** (pH 1 to 3) that is inhospitable to most microorganisms. This acidity denatures proteins and disrupts the membranes of ingested pathogens, killing them.
Sweat	Sweat possesses antibacterial properties that help protect the body from harmful microorganisms. In addition to lysozymes mentioned above, sweat contains **antimicrobial proteins**, such as dermcidin, which can disrupt bacterial membranes and inhibit their growth. Sweat also has a **slightly acidic pH**, typically ranging between 4 and 6, which creates an environment that is unfavourable for many bacteria. Additionally, sweat contains **salts that can dehydrate and inhibit bacterial growth** through osmotic stress.

Chemical barrier	Explanation of protective action
Sebum	Sebum is an oily, waxy substance produced and secreted by the sebaceous glands in the skin (see Figure 2.6.4). Sebum covers and protects the skin by providing an oily waterproof layer that repels water and therefore prevents the entry of microbes. It consists of a mixture of lipids including triglycerides that are broken down by beneficial skin bacteria into acidic free fatty acids, helping to create an **acidic environment on the skin that inhibits microbial growth**. Additionally, sebum can contain **antimicrobial proteins** that can inhibit bacterial growth or kill them outright.
Earwax	It is well known that the sticky consistency of earwax traps dust, debris, and microorganisms, preventing them from reaching deeper parts of the ear, however earwax also has antimicrobial properties that help protect the ear canal from infections. Earwax consists of two secretions: sebum from sebaceous glands and cerumen from ceruminous glands. In addition to the antimicrobial properties and the **acidic environment** produced through the release of sebum (explained above), cerumen consists of **lysozymes** and other **antimicrobial proteins** that can kill bacteria.

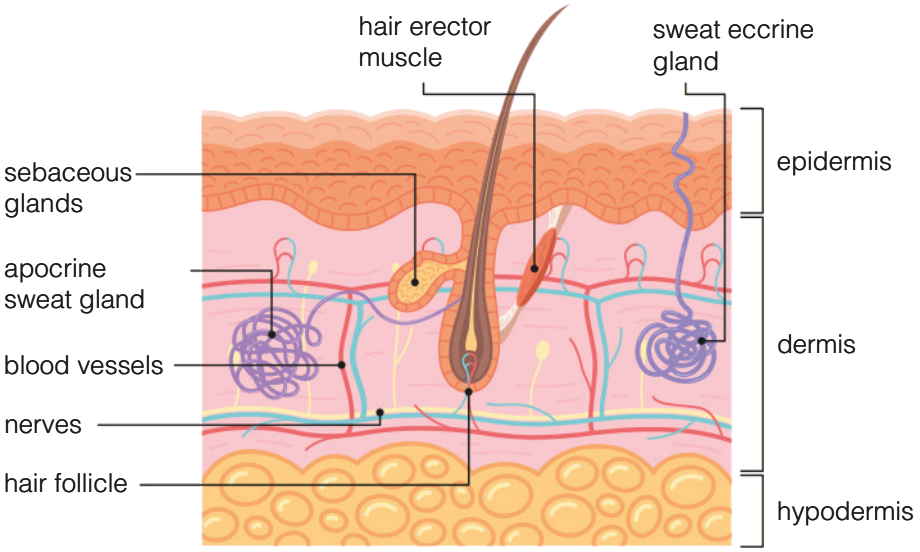


Figure 2.6.4: The upper layer of skin called the epidermis is an almost impenetrable physical barrier to pathogens. However, the skin also secretes sebum and sweat from their respective glands onto the surface of the skin providing chemical barriers to help prevent the entry of pathogens.

Helpful online resources

TED-Ed: How mucus keeps us healthy – Katharina Ribbeck

https://www.youtube.com/watch?v=WW4skW6gucU&t=67s

Dr Paulien Moyaert: Acne basics | Pathophysiology & Treatment | 3D Animation

https://www.youtube.com/watch?v=xbEqpYTkuXg

Biological barriers

The biological barriers of the first line of defence in the human immune system involve the activity of the various beneficial microorganisms that live on and inside the body. These include the normal flora, which are harmless bacteria found on the skin, in the gut, and in other areas like the mouth, nose and urogenital openings. These microorganisms compete with harmful pathogens for space and nutrients, preventing their growth and colonisation. This is known as the **competitive exclusion principle** (see Figure 2.6.5). An example of this can be seen on the skin. Sebum is secreted on the skin which contains lipids including triglycerides that the beneficial skin bacteria can metabolise more effectively than pathogenic bacteria. This gives them a competitive edge as they can access

vital nutrients required for growth and division more effectively, allowing them to outcompete pathogenic bacteria, helping to maintain microbial balance on the skin. Some beneficial microbes also produce **antimicrobial proteins** that inhibit or kill harmful bacteria. By maintaining a balanced microbial environment, this biological barrier plays a crucial role in protecting the body from infection.

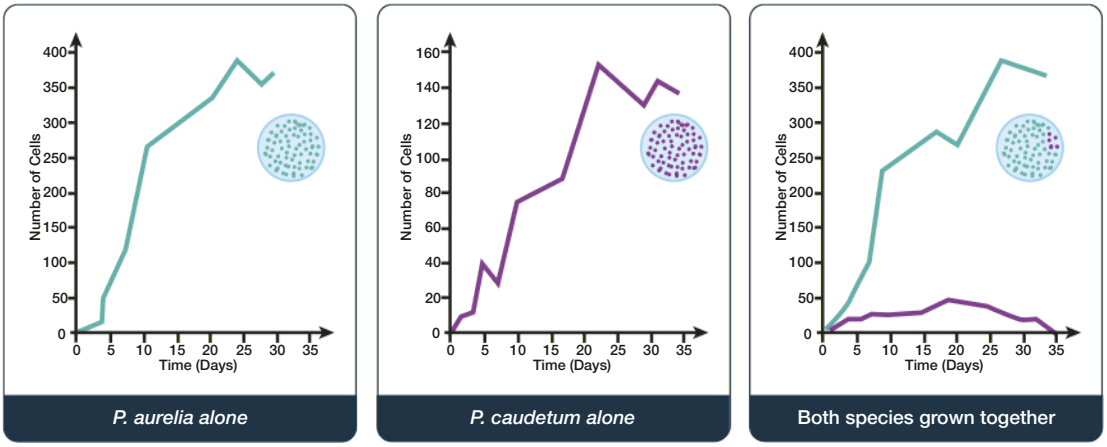


Figure 2.6.5: An experimental example of the competitive exclusion principle on two protozoan species. Both P. aurelia and P. caudetum exhibit similar growth and division when grown individually, but when grown together P. aurelia is better adapted to outcompete P. caudetum for resources allowing it to thrive and resulting in the eventual extinction of P. caudetum.

2.6 Review questions

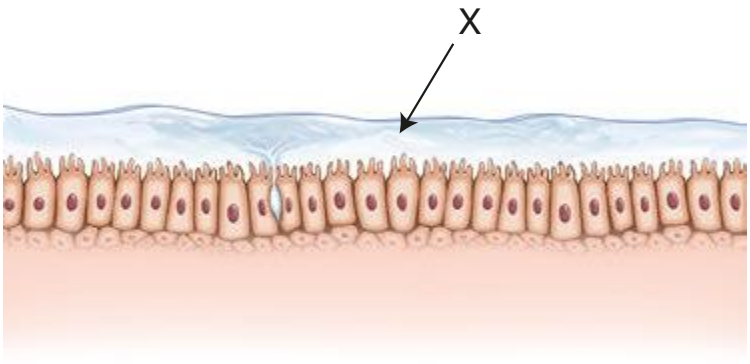
Multiple choice questions

1. Humans are born with
   - J the adaptive immune system.
   - K physical, chemical and biological barriers but no other defences.
   - L the first and second lines of defence.
   - M developed specific and non-specific defence mechanisms.
2. The first line of defence
   - J only consists of physical barriers.
   - K provide the body's secondary protection against pathogens.
   - L is not suited to prevent the constant entry of well adapted microbes.
   - M is less effective when skin is damaged.
3. Which of the following secretions are lysozymes **not** found in?
   - J Human milk
   - K Bile
   - L Mucus
   - M Saliva
4. What distinguishes mucous membranes in the respiratory tract from other physical barriers?
   - J They primarily destroy pathogens with antimicrobial proteins.
   - K They maintain a very acidic environment that is not suitable for the survival of most pathogens.
   - L They are lined with cilia that help move trapped pathogens out of respiratory tract.
   - M They contain hairs that can assist with protecting the eyes from invading pathogens.
5. With regard to defence against pathogens, which of the following options distinguishes tears from other secretions in the first line of defence?
   - J They are the only secretion that contains antibodies.
   - K They combine physical flushing with the enzymatic action of lysozymes.
   - L They create a highly acidic barrier around the eye.
   - M The can communicate when an individual is feeling upset.

6. Which of the following options correctly identifies a physical and chemical barrier that are both associated with the skin?

	Physical barrier	Chemical barrier
J	Shedding of dead cells	Sebum secretion
K	Trapping pathogens in mucus	Lysozymes
L	Effective waterproof barrier	Hydrochloric acid secretion
M	Antimicrobial proteins	Sweat secretion

7. *Refer to the image below showing some cells that line the trachea in the respiratory system to answer the following question.*



The substance labelled 'X' in the image is most likely

J a layer of water.
K colonies of native bacteria.
L a layer of mucus.
M inhaled air.

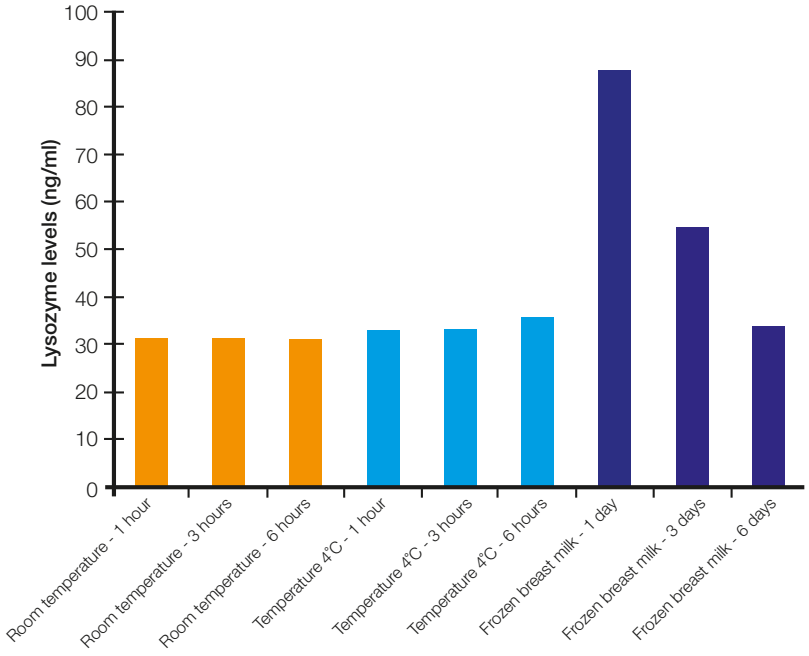
8. An example of the cooperation between a biological barrier and a chemical barrier in the first line of defence is

J how beneficial bacteria competes with pathogens for space on the skin.
K when pathogens succumb to the antimicrobial proteins secreted in sebum.
L how sweat secretes salts that can dehydrate and inhibit the growth of both the beneficial bacteria and pathogenic bacteria on the skin.
M how beneficial skin bacteria digest the triglycerides secreted in sebum to produce acidic free fatty acids that increase the acidity of the skin.

9. Identify the answer in the table below that correctly categorises a physical, chemical and biological barrier to pathogens.

	Physical barrier	Chemical barrier	Biological barrier
J	Mucus	Sneezing	Hair
K	Sebum	Mucous membranes	Beneficial microbiota
L	Beneficial microbes	Earwax	Antimicrobial proteins
M	Urine	Lysozymes	Native flora

10. *Refer to the image below which shows the levels of lysozyme in human milk at different temperatures and duration of storage time to answer the following question.*



Which of the following options is a valid conclusion based on the results of this investigation presented in the graph?

J Human breast milk is essential for the healthy development of infants.

K Frozen human milk stored for the first six days was observed to have a significantly increased lysozyme level.

L The lysozyme levels at room temperature were significantly reduced compared to those in frozen human milk.

M The lysozyme levels in human breast milk were not affected by temperature.

Free response questions

1. a) Identify the **two** main components of the human immune system.

b) Compare the main features of the two components identified in part (a).

2. Outline the difference between the physical and chemical barriers of the first line of defence.

3. Complete the table below by identifying the following first line of defence mechanisms as physical, chemical or biological:

First line defence mechanism	Type of barrier	First line defence mechanism	Type of barrier
Sebum secretion		**Vaginal microbiota**	
Mucous membranes		**Secretion of stomach acid**	
The shedding of dead skin cells		**Blinking**	
Nasal hairs		**Urinating**	

4. Outline **three** ways in which the skin is ideally suited to providing a barrier to pathogens.

5. Explain how stomach acid contributes to the first line of defence.

6. Describe how sneezing helps to reduce the risk of infection.

7. a) Identify **three** secretions of the first line of defence that contain lysozymes.

   b) Describe the protective action of lysozymes against pathogens.

8. Mucus is important in our defence against disease.
   a) Describe the physical action of mucus in preventing pathogens from traveling further into the respiratory system.

   b) Describe how the mucous membrane physically removes pathogens from the respiratory tract.

   c) Describe why mucus production increases when an individual is infected by a common cold virus.

9. Explain why burns victims are highly susceptible to infection.

10. Explain **two** reasons why healthcare professionals caution people about attempting to remove earwax from the ear canal with cotton buds.

11. Discuss how the normal skin microbiome contributes to the first line of defence against pathogens.

Chapter 2.7 The second line of defence

Science Understanding

The different responses of the innate system work together with a first line of defence to neutralise or prevent entry of pathogens.

Many organisms have an innate (non-specific) immune system to the presence of pathogens:

- Recognise that the innate (non-specific) immune system is the second line defence with responses that are non-specific
- Recognise that most organisms, including bacteria, fungi, plants, invertebrates and vertebrates display innate immune responses as a first line of defence against pathogens (e.g. histamine, complement, antibiotics etc.)

The second line of defence is triggered after the first line is penetrated and therefore consists of internal defences that aim to slow the spread of or neutralise pathogens. In humans, the main responses of the second line of defence are inflammation, fever, phagocytosis and the complement system.

Humans are born with the ability to generate an innate immune response to non-self-antigens and this response is **broad** and the same for all non-self-antigens, **it does not change or adapt during their lifetime**. In addition to vertebrates (animals with a backbone), innate immune responses are also exhibited by other species including bacteria, fungi, plants and invertebrates (animals without a backbone). Ultimately, the innate immune system is a **rapid and non-specific response** that responds in the same manner for all pathogens.

Non-specific recognition of innate immune system

All cells have antigens on their surface membranes. An individual's cells are recognised by the immune system due to the presence of self antigens and an immune response is not initiated. Foreign cells however contain non-self antigens which results in an immune response being triggered.

The cells of the innate immune system recognise these non-self antigens using special **pattern recognition receptors** that detect common patterns found on pathogens, which are not found on host cells. These unique surface structures are called pathogen-associated molecular patterns (PAMPs). The innate immune system cannot differentiate between different types of pathogens, it can only detect that a cell/particle is non-self. Once detected, the innate system responds by **activating immune cells**, such as macrophages, which engulf and destroy the invaders, and **release chemicals like histamine** that contribute to **inflammation** to help fight the infection.

Cells of the innate immune system

There are many types of **white blood cells**, also called **leukocytes,** that work to defend and protect the human body. Some leukocytes are non-specific in their action against pathogens and are part of the innate immune system, whereas others are specific in their action and are part of the adaptive immune system (covered in Chapter 2.8). The leukocytes of the adaptive immune system are called **lymphocytes**. Natural killer cells are an exception though. Natural killer cells are lymphocytes, but they are not part of the adaptive immune response, they are part of the innate immune response.

These leukocytes generally form in the bone marrow and can migrate to other areas of the body (see Figure 2.7.1). To patrol the entire body, leukocytes generally travel in the circulatory system and migrate to infected tissues during immune responses. The lymphocytes, however, generally travel through the lymphatic system to sites of infection (covered in Chapter 2.8). Some of the main cells of the innate immune response are outlined in Table 2.7.1).

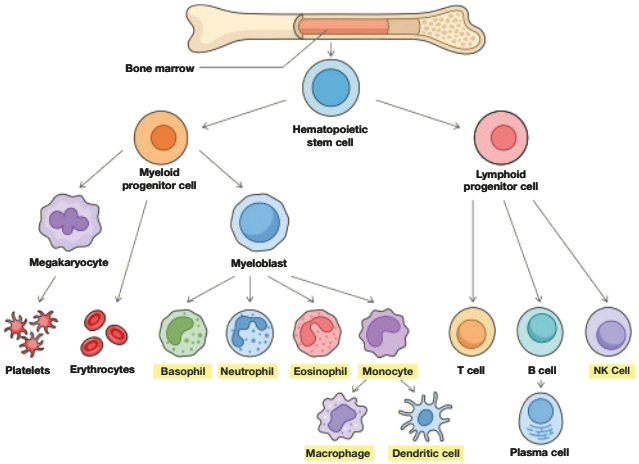
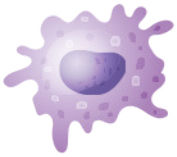
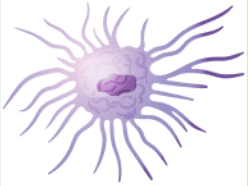


Figure 2.7.1: Leukocytes form in the bone marrow.
The leukocytes involved in the innate immune response are highlighted in yellow.

Table 2.7.1: Some of the main white blood cells (leukocytes) that are involved in coordinating an innate immune response.

Cell type	Image	Role in innate immune system response
Monocytes		Circulate in the blood and migrate to infected tissues where they can differentiate into macrophages and dendritic cells in response to inflammation.
Neutrophils		Neutrophils are the most abundant type of white blood cell. They play a critical role in the early immune response as they are generally the first cells that respond and migrate to the site of infection facilitating a rapid response to infection. Neutrophils are **phagocytic cells** that engulf and destroy invading pathogens. They are not involved in antigen presentation and are short lived **contributing to the formation of pus**.
Mast cells		Mast cells are abundant in tissues. In response to tissue damage or immune signals they help initiate inflammation by releasing **histamines**, which are responsible for dilating blood vessels and increasing their permeability.
Macrophages		Macrophages are **phagocytic cells** that develop from monocytes. They are the most efficient phagocytic white blood cell and can engulf a substantial number of pathogens and/or other infected cells. Macrophages can also **release cytokines** attracting other white blood cells to the site of infection. Furthermore, they are **antigen presenting cells** that can activate the adaptive immune system.
Dendritic cells		Dendritic cells are generally located in the tissue fluid and also develop from monocytes. They are also phagocytic cells but are better known for their role as **antigen presenting cells** that can activate the adaptive immune system.
Natural killer cells		Natural killer cells **destroy cancerous or virus-infected host cells**, stopping the spread of infection. They do not directly attack invading pathogens. They have a similar role to T-cytotoxic cells (covered in Chapter 2.8), but are **non-specific** in their action.

Phagocytosis

One of the most important responses in the second line of defence is the action of certain leukocytes called **phagocytes** which can carry out the process of **phagocytosis** (or endocytosis). In this process, the phagocytic cells recognise and bind to non-self surface molecules on pathogens, and then engulf them forming a phagosome. Inside the phagocytic cell, **lysosomes containing digestive enzymes**, fuse with the phagosome and destroy the trapped pathogen (see Figure 2.7.2).

The three types of phagocytic leukocytes are **neutrophils**, **macrophages and dendritic cells**. These cells can reside permanently in some tissues, circulate the body in the circulatory system patrolling for invading pathogens, or be called to sites of infection by the release of **cytokines**.

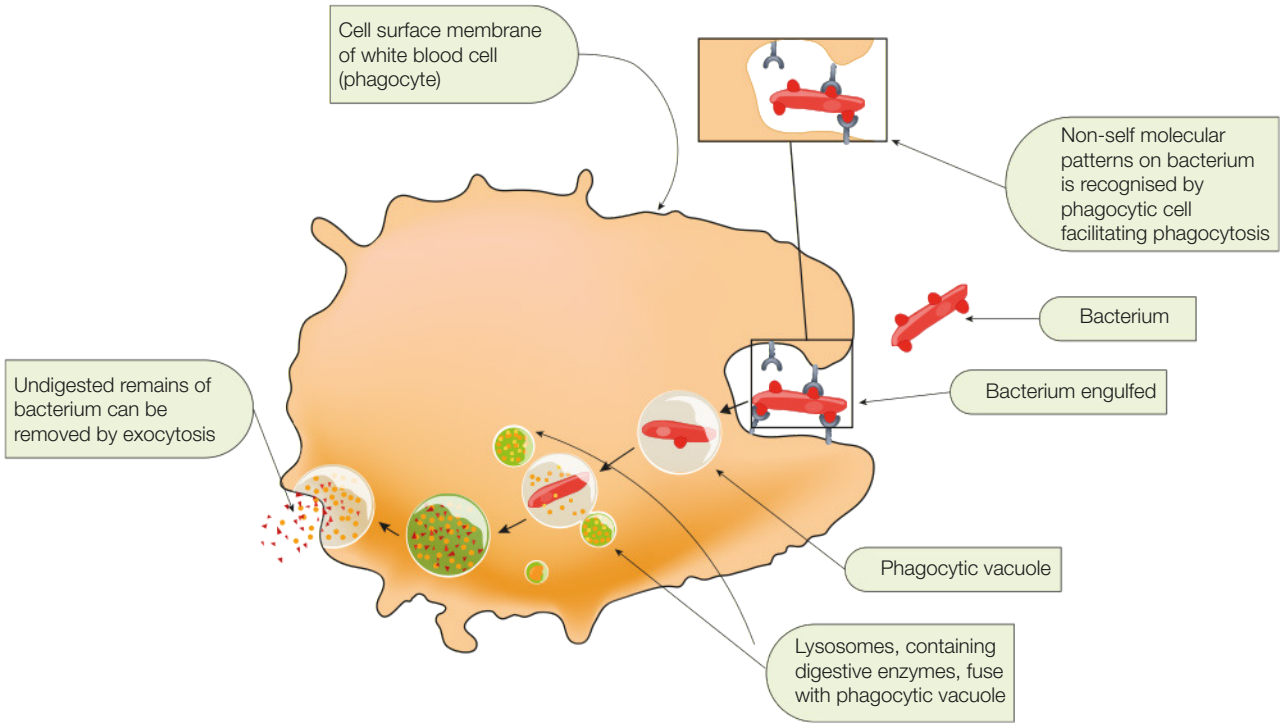


Figure 2.7.2: Phagocytic cells in the second line of defence recognise non-self molecular patterns on pathogens which facilitates them being engulfed and then destroyed by digestive enzymes.

Helpful online resources

Kurzgesagt – In a Nutshell: Your Tattoo is INSIDE Your Immune System. Literally

https://www.youtube.com/watch?v=nGggU-Cxhv0

Chemicals of the innate immune system

Cytokines

Cytokines are signalling proteins secreted by leukocytes and infected cells. They are involved in communication between cells and assist in regulating inflammation and the immune response. There are over 40 types of cytokines, including chemokines, interferons and interleukins.

Chemokines

Chemokines are released in response to an infection to stimulate the migration of leukocytes to the site of infection.

Interferons

Interferons are proteins that can be secreted by host cells that are infected by viruses. They help protect neighbouring cells by signalling them to increase their defences against invading viruses, with the aim of 'interfering' with the spread of the virus. This 'interference' can be brought about through multiple actions of interferons including:

- signalling uninfected cells to destroy RNA and reduce protein synthesis (so viruses cannot replicate),
- signalling infected cells to undergo programmed cell death, and
- activating other immune cells, such as macrophages, to assist with immune response.

Interleukins

Interleukins have a variety of functions, but most are involved in directing other immune cells to divide and differentiate. They also complement antigen presenting cells (macrophages and dendritic cells) in bridging the innate and adaptive immune responses. Their name is derived from this function, the interactions between leukocytes as "inter' means between and "leukins" refers to leukocytes. However, it is now known that interleukins interact with other host cells and not just leukocytes.

Histamine

Histamine is a chemical released by cells of the immune system, such as mast cells, in response to injury, inflammation and allergic reactions. Histamines cause dilation of capillaries making them more permeable, which facilitates the migration of leukocytes, and other substances, from the blood into the site of the infection. It is not classified as a cytokine.

The complement system

The complement system is an important part of the innate immune system that helps eliminate pathogens and enhances immune responses. It evolved over 700 million years ago and the current complement system in humans **involves over 30 different proteins**. These antimicrobial protein molecules are primarily synthesised by the liver but some other cells, such as macrophages, can synthesise smaller amounts of them. The complement proteins reside in the blood plasma and can also be found in tissue fluid. It remains here in an inactive form waiting to be activated in response to an infection or tissue damage.

Upon activation, **complement proteins bind to the surface of pathogens**. They are particularly attracted to pathogens that have already been tagged by antibodies secreted by the adaptive immune system (covered in Chapter 2.8). These antibodies provide an attachment site for the complement proteins to bind to. This is how the complement system received its name, it complements both the innate and adaptive immune responses. This binding of the first complement protein to a pathogen brings about the binding of a specific sequence of complement proteins in what is termed a **cascade effect** (a chain of events). This results in an amplification loop and the pathogen being coated in complement proteins, stimulating a variety of immune responses. The three main responses of the complement system are:

1. Binding to surface molecules on pathogens to attract phagocytes to the site of infections and enhance their identification for phagocytosis (see Figure 2.7.3a).
2. Binding to and puncturing holes in the pathogen's cell membrane causing it to rupture (see Figure 2.7.3b).
3. Binding to mast cells and stimulating them to release histamine, which intensifies the inflammatory response by dilating blood vessels and helping recruit more leukocytes to the site of infection (see Figure 2.7.3c).

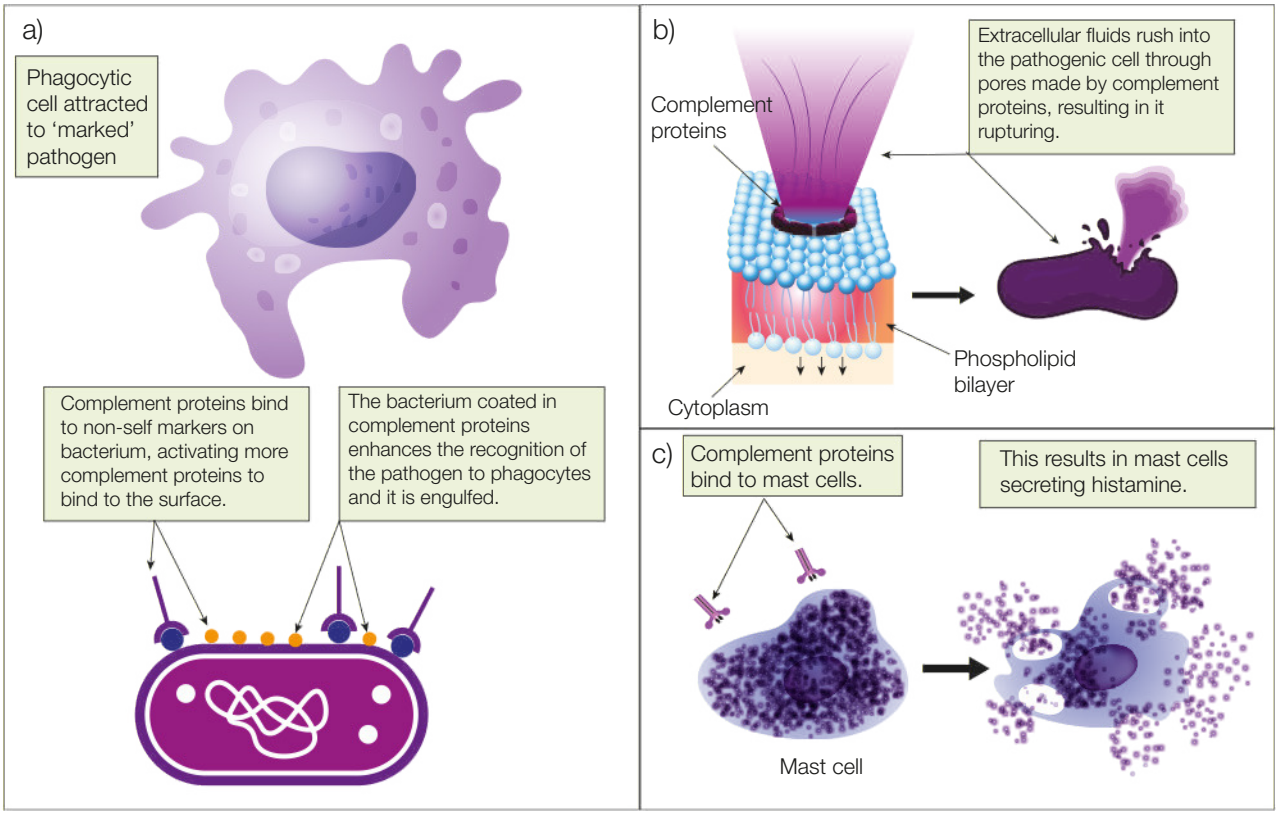


Figure 2.7.3: The three main actions of the complement system in response to the detection of a pathogen.

Helpful online resources

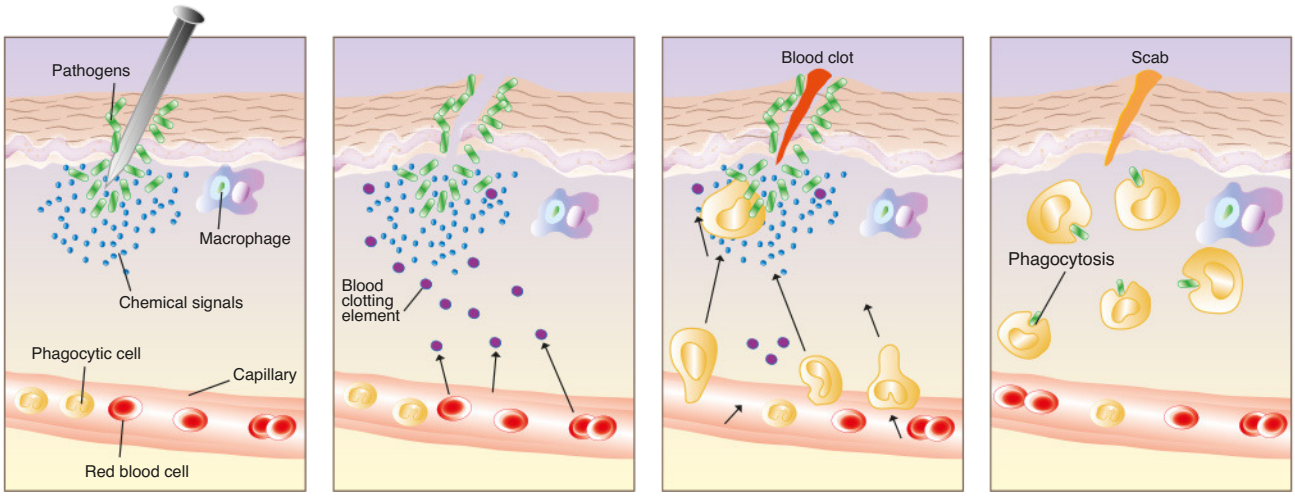
Kurzgesagt – In a Nutshell: Tiny Bombs in your Blood–The Complement System

https://www.youtube.com/watch?v=BSypUV6QUNw

The inflammatory response

The inflammatory response is the body's immediate reaction to infection or injury, aimed at containing damage, eliminating pathogens, and initiating healing (see Figure 2.7.4). It is initiated when damaged cells or immune cells detect harmful stimuli, such as pathogens or tissue injury, and release signalling molecules like cytokines and histamines. These molecules trigger **vasodilation** (widening of blood vessels) and **increased blood vessel permeability**, allowing immune cells like neutrophils and macrophages to migrate to the affected area. Chemokines, a type of cytokine, guide these cells to the site of infection or damage, where they eliminate pathogens through phagocytosis. These immune cells also release factors that promote tissue repair, such as **blood clotting factors** that seal the wound leading to the formation of a **scab**. Often accompanying a developing scab is **pus**, which largely consists of the buildup of dead neutrophils.

The classic signs of inflammation, **heat, redness, pain, and swelling** are caused by these processes. Heat and redness occur due to increased blood flow to the area, delivering oxygen and immune cells. Swelling arises from fluid leaking into the tissues as blood vessel permeability increases. Pain is caused by pressure from the swelling and the release of pain-inducing chemicals like prostaglandins. These symptoms, while uncomfortable, **help localise the response**, recruit immune cells, and ultimately heal the wound.



Chemical signals, such as histamine, are released by mast cells and macrophages at the injury site which causes nearby blood vessels to widen and become more permeable.

Fluid, clotting elements and microbial proteins move from the blood to the site. Clotting of blood begins.

Cytokines released by various kinds of cells attract more phagocytic cells from the blood to the site of injury. A scab starts to form.

Macrophages and neutrophils engulf pathogens and cell debris at the site forming pus and the tissue heals.

Figure 2.7.4: A summary of the inflammatory response

Helpful online resources

Nucleus Medical Media: Inflammation: Immune Response to Tissue Injury or Infection

https://www.youtube.com/watch?v=XS30Rnpka8M

2.7

Fever

Fever is a non-selective response that can result in an abnormally high temperature in response to an infection. The normal internal body temperature of a human is approximately 37°C. When an infection is detected, signals are sent to the hypothalamus of the brain to raise the body's internal temperature. An individual is considered to have fever when their **internal body temperature increases above 38°C** (see Figure 2.7.5).

Fever enhances the immune response by creating an environment less favorable for pathogens and boosting the body's defense mechanisms. The elevated temperature **inhibits the growth of many bacteria and viruses**, accelerates immune cell activity, and improves the production of infection-fighting molecules like antibodies.

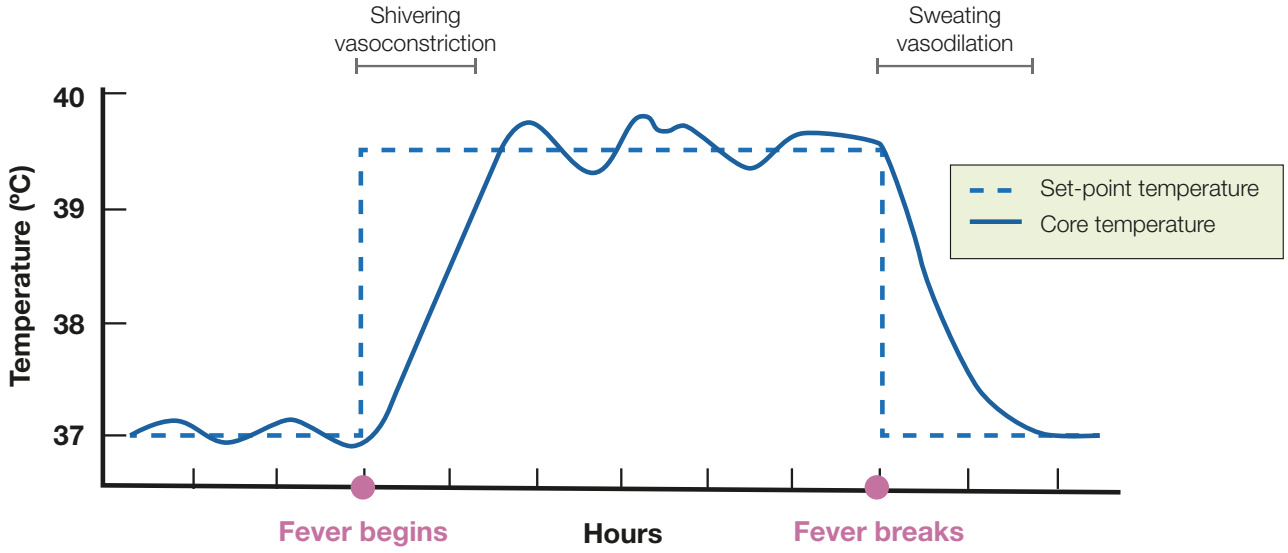


Figure 2.7.5: During fever the internal body temperature in elevated above 38°C to inhibit the growth and division of pathogens and aid the immune response.

Helpful online resources

Kurzgesagt – In a Nutshell: Fever Feels Horrible, but is Actually Awesome!

https://www.youtube.com/watch?v=cRZOUcpiOxY

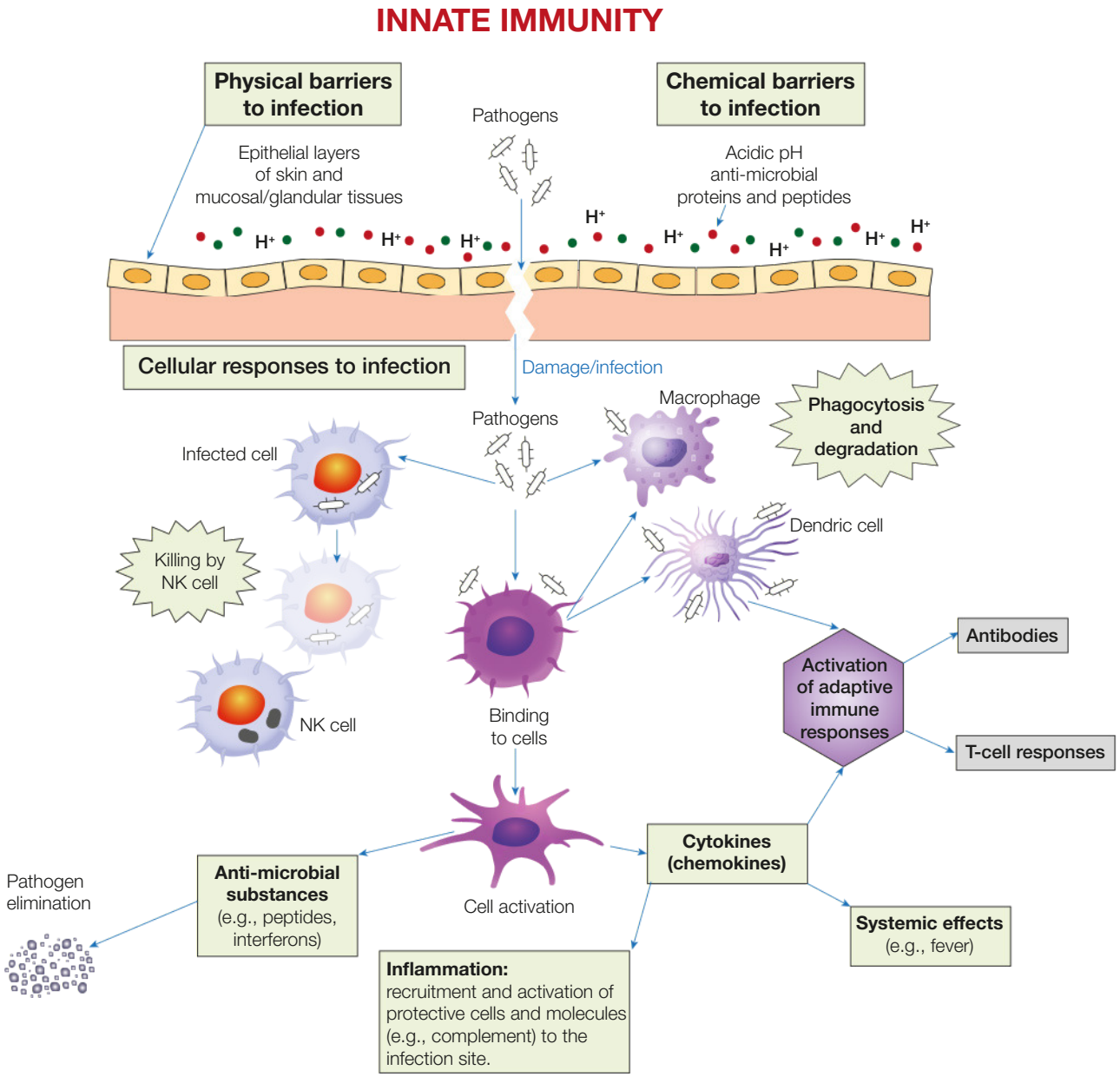


Figure 2.7.6: A summary of the innate immune responses and the link between the innate immune response and the adaptive immune system (third line of defence).

Innate immune responses in other organisms

Vertebrates have both innate and adaptive immunity (covered in Chapter 2.8). However, **fungi, invertebrates and plants rely solely on their innate immune systems because they do not have adaptive immunity**. Their innate defences provide immediate, non-specific protection against a wide range of pathogens. Invertebrates and plants both exhibit physical barriers to pathogens and the ability to produce and secrete antimicrobial chemicals. Additionally, they both use **pattern recognition molecules** to detect non-self antigens in a non-specific fashion, just like vertebrates.

Invertebrates

Invertebrates are animals without a backbone, making up the majority of animal species. Examples include insects (ants and beetles), arachnids (spiders), molluscs (snails and octopuses), and crustaceans (crabs and shrimp).

Their innate immune responses are crucial for survival. **Exoskeletons**, made of tough materials like chitin, act as a physical barrier against pathogens. **Hemocytes**, immune cells in their hemolymph (blood equivalent), perform phagocytosis to engulf and destroy pathogens and release signalling molecules to coordinate responses. Invertebrates use **pattern recognition molecules** to detect pathogens and activate immune defences. Additionally, they secrete **antimicrobial chemicals**, such as lysozymes and antimicrobial peptides, to neutralise or kill invading microbes.

Plants

Plants are multicellular, photosynthetic organisms that form the basis of most ecosystems. Examples include trees (wattle and eucalypt), grasses (wheat and rice), and flowering plants (roses and daisies).

Plants rely on innate immune responses to defend against pathogens and resist infections despite their immobility. **Physical barriers** like the waxy cuticle, cell walls, and bark help to prevent pathogen entry (see Chapter 3.7 for more information). Some plants shed infected leaves in a process called **leaf dropping** to isolate and remove the infection. They use **pattern recognition molecules** to detect pathogens, triggering defence responses. Additionally, plants secrete **antimicrobial chemicals**, such as **caffeine, cocoa and nicotine**, which can be toxic to some bacteria, fungi and insects. Humans have harvested many of these antimicrobial chemicals and used them for their own benefit including:

- caffeine, which is widely consumed by humans as a stimulant,
- cocoa, which is widely used in the food manufacturing industry to make chocolate and other chocolate based products,
- nicotine, which is used in some insecticides and is a very addictive drug in tobacco and vapes,
- quinine, which is used as an antimalarial drug and in tonic water, and
- pyrethrins, which are plant-based insecticides that are widely used to control pests.

Figure 2.7.7: The waxy cuticles, which are protective layers on the top of leaves (left), and bark, which is the outermost layer of stems and roots of woody plants (right), both provide physical barriers to help prevent the entry of pathogens.

Fungi

Fungi and bacteria possess innate immune responses to defend against pathogens and environmental threats. Fungi rely on physical barriers like their rigid cell walls, composed of chitin, to prevent pathogen entry. They also produce antimicrobial chemicals to inhibit or kill competing microorganisms, such as the antibiotic **penicillin**.

Bacteria

Bacteria also exhibit innate immune responses. Like fungi, bacteria produce **antibiotics** as part of their innate immune response to defend against competing bacteria in their environment. For example, bacteria like *Streptomyces* produce a wide variety of antibiotics, including streptomycin and tetracycline, which inhibit protein synthesis in other bacteria. Bacteria can form **biofilms** however that can protect them from antibiotics produced by competing microorganisms as these chemicals often cannot penetrate the biofilm (see Chapter 2.5 for more information on biofilms).

In nature, viruses, especially bacteriophages, are constantly infecting bacteria and killing them. In response, bacteria have developed some innate immune responses to defend themselves against viruses, such as the use of restriction enzymes and CRISPR. **Restriction enzymes** act like molecular "scissors" by recognising and cutting DNA at specific sequences, known as restriction sites. When a bacterium is infected by a virus, the viral DNA is recognised as foreign and is cut by the bacterial restriction enzymes, preventing the virus from using the bacterial cell to replicate. Restriction enzymes are part of an innate immune response because they provide a non-specific defence against foreign DNA, such as that from viruses.

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is also a defence mechanism that targets viral DNA; however, it **displays a unique adaptive component** that remembers past viral infections. When a bacterium is infected by a virus, it stores fragments of the viral DNA in its CRISPR sequence as memory. If the same virus attacks again, the CRISPR system uses these stored sequences to direct **Cas** (**C**RISPR-**as**sociated) proteins to the matching viral DNA, cutting and disabling it. This process allows bacteria to adapt to new viral threats over time.

Both restriction enzymes and CRISPR bacterial defence mechanisms are used by humans in the field of genetic engineering. This is explored further in Stage 2 Biology.

Helpful online resources

Kurzgesagt – In a Nutshell: The Deadliest Being on Planet Earth – The Bacteriophage

https://www.youtube.com/watch?v=Yl3tsmFsrOg

2.7 Review questions

Multiple choice questions

1. What distinguishes the innate immune system from the adaptive immune system?
   - J It only responds to bacterial infections.
   - K It is slower to respond than the adaptive system.
   - L It involves antibody production.
   - M It does not rely on memory of past infections.
2. Cells in the human immune system can distinguish self cells from non-self cells
   - J because non-self cells are always smaller in size than self cells.
   - K when complement proteins have bound to non-self cells.
   - L due to the presence of antigens on non-self cells.
   - M because pathogens generally have a faster reproduction rate or lifecycle.
3. Inflammation helps the immune response because
   - J It reduces blood flow to the affected area.
   - K It increases the internal body temperature to above 38°C.
   - L It isolates the infection site and recruits immune cells.
   - M It triggers the production of antibodies.
4. Which type of leukocyte is primarily responsible for releasing histamine during the inflammatory response?
   - J Macrophages
   - K Mast cells
   - L Neutrophils
   - M Cytokines
5. Natural killer (NK) cells are involved in which of the following processes?
   - J Phagocytosis
   - K Antigen presentation
   - L Destroying virus-infected or cancerous cells
   - M Destroying free floating pathogens

6. The main role of fever response during an infection is to

   J inhibit the growth of pathogens and enhances immune activity.
   K destroy all pathogens immediately.
   L increase temperature to enhance the survival of pathogens.
   M facilitate the release of cytokines.

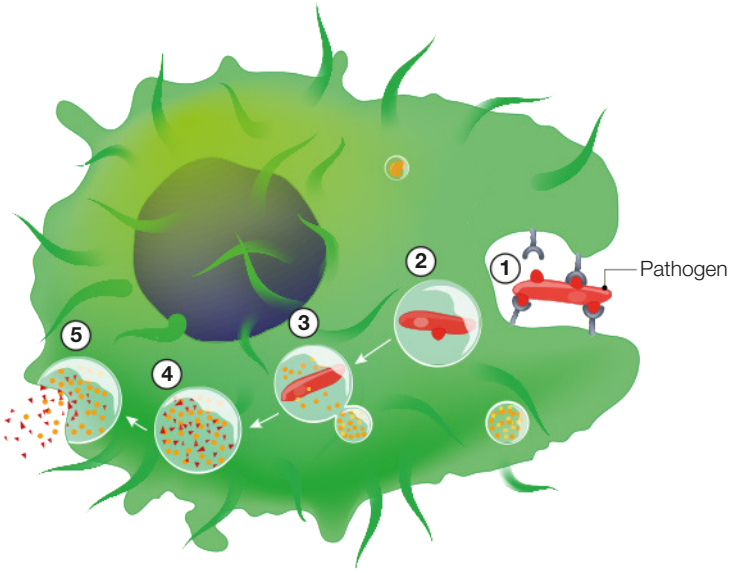
7. Invertebrates and plants rely more heavily on their innate immune system than humans because

   J their specific immune system is less complex than humans.
   K the exoskeletons of insects and bark of trees are the only defence mechanisms these organisms have against pathogens.
   L they do not have an adaptive immune system.
   M the human innate system is not very complex.

8. Cytokines are

   J signalling proteins released by pathogens.
   K toxins released by pathogens.
   L proteins involved in coordinating the complement system.
   M secreted chemicals that can aid in the communication between immune cells.

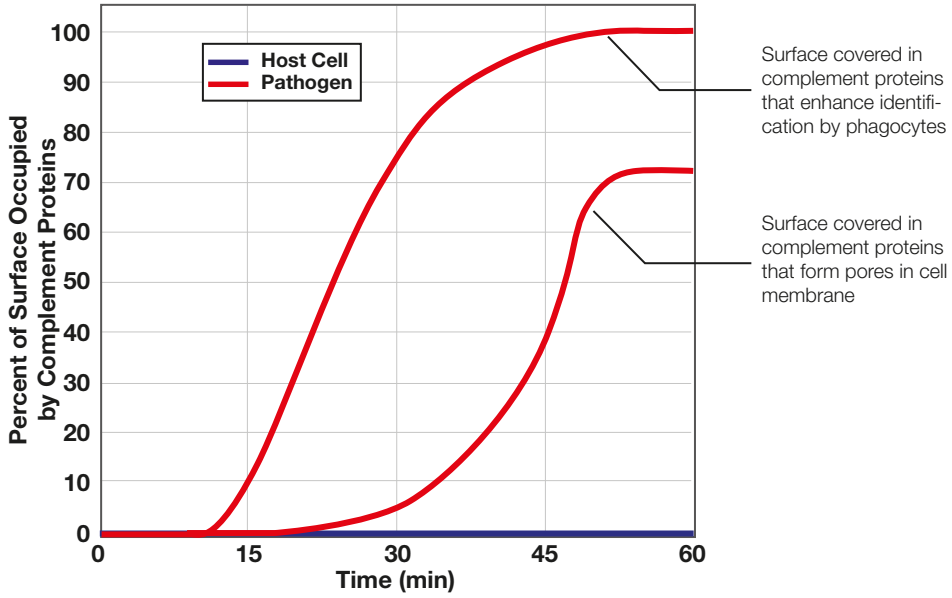
9. *Refer to the image below which shows a phagocytic cell to answer the following question.*



Which of the following options correctly identifies a type of phagocytic cell and the processes happening at steps 1, 3 and 5 in the phagocytic cell above?

	Possible phagocytic cell	1	3	5
J	**Dendritic cell**	Antibodies are killing pathogen	Fusion of lysosome with phagocytic vesicle	Exocytosis of cytokines
K	**Neutrophil**	Pathogen recognition	Fusion of lysosome with phagocytic vesicle	Exocytosis of digested pathogen
L	**Natural killer cell**	Antibodies are killing pathogen	Fusion of lysozyme with phagocytic vesicle	Exocytosis of cytokines
M	**Macrophage**	Pathogen recognition	Fusion of lysozyme with phagocytic vesicle	Exocytosis of digested pathogen

10. *Refer to the graph below which shows the percentage of an E. coli bacterial cell covered with complement proteins over time to answer the following question.*



According to the graph, a likely conclusion is that

J the complement proteins bind to the pathogen at a constant rate.
K there are only 2 types of complement proteins that act on pathogens.
L only 50% of the bacterium can be covered in complement pore forming proteins before the cell ruptures.
M it takes complement about 50 minutes to coat the entire surface of an E.coli bacterium.

Free response questions

1. Describe why the innate immune response is considered non-specific, broad and rapid.

a) Non-specific

b) Broad

c) Rapid

2. Complete the table by outlining the main role(s) of the cells of the innate immune system:

Leukocyte	Role(s)
Neutrophils	
Mast cells	
Macrophages	
Dendritic cells	
Natural killer cells	

3. a) State the name of the chemical released to attract phagocytic cells to a site of injury.

   b) State the name of the most abundant phagocytic cell in the innate immune system.

   c) Describe how phagocytic cells recognise and engulf a pathogen.

   d) Describe the events that occur inside a phagocytic cell to destroy the pathogen.

4. a) Describe what fever is.

   b) Describe how fever assists the innate immune response.

5. During a viral infection, viruses enter host cells and use their machinery to replicate. Infected cells can communicate with uninfected cells.
   a) State the name of the chemical released by infected cells to communicate with uninfected cells.

   b) Describe **two** actions these chemicals can initiate in uninfected cells to increase their defences against the invading virus.

6. An individual was completing a woodwork project at school and noticed that a splinter had penetrated the skin.
   a) State the role(s) of inflammation.

   b) State the symptoms that this individual is likely to exhibit.

c) Explain the mechanisms involved in the inflammatory response that is activated once the splinter penetrated the skin.

7. a) Describe what the complement system is.

b) Describe what happens when the complement system is activated.

The complement system can stimulate a variety of immune responses.

c) Describe the **three** main responses of the complement system.

8. Other organisms such as invertebrates, plants and fungi also have innate immune responses.

a) State **one** physical barrier that insects have to help prevent the entry of pathogens.

b) State **two** physical barriers that plants have to help prevent the entry of pathogens.

c) (i) State **two** antimicrobial chemicals that plants secrete.

(ii) Describe how humans use the two chemicals identified in part (c)(i) above.

d) Describe how insects and plants recognise pathogens that penetrate their physical barriers.

e) (i) State **one** chemical barrier that fungi have developed to defend themselves against bacteria.

(ii) Explain the function of the chemical barrier identified in part (e)(i).

f) Describe **two** innate immune responses that bacteria have developed to defend themselves against invading microorganisms.

Chapter 2.8 The third line of defence

Science Understanding

- Describe how the adaptive (acquired) immune system responds specifically to antigens.
- Describe how the human body responds specifically to foreign antigens by the adaptive immune system.

Exposure to an antigen is required for acquired immunity. This may be acquired through passive or active processes.

Passive immunity may be acquired from maternal antibodies or antibody serum injection.

Active immunity may be acquired through natural exposure to a pathogen or through vaccination.

The third line of defence is the **adaptive immune system**, also known as the acquired immune system, which is characterised by its **specificity** and ability to retain **memory** of prior infections. Infections can be caused by pathogens that exist either intracellularly (inside host cells, such as viruses and some bacteria) or extracellularly (outside host cells, such as most bacteria, fungi, and parasites). **Intracellular pathogens are targeted by the cell-mediated immune response**, which relies on T cells to destroy infected cells or activate other immune cells. **Extracellular pathogens are primarily countered by the humoral immune response**, in which B cells produce antibodies to neutralise pathogens and facilitate their clearance, making both arms of the immune system essential for widespread protection.

The lymphatic system

The human lymphatic system is an essential component of the body's immune and circulatory systems, playing a crucial role in **defending against infections**, maintaining fluid balance (see Chapter 3.4: The circulatory system), and facilitating the absorption of dietary fats (see Chapter 3.5: The digestive system). The lymphatic system is a network of vessels, lymph nodes, and specialised organs that circulates **lymph**, **a fluid containing lymphocytes**, and filters it to remove pathogens, cellular debris, and foreign particles.

Scientists classify the lymph organs as primary and secondary. The primary organs are those where the **lymphocytes** mature, such as the **bone marrow** (B cells) and **thymus gland** (T cells). Some secondary organs include the lymph nodes, spleen, tonsils and adenoids. Lymph nodes filter lymph and house immune cells. The spleen filters blood, removes old red blood cells, and provides a site for immune cell activation and the tonsils and adenoids trap pathogens entering through the mouth and nose (see Figure 2.8.1).

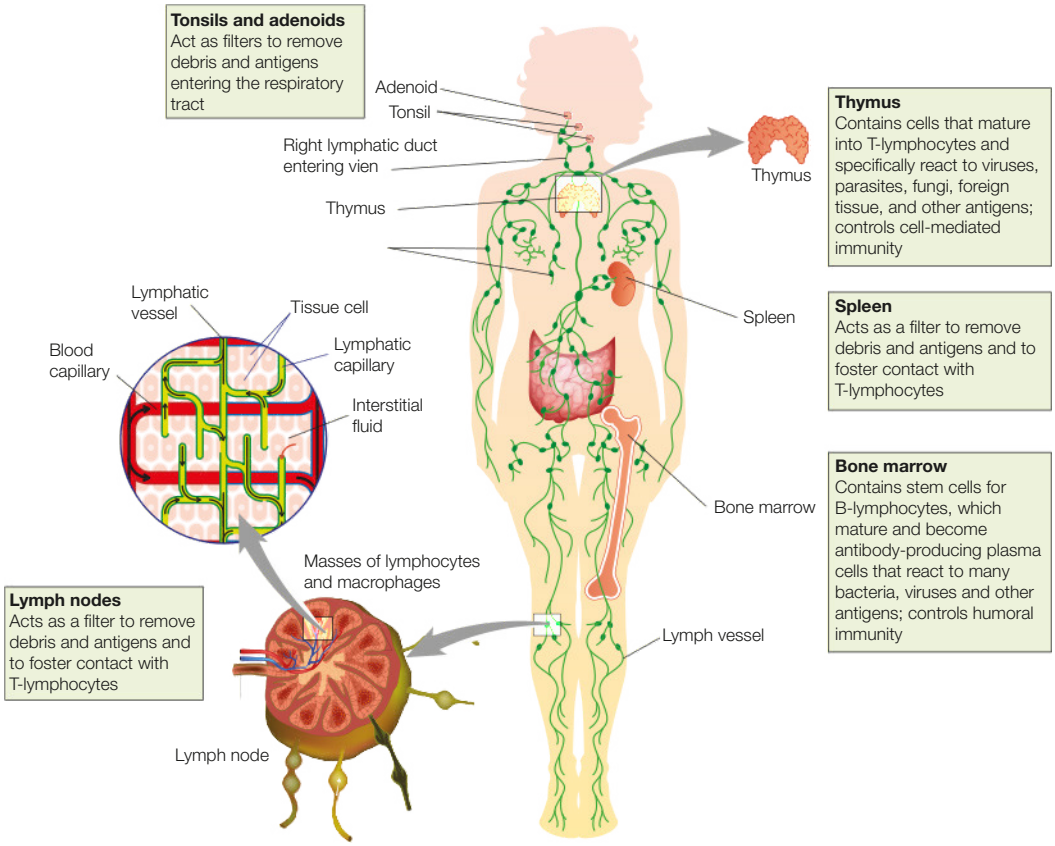


Figure 2.8.1: An overview of the lymphatic system.

Major histocompatibility complex (MHC) proteins

The major histocompatibility complex (MHC) proteins are cell-surface markers that play a critical role in the immune system by distinguishing between self and non-self. They are different to the pattern recognition molecules of the innate immune cells as they **present antigens for specific recognition**, not general patterns. There are two types of MHC proteins, MHC class I and MHC class II. **MHC Class I** molecules are found on the surface of nearly all cells with a nucleus (nucleated cells). **They present peptide fragments from intracellular proteins**. Healthy cells display normal self peptides, while infected or abnormal cells present foreign or altered peptides (non-self), signalling the immune system to destroy them. **MHC Class II** molecules are expressed primarily on antigen-presenting cells (APCs) and **present peptides from extracellular pathogens**, activating the adaptive immune system.

Antigen-presenting cells

The adaptive immune system is activated by antigen-presenting cells (APCs) of the innate immune system. Antigen-presenting cells, such as **dendritic cells and macrophages**, detect, engulf and digest pathogens as part of the innate immune response. These phagocytic cells can transport and **present digested fragments (antigens)** of the pathogen to the cell's surface using **MHC Class II proteins**. Here, the displayed antigens act as an indicator to T-helper lymphocytes, which then activate other adaptive immune cells. This interaction triggers the adaptive immune response, enabling a targeted attack on the specific pathogen.

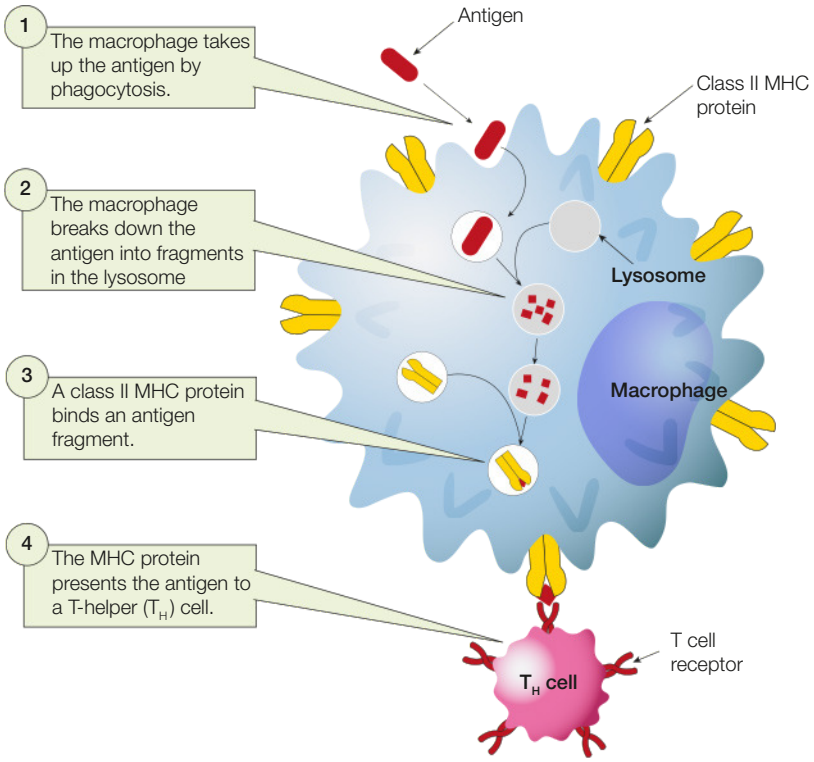


Figure 2.8.2: Antigen-presenting cells (APCs), such as dendritic cells and macrophages, bridge the innate and adaptive immune systems by presenting antigens to T-helper (T_H) cells using MHC Class II surface proteins.

Lymphocytes

Lymphocytes are a type of white blood cell (leukocyte) that plays a central role in the adaptive immune response, helping the body recognise and **combat specific pathogens**. The **two major types of lymphocytes are B cells and T cells**. B cells are responsible for producing antibodies that target extracellular pathogens, while T cells mediate cellular immunity, with cytotoxic T cells killing infected or abnormal cells and helper T cells coordinating immune responses. Both types of lymphocytes develop in the bone marrow. **B cells stay and mature in the bone marrow, but T cells migrate to and mature in the thymus.**

Helpful online resources

Kurzgesagt – In a Nutshell: How The Immune System ACTUALLY Works – IMMUNE

https://www.youtube.com/watch?v=lXfEK8G8CUI

T lymphocytes and the cell-mediated response

Cell-mediated immunity is an adaptive immune response **targeting infected or abnormal cells**. It generally begins when antigen-presenting cells (APCs) display antigens on their surface using MHC Class II molecules, activating **T-helper cells**. Every individual has billions of unique T-helper cells, each with their own specific antigen binding capability (see Figure 2.8.3). This technically means that every individual has a T-helper cell specific to every possible pathogen. This allows humans to combat pathogens that are constantly adapting through random mutations that result in antigenic variation (see Chapter 2.5). These T-helper cells remain in the lymphatic system awaiting activation by antigen-presenting cells (APCs). Once the unique T-helper cell is activated, it divides into thousands more unique T-helper cells, which then perform multiple roles such as:

- migrating to the site of infection or injury to help with the immune response directly
- differentiating into T-cytotoxic cells, which recognise and kill infected cells (if the pathogen enters host cells)
- searching for and activating the corresponding unique B cells through secretion of cytokines (activating the humoral immune system)
- differentiating (changing) into T-memory cells at the conclusion of the response, that remain in circulation and enable a quicker and stronger response if the pathogen invades again.

It takes time for the APC to locate the unique T cell among the billions of different T cells. It also takes time for this original T-helper cell to divide into thousands of copies once located and for one of them to locate the corresponding B cell in the lymphatic system. The time taken for these events to occur contribute to the delay in the immune system mounting a specific response during the first time a pathogen is encountered, also called the **primary response**.

Additionally, T-suppressor cells (also known as regulatory T cells) mature in the thymus and play a role in downregulating immune responses, preventing excessive activation and autoimmune diseases. Refer to Table 2.8.1 for a summary of the four types of T cells and their roles in the adaptive immune system.

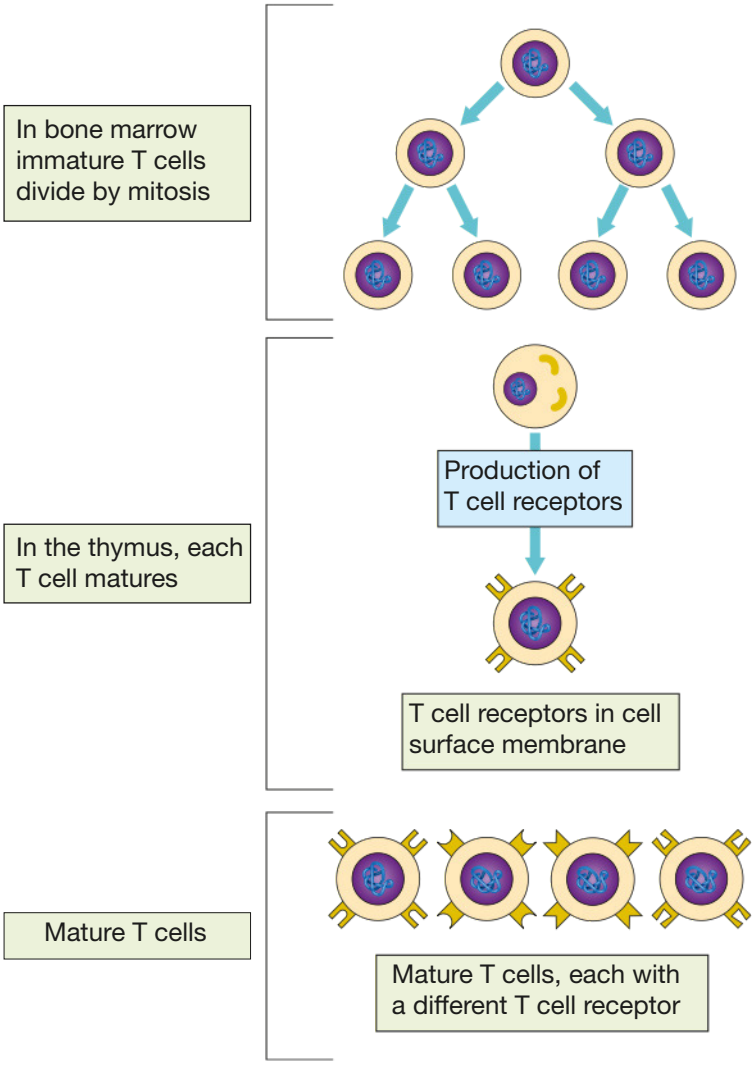


Figure 2.8.3: T lymphocytes develop in the bone marrow but migrate to the thymus where they mature into billions of unique T-helper cells each with a unique receptor for a specific antigen.

Table 2.8.1: A summary of the four types of T-cells.

T-cell	Description of role(s) in adaptive immune system
T-helper	T-helper cells are the bridge between innate and adaptive immune responses. T-helper cells are activated by antigen-presenting cells when presented with a specific antigen. They then activate T-cytotoxic cells and B-cells by secreting communication proteins called cytokines.
T-cytotoxic	Also known as T-killer cells, T-cytotoxic cells directly kill infected, cancerous, or abnormal cells by recognising non-self antigen fragments presented on MHC Class I molecules on host cells. They achieve this by secreting chemicals that induce apoptosis, which is a clean cell death.
T-memory	T-memory cells are long-lived T cells that remember specific pathogens the immune system has previously encountered. Upon re-exposure to the same pathogen, they rapidly activate and mount a faster, stronger immune response, providing long-term specific immunity.
T-suppressor	T-suppressor cells, also known as regulatory T cells, help maintain immune system balance by suppressing excessive immune responses and preventing autoimmunity.

Helpful online resources

Kurzgesagt – In a Nutshell: You Are Immune Against Every Disease

https://www.youtube.com/watch?v=LmpuerlbJu0

B lymphocytes and humoral immunity

Humoral immunity is an adaptive immune response that **targets pathogens in extracellular spaces**, such as the blood and lymph. Every individual has billions of unique B cells, each with their own specific antigen binding capability, just like T-helper cells (see Figure 2.8.4). However, these B cells have a different role to T-helper cells, they differentiate into **B-plasma cells and produce and secrete specific antibodies** into the bloodstream to neutralise pathogens.

B cells can be activated by directly recognising specific antigens through their surface antibodies, by antigens being presented to them by T-helper cells, and by signals from cytokines released by T-helper cells. Once activated, the unique B cell differentiates and divides into B-plasma cells and continues to divide until there are thousands of copies of the cell. They then migrate to the site of infection/injury where they secrete approximately 2000 antibodies per second. Additionally, some activated B cells differentiate into **B-memory cells**, which persist in the body and **provide immunity** by enabling a faster and stronger response upon subsequent exposure to the same antigen, called a **secondary response** (see Figure 2.8.4).

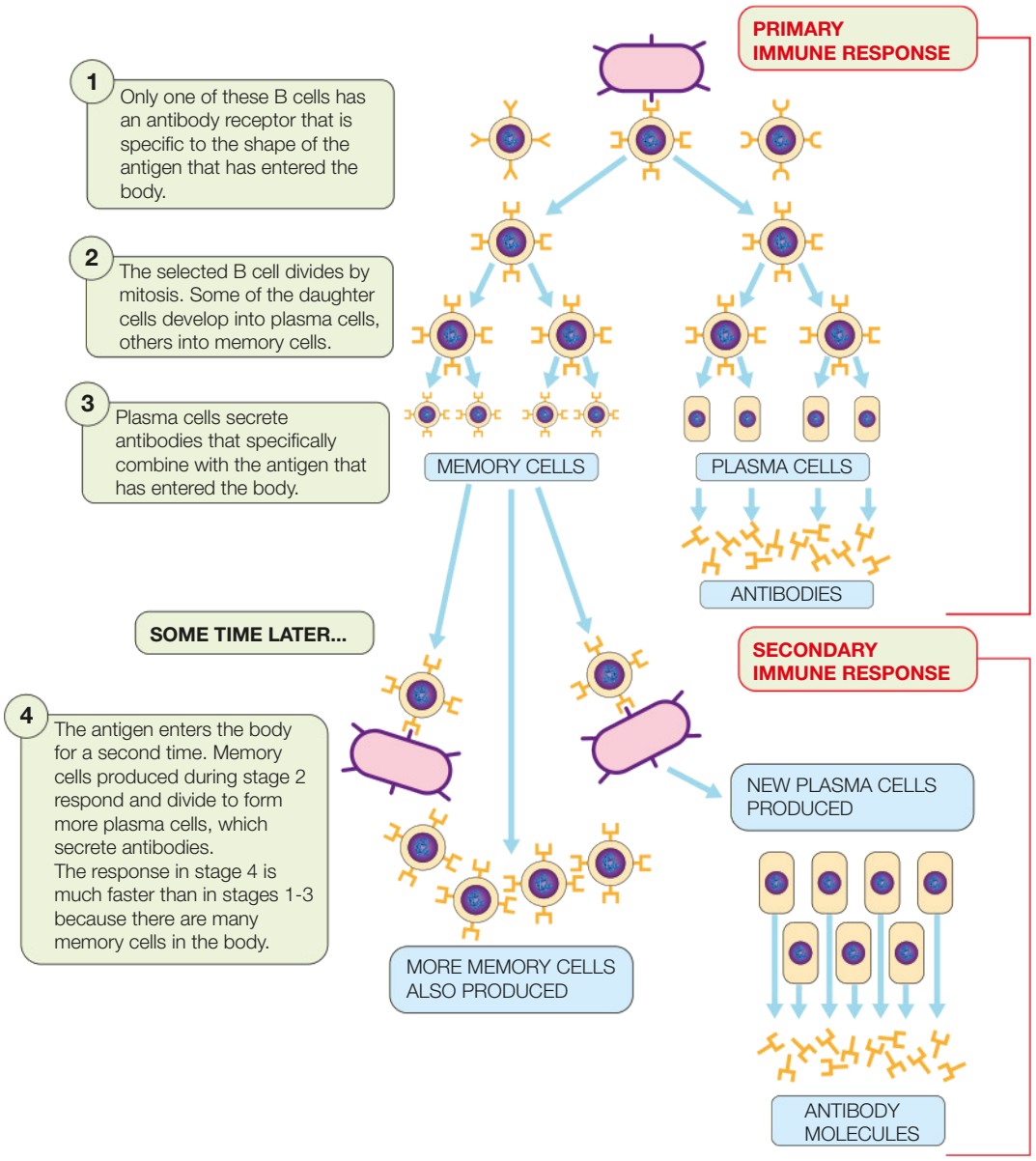


Figure 2.8.4: An overview of the humoral immune response.

Antibodies

Antibodies are Y-shaped proteins produced by B-lymphocytes that play a crucial role in the immune response by binding to specific antigens, which can include pathogens, their toxins, pollen, blood cell surface molecules, and proteins on transplanted tissues (see Figure 2.8.5). Each antigen has a corresponding specific antibody. The primary functions of antibodies include:

- neutralising pathogens and their toxins by blocking their ability to infect or damage cells
- acting as anti-toxins by binding to harmful toxins and rendering them harmless
- marking pathogens for easier identification and engulfment by phagocytes
- immobilising bacteria by binding to their flagella
- reducing the spread of pathogens by clumping them together (called agglutination) making it easier for phagocytic cells to engulf them, and
- in some cases, they can assist in activating the complement system, which results in pore formation in the pathogens cell wall/membrane and the pathogen bursting open.

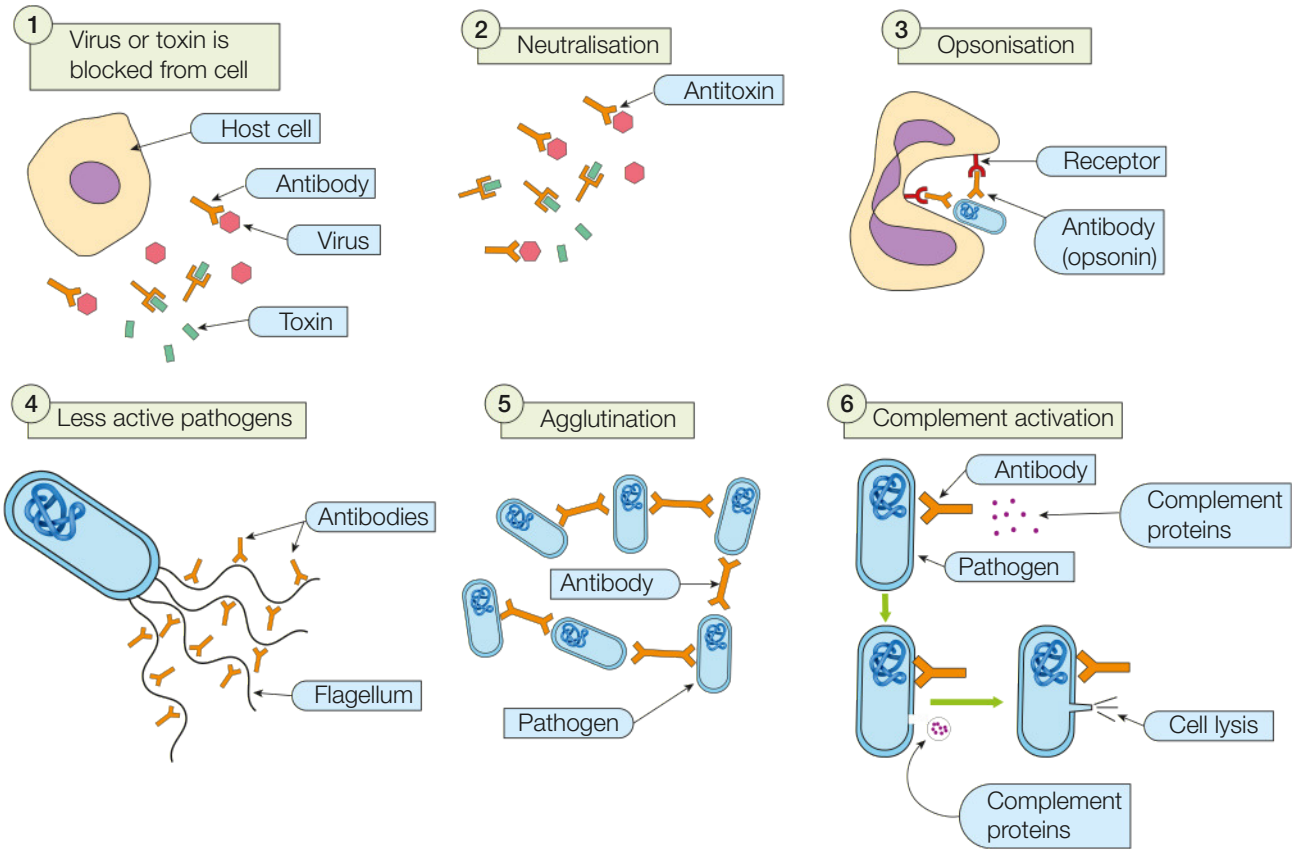


Figure 2.8.5: A visual representation of the main functions of antibodies.

Primary vs secondary responses

The primary adaptive immune response occurs when the immune system encounters a pathogen for the first time, leading to a slower response as immature T and B cells are activated and antibodies are produced (see Figure 2.8.6). It takes days to weeks to develop, with lower antibody levels and less specificity. In contrast, the secondary adaptive immune response is faster, stronger, and more specific due to the activation of memory T and B cells generated during the primary response. This results in higher antibody levels and a quicker elimination of the pathogen, providing more effective immunity (see Figure 2.8.7).

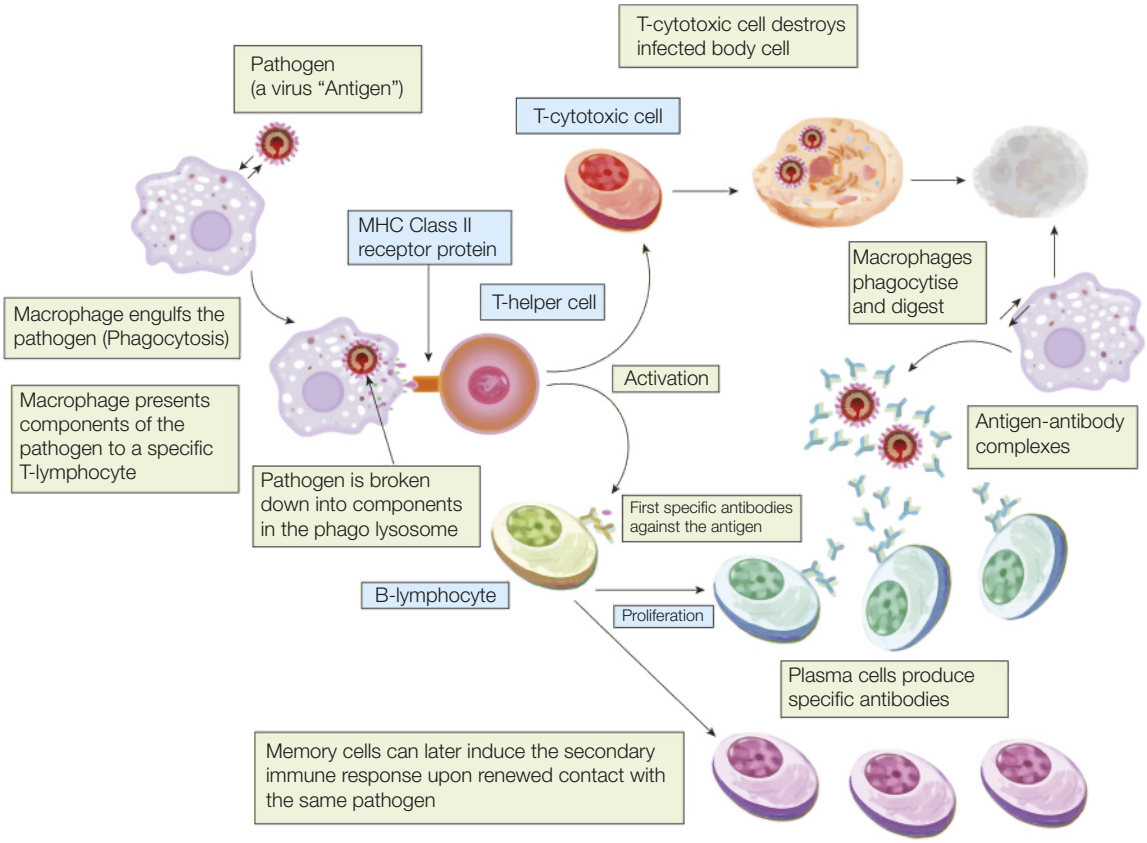


Figure 2.8.6: A summary of the processes in the primary immune response.

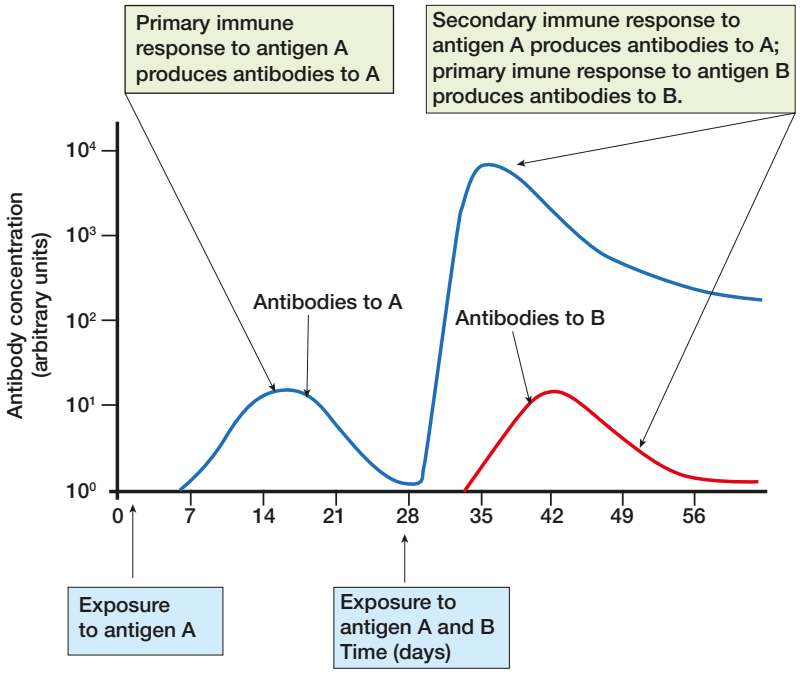


Figure 2.8.7: A comparison of the concentration of antibodies secreted and time taken for antibody secretion to occur post-exposure for a primary and secondary response.

Active and passive immunity

Exposure to an antigen is required for acquired immunity. The four types of immunity are classified based on how immunity is acquired and whether it is active or passive (see Table 2.8.2 and Figure 2.8.8). Active immunity develops when an individual's adaptive immune system is responsible for the protection, whereas passive immunity is when immunity is gained from someone else. Additionally, natural immunity occurs when immunity is acquired through natural exposure to a pathogen or transfer of antibodies, while artificial immunity is gained through medical interventions.

Table 2.8.2: The four types of immunity individuals can develop throughout their life.

Type of immunity	Description of type of immunity
Natural active immunity	This occurs when the body produces its own immune response to a pathogen **after natural exposure**. For example, recovering from an illness like influenza results in the development of memory cells, providing long-term protection.
Artificial active immunity	This develops when the body produces an immune response after being **exposed to antigens through vaccination**. Vaccines stimulate the immune system to form memory cells without causing disease.
Natural passive immunity	This involves the transfer of antibodies from one individual to another without the recipient's immune system producing them. An example is **maternal antibodies passed to a baby through the placenta or breast milk**, providing short-term protection.
Artificial passive immunity	This occurs when **pre-made antibodies are injected into a person** to provide immediate, short-term protection. For example, antivenoms for snake bites or antibody treatments for particularly virulent pathogens, such as the rabies virus, confer this type of immunity.

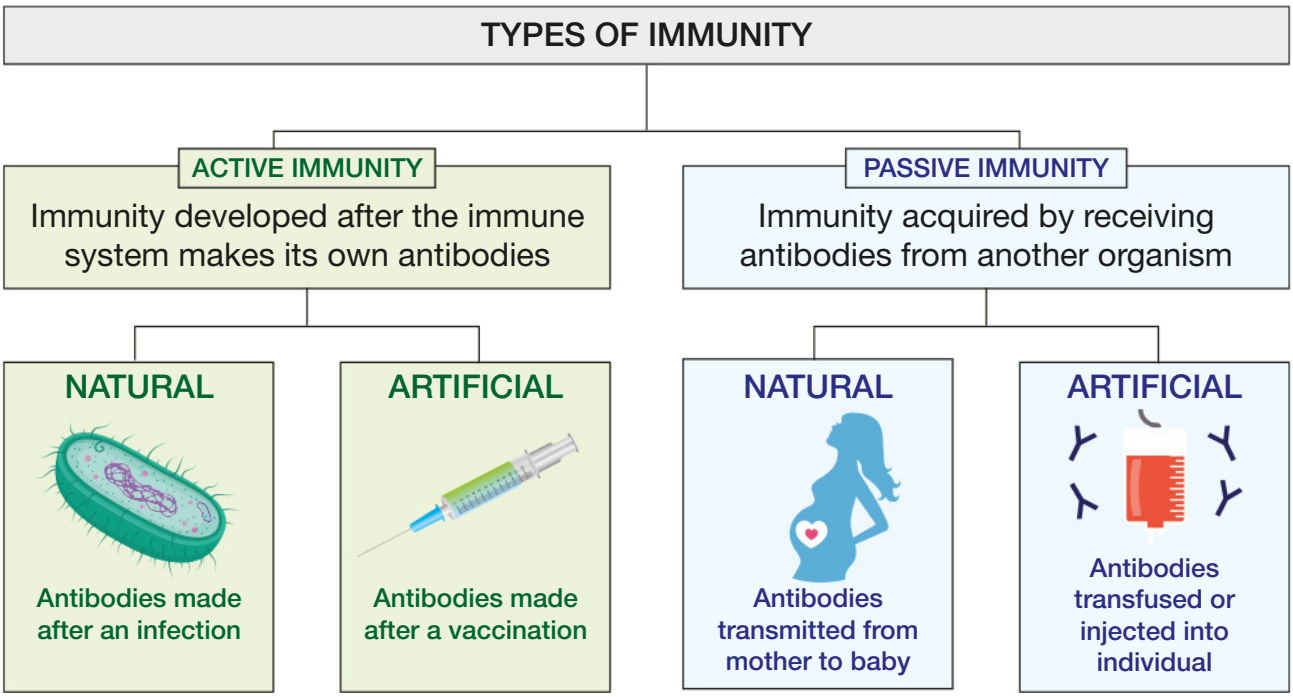


Figure 2.8.8: A summary of the four types of immunity.

2.8 Review questions

Multiple choice questions

1. Which of the following is **not** a characteristic of adaptive immunity?
   - J Specificity for antigens
   - K Immunological memory
   - L Rapid response within hours
   - M Can eliminate targets inside and outside cells
2. The main two types of lymphocytes in the adaptive immune system are
   - J natural killer cells and B cells.
   - K T cells and B cells.
   - L B cells and macrophages.
   - M T cells and dendritic cells.

3. T lymphocytes mature in the

   J bone marrow.
   K lymph node.
   L spleen.
   M thymus.

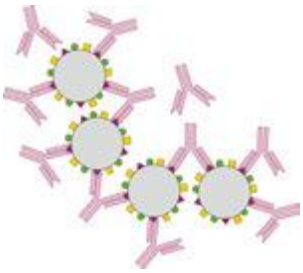
4. Following an influenza vaccination, the adaptive immune system is triggered. Which of the following types of cells is responsible for the production of antibodies?

   J T-helper cells
   K T-cytotoxic cells
   L B-plasma cells
   M B-memory cells

5. Which of the following options correctly identifies three features of the adaptive immune system?

	Antibodies synthesised	Involves memory	Effective period
J	Yes	Yes	Long term
K	Yes	No	Short term
L	No	Yes	Long term
M	No	No	Short term

6. *Refer to the image to the right which shows some antibodies responding to some pathogens to answer the following question.*



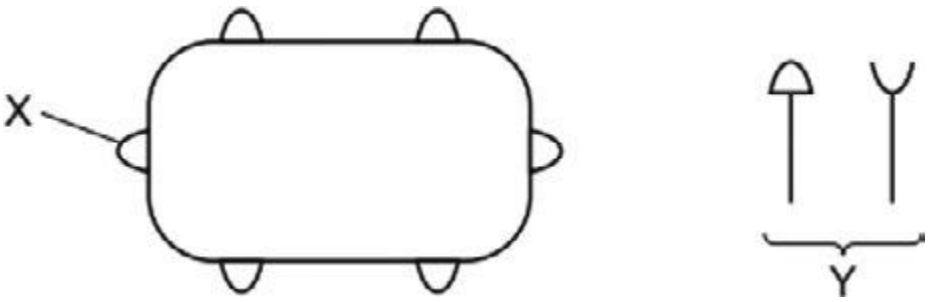
   The vital function of the antibodies displayed is

   J the neutralisation of toxins.
   K the direct destruction of the pathogens.
   L the prevention of pathogens binding to antigens.
   M agglutination, which makes the role of phagocytes easier.

7. Which of the following options best describes why both the cell-mediated and humoral immune responses are required for adaptive immunity?

   J Only the humoral immune response produces memory cells and therefore both immune responses are required for secondary exposures.
   K The cell-mediated response provides a general non-specific immune response whilst the humoral immune response provides a targeted and specific response.
   L Adaptive immunity requires the action of antigen presenting cells of the cell-mediated response and the T-helper cells of the humoral response to activate B memory cells.
   M The cell-mediated response defends against infected cells and the humoral response defends against extracellular pathogens.

8. *Refer to the diagram below which shows a bacterium with a structure labelled 'X' and some proteins made by the human body labelled 'Y' to answer the following question.*



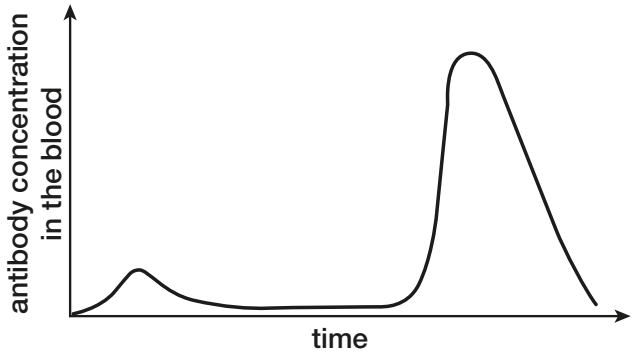
   Which of the following options correctly identifies X, Y and the correct shape of Y to aid in the bacterium's destruction?

	Name of X	Name of Y	Correct shape of Y
J	Antigen	Antigen	
K	Antigen	Antibody	
L	Antibody	Antigen	
M	Antibody	Antibody	

9. Which of the following options correctly identifies an example of artificial passive and natural active immunity?

	Artificial passive immunity	Natural active immunity
J	Receiving antibodies to rabies in injection	Immunity to whooping cough developed after vaccination
K	Receiving antibodies to whooping cough in breastmilk	Immunity to whooping cough developed after vaccination
L	Receiving antibodies to rabies in injection	Immunity to influenza developed after infection
M	Receiving antibodies to whooping cough in breastmilk	Immunity to influenza developed after infection

10. *Refer to the graph below which shows the concentration of measles antibodies in a child's bloodstream during a period in which the child was vaccinated against measles and later infected with the measles virus to answer the following question.*



Which of the following statements is consistent with the information displayed in the graph?

J The vaccination against measles was insufficient due to the large spike displayed during the second exposure.

K The vaccination produced a small increase in antibodies but did not produce memory cells, however the second exposure did produce memory cells.

L When the measles antigen was detected by the T-memory cells during the second exposure they immediately started secreting antibodies, hence the greater concentration in the blood during the second exposure.

M Repeated exposures to the measles pathogen allows the immune system to produce stronger and faster immune responses.

Free response questions

1. Describe **two** main ways that the adaptive immune response differs from the innate immune response.

2. Describe why both B and T lymphocytes are required in the adaptive immune response.

3. The lymphatic system is an essential component of the immune system.
   a) Outline what the lymphatic system is.

   b) State the primary organs where B lymphocytes and T lymphocytes develop and mature respectively.

Type of lymphocyte	Primary organ of lymphatic system where they develop	Primary organ of lymphatic system where they mature
B lymphocytes		
T lymphocytes		

4. a) Outline what the major histocompatibility complex (MHC) proteins are.

   b) Compare the roles of MHC Class I and MHC Class II molecules.

5. Place the terms listed below into the table in their correct category to illustrate your understanding of the first, second and third lines of defence:

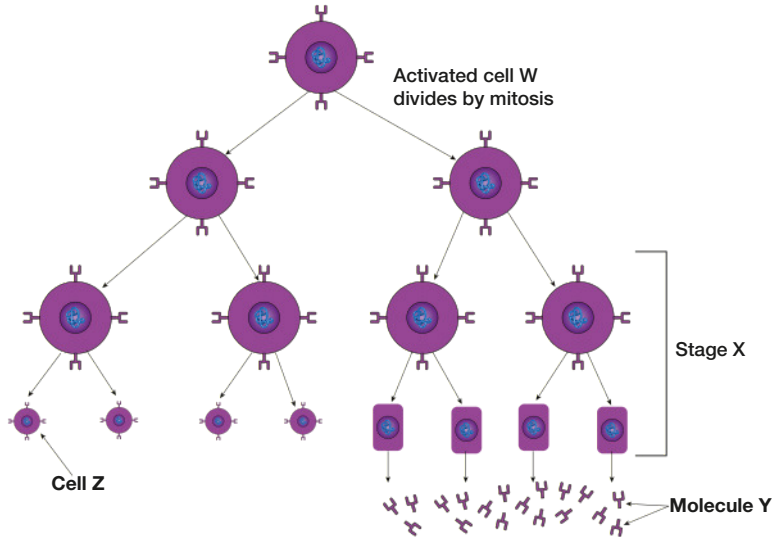
   antibodies, earwax, macrophages, cytokines, skin, inflammation, B cells, Major Histocompatibility Complex (MHC), T-cytotoxic cells, lysozymes, neutrophils.

First line of defence	Second line of defence	Third line of defence

6. Below is a list of processes (a to h) that can occur as part of the adaptive immune response. These processes are not in the correct order. Determine the correct order that these steps would generally occur in for a viral infection.

   a) B plasma cells release antibodies.
   b) T-cytotoxic cells release chemicals to destroy infected cells.
   c) Macrophages display antigen fragments using MHC proteins.
   d) Antibodies neutralise antigens.
   e) Macrophages engulf pathogens.
   f) T-helper cells activate other B and T lymphocytes.
   g) T-helper cells bind to antigens attached to the MHC and then multiply.
   h) Memory cells move to the spleen and lymph nodes.

7. *Refer to the diagram below which shows part of the adaptive immune response to answer the following questions.*



   a) Identify cell W.

   b) State **one** way that cell W could be activated to bring about the processes displayed in the diagram above.

   c) Describe the process occurring at Stage X.

   d) (i) Identify molecule Y.

      (ii) Describe **three** primary functions of molecule Y.

   e) (i) Identify cell Z.

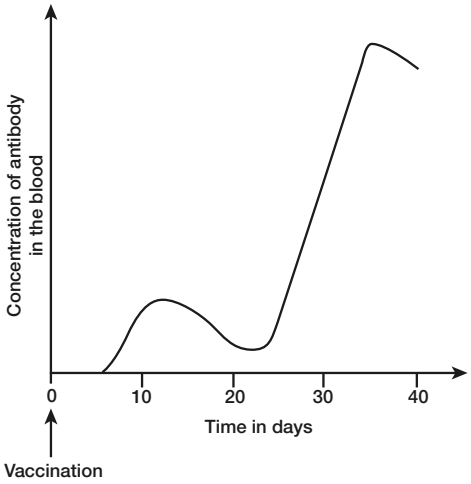
(ii) Describe the role of cell Z in the adaptive immune response.

8. a) Describe the difference between active and passive immunity.

b) Describe the difference between naturally acquired and artificially acquired immunity.

9. Discuss how the innate and adaptive immune responses work together to help eliminate pathogens.

10. *Refer to the graph below which shows the concentration of an antibody produced in response to an antigen in a vaccine (at day 0) to answer the following questions.*



a) Describe what a vaccination is.

b) (i) State **two** reasons why the antibody concentration in the blood remains at 0 units between days 0 and 5.

(ii) Explain the main events of the adaptive immune system occurring between days 0 and 5.

c) With reference to the graph, explain what is happening between days 5 and 20.

d) (i) Identify the likely event that occurred at day 23.

(ii) Describe the trend in the concentration of the antibody in the blood after day 23.

(iii) Explain the difference in the concentration of the antibody in the blood after day 23 when compared to trend observed in the previous 22 days.

11. Every year in Australia people die after being bitten by venomous snakes.

a) Explain why a vaccination designed to stimulate the lymphocytes would be an ineffective treatment to administer immediately after a person is bitten by a snake.

b) Identify **and** explain the treatment option that should be used to save the life of a person who was bitten by a poisonous snake.

Topic 2 Review Test: Infectious Disease

It is recommended that 85 minutes is allocated to complete this test. Indicate your choice for each multiple choice question (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks allocated for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (10 marks)

1. Which of the following options is correct regarding infectious and infectious disease?

   J Non-infectious diseases are caused by pathogens.
   K Vectors are always required for the spread of pathogens.
   L A pandemic is confined to a particular country or region.
   M An epidemic is a disease that affects a large number of people in a population.

2. Which of the following would be the least effective in controlling the spread of malaria?

   J Isolating infected individuals in quarantine.
   K Spraying with insecticides.
   L Using netting surrounding sleeping areas at night.
   M Wearing clothing that fully covers the skin.

3. Which one of the following correctly identifies a disease, the microbe that causes this disease and the most frequent mode of transmission of the disease?

	Disease	Type of microbe	Method of transmission
J	Influenza	Bacteria	Droplet infection
K	Rabies	Virus	Vector
L	Cholera	Virus	Faeces
M	Ring worm	Fungus	Airborne spores or contact

4. Which of the following options provides two cellular pathogens?

   J Bacteria and viruses.
   K Parasites and prions.
   L Paramecia and viruses.
   M Fungi and bacteria.

5. Which of the following options is **not** a true statement regarding herd immunity?

   J It provides general protection for a population which arises as large numbers of the population are immune to a specific infection.
   K It can be brought about by natural or artificial means.
   L It only provides protection to those members of the population who have been exposed to the pathogen.
   M The immunity refers to a specific pathogen.

6. The number of susceptible hosts over the course of an influenza epidemic will

   J Fluctuate
   K Increase
   L Decrease
   M Stay the same

7. Which one of the following identifies a component or response by the human immune system in each of the appropriate categories?

	First line of defence	Innate response	Adaptive response
J	Skin	Phagocytosis	Inflammatory response
K	Coughing/sneezing	Fever	Antibodies
L	Stomach acid	Antibodies	Helper T cells
M	Mucus	Inflammatory response	Complement proteins

8. Which of the following cells directly destroys virus infected cells during an innate immune response?

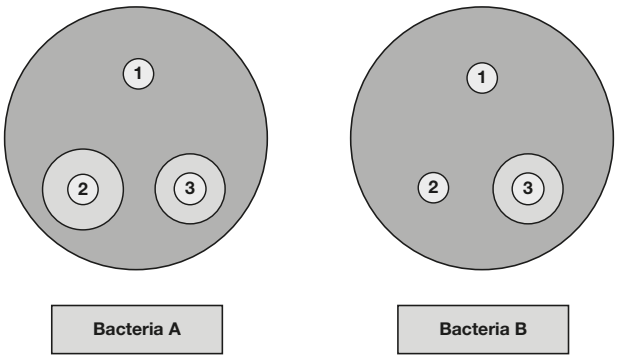
J T-cytotoxic cells
K Complement proteins
L Natural killer cells
M B-plasma cells

9. Influenza is an infectious disease that is highly prevalent in many countries and annual outbreaks are common.

Vaccination programs have not been able to eradicate influenza because

J the pathogen is airborne and spreads rapidly.
K influenza is resistant to antibiotics
L influenza mutates rapidly.
M influenza form biofilms which increase their protection from the immune system.

10. *Refer to the diagram below which shows the results of an investigation into the susceptibility of two different bacteria (A and B) to three different antibiotics to answer the question that follows.*



Which of the following options is correct based on the results of this investigation?

J Bacteria A is more resistant to the three antibiotics tested than bacteria B.
K Bacteria A is multi-resistant.
L Bacteria B is the most sensitive to antibiotic 3.
M Bacteria B has less treatment options than bacteria A.

Section 2: Free response questions (70 marks)

11. Diseases can be spread in a range of ways. Droplet infection is one of these mechanisms.

a) Explain what droplet infection is, how it enables the spread of the pathogen and give an example to illustrate your answer.

(3 marks)

b) State **one** other way in which a pathogen can be transmitted, giving an example to illustrate your answer.

(2 marks)

12. The SARS-CoV-2 virus caused the Covid-19 pandemic. There have been multiple strains of SARS-CoV-2 develop since the initial strain. Covid-19 is still spreading through communities and causing widespread impact.

a) Explain the difference between an epidemic and a pandemic.

(2 marks)

b) Explain how multiple strains of SARS-CoV-2 develop.

(4 marks)

c) Explain why individuals who were infected by the original SARS-CoV-2 strain and survived have not necessarily been immune to future strains.

(4 marks)

13. Bacteria have evolved various adaptations to assist their entry and survival in hosts.

a) Describe how pili aid bacteria in the endeavour to infect hosts through the urinary tract.

(2 marks)

Humans have developed many antibiotics to combat bacterial infections but bacteria continue to adapt and develop resistance to antibiotics.

b) Explain **two** ways that antibiotic resistance can spread between bacteria.

(4 marks)

Bacteria have developed an adaptation called biofilm formation.

c) Describe how biofilm formation has helped bacteria adapt to the presence of antibiotics.

(2 marks)

Some antibiotics like sulfamethoxazole inhibit bacteria from synthesising their own folate, which is required for DNA synthesis.

d) Explain why this type of antibiotic is considered bacteriostatic (slows bacterial spread) and not bactericidal (kills bacteria).

(2 marks)

e) Outline **one** other mechanism of antibiotics that bring about their antibacterial effects.

(2 marks)

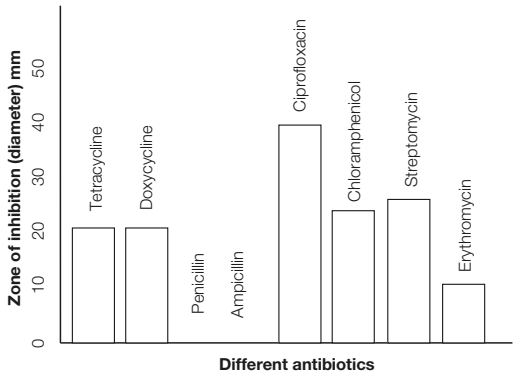
In 2022, researchers discovered a new mechanism of antibiotic resistance in Group A Streptococcus, which bypasses traditional antibiotics by acquiring folates directly from the human host instead of synthesising its own. This is the first time this type of resistance has been discovered in bacteria. This resistance renders the antibiotic sulfamethoxazole ineffective during infections, as the bacteria obtain folate directly from their hosts. This method of resistance is undetectable using current processes in pathology labs as sulfamethoxazole works when tested in vitro (i.e. outside a host using agar plates).

Use your understanding of the interaction between science and society to answer part (f).

f) Discuss the applications and limitations of this investigation.

(6 marks)

Refer to the graph below of an investigation into the effectiveness of eight different antibiotics on the growth of one bacterial species. The antibiotics were soaked into filter paper and placed on an agar plate coated with the bacteria. The agar plate was then incubated for 48 hours at 37°C and the zones of inhibition were measured immediately after removing from the incubator.



g) State the dependent variable of this investigation.

(1 mark)

h) (i) Based on the results of this investigation, state which antibiotic would be the most effective to administer to an individual infected with this particular strain of bacteria.

(1 mark)

(ii) Justify your answer to part (h)(i)

(2 marks)

i) (i) Identify **one** possible systematic error that could have affected the results of this experiment.

(1 mark)

(ii) Explain the impact on the data if the error identified in part (i)(i) occurred.

(2 marks)

Prior to spreading the bacteria on the agar plate, the investigators used an aseptic technique, which is a procedure that is used to prevent the spread of bacteria that cause infection. This involved the use of antiseptics.

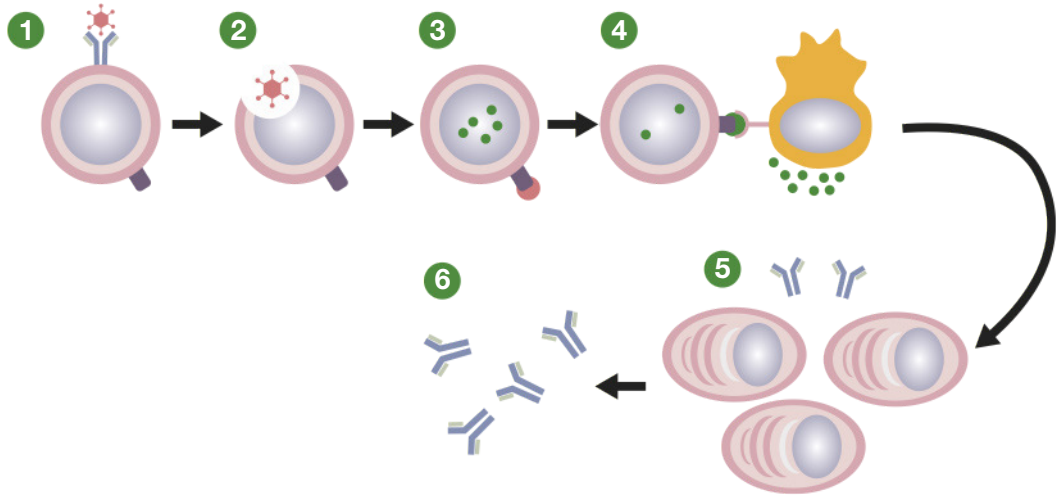
j) Describe what an antiseptic is **and** compare the application of antibiotics and antiseptics.

(3 marks)

k) Explain the impact on the results if the aseptic technique was unsuccessful and there was more than one species of bacteria discovered growing on the agar plate from which the results displayed were collected?

(2 marks)

14. *Refer to the diagram below showing the detection of a viral pathogen by an immune cell (at step 1) and some of the processes that followed in this immune response (steps 2 to 6) to answer the following questions.*



This viral pathogen was able to penetrate through this host's first line of defence.

a) Explain how mucous membranes of the respiratory tract generally protect against pathogens even though it was not successful this time.

(4 marks)

b) Describe the lifecycle of a virus.

(3 marks)

c) Identify the type of cell displayed at step 1.

(1 mark)

d) Describe the processes occurring in steps 2 and 3.

(4 marks)

e) Identify the new cell introduced at step 4 **and** explain the process occurring during this step.

(4 marks)

The cells at step 5 are then activated and they release the molecules shown at step 6.

f) State the name of the immune response that the cells displayed in step 5 are a part of.

(1 mark)

g) Identify the molecules displayed at step 6 **and** describe **two** different ways that they assist this immune response.

(3 marks)

Many of the host's body cells have been infected by this viral pathogen.

h) Explain why the processes shown in this diagram alone are not enough to clear this infection from the host's body.

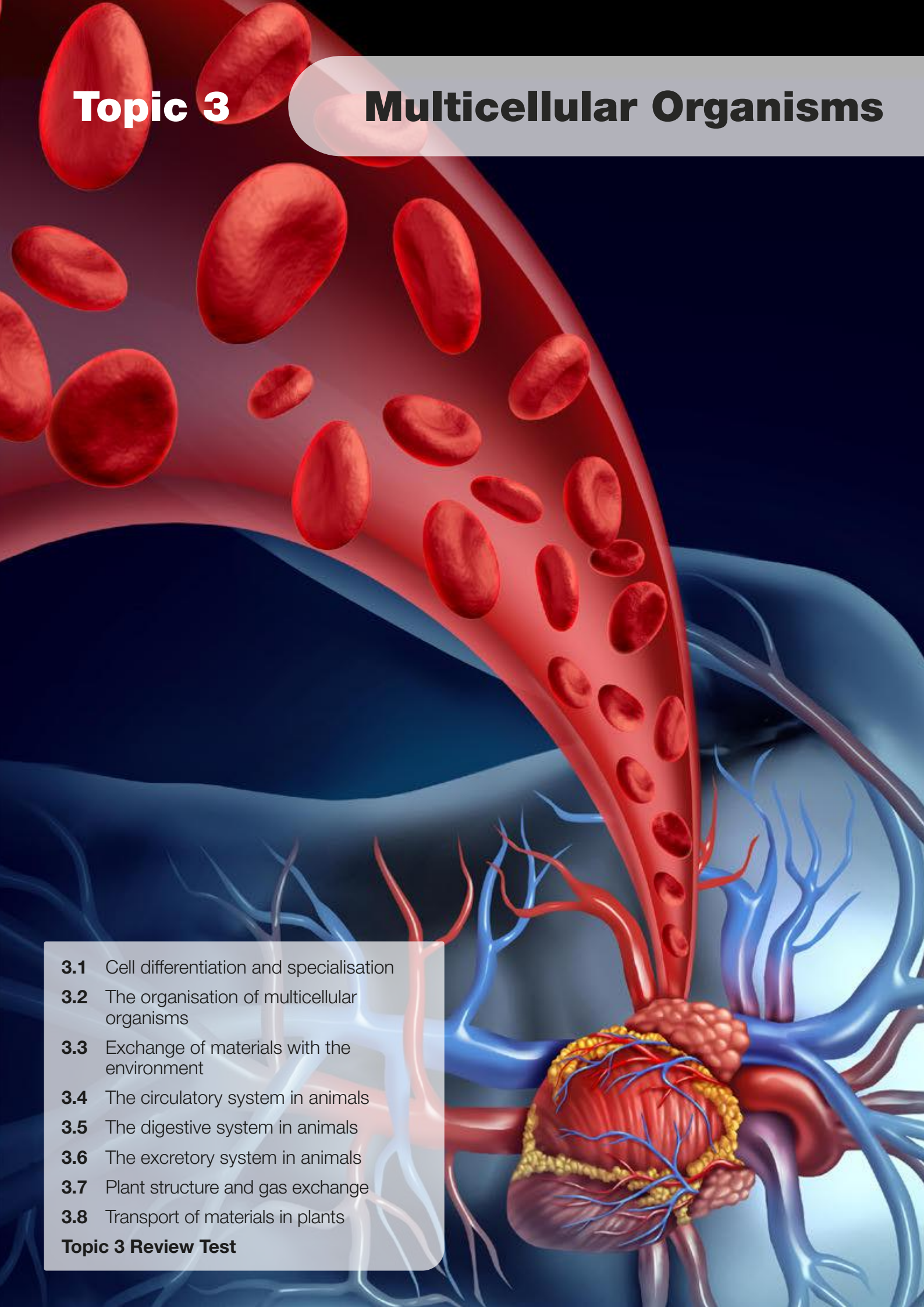
(4 marks)

i) Identify the type of immunity developed against this virus following the completion of this immune response.

(1 mark)

Total: /80

Topic 3 Multicellular Organisms



Chapter 3.1 Cell differentiation and specialisation

Science Understanding

Specific cell structure and functions develop through cell differentiation.

Different bacteria require specific conditions for growth.

- Recognise that:
  - cells in a multicellular organism are genetically identical
  - gene expression is responsible for cell specialisation.

The genetic code

The genetic code is the set of rules by which the information encoded in DNA sequences is translated into proteins by living cells. The **genetic code is universal across all living organisms**, highlighting its fundamental role in biology and evolution.

DNA

Deoxyribonucleic acid (DNA) is a very long molecule that carries genetic information, which is a 'blueprint' of instructions for an individual. Each DNA molecule consists of regions of coding DNA, called exons, and regions of **non-coding DNA**, called introns. DNA molecules consist of **two complementary strands** that wind around each other to form a **double helix** (see Figure 3.1.1). Each strand consists of a sugar-phosphate backbone and a specific sequence of DNA bases. There are four DNA bases: adenine (A), thymine (T), cytosine (C) and guanine (G). Each base forms **weak hydrogen bonds** with its complementary base located at the same position on the other strand (see Figure 3.1.1). The DNA base pairing rules are:

- **A and T:** A only base pairs with T with 2 hydrogen bonds forming between the base pair
- **C and G:** C only base pairs with G with 3 hydrogen bonds forming between the base pair

The complementary nature of the two DNA strands allows it to be replicated prior to cellular division so the genetic information can be passed from parents to their offspring.

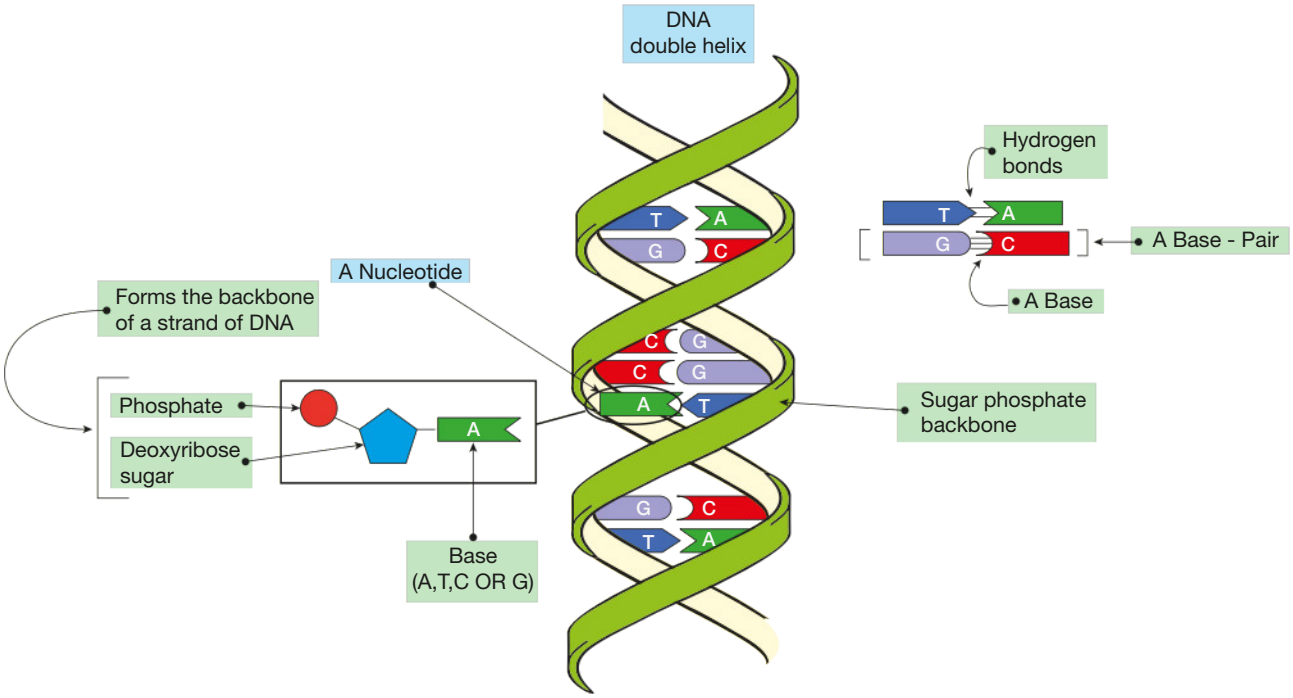


Figure 3.1.1: The basic structure of a nucleotide and a DNA molecule.

Genes

Genes are heritable units that code for making specific proteins that lead to the expression of a particular physical characteristic or trait. This includes proteins involved in performing a particular function in a cell, to proteins that determine eye colour. An organism's cells contain many different genes and can therefore produce many different proteins.

A single gene is a sequence of DNA nucleotides that are arranged in a specific order. The sequence of nucleotides determines the sequence of amino acids that make up the resulting protein. Any changes to this nucleotide sequence, called **mutations**, can change the amino acid sequence and the protein it codes for. A gene is therefore defined as **a unique sequence of DNA nucleotides that code for a polypeptide chain, protein or an RNA molecule.**

The collection of genes in one cell of a multicellular organism is called the genome. Recent research estimates the human genome is composed of approximately 21,000 genes. Individual chromosomes have varying numbers of genes linked to them, ranging from several hundred, to a few thousand. Each gene is located at a specific site on a particular chromosome, which is known as its **locus** (see Figure 3.1.2).

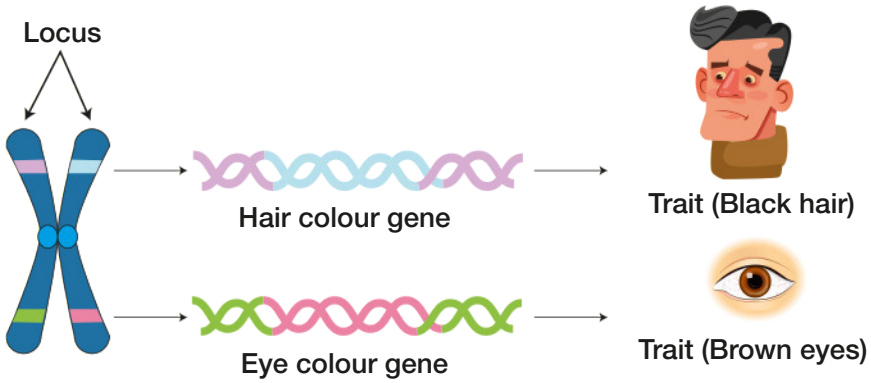


Figure 3.1.2: A gene is specific sequence of DNA nucleotides that is located at a specific site on the DNA molecule (its locus) within a specific chromosome and codes for a specific trait.

3.1

Helpful online resources

TED-Ed: Where do genes come from?–Carl Zimmer

<https://www.youtube.com/watch?v=z9HIYjRRaDE>

Chromosomes

Chromosomes are structures within cells that contain an organism's genes. In eukaryotic organisms, chromosomes reside in the **nucleus** of cells (see Figure 3.1.3).

Chromosomes consist of a double stranded DNA molecule wrapped around histone proteins (see Figure 3.1.3). When the DNA molecule is tightly coiled around the histone proteins (condensed) it is called a chromosome. However, when the DNA molecule is loosely packed around histone proteins (decondensed) it is not called a chromosome. This **decondensed structure is called chromatin** (see Figure 3.1.3).

Chromatin is present in the nucleus of cells throughout the life cycle of the cell (excluding cell division). It is important that the genetic code is accessible during the growth and development of a cell so that DNA synthesis, protein synthesis and RNA synthesis can occur. If the DNA molecule is condensed, the genetic code is very hard to access, and these processes are unlikely to occur.

Conversely, it is important for the **chromatin to condense into chromosomes prior to cell division** to protect the genetic code and ensure identical copies are transferred to both daughter cells. Chromosomes are therefore only visible under a light microscope during cell division. Each human somatic cell contains about 2 to 3 metres of DNA when completely decondensed to linear form. If chromatin was present during cell division, it is likely that the decondensed DNA would get tangled and result in DNA breakages.

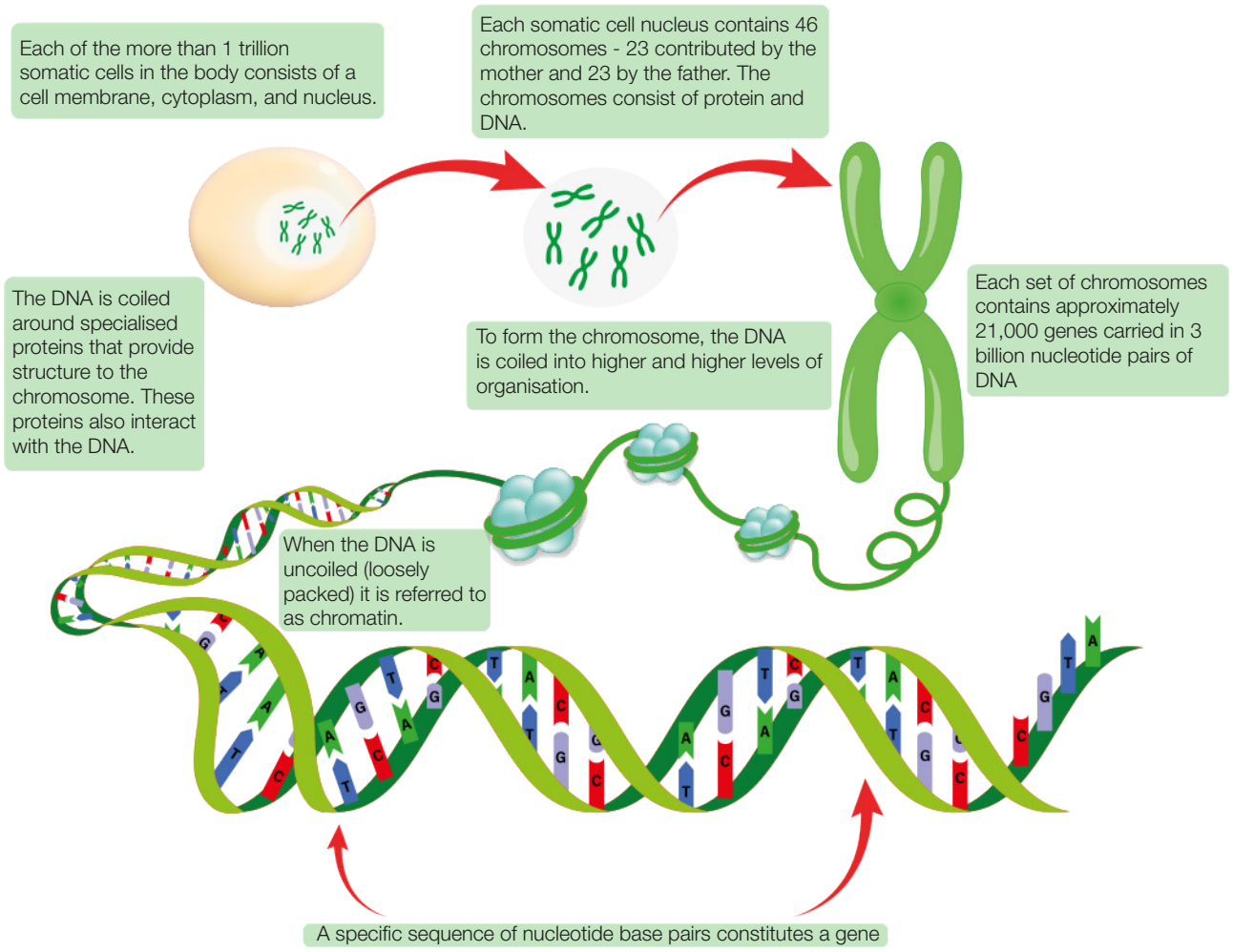


Figure 3.1.3: A DNA molecule is very long and is condensed into tightly packed structures called chromosomes by wrapping around histone proteins.

Diploid cells

Human somatic (body) cells contain 46 chromosomes, which are organised into 23 pairs. There are 22 pairs of autosomal (non-sex) chromosomes and one pair of sex chromosomes (either XX for female or XY for male). Somatic cells are diploid cells because they contain a **full set of chromosomes**. With the exceptions of red blood cells. sperm and ova, **all human cells are genetically identical diploid cells**, as they were all produced by **mitosis** (see Figure 3.1.4). Each chromosome in the pair is the same in size and general structure. One chromosome in each pair originated from the mother and is called the maternal chromosome; the other originated from the father and is called the paternal chromosome. The two chromosomes that form the pair are called homologous chromosomes.

Haploid cells

Sperm and ova (sex cells) are formed through a process called **meiosis**. They do not carry a full set of chromosomes. Instead, these cells have one chromosome from each homologous pair, which means they carry 23 chromosomes instead of 23 pairs of them. Cells that carry one set of chromosomes are called haploid cells. It is important that each sex cell only contains one set of chromosomes, because when they fuse during **fertilisation**, the chromosome number doubles, and the diploid number is restored in the resultant **zygote** (see Figure 3.1.4).

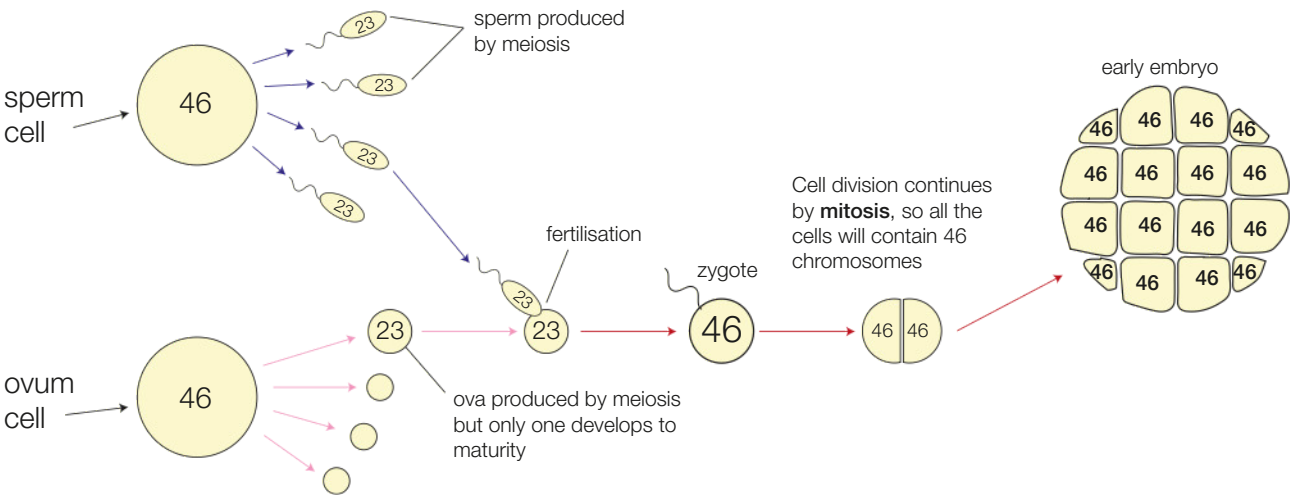


Figure 3.1.4: The process of fertilisation, where two haploid sex cells fuse, restoring the diploid number to form a zygote.

Helpful online resources

Global Education – FuseSchool: What are chromosomes?

<https://www.youtube.com/watch?v=Bgpq5ablvio>

Protein synthesis (DNA to protein)

Proteins are essential molecules for the survival of cells and therefore all cells can synthesise proteins using the genetic information encoded in their genes. **Protein synthesis consists of two distinct processes, transcription and translation**, which facilitate the flow of information from DNA to RNA to protein (see Figure 3.1.5). Protein synthesis is also referred to as **gene expression**,

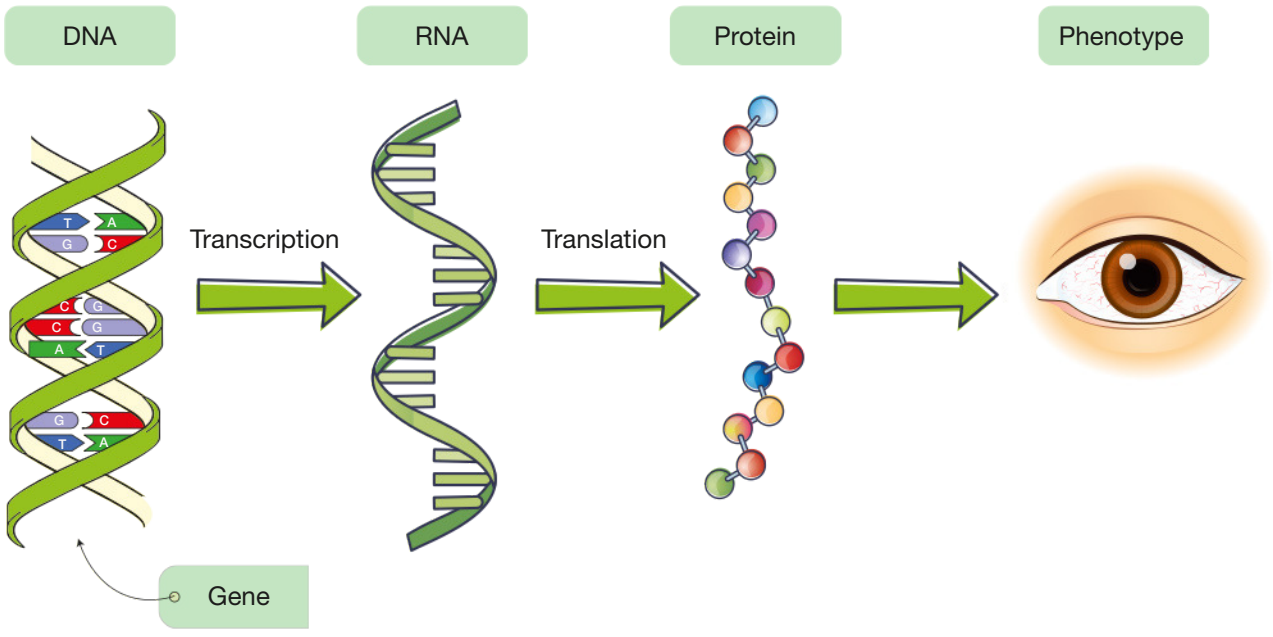


Figure 3.1.5: Genes are expressed as functional proteins through the process of protein synthesis.

Transcription

Protein synthesis requires the assistance of ribosomes to translate the genetic code into proteins, however eukaryotic DNA is located in the nucleus and ribosomes are located in the cytoplasm (generally on the rough endoplasmic reticulum). As DNA is the blueprint for every protein that makes up an organism, it does not leave the nucleus where it is protected. Instead, **a gene is transcribed** (copied) by a protein called **RNA polymerase** into a **messenger RNA** molecule (mRNA) that delivers the 'message' from the nucleus to the ribosome (see Figure 3.1.6). The mRNA molecule produced through transcription is a copy of a gene with a specific sequence of nucleotides that determine the specific order of amino acids in the protein it codes for. It is the role of ribosomes to translate the message encoded in the mRNA code into a polypeptide chain (protein).

A basic overview of **transcription** is:

1. A protein called RNA polymerase binds to DNA near the gene coding for required protein.
2. RNA polymerase unwinds the DNA double helix to 'expose' the nucleotide base sequence of this gene.
3. RNA polymerase moves along the exposed gene to synthesise a mRNA molecule, which is a working copy of the gene that can travel out of the nucleus to be translated.

Translation

There are 20 different amino acids that make up proteins, which humans obtain by consuming and digesting protein sources in their diet (see Chapter 3.6 for more information). These amino acids are carried to a ribosome during translation by another type of RNA called **transfer RNA** (tRNA). Each transfer RNA molecule can only carry **one specific amino acid** and will only bond to a specific three base section of the mRNA that it is complementary to. During translation, a ribosome moves along a strand of mRNA, whilst tRNA molecules carry specific amino acids to the ribosome, based on the order of nucleotides in the mRNA molecule. As each amino acid is brought into its correct position in the growing chain of amino acids, **the ribosome facilitates the formation of strong peptide bonds** between them, eventually producing a **polypeptide chain** (see Figure 3.1.5). Many proteins consist of more than one polypeptide chain bonded together. A polypeptide, or several polypeptides, fold in a precise way to form a molecule called a protein. **Every protein has a specific shape based on the order of amino acids it consists of, and this shape determines the function of the protein.** Some cells specialise in synthesising proteins and contain larger numbers of ribosomes such as pancreatic beta cells that synthesise and secrete the hormone insulin.

A basic overview of **translation** is:

1. Messenger RNA (mRNA) is transported out of the nucleus to ribosomes in the cytoplasm.
2. Ribosomes movie along the mRNA strand and assemble amino acids in a specific order with the help of transfer RNA (tRNA) molecules, forming a polypeptide.
3. The polypeptide then folds into a precise 3D shape forming a functional protein.

Table 3.1.1: A summary of the differences between transcription and translation.

Order of process in protein synthesis	Name of process	Site in cell where process occurs	Substrate used in process	Product produced
1	Transcription	Nucleus	RNA nucleotides	Messenger RNA molecule (mRNA)
2	Translation	Cytoplasm	Amino acids	Polypeptide chain (protein)

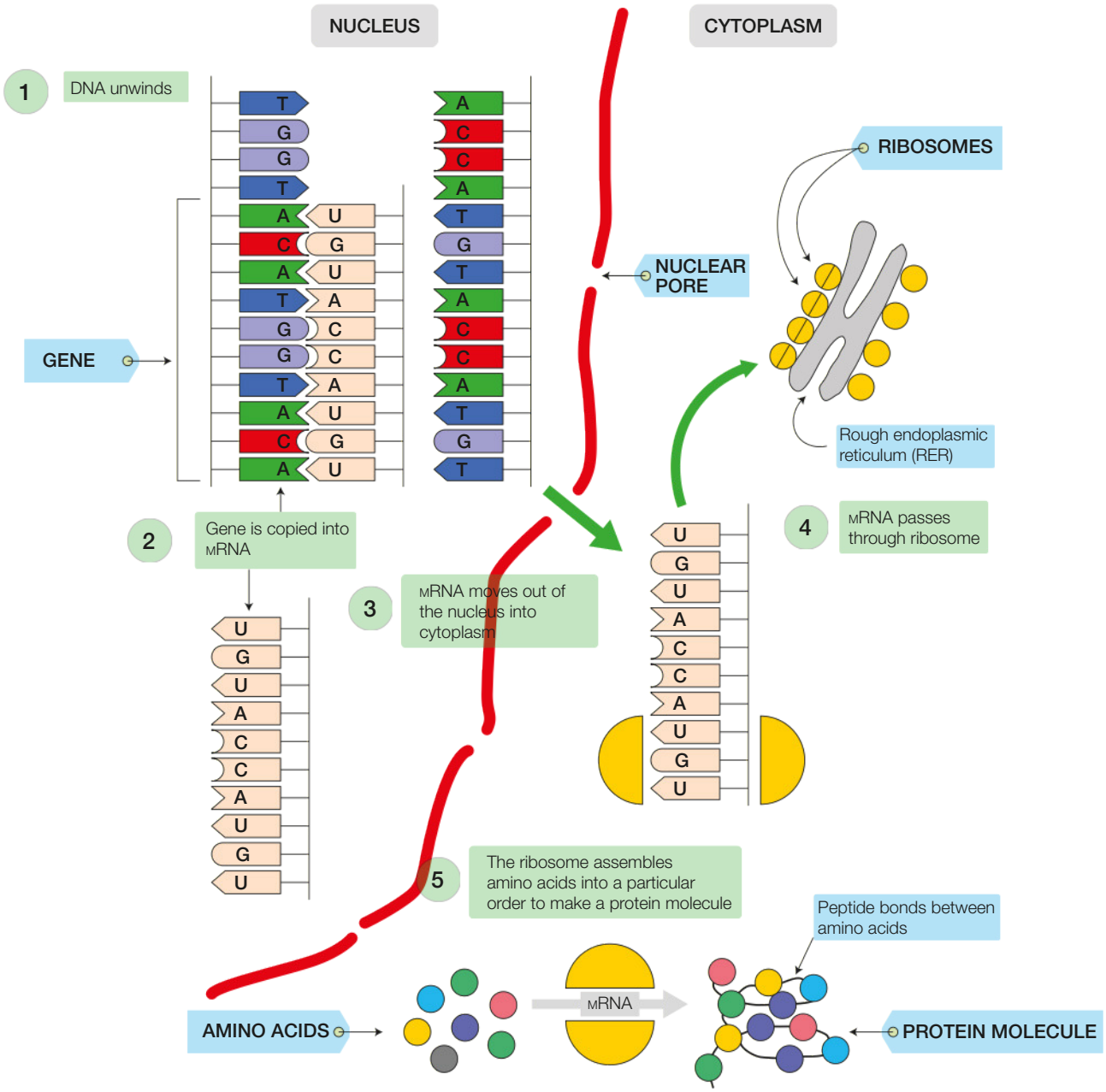


Figure 3.1.6: A basic representation of transcription (steps 1 and 2) and translation (steps 3 to 5).

Helpful online resources

Global Education – FuseSchool: Protein Synthesis

<https://www.youtube.com/watch?v=x5ZXQo-xeMo>

Cell specialisation

Eukaryotic multicellular organisms consist of large numbers of different types of cells. These different cells have **specific adaptations**, and therefore structures, such as its shape, size and number and type of organelles. This is why eukaryotic cells can look very different to one another (see Figure 3.1.7). A cell's structure is adapted to perform its specific function within an organism (see Table 3.1.2). This is called **cell specialisation**. The specialised cells in multicellular organisms allow for the **division of work** within an organism that is required to keep it alive. The development of specialised cells occurs after fertilisation by a process called **differentiation.**

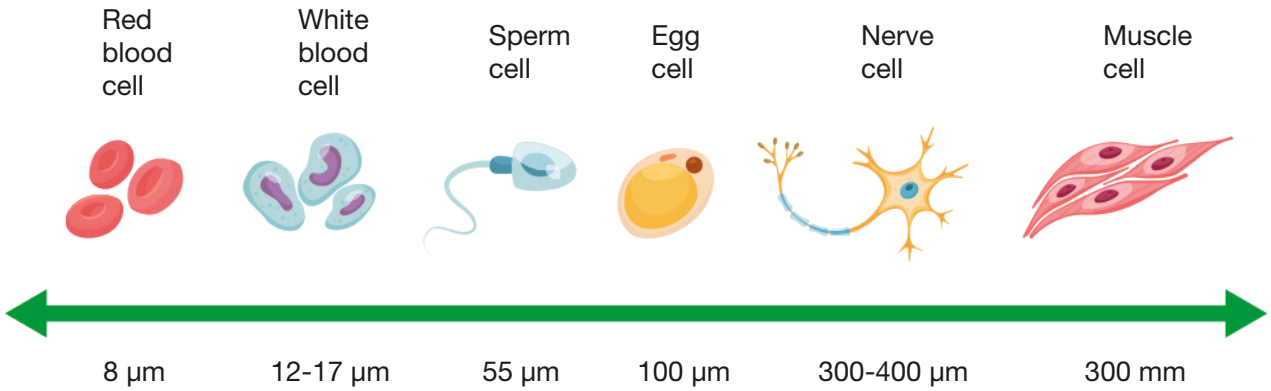


Figure 3.1.7: Specialised cells have different shapes and sizes.

Table 3.1.2: Some examples of specialised cells and a specific structural adaptation that is important for the cell to perform its role within a multicellular organism.

Cell type	One structural aspect	Function
Sperm cell	Has a tail-like structure called a flagellum	To move sperm towards an ovum
Motor neuron	Has a very long insulated extension called an axon	To transmit nerve impulses efficiently and at high speed to a muscle or a gland
Red blood cell	Has a cytoplasm without a nucleus packed with haemoglobin	To help maximise the transport of oxygen in blood around the body
Palisade cell (in leaves)	Has a cytoplasm with large numbers of chloroplasts	To help maximise the absorption of light for photosynthesis
Xylem cell (in roots, stems and leaves)	Has a tube-like structure supported by rings of a substance called lignin	To transport water and dissolved minerals from the roots to cells in leaves
Root epidermis cell	Has a thin cell wall and a cytoplasm extension called a root hair	To maximise the absorption by roots of water by osmosis and minerals by active transport

Helpful online resources

Amoeba Sisters: Specialized Cells: Significance and Examples

<https://www.youtube.com/watch?v=wNe6RuK0FfA&t=26s>

Cell differentiation and gene expression

All sexually reproducing eukaryotic organisms start life as a single cell called a **zygote**. After fertilisation, the zygote divides many times by mitotic division, resulting in a ball of **genetically identical** embryonic stem cells. Stem cells are **unspecialised** cells that can divide an unlimited number of times and have the potential to remain as stem cells or change into **specialised cells** that make up the tissues and organs of an organism, in a process called **differentiation**. The two main types of stem cells are embryonic stem cells and adult stem cells (see Table 3.1.3).

Table 3.1.3: A brief summary of the differences between the two main types of stem cells in a multicellular organism.

Type of stem cell	Potency	Description	Example
Embryonic	Pluripotent	Stem cells that have the potential to differentiate into any of the approximate 230 human cell types.	See Figure 3.1.9.
Adult (tissue)	Multipotent	Stem cells that can only differentiate into a limited range of closely related cell types.	Bone marrow stem cells differentiating into different blood cells.

Every somatic cell in multicellular organisms have the same **genome**. Even though these somatic cells are **genetically identical**, not every gene is activated, or switched on, at the same time. **Only some specific genes are switched on** producing specific proteins, **whereas others are switched off**, or remain silent, for each cell type. This is called **gene expression** (see Figure 3.1.8). The structure and function of specialised cells are therefore determined by the specific genes that are expressed within that cell (see Figure 3.1.9).

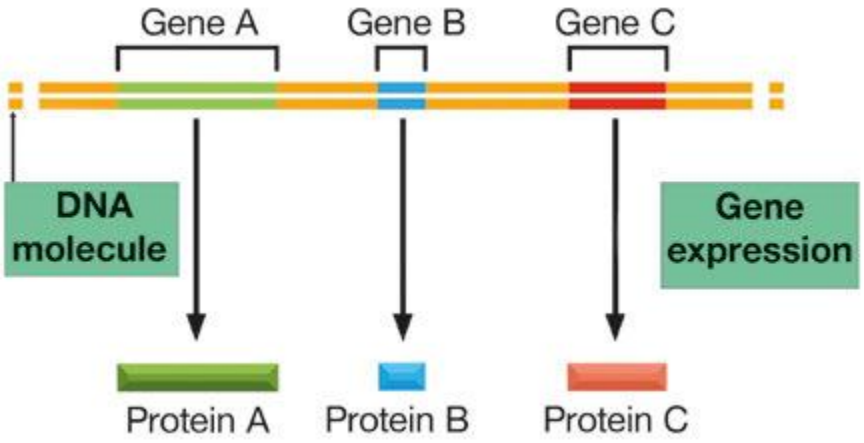


Figure 3.1.8: Genes A, B, and C are switched on and expressed as proteins A, B and C respectively, whereas the remaining genes on the DNA molecule (yellow) are switched off and not expressed.

Specialised cells have specific chemical tags, also known as **epigenetic tags**, that help activate and silence specific genes. Once a cell becomes specialised, it cannot differentiate into another type of specialised cell. One reason for this is that epigenetic tags can be passed on from parent cells to their daughter cells though mitosis. The inheritance of these tags ensures that the daughter cells will also become the same type of specialised cell and will therefore be the correct type of cell for that specific tissue or organ. This is essential for the development of multicellular tissues and organs.

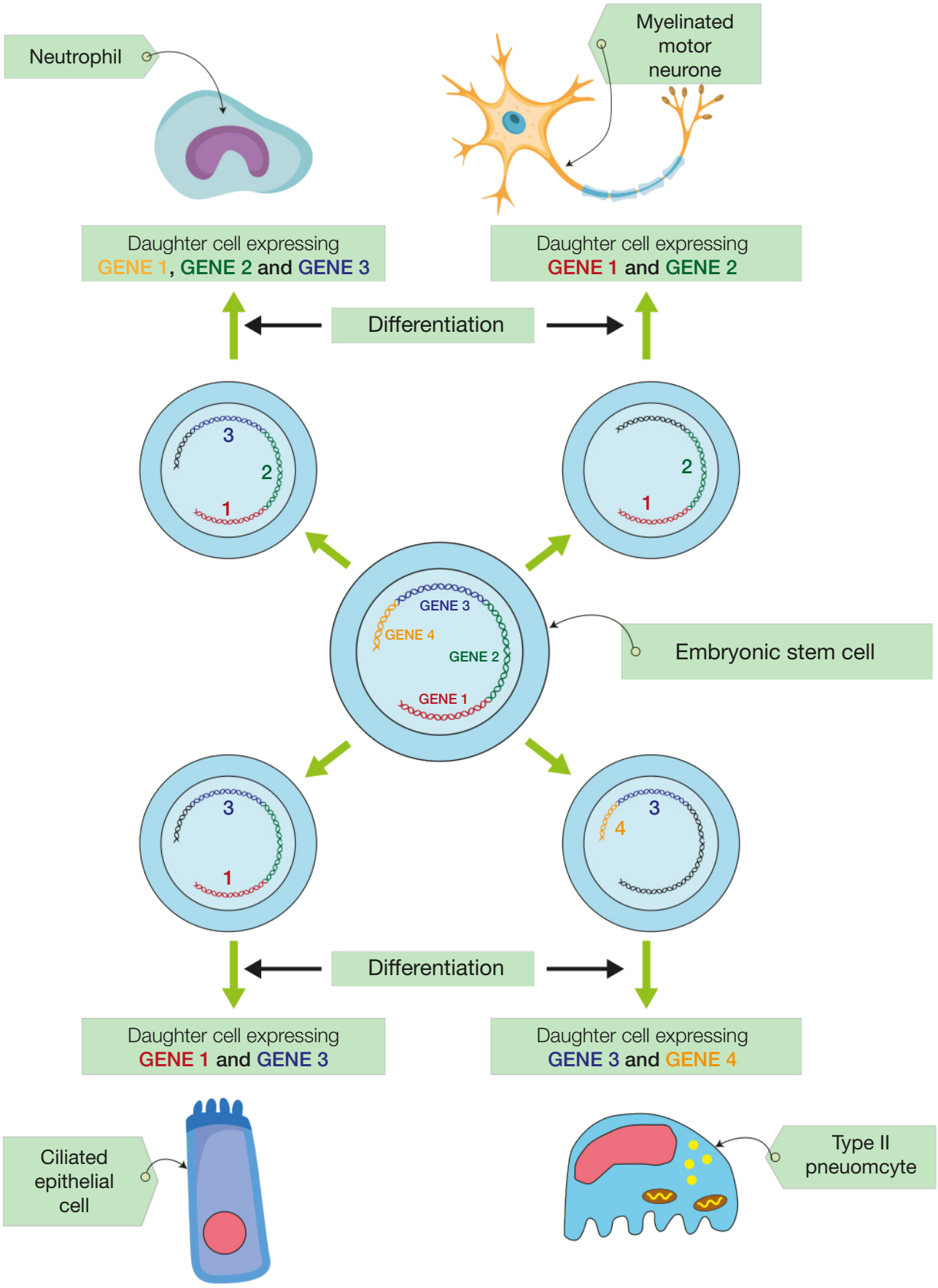


Figure 3.1.9: A basic representation of cell differentiation from an embryonic stem cell. The four cells above are genetically identical, but expressing different genes generates different cell types.

Helpful online resources

Global Education – FuseSchool: Cell differentiation

https://www.youtube.com/watch?v=gwAz_BtVuLA

Control of gene expression

Gene expression is tightly regulated by a range of cellular processes. Genes can be 'switched on' causing transcription to take place, and 'switched off' preventing transcription. Some genes are expressed continuously whereas others are only switched on at particular times. Two mechanisms by which genes are turned "on" or "off" are **transcription factors** and **epigenetic tags.**

Transcription factors

Transcription factors are proteins that affect the binding of RNA polymerase to a particular gene on the DNA molecule. Each gene has a short section of DNA called a **promoter region** that is located just before the gene on the DNA molecule. If RNA polymerase can bind to the promoter region of a gene, it is switched on and transcription can occur. Transcription factors called **activators** can bind to the promoter region increasing the rate of transcription. A gene can be switched off however, when RNA polymerase cannot bind to the gene's promotor region. Other transcription factors, called **repressors**, can bind to the promoter region and block RNA polymerase from transcribing the gene.

Epigenetic tags

Epigenetics is the study of how the environment influences gene expression. As we develop, our DNA accumulates 'chemical tags' that are collectively called the **epigenome**. The epigenome is an additional level of coding on top of the DNA base sequence. These chemical tags do not affect the DNA base sequence, instead they change how our cells read the DNA and express it. The two main types of **epigenetic tags** are the **methylation of cytosine bases and acetylation of histone proteins**. Refer to Table 3.1.4 and Figure 3.1.10 for further information on these two epigenetic tags and how they affect gene expression.

Table 3.1.4: The effects of the two main types of epigenetic tags on gene expression.

Epigenetic tag	Effect on gene expression	Explanation
Increased methylation of cytosine DNA bases	Decreases	Inhibits RNA polymerase from binding to the promoter region, and hence transcription.
Decreased methylation of cytosine DNA bases	Increases	RNA polymerase is less inhibited, or not at all inhibited, from binding to the promoter region, and hence transcription of the gene can occur.
Increased acetylation of histone proteins	Increases	Increased acetylation of histone proteins causes the chromatin to decondense resulting in loose packing of the histone proteins. This allows RNA polymerase to access the gene and express it.
Decreased acetylation of histone proteins	Decreases	Deacetylation of histone proteins causes the chromatin to condense resulting in more tightly packed histone proteins. As a result, the gene becomes inaccessible and RNA polymerase is unable to bind to the DNA and transcribe the gene.

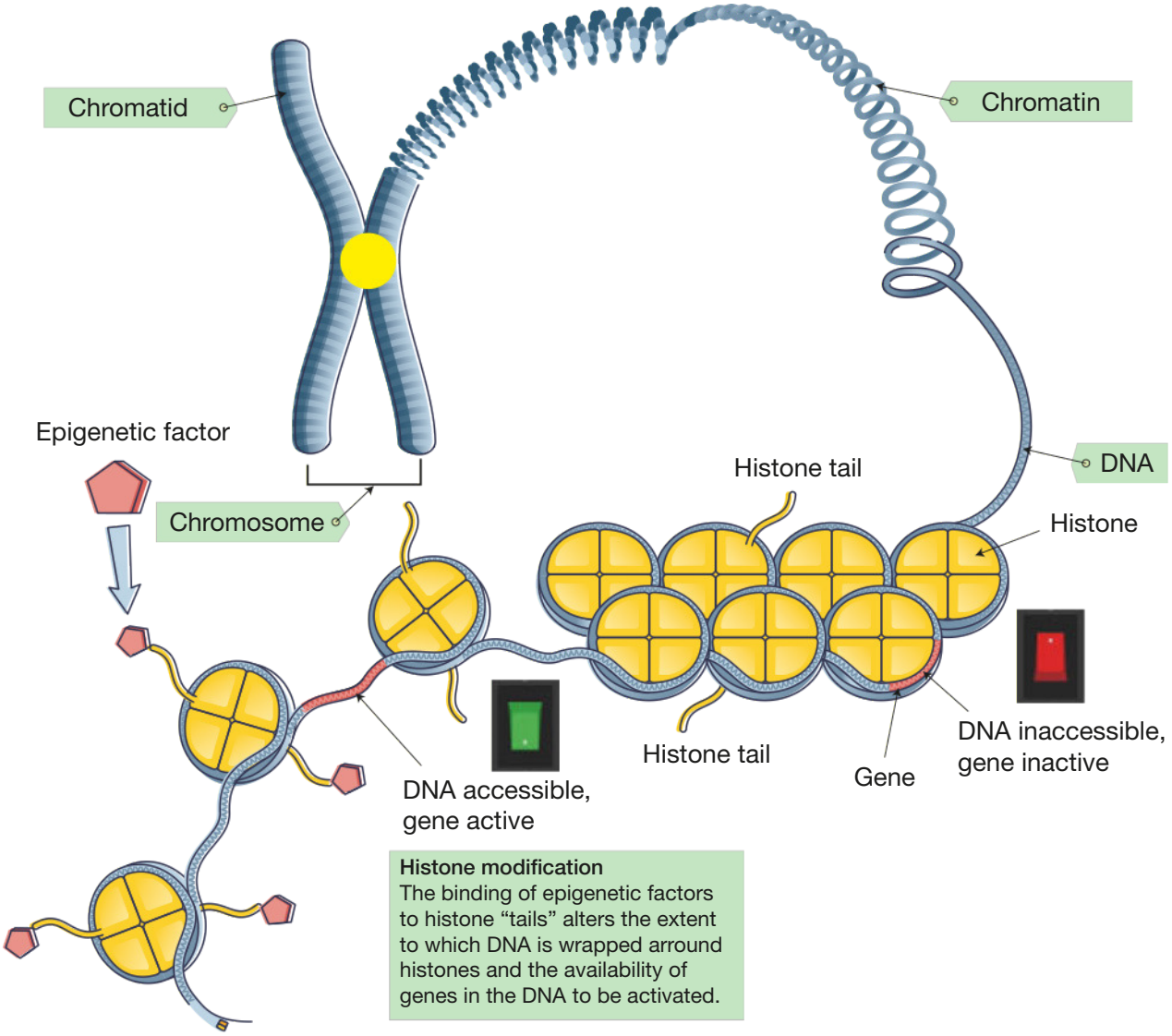


Figure 3.1.10: The binding of acetyl groups (epigenetic factors) to histone proteins causes the chromatin to decondense making genes accessible to transcribe (switched on). However, the removal of these acetyl groups from histone proteins (deacetylation), causes the chromatin to condense, resulting in the genes becoming inaccessible (switched off).

Helpful online resources

TED-Ed: What is epigenetics? – Carlos Guerrero-Bosagna

<https://www.youtube.com/watch?v=_aAhcNjmvhc>

The role of environmental factors in gene expression

Epigenetic tags can be inherited from parents through the sperm and eggs. Once born, the epigenome of cells can be altered by environmental factors they are exposed to. The epigenome can be affected by both positive and negative experiences and can be temporary or permanent. The different experiences individuals have as they develop alter the number and location of these epigenetic tags. This is why identical twins can exhibit different physical traits, behave differently, and have different health issues. **Even though identical twins are genetically identical, they are epigenetically different.** Therefore, the physical factors expressed, known as the phenotype, of a multicellular organism is controlled by both the genotype and the environment an organism is exposed to throughout their life. There are many different environmental factors that can affect the expression of genes including temperature, diet, lifestyle, chemical exposure, stress, and trauma (see Figure 3.1.11).

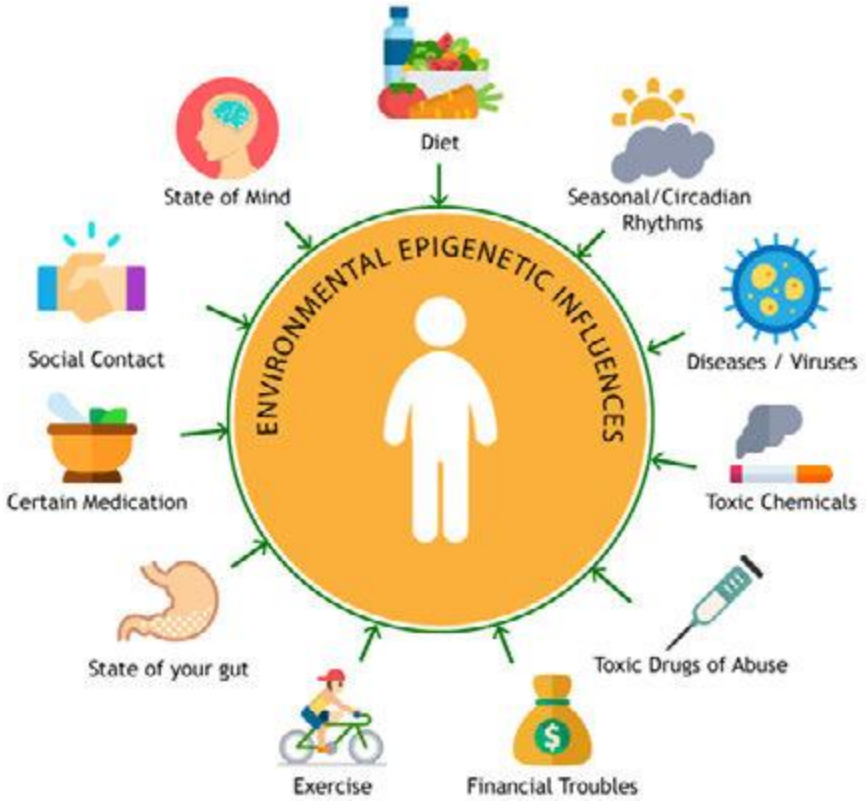


Figure 3.1.11: Some examples of the many environmental factors that can affect the epigenome and hence, gene expression.

Helpful online resources

FuseSchool – Global Education: Nature vs Nurture

<https://www.youtube.com/watch?v=EmctxRcmloc>

3.1 Review questions

Multiple choice questions

1. A chromosome is a
   - J a condensed structure consisting of a double stranded RNA molecule and proteins.
   - K a decondensed structure that is found in the nucleus of all living cells.
   - L structure that consists of a DNA molecule and proteins.
   - M section of DNA that codes for a trait.
2. Which of the following is a viable DNA nucleotide base pair?
   - J Adenosine and Triphosphate
   - K Cytosine and Glutamic acid
   - L Guanine and Cytosine
   - M Adenosine and Tryptophan
3. Which of the following is **not** a possible definition of a gene?
   - J A gene codes for a polypeptide chain.
   - K A gene codes for a messenger RNA molecule.
   - L A gene is a specific sequence of DNA nucleotides on a chromosome.
   - M A gene is a double stranded DNA molecule.

4. Stem cells

   J undergo mitotic division.
   K are only located in embryos.
   L are specialised cells that can undergo differentiation.
   M are found in all prokaryotic and eukaryotic organisms.

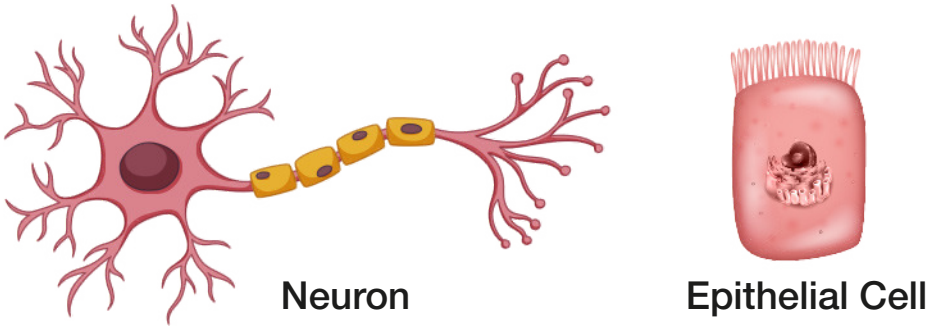
5. Which of the following options is the best definition for the function of a ribosome in gene expression?

   J It is the site of protein synthesis.
   K It is the site of transcription.
   L It is the site of translation.
   M It is where polypeptides are synthesised using nucleotides.

6. An example of cell differentiation is

   J the division of a zygote into many genetically identical cells.
   K the division of a skeletal muscle cell into another skeletal muscle cell.
   L the development of specialised cells from the division of unspecialised cells.
   M the changing of a nerve cell into a cardiac muscle cell.

7. *Refer to the images below showing two cells in a multicellular organism.*



   The structure of these two cells are different because they

   J are epigenetically different.
   K contain different genes that code for different proteins.
   L have different functions.
   M genetically identical but have acquired new genes through mutations.

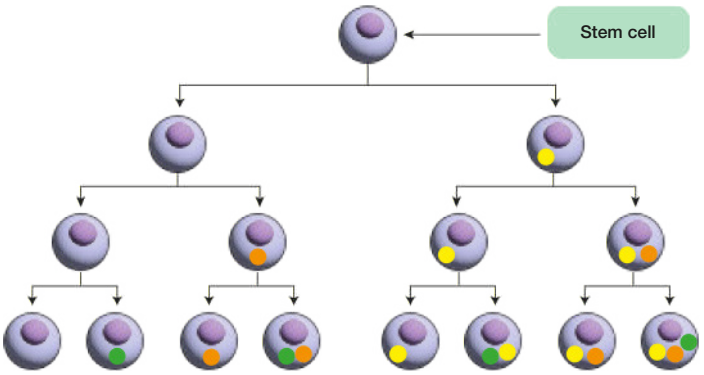
8. Which of the following statements is true about embryonic stem cells and adult (tissue) stem cells?

   J There is no difference between these stem cells.
   K Embryonic stem cells can give rise to all forms of cell types whereas adult (tissue) stem cells are limited.
   L Adult stem cells are pluripotent and give rise to all forms of cell types.
   M Embryonic stem cells differ genetically to adult stem cells, and this results in a difference in potency.

9. Environmental factors

   J rarely affect cell differentiation and the development of an organism.
   K and genes work together to build an organism.
   L such as diet and lifestyle affect the development of an organism but psychological issues like trauma do not.
   M that impact the epigenome of parents cannot be inherited by their offspring.

10. *Refer to the following image which shows a cell lineage deriving from a single stem cell to answer the following question.*



Each coloured dot within a cell represents a different active gene in the respective cell.

Based on the information provided above, how many different specialised cell types are represented by this cell lineage?

J 7
K 8
L 12
M 15

Free response questions

1. Describe the structure of DNA.

2. a) Compare the structure of a chromosome with a gene.

b) Define the function of a gene.

c) Compare the structure of a chromosomes with chromatin.

3. The making (synthesis) of polypeptides and proteins in cells is a vital process for cell growth and functioning. Protein synthesis consists of two main processes.

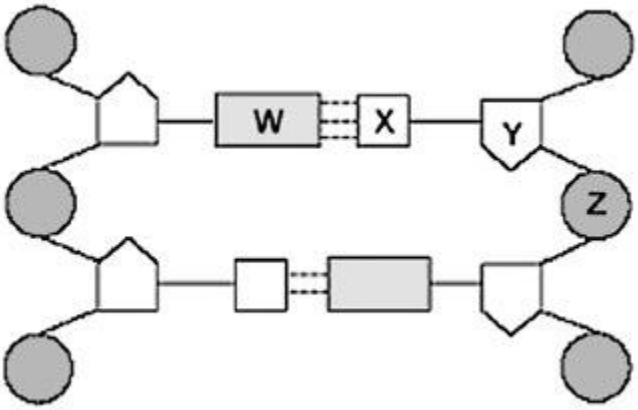
a) Explain the difference between a polypeptide and a protein.

b) Identify the two processes that protein synthesis consists of **and** briefly describe the events that occur in these two distinct processes.

Process 1:

Process 2:

4. *Refer to the image below showing a short section of a DNA molecule to answer the following questions.*



a) Identify the following parts of the DNA molecule:

X:

Y:

Z:

W and X:

X, Y and Z:

b) Describe how W and X are held together.

5. Using an example for each, explain the difference between a specialised and an unspecialised cell.

6. Stem cells have the potential to treat many diseases such as diabetes and Parkinson's. These diseases are caused by the death or malfunction of specific cell types.

Explain the difference between an embryonic stem cell (pluripotent) and an adult stem cell (multipotent).

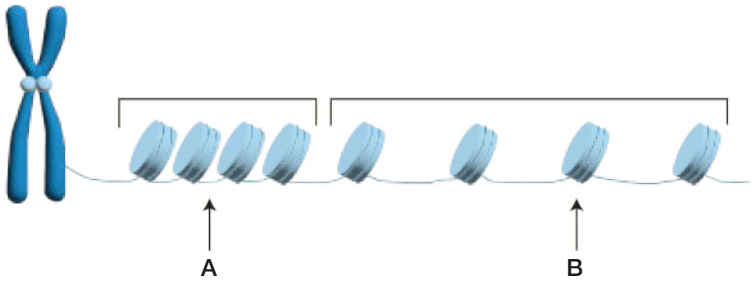
7. The development of a multicellular organism from a single zygote can be compared to a movie script. A movie consists of different actors. They all read from the same script, but they only read their part of the script.

   a) Name the process that occurs to form the many cells that make up a foetus from a single zygote.

   b) Explain how the movie script analogy above can be compared to the development of a multicellular cellular organism from a single zygote.

8. Compare the actions of activators and repressors in controlling gene expression.

9. *Refer to the following diagram to answer part (b).*



   a) Define epigenetics.

   b) Explain the mechanism that causes the structures at 'A' and 'B' to form in the diagram above and the effect this has on gene expression.

   c) Discuss the likely outcome to an organism of increased methylation of cytosine bases for genes that code for suppressing the growth of tumours.

10. Genetically identical organisms, humans and otherwise, rarely appear the same, particularly when they are mature. Explain how such organisms become different as they grow and develop.

Chapter 3.2 The organisation of multicellular organisms

Science Understanding

Multicellular organisms have a hierarchical structural organisation of cells, tissues, organs and systems.

- Use examples from animals to explain organisation of cells into tissues, tissues into organs, organs into systems.
- Illustrate the relationship between the structure and function of cells, tissues, organs and/or systems

Organ systems in a multicellular organism are interdependent and function together to ensure the survival of the organism.

Lifestyle choices affect the functioning of organs and systems.

Author's note: *Please note that Chapter 3.2 starts with a general focus on the hierarchy of all multicellular organisms, but then focuses on the hierarchy of animals. For further information on the hierarchy of plants, please see Chapter 3.7.*

Hierarchical structure of organisation

A system that is based on different levels of organisation in which each level of organisation forms part of the next higher level is called a **hierarchy**. An example of a hierarchy is an army. In an army soldiers report to Sergeants who report to Majors who themselves report to Colonels who are supervised by Generals.

In multicellular organisms, cells are specialised and contain **organelles**. They rely on other cells to continue living and this interdependence of specialised cells contributes to the hierarchical structure of organisation. A multicellular organism's **cells** are organised into **tissues**, different tissues are organised into **organs**, and different organs are organised into **organ systems** (see Figure 3.2.1).

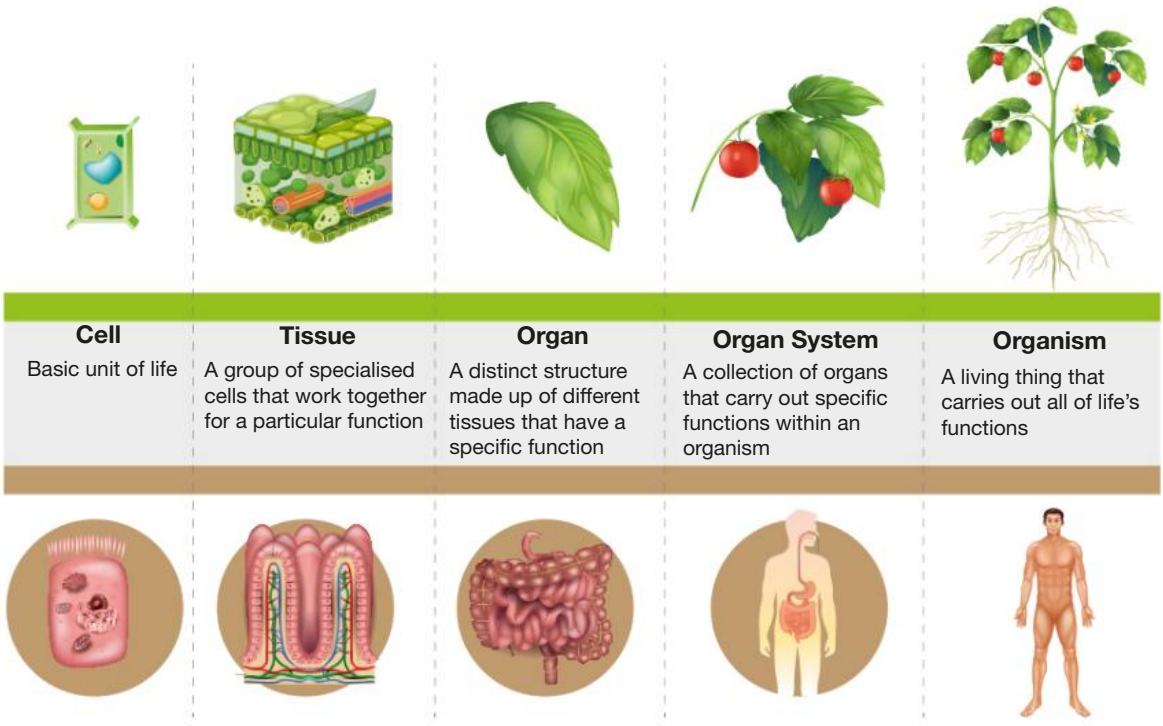


Figure 3.2.1: The hierarchy of organisation in living things.

Helpful online resources

FuseSchool–Global Education: Levels of organisation an organism

<https://www.youtube.com/watch?v=SzKKYYIlJ-c>

Animal cells and tissues

A good example of the way an animal is organised is a human being. As the embryo develops, the differentiated (or specialised) cells continue to divide by mitosis forming many more cells of the same type. The collection of the same type of specialised cells grouped together to perform a specific function is called a tissue. There are four main types of human tissue: nervous, muscle, epithelial and connective tissue (see Table 3.2.1 and Figure 3.2.2 for more information).

Table 3.2.1: Some general information about the four main types of tissue.

Tissue	Examples	Description
Nervous	Nervous tissue of the: • Brain • Spinal cord • Peripheral nervous system	Consists of bundles of cells called neurons that transmit electro-chemical nerve impulses to communicate with other tissues/organs.
Muscle	• Skeletal • Smooth • Cardiac	Consists of muscle fibres that contract under nervous stimulation to provide movement. Skeletal muscles are controlled voluntarily, whereas smooth and cardiac muscles are involuntarily (automatically) controlled.
Epithelial	• Squamous • Columnar • Ciliated	Cover and protect the internal and external surfaces of our organs. Some epithelial cells can produce glandular secretions and others are involved in absorption of nutrients.
Connective	• Blood • Adipose (fat) • Bone • Cartilage	Provides structural support for other tissues by binding them together.

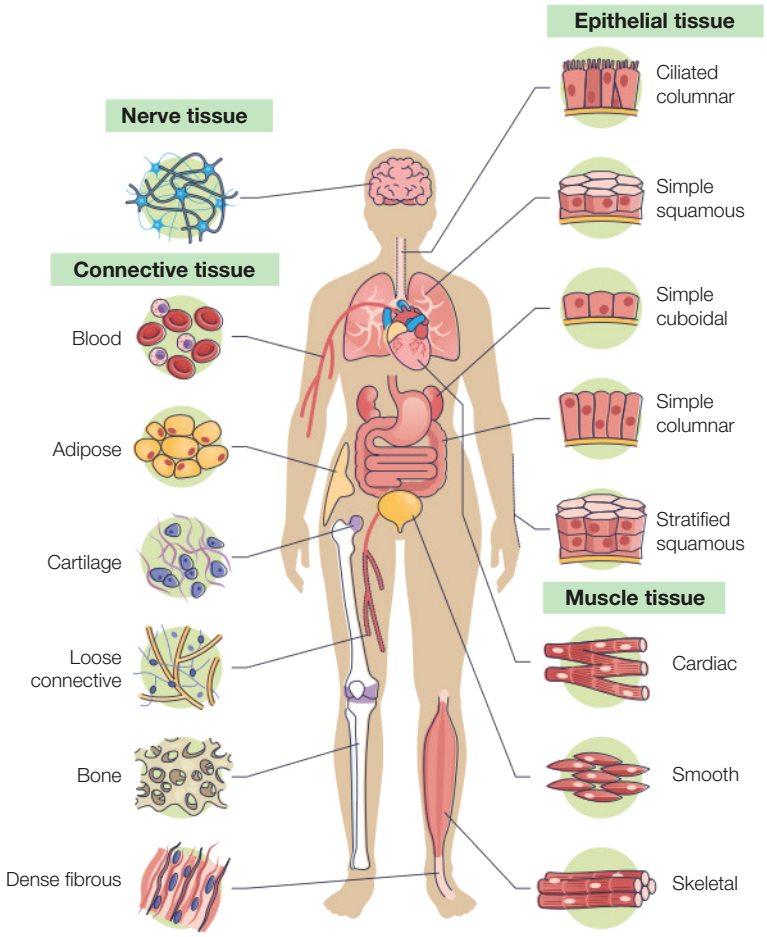
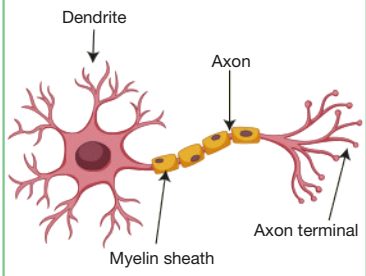
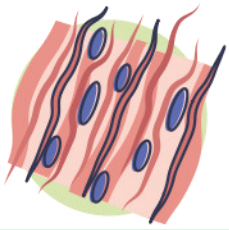
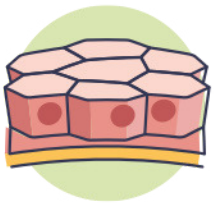
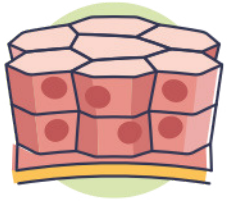


Figure 3.2.2: Some examples of the four main types of tissue and some sites in the body where they are located.

The structure and function of animal tissues

Different tissues in the body consist of different specialised cells to permit them to perform a specific function. Table 3.2.2 highlights some examples of tissues that have specific structural characteristics that are well suited to its function.

Table 3.2.2: Some examples of how the structure of tissues suit their functions.

Specific tissue type	Image	Description of the characteristics of tissue that make it well adapted to its function
Nervous tissue		Neurons are cells that are well adapted to transmit and receive electro-chemical messages. A neuron consists of dendrites, axon, and axon terminals. Some neurons also have myelin sheaths. The dendrites are adapted to receive messages, whereas axons transfer the message to the axon terminals, which are adapted to transmit the signal to other neurons. The myelin sheath is a fatty protective coating surrounding an axon that can speed up the transmission of the signal. The neurons that are used frequently adapt and have thicker myelin sheaths.
Dense fibrous connective tissue		These connective tissues produce a matrix of dense collagen fibres for strength and flexibility. This makes them well suited to function as tendons and ligaments that join bones to muscles and bones to bones respectively.
Simple squamous epithelial tissue		The word 'simple' in this tissue's name refers to one single layer of squamous cells. This makes the tissue very thin and the squamous cells themselves are also very thin making this tissue well adapted for lining gas exchange surfaces (e.g. alveoli and capillaries) due to their high permeability (thin distance to cross).
Ciliated columnar epithelial tissue		The word 'ciliated' in this tissue's name refers to the hair-like extensions, called cilia, that project from the top of the epithelial cells. Ciliated columnar tissue is well adapted to protect internal surfaces such as the trachea. Goblet cells are scattered throughout these ciliated cells, which secrete mucous to aid in trapping the dirt, debris, and pathogens that we breathe in. The cilia move in a wave like motion, moving the dirt and pathogen coated mucous back to the throat to eventually be removed from the body and prevent damage to the respiratory system.
Stratified squamous epithelial tissue		The word 'stratified' in this tissue's name refers to several layers of squamous cells. The outer layer of skin (epidermis) consists of tightly packed stratified squamous epithelial cells, which serves as a barrier to protect underlying tissues from dehydration, invasion by pathogens and other damage.

Helpful online resources

TED-Ed: The science of skin–Emma Bryce

<https://www.youtube.com/watch?v=OxPlCkTKhzY>

Animal tissues and organs

Humans are multicellular organisms that contain organs such as a brain, a heart and a small intestine. All organs consist of at least two different types of tissue, but most contain all four types. The tissues in an organ are organised to serve a specific function. Table 3.2.3 highlights some examples of some human organs and their specific functions.

Table 3.2.3: Some examples of some human organs and the tissues that help them perform a specific function.

Organ	Tissues in the organ	Function of the organ
Brain	• Nerve tissue • Blood (connective tissue) • Ciliated columnar epithelial tissue • Dense fibrous connective tissue	Processes information and controls activities of the body including, breathing, movement, thoughts, memory, hunger, etc.
Heart	• Cardiac muscle tissues • Nerve tissue • Blood (connective tissue) • Dense fibrous connective tissue • Simple squamous epithelial tissue	Pumps blood around the body transporting nutrients to other organs and waste products to the lungs and kidneys for removal.
Small intestine	• Smooth muscle tissue • Blood (connective tissue) • Nervous tissue • Simple columnar epithelial	Completes the digestion of macromolecules and absorbs nutrients into blood and lymph to be transported around the body.

The structure and function of animal organs

The structure of an animal organ is related to its function. For example, the function of the stomach is to help mechanically digest food, kill bacteria and start chemical digestion of protein. Mechanical (or physical) digestion involves forces breaking down food into smaller pieces. The stomach can contribute to this type of digestion because its walls contain smooth muscle tissue that can contract, slowly churning its contents. This function of the stomach is supported by the presence of loose connective tissue in the walls. Furthermore, the stomach can kill bacteria in food because cells in its epithelial tissue lining the inner surface can produce and release an acid into the stomach called hydrochloric acid. The stomach is also able to begin chemical digestion of proteins in food because there are cells in its epithelial tissue that produce and release protein-digesting enzymes called proteases. These types of tissue and how they are organised in the stomach is shown in Figure 3.2.3.

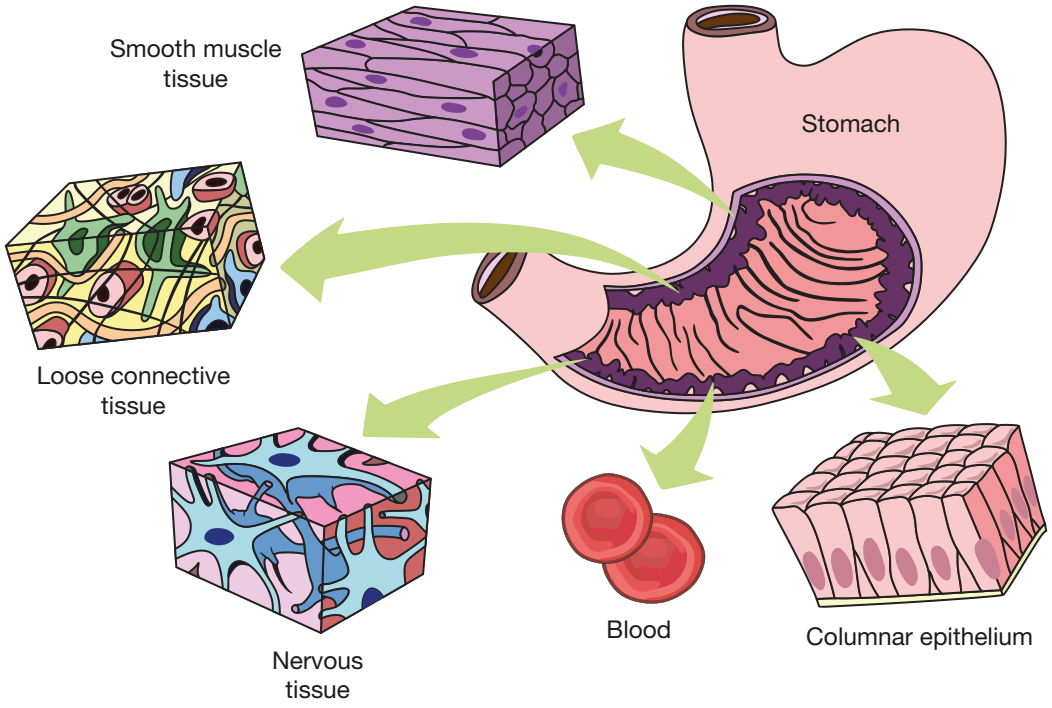


Figure 3.2.3: Organs consist of different tissues that are organised in specific ways to perform a specific function.

Animal organ systems and their interdependence

Different organs grouped together to carry out a function are called an organ system (see Table 3.2.4). **Organ systems do not operate in isolation.** They are interdependent. The function of each one is dependent on the proper function of the other organ systems in the multicellular organism. The interdependence of a multicellular organism's organ systems ensures that all of them can function effectively together to ensure its health and survival. This interdependence is highlighted by the importance of one particular organ system, the circulatory system. The circulatory system collects nutrients from the digestive system and oxygen from the respiratory system and delivers them to every organ system in the body. It also collects the waste products from all organ systems, such as carbon dioxide and urea that are transported to the respiratory system and excretory system respectively to be excreted.

Table 3.2.4: Some examples of organ systems that make up the human body and their main functions.

Organ system	Major organs involved	Main function in the body
Respiratory system	Trachea, lungs, bronchi, bronchioles, diaphragm	Delivers air to the lungs so the exchange of oxygen and carbon dioxide can occur.
Immune system	Thymus, bone marrow, lymph vessels and nodes, spleen, skin	Defends the body from foreign pathogens.
Circulatory system	Heart, arteries, veins	Transports blood around the body to deliver nutrients to cells and collect waste products from cells.
Hormonal system	Endocrine glands such as the adrenal gland, pancreas, ovaries, testes, thyroid, anterior pituitary gland	One form of communication within an organism that's involved in regulation and control (e.g. growth).
Nervous system	Brain, spinal cord, nerves, sensory organs	Coordinates body activities and detects and responds to stimuli quickly.
Excretory system	Kidneys, ureters, bladder, urethra	Maintains the water/salt balance in blood by removing excess water, salts and metabolic waste products (e.g. urea) from the blood.
Reproductive system	Testes, ovaries, penis, vagina	To produce sperm/egg and facilitate genetic information being passed on to the next generation.
Digestive system	Mouth, oesophagus, stomach, small intestine, large intestine, pancreas, liver, gall bladder	Digests foods consumed into their smaller subunits so that they can be absorbed.
Skeletal system	Bones, cartilage, ligaments, tendons	Protects vital organs, provides support and allows movement.

Helpful online resources

Amoeba Sisters: Human Body Systems Overview (Updated 2024)

<https://www.youtube.com/watch?v=0JDCViWGn-0&t=52s>

Lifestyle choices and the function of organ systems

A person whose organ systems are functioning efficiently is said to be in good health, or healthy. The 'lifestyle' of an individual plays a major role in determining how efficiently their organ systems function day-to-day. This not only affects how healthy they are now but also the state of their health when they are older.

People can control many aspects of their lifestyle. These are called lifestyle choices. Over time an individual's lifestyle choices may enhance their health and well-being, or harm it. Some possible implications of several lifestyle choices are shown in Table 3.2.5 and Figure 3.2.5. There are many other disorders and diseases that are contributed to by multiple lifestyle choices not mentioned in the sources below such as many types of cancer, obesity, mental health disorders and cognitive decline. Research continues into the many factors that contribute to these and other conditions and there are new developments occurring frequently. For example, new research

is linking the exposure to microplastics to many disorders, including obesity, cardiovascular disease and even reduced fertility. Furthermore, lifestyle choices that negatively impact the human microbiome have been linked to increased risk of developing mental health conditions.

Table 3.2.5: Some examples of disorders that reduce the efficiency of organ systems and how some lifestyle factors can contribute to/reduce the risk of the disorder developing.

Disorder	Description of disorder	How lifestyle can contribute to disorder developing	How lifestyle can reduce risk to disorder developing
Type 2 diabetes	Hormonal system has a reduced ability to control blood glucose levels due to increased insulin resistance, predominantly attributed to poor diet and lifestyle choices.	Pancreatic cells that produce insulin become reduced in number due to factors such as inflammation (from diet high in saturated fats) and the overstimulation of pancreatic cells to produce insulin (diet high in simple sugars), over a long period of time (they tire and die off).	Exercise is energy intensive. It lowers blood glucose levels and burns fat resulting in weight loss and a reduced risk of developing type 2 diabetes. It also increases insulin sensitivity. Consuming a balanced diet low in simple sugars and saturated fats to reduce risk of insulin resistance developing.
Hypertension (high blood pressure)	Hypertension is when the pressure in the blood vessels is too high (140/90 mmHg or higher). Chronic high blood pressure can stiffen and injure the walls of arteries, which can accelerate atherosclerosis. If left untreated, heart failure can develop.	A diet high in sodium (salt) can increase the risk of hypertension. This is because the kidneys cannot excrete the sodium from the blood efficiently enough at high levels and water is retained by the body to dilute the sodium in the blood. This increases blood volume, which increases blood pressure. Chronic stress can increase blood pressure due to the release of stress hormones that activate pathways to increase heart rate and blood pressure.	Regular physical activity can reduce blood pressure by making the heart stronger. It can also help to reduce stress. Meditation and other mindfulness techniques can reduce stress. Consuming a diet low in sodium and simple sugars leading to less water retention in blood and a lowered blood pressure.
Atherosclerosis	Atherosclerosis is the build-up of fatty deposits in arteries, forming plaques. This thickens of artery walls and narrows the channel reducing blood flow and ability to deliver nutrients to organ systems (see Figure 3.2.4). Full blockage can result in a heart attack or stroke.	A diet high in saturated and trans fats increase blood cholesterol levels which increases the risk of fatty deposits building up against the walls of blood vessels. Additionally, a diet that is low in fibre providing plant-based foods increases the risk as fibre can help to lower cholesterol levels.	Exercise increases the production of good cholesterol levels, which in turn lowers the bad cholesterol levels in the blood, decreasing the risk of atherosclerosis. Exercise also reduces blood pressure, which is a risk factor for atherosclerosis. Consuming a balanced diet high in plant-based foods, fatty fish (contains omega-3) and low in saturated and trans fats.
Osteoporosis	Osteoporosis is a condition where bones become weak and fragile due to reduced bone density. This can also result in the curvature of the spine and increased risk of bone fractures/breakages.	A sedentary lifestyle can result in poor bone density. Weight bearing exercise is required for the development and maintenance of bones. A diet low in calcium and vitamin D is also a risk factor. Vitamin D is required to absorb calcium, which is required for bone formation. A lack of exposure to sunlight can result in low vitamin D levels.	Completing weight bearing exercise regularly and exercising outside to allow body to synthesise vitamin D from sunlight. Consuming a diet that includes dairy products (or dairy alternatives) and dark leafy greens that are high in calcium.

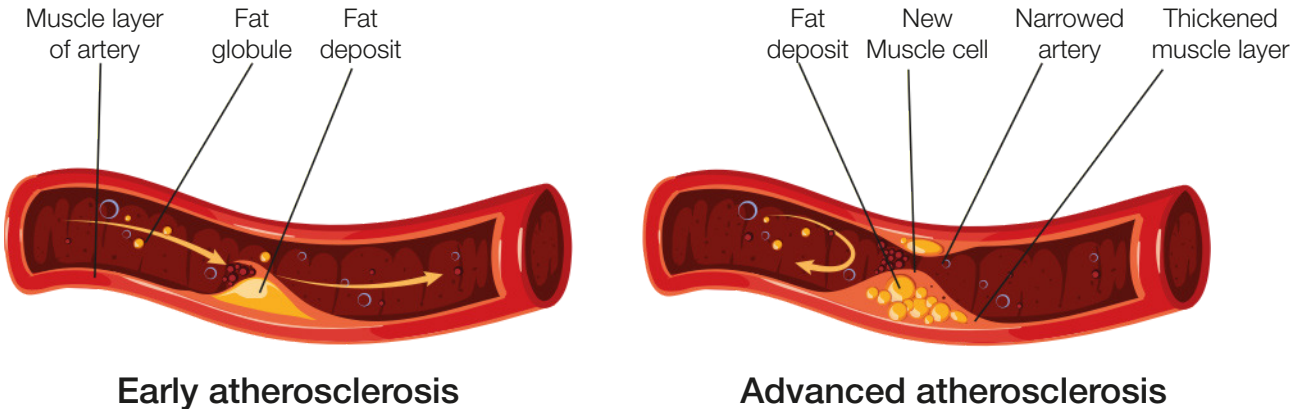


Figure 3.2.4: The buildup of fatty deposits against the walls of arteries can narrow the diameter of the lumen and reduce blood flow. This can result in less efficient delivery of nutrients, such as glucose and oxygen, to all organ systems, negatively affecting their function.

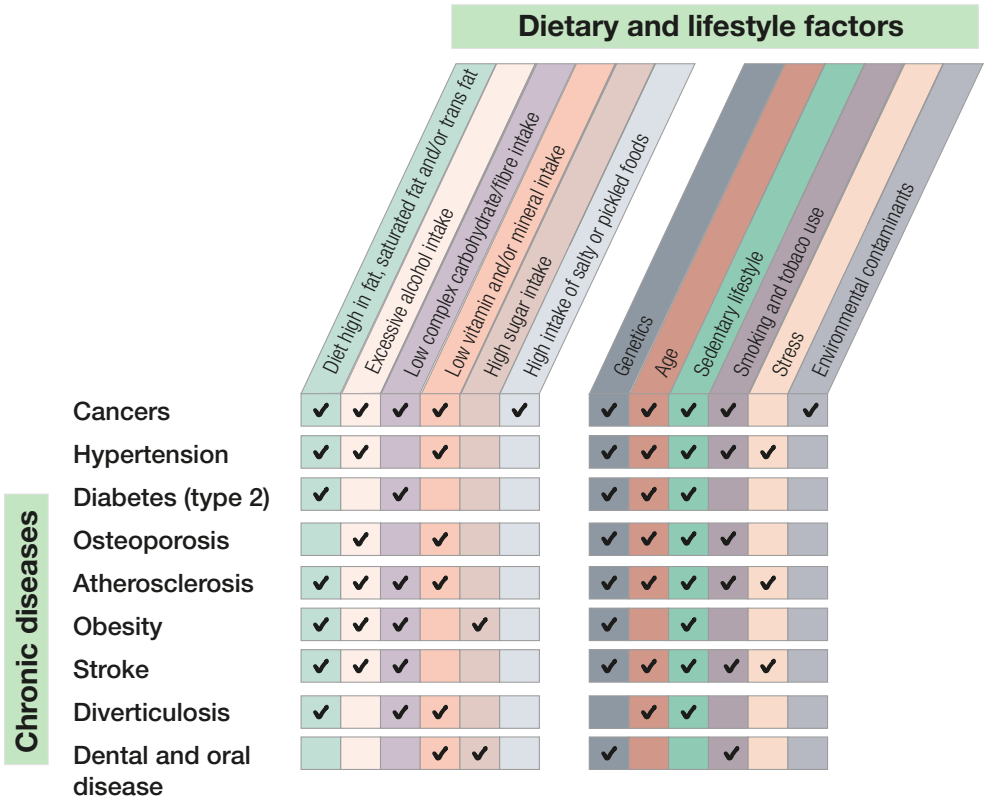


Figure 3.2.5: A chart highlighting some dietary, lifestyle and additional factors that can decrease the efficiency of some organ systems and increase the risk of developing some chronic diseases.

Helpful online resources

FreeMedEducation: What Happens During A Heart Attack? – What is Coronary Heart Disease?

<https://www.youtube.com/watch?v=xBAvxnT0ZvI>

TED-Ed: How do cigarettes affect the body? – Krishna Sudhir

<https://www.youtube.com/watch?v=Y18Vz51Nkos>

3.2 Review questions

Multiple choice questions

1. Which of the following options correctly shows a section of the hierarchy of a multicellular organism?

   J Cell → Tissue → Organelle
   K Organ → Organelle → Organism
   L Tissue → Organ system → Organelle
   M Organelle → Cell → Tissue

2. A major role of connective tissue is to

   J contract and provide movement.
   K communicate with other tissues.
   L absorb nutrients.
   M provide structural support.

3. Which type of epithelial cell lines the outer layer of the skin?

   J Stratified squamous epithelial
   K Simple squamous epithelial
   L Ciliated columnar epithelial
   M Simple columnar epithelial

4. Which of the following options incorrectly identifies a lifestyle related disorder and the main organ system it directly affects?

	Organ system directly affected	Lifestyle related disorder
J	Skeletal	Osteoporosis
K	Hormonal	Type 2 diabetes
L	Circulatory	Hypertension
M	Digestive	Atherosclerosis

5. Skeletal muscle is classified as a tissue because

   J it attaches to bones of the skeletal system.
   K it is a group of specialised cells that perform a specific function.
   L it is a group of many different specialised cells that perform different functions within an organism.
   M it is a group of tissues in a living organism that have adapted to perform a specific function within an organism.

6. Select the row below that contains three of the four different types of tissue.

J	Cartilage tissue	Ciliated tissue	Cardiac tissue
K	Adipose tissue	Cardiac tissue	Blood tissue
L	Blood tissue	Bone tissue	Nerve tissue
M	Squamous tissue	Nerve tissue	Simple columnar tissue

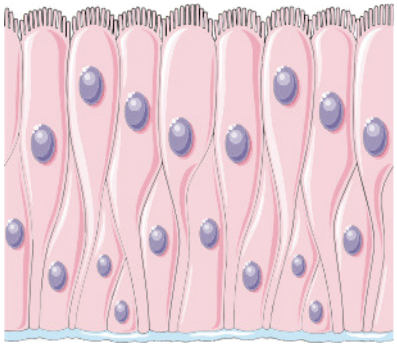
7. Organ systems

   J work independently of each other.
   K are different tissues grouped together to carry out a function.
   L depend on other organ systems to work efficiently.
   M include examples such as respiratory, circadian, and connective systems.

8. Select the row below that correctly identifies a human organ system, two organs involved in that organ system and its main function.

	Organ system	Major organ involved	Major organ involved	Main function of organ system in human
J	Excretory	Kidneys	Urea	To filter blood and excrete waste products.
K	Digestive	Stomach	Bladder	To digest and absorb nutrients from foods.
L	Respiratory	Heart	Lungs	To perform aerobic respiration.
M	Circulatory	Heart	Blood vessels	To circulate blood to all cells within the body.

9. *Refer to the image below to answer the following question.*



The structure shown in the image above is

J at the cellular level of the hierarchy of an organism.
K at the tissue level of the hierarchy of an organism.
L at the organ level of the hierarchy of an organism.
M at the organ system level of the hierarchy of an organism.

10. Which of the following statements is the most correct regarding the effect of lifestyle factors on the efficiency of organ systems.

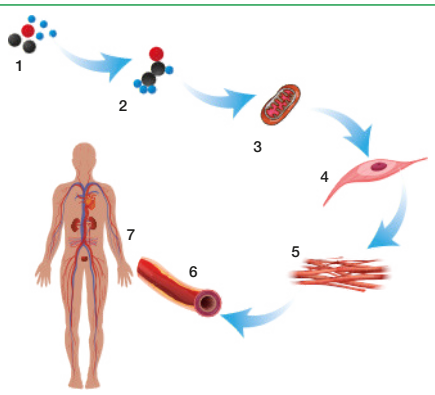
J Eating a diet containing simple sugars and saturated fat will cause atherosclerosis.
K Exercising outside in the sunlight is a major risk factor for developing osteoporosis.
L Chronic stress is a major risk factor for the development of hypertension.
M Type 2 diabetes is only caused by the consumption of too many simple sugars over a long period of time.

Free response questions

1. Describe the hierarchical organisation in multicellular organisms.

2. Identify the numbered levels of structural organisation represented in the image below.

	Level of structural organisation
1	Atom
2	Molecule
3	
4	
5	
6	
7	



3. a) Explain why blood is considered a tissue.

b) Explain why blood is classified as a connective tissue.

4. The human stomach is a vital organ in our body.
   a) State **two** different tissues present in the human stomach.

   b) Name the main organ system that consists of the stomach.

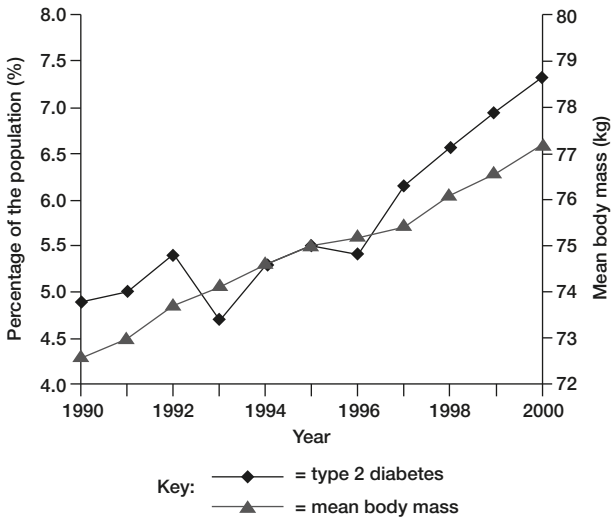
   c) Describe **two** functions of the human stomach.

5. Identify **two** factors that can increase the risk of developing osteoporosis.

6. Explain why organs are made up of two or more types of tissues and not just one.

7. Discuss how the respiratory, circulatory, digestive and excretory systems depend on each other to function efficiently.

8. *Refer to the graph below that shows the percentage of the population with type 2 diabetes and the average body mass of the population from 1990 to 2000 to answer the following questions.*
   a) Using data, describe the observed relationship between type 2 diabetes and average body mass.



b) Discuss **one** limitations of this investigation.

c) Discuss how an individual's diet could increase their risk of developing type 2 diabetes.

d) Discuss how an individual's exercise level could reduce the risk of developing type 2 diabetes.

9. Exposure to microplastics has been linked to many lifestyle-related disorders. Researchers have recently discovered microplastics building-up in many organs including the testes and penis of human males, which is likely contributing to reduced male fertility. They also discovered them in human blood. Researchers established that these microplastics were actually contributing to atherosclerosis. The microplastics are also building-up against the blood vessel walls with the fatty deposits, contributing to plaque development.

a) Use your understanding of Science as a Human Endeavour to discuss how society influences research into the effects of microplastics on the efficiency of human organ systems.

b) Use your understanding of Science as a Human Endeavour to discuss how the recent discovery of microplastics affecting male fertility could influence society.

Chapter 3.3 Exchange of materials with the environment

Science Understanding

Multicellular organisms exchange materials with their environment.

Exchange surfaces in an organism must be thin, moist and have a large surface area. In many animals a rich blood supply is also essential.

In animals, the exchange of gases by diffusion between the internal and external environments of the organism is facilitated by the structure and function of the respiratory system.

- Describe the process of diffusion of respiratory gases as a passive process that does not require additional input of energy.

Exchange with the environment

When discussing exchange of materials by multicellular organisms it is helpful to refer to the environment around exchange surfaces as the external environment. For example, nutrients in the digestive tract are considered to be in the external environment because unless they are absorbed across the villi of the small intestine, they are going to be removed from the body through defecation. The blood supply and body cells of a multicellular organism therefore form the inside, or internal environment. The function of exchange surfaces then, is to permit the exchange of materials between the internal and external environments of the organism.

Exchange surfaces

Unicellular organisms exchange materials directly with the environment. For most cells in a multicellular organism this cannot happen because they are not in direct contact with the environment. To cope with this problem, multicellular organisms have structures composed of cells in certain organs specialised for exchange called exchange surfaces (see Table 3.3.1 for some examples).

Table 3.3.1: Some examples of exchange surfaces in humans and some other multicellular animals.

Exchange surface	Organ located in	Organ system	Substances exchanged
Alveoli (singular alveolus)	Lungs	Respiratory system	Oxygen, carbon dioxide, water vapour
Villi (singular villus)	Small intestine	Digestive system	Glucose, amino acids, fatty acids and glycerol, water
Nephrons	Kidneys	Excretory system	Urea, water, salts

To ensure the exchange of materials is efficient, exchange surfaces:

- are **thin**, which reduces the distance that materials need to move during exchange.
- are **moist**, which allows substances to dissolve in water, assisting in its transport across the exchange surface.
- have a **large total surface area**, which provides more surface for exchange to take place.
- have a **rich blood supply** to transport substances to and from exchange surfaces, and to maintain concentration gradients required for the exchange of substances.

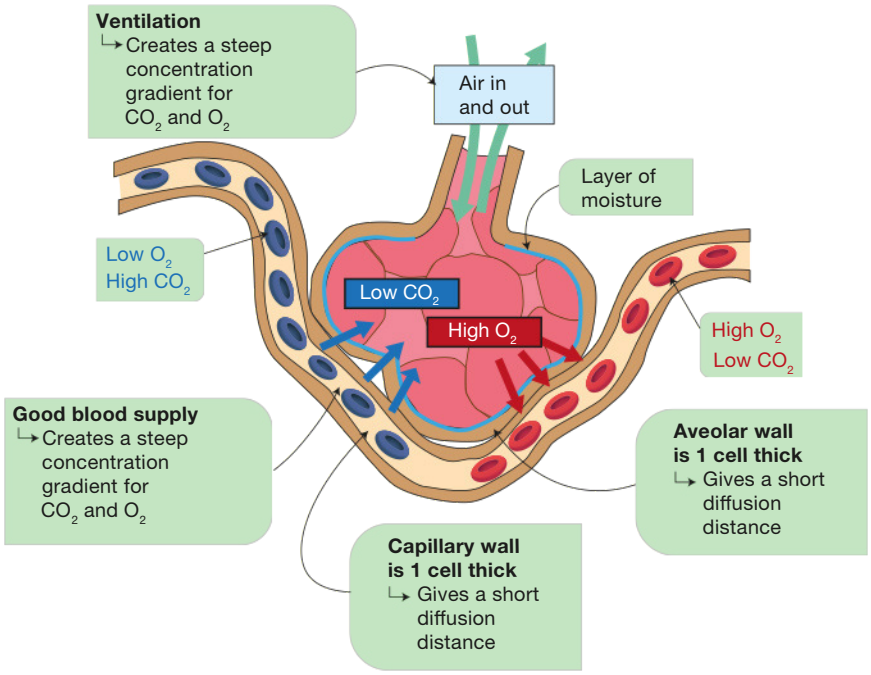


Figure 3.3.1: The alveolar exchange surface in the lungs is one example where the four common features of exchange surfaces are present.

In animals, the circulatory system is the central link between organ systems and their respective exchange surfaces, in terms of transporting useful and waste products. More specifically, the capillaries of the circulatory system are semi-permeable and allow the exchange of materials. An essential example of this is **aerobic cellular respiration**, which supplies all body cells with usable energy. The glucose and oxygen required for this reaction are needed at the same destination, but they enter the body through different exchange surfaces. Oxygen enters through the alveoli of the respiratory system, whereas glucose enters through the villi of the digestive system. They are both transported by the circulatory system to body cells for aerobic cellular respiration to occur. **Metabolic waste products** are also exchanged and transported by the circulatory system to be excreted. Carbon dioxide is a metabolic waste product of aerobic cellular respiration and urea is a metabolic waste product of the breakdown of protein. Carbon dioxide is transported to the alveoli of the respiratory system and urea to the nephrons of the excretory system to be excreted (see Figure 3.3.2).

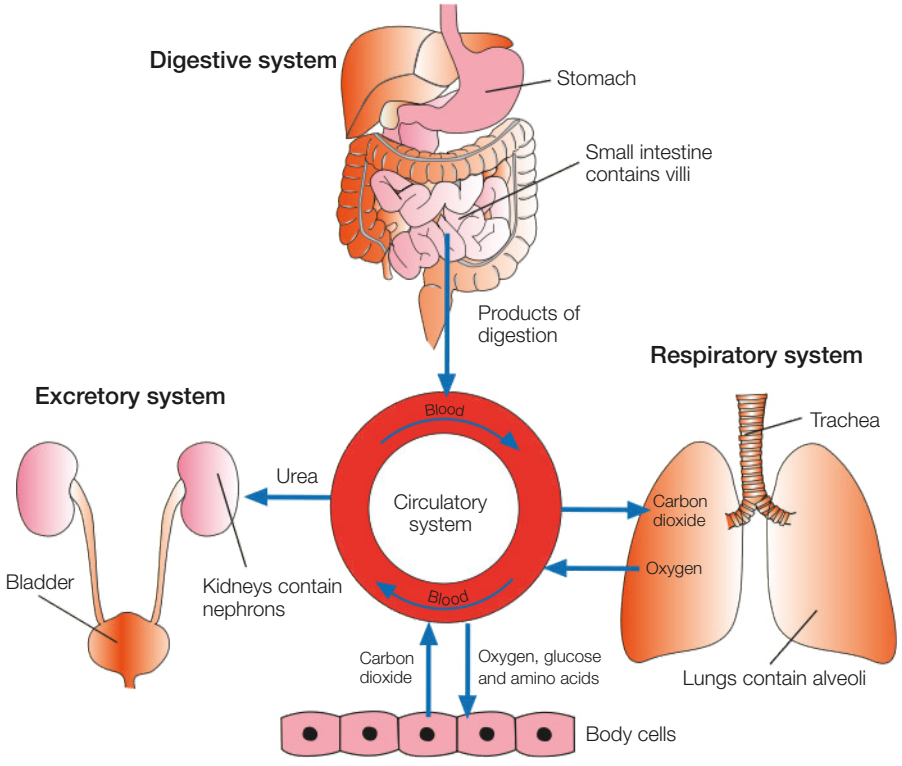


Figure 3.3.2: The circulatory system connects exchange surfaces and body cells.

Diffusion

Simple diffusion is the passive movement of molecules from a region of high concentration to a region of lower concentration until an overall even concentration is reached. The steeper the concentration gradient, the greater the rate of diffusion (see Figure 3.3.3). Small, uncharged molecules such as oxygen and carbon dioxide are free to cross membranes by diffusing between the phospholipids that make up cell membranes.

For more information on diffusion, factors that affect diffusion and other transport processes, please refer back to Topic 1.5.

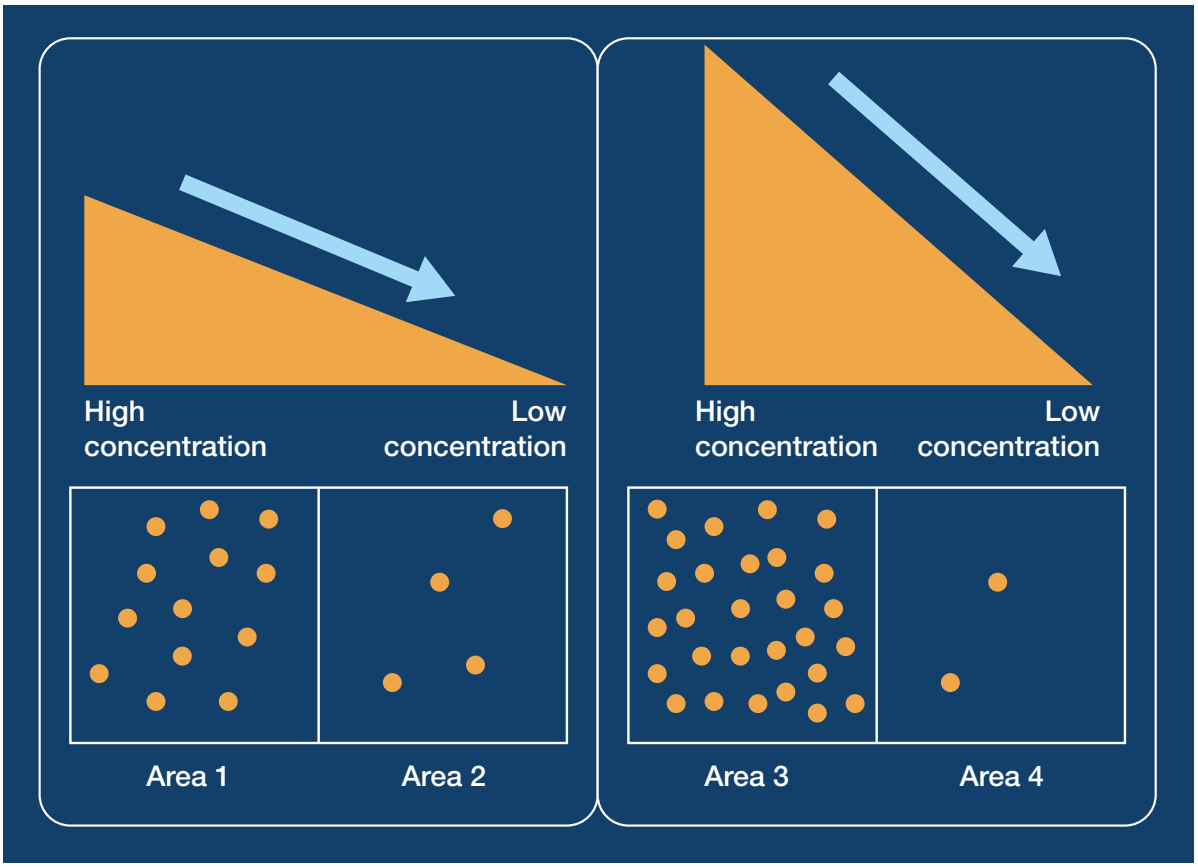
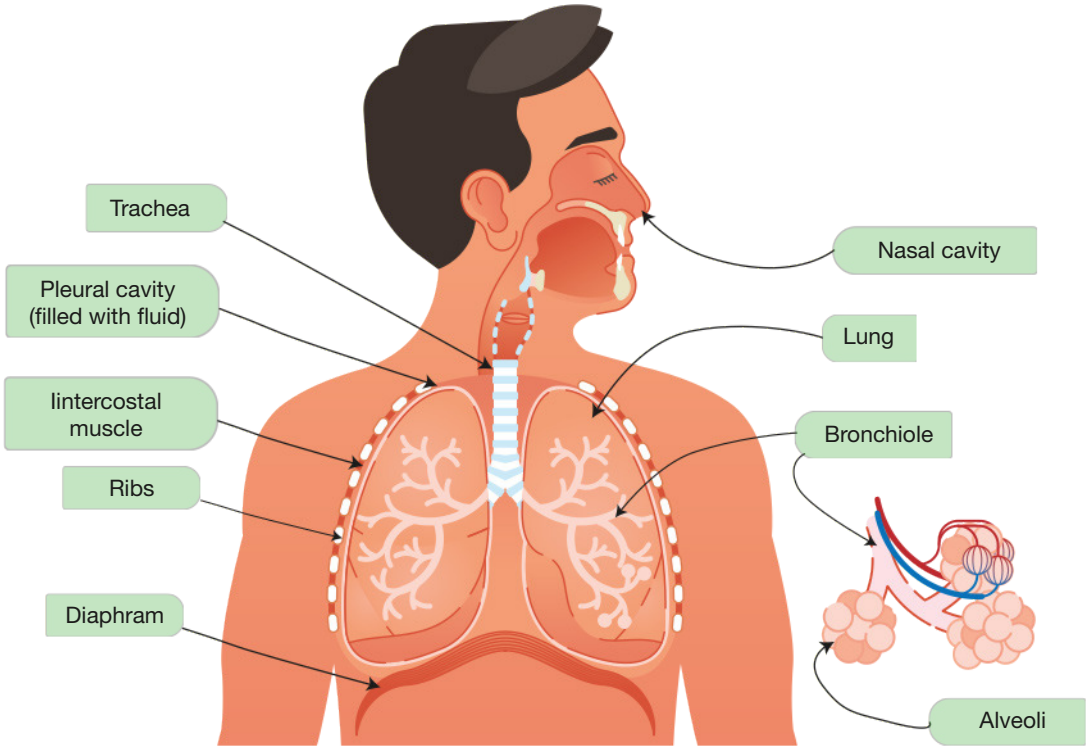


Figure 3.3.3: The greater the difference in concentration gradient between two areas, the greater the rate of diffusion.

The respiratory system

The exchange of gases between the internal and external environments in animals is called **respiration**. More specifically, oxygen moves from the external environment to the internal environment and carbon dioxide moves in the opposite direction. Respiration is carried out by the respiratory system and consists of two processes, **ventilation (breathing) and gas exchange**. Ventilation consists of two phases, inspiration (inhalation) and expiration (exhalation). The major organs involved in these processes are shown in Figure 3.3.4.

Respiration by the respiratory system is **not the same process as cellular respiration**, which is a metabolic process that occurs within cells. Respiration does however supply the oxygen required for aerobic cellular respiration and excrete the carbon dioxide produced by cells through aerobic cellular respiration.



Figures 3.3.4: The major organs of the respiratory system and their relative positioning within the human body.

Organs of the respiratory system

The respiratory system allows the flow of gases from the external environment through a continuous system of channels, called the **respiratory tract**, to the internal environment. The respiratory tract can be divided into two sections, **the upper respiratory tract** (see Figure 3.3.5) and **lower respiratory tract** (see Figure 3.3.6). The upper respiratory tract organs are involved in moving the air towards the lungs, but no gas exchange occurs here. They also assist in smelling, warming, moistening, and cleaning the air. The lower respiratory tract moves the air between the upper respiratory tract and the lungs so that gas exchange can occur at the alveoli.

There are some additional organs required for respiration to occur that are not part of the respiratory tract. Most of these additional organs assist in the ventilation process such as the diaphragm, ribs and intercostal muscles. Refer to Table 3.3.2 for the structures and functions of the major organs of the respiratory system.

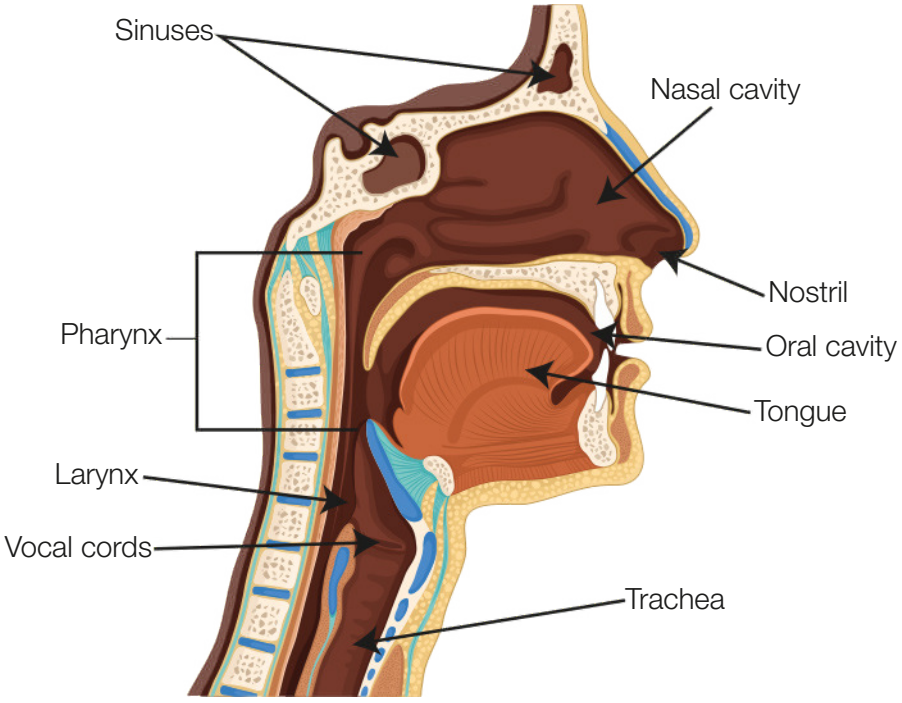


Figure 3.3.5: The structures of the upper respiratory system.

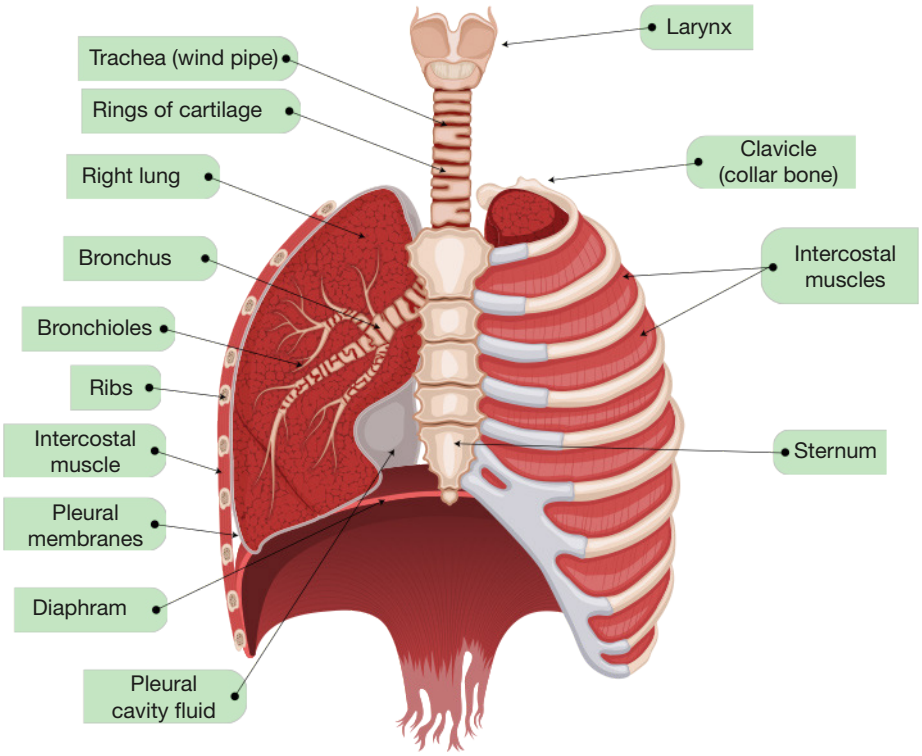


Figure 3.3.6: The structures of the lower respiratory system.

Table 3.3.2: Some structures and functions of the major parts of the respiratory system.

Part of the respiratory system	Structure and function(s)
Nose and nasal cavity	Provides warmth and humidity to the air breathed in and is the first line of defence against microorganisms and other particles. The nostrils (of the nose) contain hairs and mucous that help to trap and prevent foreign matter from entering the lower respiratory system. Chemoreceptors that are required for smelling and that contribute to the sense of taste are also located here.
Pharynx	A hollow space sitting behind the nose and mouth, the pharynx aids in the passage of air and food.
Larynx	Sitting below the pharynx and above the trachea, the larynx contains the epiglottis which aids in preventing food entering the trachea during breathing. The larynx is informally called the voice box as it contains the vocal cords that vibrate as air passes over them.
Trachea	The trachea connects the larynx to the lungs. It is a wide tube that branches off into the right bronchus and left bronchus (the two bronchi) allowing air to flow through the respiratory tract. The trachea is very strong as it consists of strong horseshoe shaped rings of cartilage to protect the airway from collapsing. The trachea also helps filter the air and protect the respiratory system from infections (see Figure 3.3.10).
Pleural cavity	The pleural cavity is the fluid filled space surrounding each lung. The pleural fluid acts as a lubricant, helping to cushion the lung and reduce friction as the lungs expand and contract.
Bronchi and bronchioles	The two bronchi connect the trachea to the two lungs. The bronchi branch off into smaller bronchioles that terminate in clusters of alveoli (air sacs). The bronchi carry air to and from the lungs.
Lungs	Lung tissue mainly consists of alveoli, which are the functional unit of the lungs where gas exchange occurs. The left lung is smaller than the right lung providing space for the heart.
Diaphragm	A dome shaped muscle sitting below the lungs that expands and contracts, pulling air into the lungs and expelling air from the lungs respectively.
Ribs	A framework of bones that protects the lungs from physical damage and helps facilitate breathing.
Intercostal muscles	These muscles between the ribs contract and relax to elevate and lower the ribs respectively.

Functions of the respiratory system

Ventilation

Ventilation, also called breathing, consists of two phases:

- inspiration (inhalation), when air enters the lungs, and
- expiration (exhalation), when air is expelled from the lungs.

During inhalation, air enters the respiratory tract through either the mouth or the nose. As air passes through the nasal cavity, it is smelt, warmed, filtered, and moistened. The air passes through the pharynx and larynx to the trachea but is split when it reaches the two bronchi. Each bronchus is connected to a large air sac called a lung, which is filled with the inhaled air, causing it to expand. Following gas exchange, the expanded lungs deflate, and air is forced back up the respiratory tract to the oral or nasal cavity and expelled through the mouth or nose respectively. A balloon lung model can be used to visualise ventilation (see Figure 3.3.7). Pulling the rubber sheet down, inflates the balloons and models inhalation, whereas releasing the rubber sheet deflates the balloons and models exhalation.

This movement of air during breathing is achieved by generating **changes of pressure in the chest cavity** (see Figure 3.3.8). The intercostal muscles, ribs and the diaphragm, are all involved in generating these pressure changes. During **inhalation**, the dome shaped diaphragm contracts and flattens and the intercostal muscles contract elevating the rib cage upward and outward, producing more space for the lungs to expand into. This increases the volume of the chest cavity and lowers the air pressure inside the lungs compared the air pressure outside the body (see Figure 3.3.9).

During **exhalation**, the diaphragm relaxes and returns to its resting dome shape and the intercostal muscles also relax depressing the ribs downward and inward. This decreases the volume of the chest cavity and increases the air pressure inside the lungs compared the air pressure outside the body, expelling the air from the lungs (see Figure 3.3.9).

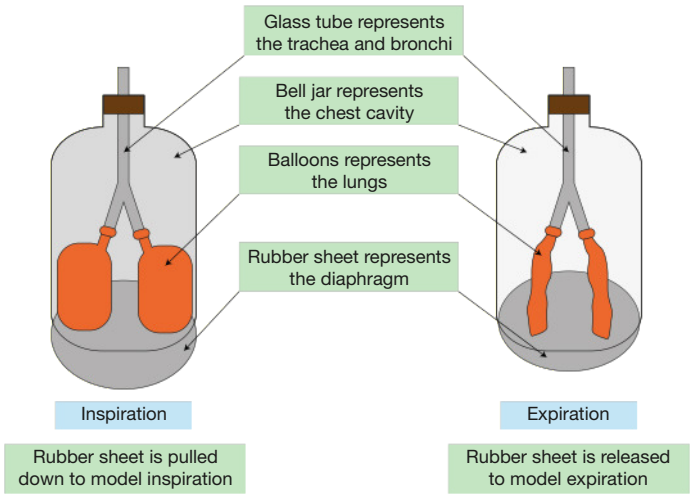


Figure 3.3.7: The balloon lung model can be used to visualise ventilation.

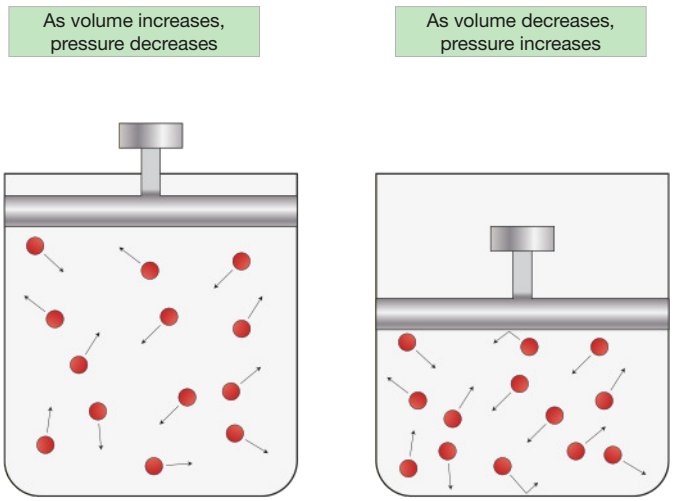


Figure 3.3.8: A simple representation of how changing the volume changes the pressure.

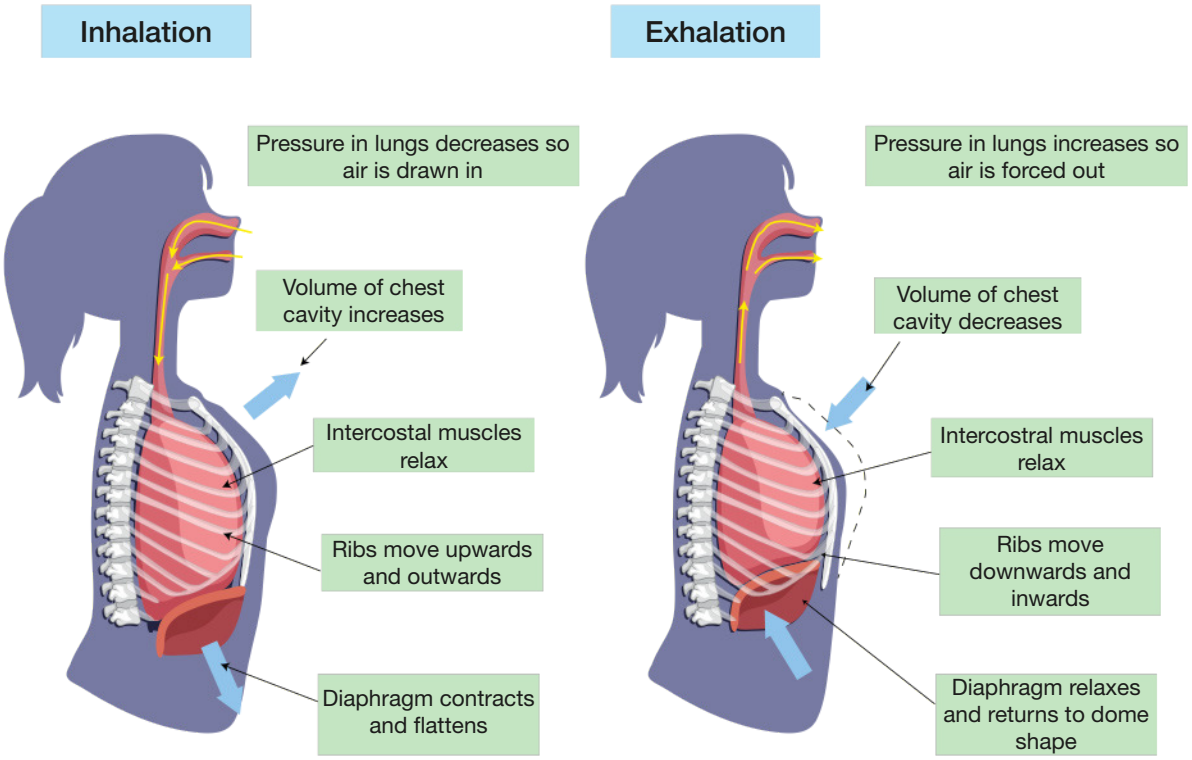


Figure 3.3.9: A summary of the inhalation and exhalation processes.

Gas exchange in alveoli

Gas exchange occurs between alveoli and the capillaries surrounding them. The capillaries carry blood that has come from the right side of the heart and has a low oxygen concentration and high carbon dioxide concentration. In contrast, the air inside the alveoli has just been breathed in and has a high concentration of oxygen and low concentration of carbon dioxide. This causes oxygen to diffuse out of the alveoli and into the capillaries along its concentration gradient. Simultaneously, carbon dioxide diffuses along its concentration gradient in the opposite direction, from the capillaries into the alveoli (see Figure 3.3.10). Due to this gas exchange the inhaled air and exhaled air consist of different concentrations of gases (see Table 3.3.3).

The exchange of gases by diffusion at alveoli is facilitated in several ways including:

- Each lung is made of millions of smaller air sacs called alveoli (approximately 350 million in each lung). The **total surface area** within the lungs is therefore **extremely high** and covers approximately 100m^2 in an average sized adult.
- The outside surface of alveoli is covered with a lot of **capillaries** that transport blood to/from them.
- The distance for diffusion is very short because the alveoli surface and the capillary walls both consist of a single layer of epithelial tissue which makes them **very thin**.
- The exchange of gases across alveoli is assisted by the presence of a film of **moisture** that covers the inside surface of them. This allows gases to dissolve in the moisture and diffuse across the alveolar exchange site.

Refer back to Figure 3.3.1 to review the key features of gas exchange surfaces and more specifically how they present in the gas exchange sites of the respiratory system.

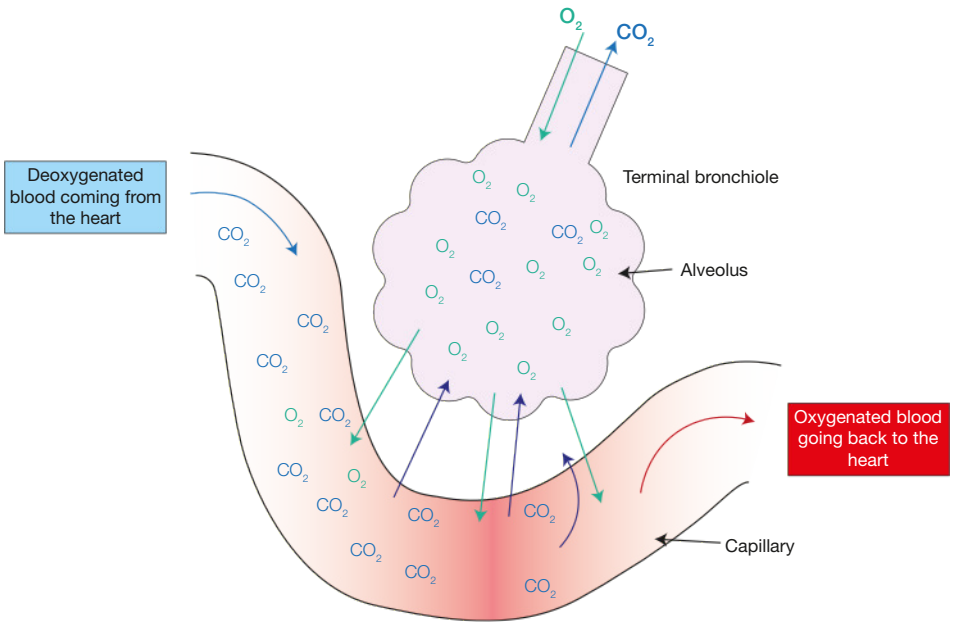


Figure 3.3.10: A representation of the differences in the carbon dioxide and oxygen concentration gradients between an alveolus and capillary where gas exchange occurs.

Table 3.3.3: The approximate concentrations of the major gases inhaled and exhaled.

Gas	Inhaled air (%)	Exhaled air (%)	Explanation
Oxygen (O_2)	21	16	Required for cellular respiration and diffuses into deoxygenated blood so there is a lower concentration in the exhaled air.
Carbon dioxide (CO_2)	0.04	4	Product of cellular respiration which is brought back to the lungs via the circulatory system to be excreted.
Nitrogen (N_2)	78	78	Not used by cells and does not dissolve in water so it cannot be exchanged.
Water vapour (H_2O)	Small amount	Large amount	Product of cellular respiration that can be excreted. Upper respiratory tract humidifies air which makes the alveolar air have a higher water vapour concentration than external air.

Additional functions

Some additional functions of the respiratory system are outlined in Table 3.3.4:

Table 3.3.4: Descriptions of some additional functions of the respiratory system..

Function	Description
Involved in smelling	Chemicals present in air bind to receptors in the nasal cavity allowing them to be smelt.
Involved in speaking	As air passes through the vocal cords, it causes them to vibrate creating sounds.
Filtering the air	This helps protect the body from particles and microbes inhaled (see Figure 3.3.11 for an example of this occurring in the trachea).
Warming and adding moisture to the inhaled air	This is critical to ensure the respiratory epithelial tissue is not damaged and its functioning is therefore not affected (e.g. filtering the air).

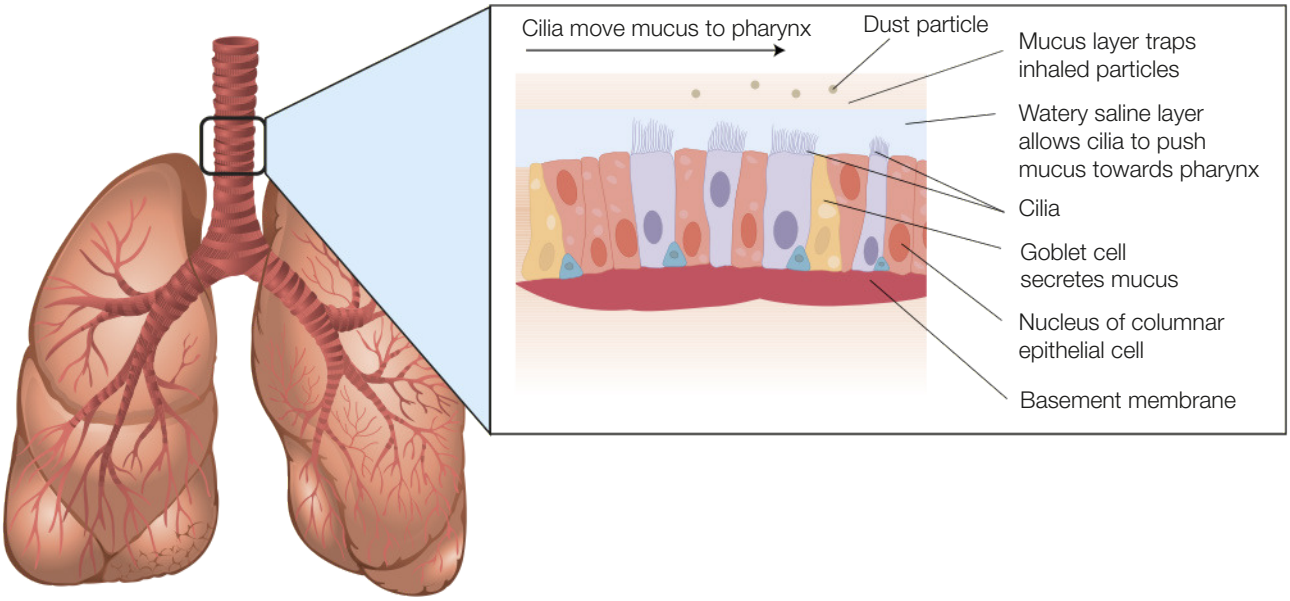


Figure 3.3.11: The specialised goblet cells that line the trachea secrete mucous to trap particles and microorganisms, and the cilia that project from epithelial cells push the mucous (with trapped materials) back towards the pharynx, where it can be swallowed and exposed to the acidic nature of the stomach or discharged from the body through spitting.

Helpful online resources

FreeMedEducation: This is What Actually Happens When We Breathe

<https://www.youtube.com/watch?v=bNIxsKT_qdA>

TED-Ed: How mucus keeps us healthy - Katharina Ribbeck

<https://www.youtube.com/watch?v=WW4skW6gucU>

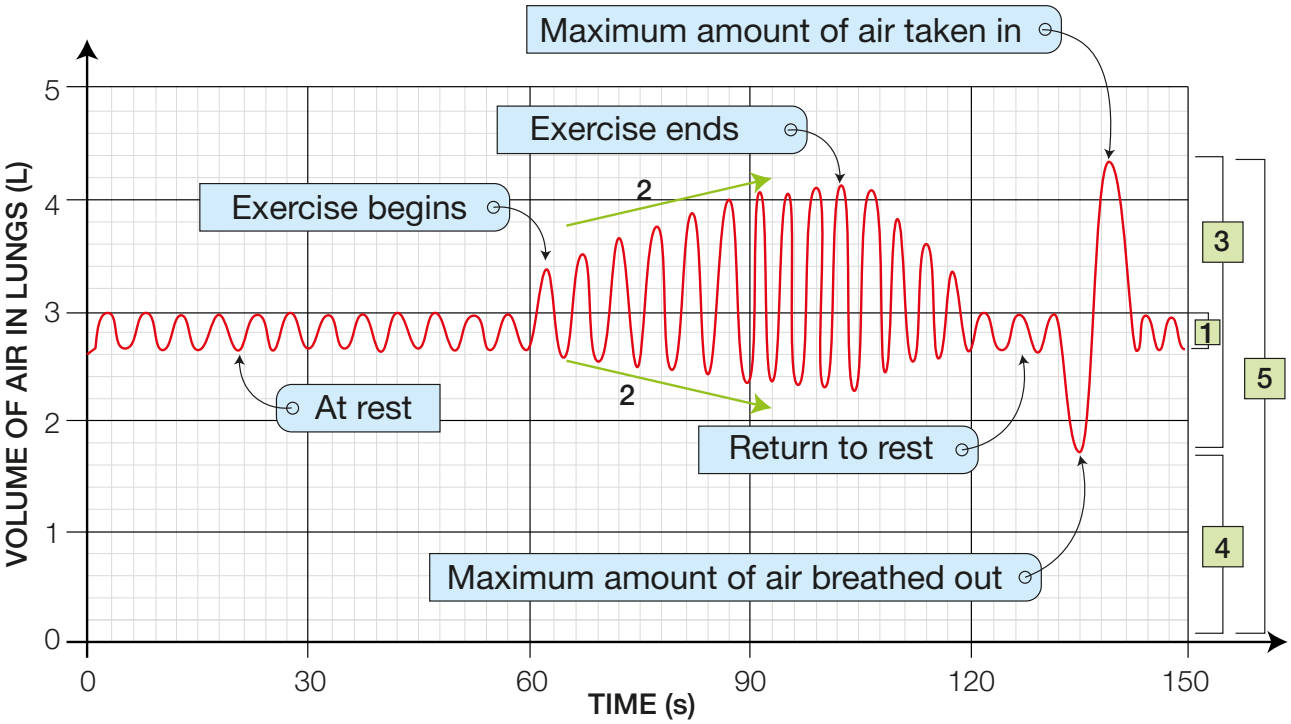
3.3

Lung capacity and breathing rate

The movement of air into and out of the alveoli is often simply referred to as breathing. Air moving into the lungs causes them to inflate while air moving out deflates them. The total volume of the lungs when they are fully inflated with air is called the **total lung capacity.** In an adult human this is about 5 litres. During breathing at rest, a person only breathes in and breathes out about 10% of the lung capacity, or about half a litre of air. This volume is called the **tidal volume**.

During forced breathing the tidal volume increases. Taking an extra deep breath in increases the volume of air taken into the lungs and taking an extra deep breath out forces a larger volume of air out. The maximum possible tidal volume is called the **vital capacity**. It is not possible to breath out all the air in the lungs. A certain volume of air remains regardless of how hard a person breathes out. This volume is called the **residual volume**.

The number of times air is inhaled and exhaled per minute is called the ventilation rate, or breathing rate (breaths per minute). At rest, the breathing rate is typically about 15 breaths per minute. When exercising, both the breathing rate and the tidal volume can increase to supply the extra oxygen required for cellular aerobic respiration. A **spirometer** can be used to measure the amount of air breathed in and the breathing rate (see Figure 3.3.12).



1 = Tidal volume (rest)
2 = Tidal volume (exercise)
3 = Vital capacity
4 = Residual volume
5 = Total lung capacity

Figure 3.3.12: A spirograph displaying the tidal volume (1) at rest and how exercise can increase the tidal volume and ventilation (breath rate) during exercise (2). The maximum amount of air taken in and breathed out is achieved by measuring a forced deep breath and is called the vital capacity (3). The residual volume (4) and the total lung capacity (5) are also displayed.

Asthma

One medical condition that disrupts healthy breathing and gas exchange is asthma. This is usually an allergic reaction to an inhaled trigger like pollen, fur from pets or dust mites. These irritants cause the bronchioles to become hyperactive which results in bronchiole constriction and swelling and inflammation of the bronchiole walls, reducing their diameter. Subsequently, breathing is characterised by shortness of breath and wheezing until treated by medication. Ventilators contain reliever medicine that helps reduce the constriction of the smooth muscle in the bronchioles.

Helpful online resources

TED-Ed: How does asthma work? - Christopher E. Gaw

<https://www.youtube.com/watch?v=PzfLDi-sL3w>

Lifestyle related diseases of the respiratory system

An individual's lifestyle can contribute to the development of a variety of lifestyle related diseases that affect the respiratory system. Refer to Table 3.3.4 for some information on three examples.

Table 3.3.4: Three examples of respiratory system diseases that are related to particular lifestyle factors in many cases.

Lifestyle disease	Consequences of the disease	Lifestyle factors
Emphysema	The alveoli are damaged leading to reduced surface area for gas exchange and therefore lung capacity (see Figure 3.1.13). This can cause shortness of breath even during mild activity, and general fatigue.	Repeated exposure to some chemical irritants, for example, vaping or cigarette smoking, working in a cigarette smoke-filled environment, or working with certain industrial chemicals can increase the damage to the alveoli and result in emphysema.
Some lung cancers	Uncontrolled cell division in the bronchioles or bronchi leading to lung tumours which cause impaired function, mucus coughed up streaked with blood, and pain when coughing.	Long-term exposure to cancer-causing chemicals or carcinogens such as cigarette smoking, living and/or working in city smog, or working with asbestos can increase the risk of lung cancer development.
Pneumonia	Pneumonia can be caused by bacterial, viral and fungal infections. They infect the lungs, mainly the pleural membranes, causing them to produce a greater amount of fluid (which normally act as a lubricant) filling the alveoli. This reduces gas exchange and impairs oxygen supply to the tissues. It can also lead to breathing difficulties, high breathing rate, fever, and prolonged fatigue.	Lifestyle habits such as cigarette smoking, heavy alcohol use and malnourishment can increase the risk of developing pneumonia. Not washing hands with soap and water can increase the risk of pneumonia causing microorganisms entering the body.

Healthy lung Emphysema

Figure 3.3.13: A comparison of a healthy lung with a lung affected by emphysema which has many damaged alveoli, reducing the lungs surface area and total lung capacity.

Helpful online resources

David Geffen School of Medicine at UCLA: Electronic Cigarettes and Vaping

<https://www.youtube.com/watch?v=9dZS_Rniak0>

3.3 Review questions

Multiple choice questions

1. Which of the following is **not** a function of the respiratory system?

   J To excrete carbon dioxide.
   K To pump oxygenated blood to all body cells.
   L To move air in and out of the lungs.
   M To assist with smelling.

2. Which of the following is **not** true of alveoli?

   J The alveoli are made of one layer of thick epithelial cells.
   K They are present in clusters to increase surface area.
   L Each alveolus has its own blood supply.
   M Its layer of moisture helps facilitate gas exchange.

3. Oxygen and carbon dioxide move in opposite directions during gas exchange between the alveoli and blood capillaries. This is because

   J of the small surface area of the alveoli.
   K oxygen and carbon dioxide are different in size.
   L they are facilitated by proteins to move in different directions.
   M of differences in the concentration gradient of oxygen and carbon dioxide.

4. *Refer to the table below showing the approximate composition of gases in the air exhaled by a human.*

Gas	Percentage composition of air exhaled (%)
Carbon dioxide	4
Oxygen	16
Nitrogen	80

   The nitrogen gas exhaled is

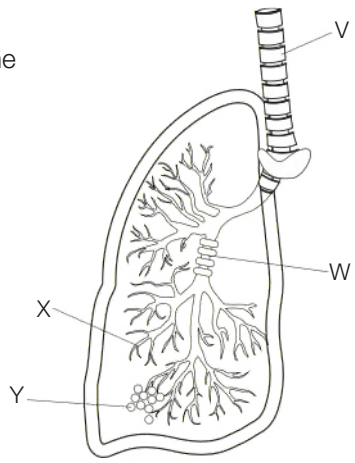
   J a product of respiration.
   K a product of the digestion of amino acids.
   L in the air inhaled.
   M exchanged with oxygen across the alveoli.

5. Select the statement that best describes how humans inhale.

   J The diaphragm contracts to flatten and the intercostal muscles contract.
   K The diaphragm relaxes to flatten and the intercostal muscles contract.
   L The diaphragm contracts to flatten and the intercostal muscles relax.
   M The diaphragm relaxes to flatten and the intercostal muscles relax.

6. *Refer to the diagram to the right of a lung to answer the following question.*

   Select the row in the table below that correctly identifies the four parts of the lung labelled V to Y.



	Name of V	Name of W	Name of X	Name of Y
J	Trachea	Bronchus	Bronchiole	Alveoli
K	Trachea	Bronchiole	Alveoli	Broncheolus
L	Bronchitis	Bronchus	Bronchiole	Alveoli
M	Bronchitis	Bronchiole	Alveoli	Broncheolus

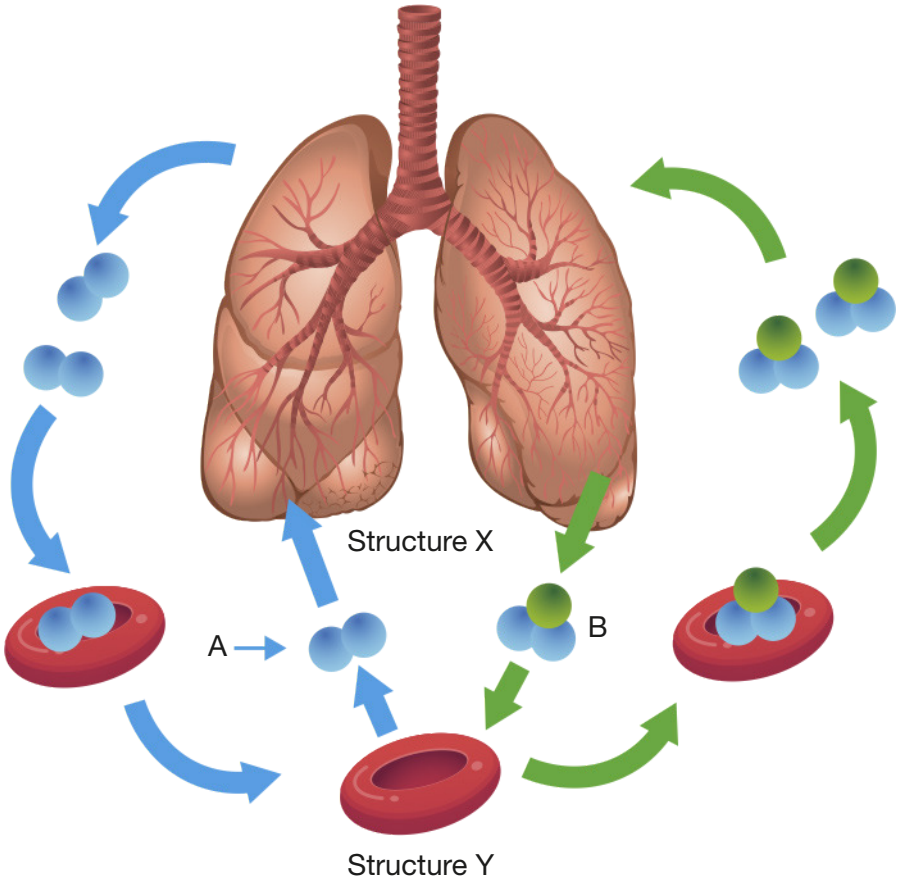
7. Inhalation can be demonstrated using a balloon lung model. A rubber membrane at the base of a glass jar can be stretched, which inflates two balloons inside the glass jar. The rubber membrane represents the

   J pleural membrane.
   K intercostal muscles.
   L diaphragm.
   M lungs.

8. The maximum volume of air that can be inhaled and exhaled in one breath is called the

   J tidal volume.
   K vital capacity
   L residual volume.
   M total lung capacity.

9. *Refer to the diagram below to answer the following question.*



Which of the following options correctly identifies the two gases (A and B), the process occurring inside structure X that produces gas B and the process occurring between structures X and Y?

	Name of gas A	Name of gas B	Name of process that produces gas B in Structure X	Name of process occurring between structures X and Y
J	Carbon dioxide	Oxygen	Aerobic respiration	Facilitated diffusion
K	Carbon dioxide	Oxygen	Anaerobic respiration	Diffusion
L	Oxygen	Carbon dioxide	Aerobic respiration	Diffusion
M	Oxygen	Carbon dioxide	Anaerobic respiration	Facilitated diffusion

10. *Refer to the diagram below showing the alveoli of a healthy lung compared with one that is affected by emphysema to help answer the following question.*

Healthy lungs Emphysema

Which one of the following combinations correctly identifies how emphysema affects the lungs compared to a normal lung?

	Surface area	Number of capillaries	Air spaces
J	Smaller	Smaller	Larger
K	Smaller	Larger	Smaller
L	Larger	Smaller	Larger
M	Larger	Larger	Smaller

Free response questions

1. Explain how the surface area of a cell can affect its ability to exchange materials with its environment.

2. Complete the following table about the exchange surfaces in three organs of the human body.

Organ	Materials exchanged	How surface area is maximised
Lungs		
Intestine		
Kidney		

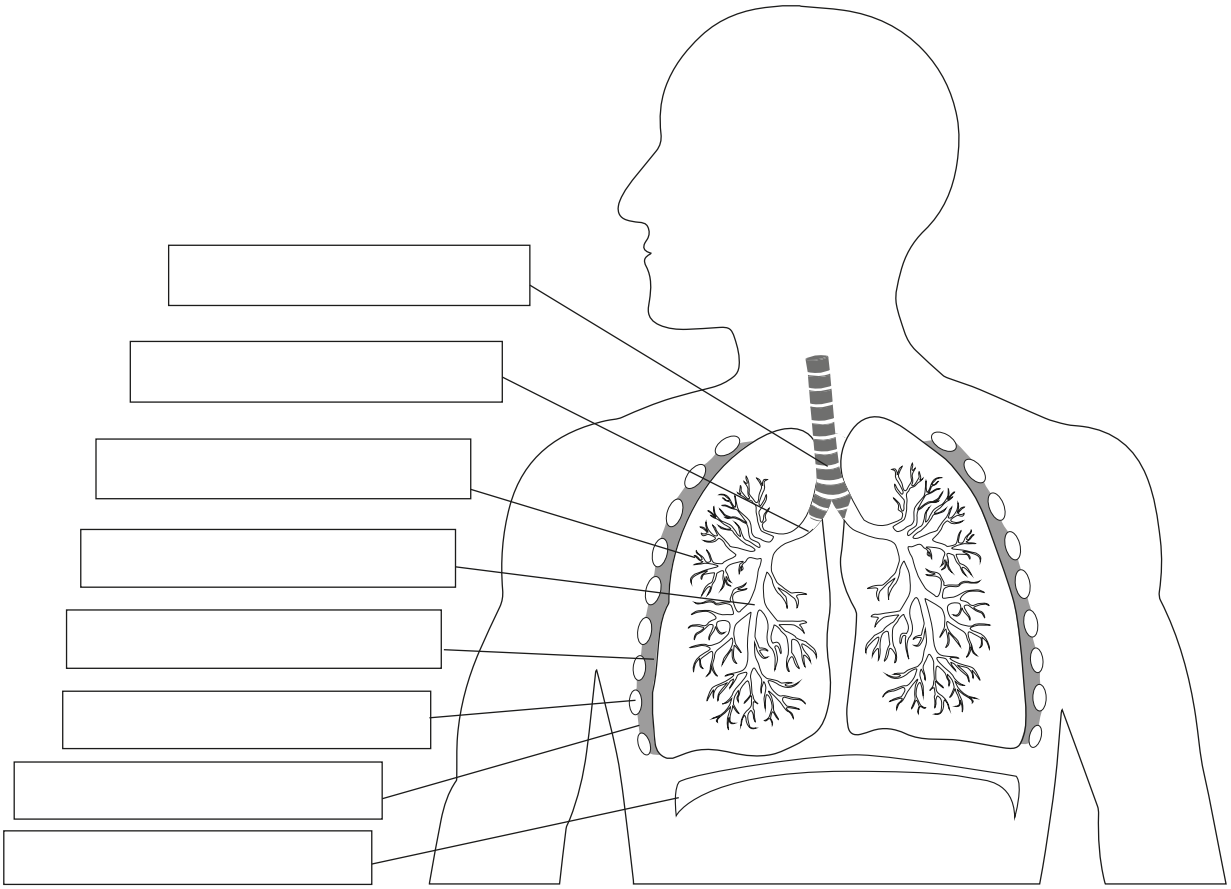
3. Outline how each of the following three characteristics of exchange surfaces assist in the exchange of materials by diffusion between an organism and its environment.

   a) Thin

   b) Moist

   c) Large surface area

4. Label the following organs of the respiratory system:



5. Using only the list of words below, complete the following table about inhalation and exhalation.

moves down and in, contracts, contracts, increases, increases, flattens, inflates, relaxes, relaxes, moves up and out, decreases, decreases, deflates, dome shaped,

Feature	Inhalation	Exhalation
Diaphragm muscle		
Diaphragm shape		
Intercostal muscles		
Ribs		
Lungs		
Volume of chest cavity		
Air pressure in lungs		

6. a) Explain the difference between tidal volume and residual volume.

b) Explain the importance of aerobic training for an athlete with regard to their vital capacity.

7. Explain how the respiratory tract could be likened to an upside-down tree.

8. Suppose that the bronchioles of a person suddenly narrow to half their usual diameter.

a) Predict the likely changes to breathing that the person would experience.

b) Suggest a likely treatment that might help manage the situation.

9. The oxygen and carbon dioxide content of inhaled and exhaled air is shown in the following table.

Gas	Inhaled air (%)	Exhaled air (%)
Oxygen	20	16
Carbon dioxide	0.04	4

a) Generally, one fifth of inhaled oxygen diffuses out of the alveoli into the blood. Use the data in the table above to verify this mathematically.

b) Explain how the percentage of carbon dioxide in the exhaled air is greater than the percentage of carbon dioxide in the inhaled air.

10. a) Complete the table to the right to indicate the order (1st to 6th) that air passes through the listed structures during exhalation.

b) Describe what happens to the air as it flows through the respiratory tract.

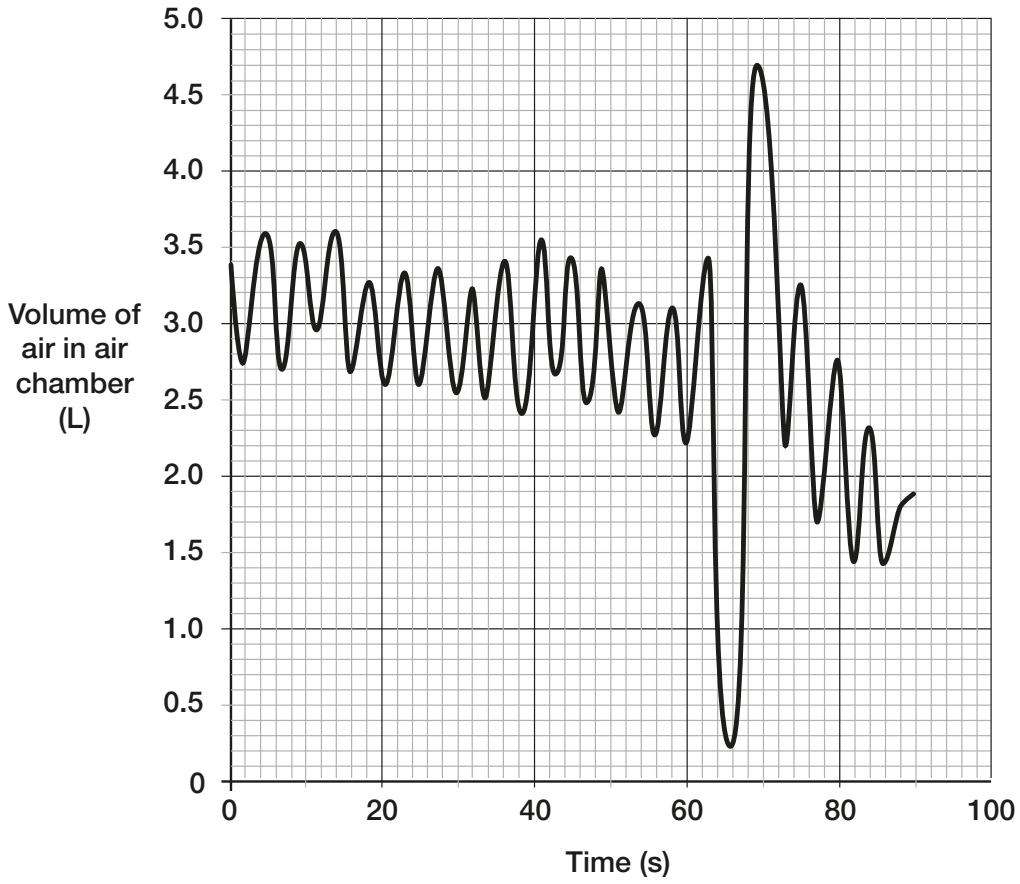
Structure	Order
Bronchus	
Alveolus	
Nasal cavity	
Bronchiole	
Nose	
Trachea	

c) Explain how the trachea helps to remove foreign particles from the inhaled air.

Inhalation and exhalation create air movements that can be measured and recorded.

d) Name the diagnostic apparatus used to measure and record these air movements.

The spirometer trace below shows a recording of the inhalation and exhalation movements of an individual. After 60 seconds the individual was asked to forcefully breathe out as much as possible and breathe in as deeply as possible.



e) State the maximum tidal volume of the individual in the first 50 seconds.

f) State the number of breaths taken in the first minute of recording.

g) State the vital capacity of this individual.

Chapter 3.4 The circulatory system in animals

Science Understanding

In many animals, the transport and exchange of materials is facilitated by the structure and function of the circulatory system.

The lymphatic system is closely connected to the circulatory system.

- Compare the role of blood capillaries and lymph capillaries in the exchange of materials.

Internal transport of materials

Cells require a supply of nutrients like glucose, amino acids, water and oxygen. They also need to remove the wastes produced by metabolism such as carbon dioxide and urea. As multicellular organisms can consist of trillions of cells, they require an internal transport system to deliver nutrients to all the body's cells and remove their wastes. In animals, the internal system responsible for this is the **circulatory system**, and in many animals, the fluid that carries substances to and from the body's cells is called the blood.

Blood

Blood is a tissue that consists of a liquid called plasma and three main types of cells: red blood cells, white blood cells and platelets. Plasma mostly consists of water which contains a wide variety of substances (see Figure 3.4.1).

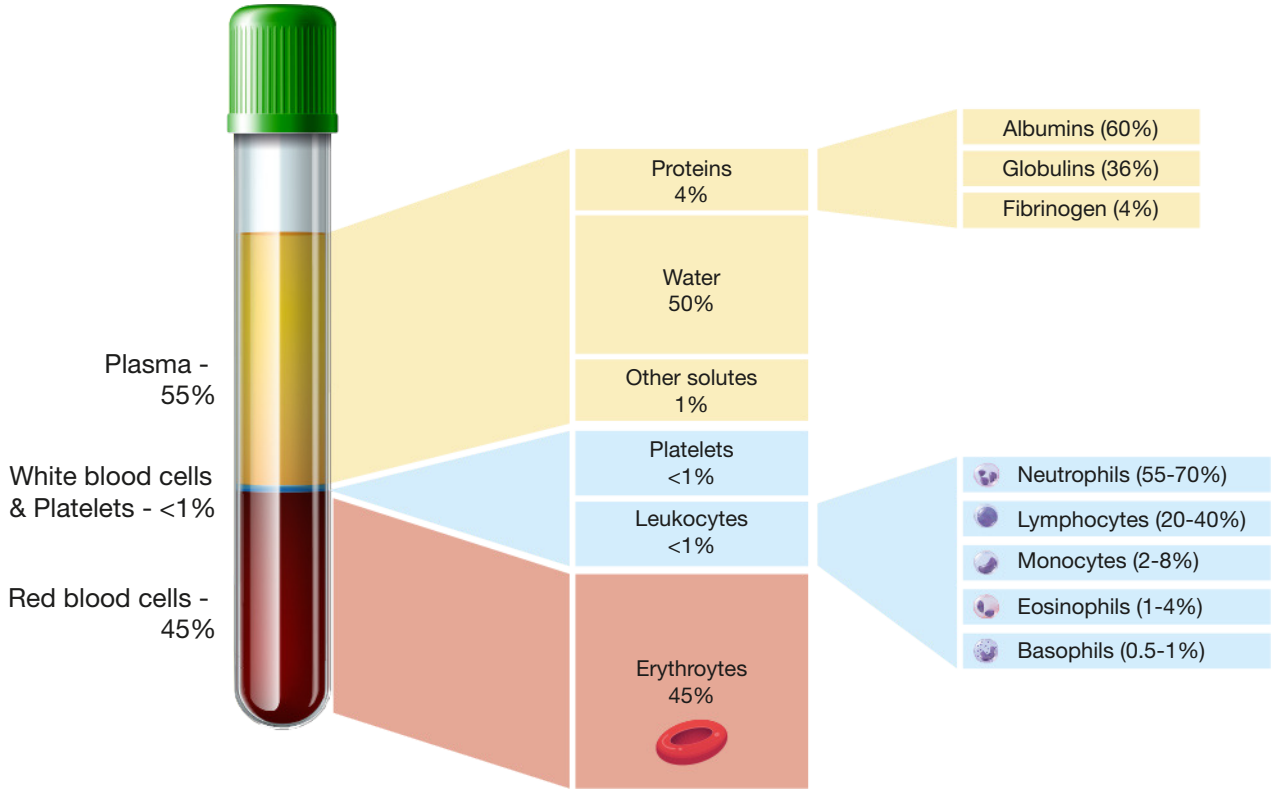


Figure 3.4.1: The different components of human blood.

Helpful online resources

FreeMedEducation: What is blood?

<https://www.youtube.com/watch?v=Eh1yMDi6wAo>

Red blood cells

Red blood cells, also called erythrocytes, **transport oxygen** to the body's cells from the lungs. They have a **bi-concave shape** creating a large surface area which makes them very efficient at exchanging oxygen with the body's cells. Red blood cells are tightly packed with a protein called **haemoglobin** that oxygen binds to reversibly. They **do not contain a nucleus** allowing more space for haemoglobin molecules and hence more oxygen to be transported to the body's cells (see Figure 3.4.2). When oxygen binds to haemoglobin it makes red blood cells appear **bright red**. However, when oxygen diffuses from the red blood cells into the body's cells, they become deoxygenated and appear a **dull dark red** colour.

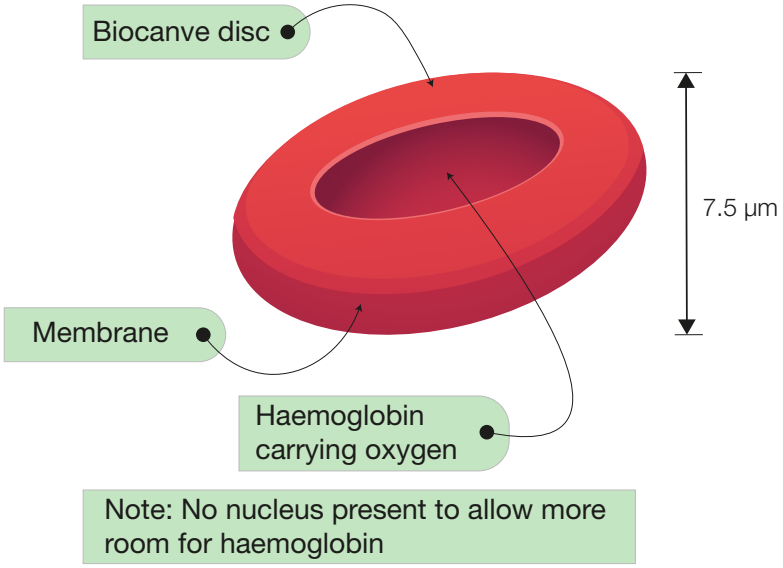


Figure 3.4.2: Red blood cells (erythrocytes) have specific specialisations that help them perform their function of transporting oxygen to the body's cells efficiently.

White blood cells

White blood cells, also called leukocytes, **protect the body from infectious disease** by fighting invading pathogenic microorganisms that can cause infection. White blood cells are the largest type of blood cell (ranging from 12 to 17mm) and they contain a **nucleus**. They do not have a regular shape and can generally change their shape to squeeze through the thin gaps between epithelial cells of capillaries into the surrounding tissue fluid, to fight off infections at various locations. There are several different types of white blood cells including neutrophils, macrophages, B lymphocytes and T lymphocytes. This is explored in more depth in Topic 2: Immune system.

Platelets

Platelets are cell fragments that are involved in the process of **blood clotting** and help to prevent blood loss and the entry of infectious microorganisms. They are much smaller than red and white blood cells and **do not have a nucleus**. When damage occurs to a blood vessel, platelets move to the site of damage and stick to it forming a temporary plug, or clot. They also release chemical signals to attract more platelets to help with the blood clotting (see Figure 3.4.3).

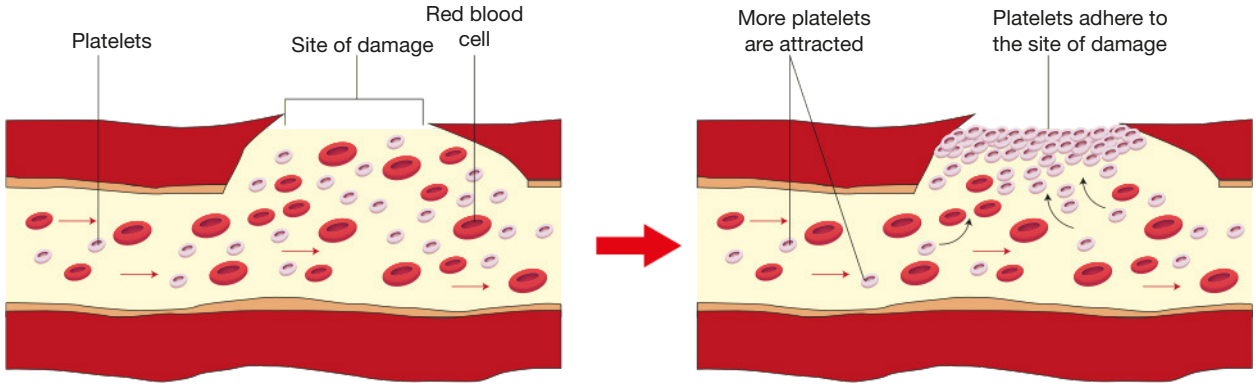


Figure 3.4.3: When a blood vessel is damaged, platelets are attracted to the site of damage and adhere to it and each other. They also send out chemical messages to attract more platelets to the damaged site to form a plug (clot) at the site of damage.

Helpful online resources

Global Education – FuseSchool: Platelets & Blood Clotting

<https://www.youtube.com/watch?v=gExUCrpAKyQ>

Plasma

Plasma is the fluid component of blood that carries blood cells and other substances around the circulatory system (see Figure 3.4.1). Some of these other substances include:

- nutrients from digestion such as glucose and amino acids that cells require for energy and growth purposes,
- hormones that are transported to cells to communicate specific messages,
- salts that help maintain osmotic pressure and are important for muscle contraction,
- carbon dioxide that is a metabolic waste product and must be transported to the lungs for excretion,
- urea which is also a metabolic waste product and is transported to the kidneys for excretion,
- antibodies that bind to pathogens and help fight off infectious disease.

Blood vessels

In the human circulatory system, there are three main types of blood vessels: arteries, veins and capillaries. These blood vessels have different structures and functions (see Figure 3.4.4). Blood vessels circulate **deoxygenated blood (represented using blue)** back to the lungs to become **oxygenated (represented using bright red)**.

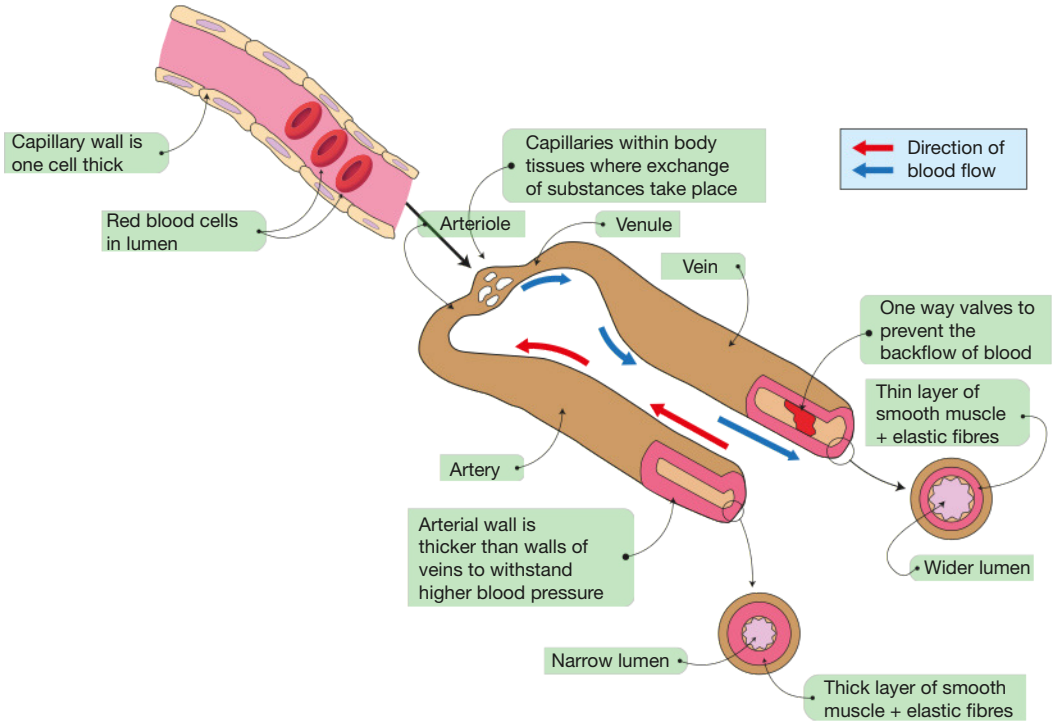


Figure 3.4.4: A visual depiction of the three main types of blood vessels and some of their structural features that help them achieve their respective functions in the circulatory system.

Arteries

Arteries are defined as blood vessels that take blood **away from the heart**. **All arteries carry oxygenated blood except for the pulmonary artery which carries deoxygenated blood** away from the heart to the lungs. The blood in the arteries is transported to the body's cells through their **narrow central core** under **high pressure**. To cope with this high pressure, arteries have walls that consist of a **thick layer of smooth muscle and elastic fibres**. The arteries branch into **arterioles** which are smaller arteries that lead to capillaries (see Figure 3.4.4).

With each heartbeat a surge of blood enters the arteries, and they **expand** to cope with the increased blood flow. This expansion and recoil of the artery is felt as a **pulse**. You can feel your pulse because of the stretching of an artery that passes between bone and the surface of the skin.

The contraction and relaxation of the smooth muscles within the arteries is involuntarily controlled by the central nervous system. This allows the body to adjust the flow of blood within the body when required. For example, during exercise, blood flow to the digestive system is reduced and blood flow to the skeletal muscles is increased.

Veins

Very small veins called **venules** extend from capillary beds and intersect to form veins (see Figure 3.4.4). Veins are defined as blood vessels that take blood back **into the heart**. **All veins carry deoxygenated blood except for the pulmonary vein which carries oxygenated blood** back into the heart from the lungs. The largest vein in the body is the **vena cava** that takes the blood directly into the right side of the heart. Veins consist of a **thin layer of smooth muscle and elastic fibres**. They also have a **wide central tube** and are the only blood vessel to contain **valves**, which only open in one direction to help prevent the backflow of blood (see Figure 3.4.5).

The blood pressure in veins is much **l**ower than in the arteries and the flow of blood is slower than arteries. This is partly due to the greater distance from the heart and their wide central tubes. The movement of blood through the veins can be facilitated by the contraction of adjacent skeletal muscles. When muscles contract and expand, they can supply pressure on adjacent veins, adding pressure for blood to flow through the one directional valves and back towards the right side of the heart (see Figure 3.4.5).

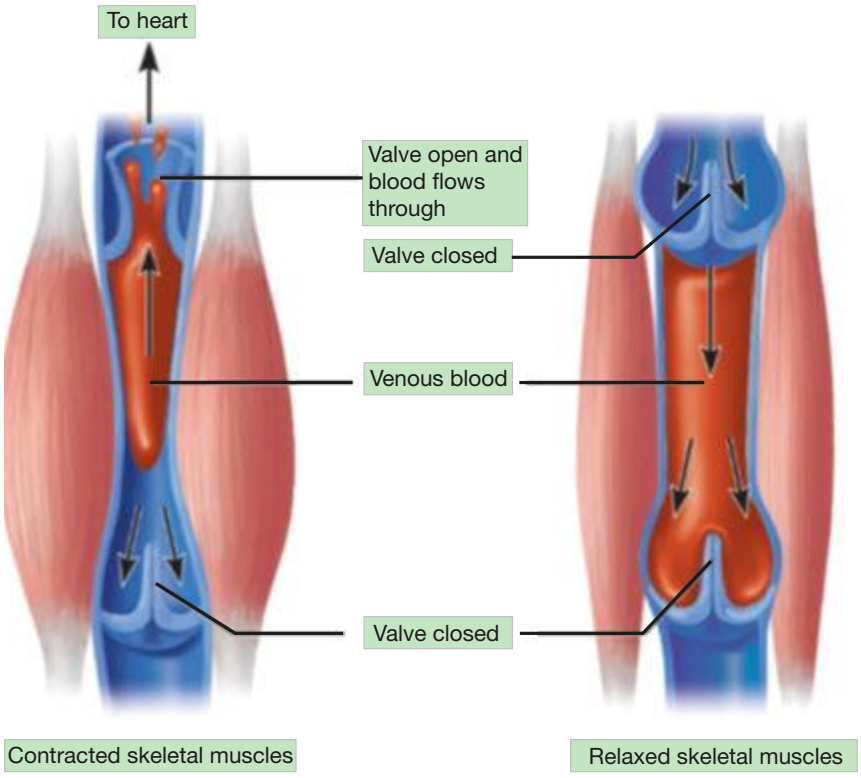


Figure 3.4.5: Closed valves in veins prevent the backflow of blood but the contraction of skeletal muscles can squeeze the veins forcing blood out of the vein and back towards the right side of the heart at low pressure.

Capillaries

Capillaries connect arteries with veins, more specifically, they connect arterioles with venules (see Figure 3.4.4). Capillaries are the **only blood vessels** where substances can be **exchanged** between the blood and body's cells. Capillaries generally consist of a **single layer of epithelial cells** and their **central core is very narrow** with a diameter of 5 to 10mm. This very narrow diameter ensures that red blood cells, with a diameter of 6 to 8mm, flow through in a single file, **reducing the distance** for gas exchange between red blood cells and body cells (see Figure 3.4.4).

The capillaries are involved in the exchange of both useful and waste products. **Oxygenated blood enters capillaries** containing a high concentration of oxygen, low concentration of carbon dioxide and high concentrations of other useful substances, such as glucose, amino acids. Oxygen and the other useful substances **diffuse** with their concentration gradients across the capillary wall and into the surrounding tissue fluid and body cells (see Figure 3.4.6). As blood travels along the capillaries, it also collects waste products, such as carbon dioxide and urea, which **diffuse** with their concentration gradients from the surrounding body cells and tissue fluid into the blood (see Figure 3.4.6). After blood has moved through a capillary bed, from artery/arteriole end to venule/vein end, it has a reduced oxygen concentration and an increased carbon dioxide concentration. Therefore, the **blood leaving capillaries** is **deoxygenated blood** (see Figure 3.4.6).

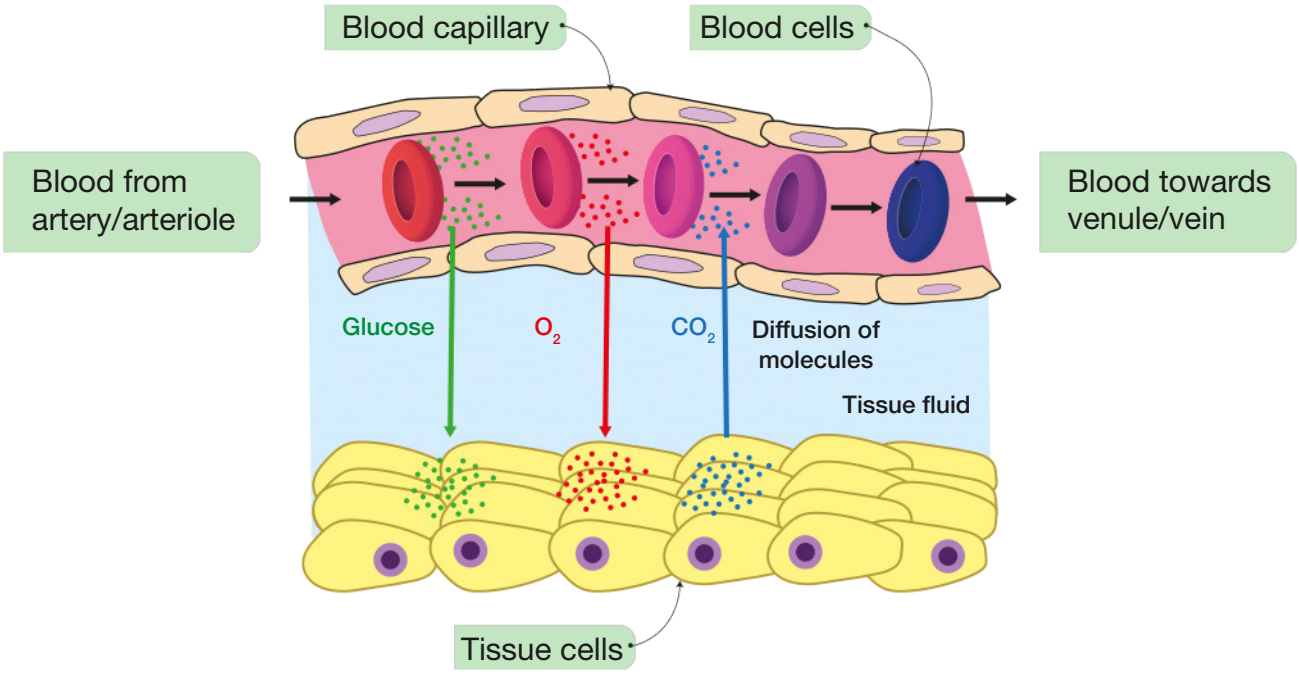


Figure 3.4.6: Capillaries are permeable and facilitate the exchange of substances to and from tissue cells. As blood passes from artery/arteriole end to the venule/vein end the blood becomes deoxygenated as oxygen diffuses with its concentration gradient into the tissue fluid and tissue cells.

Helpful online resources

Cognito: GCSE Biology - Blood Vessels

<https://www.youtube.com/watch?v=AlSQEs694qY>

Circulatory systems

Open circulatory system

In animals, the transport of materials is facilitated by a circulatory system that consists of tubes, a fluid pushed through them, and a pump. Insects have an open circulatory system. This means movement of the fluid, which in insects is called haemolymph, is not wholly confined to tubes. Instead, it is pumped through vessels by a tube-like heart before passing into spaces in which organs sit, called sinuses, where materials are exchanged between the haemolymph and cells. Haemolymph returns to the heart through pores called ostia (see Figure 3.4.7).

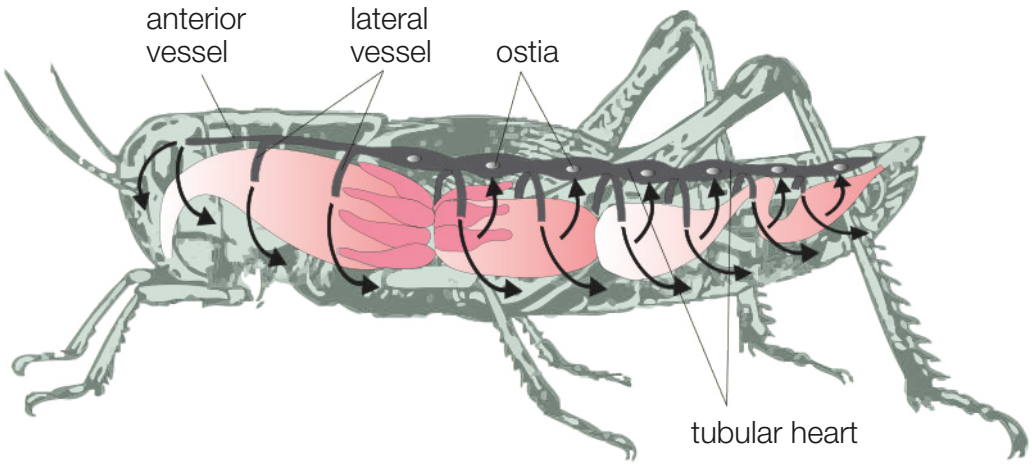


Figure 3.4.7: The open circulatory system of a grasshopper.

Closed circulatory systems

In a closed circulatory system, the movement of the fluid, usually blood, is completely confined to tubes called blood vessels. Blood is pumped through arteries by a heart before passing through tiny blood vessels located next to cells called capillaries where materials are exchanged between the blood and cells. Blood is returned to the heart in veins.

Fish have a **two-chambered heart** and a **single circulation system** in which blood only passes through the heart once per circulation (see Figure 3.4.8(a)). Humans and other mammals have a **four-chambered heart** and a double circulation system in which blood passes through the heart twice per circulation (see Figure 3.4.8(b)).

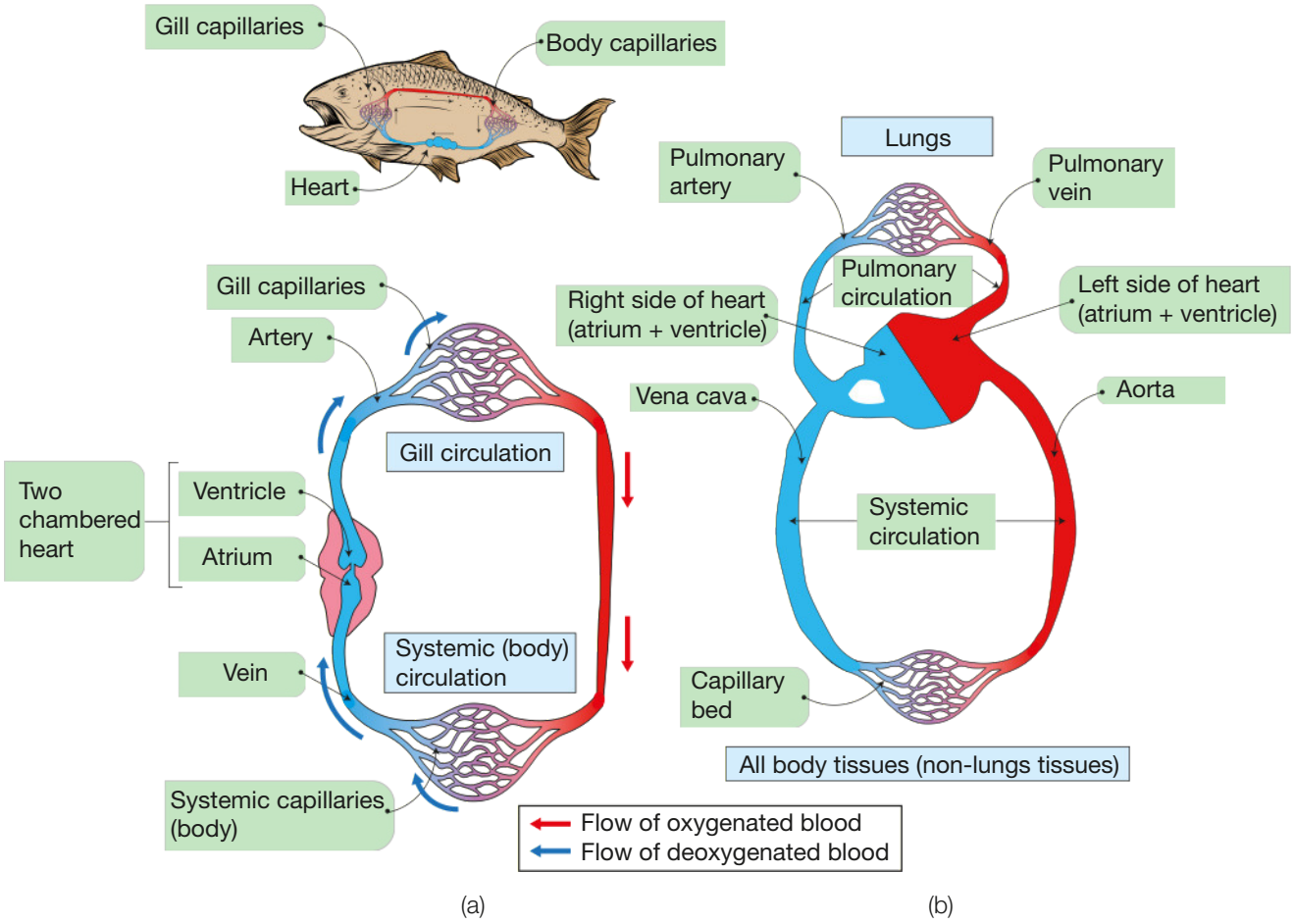


Figure 3.4.8: The single circulation system with a two chambered heart of fish (a) compared to the double circulation system with a four chambered heart of humans and other mammals (b).

Helpful online resources

FuseSchool – Global Education: Intro to the circulatory system

<https://www.youtube.com/watch?v=73ei6YD0VnM>

The human circulatory system

The human circulatory system consists of a four chambered heart and a double circulation, the **pulmonary and systemic circulations** (see Figure 3.4.8(b)). The **right side of the heart** pumps **deoxygenated blood** to the lungs where the blood is oxygenated before returning to the left side of the heart. This is the pulmonary circulation. The **left side of the heart** pumps the **oxygenated blood** to the rest of the body supplying the cells with oxygen and other nutrients. In doing so, the blood becomes deoxygenated and metabolic waste products such as carbon dioxide also diffuse into the blood. This deoxygenated blood moves back to the right side of the heart completing the systemic circulation. The double circulation means that blood travels through the heart twice to complete one full circulation of the body (see Figure 3.4.9).

When blood travels through the lungs a lot of blood pressure is lost along the capillaries and therefore the speed at which it travels also slows down. If the blood was to travel directly from the lungs to the body's cells, it would be doing so at a lower blood pressure and it would not be able to deliver oxygen and other nutrients fast and frequently. By travelling back to the left side of the heart, the oxygenated blood can be **pumped at high pressure** so that all body cells receive their blood supply quickly and frequently. This is an advantage of the double circulation system.

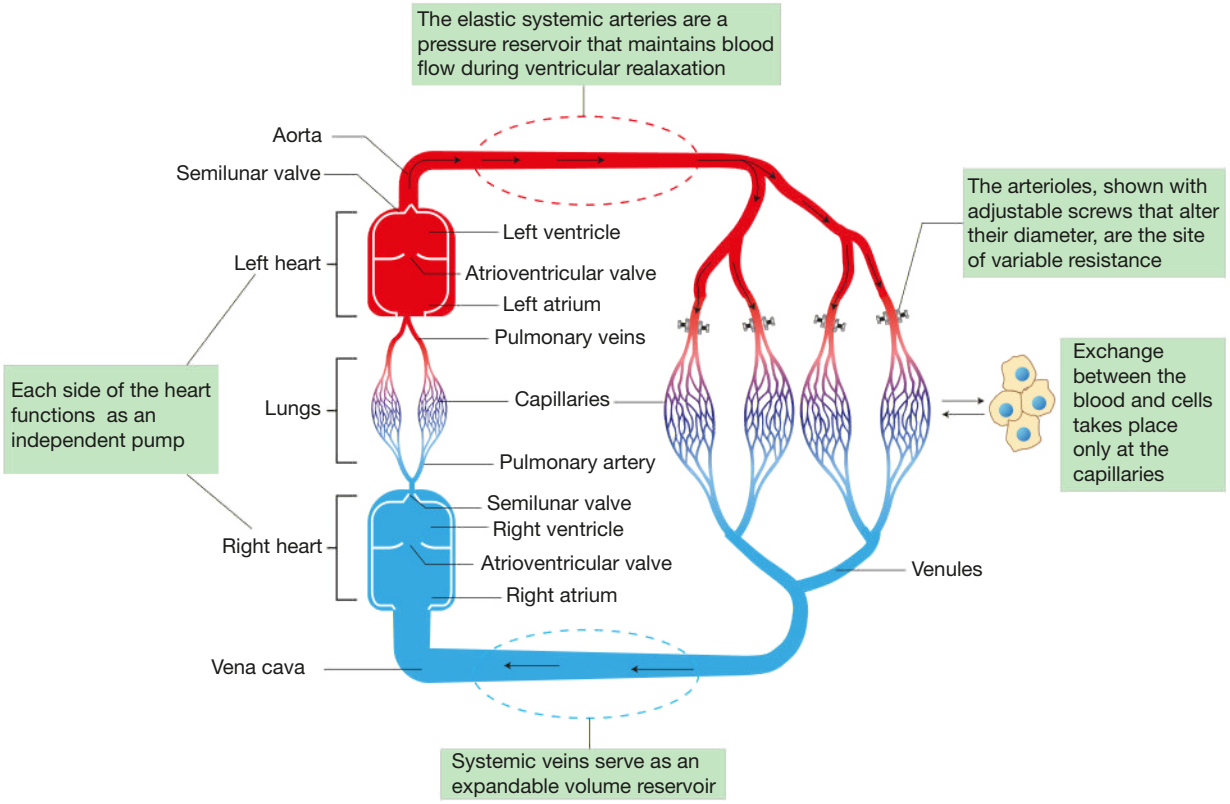


Figure 3.4.9: A functional model of the human double circulation system shown as a single closed loop.

The heart

The human heart is located in the thorax (chest cavity) between the lungs. The **cardiac muscle** of the heart is supplied with **oxygenated blood** by **coronary arteries** and **deoxygenated blood** leaves cardiac muscle in **coronary veins** (see Figure 3.4.10(a)).

The heart is divided into **four chambers**. The two on the right are separated from two on the left by a wall-like **septum**. Blood enters the heart via two upper chambers called **atria** (singular: atrium). Blood is pumped out of the heart by the muscular walls of two lower chambers called ventricles (see Figure 3.4.10). The left ventricle wall is the thicker of the two as it must pump blood at high pressure to ensure **oxygenated** blood reaches all body cells. Whereas the thinner walls of the right ventricle only have to pump **deoxygenated** blood a shorter distance to the nearby lungs (also in the chest cavity). Refer to Figure 3.4.10(b) for a comparison of the thickness of the two ventricles.

The heart has **four valves**, which maintain the direction of blood flow through the heart by **preventing backflow**. Two valves called atrioventricular valves (AV) reside between the atria and ventricles and prevent blood from the ventricles flowing back to the atria. The other two valves are called semilunar valves. One separates the right ventricle and the pulmonary artery while the other one separates the left ventricle from the aorta. These valves prevent blood flowing back into the ventricles. All four valves are connected to the inner walls of the heart by tough **tendons**, which are made of connective tissue (see Figure 3.4.10(b)).

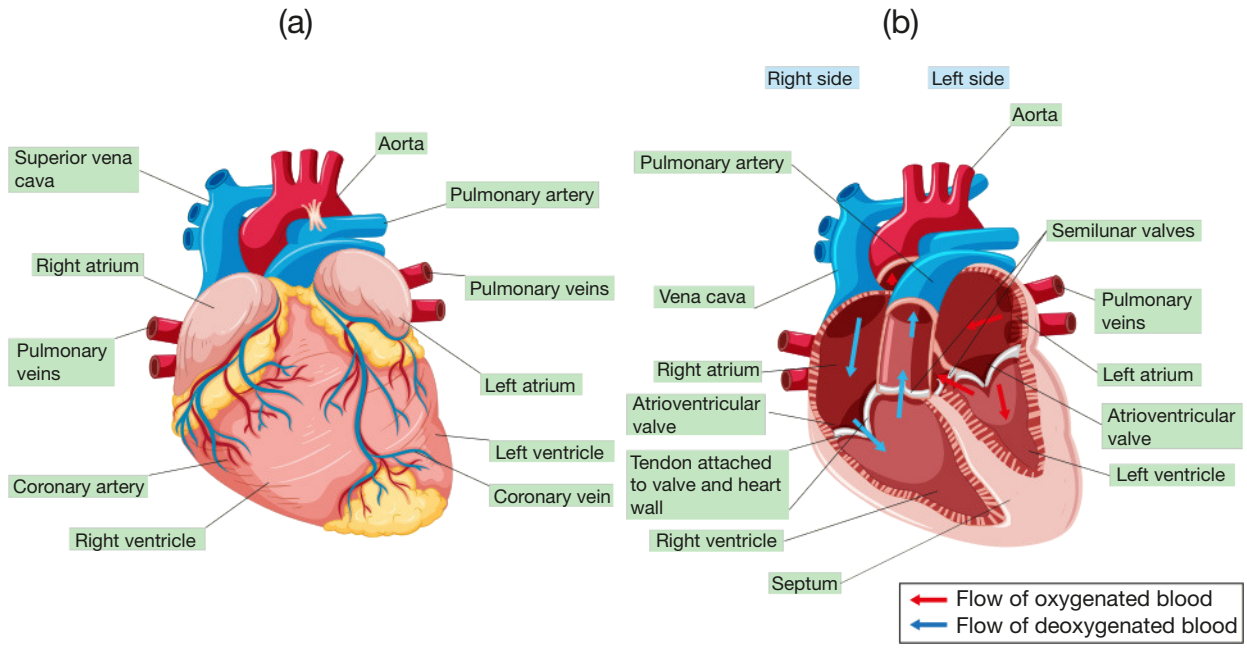


Figure 3.4.10: The outside the heart (a) and a cross section of heart (b) highlighting the four heart chambers, four valves and four major blood vessels.

Helpful online resources

Global Education – FuseSchool: The structure of the heart

<https://www.youtube.com/watch?v=y1DsaAzYamQ>

The cardiac cycle

For the average adult at rest, the heart pumps approximately 70-80 times per minute. However, with physical training, this resting heart rate can be reduced as the heart becomes stronger and the circulatory system becomes more efficient.

The cardiac cycle refers to the sequence of events of heart contraction and blood flow through the heart (a heartbeat). When the heart is relaxed blood flows into the heart at the two atria. The atria then contract forcing the blood into the ventricles. The ventricles contract and the blood pressure inside the ventricles begins to rise. The rising blood pressure closes the atrioventricular valves, making a LUBB sound and preventing backflow into the atria. The rising pressure then pushes open the semilunar valves and blood flows into the two arteries leading away from the heart, aorta and pulmonary artery. When the ventricles finish contracting, the blood pressure in the ventricle starts to fall and the semilunar valves close making a DUBB sound and preventing backflow into the ventricles (see Figure 3.4.11).

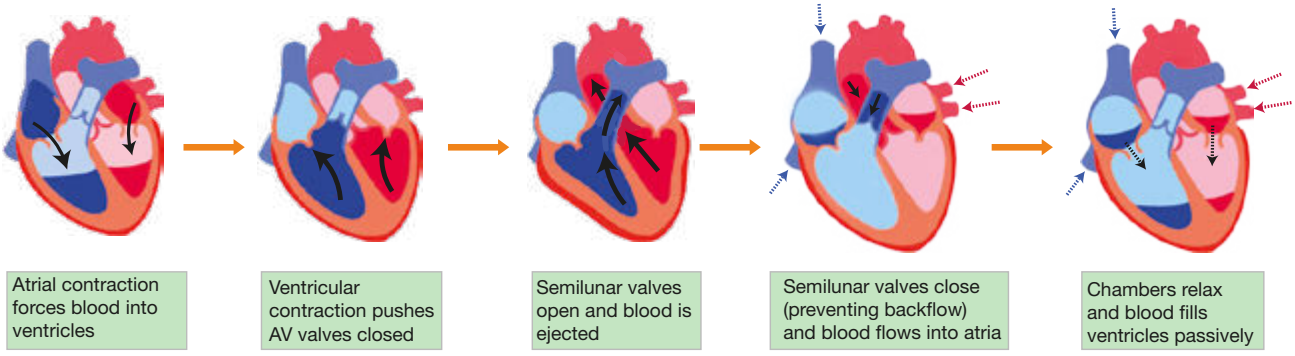


Figure 3.4.11: A visual representation of the steps that occur in the cardiac cycle.

Helpful online resources

TED-Ed: How the heart actually pumps blood - Edmond Hui

<https://www.youtube.com/watch?v=ruM4Xxhx32U>

The lymphatic system

The human lymphatic system is an essential component of the body's circulatory and immune systems, playing a crucial role in **maintaining fluid balance**, defending against infections (see Chapter 2.8: The adaptive immune system), and facilitating the absorption of dietary fats (see Chapter 3.5: The digestive system). To help maintain fluid balance the lymphatic system **absorbs excess tissue fluid**, a process vital for preventing fluid accumulation in tissues, which can lead to swelling or oedema.

Structure of the lymphatic system

The lymphatic system is a network of vessels that runs throughout the body and is just as extensive as the circulatory system. The lymphatic system does not form a full circulating system though and is not pressurised by the heart. As a result, the fluid that moves through the lymphatic system, called **lymph**, moves slower than blood moves through the circulatory system.

The lymphatic system network comprises tiny **lymphatic capillaries** that are closed at one end and located in the spaces between cells throughout the body (see Figure 3.4.12). These lymphatic capillaries collect excess fluid from tissues. The lymph is then transported through larger **lymphatic vessels**. These vessels contain **valves**, which prevent the backflow of lymph and allow the lymphatic system to function without a heart. Lymphatic vessels pass through **lymph nodes**, which are small, bean-shaped structures that filter out pathogens and debris. Lymph nodes therefore play an important role in the immune system. Lymph, and its excess water collected, are returned to blood plasma via **thoracic ducts** that are connected to veins in the neck (see Figure 3.4.12).

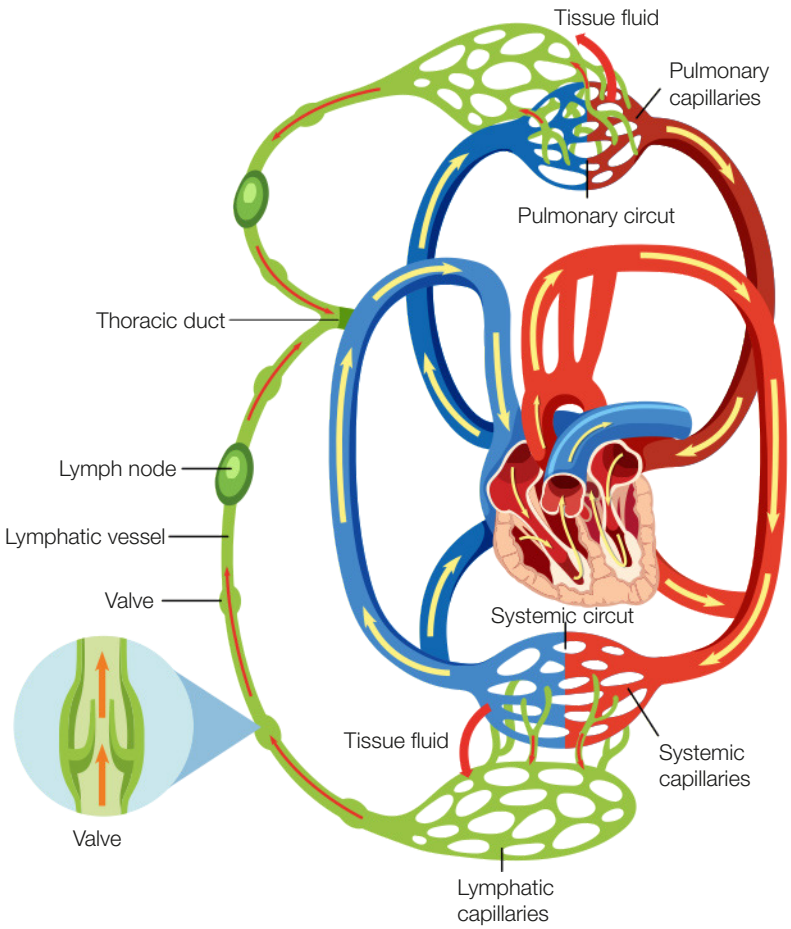


Figure 3.4.12: The circulatory system and the lymphatic system are connected by the thoracic ducts where lymph flows into the veins of the circulatory system. The lymphatic capillaries are closed at one end and extend between the capillary bed and into the tissue fluid between tissue cells.

Helpful online resources

FuseSchool – Global Education: The lymphatic system

<https://www.youtube.com/watch?v=o0-1OknbO3M>

Excess tissue fluid

Blood pumped from the left side of the heart is transported by arteries to all parts of the body. Arteries divide into smaller arterioles that carry blood into a network of blood capillaries. Capillary networks ensure all body cells are very close to a blood capillary. As blood flowing into its capillary network, it does so at **high pressure**, and some of the plasma is forced out of blood capillaries into the fluid surrounding and bathing body cells. This fluid is called tissue fluid, or interstitial fluid. Tissue fluid has a similar composition to plasma except it has a lower concentration of proteins, which are generally too big and remain in the blood capillaries. The capillaries join larger venules that carry blood at **very low pressure,** and this promotes the movement of fluid from the tissue fluid back into the blood capillary network. However, the fluid that leaves the blood capillaries at the arteriole end is approximately 10% greater than the fluid that enters the blood capillaries at the venule end of a capillary network. To prevent the buildup of tissue fluid and abnormal swelling (oedema), the **lymphatic capillaries absorb the excess fluid** (see Figure, 3.4.13) and it is transported to the thoracic duct where it re-enters the circulatory system through a vein.

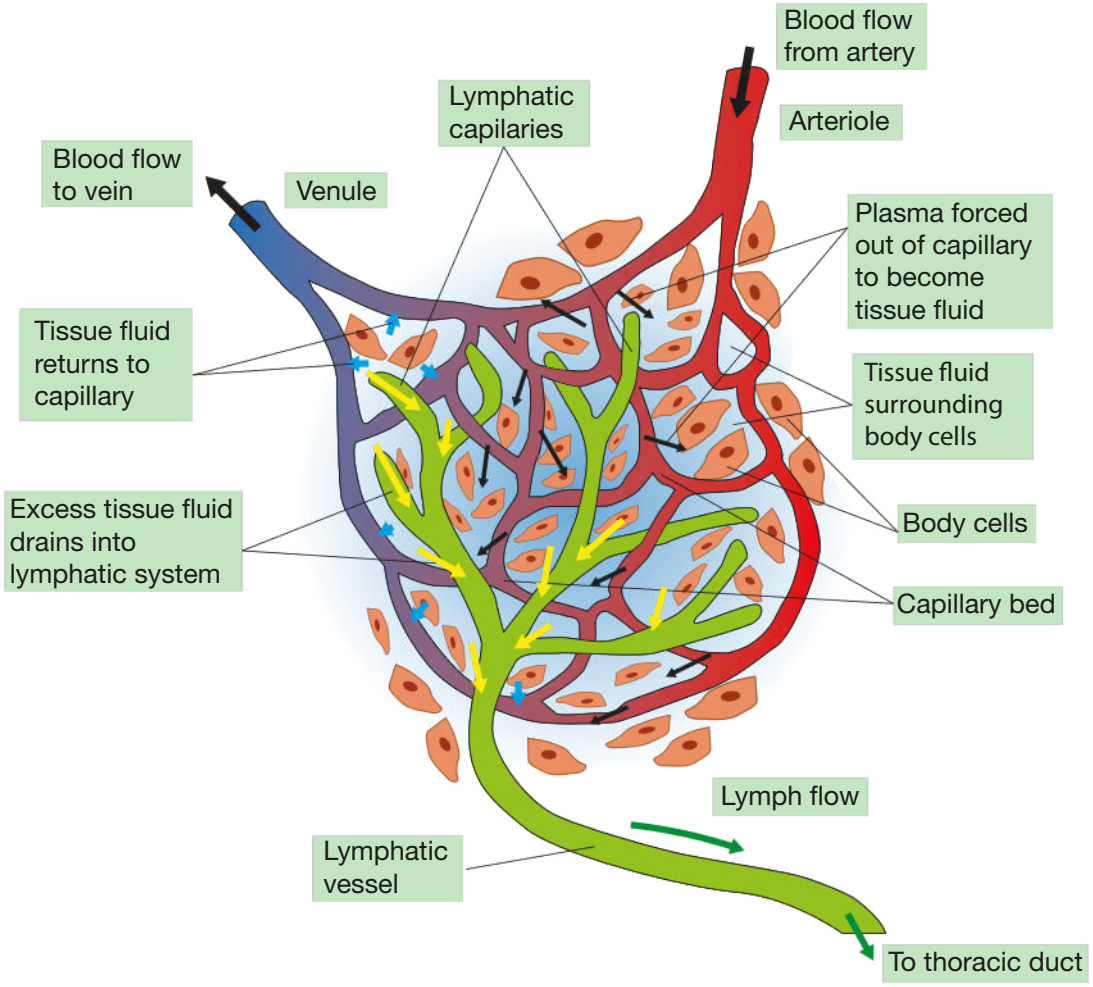


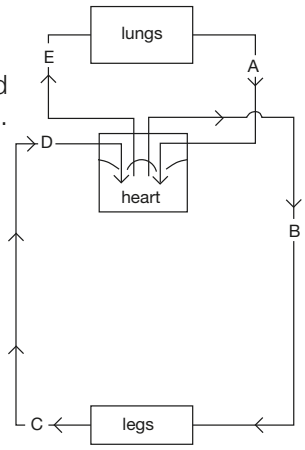
Figure 3.4.13: A close-up view of a capillary bed and lymphatic capillaries surrounded by tissue cells and tissue fluid. Plasma is forced out of the blood into the tissue fluid at the arteriole end and approximately 90% of it returns to the blood at the venule end. The lymph capillaries absorb the 10% excess tissue fluid.

3.4 Review questions

Multiple choice questions

1. The part of the blood that carries glucose to the body cells is
   - J the red blood cells.
   - K the white blood cells.
   - L the blood proteins.
   - M plasma.
2. Compared with the pulmonary veins, the pulmonary arteries have
   - J less oxygen in the blood.
   - K more valves.
   - L a lower blood pressure.
   - M thinner walls.
3. Which of the heart's chambers produces the highest blood pressure?
   - J Right atrium
   - K Left atrium
   - L Right ventricle
   - M Left ventricle
4. The beating sound that a human's heart makes originates from
   - J valves closing.
   - K ventricles contracting.
   - L blood filling the chambers.
   - M cardiac muscle relaxation.
5. *Refer to the diagram to the right showing a mammalian circulatory system to answer the following question.*

   Which of the following options correctly identifies a feature about the blood or blood vessel at the five locations indicated in the adjacent mammalian circulatory system.



	Oxygen concentration in blood at A	Blood pressure at B	Glucose concentration in blood at C	Blood pressure at D	Type of blood vessel at E
J	Oxygenated	High	Low	Low	Artery
K	Oxygenated	Low	High	High	Vein
L	Deoxygenated	High	Low	High	Artery
M	Deoxygenated	Low	High	Low	Vein

6. Which of the following statements about blood vessels is incorrect?
   - J Upon waking, a full body morning stretch can increase venous flow back to the right side of the heart.
   - K Coronary arteries supply cardiac muscle with oxygenated blood supply.
   - L The diameter of veins' central cores are wider than arteries because the volume of plasma is greater in veins than arteries after collecting more from the tissue fluid .
   - M Capillaries have a very narrow lumen and only one red blood cell generally travels through them in a single file, one at a time.
7. Which of the following options correctly differentiates the lymphatic capillaries and blood capillaries?
   - J They both transport blood back to the right side of the heart.
   - K The lymph capillaries are closed at one end.
   - L Only blood capillaries can exchange materials with its surrounding environment.
   - M Plasma is forced out of both types of capillaries into the tissue fluid.

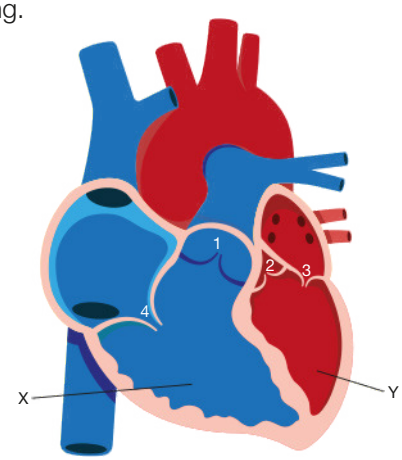
8. Varicose veins are a common condition where veins become visibly swollen and bulge just under the skin's surface. They commonly occur in the legs of older individuals.

   The swollen and bulging varicose veins in legs are caused by

   J the high blood pressure flowing through veins causing damage.
   K increased plasma being forced out of veins into surrounding tissue fluid.
   L faulty valves failing to prevent backflow of blood.
   M the pulmonary vein leaking plasma due to the wear and tear of ageing.

9. *Refer to the diagram to the right of a cross section through a mammalian heart to answer the following question.*

   Determine the status of the valves labelled 1 to 4 when chambers X and Y empty their blood during the cardiac cycle.



	Valves 1 and 2	Valves 3 and 4
J	Open	Open
K	Open	Closed
L	Closed	Open
M	Closed	Closed

10. *Refer to the table below showing the composition of blood, tissue fluid and lymph to answer the following question.*

Component of fluid	Blood	Tissue fluid	Lymph
Red blood cells (per mm^{-3})	5.1×10^6	0.0	0.0
White blood cells (per mm^{-3})	9,000	75	1,000,000
Glucose (g/dm^3)	800	800	775
Protein (g/dm^3)	71	1	26

   Which of the following options incorrectly explains a difference in composition between these fluids?

   J The tissue fluid and lymph do not normally contain red blood cells as they are too big to diffuse into the tissue fluid and therefore there is also none in the lymph.
   K Blood and tissue fluid have the same concentration of glucose to help maintain fluid balance.
   L Plasma proteins are too big to diffuse into the tissue fluid and generally remain in the blood, helping to attract water back into blood at venule end of capillary bed.
   M Tissue fluid contains the least white blood cells because they are not needed in the spaces between body cells.

Free response questions

1. Outline the composition of human plasma.

2. State the main function of each of the three types of blood cells.

   Red blood cells:

   White blood cells:

   Platelets:

3. Explain how red blood cells' structure suits its function.

4. The white blood cell count of an average healthy adult is 4000 – 11,000 per µL of blood. Explain the significance of an individual who receives blood test results showing a white blood cell count of 17,000 per µL.

5. Complete the following table comparing some features of the three main blood vessels regarding the systemic circulation.

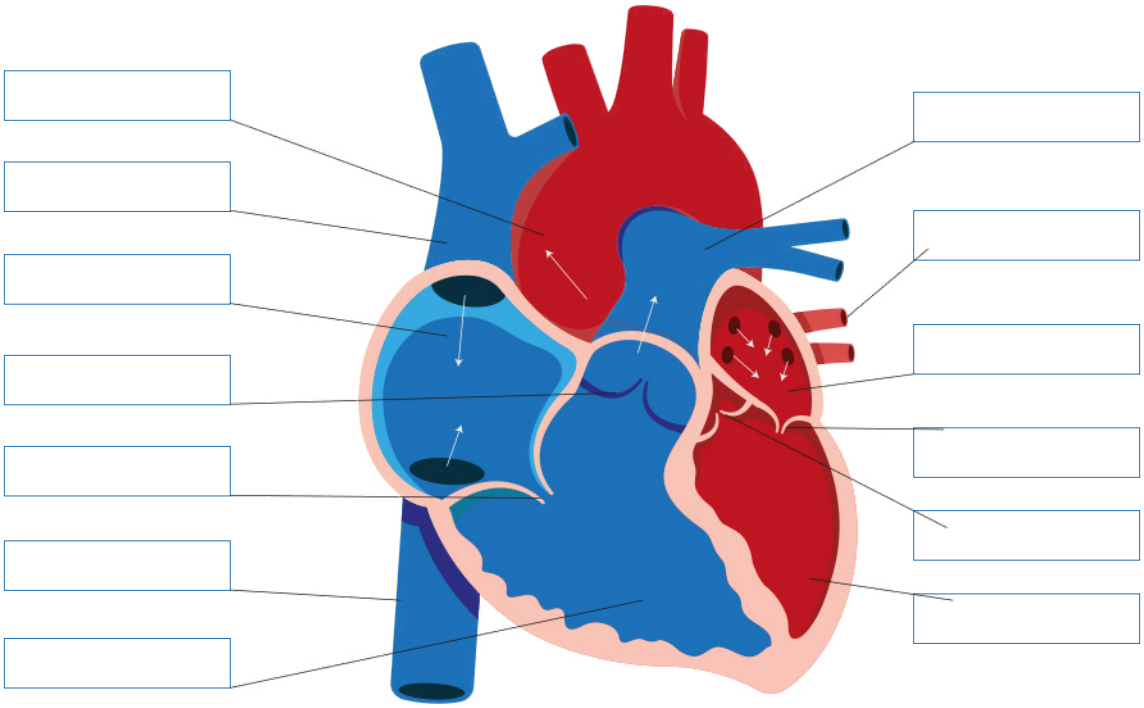
Feature	Blood vessel		
	Artery	Capillary	Vein
Oxygen concentration in blood			
Carbon dioxide concentration in blood			
Direction of blood flow			
Amount of muscle and elastic tissue			
Blood pressure			
Diameter of lumen			
Presence of valves			

6. a) Describe what a double circulatory system is.

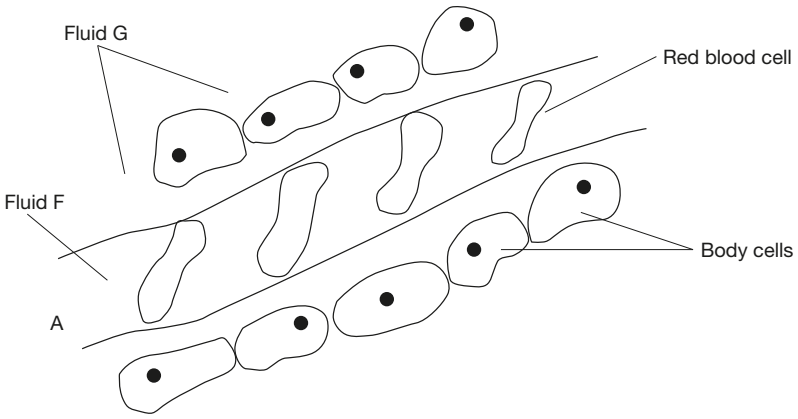
b) State the names of the two circulations **and** describe the direction of blood through each circulation.

c) Explain **one** advantage this type of circulation has over a single circulation system.

7. Label the heart's four chambers, four valves and the major blood vessels that enter/exit the heart in the diagram below.



8. *Refer to the diagram below showing a section of a blood vessel and its immediate surroundings to answer the following questions.*



a) Name Fluid 'F'.

b) Name Fluid 'G'.

c) State **one** way that Fluid F's composition is different to Fluid G's.

d) Describe how glucose moves from Fluid F to Fluid G.

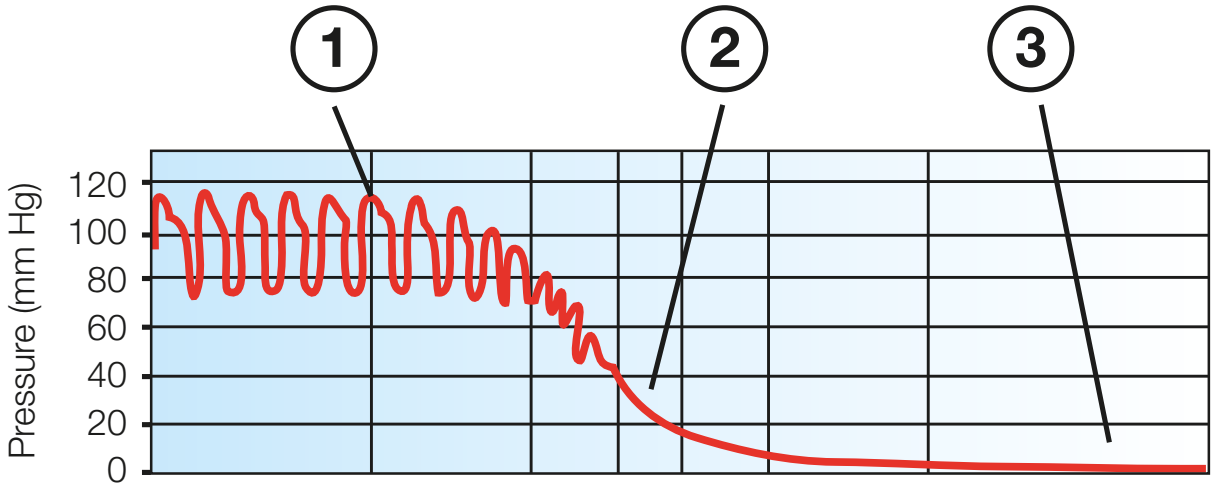
e) Fluid F enters this capillary at 'A' on the diagram. Identify **and** explain the movement of oxygen and carbon dioxide between Fluids F and G.

9. a) Describe the structure of the lymphatic system.

b) Explain the lymphatic system's role in maintaining fluid balance.

c) Explain why the lymphatic system's role in maintaining fluid balance is important for the organism.

10. *Refer to the graph below which shows the blood pressure in the human circulatory system at three different locations.*



Identify the likely locations in the circulatory system for the readings at points 1, 2 and 3 on the blood pressure graph above **and** explain why.

Chapter 3.5 The digestive system in animals

Science Understanding

In animals, the digestive system is responsible for the breakdown of food and absorption of nutrients required for survival.

- Relate the structure of organs of the digestive system to their function.
- Describe the structure and function of villi in the human digestive system.

A living organism that cannot synthesise the nutrients required for survival is called a **heterotroph**. All animals are heterotrophs. To obtain the nutrients they require animals depend on a regular supply of food. This comes in the form of other organisms (or parts of them) that must be consumed or **ingested**.

Digestion is the process by which the insoluble macromolecules (polymers) in our food sources, such as carbohydrates, protein, and lipids, are broken down into their basic soluble subunits (monomers) in the gastrointestinal tract. Digestion is required because large molecules are unable to be absorbed into microscopic cells; the macromolecules are simply too big. Once digested, the body can then absorb these nutrients and transport them to cells to provide energy, grow, repair and divide into new cells.

There are two types of digestion, chemical and mechanical. **Chemical digestion** involves **enzymes** that chemically break down large molecules into smaller molecules by facilitating the breaking of chemical bonds between subunits. Chemical digestion produces new products, for example, the enzyme lactase chemically breaks down lactose (reactant) into glucose and galactose (products). **Mechanical digestion** involves physically breaking food into smaller pieces. Mechanical digestion results in the same product but because the pieces are smaller, the **surface area of the food is increased**. This allows the enzymes to access a greater proportion of the food and increases the efficiency of chemical digestion. Both forms of digestion are very important, and they work together to maximise the digestion of nutrients and increase the availability of nutrients for the body.

Helpful online resources

FreeMedEducation: How our digestive system works

<https://www.youtube.com/watch?v=P16ik1pH4_8>

Organs of the digestive system

The digestive system consists of the **gastrointestinal tract** and **accessory organs**. The gastrointestinal tract, also known as the alimentary canal, is a series of connected hollow organs starting from the mouth and ending at the rectum. The gastrointestinal tract consists of the mouth, pharynx, oesophagus, stomach, small intestine, large intestine, rectum and anus. **The organs of the gastrointestinal tract contain muscles that enable their walls to move**. The movement of organ walls can propel food and liquid and can also mix the contents within each organ. Typical movement of the oesophagus, stomach, and intestine is called **peristalsis**. Accessory organs are connected to organs of the gastrointestinal tract and perform vital functions for the digestion of food, but food does not pass through them. Some of the major accessory organs are salivary glands, epiglottis, gall bladder, liver and pancreas. Figure 3.5.1 highlights the major organs in the digestive process and some of their major functions.

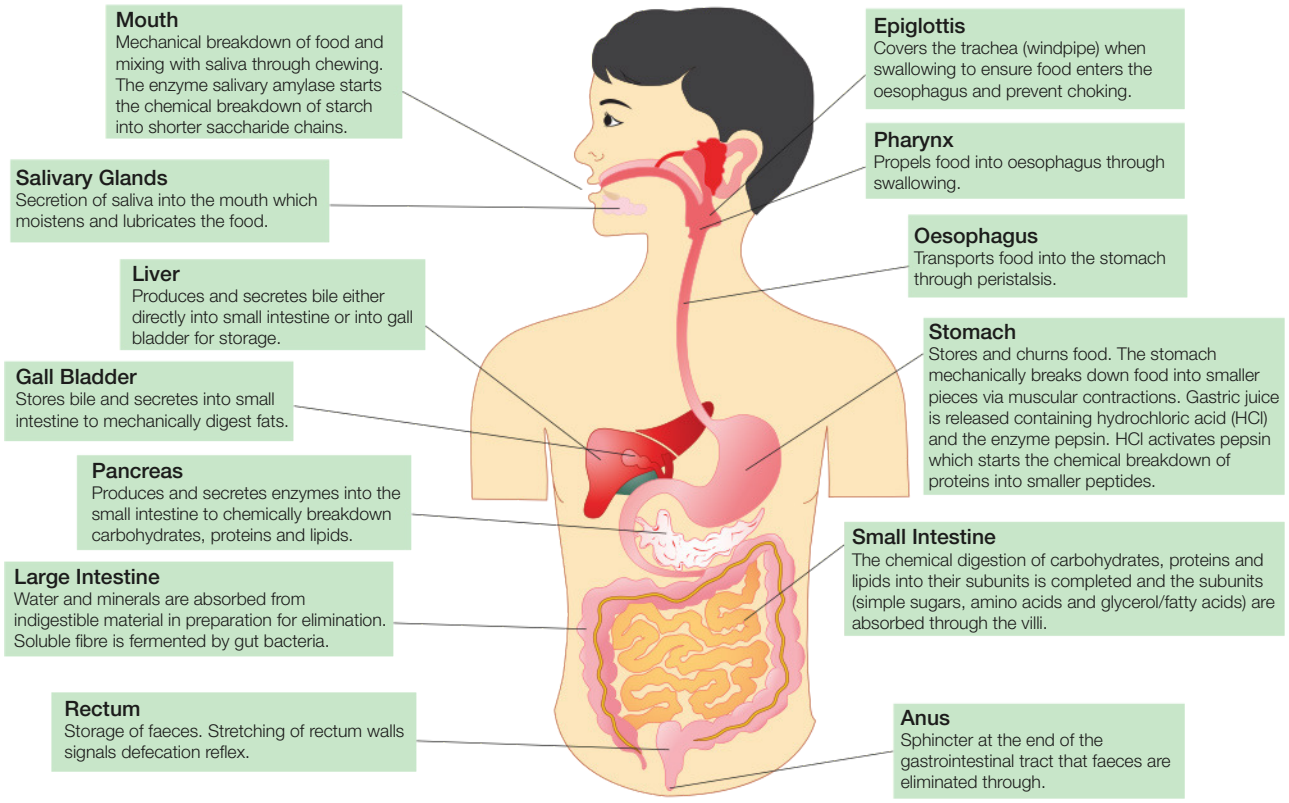


Figure 3.5.1: A summary of the major organs involved in the digestive system and a brief overview of their functions.

The digestive process

Ingestion and digestion

Food is ingested through the mouth and this is where digestion begins. In the mouth, food is mechanically broken down by **teeth** through **chewing** (also known as **mastication**). Chewing also mixes the food with saliva released from the **salivary glands**. This lubricates the food making it easier to swallow and **increases the surface area** for the enzyme **salivary amylase** to start chemically breaking down the complex carbohydrate starch into shorter polysaccharides and maltose (a simple sugar).

Food is then swallowed through the pharynx (throat) into the **oesophagus**. During the swallowing reflex the **epiglottis**, a flexible flap in the throat, extends and covers the trachea (windpipe). This helps to guide the food down the oesophagus (see Figure 3.5.2). If food was to enter the trachea, it could block air entering the lungs and result in choking.

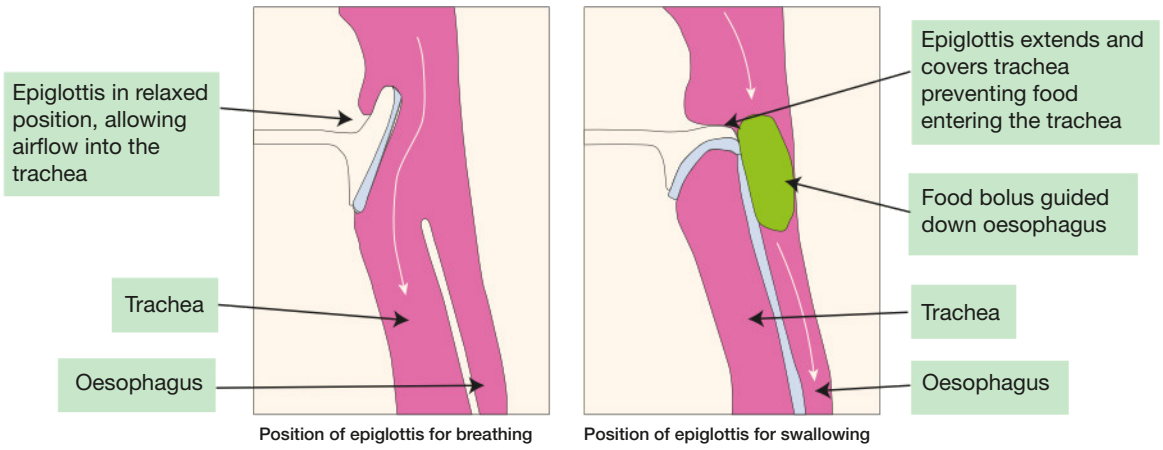


Figure 3.5.2: The epiglottis covers the trachea during swallowing to guide food down the oesophagus and prevent choking.

The oesophagus is a hollow muscular tube connecting the pharynx to the stomach. After swallowing, a process called peristalsis propels the bolus of food down the oesophagus to the stomach. **Peristalsis is an involuntary wave of sequential smooth muscle contractions** that pushes food down the oesophagus (see Figure 3.5.3).

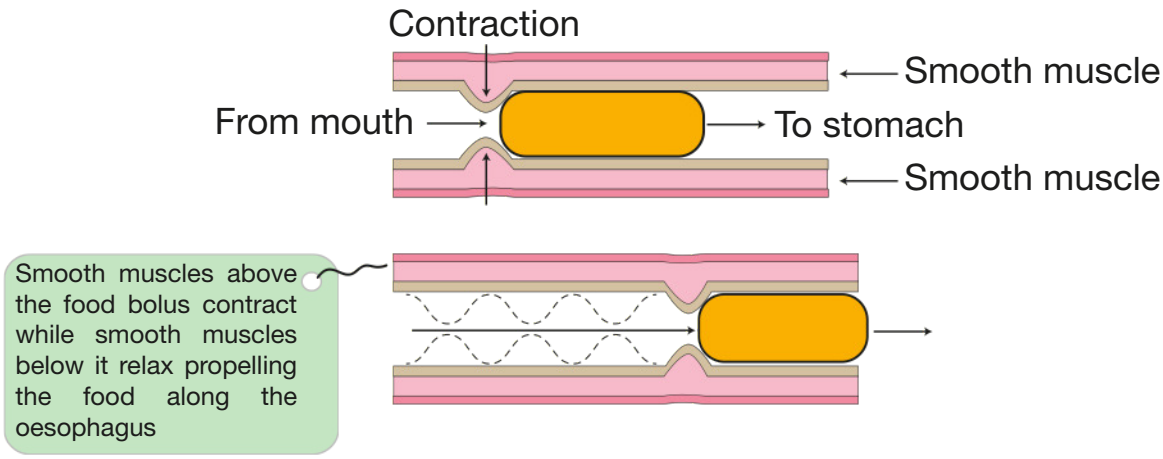


Figure 3.5.3: Peristalsis involves a wave of smooth muscle contractions pushing food down into the stomach.

Cells lining the stomach release **gastric juices** consisting of **mucus, hydrochloric acid, and pepsinogen**. Mucus lines the stomach protecting the internal epithelial cells from the hydrochloric acid. The hydrochloric acid lowers the pH of the stomach to between 1.5 and 3.5. The acidic environment of the stomach kills pathogens such as bacteria on our food, denatures proteins, and activates pepsinogen into its active form, **pepsin**. Pepsin is an enzyme that initiates the breakdown of protein in our food. It starts breaking down protein into partially digested protein chains called peptides (see Figure 3.5.4). The acidic environment of the stomach deactivates salivary amylase and consequently the chemical digestion of carbohydrates does not occur in the stomach.

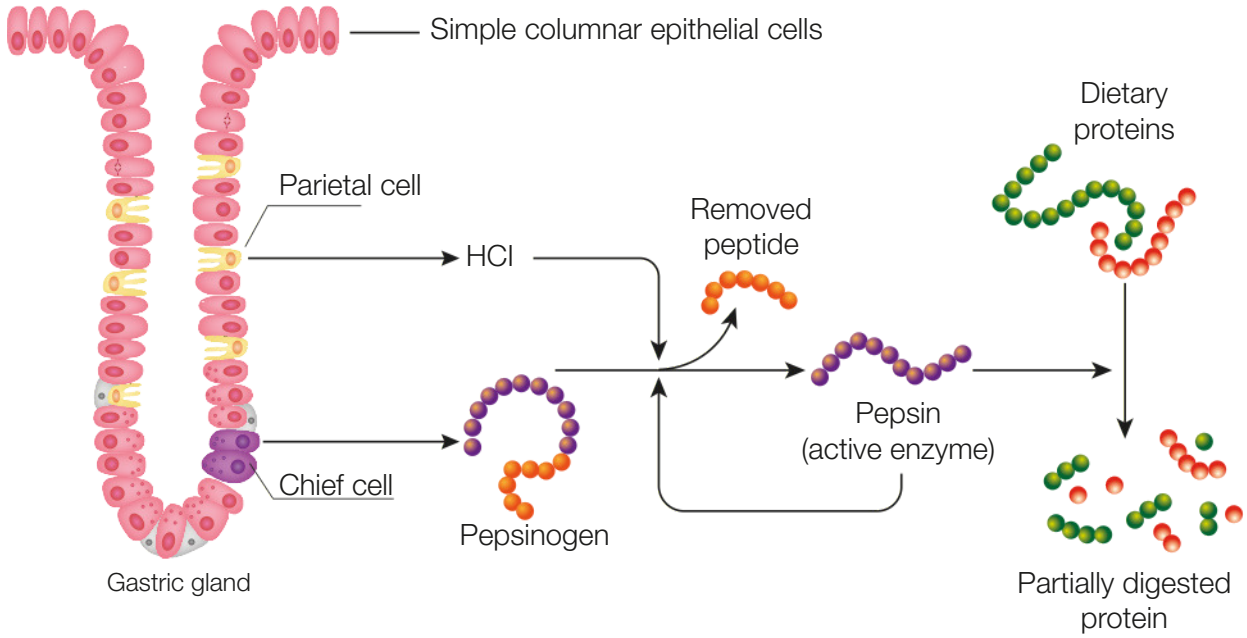


Figure 3.5.4: Hydrochloric acid activates pepsinogen into the enzyme pepsin, which can then start digesting protein in the stomach.

Mechanical digestion also occurs in the stomach. The smooth muscle tissue of the stomach contracts to churn the contents of the stomach. These peristaltic waves mix the food bolus with gastric juices, increasing the surface area that pepsin can access. The result of the physical and chemical digestion of a food bolus in the stomach is a partially digested fluid-like substance called chyme. The stomach temporarily stores the chyme and slowly releases small amounts of it through the pyloric sphincter into the **small intestine** through peristaltic contractions (see Figure 3.5.5). It is very important that only small amounts are expelled because it ensures the small intestines are only processing a small amount of food at a time, maximising the digestion and absorption of nutrients. If the stomach did not release the partially digested food slowly, the intestines would not cope with the load and a significant proportion of the nutrients would pass straight through without being digested and absorbed.

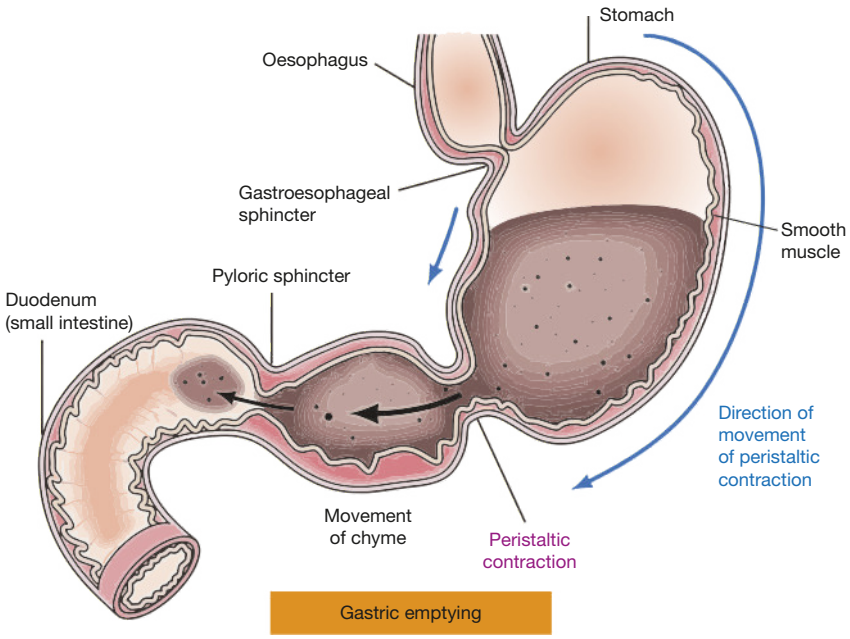


Figure 3.5.5: The stomach stores chyme and releases small amounts into the small intestine intermittently through peristaltic contractions.

The duodenum is the first section of the small intestine; it is also the shortest section. **Pancreatic juice** and **bile** are both secreted into the duodenum to help with the digestion of the macronutrients in our food. Both these secretions are alkaline, which helps neutralise the acid from the stomach. This raises the pH of the small intestine to approximately 7.8, providing a more suitable environment for the pancreatic enzymes to function. The pancreas produces and secretes the pancreatic juice which consists of **pancreatic amylase, trypsin** and **pancreatic lipase**. The **liver produces bile** and can secrete it directly into the duodenum or into the **gall bladder** for storage. The gall bladder can then secrete the stored bile into the duodenum. Bile **emulsifies** large fat droplets into many smaller fat droplets. This **emulsification is a form of mechanical digestion** increasing the surface area of the fat droplets so pancreatic lipase can chemically digest fat more efficiently (refer to Figure 3.5.6).

The majority of chemical digestion occurs in the duodenum by the pancreatic enzymes. Pancreatic lipase digests fats into glycerol and fatty acids (see Figure 3.5.6), pancreatic amylase digests complex carbohydrates into simple sugars (see Figure 3.5.8), and trypsin digests amino acids and partially digested proteins into amino acids (see Figure 3.5.8). A small amount of absorption of some nutrients occurs in the first section of the small intestine (duodenum).

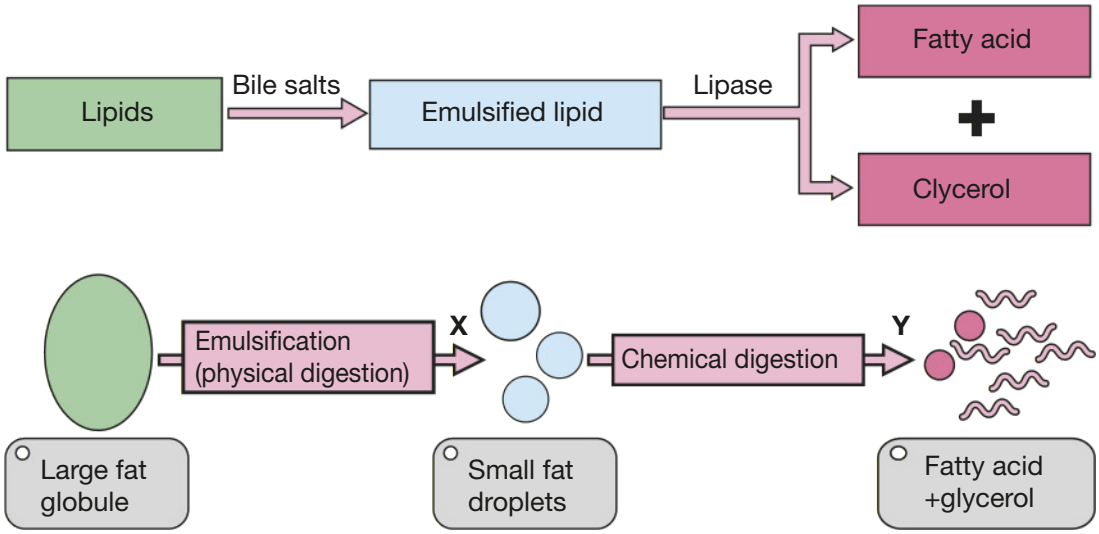


Figure 3.5.6: Bile mechanically digests large fat droplets into many smaller fat droplets allowing pancreatic lipase to chemically digests fats into their glycerol backbone and three fatty acid chains more efficiently.

Helpful online resources

FuseSchool – Global Education: Bile and emulsification

<https://www.youtube.com/watch?v=TNG-RRzwBVU>

FuseSchool – Global Education: Digestive Enzymes

<https://www.youtube.com/watch?v=a0yGDipKWlo>

Absorption

The small intestine is a hollow tube-like structure consisting of smooth muscle. The smooth muscle is responsible for the peristaltic waves that propel the mass through the three sections of the small intestine, duodenum, jejunum, and ileum. The inner lining of the entire small intestine is covered with finger like projections called **villi** (see Figure 3.5.7), which **absorb** the digested nutrients. The villi are structurally important because they **increase the surface area** of the small intestine resulting in a more efficient absorption of nutrients. Most of this absorption occurs at the second section of the small intestine, called the jejunum. The **single layered epithelial lining** of the villi reduces the distance for nutrients to be absorbed across. It is also **moist**, increasing its permeability. Simple sugars and amino acids are absorbed across the epithelial lining into the blood capillaries of the villi, while fatty acids and glycerol are absorbed into the lacteal. The lacteal is a lymph capillary which is part of the lymphatic system. These nutrients are then processed by the liver and are available to the body for use in various functions. Refer to Table 3.5.1 and Figure 3.5.8 for a summary of the digestion and absorption process.

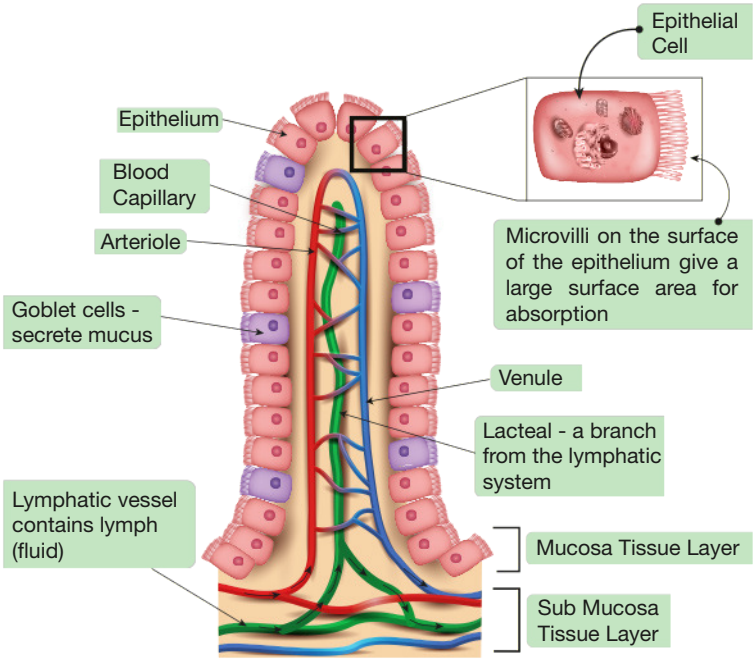


Figure 3.5.7: The structure of a single villus. Villi increase the surface area of the internal lining of the small intestine, increasing the efficiency of nutrient absorption.

Table 3.5.1: A summary of the chemical digestion of macronutrients through the gastrointestinal tract.

Macromolecule (polymer)	Sites of chemical digestion	Product(s) of digestion	How it is transported around the body
Carbohydrates (e.g. starch)	Starts in the mouth (salivary amylase) and finishes in the small intestine (pancreatic amylase)	Simple sugars such as glucose	Blood
Protein	Starts in the stomach (pepsin) and ends in the small intestine (trypsin)	Peptides or amino acids	Blood
Lipids	Starts and finishes in the small intestine (pancreatic lipase)	Fatty acids and glycerol	Lymph

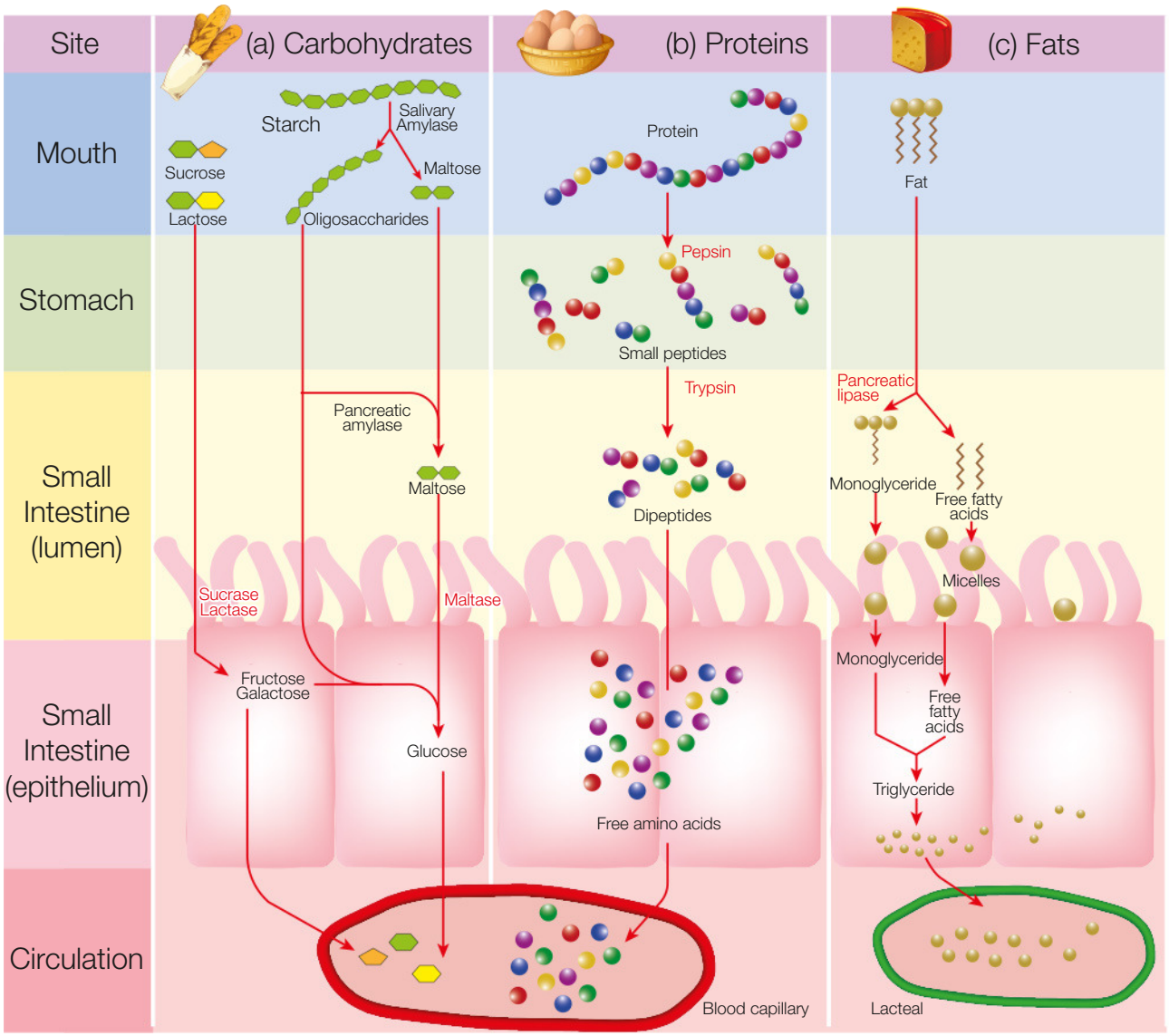


Figure 3.5.8: A visual summary of the chemical digestion of carbohydrates, protein and fats.

Helpful online resources

FuseSchool – Global Education: Small intestine and food absorption

<https://www.youtube.com/watch?v=cEh2Qip0-E4>

The colon and egestion

The remaining contents that reach the **large intestine**, also known as the **colon**, include undigested materials such as dietary fibre, water, a few dissolved salts, and older cells that have been shed from the lining of the gastro-intestinal tract. The colon absorbs water and dissolved salts from the undigested materials and transports the stool through peristaltic movements to the **rectum** in preparation for elimination. Intestinal bacteria ferment **dietary fibre** in the large intestine producing short chain fatty acids, vitamin K, water, and gases. Dietary fibre is a type of carbohydrate found in plant-based products that humans cannot digest because they do not possess the required enzymes. However, many beneficial bacteria in the large intestine do have enzymes that can break down some dietary fibre. Some dietary fibre cannot be digested by humans or the microbiome. An indigestible mass known as **faeces** is what remains, and it is stored in the **rectum** until it is expelled by a bowel movement (egestion) via the **anus.**

3.5 Review questions

Multiple choice questions

1. A definition of digestion is

   J small soluble monomers pass through the small intestine lining.
   K large insoluble molecules are changed into faeces.
   L small soluble molecules are transported to the body's cells.
   M large insoluble molecules are converted to small soluble molecules.

2. Which of the following is an accessory organ?

   J Mouth
   K Oesophagus
   L Liver
   M Small intestines

3. The cells that make up the inner lining of the intestines are

   J lymphatic cells.
   K columnar epithelial cells.
   L fibrous connective tissue cells.
   M smooth muscle cells.

4. Identify the nutrient that does **not** need digesting.

   J Glycerol
   K Saturated fat
   L Starch
   M Protein

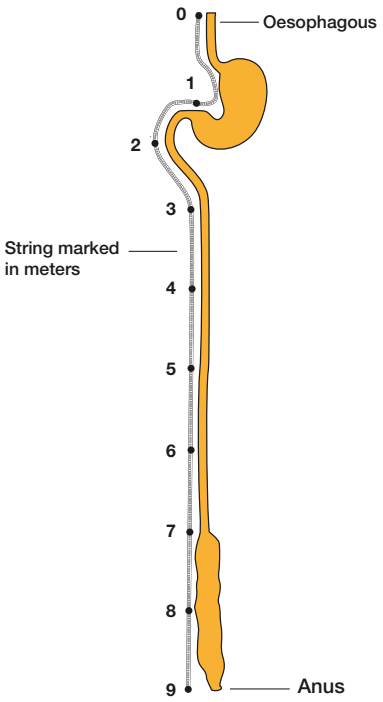
5. Identify the row below that correctly matches a macromolecule with an enzyme involved in its digestion, and a monomer that it is digested into.

	Macromolecule	Enzyme involved in digestion	Monomer
J	Saturated fat	Lipase	Galactose and amino acids
K	Protein	Pepsin	Fatty acids
L	Starch	Starchase	Maltose
M	Carbohydrate	Amylase	Glucose

6. The emulsification of fats

   J involves lipases.
   K primarily occurs in the stomach.
   L is an example of physical digestion.
   M is an example of chemical digestion.

7. *Refer to the diagram below showing a human gastrointestinal tract with a string beside it marked in metres.*



The length of the small intestine is

J 2 metres.
K 6 metres.
L 8 metres.
M 9 metres.

8. Hydrochloric acid in the stomach is **not** required for which of the following options?

J Killing pathogenic microorganisms.
K Setting the correct pH environment for the chemical digestion of protein.
L Denaturing the shape of proteins to make them easier for pepsin to digest.
M Killing probiotic bacteria.

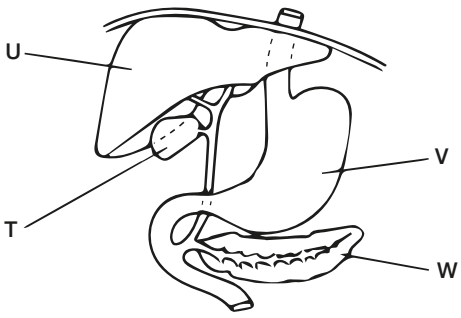
9. Identify the most suitable environmental conditions for the optimal digestive action of trypsin.

	pH	Temperature (°C)
J	2	27
K	2	37
L	8	27
M	8	37

10. *Refer to the diagram below showing some organs in the animal digestive system to answer the following question.*

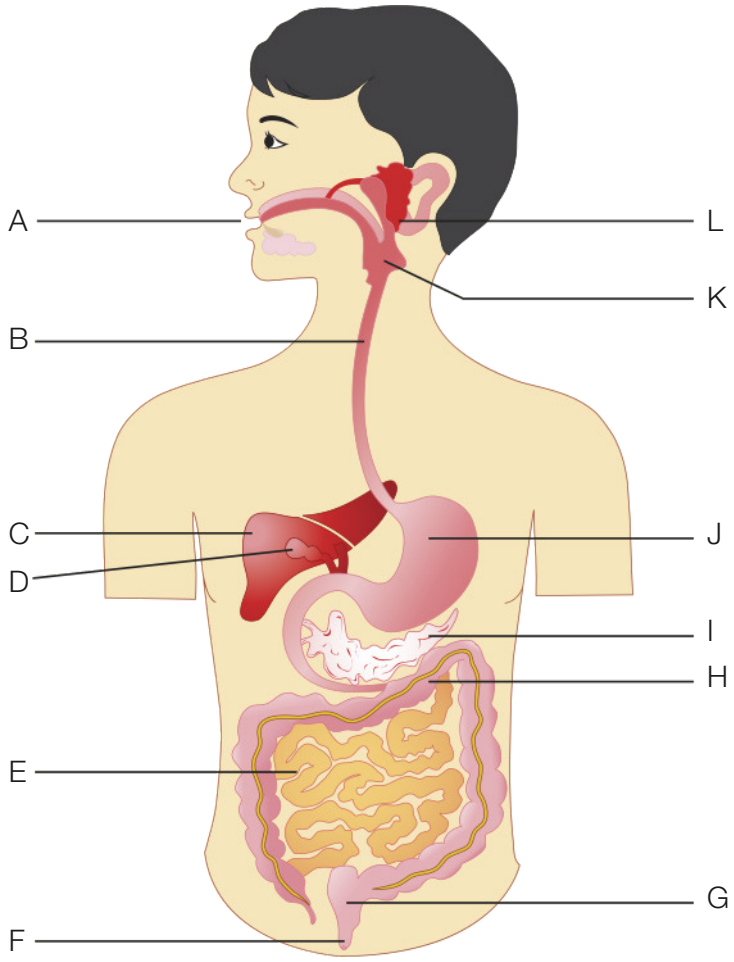
Identify the two organs that secrete enzymes involved in the digestion of protein.

J V and W
K U and V
L T and W
M W and U



Free response questions

1. *Refer to the diagram below to answer the following questions.*



Identify the organs in the picture above **and** describe their major function(s).

Organ	Organ Name	Functions
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K		
L		

2. Explain **two** ways that the structure of the stomach enables it to perform its function.

3. a) Draw a labelled diagram of a single villus in the space provided.

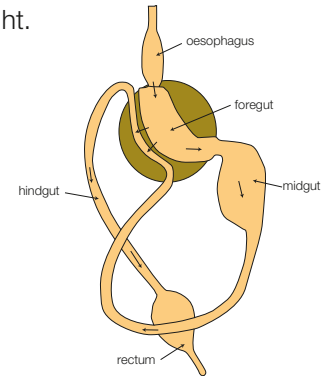
   b) Explain how the structure of villi help to increase the absorption of nutrients.

4. Describe **two** functions of saliva.

5. Explain the differences between mechanical (or physical) digestion and chemical digestion, using one example of each in the human digestive system.

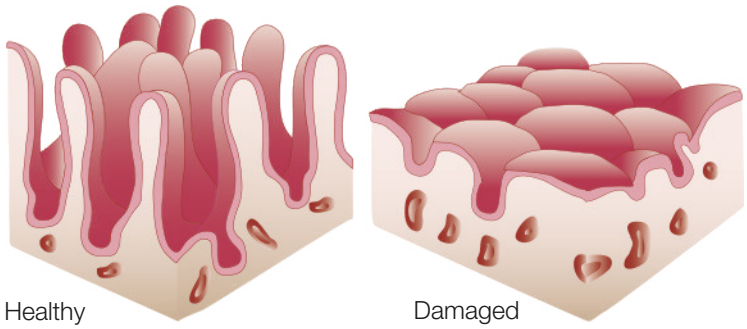
6. An illustration of the 'inside' of a living organism is shown in the Figure on the right.

   Identify **and** explain two pieces of evidence from the diagram that suggests the living organism is a type of animal.



7. Compare the function of the duodenum (first part of small intestine) in the human body with the function of the colon.

8. Coeliac disease occurs when the immune system responds abnormally to a protein found in some foods called gluten. One consequence of this is villi in the small intestine become inflamed and flattened. Refer to the Figure below showing a section of the internal lining of a 'healthy' and 'damaged' intestinal lining.



a) Describe the effect of coeliac disease on the internal lining of the small intestine.

b) Explain the likely impact that a 'damaged' intestinal lining (shown above) could have for an individual with coeliac disease.

c) Explain why an individual with coeliac disease could experience fatigue and weight loss.

9. Discuss how the circulatory and digestive systems work together within an animal.

10. The relative amounts of five substances in the mouth, the second section of the small intestine (jejunum), and the colon, during and after a person eats a meal is shown in the following table.

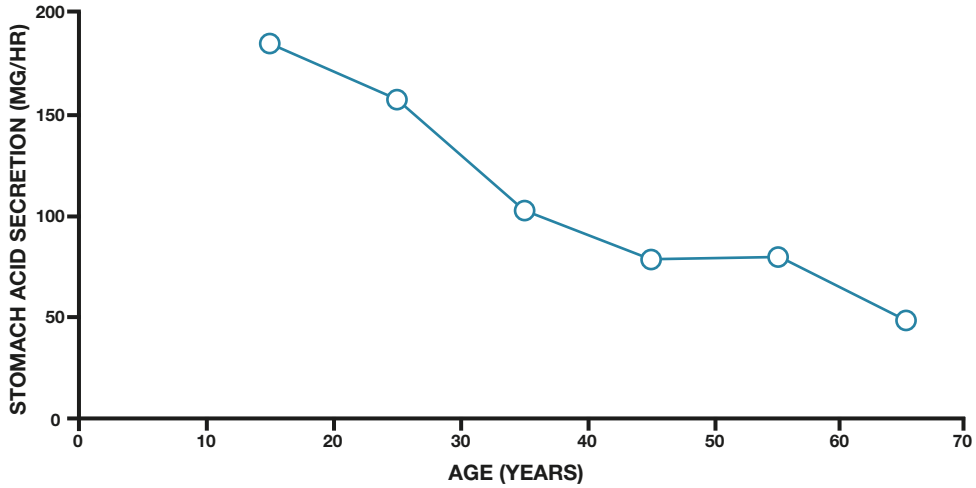
Substances	Amount in mouth	Amount in jejanum	Amount in colon
Starch	High	None	None
Glucose	Very little	High	None
Protein	High	None	None
Amino acids	None	High	None
Fibre	High	High	High

a) Explain the observations for starch and glucose.

b) Suggest reasons for the high levels of glucose and amino acids in the jejunum.

c) Explain why the amount of fibre in the colon is high.

11. *Refer to the graph below showing stomach acid secretions (in mg per hour) as humans age to answer the following questions.*



a) Use data to describe the shape of the graph.

b) Based on the information presented in the graph, explain **one** possible impact on the digestion of food as we age.

The stomach is often referred to as a temporary storage organ as it gradually releases chyme, the partially digested food mixed with gastric juice, into the small intestine.

c) Explain why it is important for the stomach to gradually release chyme rather than allow it to all flow through immediately.

Chapter 3.6 The excretory system in animals

Science Understanding

In animals, the excretory system is responsible for the removal of wastes.

- Describe the structure and function of nephrons in the kidney in the human excretory system.
- Explain the importance of filtration and reabsorption.

Metabolic wastes

All the biochemical reactions carried out by a living thing are collectively called **metabolism**. Some of the metabolic reactions in cells produce **metabolic wastes**, which are generally toxic at high concentrations and therefore need to be removed from the body. The removal of metabolic wastes and unnecessary by-products is called **excretion**. In animals, metabolic wastes that are excreted include carbon dioxide, nitrogen-containing waste products (e.g. urea) and breakdown products of hormones and chemical exposures (e.g. medicines). Excess water and salts are two examples of unnecessary metabolic by-products (see Figure 3.6.1). Nitrogen-containing waste products, such as ammonia, uric acid and urea, are produced from the breakdown of excess nucleic acids and protein. Ammonia is highly toxic to animals and must be converted to less toxic chemicals such as urea or uric acid. In humans, and other mammals, the **liver** converts ammonia to urea. Ammonia is converted to uric acid in invertebrates (animals without a backbone).

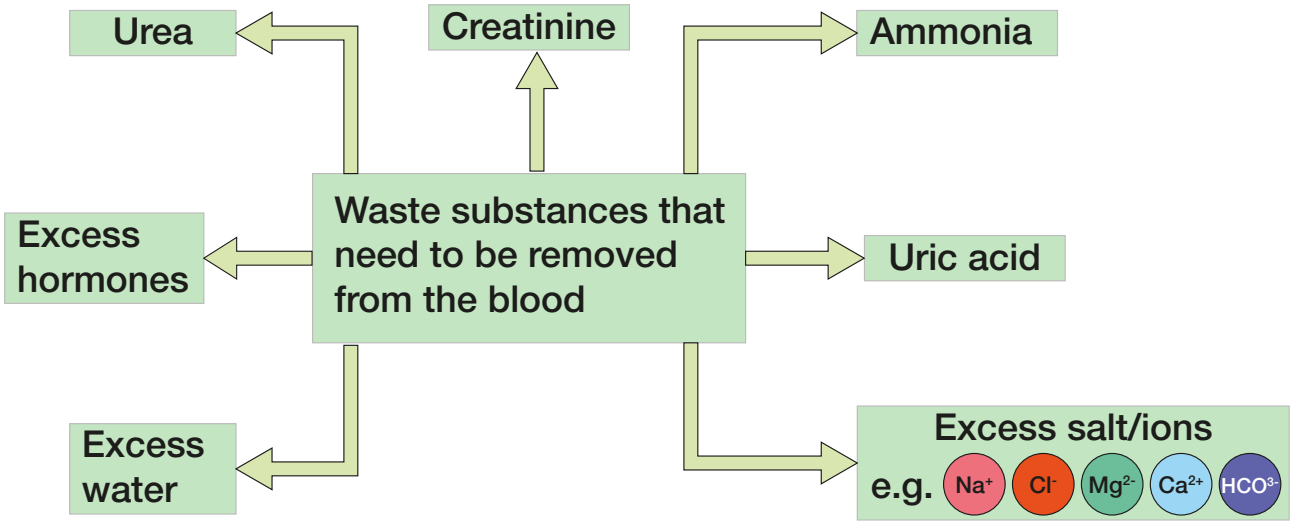


Figure 3.6.1: Some examples of metabolic wastes and unnecessary metabolic by-products that are excreted from the body.

3.6

Types of excretion

Organs that permit excretion are called **excretory organs** (see Figure 3.6.2). Carbon dioxide is a metabolic waste product of aerobic respiration in animals and is excreted through the **lungs** of the respiratory system as discussed in Chapter 3.3. Sweating is also a type of excretion humans and some other animals. Sweat mostly consists of water but also excretes small amounts of salts and urea through the **skin**. Some metabolic wastes can be excreted in the faeces, such as the breakdown products of some medicines in the liver. The majority of faecal matter however are not produced by metabolic processes and are actually indigestible food material; therefore, faeces is generally not considered a metabolic waste.

Although there are multiple types of excretion, the majority of metabolic waste products are excreted through the **renal (urinary) system** and it is therefore commonly referred to as the excretory system. The **kidneys** of the renal system, filter metabolic wastes and unnecessary by-products from the blood to produce urine. As per the Stage 1 Biology subject outline, the focus of Chapter 3.6 is the removal of wastes through the kidneys in animals.

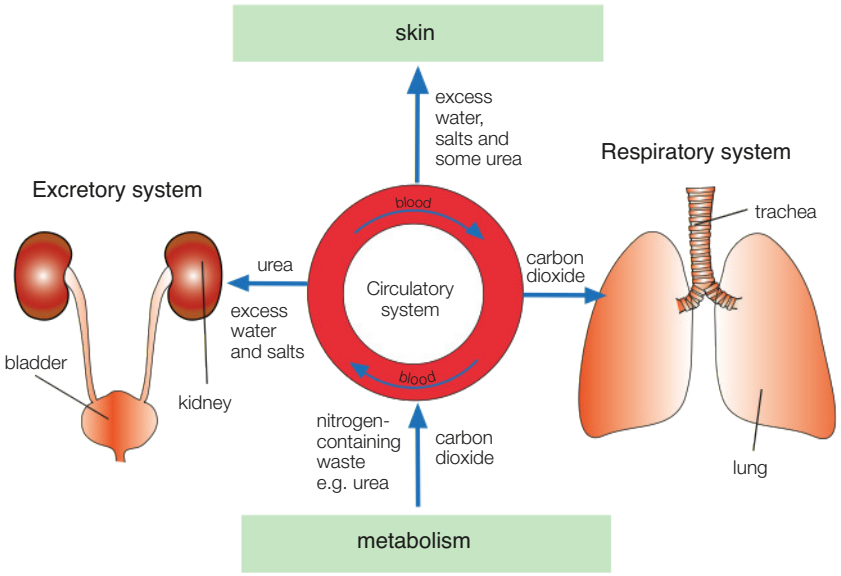


Figure 3.6.2: Some organs and organ systems involved in the excretion of metabolic wastes and unnecessary waste products.

The excretory system

In humans, the excretory system is located in a region of the body below the diaphragm called the **abdominal cavity**. Blood flows into a kidney in an artery called the **renal artery**. Blood that has passed through a kidney flows out of it in a vein called the **renal vein**. The kidneys filter the blood, producing urine, which is stored in the bladder until it is excreted through urination. The major organs of the excretory system and their function(s) are shown in Table 3.6.1 and Figure 3.6.3.

Table 3.6.1: The major organs of the excretory system and their respective functions.

Organ	Function(s)
Kidney	Produces urine to remove nitrogen-containing metabolic wastes and maintains the balance of water and salts in the blood
Ureter	Transports urine from the kidneys to the bladder
Bladder	Stores urine
Urethra	Transports urine out of the bladder during urination

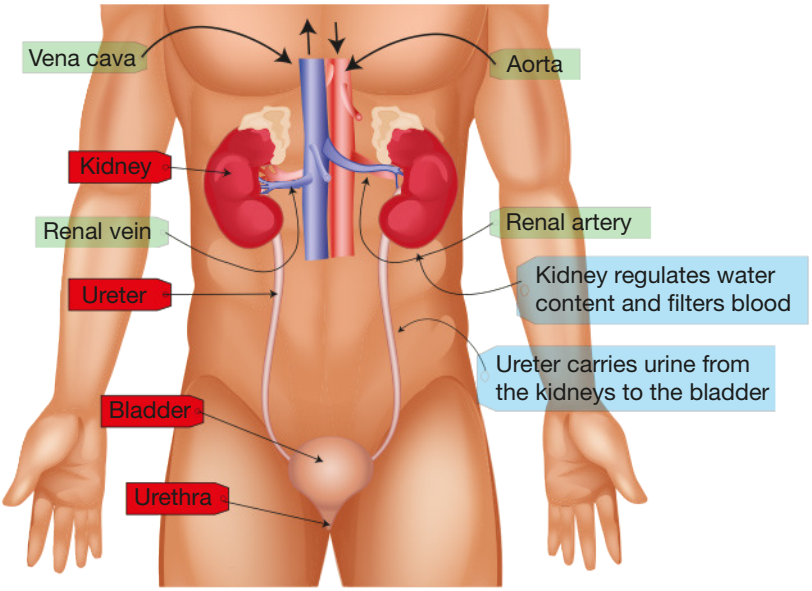


Figure 3.6.3: The structure of the human excretory system.

Helpful online resources

TED-Ed: How do your kidneys work?–Emma Bryce

<https://www.youtube.com/watch?v=FN3MFhYPWWo>

Kidney tissue

Each kidney is packed with tiny renal tubules that consist of simple cuboidal epithelial tissue. Renal tubules also have blood vessels associated with them and are held in place by connective tissue. The kidney tissue consists of two distinct regions. The outer region is called the **cortex**, and the inner region is called the **medulla**. The structural and functional unit of the kidneys are called **nephrons**.

The nephron

There are over a million nephrons in each kidney, providing a large surface area for the processes of **filtration and selective reabsorption** that occur in the nephrons. Each nephron consists of a:

- Bowman's capsule,
- Glomerulus, and
- a long renal tubule (see Figures 3.6.4 and 3.6.5).

The glomerulus is a cluster of capillaries located in the cup-like structure of the nephron called a Bowman's capsule. The **renal tubule** is a long structure that extends from the Bowman's capsule and can be divided into three parts:

- the proximal tubule,
- the loop of Henle, and
- the distal tubule (see Figures 3.6.4 and 3.6.6).

The end of each tubule joins a tube called a **collecting duct** that in turn connects to the ureter. The collecting duct transports the remains of the filtered blood (urine) to the ureter, which delivers it to the bladder.

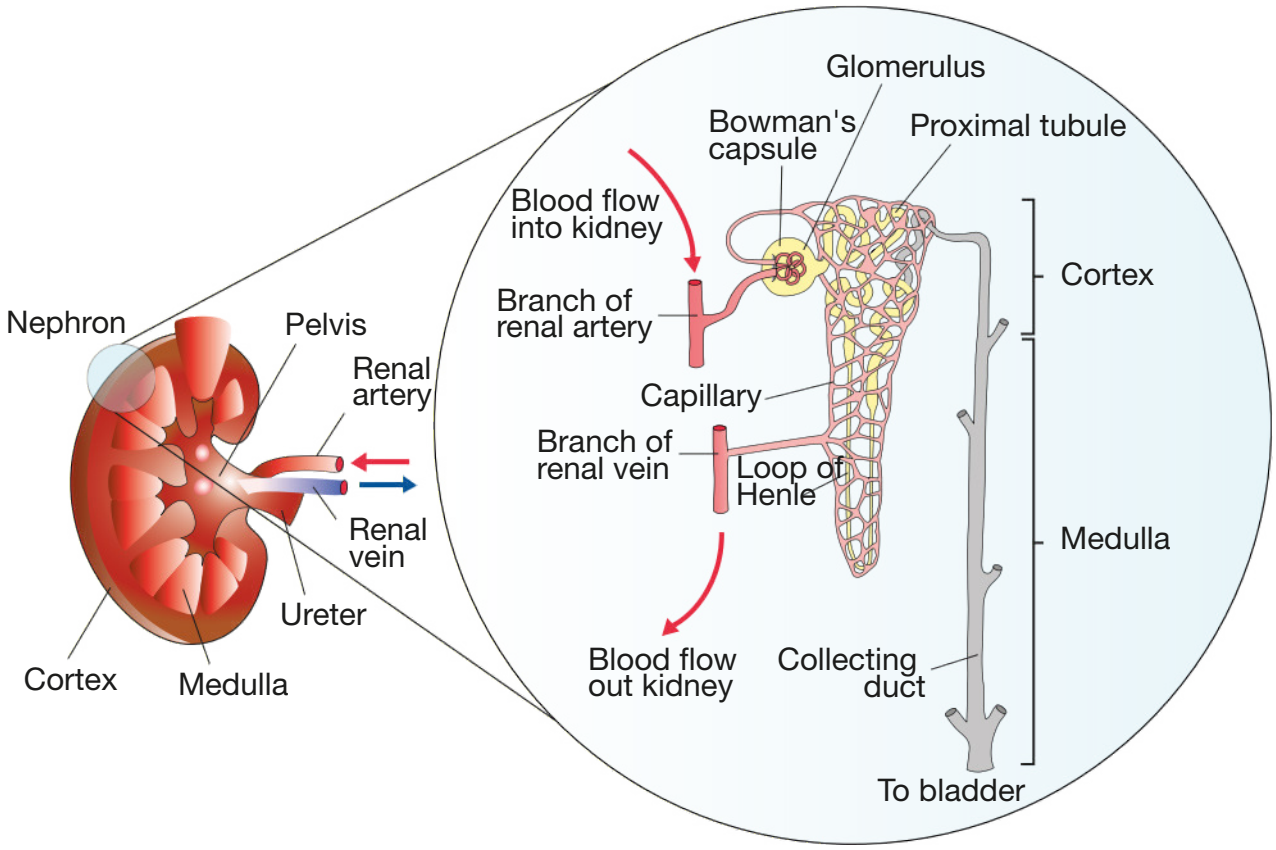


Figure 3.6.4: A close-up view of the positioning of a nephron in the kidney, which highlights how the approximate top third of the nephron is located in the cortex section of the kidney and the approximate bottom two thirds of the nephron is located in the medulla section of the kidney.

Filtration

Blood transported into a kidney passes from a branch of the renal artery under **high pressure** into the glomerulus where it undergoes a process called **filtration**. This high blood pressure causes water and other small substances to pass through the capillary walls and enter the Bowman's capsule; for example, glucose, amino acids, salts and the nitrogen-containing waste products. The larger components of blood (blood cells and plasma proteins) are not filtered as they are too big to pass through the capillary walls, and thus remain in the blood. The liquid that passes into the Bowman's capsule is called the glomerular **filtrate**.

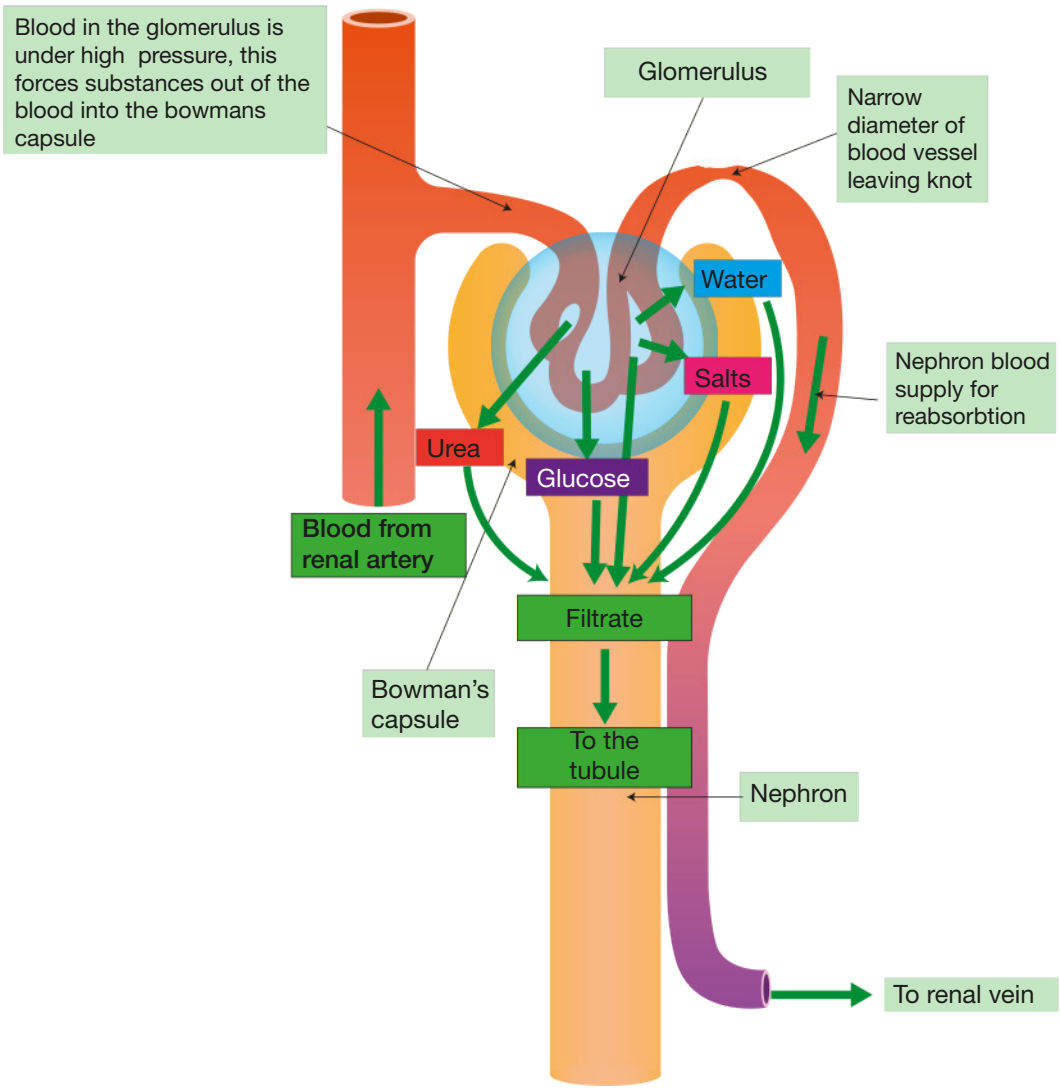


Figure 3.6.5: The basic process of filtration.

Selective reabsorption

The filtration process does not discriminate between useful and waste products, but the process that follows, called **selective reabsorption**, does. The filtrate in the Bowman's capsule flows into the tubule, where **useful substances are reabsorbed** back into the blood. Reabsorption occurs across the length of the tubule and some substances are also reabsorbed across the collecting duct, such as water (see Table 3.6.2 and Figure 3.6.6).

Under normal circumstances, 100% of the essential materials such as glucose and amino acids are reabsorbed at the proximal tubule. A large part of the water and salts are also reabsorbed at the proximal tubule. Generally, 99% of the filtered water is reabsorbed by osmosis across the tubule and collecting duct, but this can vary depending on an individuals' diet, medications, and other environmental factors. The amount of salts reabsorbed varies and is also dependent on these factors. This is covered in more detail later in this chapter. Approximately 50% of the filtered urea is reabsorbed passively along the length of the tubule to help maintain water/solute balance. If required, the collecting duct can reabsorb more. The remaining urea, additional nitrogen-containing waste products, water and other substances that are not reabsorbed from the tubule, will flow out of the collecting duct towards the bladder, in the urine. Furthermore, the filtered blood with reabsorbed substances passes to a branch of the renal vein for transport out of the kidney and back to the heart. Refer to Table 3.6.3 for a summary of the parts of a nephron and their roles in filtration and reabsorption.

Table 3.6.2: A summary of some filtered substances and how they are reabsorbed.

Substance	Percentage reabsorbed under normal circumstances (%)	Process by which reabsorption occurs	Site(s) of reabsorption
Glucose	100	Active transport	Proximal tubule
Amino acids	100	Active transport	Proximal tubule
Water	99	Osmosis	Proximal tubule (70%), loop of Henle, distal tubule and collecting duct
Urea	50	Facilitated diffusion	Proximal tubule (50%), distal tubule and collecting duct
Sodium (Na^+)	99	Active transport	Proximal tubule (65%), loop of Henle, distal tubule and collecting duct

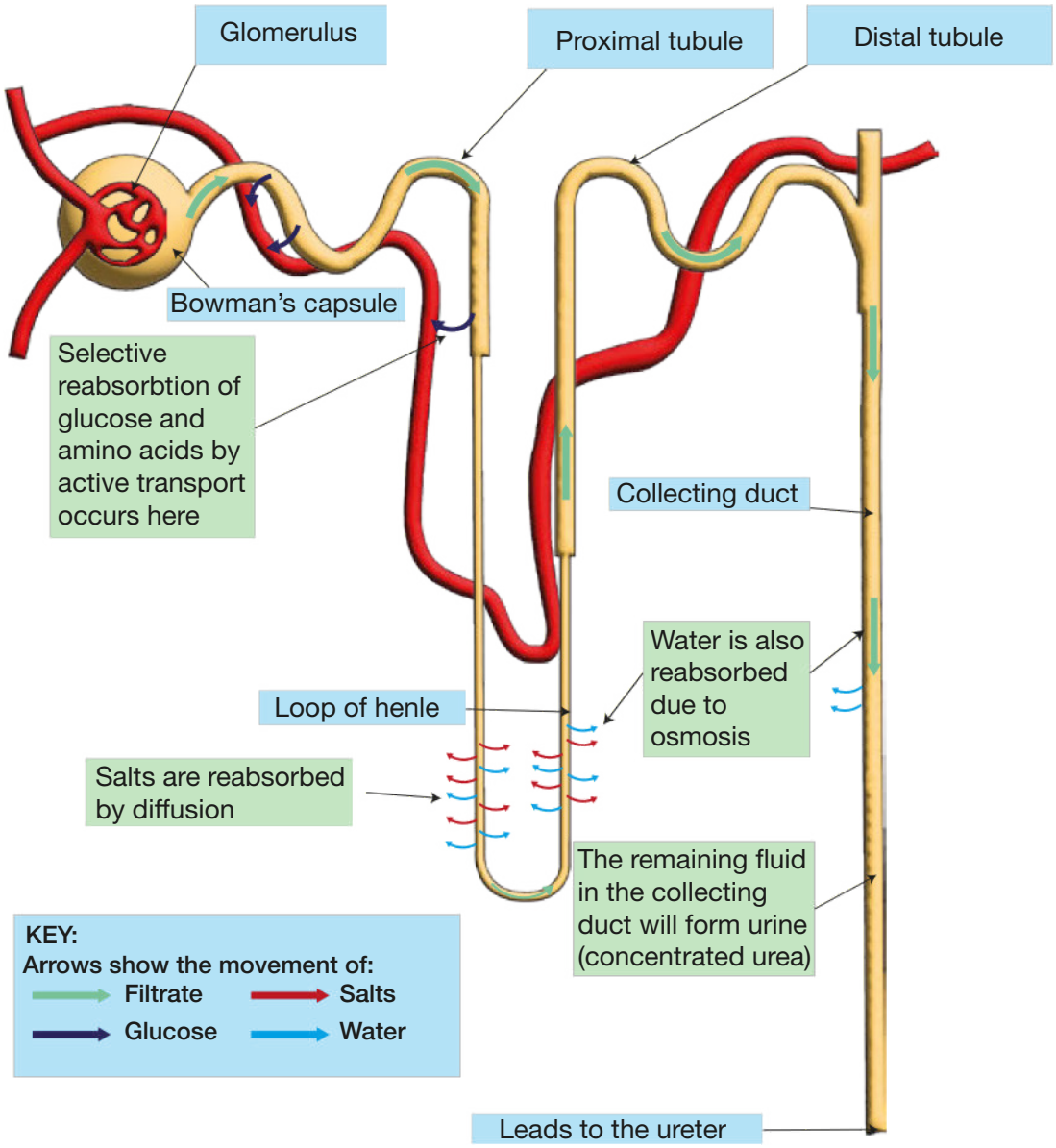


Figure 3.6.6: The basic process of selective reabsorption.

Table 3.6.3: A summary of parts of the nephron and how their structures suit their functions.

Part of nephron	Structure	Function
Glomerulus	A cluster of semi-permeable capillaries.	To allow small molecules to pass through the capillary walls and into the tubule, especially nitrogen-containing waste products.
Bowman's capsule	Cup-shaped and hollow structure that extends into the proximal tubule.	Participates in filtration by surrounding the glomerulus to collect the filtrate and allow it flow into the proximal tubule.
Proximal tubule	Tube-like structure consisting of walls lined with micro-villi. The walls are also very thin and moist. It is also surrounded by capillaries that provide blood for reabsorbed substances to flow into.	Reabsorbs approximately 65% of the total filtrate. It is important for the reabsorption of essential substances and some salts, urea and water. The remaining filtrate is also transported from the proximal tubule to the loop of Henle for further reabsorption.
Loop of Henle	Consists of a long "U-shaped" tubule with a thin descending limb and a thin and thick ascending limb. The long length of this part of the tubule provides a large surface area for reabsorption to occur into the rich supply of capillaries that surround it.	Contribute to the reabsorption of water and salts to help maintain the water/solute balance in the blood.

Osmoregulation

In order for the body to function normally, the temperature and content of its body fluids have to be kept relatively constant. Maintaining a stable internal environment is called **homeostasis**. One example of homeostasis is **osmoregulation** which involves maintaining the correct balance of water and salts (osmotic balance) in the blood.

An increase in the volume of the blood increases blood pressure, which applies extra stress to the circulatory system. Chronic high blood pressure can increase the risk of disorders such as atherosclerosis, heart attacks and heart failure. It is therefore very important for the osmotic balance of the blood to be maintained at a relatively constant level. Osmotic balance in the blood changes throughout the day due to factors such as diet, exercise, medications, weather, and other factors. The body needs to be able to respond to these changes and return the osmotic balance back to normal. One mechanism involved in osmoregulation is changing the permeability of the **collecting duct** to water. If the body is dehydrated and requires more water to be reabsorbed, the permeability of the collecting duct to water can be increased, reducing the loss of water by the body to urine. The opposite response is also activated when overhydrated.

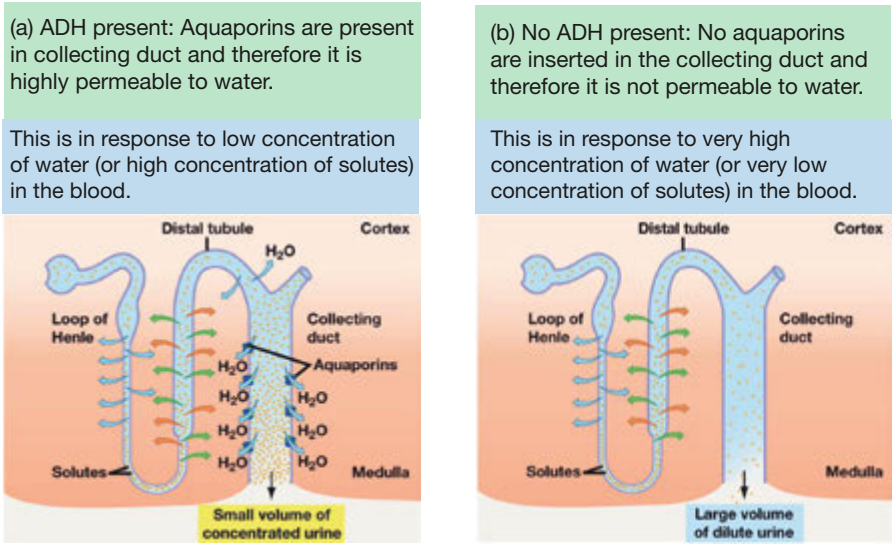


Figure 3.6.7: The role of the hormone ADH in osmoregulation. (a) When high concentrations of ADH is present, more water is reabsorbed from the filtrate into the kidney tissue and in turn, the blood. (b) When no ADH is present the collecting duct is impermeable to water. The osmotic balance of the blood and blood pressure can therefore be altered by the amount of ADH released by the pituitary gland.

One **hormone** that plays an important role in changing the permeability of the collecting duct is **antidiuretic hormone (ADH)**. ADH is released from an organ of the endocrine system called the **pituitary gland**. ADH travels through the blood to the kidneys and binds to complementary receptors at the collecting ducts. When an individual is dehydrated or there is too much salt in the blood, the pituitary gland is signaled to release more ADH. An **increased ADH** in the blood results in an **increased permeability** of the cell membranes of the collecting ducts to water. This increases the reabsorption of water back into the capillaries from the filtrate. As a result, a **lower volume of urine** is produced that will be more concentrated (see Figure 3.6.7). Conversely, when too much water or too little salt in the blood is detected, **less ADH** is released from the pituitary gland **decreasing permeability** of the collecting duct to water. This results in less reabsorption of water to the capillaries from the filtrate and an **increased volume of urine**, which is more dilute (see Figure 3.6.7).

Effect of alcohol and caffeine on osmoregulation

Substances that promote the formation of urine are called **diuretics**. Two common examples of diuretics are alcohol (in beer, wine and spirits) and caffeine (in coffee, tea and some soft drinks). Consumption of any of these beverages leads to the production of a large volume of dilute urine.

Drinking alcohol increases urine production because its presence in the bloodstream causes the pituitary gland to stop releasing ADH. This results in less water leaving the collecting ducts. Therefore, more water drains down the ureters to the bladder prompting the release of a large volume of dilute urine. Continued consumption of alcohol leads to more trips to the toilet to urinate, and dehydration, which in turn may cause the symptoms of a 'hangover'.

Caffeine can also inhibit the release of ADH from the pituitary gland, increasing urine formation, but it is also thought that caffeine may have additional diuretic effects. Caffeine may also block the action of a hormone called angiotensin. In doing so, the arterioles dilate, increasing blood flow into the glomerulus and a higher rate of filtration, and so a higher volume of glomerular filtrate. This may lead to more water passing down the collecting ducts and therefore more urine.

Changes to urine composition

The composition of urine is altered by many factors. High air temperatures, exercise and eating a high-salt meal all lead to the production of urine with a low water content, as does severe diarrhoea. Drinking water, alcohol or caffeine results in urine with a high-water content. Sudden kidney damage due to a physical blow or an accident leads to blood in urine and/or lower urine volume. The development of disease affects urine composition too; for example, diabetes leads to glucose in urine and liver disease results in a waste called bilirubin being in urine. Poor kidney function can lead to kidney disease that may result in the presence of blood and/or large proteins in urine.

Treating kidney disease

Most people are able to survive normally with one of their kidney's functioning. But near or complete breakdown of function of both kidneys results in severe kidney disease, and death if not treated. The only way to treat severe kidney disease is by some form of kidney replacement therapy.

One kidney replacement therapy is called dialysis. In this treatment, the function of the kidneys is performed artificially by a kidney dialysis machine. Blood from a vein in the arm is pumped through tubing in the dialysis machine that sits in a fluid. The walls of the tubing have lots of tiny pores in them to mimic filtration. Water and small substances including nitrogen-containing waste are filtered out of the blood into the dialysis fluid, but blood cells or large blood proteins remain in the blood. The concentration of glucose and salts the body needs in the dialysis fluid is monitored to ensure it stays higher than in the blood, therefore loss of these substances from the blood by diffusion is prevented.

A patient with severe kidney disease has to be connected to the dialysis machine up to three times a week. The alternative to dialysis is a complex surgical replacement procedure called a kidney transplant. This treatment involves removing a diseased kidney from the patient and transferring a healthy functional kidney from another person. The patient is the recipient and the person who provides the kidney is known as the donor. A live donor is an individual, often a relative, who donates one of his or her kidneys. A deceased donor is a healthy person who has died; for example, due to a car accident.

Helpful online resources

FreeMedEducation: What is kidney failure?

<https://www.youtube.com/watch?v=HHZ-M25uDfk>

3.6 Review questions

Multiple choice questions

1. The functional unit of the kidney is the

   J neuron.
   K nephroid.
   L neuter.
   M nephron.

2. Which of the following is an example of excretion in humans?

   J The removal of faeces from the anus.
   K Aerobic respiration producing carbon dioxide as a by-product.
   L The removal of excess salts from the blood.
   M The release of ADH from the pituitary gland.

3. A function of the kidneys in a healthy person is to

   J breakdown toxins.
   K help lose control of blood pressure.
   L reabsorb all glucose at the glomerulus.
   M eliminate excess sodium ions.

4. Identify how the blood changes as it passes through the kidney.

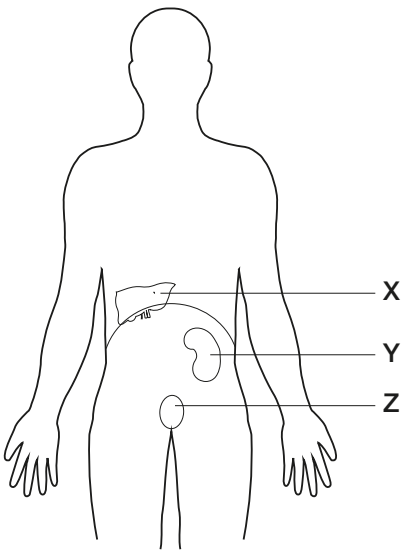
   J It gains glucose.
   K It loses protein.
   L It loses urea.
   M It gains salts.

5. Amino acids are found in the fluid contained within a normal Bowman's capsule.

   Proteins are not usually found in the fluid within the Bowman's capsule because

   J amino acids are waste products, and proteins are not waste products.
   K proteins are reabsorbed, and amino acids are not reabsorbed.
   L only small molecules are filtered from the blood.
   M only large molecules are reabsorbed.

6. *Refer to the image below showing some unidentified organs in a human to answer the following question.*

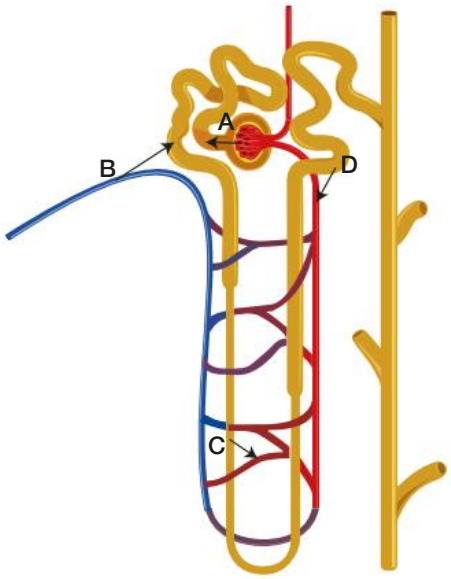


   Excess amino acids cannot be stores in the body.

   Identify the organ on the diagram where amino acids are broken down, its name, the metabolic by-product the breakdown of amino acids produces and the site this by-product is removed from the blood.

	Site of amino acid breakdown	Name of organ where amino acids are broken down	Metabolic by-product from amino acid breakdown	Site where amino acid breakdown product is removed from blood
J	X	Kidney	Urea	Z
K	Y	Kidney	Nitrogen	Y
L	X	Liver	Urea	Y
M	Y	Liver	Nitrogen	Z

7. *Refer to the diagram below to answer the following question. The arrows A, B C and D represent processes that occur in this structure.*



Which of the following combinations of the process and location in the structure that the process occurs is correct?

	Process	Location in the structure that the process occurs
J	Removal of urea from blood	A
K	Osmosis of water	B
L	Return of blood to the capillary	C
M	Reabsorption of large proteins	D

8. The average percentage of water in human urine is 96%. This percentage changes when conditions change.

Identify which set of conditions below will result in the greatest decrease in the percentage of water in the urine.

	Conditions		
	Amount of water consumed	External temperature	Physical activity level
J	High	Low	Low
K	Low	Low	High
L	High	High	Low
M	Low	High	High

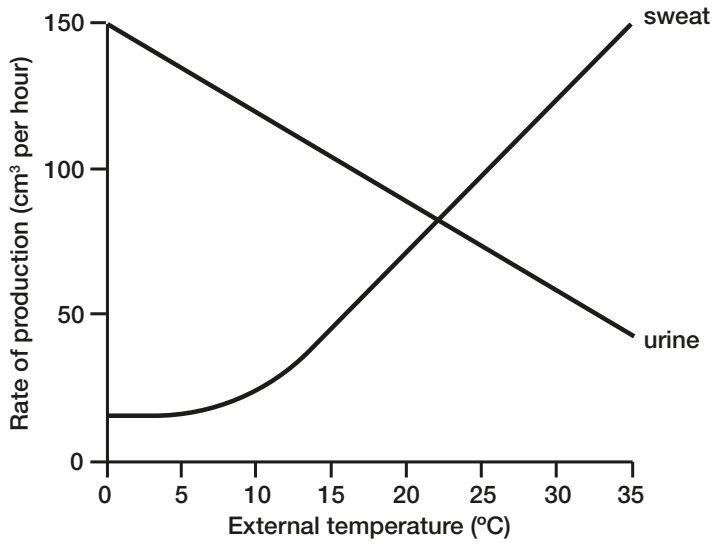
9. *Refer to the table below which shows the composition of blood of a healthy person entering the kidneys to answer the following question.*

Substance	Percentage composition of blood entering kidney (%)
Proteins	7.00
Glucose	0.20
Urea	0.02

Identify the percentage composition of the same three substances in the urine of this healthy person.

	Urine composition (%)		
	Proteins	Glucose	Urea
J	7.00	2.00	2.50
K	7.00	0.20	0.01
L	0.00	0.00	0.01
M	0.00	0.00	2.50

10. *Refer to the graph below showing the rates of urine and sweat production in humans at different external temperatures to answer the following question.*



It is reasonable to conclude that

J the rates of sweat and urine production are the same at an external temperature of 22°C.

K as the external temperature increases, the rate of sweat production increases and the rate of urine production increases.

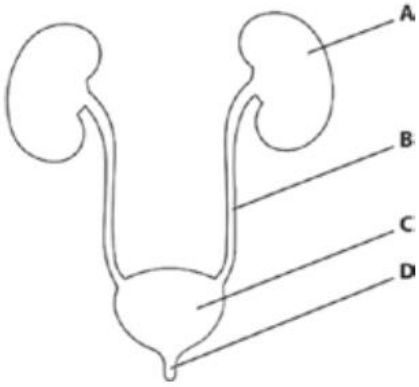
L as the external temperature increases from 0 to 35°C, the rate of sweat production increases in a linear fashion.

M the secretion of ADH decreases in response to an increase in the external temperature and this is responsible for the change in sweat production.

Free response questions

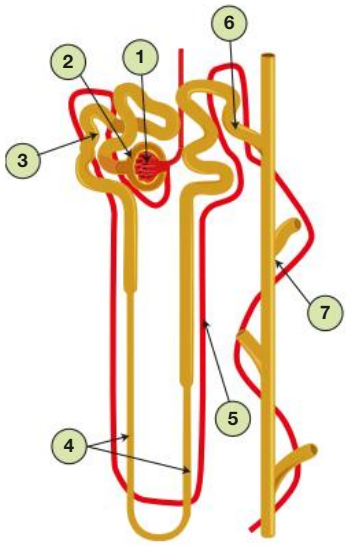
1. Define excretion in animals.

2. Identify the following organs of the excretory system:



Organ	Name of organ	Function of organ
A		
B		
C		
D		

3. *Refer to the diagram below of a nephron to answer parts a) to d).*



a) Identify the structures labelled 1 to 7.

Structure	Name of structure
1	
2	
3	
4	

Structure	Name of structure
5	
6	
7	

b) Draw **and** label arrows **on the nephron** (on the previous page) to indicate where filtration and reabsorption occur.

c) Describe the functions of structure 1, 2 and 3.

Structure	Function of organ
1	
2	
3	

d) Identify the structure that the hormone ADH acts on **and** explain the effect an increased concentration of ADH in the blood has on the concentration of urine.

4. a) Describe the process of filtration that occurs in nephrons.

b) Describe the process of selective reabsorption that occurs in nephrons.

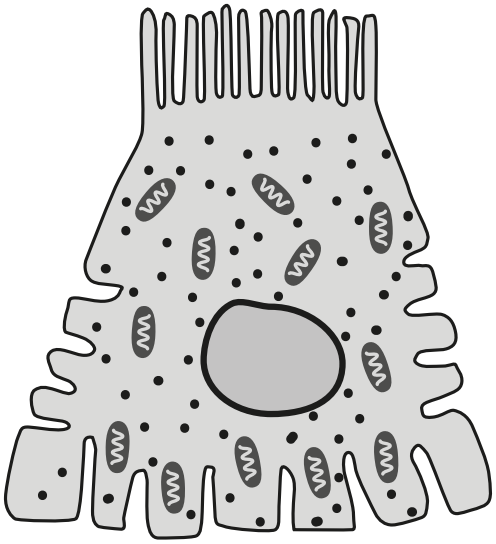
5. Explain why it is important for reabsorption in the nephrons to be '**selective**.'

6. Outline one difference in solute concentration you would expect to find between:

a) blood plasma and glomerular filtrate.

b) glomerular filtrate and urine.

7. *Refer to the diagram below which shows a cell in the proximal tubule of a mammalian nephron to answer the following question.*



Identify **three** structural features of this cell **and** explain how each feature assists the proximal tubule in performing its function.

8. The blood pressure of an individual often increases with age.

   a) Explain the effect ageing is likely to have on how much blood is filtered per unit time.

   b) Explain the effect ageing is expected to have on the volume of urine produced.

9. Explain how physical damage to the cortex section of the kidneys can result in the presence of blood in the urine.

10. Dialysis is a treatment used for people with kidney failure. Some people with kidney failure are given a kidney transplant.

    Describe **two** advantages of having a kidney transplant instead of dialysis.

11. No glucose should be found in the urine of a healthy human under normal circumstances.

    a) Explain **two** reasons for this.

    b) Suggest a likely diagnosis for an individual excreting glucose in their urine **and** provide an explanation for your diagnosis.

12. a) Explain why an individual consuming a high protein diet would produce a greater amount of urea than an individual consuming a 'balanced' diet that has a normal level of protein.

    b) Explain why consuming a high protein diet for an extended period of time can result in dehydration.

13. In 2024, scientists successfully grew lab-made kidneys with blood vessels for the first time. These mini-kidneys can mimic organ function but lack the size and complexity of adult kidneys at this time.

    Discuss how the development of lab grown kidneys demonstrates 'Influence', one of the key concepts of science as a human endeavour.

Chapter 3.7 Plant structure and gas exchange

Science Understanding

Multicellular organisms have a hierarchical structural organisation of cells, tissues, organs and systems.

- Use examples from plants to explain organisation of cells into tissues, tissues into organs, organs into systems.
- Illustrate the relationship between the structure and function of cells, tissues, organs and/or systems.

In plants, gas exchange is facilitated by the structure of the leaf.

Gases are exchanged mainly via stomata. Their movement within the plant is by diffusion and does not involve the plant transport system.

- Describe and explain how gases move into, through, and out of plants.
- Describe the loss of water through open stomates.

Hierarchical structure of organisation

In multicellular organisms, cells are specialised and contain **organelles**. They rely on other cells to continue living and this interdependence of specialised cells contributes to the hierarchical structure of organisation. A multicellular organism's **cells** are organised into **tissues**, different tissues are organised into **organs** (see Figure 3.7.1), and different organs are organised into **organ systems** (see Figure 3.2.1 in Chapter 3.2).

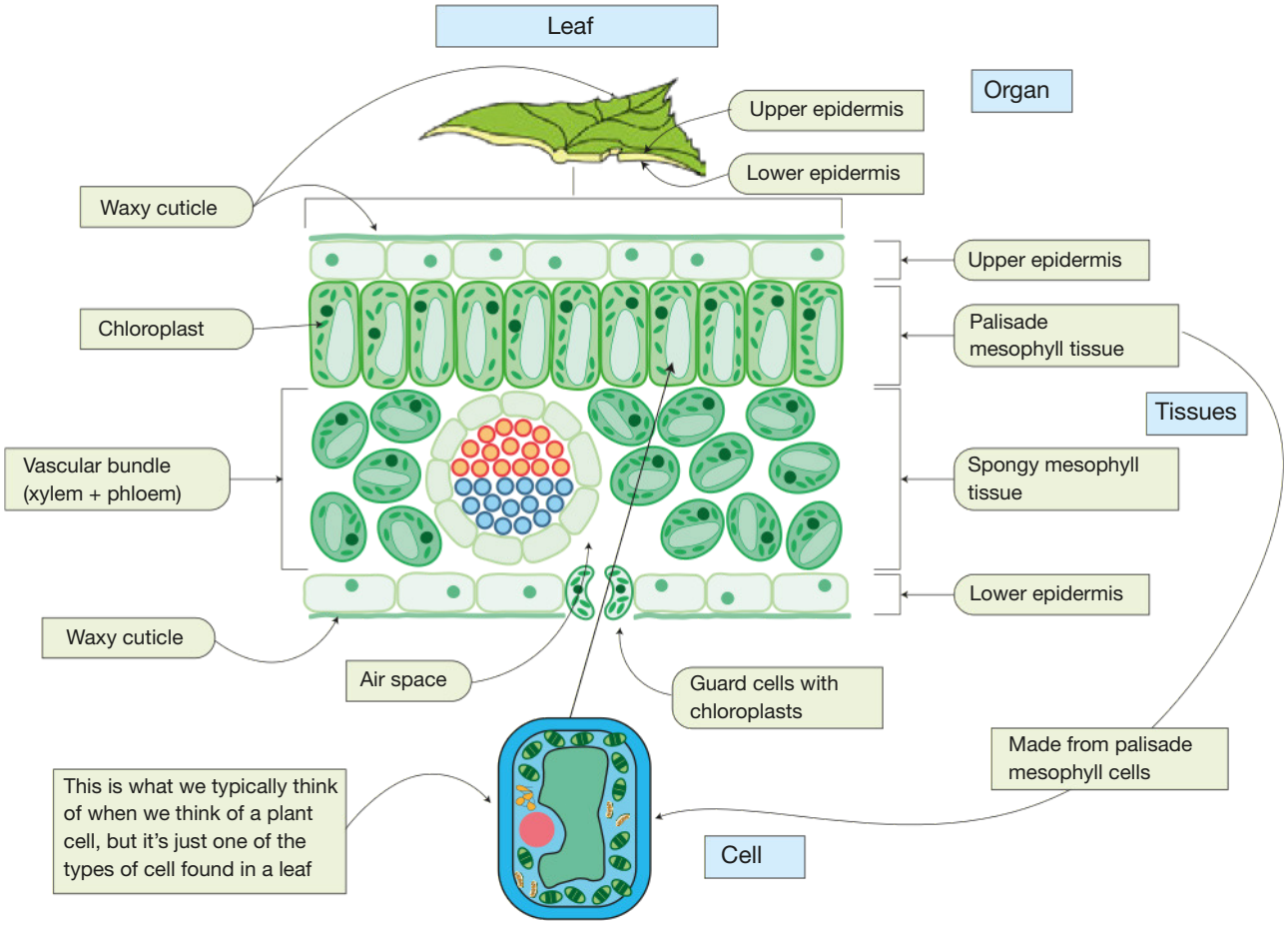


Figure 3.7.1: Plants organs such as leaves consist of different types of tissues that are made up of similar cells. The plant cells we generally learn about are palisade mesophyll cells which make up plant ground tissue.

Plant cells and tissues

Plants are multicellular organisms that consist of various cell types. Each of these cell types originate from unspecialised cells in the **meristems** of plants (see Figure 3.7.2), which are plant regions of continuous cell division and differentiation. These meristematic cells can be likened to the stem cells of multicellular animals. The differentiated specialised cells become **permanent cells** that generally do not undergo cell division. Meristems differentiate into three types of tissues: dermal, vascular and ground tissue (see Table 3.7.1).

Table 3.7.1: The three types of tissues formed from meristems and descriptions of their roles.

Tissue	Examples	Function(s)
Dermal	• Epidermal cells • Guard cells • Root hairs	Covers and protects the plant.
Vascular	• Xylem • Phloem	Transports nutrients such as water, glucose and salts throughout the plant.
Ground	• Palisade mesophyll cells • Spongy mesophyll cells	Provides a site for photosynthesis to occur, supports vascular tissue, and helps with water and nutrient storage.

Plant organs and organ systems

There are two types of plants, non-vascular and vascular. Non-vascular plants include green algae and mosses, whereas vascular plants include most plants that live on land, other than mosses. Vascular plants are plants that have vascular tissue that transport materials throughout the plant. Vascular plants consist of three main organs, **leaves, stems and roots** (see Table 3.7.2). All three organs consist of the three types of plant tissue: the skin like dermal tissue, the transporting vascular tissue and the ground tissue that fills in the spaces between dermal tissue and vascular tissue (see Figure 3.7.2).

The three main organs make up the two organ systems of vascular plants, the shoot system and the root system (see Table 3.7.3). The roots are part of the root system and the leaves are part of the shoot system. The stems, which contain the vascular tissue, connect the roots and leaves and is a part of both organ systems (see Figure 3.7.2). The shoot system performs photosynthesis and gas exchange, whereas the root system absorbs water and other nutrients from the soil. There are two types of root systems, the taproot system and the fibrous root system (see Figure 3.7.3). The taproot system consists of a thick primary root (taproot) that grows downwards, with secondary roots branching off it. The taproot anchors the plant very securely and can store a lot of carbohydrates for surviving extreme weather events, such as drought. The fibrous root system consists of many branching roots that increase the surface area for water and nutrient absorption. Lacking a primary taproot, these fibrous roots anchor the plant less securely.

Table 3.7.2: The three main plant organs and the tissues that help them perform a specific function in vascular plants.

Organ	Tissues in the organ	Function of the organ
Leaves	• Dermal tissue • Vascular tissue • Ground tissue	Leaves absorb sunlight and perform photosynthesis to produce energy-rich glucose molecules for the plant.
Stem	• Dermal tissue • Vascular tissue • Ground tissue	Stems transport essential nutrients, such as glucose, water and mineral salts, between the leaves and roots. They also help to arrange leaves effectively to maximise the absorption of light for photosynthesis.
Roots	• Dermal tissue • Vascular tissue • Ground tissue	Roots branch out into the soil to absorb water and nutrients that the plant requires for photosynthesis and growth.

Table 3.7.3: The two organ systems that make up seeded plants and their main functions.

Organ system	Major organs involved	Main function in the body
Root system	Stem, primary roots, secondary roots	Provides support by anchoring the plant in soil and absorbs water and minerals from the soil.
Shoot system	Stem, leaves, flowers, fruit	Absorbs light required to produce organic molecules through photosynthesis, transports materials and exchanges gases.

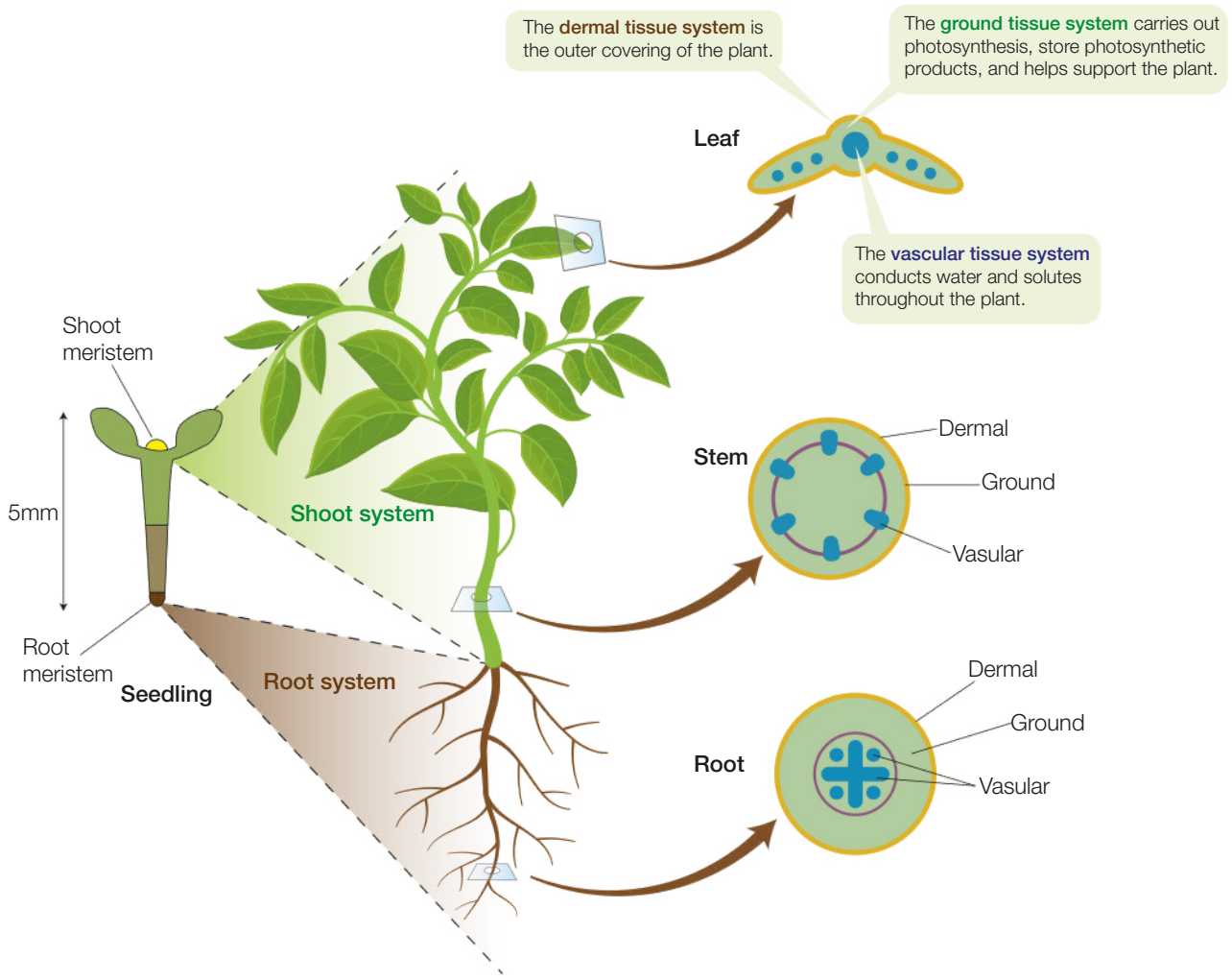


Figure 3.7.2: Vascular plants consist of three organs that make up two organ systems, the shoot system and the root system. Each organ is made up of the three types of plant tissues, which is evident in the colour-coded cross sections of the three organs displayed.

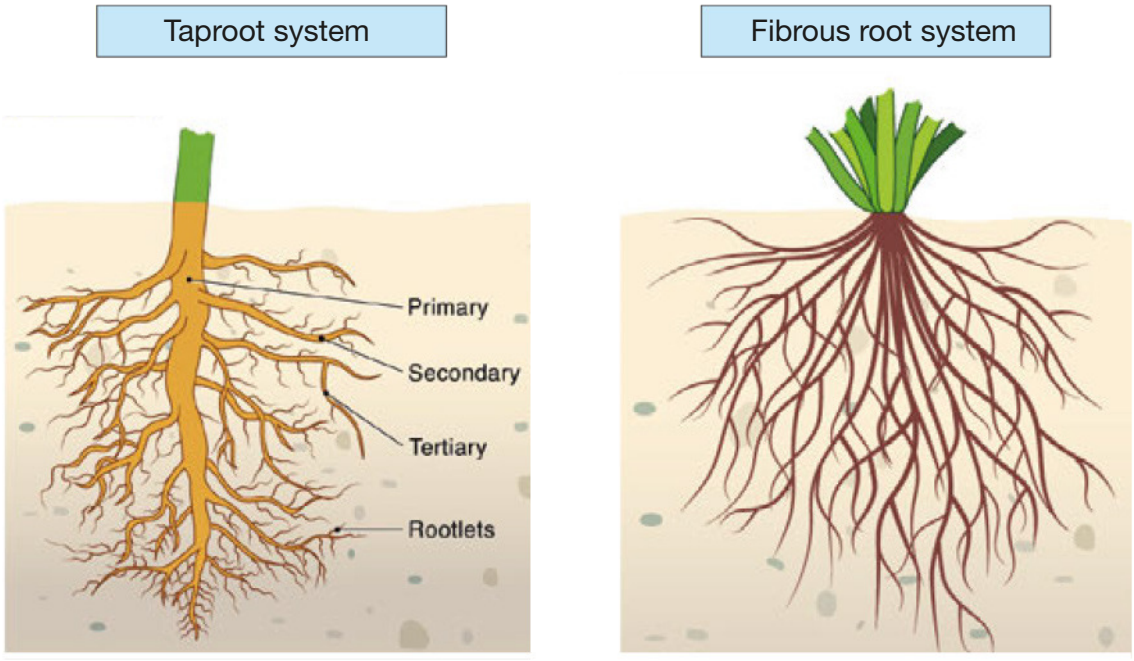
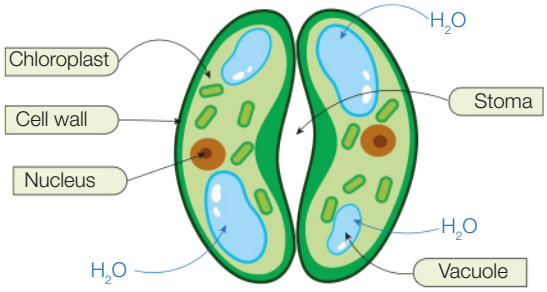
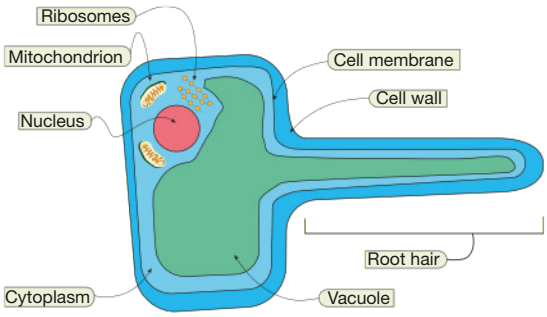
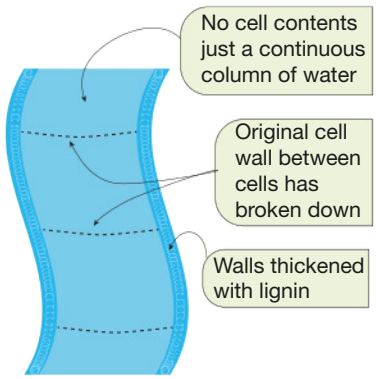
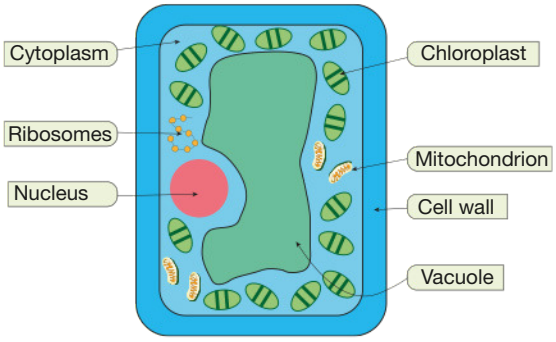


Figure 3.7.3: There are two types of root systems in vascular plants, the strong securing taproot system and the wide reaching but less secure fibrous root system.

The structure and function of plant tissues

Vascular plants have different tissues made up of groups of specialised cells that enable them to carry out specific functions. Refer to Table 3.7.4 below for some examples of some specific tissue cell types and corresponding explanations about how their structure suits their functions.

Table 3.7.4: Some examples of how the structure of plant tissues suit their functions.

Plant tissue system	Specific tissue cell type	Image	Description of the characteristics of tissue that make it well adapted to its function
Dermal	**Guard cells**		Guard cells are a pair of bean shaped cells surrounding the stoma that can open and close (allowing the diffusion of gases). They have thick cell walls facing the stoma and thin walls facing adjacent epidermal cells. They also have several smaller vacuoles instead of one large central vacuole. Guard cells open when they gain water and become turgid. The thin outer walls of the guard cells bend more easily than the thick outer cells causing them to curve and open the stoma.
Dermal	**Root hairs**		Root hairs are single-celled extensions of epidermal cells in the root. These extensions increase the surface area of the cells significantly. As root hairs absorb water and` mineral salts from the soil, this increased surface area increases their efficiency at performing this function.
Vascular	**Xylem**		Xylem vessels are long, hollow tubes consisting of dead cells. The cells are arranged end to end and have no cell walls between cells, forming a continuous tube that water can move through. They have tough walls containing a woody material called lignin that thickens the vessels. These thick walls are impermeable to water so it cannot leak out. Lignin is deposited in a spiral-shape to allow them to remain flexible.
Ground	**Palisade mesophyll**		Palisade cells reside directly under the upper epidermis and are stacked vertically to maximise the space and fit more in. These cells receive the most light and contain the most chloroplasts to maximise the absorption of this light and as a result, photosynthesis.

The structure and function of the leaf

The typical structure of a leaf is shown in Figure 3.7.4. Leaves are attached to the stem by a structure called a petiole that continues into most leaves to form the mid-rib. The surface of the leaf is called the lamina. A network of veins extends from the mid-rib across the lamina.

The structure of a plant organ is related to its function. The **leaf** has two main functions, gas exchange and to perform photosynthesis. The structure of the leaf facilitates both of these processes. The leaf has a broad and flat **lamina**, also called blade, which **increases the surface area** for light absorption and gas exchange. The leaf is also **thin** which increases the efficiency of gas exchange. Leaves contain structures called **stomata** that facilitate gas exchange and are generally located on the underside of leaves to prevent the loss of water through evaporation. Specific cells within leaves have chloroplasts that contain **chlorophyll** which absorbs light energy required for photosynthesis. Additionally, the spiraling arrangement of leaves that extend from the stem ensure that each leaf is exposed to sunlight to **minimise the shading of leaves** and maximise light absorption. Refer to Table 3.7.5 for descriptions of how structures of the leaf help facilitate the leaf's major functions of photosynthesis and gas exchange.

Table 3.7.5: How the structures of leaves are adapted to perform their functions.

Structure of leaf	Description of the characteristics of leaf structure that make it well adapted to its functions (facilitating gas exchange and photosynthesis)
Waxy cuticle	A transparent, protective layer on top of the leaf that helps maximise the absorption of light by mesophyll cells. It also protects the leaf by preventing the evaporation of water.
Upper epidermis	Is **thin** and transparent to maximise the absorption of light by mesophyll cells.
Lamina	Is broad and flat with a **large surface area**, allowing mesophyll cells to be spread out over a wide area to maximise the absorption of light and gas exchange. They are also **thin** to reduce the distance gases must move by diffusion.
Palisade mesophyll	Cells are just under the epidermis, are upright and **packed with green chloroplasts** to maximise the absorption of light.
Spongy mesophyll	Cells have chloroplasts to perform photosynthesis. Cells are loosely packed to provide internal air spaces between them allowing carbon dioxide to diffuse into mesophyll cells by **increasing the surface area to volume ratio**.
Veins (vascular bundles)	Contains xylem vessels to deliver water (for photosynthesis) and mineral nutrients to leaf cells and phloem tubes to move sugars out of leaves to other parts of the plant.
Lower epidermis	Contains **guard cells** that open and close the **stomata** to permit carbon dioxide needed for photosynthesis to diffuse into the mesophyll and oxygen produced to diffuse out during the day. Stomata close at night and are generally found on the bottom of leaves to prevent water loss.

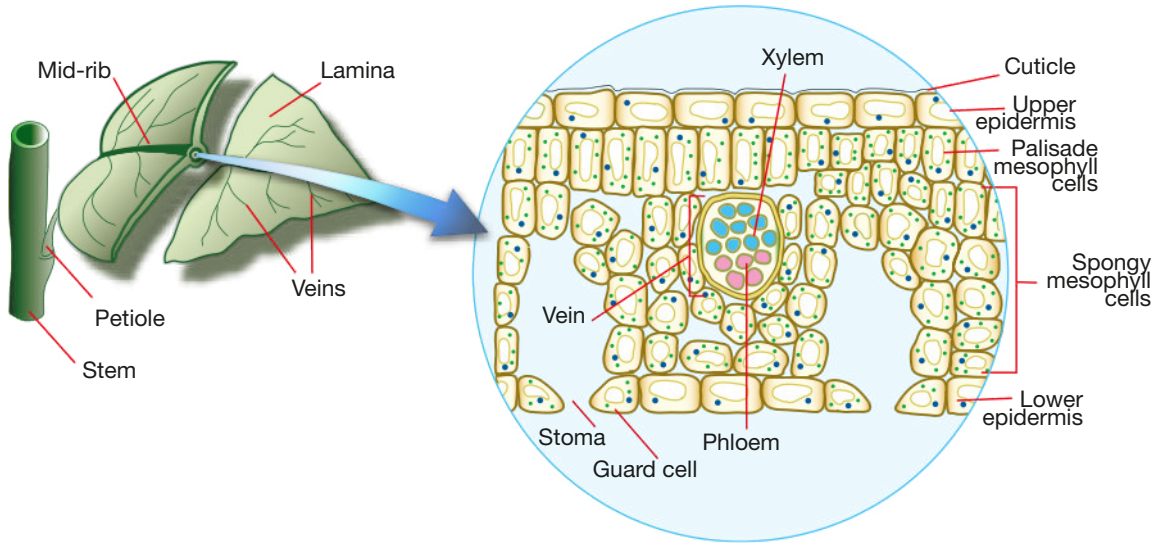


Figure 3.7.4: The parts of a leaf and a vertical slice or cross-section showing the internal structures of a leaf.

Helpful online resources

Free Animated Education: General structure of a leaf

<https://www.youtube.com/watch?v=cRsO_NXrfak&t=22s>

Plants and exchange of materials

Like animals, plants exchange materials with their environment (see Figure 3.7.4). In daylight when photosynthesis is taking place, plants take up carbon dioxide and excrete oxygen. Other materials taken in by plants during the day include liquid water and a variety of mineral salts from the soil, such as nitrates and phosphates. Water vapour is released by plants during the day through the stomata. Some plants that live in soil or mud with a very high salt content, such as mangroves, also excrete mineral salts during the day.

Photosynthesis and aerobic respiration

To understand gas exchange by leaves it is important to know more about photosynthesis and a process that occurs in all cells called aerobic respiration.

Photosynthesis is a series of biochemical reactions that takes place in cells that contain green organelles called chloroplasts, which are found in palisade mesophyll cells, spongy mesophyll cells and guard cells in leaves. Plants use photosynthesis during the day to synthesise the organic compound glucose required for survival. For this reason, a plant is called an autotroph. In photosynthesis, light energy is trapped by the green pigment **chlorophyll** and is used to break the bonds between the atoms of the reactants so they can be rearranged to form a glucose molecule and six oxygen atoms (see Figure 3.7.5).

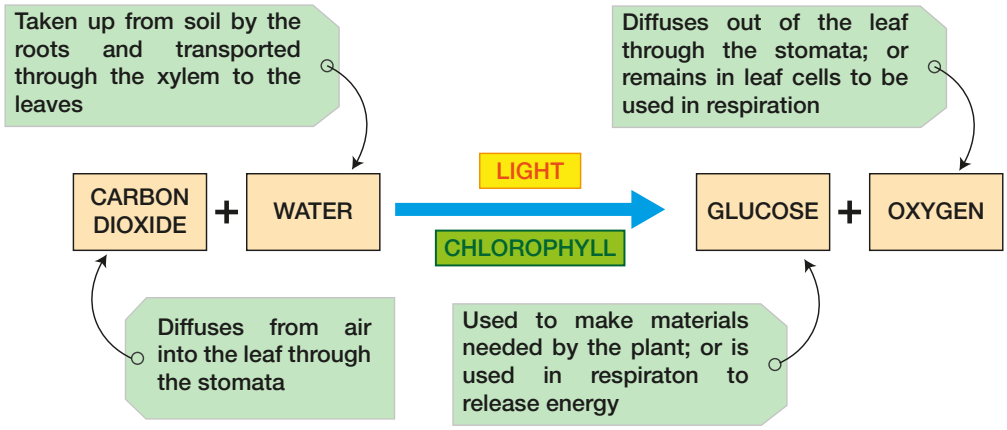


Figure 3.7.5: The word equation for photosynthesis showing how plants source their materials for the essential process of photosynthesis and how the products formed can be used as a source for other processes, such as aerobic respiration.

Aerobic respiration is a series of biochemical reactions that mostly take place in an organelle found in all cells called a mitochondrion (pl. mitochondria). Plants and animals use aerobic respiration all the time to produce a **large amount of cellular energy** (36ATPs) as the presence of oxygen allows for a more **complete breakdown of glucose**. The by-products of this process are carbon dioxide and water (see Figure 3.7.6). The **ATP** (adenosine triphosphate) produced in this reaction is the cell's **immediate source of energy** and is used for almost every energy-requiring reaction or process that occur in cells, such as active transport, protein synthesis and cell division. Additionally, the carbon dioxide and water produced by aerobic respiration can be used by the leaves for photosynthesis if there is sunlight available to do so.

For more information on autotrophs, photosynthesis, respiration and ATP synthesis, please review Chapter 1.4 where this is discussed in more detail.

Figure 3.7.6: The word and chemical equations for aerobic respiration.

Gas exchange at leaves

During daylight hours, plants perform photosynthesis and aerobic respiration. For most of the day, photosynthesis occurs at a faster rate than aerobic respiration due to the abundance of sunlight. This means all the carbon dioxide (CO_2) produced by aerobic respiration is likely to be used for photosynthesis, and there is more oxygen (O_2) produced by photosynthesis than is needed for aerobic respiration. This results in the leaves requiring an input of carbon dioxide from the atmosphere and the **excess oxygen produced being excreted during the day** (see Figure 3.7.7).

Photosynthesis occurs more slowly in low light. At some point during the early morning and in the evening, photosynthesis will occur at the same rate as aerobic respiration. This results in no nett exchange of carbon dioxide and oxygen and is known as a light compensation point (see Figure 3.7.8). After sunset when it is dark, photosynthesis does not take place, but aerobic respiration continues. As the rate of aerobic respiration is greater than the rate of photosynthesis during this time, plants require an input of oxygen from the atmosphere and excrete the **excess carbon dioxide produced at night** (see Figure 3.7.7).

Additionally, leaves **lose water vapour** (gaseous water) by evaporation. This loss of water vapour mainly occurs at **open stomata**, but water can also evaporate from the surface of leaves, flowers and stems of plants. The collective loss of water from a plant is called **transpiration** (see Figure 3.7.7). Transpiration is therefore a consequence of gas exchange. Most plants can close their stomata to prevent transpiration, but this also reduces their ability to exchange other gases and reduces the rate of photosynthesis.

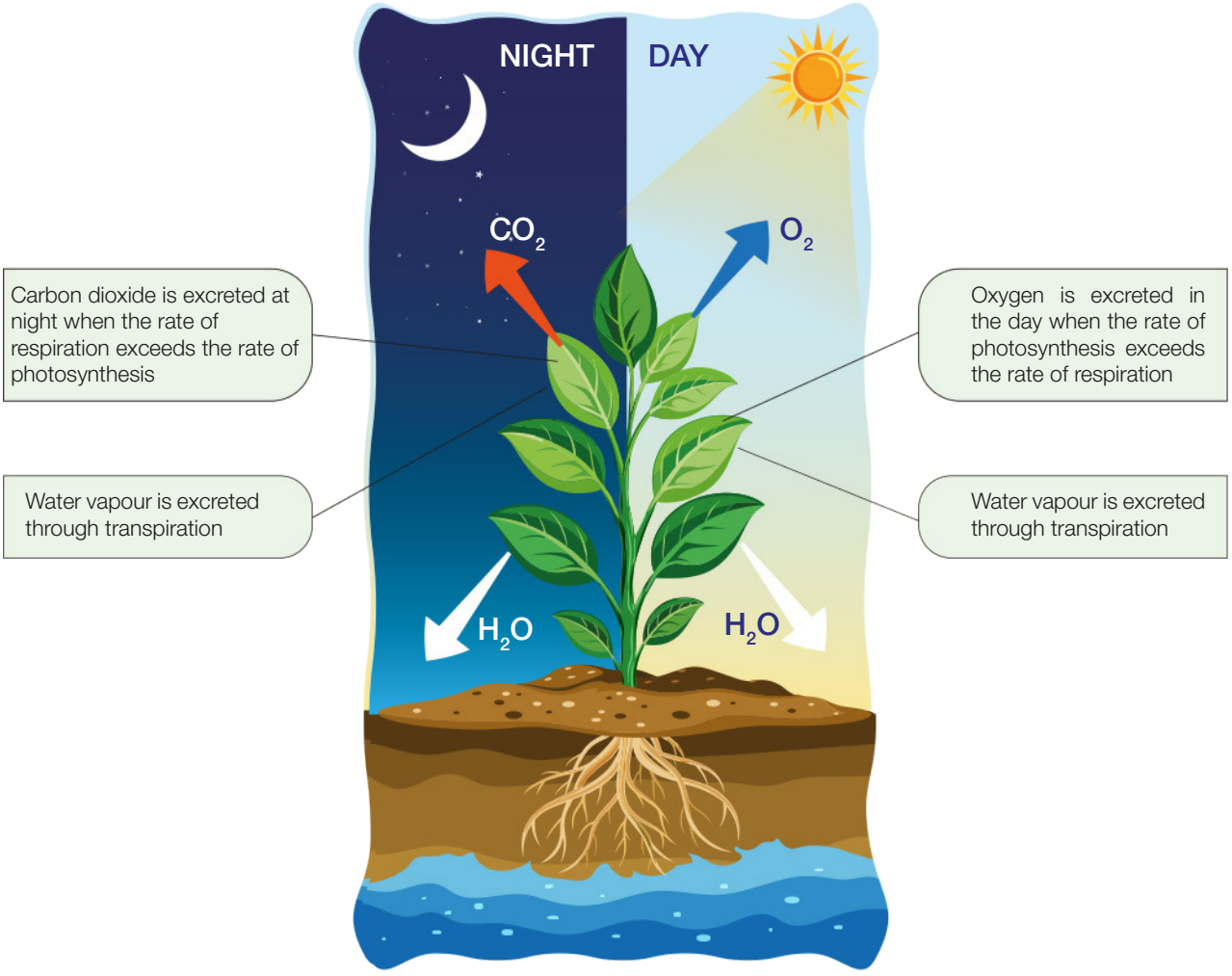


Figure 3.7.7: The nett excretion of gases from plants during the day and night.

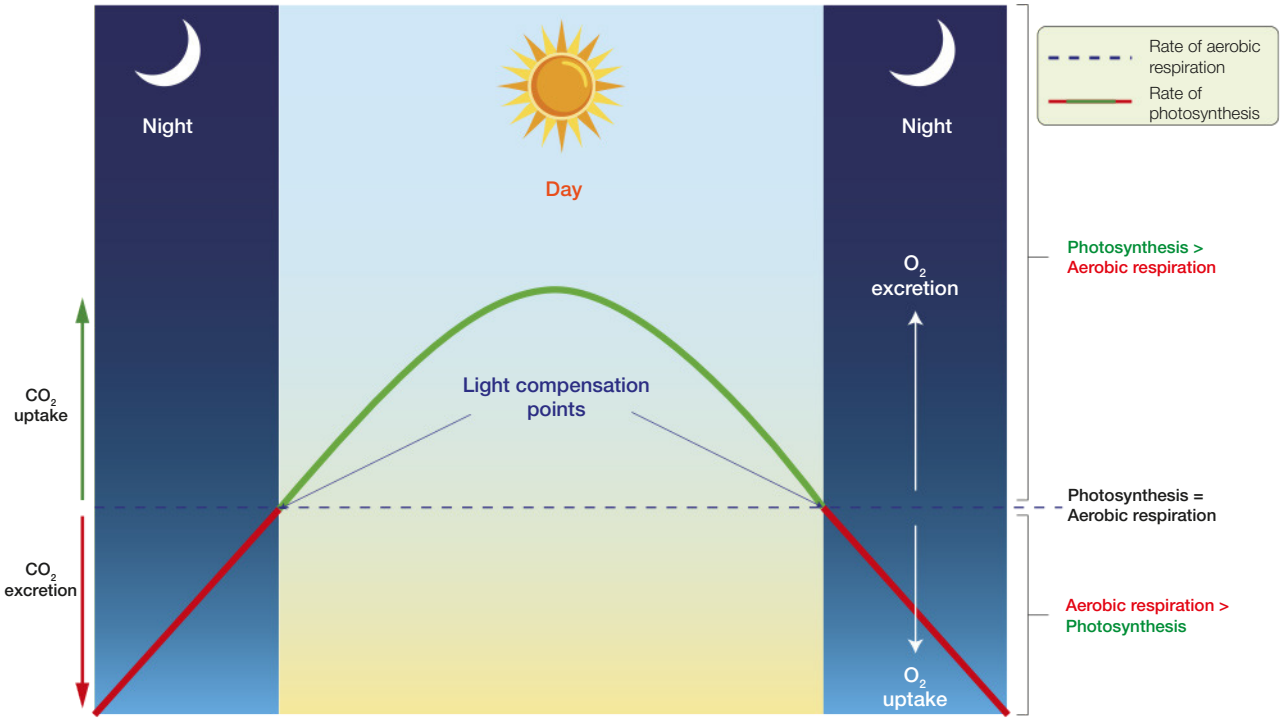


Figure 3.7.8: A graphical representation of the relationship between the rate of photosynthesis and aerobic respiration.

Leaf structure and gas exchange

In plants, the main site of exchange of gases between the external and internal environments is the leaf. As discussed earlier in this Chapter, the structure of the leaf facilitates gas exchange (see Table 3.7.5). Gases are exchanged via leaf structures called stomata. The movement of gases into and out of plants occurs through the passive process of diffusion.

Stomata

The leaves of vascular plants generally contain a large number of stomata (singular: stoma or stomate). A stoma is the pore, or space between two **guard cells** that are predominantly found in the lower epidermis of a leaf. The guard cells control the opening of that stomatal pore and as a result, gas exchange and water loss. The uneven distribution of the guard cells' cell wall plays a role in the opening and closing of the stomata. Guard cells have a thick inner cell wall and a thin outer cell wall. The **stomata open** when water availability is high and water moves into the guard cells by osmosis, causing them to become **turgid**. The thin outer walls of guard cells bend more easily than its thick inner cell walls, causing the guard cells to curve and the stomata to open. Stomata are generally open during daylight hours when there is sufficient sunlight and water. When stomata are open air can circulate in from the environment, but **water is lost via transpiration.**

In contrast, when water availability is low, the guard cells lose water by osmosis to their adjacent epidermal cells and become **flaccid**. This causes the **stomata to close** preventing the diffusion of gases through the stomata. Stomata tend to close when the sun sets and there is low light and water availability, **reducing water loss through transpiration.** To further reduce the loss of water, stomata are generally located on the underside of leaves where it is cooler so that less transpiration occurs**.**

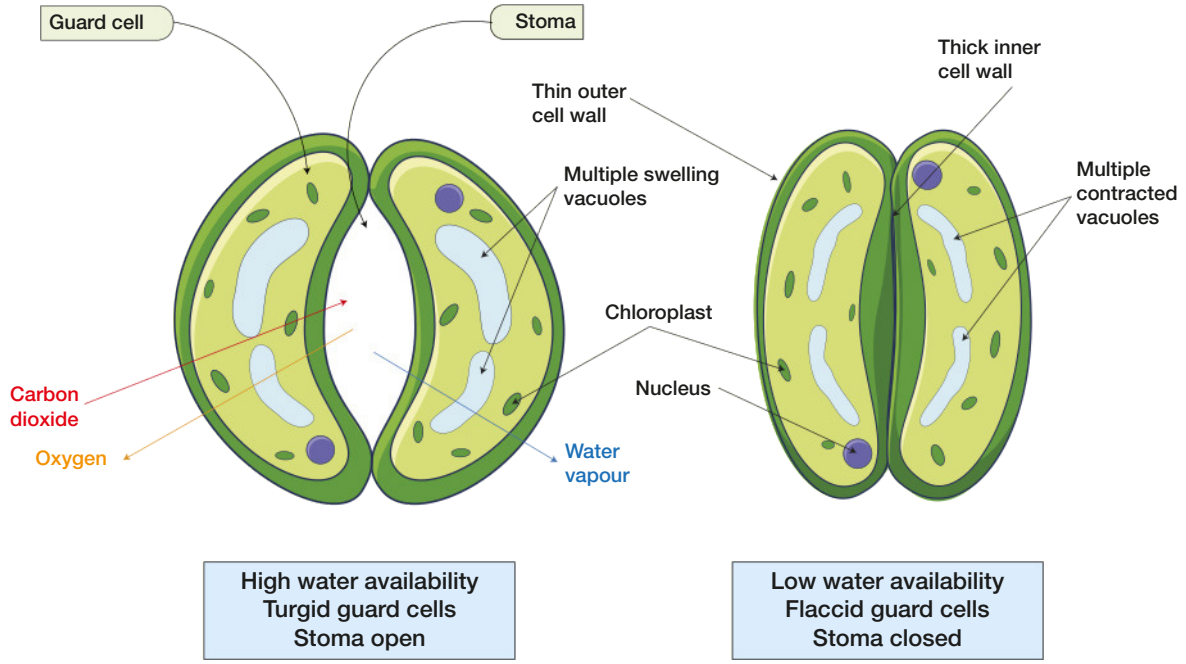


Figure 3.7.9: When there is high water availability the guard cells become turgid causing the stoma to open but when there is low water availability the guard cells become flaccid and the stoma closes preventing gas exchange through the stoma.

Helpful online resources

Free Animated Education: What is Transpiration in Plants?

<https://www.youtube.com/watch?v=5jJLfwTkGe8>

Diffusion of gases into and out of leaves

In daylight, carbon dioxide enters the air spaces in the mesophyll via the open stomata by diffusion. It then diffuses into chloroplasts in the mesophyll cells (see Figure 3.7.10). Oxygen that is produced by mesophyll cells during photosynthesis diffuses out of the mesophyll into the air spaces and then diffuses out of the leaf via the stomata.

Carbon dioxide diffuses into a leaf when mesophyll cells are photosynthesising. This causes carbon dioxide in the air spaces to remain at a concentration lower than in the outside air (see Figure 3.7.11). The result is that carbon dioxide diffuses from the outside air via stomata into the air spaces. The presence of air spaces permits the carbon dioxide concentration to increase enough for it to continue to diffuse into mesophyll cells.

Oxygen production by mesophyll cells during the day means the concentration of oxygen in the cells remains higher than in the air spaces, so oxygen diffuses into these air spaces. As the oxygen concentration in the air spaces rises, it then diffuses out through the stomata (see Figure 3.7.11).

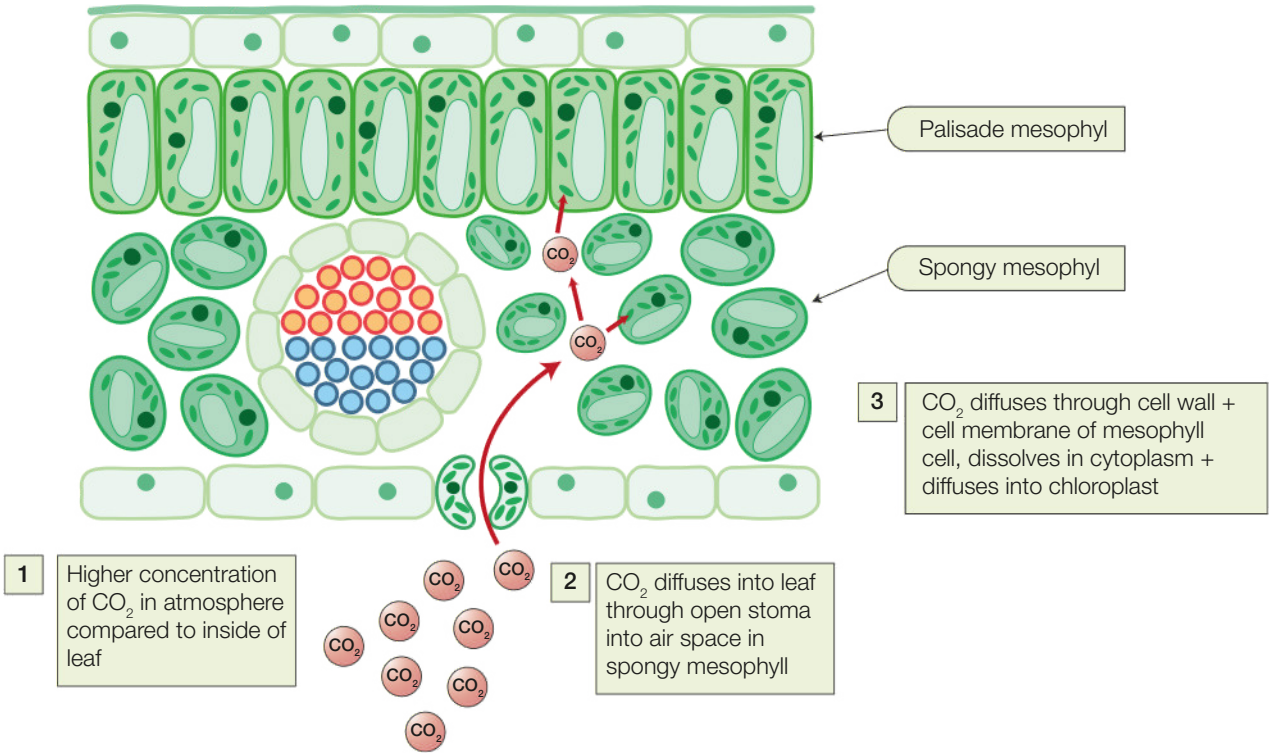


Figure 3.7.10: The diffusion of carbon dioxide to the chloroplasts of mesophyll cells for photosynthesis.

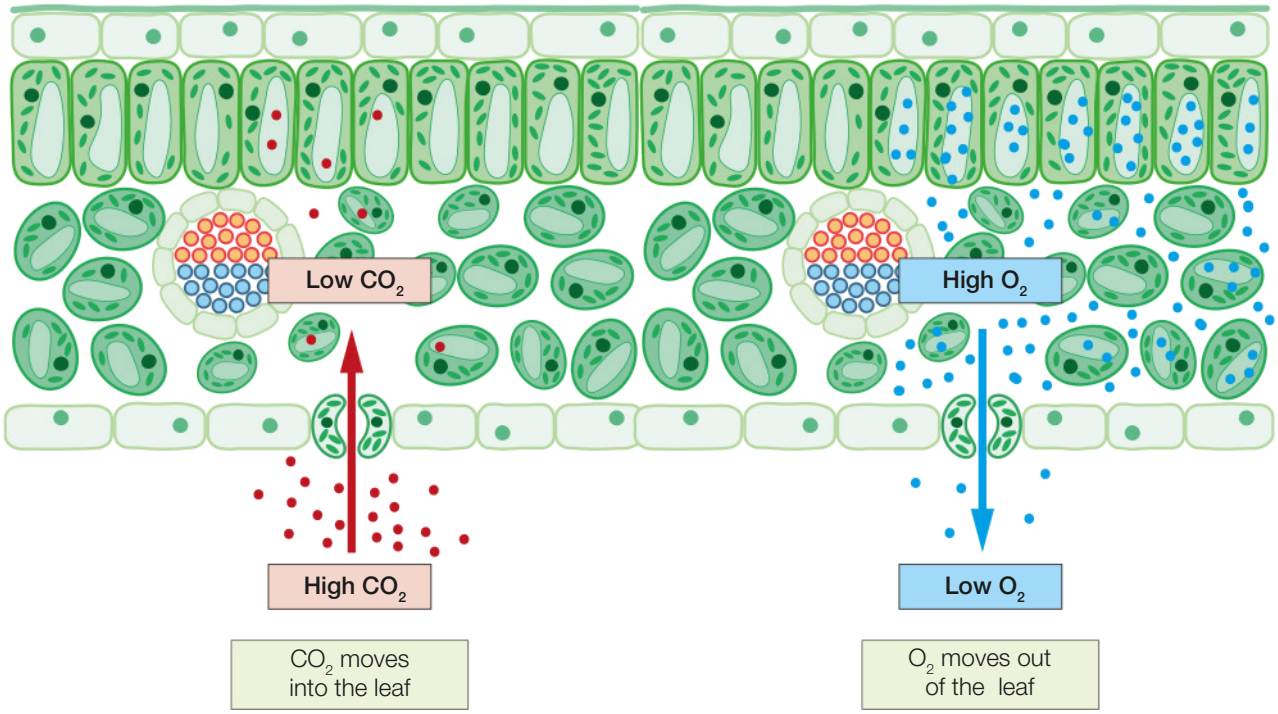
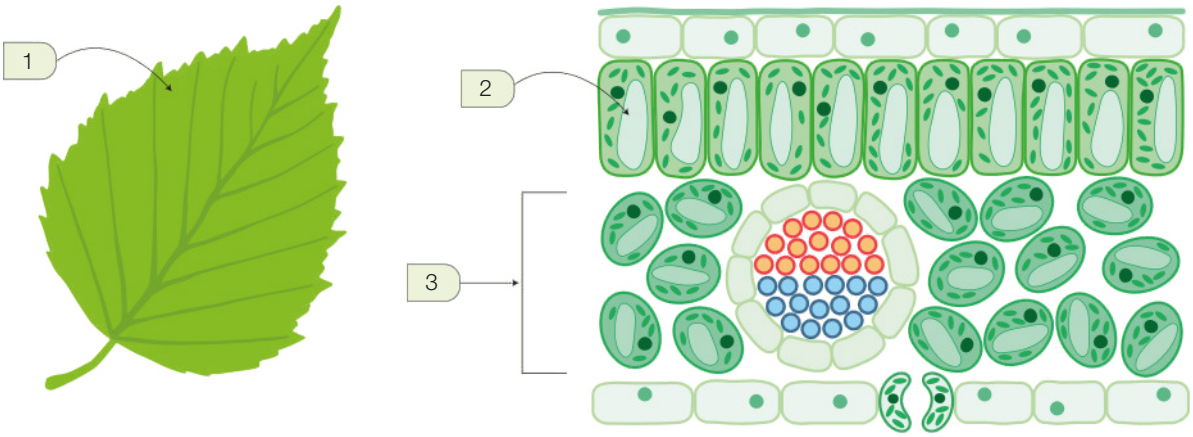


Figure 3.7.11: During the day, the photosynthetic cells in leaves require carbon dioxide as a reactant creating a low concentration inside the leaf compared the external environment and a net movement of carbon dioxide into the leaf. As oxygen is a product of photosynthesis and these cells do not use the amount produced, a high concentration of oxygen compared to the external environment is attained and a net movement of oxygen out of plant cells occur.

3.7 Review questions

Multiple choice questions

1. *Refer to the image below which shows a leaf and its internal structure to answer the following question.*



Identify the levels of organisation of the three labelled structures.

	1	2	3
J	Tissue	Cell	Organ
K	Organ	Cell	Tissue
L	Organ system	Tissue	Cell
M	Organ	Tissue	Organ system

2. *Refer to the image below showing how the leaves are arranged on a plant to answer the following question.*

The reason the leaves are arranged this way is

J so the leaves do not require stomata.
K because more insects will be attracted to the plant to eat its leaves.
L so that more light can reach the lower leaves.
M to increase water flow to the guard cells.

3. Which of the following options is not a plant organ?

J 

L 

K 

M 

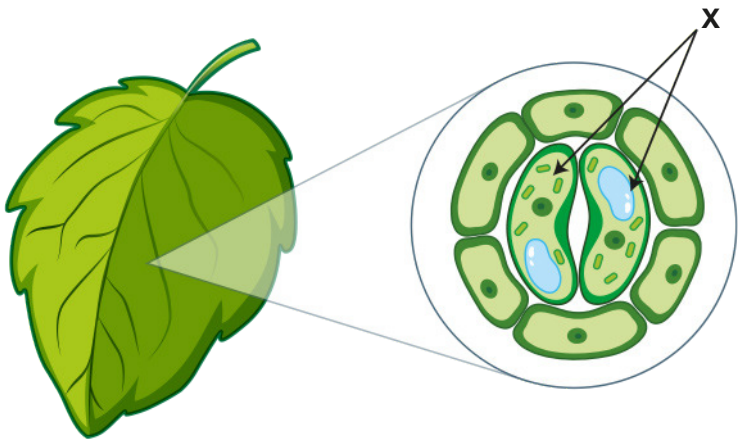
4. Blades of grass can re-grow after being mowed because

J meristem cells can continuously divide.
K specialised cells differentiate into new plant cell types.
L ground cells divide into root hair cells to increase nutrient uptake.
M specialised dermal cells replace the plant cells lost from being mowed.

5. Which of the following is **not** correct about a feature of a leaf?

J Leaves are thin to increase the efficiency of gas exchange.
K Specific cells have chloroplasts to absorb light energy for photosynthesis.
L The lamina of a leaf is broad to decrease its surface area to volume ratio.
M Spongy mesophyll cells are loosely packed to provide internal air spaces.

6. *Refer to the image below which shows some specialised plant cells to answer the following question.*



The vital function of the identified specialised cells identified by X is to

J excrete water to keep the plant hydrated.
K transport water to mesophyll cells for photosynthesis.
L control gas exchange.
M contain multiple smaller vacuoles.

7. Select the incorrect statement regarding photosynthesis and respiration in plants.

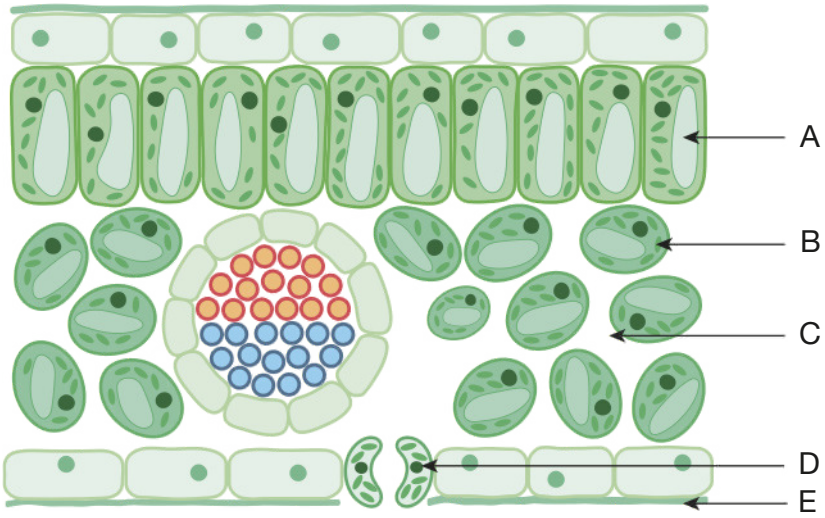
   J Oxygen is excreted in the day when the rate of photosynthesis is greater than the rate of respiration.

   K At low light the rate of photosynthesis and respiration can be the same resulting in no nett exchange of carbon dioxide and oxygen with the environment.

   L Carbon dioxide is excreted at night when the rate of respiration is greater than the rate of photosynthesis.

   M The rate of photosynthesis increases from sunrise to sunset and therefore so does oxygen excretion from plants to the atmosphere.

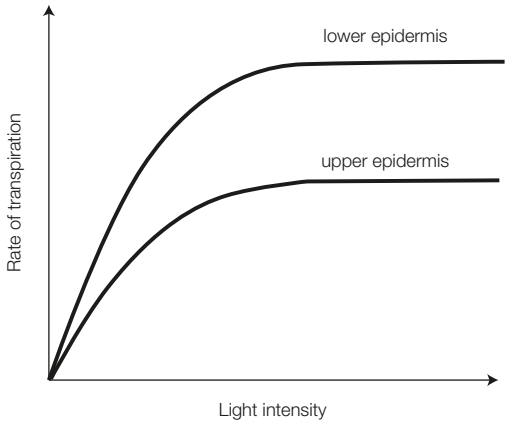
8. *Refer to the image below which shows the cross-section of part of a leaf to answer the following question.*



Identify the labelled structures.

	Structure A	Structure B	Structure C	Structure D	Structure E
J	Epidermal cell	Xylem	Air space	Ground cell	Cuticle
K	Spongy mesophyll cell	Palisade mesophyll cell	Stoma	Ground cell	Lamina
L	Palisade mesophyll cell	Spongy mesophyll cell	Air space	Guard cell	Cuticle
M	Vascular bundle	Phloem	Stoma	Guard cell	Lamina

9. *Refer to the graph below which shows the rate of transpiration at the lower and upper epidermis of a leaf as light intensity increases to answer the following question.*



The likely reason for the difference in the rate of transpiration is

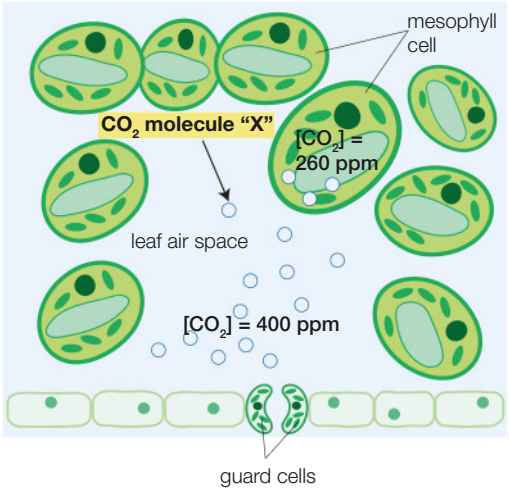
J the lower epidermis had flaccid guard cells.

K the lamina of the upper epidermis received less light and therefore less evaporation occurred.

L only the lower epidermis contains a waxy cuticle which prevents the evaporation of water.

M the upper epidermis does not contain any stomata.

10. *Refer to the image below which shows an internal section of a leaf and the concentration of carbon dioxide to answer the following question. Note that the square brackets around CO_2 represent "concentration."*



The movement of molecule "X" will likely be

J out of the leaf by diffusion because the guard cells are open.

K into a mesophyll cell by passive transport as the carbon dioxide molecules tend to follow the concentration gradient.

L out of the leaf by diffusion because the concentration of carbon dioxide in the atmosphere is higher than in the leaf air space

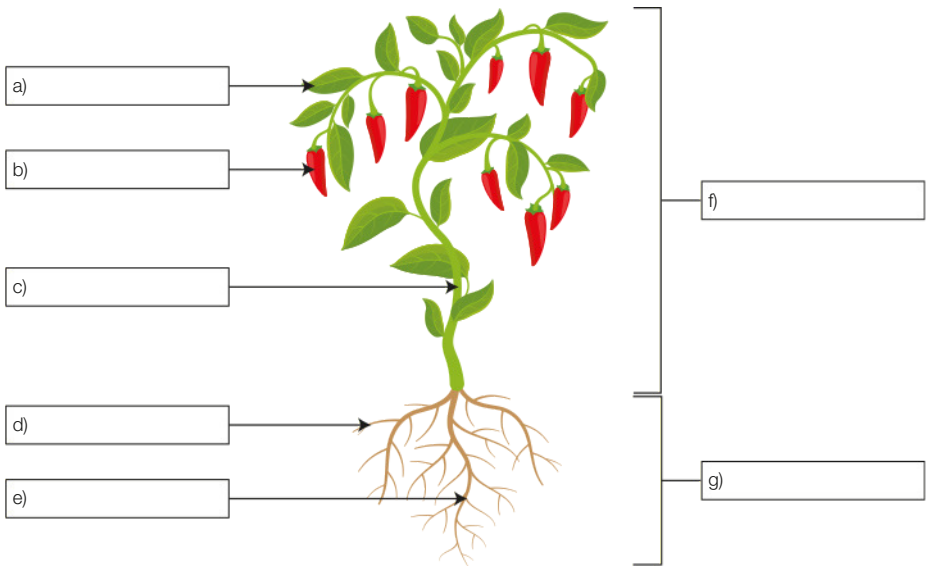
M into a mesophyll cell from an area of high concentration in the leaf air space to low concentration inside the mesophyll cell by active transport.

Free response questions

1. Identify the three types of tissue that plant organs consist of and describe the main function(s) of each type using the table below.

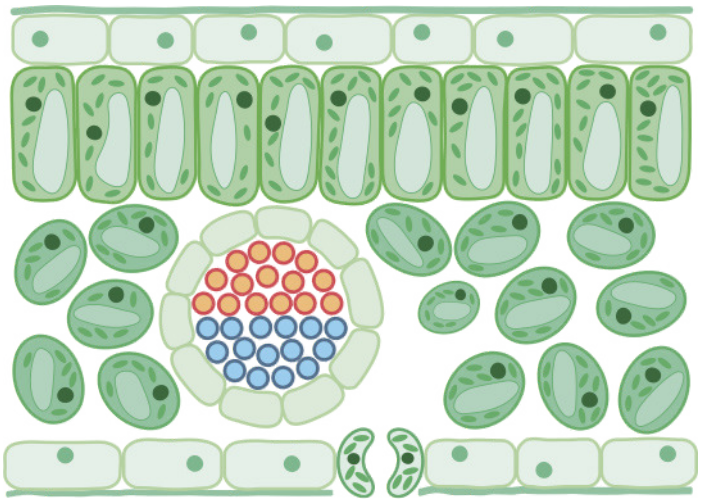
Tissue	Function(s)

2. Label the organs and organs systems of the chili plant pictured below:



3. Label the listed internal structures of a leaf using the cross-section diagram below:

a) Upper epidermis
b) Lower epidermis
c) Vascular bundle
d) Palisade mesophyll cell
e) Spongy mesophyll cell
f) Waxy cuticle
g) Guard cell
h) Internal air space



4. a) Identify the three cell types in leaves that contain chloroplasts.

b) Identify the reactants for photosynthesis **and** describe how plants obtain the reactants for this process.

5. Explain how palisade cells have adapted to suit their function.

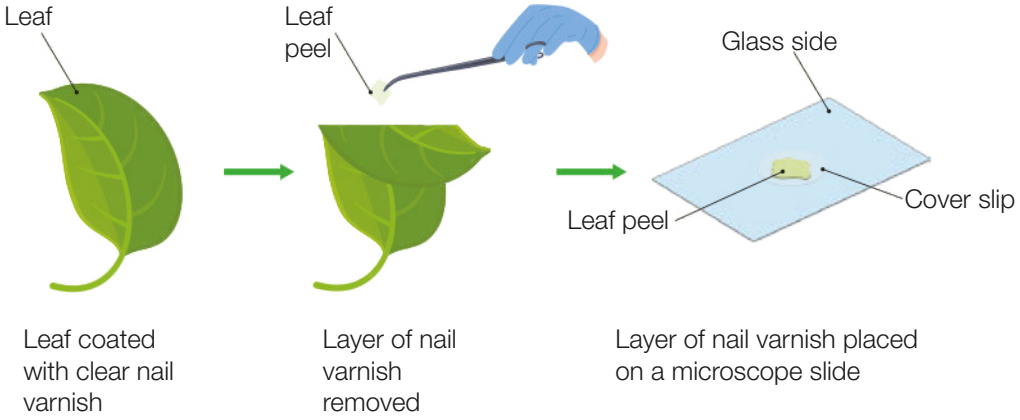
6. a) Identify the **two** main functions of leaves.

b) Explain the difference in uptake and excretion of gases by plants during the day and at night.

7. During the summer, many species of Eucalyptus drop some of their leaves. Explain how this adaptation can provide a survival advantage for these plants.

8. Leaves of plants that reside closer to the ground in tropical forests usually have a very large surface area and are very dark green in colour. Explain how these features assist these plants to survive.

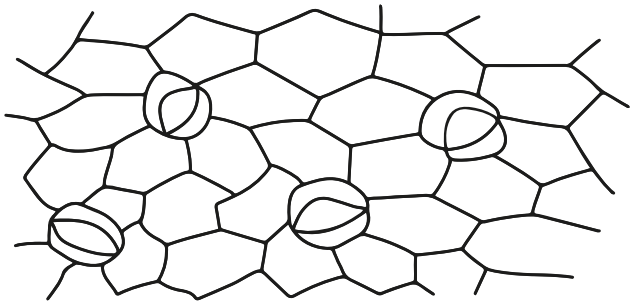
9. A student completed a leaf peel from the underside of a leaf as shown in the diagram below:



The layer of nail varnish shows an impression of the cells on the underside of the leaf.

a) Explain the function of stomata in leaves.

The student sketched a biological drawing of a section of the leaf peel viewed using a light microscope.



b) State the number of stomata in the students' sketch.

c) State the number of guard cells in the students' sketch.

The student recorded the following data from viewing the leaf peel from the underside of a leaf:

Number of stomata viewed	Number of stomata open	Number of stomata closed
30	24	6

d) Calculate the percentage of stomata that were open.

e) Complete the table below by adding a yes or no for each of the four processes to identify which are associated with the stomata opening and closing.

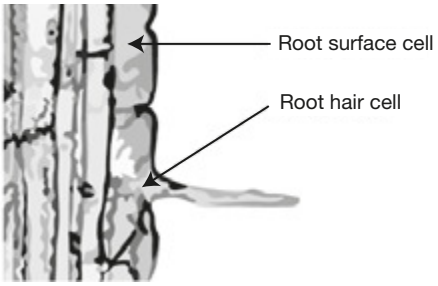
	Water moves into guard cells	Water moves out of guard cells	Cell becomes flaccid	Cell becomes turgid
Stomata open				
Stomata closed				

The student also completed a leaf peel on the upper surface of the leaf using the same process but found that no stomata were present.

f) Explain why the student observed stomata on the lower surface of the leaf but not the upper surface of the leaf.

g) Explain how the cell wall structure of guard cells aids their function.

10. *Refer to the image and table below which some root cells viewed using a light microscope and the surface area and volume of the two labelled cells to answer the following questions.*



Type of cell	Surface area (mm^2)	Volume (mm^3)	Surface area to volume ratio (SA:V)
Root surface cell	4000	204,000	
Root hair cell	37,000	222,000	

a) Use the data in the table to calculate the surface area to volume ratios of the two labelled root cells.

b) Using data from part a), explain how the structure of root hair cells aid their function.

c) Explain why root hair cells do not contain any mesophyll cells.

Chapter 3.8 Transport of materials in plants

Science Understanding

In plants, the uptake of nutrients and water is facilitated by the structure of the root system.

In plants, waste material may be removed or stored.

In plants transport of water and mineral nutrients from the roots occurs via xylem involving:

- root pressure
- transpiration
- cohesion of water molecules
- osmosis

Explain how water moves in, through, and out of a plant.

Transport of the products of photosynthesis and some mineral nutrients occurs by translocation in the phloem. They may be stored for later use.

Describe the transport and storage of materials in plants.

The root system

The root system of a plant consists of a collection of structures that usually grow down into the soil called roots. The roots are in contact with the soil solution which contains water and dissolved mineral nutrients (see Figure 3.8.1). The uptake of water and mineral nutrients is facilitated by the structure of the root system, which has an **enormous surface area**. As discussed in Chapter 3.7, there are two types of root systems in vascular plants, the taproot system and the fibrous root system (refer back to Figure 3.7.3).

A major type of vascular plants are flowering plants. There are two types of flowering plants, monocotyledons (monocots) and dicotyledons (dicots). Dicots have a root system that consists of a central root called the taproot, from which several secondary roots, called lateral roots, branch from. Some examples include roses and eucalypts. Monocots do not have a taproot. Instead, the monocot root system consists of many shallow, fibrous roots that extend from the base of the stem, for example, grasses. Additionally, the root tips of both monocots and dicots contain large numbers of cells with an extension called **root hair cells**. Both the large numbers of root hair cells and extensively branched root systems of monocots and dicots contribute to the enormous surface area of their root systems. Refer to Figure 3.8.2 for an overview of some major differences between monocots and dicots.

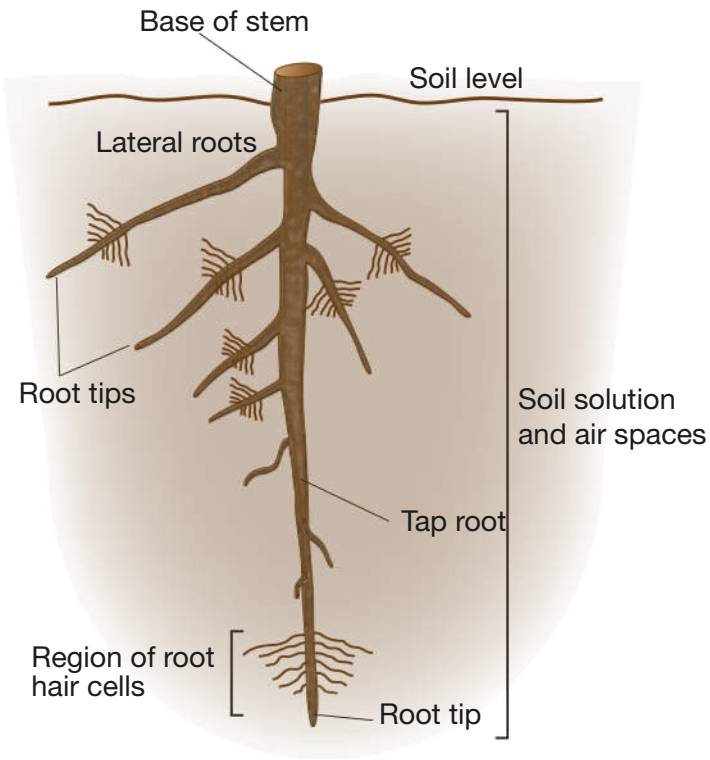


Figure 3.8.1: The structure of a dicot root system.

In addition to taking up dissolved mineral ions, water and oxygen, the root systems of some plants store sugar produced during photosynthesis in swollen roots and underground stems called **tubers**. The sugar is stored as a complex carbohydrate called **starch** in cells that make up the tuber. Carrots, turnips and beetroot are root tubers. The most common example of a stem tuber is the potato.

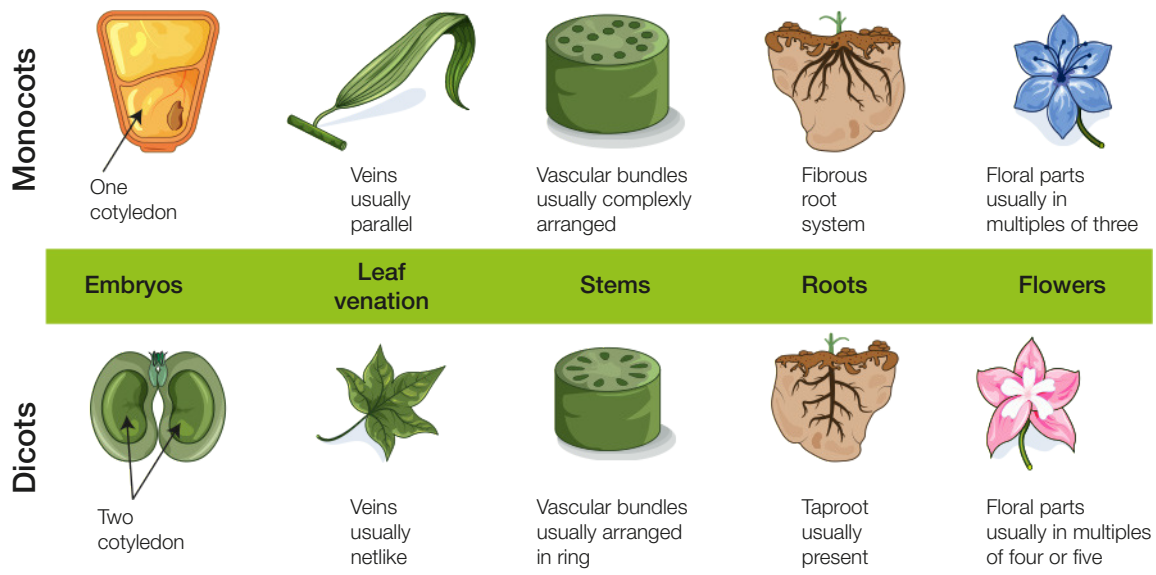


Figure 3.8.2: A comparison of some structural features of monocots and dicots.

Xylem and phloem

The xylem and phloem are transport vessels that are arranged in groups called vascular bundles (see Figure 3.8.3). Xylem and phloem tubes extend from the roots, through the stem and up to and through the leaves.

Xylem are involved in the **unidirectional passive transport** of water and mineral nutrients from the roots to other parts of the plant. The continuous upwards flow of water in the xylem vessels is known as a **transpiration stream**. Xylem vessels are long, hollow tubes consisting of fused **dead cells** with no cell contents. The cells are arranged end to end and have no cell walls between cells, forming a continuous tube that water can move through (see Figure 3.8.4). They have tough walls containing a woody material called **lignin** that thickens the vessels and helps xylem withstand the pressure of the water movement. Lignin is deposited in a spiral-shape to allow them to remain flexible.

Phloem transport organic molecules such as sucrose and amino acids synthesised by the plant. These molecules are transported to the growing parts of the plant and to the storage organs such as tubers in a process called **translocation**. The flow of molecules in the phloem is therefore **bidirectional** (up and down the phloem tubes). Phloem vessels consist of **living cells** that do not have nuclei, but do contain and porous **sieve plates** at either end of each cell so that the cytoplasm of adjacent cells are connected and molecules can move through them. Transport of molecules in the phloem **requires energy**. Each sieve tube is attached to one or more companion cells that provide this energy.

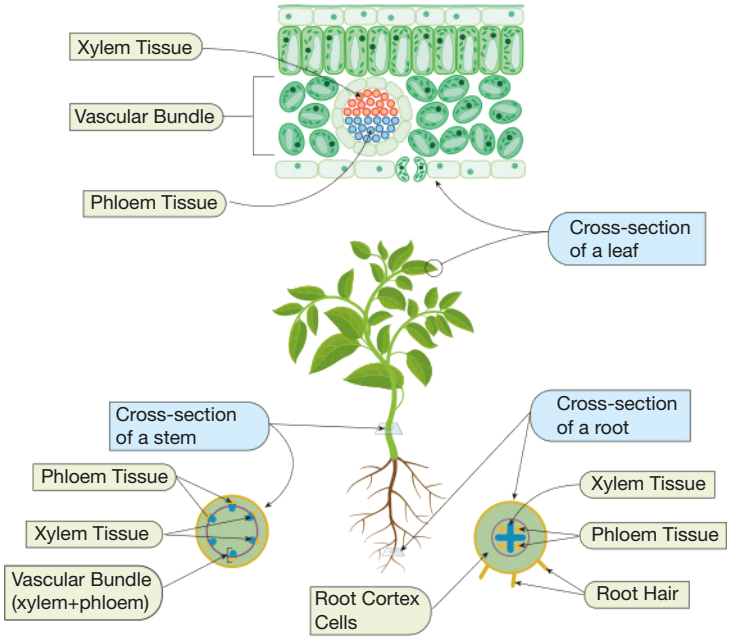


Figure 3.8.3: Cross sections of the three major organs in a dicot plant highlighting the location of xylem and phloem.

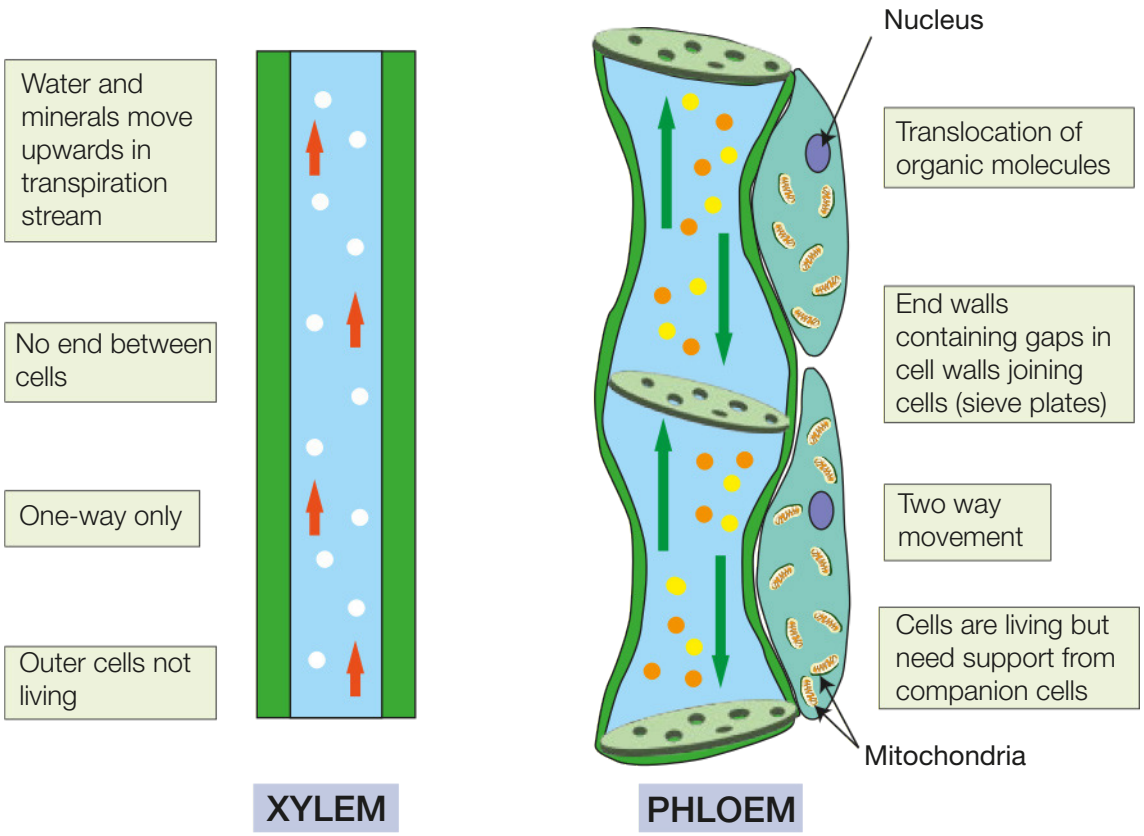


Figure 3.8.4: A comparison of the structures and functions of xylem and phloem vessels.

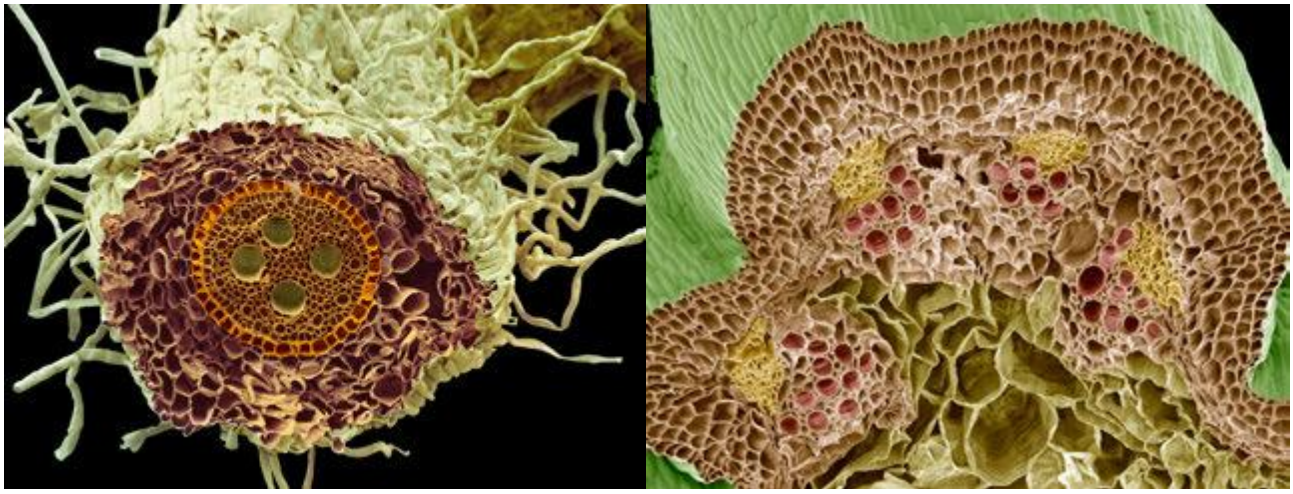


Figure 3.8.5: Scanning electron micrographs of vascular tissue in a root (left) and stem (right). In the root, the xylem is seen as the four yellow circles and the phloem surrounds them. The root hairs on the surface of the root are also clearly visible. In the stem, the vascular tissue is arranged in bundles with the xylem (pink) on the inner and phloem (yellow) on the outer edge.

Helpful online resources

Free Animated Education: Xylem and Phloem - Transport in Plants

<https://www.youtube.com/watch?v=DhyYtT1K844>

Diffusion, osmosis and active transport

Diffusion is the nett movement of a substance from a region of higher concentration to a region of lower concentration, until the two regions have an equal concentration of the substance. Diffusion is a **passive process** because it occurs without any additional input of energy.

Water moves by a process called osmosis that is also **passive**. The direction water moves is affected by the concentration of substances dissolved in it called solutes. Osmosis is the net movement of water from a region of lower solute concentration to a region of higher solute concentration until the two regions have an equal solute concentration. Another way to describe osmosis is the net movement of water from a more dilute region to a region that is less dilute, or more concentrated.

The nett movement of a substances from a region of lower concentration to a region of higher concentration is called active transport. The process is active because it only occurs across cell membranes when cells make additional energy in the form of ATP available. For more information on these processes, refer to Chapter 1.5: The cell membrane.

Uptake of water and mineral nutrients

The soil plants grow in contains air spaces and a dilute solution of water with a range of substances dissolved in it. This mixture is called the soil solution. Plants take up water by **osmosis** and mineral nutrients from the surrounding soil solution by **active transport**. Minerals are dissolved in the soil solution and exist in a charged form called an ion. Mineral ions taken into plants include nitrate, phosphate and potassium ions. The uptake of ions is carried out by the roots. Additionally, oxygen in soil air spaces is taken up by roots by **diffusion**.

Helpful online resources

FuseSchool – Global Education: Transpiration - Transport in Plants

<https://www.youtube.com/watch?v=Kv_0udatlh8&t=115s>

Transport of water and mineral nutrients via xylem

The lower solute concentration of the soil solution ensures water enters root hair cells in the epidermis by osmosis. Mineral ions are actively transported from the soil solution across root hair cell membranes. Once in the epidermis, **most water flows by osmosis to xylem vessels** in the inner root between spaces in the root cell walls (see Figure 3.8.6). Most minerals reach xylem vessels carried in this flow of water. The movement of water into **xylem vessels** generates an upward push on the fluid they contain called **root pressure** (see Figure 3.8.7).

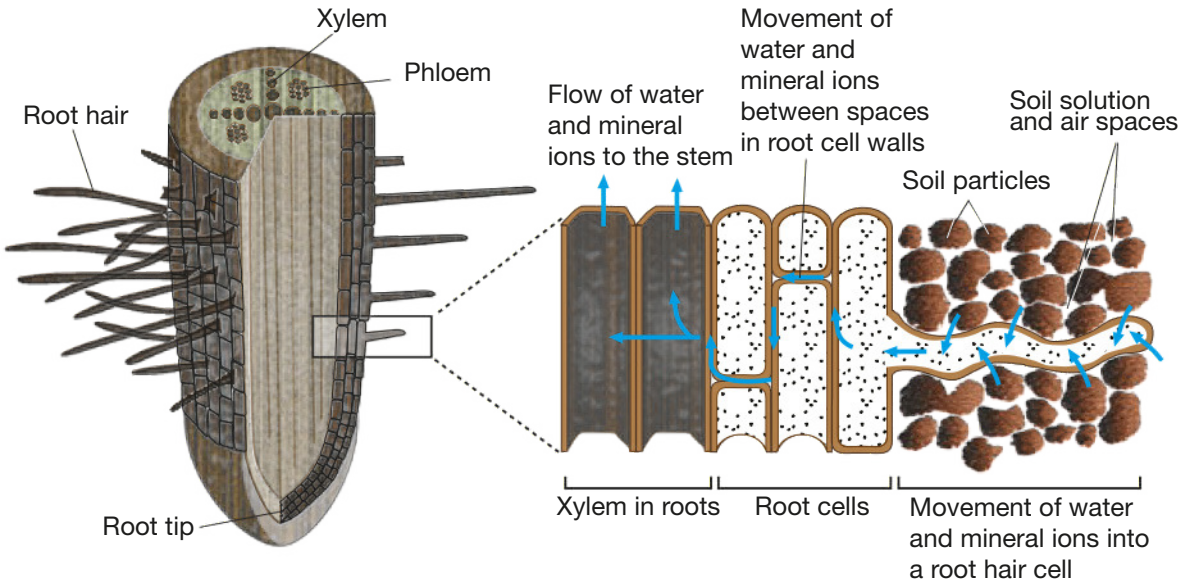


Figure 3.8.6: Water and minerals in the soil solution are absorbed and transported through root cells into xylem vessels as a result of root pressure.

Once they have entered the xylem, water and dissolved minerals are transported to the mesophyll tissue in leaves within the continuous end-to-end columns of xylem vessels. This upward flow is called the **transpiration stream** (see Figure 3.8.7).

The push of water into the xylem due to root pressure alone is insufficient to generate the transpiration stream. Instead, it is mostly a product of a strong upwards pulling force within plants. This is generated because water in the mesophyll tissue of the leaves **evaporates** during the day and forms water vapour. As was discussed in Chapter 3.7, leaves have structures in the lower epidermis called stomata. These are usually open during the day and function to exchange gases. The water vapour produced by evaporation diffuses out of leaves through the stomata, into the air. The release of water vapour from leaves in this way is called **transpiration** (see Figure 3.8.7).

The force that pulls water, and the dissolved minerals it contains, up to leaves from the roots is called the **transpiration pull**. To understand how this transpiration pull causes water to move upwards in this way it is important to know that water molecules weakly attract one another. This force of attraction is called **cohesion** (see Figure 3.8.8). As a result of cohesion, water in xylem vessels occurs in long unbroken chains. The flow of water and mineral nutrients up the xylem vessels is also assisted by attraction between water molecules and the walls of the xylem vessels. This force of attraction is called **adhesion**, which ensures that there are no air bubbles or spaces inside the xylem vessels (see Figure 3.8.8).

As water evaporates from mesophyll cells a region of low pressure is generated inside them. This causes water in nearby xylem vessels, now at a higher pressure, to move towards the mesophyll cells. As a result of this and cohesion, water is pulled up xylem vessels and passes into mesophyll cells. During the day there is constant pulling of water up the xylem vessels. The higher solute concentration in root cells ensures that the water keeps moving into the roots by osmosis from the lower solute concentration in the soil solution.

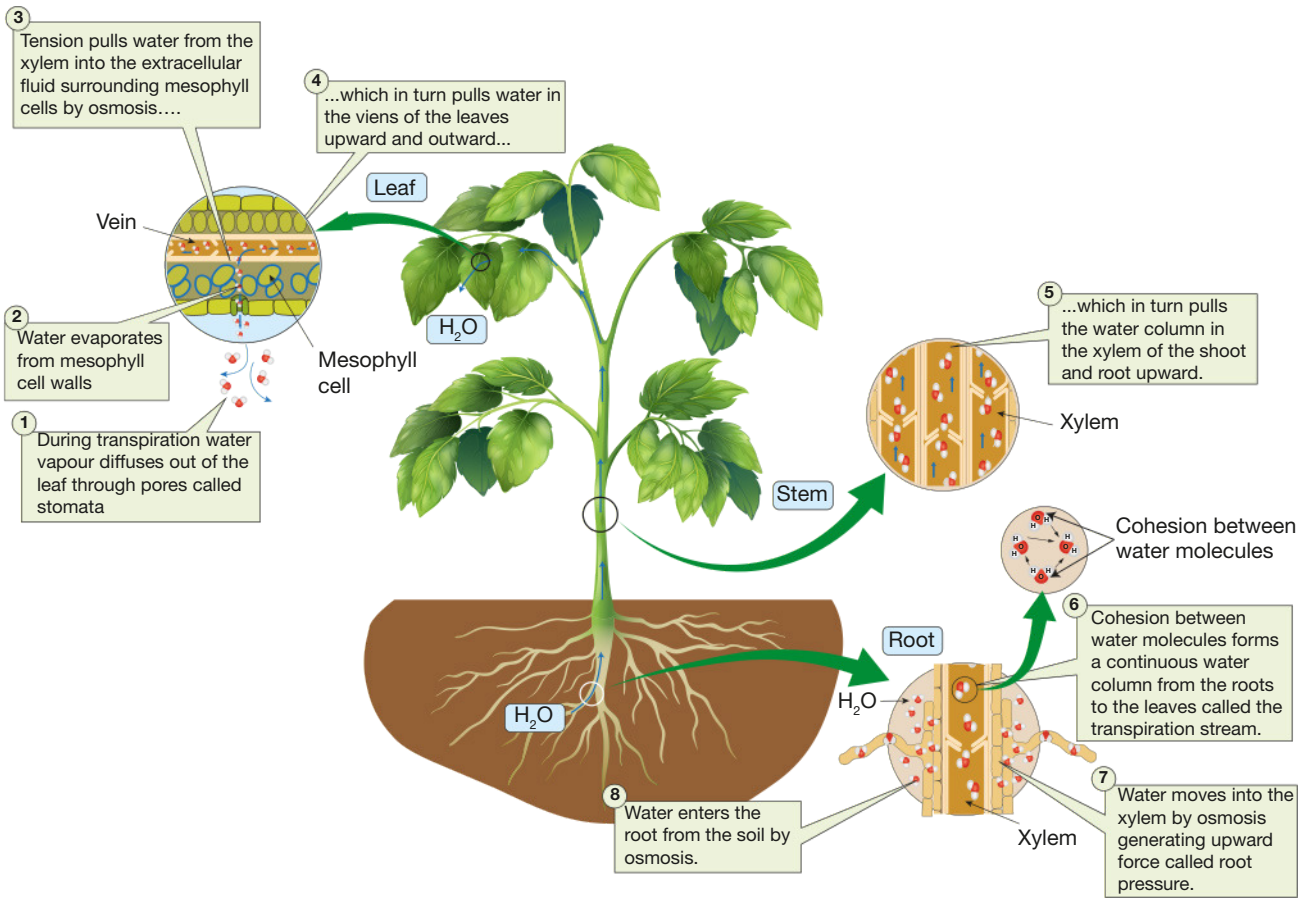


Figure 3.8.7: How water moves in, through, and out of a plant.

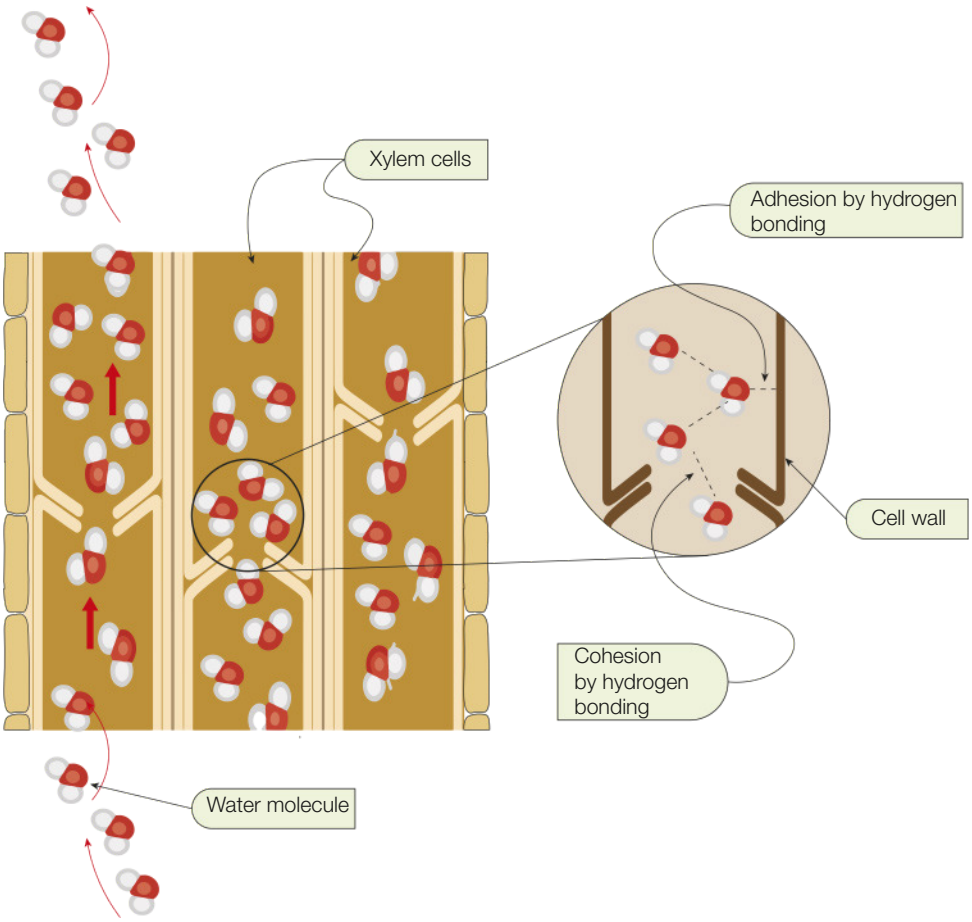


Figure 3.8.8: The cohesion forces between water molecules and adhesion forces between water molecules and the xylem cell walls play a large role in the continuous transpiration stream.

Helpful online resources

Free Animated Education: Plant Nutrition: Mineral Absorption | Part 1

<https://www.youtube.com/watch?v=iphOwk3yn10>

Free Animated Education: Plant Nutrition: Mineral Absorption | Part 3

<https://www.youtube.com/watch?v=aHEEAFFBA6Q>

Dealing with waste products

Metabolic reactions generate waste products that must be removed by organisms. The term waste is also used to refer to non-useful substances. Some plants, particularly trees, 'remove' non-useful substances by storing them in dead woody tissue in the middle of the trunk. Trees may also store wastes within leaves or bark which are lost to the ground from time to time.

In all plants, the carbon dioxide waste produced by aerobic respiration is excreted by diffusion. When plants are not photosynthesising, carbon dioxide is excreted out of leaves via stomates. Carbon dioxide produced by all the cells in the stem of woody shrubs or tree trunks is excreted through tiny pores called lenticels. In roots, excretion of carbon dioxide occurs via the epidermis.

Plants living in environments that are salty need to excrete salt due to the large quantity of it that is transported to their leaves in the transpiration stream, such as mangroves and saltbush. Some species of mangroves store salt in the vacuoles of cells in certain leaves where it accumulates before it exits the plant by leaf fall. Others have leaves with salt glands that pump salt out of the leaf by active transport where it forms salt crystals that are blown or washed away (see Chapter 4.3: Adaptations for more information on mangroves).

Translocation in phloem

Only three cell types in plants can perform photosynthesis to produce glucose, palisade mesophyll cells, spongy mesophyll cells and guard cells. These three cell types are predominantly found in leaves. Other cell types and other parts of plants that do not perform photosynthesis require sugar to be transported to them by the phloem.

The immediate organic product of photosynthesis is glucose, but additional organic molecules can be synthesised by plant cells using glucose as a reactant and specific enzymes. A prime example is the synthesis of another simple sugar called **sucrose**, which is a glucose molecule and fructose molecule chemically bonded together. Another example is **amino acids.** Plants synthesise amino acids, that are required to make proteins, by combining glucose with nitrogen minerals absorbed from the soil through a range of different metabolic pathways. Collectively, the products of photosynthesis, whether immediate or further processed are called **photosynthates**. The structures of plants that can produce photosynthates are called **sources**. The structures in plants that photosynthates are delivered to are called **sinks**. Transport of the some of these photosynthates in solution, also known as sap, in the phloem is called translocation. Sap generally contains water, some mineral nutrients and the organic molecules sucrose and amino acids. Most sugar made by photosynthesis is translocated as sucrose, which is actively transported out of mesophyll cells and then diffused through the extracellular fluid to the phloem (see Figure 3.8.9).

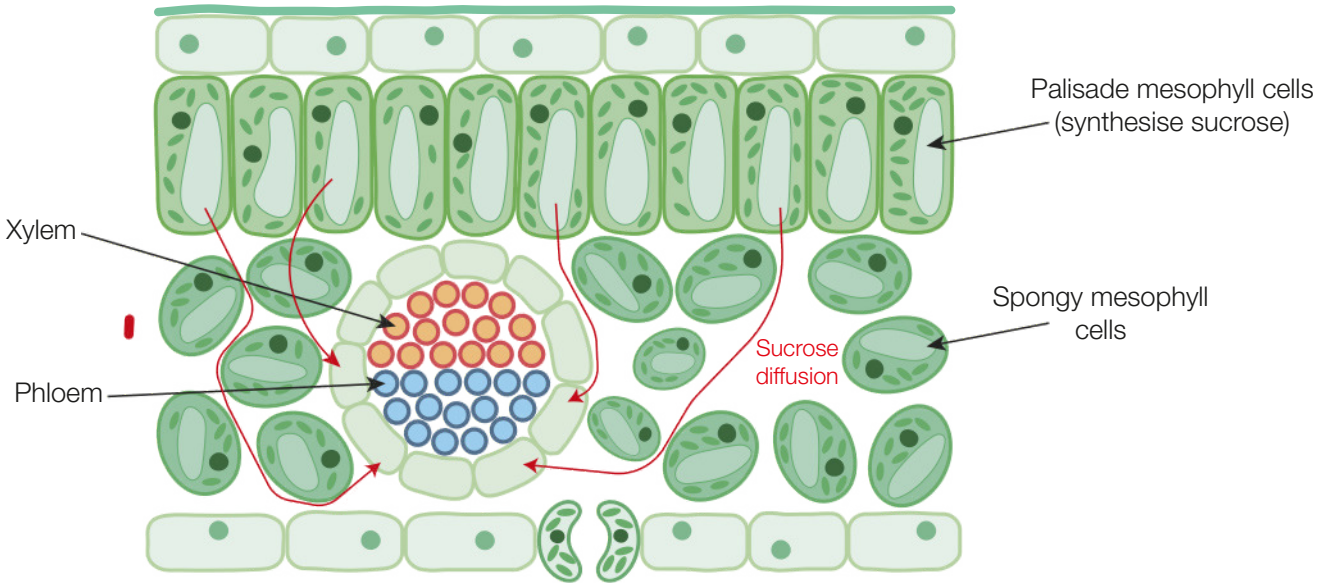


Figure 3.8.9: Photosynthesis produces glucose, but mesophyll cells can convert glucose into another simple sugar called sucrose (table sugar) and actively transport it into the extracellular fluid, where it diffuses into the phloem.

As a result of sap entering the phloem sieve tubes in leaves, the solute concentration in the sieve tubes increases, which causes water to move into them from mesophyll cells by osmosis. The movement of water into phloem sieve tubes raises the pressure of the phloem sap in the leaves, which forces it to move towards a region of lower phloem sap pressure, in this case, towards the roots. Once in the roots, sugar is pumped out of phloem sieve tubes into roots cells by active transport where it is converted to another photosynthate starch for storage. Some water follows by osmosis which helps to maintain the phloem sap pressure gradient. The remaining water flows into the xylem where it is returned to mesophyll cells via the transpiration stream (see Figure 3.8.10).

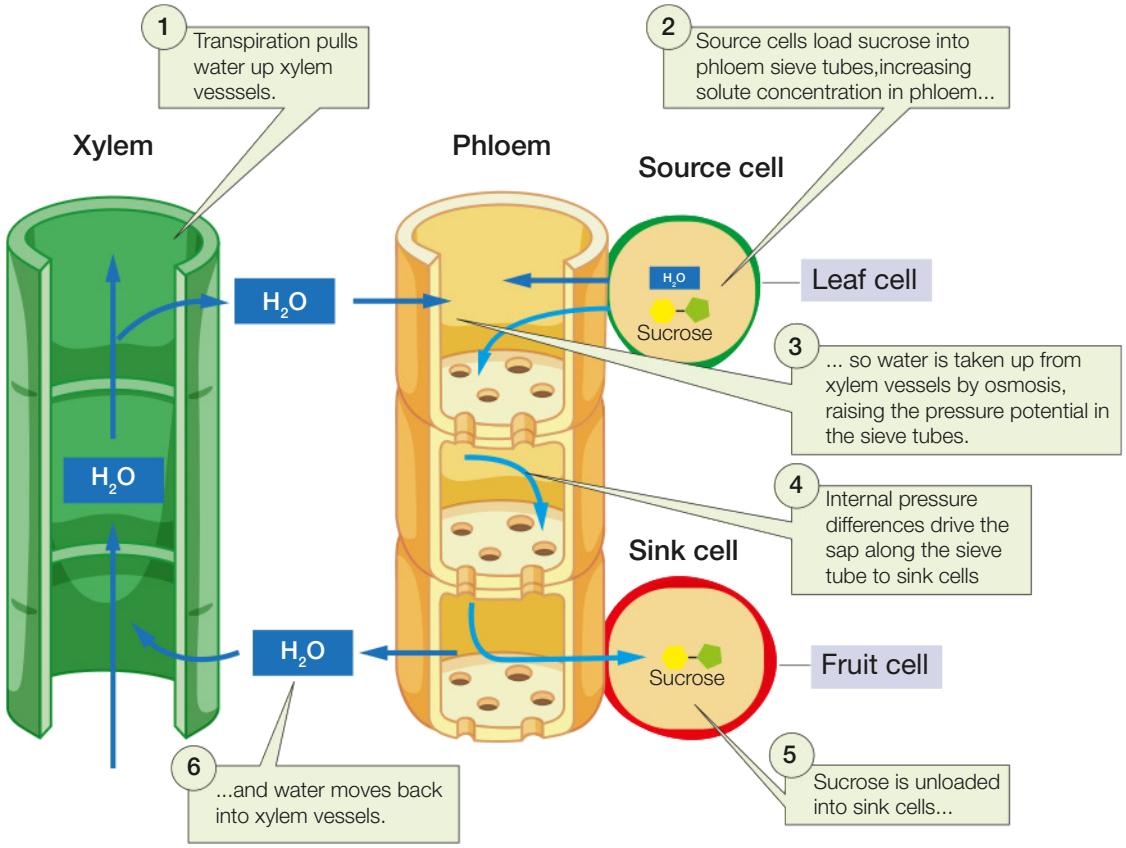


Figure 3.8.10: Transport of the products of photosynthesis and some mineral nutrients occurs by translocation in the phloem and can be stored for later use in sinks such as tubers.

Helpful online resources

GCSE Biology: Transport in plants - Translocation (Phloem) and Transpiration (Xylem)

<https://www.youtube.com/watch?v=9FTafxnbwHQ&t=8s>

Use and storage of sugar produced by photosynthesis

As discussed earlier, the products of photosynthesis can be used immediately as a source of energy or stored as starch for later use. Starch is often stored in tubers but may also be stored in shortened below-ground stems, usually called bulbs, such as daffodil bulbs and onions.

The transport of sugars in the phloem, usually dissolved sucrose, can occur from where it is made (sources) to where it is stored (sinks) or the opposite direction. The direction of flow depends on the time of the year, weather and stage of the plant's development. For example, in spring, the sinks become the sources and their stored starch is often broken down and converted to sucrose for translocation to areas of growth. Once there, it is converted to glucose to be used in aerobic respiration. This is evident in flowering plants, where leaves and flowers are growing, and fruits and seeds are developing in spring. In this example, the tubers and bulbs become the sources and provide sugars to the flowering parts of the plant that become the sinks. Following this growth period, generally in summer, the leaves have abundant sunlight and produce large quantities of sugars through photosynthesis. The leaves become the sources and dissolved sucrose is translocated to the roots (sinks) to store the excess as starch.

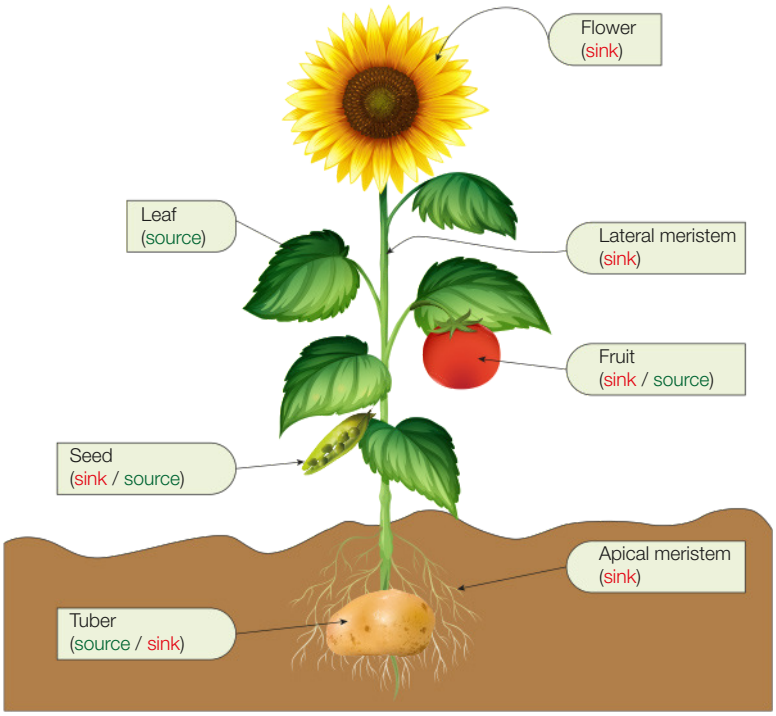


Figure 3.8.11: The leaves of plants are sources of sugars through photosynthesis and supply sugar to other parts of the plant for use and storage, also known as sinks. Sinks can become sources of sugars for plants when required by breaking down the stored starch into simple sugars that can translocate up or down the phloem as required. Note that the meristems are parts of the plant that can continuously divide and differentiate to create new plant tissue and therefore they are 'sinks' as the energy is stored in the new tissue.

3.8 Review questions

Multiple choice questions

1. Translocation in plants transports
   - J sucralose
   - K starch
   - L glucagon
   - M sucrose
2. Phloem
   - J are continuous hollow tubes.
   - K only carry water and mineral nutrients.
   - L consist of fused dead cells and are involved in bi-directional transport of materials.
   - M require energy to transport sap from a source to a sink.
3. Which of the following options best suggests how xylem provide support to plants?
   - J Xylem contain sieve plates.
   - K Xylem walls contain lignin.
   - L Xylem contain companion cells.
   - M Xylem facilitate unidirectional transport of water and minerals.
4. Tubers
   - J are known as sinks that can synthesise and store glucose independently.
   - K store sugars as glycogen.
   - L can be sources of sugars for periods of increased plant development and growth.
   - M translocate starch to other parts of the part through the phloem when required.

5. Water helps move sugars through the phloem by

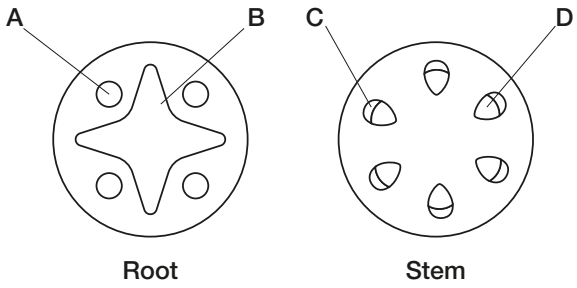
   J evaporating through the stomata, resulting in a transpiration pull of water and sugars through the phloem.

   K entering the phloem, which causes pressure to build up and the sugars to move from the phloem to the xylem.

   L dissolving the sugars allowing them to be carried with the water as it moves through the phloem.

   M providing the energy for sugars to be actively transported from an area of low concentration to an area of high concentration.

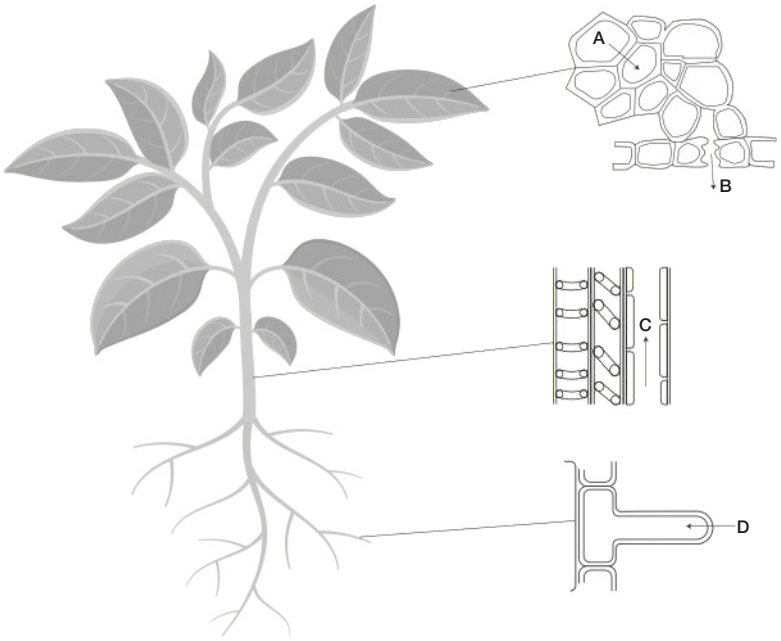
6. *Refer to the image below which shows cross-sections of a root and stem of the same plant to answer the following question.*



Which of the following options correctly identifies the xylem and phloem in both the root and stem cross-sections?

	A	B	C	D
J	Xylem	Phloem	Phloem	Xylem
K	Xylem	Phloem	Xylem	Phloem
L	Phloem	Xylem	Phloem	Xylem
M	Phloem	Xylem	Xylem	Phloem

7. *Refer to the images below of plant structures to answer the following question.*



Which of the following options best identifies the processes involved in the movement of water molecules indicated by the four labelled arrows?

	A	B	C	D
J	Osmosis	Evaporation	Transpiration stream	Osmosis
K	Diffusion	Transpiration	Transpiration stream	Root pressure
L	Osmosis	Diffusion	Cohesion	Root pressure
M	Diffusion	Adhesion	Cohesion	Osmosis

8. Some events in the flow of materials that occurs in phloem vessels in plants are listed below, but not in the correct order.

a.	Solutes are actively transported into the sieve tubes.
b.	Sugar moves down the stem.
c.	Leaf cells produce sugar by photosynthesis.
d.	Water moves into the sieve tubes of phloem by osmosis.
e.	Sugar is transported from cell to cell in the leaf.

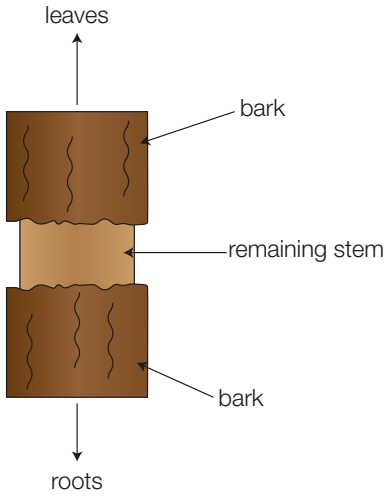
Which of the following options correctly identifies the order of the events listed above?

J c – e – a – d – b.
K c – a – d – b – e.
L c – e – d – a – b.
M c – a – e – d – b.

9. *Refer to the image to the right showing some damage to the bark on a section of a tree to answer the following question.*

The damage to this section of the tree is all the way around the stem forming a ring of damage and was caused by animals eating the bark and phloem. The likely outcome for the damaged tree is that

J swelling occurs below the ring because water cannot move from the leaves to the roots.
K swelling occurs above the ring because water cannot move from the leaves to the roots.
L swelling occurs below the ring because sugars cannot move from the leaves to the roots.
M swelling occurs above the ring because sugars cannot move from the leaves to the roots.



10. *Refer to the table to the right which shows the rate of water flow through a tree over 12 hours to answer the following question.*

A conclusion that can be drawn from the data is

J water does not flow through the tree overnight.
K the intensity of light affects the rate of water flow through the tree.
L the greatest increase in the rate of water flow in a 2 hour period is between 10:00 and 12:00.
M the rate of water flow continuously increases from 6:00 to 16:00.

Time of day	Rate of water flow (cm/hour)
6:00	110
8:00	130
10:00	150
12:00	260
14:00	310
16:00	270
18:00	190

Free response questions

1. The table below shows some materials that are taken into plants via roots. Complete the table to show how each material is taken into the plant roots and explain why this process is used.

Material	Process used to take up material by roots	Explanation of why this process is used by roots
Mineral nutrients		
Oxygen		
Water		

2. Complete the following table comparing the properties of the two plant transport vessels.

Transport vessel	Substances transported	Process that occurs in transport vessel	Direction of flow	Status of cells that tubes consist of
Xylem				
Phloem				

3. Glucose produced by photosynthesis can be stored in particular structures in plants.

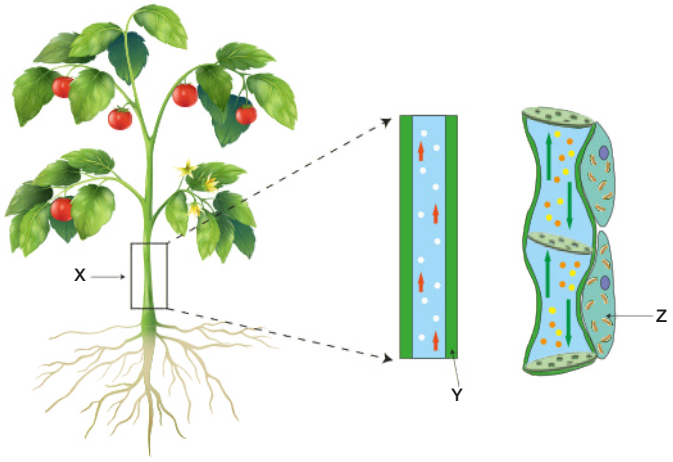
   a) Name the carbohydrate that glucose is converted into to be transported in the plant.

   b) Name the carbohydrate plants use to store sugar produced by photosynthesis.

   c) Name **two** structures in which this carbohydrate identified in (b) can be stored.

   d) The stored carbohydrate in plants can be broken down and transported to other areas of the plant. Discuss the likely factors involved for this to occur.

4. *Refer to the image below showing the two transport vessels in a plant to answer the following questions.*



   a) Identify the plant organ labelled 'X.'

   b) Identify the transport vessels labelled 'Y' and 'Z.'

      Y:

      Z:

   c) Describe **two** features of the structure of the transport vessel labelled 'Y' that can be seen in the image to justify your answer in part (b).

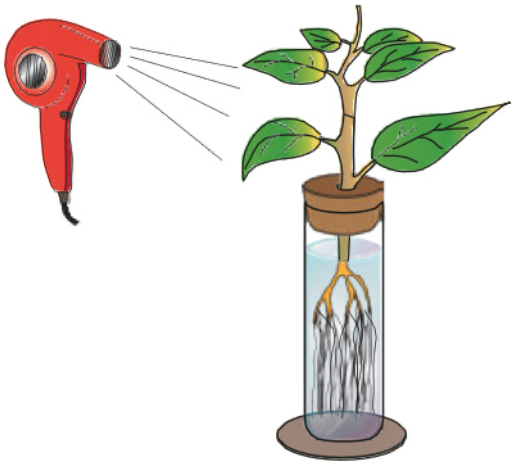
d) Describe **two** features of the structure of the transport vessel labelled 'Z' that can be seen in the image to justify your answer to part (b).

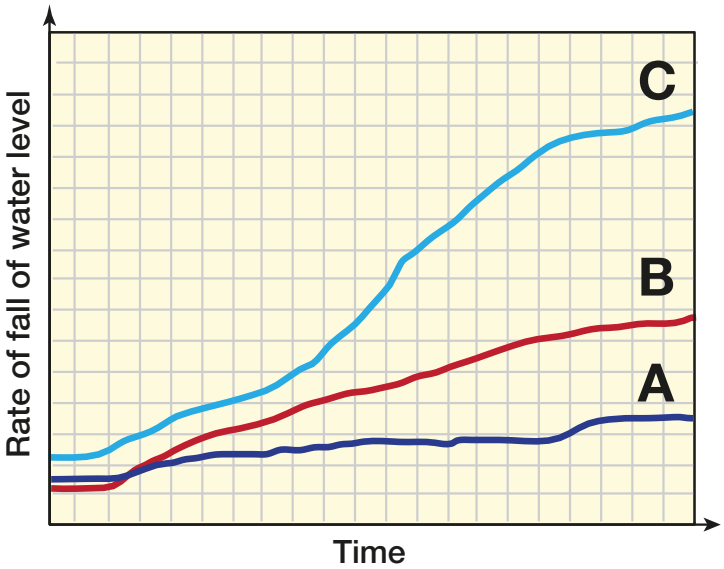
5. Explain the role of root pressure in the movement of water from the soil solution through the root to xylem vessels.

6. Explain how evaporation in the mesophyll and cohesion of water molecules leads to water being pulled up the xylem to leaves.

7. Explain why carnivorous plants can grow in soils very low in nitrates and other mineral nutrients.

8. A hair drier with settings A = 30°C, B = 40°C and C = 0°C was used to investigate the effect of air temperature on water uptake by a plant. The equipment used and the data obtained are shown in the Figure below.





a) Suggest a likely hypothesis for this investigation.

b) State the independent variable.

c) State the dependent variable.

d) Suggest **one** likely conclusion based on the data.

e) Explain the change in the rate of fall of water level for A, B and C in this investigation.

f) Discuss some possible limitations of the conclusion provided in part (d) above.

9. Global warming and climate change are affecting developmental and physiological plant processes. Elevated temperatures, reduced rainfall, and increased soil erosion associated with stronger winds and storms are providing greater challenges for plant growth.

   Use one or more of the key concepts of Science as a Human Endeavour to discuss how global warming and climate change is likely to impact society.

Topic 3 Review Test Part 1: Multicellular Organisms – Animals

Author's note: *The Topic 3 Review Test has been split into two parts. Part 1 includes questions related to Chapters 3.1 to 3.6 with a focus on multicellular animals, and more specifically, humans. Part 2 includes questions related to Chapters 3.7 and 3.8 with the focus on multicellular plants, and more specifically, vascular plants.*

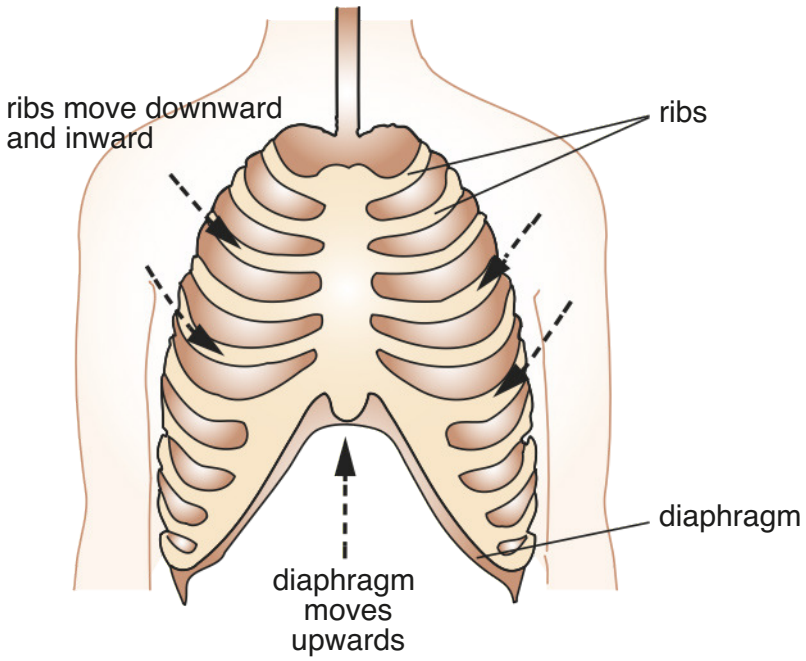
It is recommended that 65 minutes is allocated to complete this test. Indicate your choice for each multiple choice question (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks allocated for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (10 marks)

1. Which of the following options correctly identifies an example of a cell, tissue, organ and organ system (not all necessarily in the one organ system)?

	Cell	Tissue	Organ	Organ system
J	Blood	Nerve	Diaphragm	Respiratory
K	Nephron	Stomach	Epithelium	Lung
L	Neuron	Blood	Lung	Excretory
M	Lung	Connective	Cartilage	Smooth muscle

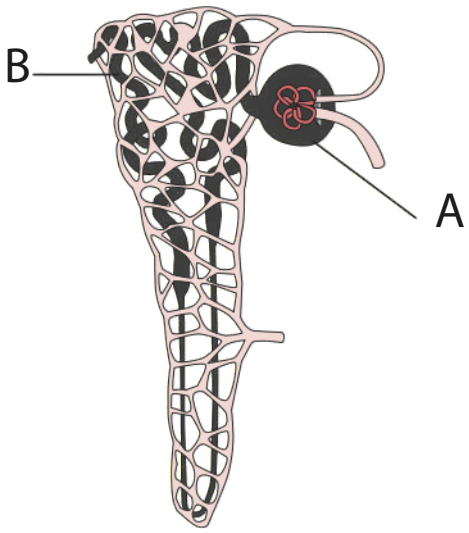
2. *Refer to the image below to answer the question that follows:*



The events displayed on the image above suggest that

J inhalation is occurring where the diaphragm and intercostal muscles relax.
K exhalation is occurring where air pressure is greater in the lungs than air pressure outside the body.
L inhalation is occurring where air pressure is greater outside the body than in the lungs.
M exhalation is occurring where the diaphragm and intercostal muscles contract.

3. *Refer to the diagram to the right and table below showing the structure of a kidney nephron and the composition of four substances at two highlighted structures of the nephron to answer the following question.*

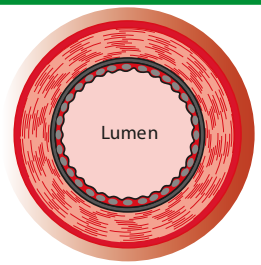
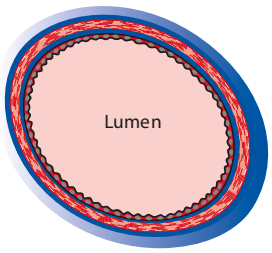
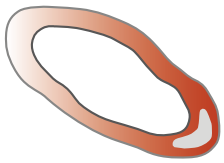


Substance	A	B
Glucose	0.10%	0.0%
Urea	0.03%	2.0%
Protein	8.00%	0.0%
Ions	0.75%	1.5%

Which of the following events occurring in the nephron could give rise to the differences in composition between locations A and B?

J Ions are filtered into the Bowman's capsule but not reabsorbed back into the blood.
K Proteins are filtered in the Bowman's capsule and then reabsorbed back into the blood.
L Glucose is filtered into the Bowman's capsule but not reabsorbed back into the blood.
M Reabsorption of water by osmosis is a major factor contributing to the increase in concentration of urea from A to B.

4. *Refer to the table below showing three blood vessels in the human circulatory system to answer the following question. Note that they are not drawn to scale.*

Blood vessel A	Blood vessel B	Blood vessel C
		

Which of the following options correctly identifies the vessel and describes a corresponding structural feature that is related to its function?

J B is an artery with a tough outer layer that helps pump blood in the circulatory system.
K A is an artery with an elastic middle layer that helps maintain blood pressure.
L C is a vein that prevents the backflow of blood.
M B is a capillary with a wall that is one cell thick to maximise the exchange of materials.

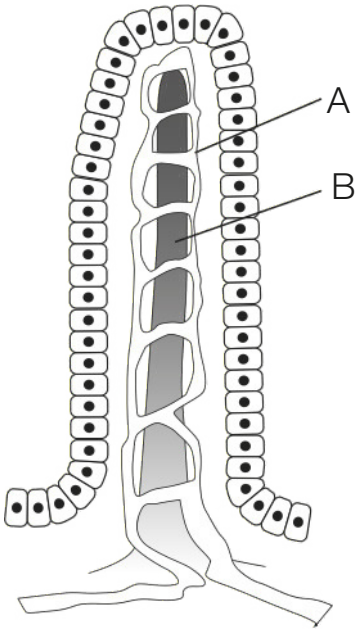
5. Which of the following options is **not** true of the exchange of oxygen at the lungs?

J Capillaries are thick and provide a rich blood supply to alveoli.
K The alveolar lining is moist.
L The concentration of oxygen in the blood is lower than in the alveoli.
M Alveoli are one cell thick and have a large surface area.

6. A function of the mouth in digestion is to

J start chemically digesting all the nutrients in food consumed.
K use peristalsis to physically digest food.
L chemically digest lipids by secreting saliva and bile.
M increase the surface area of the food for chemical digestion.

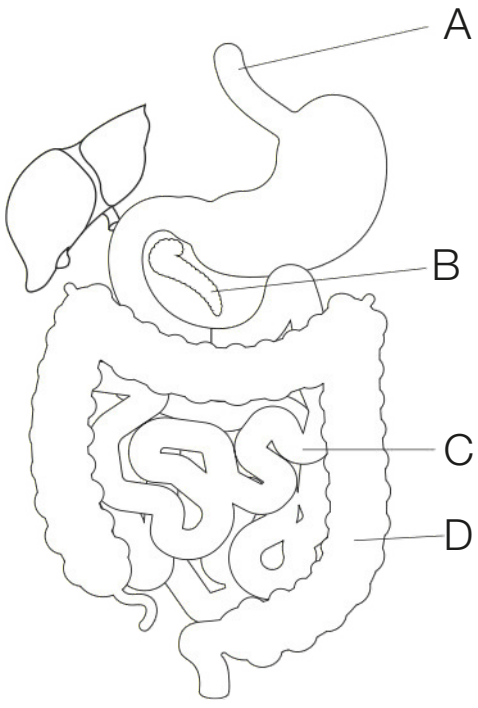
7. *Refer to the diagram below to answer the following question.*



Which of the following statements is correct?

J Structure A is called a villus.
K Structure B absorbs lipids from structure A.
L Structure A absorbs the excess fluid from the extracellular environment.
M Structure B transports lipids.

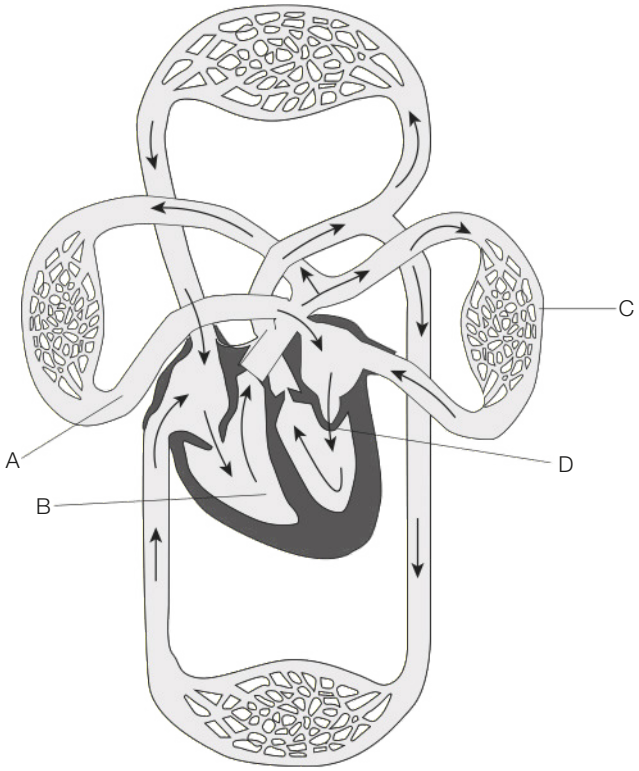
8. *Refer to the labelled diagram of an alimentary canal to answer the following question.*



The structure that produces digestive enzymes is

J A
K B
L C
M D

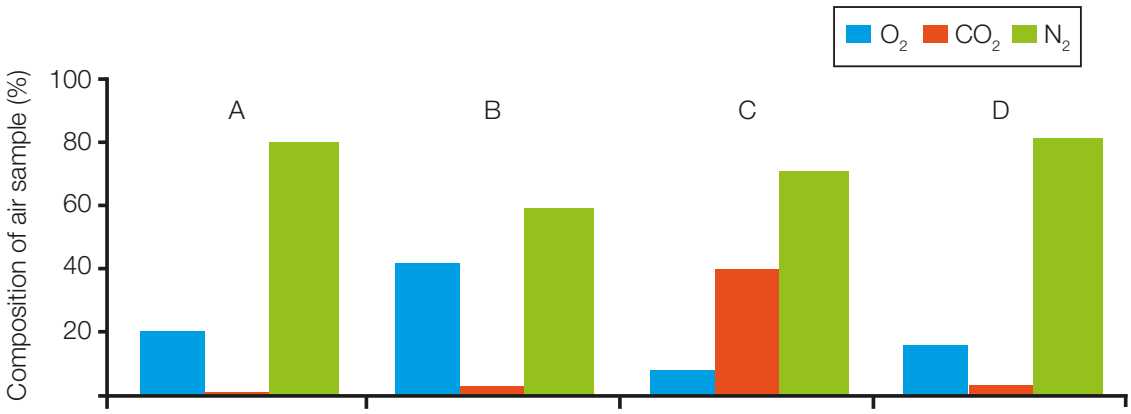
9. *Refer to the diagram below of the circulatory system to answer the following question.*



Select the combination below that correctly identifies the four structures of the circulatory system.

	A	B	C	D
J	Vena cava	Left ventricle	Right lung	Semilunar valve
K	Vena cava	Right ventricle	Left lung	Atrioventricular valve
L	Pulmonary vein	Left ventricle	Right lung	Semilunar valve
M	Pulmonary vein	Right ventricle	Left lung	Atrioventricular valve

10. *Refer to the Figure below showing the composition of four samples of air to answer the following question.*

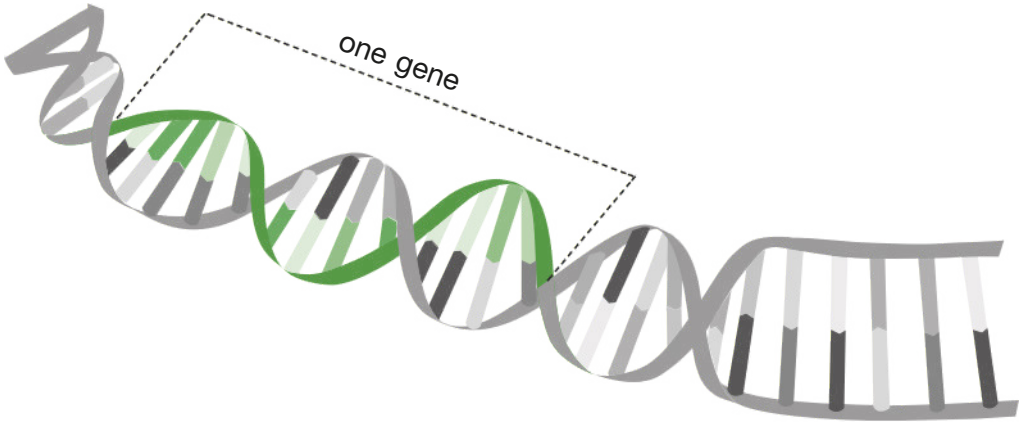


Identify which of the four samples is inspired air and which is expired air.

	Inspired air	Expired air
J	B	A
K	D	C
L	A	D
M	C	B

Section 2: Free Response Questions (50 marks)

11. *Refer to the diagram below which shows a very short part of a DNA molecule and a hypothetical gene to answer the following questions.*



a) Describe the structure of one nucleotide in the DNA molecule.

(2 marks)

b) Describe the structure of a gene.

(1 mark)

c) State the function of a gene.

(1 mark)

d) Compare the genetic makeup of a skin cell and a cardiac muscle cell.

(1 mark)

e) Explain **one** way that a gene, like the one pictured above, can be switched on or off.

(3 marks)

f) (i) Describe what an embryonic stem cell is.

(2 marks)

(ii) Explain how embryonic stem cells produce specialised cells.

(3 marks)

Researchers are discovering new ways that epigenetic changes can contribute to weight gain and obesity. Some research is showing that early-life nutrition can induce long-term epigenetic changes and predispose individuals to disorders such as obesity. For example, high fat diets can increase the epigenetic changes in genes associated with obesity. Additional research has shown that sleep disturbances can induce epigenetic changes that can contribute to the development of obesity and other metabolic disorders. Scientists are also looking into identifying the specific genes that are being switched on and off by these lifestyle factors, and interventions to reverse the changes. Research has identified specific nutrients that can reverse some of these epigenetic changes and improve obesity outcomes in mice.

Use your understanding of the interaction between science and society to answer the following questions.

g) (i) Discuss how society influences this type of research.

(2 marks)

(ii) Discuss **one** development that could eventuate as an obesity intervention from this research and the impact this could have on society.

(2 marks)

12. Multicellular organisms exchange materials with the environment around them using specialised exchange surfaces.

a) State a definition of a tissue.

(1 mark)

b) State **two** features of exchange surfaces.

(1 mark)

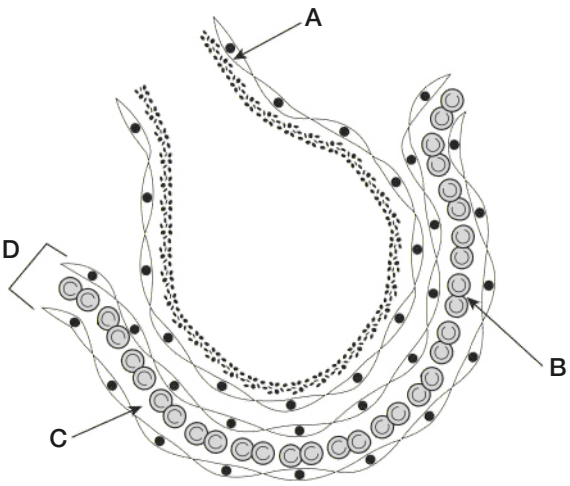
One example of an exchange surface in humans is shown below.

c) Identify this exchange surface.

(1 mark)

d) Name the labelled structures on the exchange surface pictured to the right.

	Name of structure
A	
B	
C	
D	



(2 marks)

e) (i) Draw labelled arrows on the exchange surface pictured above to show the net movement of oxygen and carbon dioxide that occurs here under normal circumstances.

(2 marks)

(ii) Explain the net movement of oxygen and carbon dioxide at this exchange surface.

(4 marks)

Scientists have uncovered evidence that vaping e-cigarettes can increase the risk of developing emphysema like cigarette smokers.

f) Explain how emphysema affects the structure and function of the lungs.

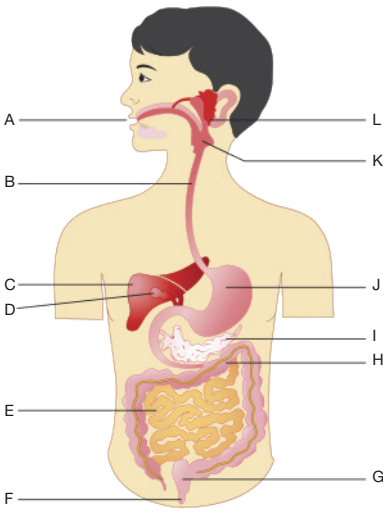
(2 marks)

13. *Refer to the adjacent diagram showing some organs of the human digestive system to answer the following questions.*

a) (i) State the letter on the adjacent diagram that correctly identifies the oesophagus.

(1 mark)

(ii) Name the type of muscle tissue that the oesophagus consists of **and** explain how it contributes to the function of the oesophagus.



(2 marks)

b) State **one** function of H.

(1 mark)

In some cases, the duct from organ D to organ E can become blocked.

c) (i) Name the substance secreted by D.

(1 mark)

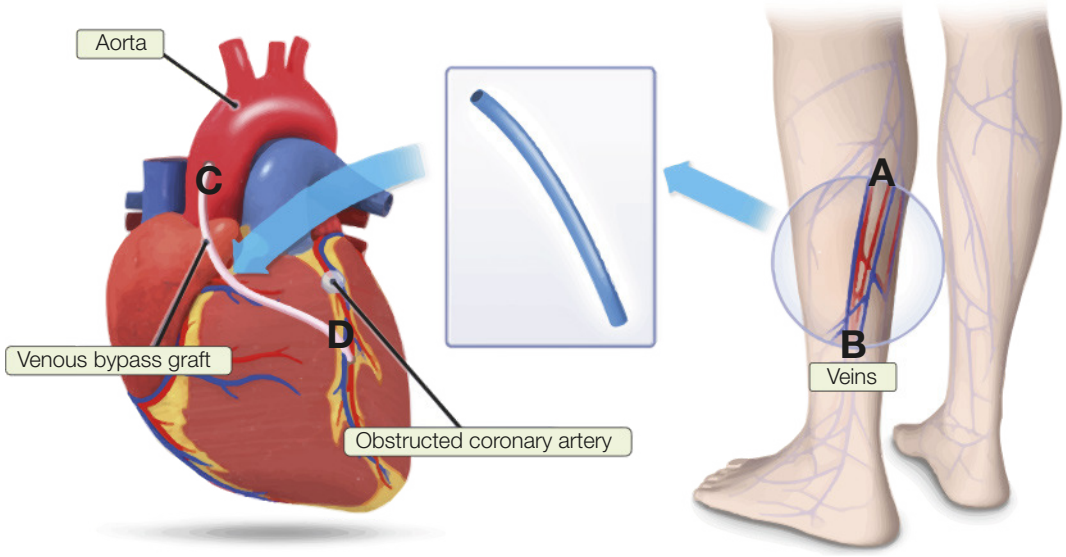
(ii) Identify the organ E.

(1 mark)

(ii) Identify the macromolecule that the substance secreted by D helps to digest in organ E **and** explain how.

(3 marks)

14. *Refer to the diagram below, which shows how a vein in the lower leg can be used in a heart bypass surgery to take over the function of a blocked artery.*



A segment of vein (AB) is removed from a patient's leg and attached to the aorta (C) and the outside of the heart and below the blockage (D).

a) Explain why the surgeon must attach 'A' to 'D' and 'B' to 'C' for this heart bypass surgery to be successful.

(2 marks)

b) Explain the likely consequence for this patient's heart if the coronary artery remains obstructed and the heart bypass surgery does not occur.

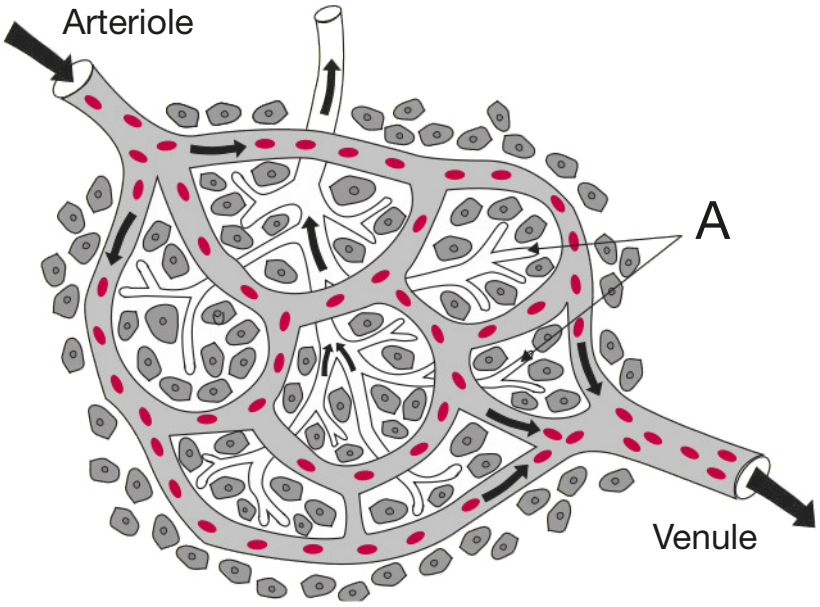
(2 marks)

TEST

c) Explain **one** lifestyle factor that could have contributed to the coronary artery obstruction.

(2 marks)

The heart pumps oxygenated blood to the body's cells through arteries that flow into networks of capillaries. Refer to the diagram below which shows blood flow into and out of a network of capillaries in a muscle tissue.



d) Name structure A.

(1 mark)

e) Structure A and the muscle cells are surrounded by tissue fluid. Describe the origin of tissue fluid.

(2 marks)

f) Explain a likely consequence for this muscle tissue if structure A is damaged and cannot perform its function.

(2 marks)

Total: /60

Topic 3 Review Test Part 2: Multicellular Organisms – Plants

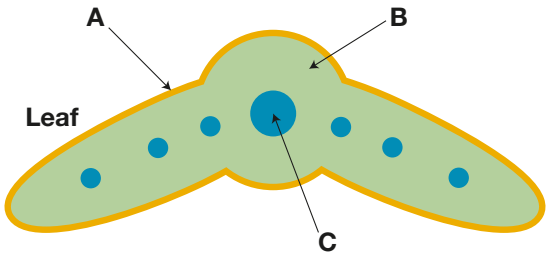
It is recommended that 30 minutes is allocated to complete this test. Indicate your choice for each multiple choice question (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks allocated for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (5 marks)

1. Which one of the following options correctly identifies a substance, the plant transport vessel it moves in, and the process by which it moves?

	Substance	Vessel	Process
J	Mineral ions	Phloem	Transpiration
K	Water	Xylem	Translocation
L	Sugar	Phloem	Translocation
M	Carbon dioxide	Xylem	Transpiration

2. *Refer to the cross-section of a leaf pictured below to answer the following question.*



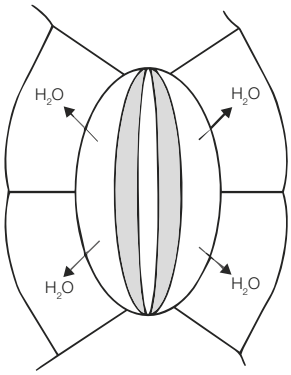
Identify the three types of tissue labelled A, B and C in the leaf above.

	A	B	C
J	Dermal	Vascular	Ground
K	Vascular	Dermal	Ground
L	Ground	Vascular	Dermal
M	Dermal	Ground	Vascular

3. Which of the following options is correct regarding the movement of gases through stomata during daylight?

J There is a nett movement of CO_2 into the leaf spaces and a nett movement of O_2 out of the leaf by diffusion.
K There is a nett movement of CO_2 out of the leaf spaces and a nett movement of O_2 into the leaf by diffusion.
L There is a nett movement of CO_2 out of the leaf spaces and a nett movement of O_2 into the leaf by active transport.
M There is a nett movement of CO_2 into the leaf spaces and a nett movement of O_2 out of the leaf by active transport.

4. *Refer to the image to the right showing a section of a leaf with two guard cells and the net movement of water into the surrounding epidermal cells to answer the following question.*



Given that this section of the leaf is in direct sunlight, a likely immediate effect is that

J carbon dioxide will accumulate in the air space inside the leaf.
K the two guard cells will stop photosynthesising.
L the diameter of the stoma's opening will decrease.
M evaporation of water from the stoma will increase.

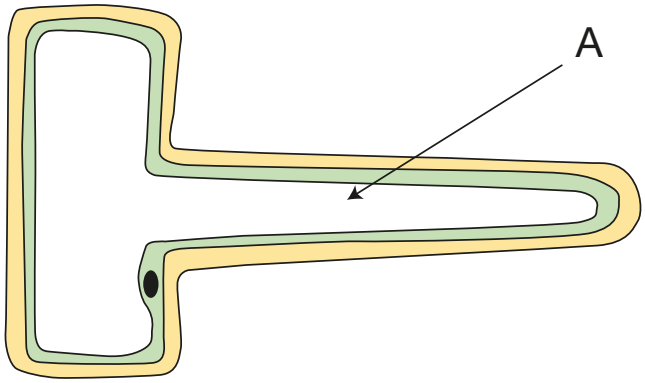
TEST

5. Which one of the following options correctly identifies how the transport systems of humans and trees differ?

	Human	Tree
J	Contains vessels	No vessels
K	Must carry oxygen	Does not need to carry oxygen
L	Carries mineral ions	Does not carry mineral ions
M	Does not transport cells	Transports cells

Section 2: Free Response Questions (25 marks)

6. *Refer to the image below to answer the following questions.*



a) Identify the type of plant cell shown above:

(1 mark)

Plants have developed specialised systems to exchange materials with their environment.

b) Describe **one** structural adaptation of this cell **and** explain how the feature helps its function.

(3 marks)

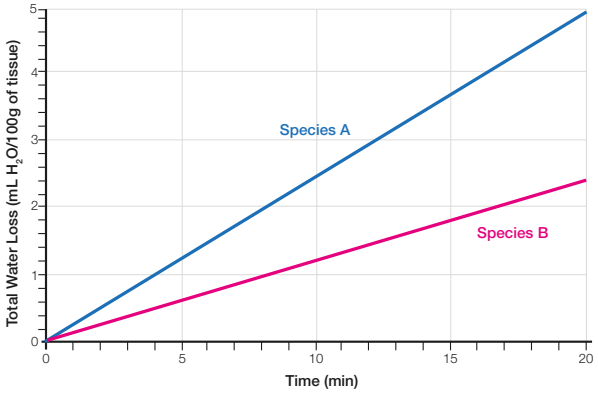
This type of plant cell exchanges materials with its environment including an essential material labelled 'A.'

c) Discuss the pathway that material 'A' takes as it enters a plant at the roots, moves through the stem and is removed at the leaves. In your answer, include the following processes and structures:

- Osmosis
- Stomata
- Transpiration stream
- Transpiration
- Xylem vessels
- Root pressure
- Cohesion

(7 marks)

Refer to the graph below showing the results of an investigation on the transpiration rate of two plant species.



d) (i) Use data to compare the transpiration rate of species A and species B.

(2 marks)

(ii) Explain **one** structural adaptation that could explain the different transpiration rates exhibited by species A and B.

(2 marks)

7. *Refer to the graph below showing the mass of glucose produced (mg/hour) at different parts of a leaf.*

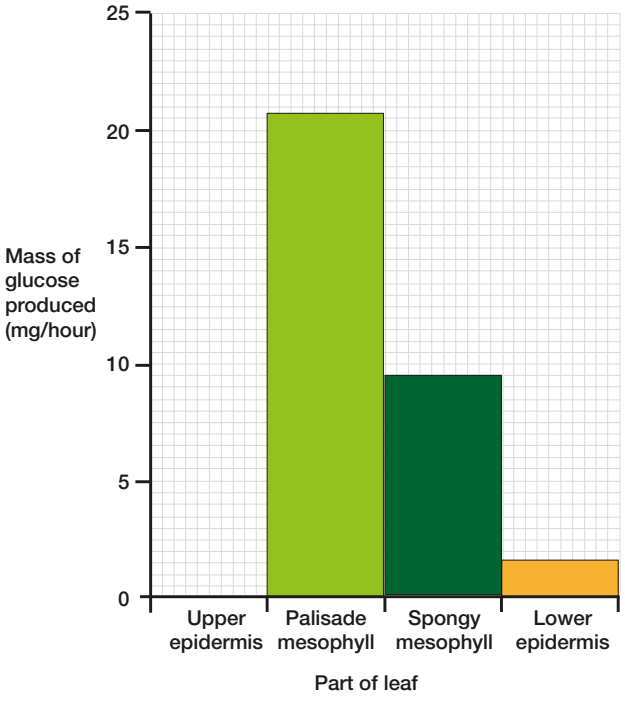
a) Using data, describe the difference in the mass of glucose produced per hour by the palisade and spongy mesophyll parts of a leaf.

(2 marks)

b) Use your understanding of the structure of a leaf to explain the results observed in the graph.

(3 marks)

c) Explain in detail how the excess glucose produced in this leaf is transported to the roots for storage.

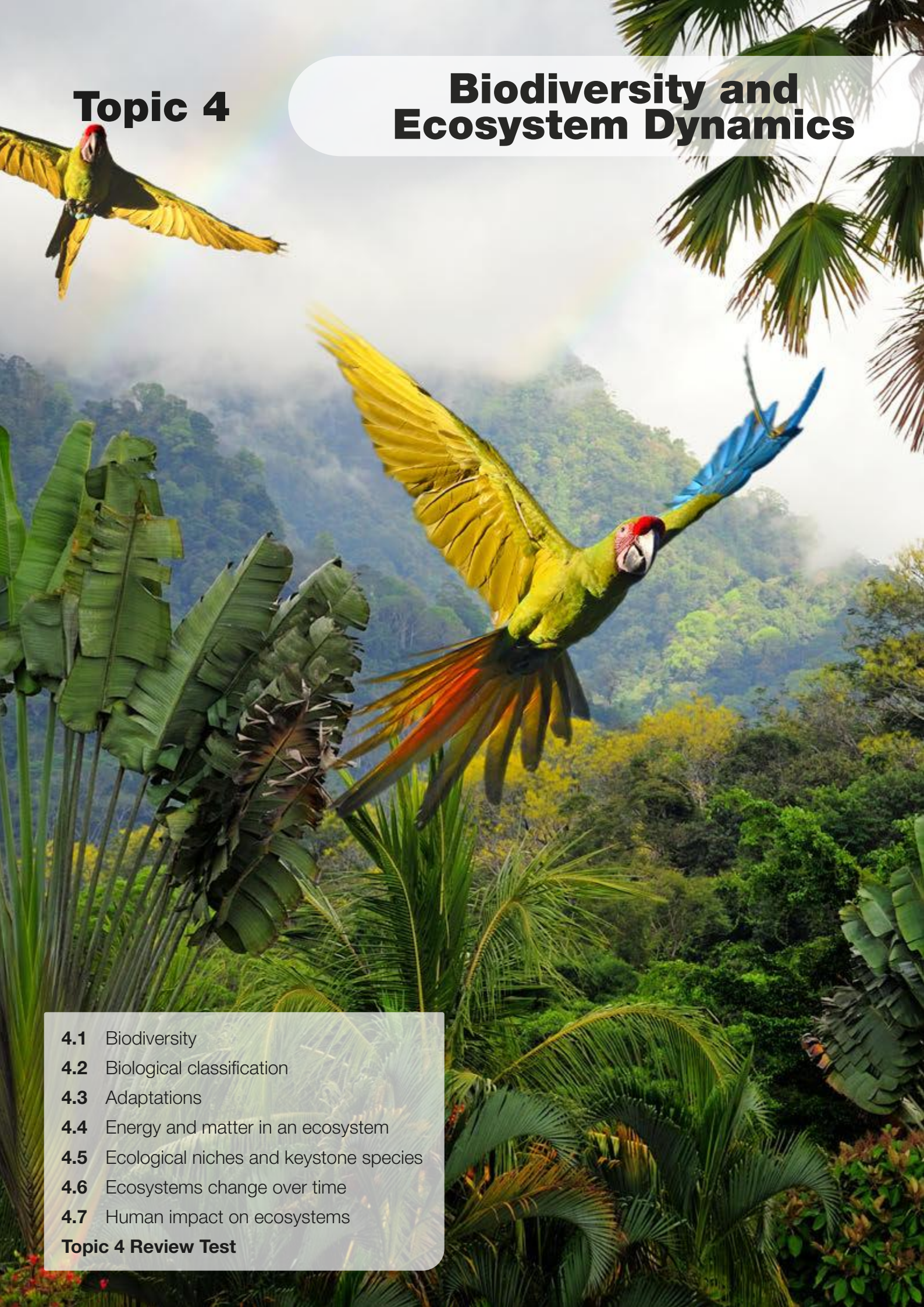


(5 marks)

Total: /30

Topic 4

Biodiversity and Ecosystem Dynamics



Chapter 4.1 Biodiversity

Science Understanding

Biodiversity is the variety of all living things and includes diversity in genetics, species and ecosystems.

- Distinguish between a species, population, community, and an ecosystem.
- Describe diversity in examples of:
  - species
  - ecosystems.

Ecosystems can be diverse, and can be defined by their biotic and abiotic components and the interactions between elements of these components.

- Distinguish between biotic and abiotic components of ecosystems.

In general, the higher the biodiversity of an ecosystem the more stable it is.

Populations with reduced genetic diversity face increased risk of extinction.

- Explain why genetic diversity is important for a species' survival in a changing environment.

It is estimated that there are over 13 million different species of organisms on earth, from microorganisms to a large range of plants and animals. Australia has around 1 million known species representing about 7% of the world's total. More than 80% of our plant and animal species are **endemic**, meaning that these species are only found naturally in Australia (see Figure 4.1.1). No other country has as many endemic flowering plants or marsupials (pouched mammals) as Australia. As such, Australia is regarded as **mega-diverse**, possessing a high level of diversity of species and ecosystems.

Figure 4.1.1: Three species endemic to Australia: a rosella parrot, a platypus and a species of banksia (from left to right).

Levels of ecological organisation

Ecosystems are organised into different levels, from an individual species to the biosphere. These ecological levels can be studied to discover information such as the distribution and abundance of life and interactions between different species and their physical environment. Ultimately, this research can be used to determine the influence of human impact and other physical factors on the environment and whether species are endangered or extinct. This will be explored further throughout the topic.

There are five main levels of ecological organisation (see Figures 4.1.2 and 4.1.3). These levels of organisation are displayed in ascending order from smallest to largest.

Organism → Population → Community → Ecosystem → Biosphere

Figure 4.1.2: The five levels of ecological organisation listed in an increasing order (left to right) according to their size.

Organism

This is the lowest level of ecological organisation. An organism is an individual that exhibits all the characteristics of life (see Chapter 1.1 for more information). Organisms can be unicellular, such as an *E. coli* bacterium, or multicellular, such as a platypus. At this level, researchers study the adaptations that allow individuals to survive in their respective environments.

Population and species

A **population** is a group of organisms of the **same species** in a particular geographical area at a particular time, for example, the population of pigeons in Adelaide, South Australia. A **species** is a group of organisms with similar characteristics. They usually share similar anatomical characteristics and a common gene pool. Organisms of the same species can **interbreed to produce fertile offspring** but those from different species cannot. They also compete with each other for resources. Research on populations regularly focuses on the size of populations in a specific area and how they change over time.

Community

A **community** is the sum of all the living organisms of different species, or **biotic factors**, in a common geographical area. These different species are interdependent and exhibit a range of interactions. Research on communities generally focuses on these interactions between species, including the factors affecting them and the consequences for communities if a species is removed from a community.

Ecosystem

An **ecosystem** is the interaction of **living (biotic) factors**, such as communities of organisms, and **non-living (abiotic) factors**, such as the physical surroundings. Interactions exist between the living and non-living components within ecosystems. Research conducted on ecosystems analyses how nutrients and energy are stored and how they flow through ecosystems.

Biosphere

The **biosphere** is the highest level of ecological organisation. It is the global ecosystem, or zone of life on Earth, which is made up of all the ecosystems on Earth.

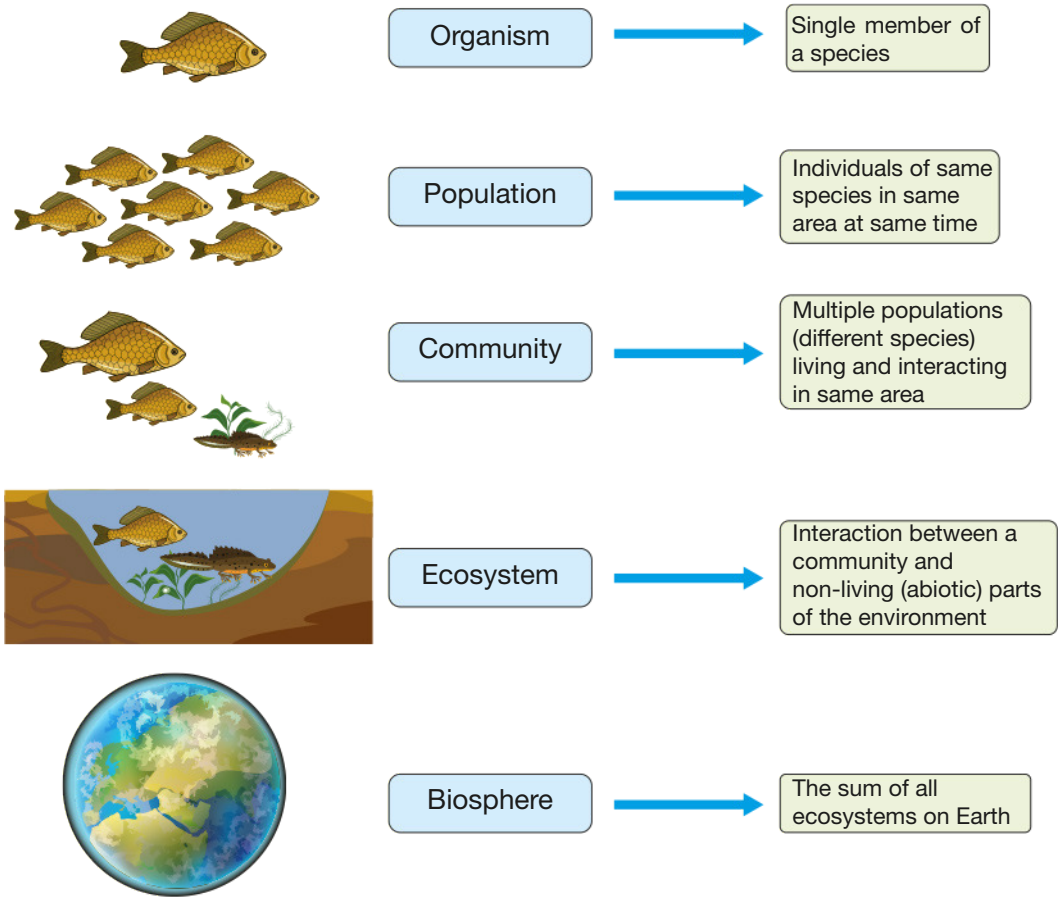


Figure 4.1.3: A comparison of the five levels of ecological organisation.

Helpful online resources

FuseSchool - Global Education: Key Ecology Terms

<https://www.youtube.com/watch?v=E6WAQpRulhA>

Biotic and abiotic factors

Ecosystems consist of living and non-living things. The **living components** of ecosystems are called the **biotic factors**, and the **non-living components** (physical components) are called the abiotic factors. Biotic and abiotic factors shape ecosystems and the interactions between them are critical to an ecosystem's survival. A prime example of the importance of the interactions between abiotic and biotic factors is seen in soil. Refer to the video link below titled 'Why soil is one of the most amazing things on Earth' for more information. Some examples of biotic and abiotic factors and how they affect ecosystems are presented in Tables 4.1.1 and 4.1.2.

Helpful online resources

BBC Ideas: Why soil is one of the most amazing things on Earth

<https://www.youtube.com/watch?v=OiLITHMVcRw>

Table 4.1.1: Some examples of biotic factors and how they can affect ecosystems.

Biotic Factor	How biotic factor affects ecosystem
Availability of food (prey)	If food or prey is abundant and easily accessible, then populations can increase as there is a higher chance of more organisms being able to survive to reproduce.
Predators	Predators kill and consume their prey. If there is enough food for predators, then the size of the prey populations should also remain stable. However, if there are disturbances such as an extinction of one species of prey, predators will hunt and kill more of the other species of prey, decreasing their population size.
Competition between species	If two or more species compete for the same resources, one may be better adapted to outcompete the others and take these resources. As a result, the other species' populations may decrease in number due to being outcompeted.
Pathogens	Pathogens are disease causing microorganisms. If a pathogen spreads through a population, it can decrease the population size and even wipe out that population. This would have many consequences that would filter through the food web(s) of that ecosystem.
Human impact	Humans can have both direct and indirect impacts on ecosystems. Humans have introduced foreign species to ecosystems that disrupt natural food webs. Humans hunt animals for food and as a recreation. Humans have also cleared land to establish cities and farms, wiping out ecosystems (see Chapter 4.7 for more information).

Table 4.1.2: Some examples of abiotic factors and how they can affect ecosystems.

Abiotic Factor	How abiotic factor affects ecosystem
Sunlight	Light is required by plants for photosynthesis. Photosynthesising organisms in ecosystems that receive a greater amount of light can perform photosynthesis at a greater rate and therefore have a greater growth rate. Other abiotic factors also need to be favourable in these ecosystems though.
Temperature	Photosynthesis requires a suitable temperature. Very hot temperatures and very cold temperatures are less suitable for photosynthesis and life. In very hot ecosystems, water is evaporated and there may not be enough to sustain plant and animal life. Very cold temperatures can freeze water making liquid water unavailable for plants to use.
Rainfall	Water is required by animals and plants to survive. Water is an essential reactant for photosynthesis and animals require it for many chemical reactions. Ecosystems with high rainfall can support more life (e.g. rainforests), whereas ecosystems with low rainfall tend to have less available water and support less life (e.g. deserts).
Soil quality	Different plant species have adapted to different soil qualities. Some factors include the pH of soil, the mineral content and retention of soils, the salinity of soils and the structure and depth of soils (which can affect the ability of plants to establish their roots). Insectivorous plants are often found in nutrient-poor soils and rely on obtaining nutrients from animals' bodies.
Wind	The speed and direction of wind can impact plant growth. Plants tend to prefer areas that are sheltered from wind. Plant species that can survive strong winds need to have a deeper or more extensive root system to provide stability in these regions. Wind speed can also affect the rate of transpiration in plants, which affects the rate of photosynthesis and the plants' growth.
Oxygen availability	Many aquatic animals require a high concentration of oxygen dissolved in water for gas exchange and use in aerobic respiration. Some aerobic microorganisms living in soil also require oxygen for aerobic respiration. The amount of oxygen in the pores of soil can therefore affect the size of populations of these microorganisms.
Pollution	Both soil pollution and air pollution can negatively impact plant growth. Toxic chemicals in the soil can damage root cells and reduce the transport of water and mineral nutrients throughout plants, reducing growth. Some gases released from fossil fuel combustion can be very toxic to plants. They can discolour leaves, disrupt the process of photosynthesis, and reduce growth. Additionally, plastic pollution can kill animal life (see Chapter 4.7 for more information).

Helpful online resources

Cognito: GCSE Biology - Biotic and Abiotic Factors

<https://www.youtube.com/watch?v=0mjafH5pVLA>

Interactions between species

Organisms do not live in isolation. They require interactions with other organisms in their ecosystem to obtain a range of different resources. Interactions between organisms can be between members of the same species, known as intraspecific interactions, or between members of different species, known as interspecific interactions. These interactions can generally be classified into three main areas: **competition**, **predation** and **symbiosis**.

Competition

Organisms compete for the same resources, such as light, oxygen, nutrients, prey, space and sexual partners (see Figure 4.1.4). A specific example is the competition of the grey kangaroos and rabbits for grasses as a food source. No two species have identical requirements, but often there is overlap and this is usually where there is competition for resources. The outcome of competition generally has negative effects on the weaker competitors. This competition is generally most intense between members of the same species, however competition amongst two species with similar requirements can also be strong. Two species can coexist in the same ecological niche, but the species that is outcompeted must adapt to the remaining available resources or it could become extinct. This competition for resources between species is a significant driver of natural selection and evolution.

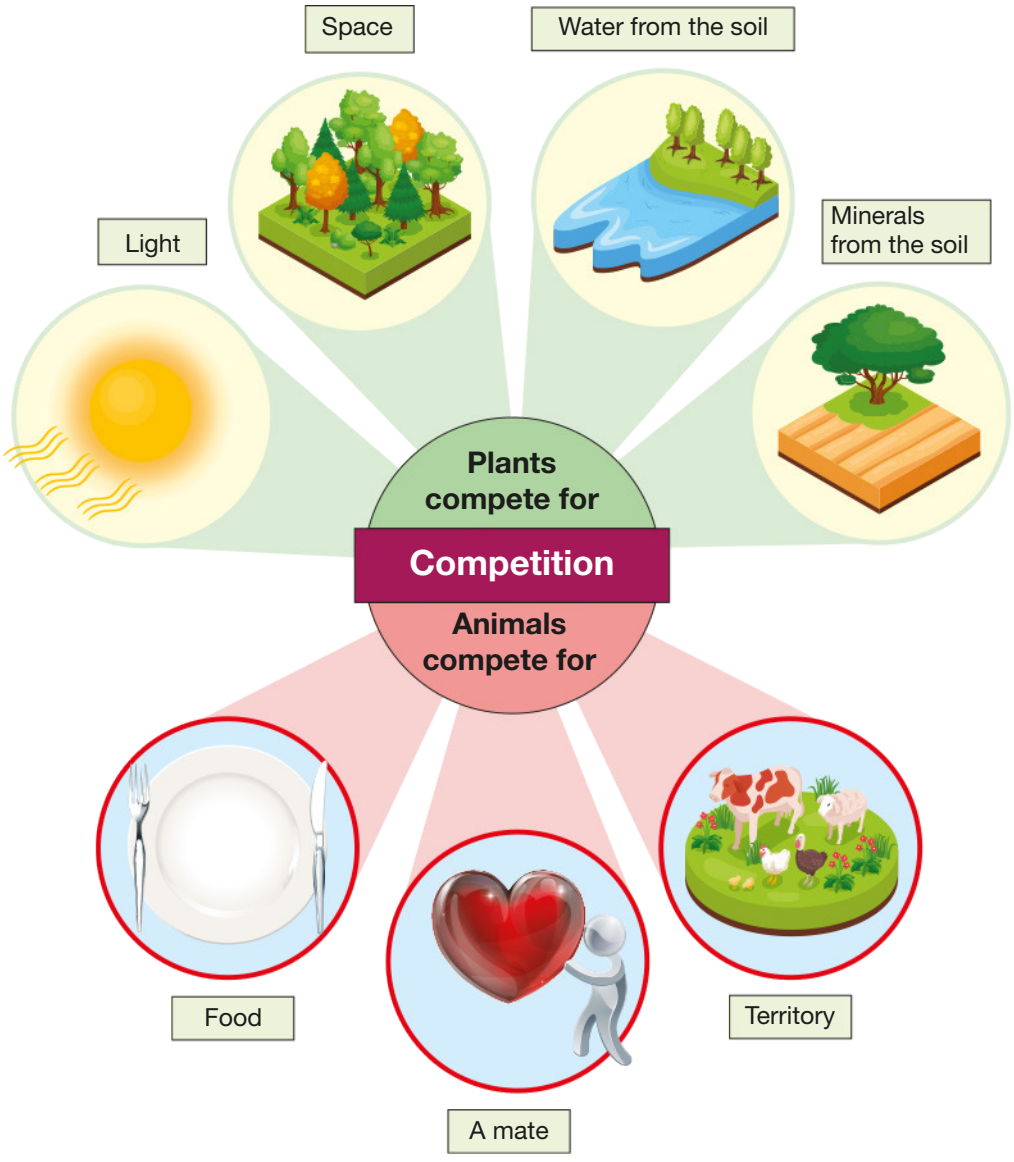


Figure 4.1.4: Some examples of resources plants and animals compete for.

Helpful online resources

Cognito: GCSE Biology - Interdependence - Community and Competition

<https://www.youtube.com/watch?v=XVD5izWXmKo>

Predation

Predation is when one organism, the **predator**, kills and consumes another organism (or parts of it), the **prey**. Predation generally occurs between different species of animals but can occur between individuals of the same species, which is called cannibalism (see Figure 4.1.5). Cannibalism can help species survive times of limited resources. Predation can also occur between some other types of organisms:

- some plants that can trap and digest insects such as the Venus flytrap,
- some protozoans prey on bacteria and others on insects.

Predation shapes the community. It affects the number of organisms in a population, the biodiversity of the community and the evolution of the organisms involved.

Figure 4.1.5: A species of heron consuming a lizard (left) and a predatory mite attempting to eat another mite (right).

Herbivory

Herbivory is the consumption of all or part of a photosynthetic organism, generally a plant, by an animal. Herbivory can result in the death of the photosynthetic organism, but not always. Herbivory interactions also contribute to shaping a community. Photosynthetic organisms are the **producers** in most food chains. The interactions between the plants and the animals that consume them, called **herbivores**, drive adaptations in both species. Herbivores have developed adaptations to digest and extract nutrients from plant matter. In contrast, plants have developed physical defenses such as thorns, and chemical defenses, such as nicotine. Nicotine is a potent insecticide and occurs naturally in a variety of plants including tobacco plants. These plants store nicotine in their leaves to help protect themselves from insect consumption.

Symbiosis

Symbiotic relationships are distinct relationships between organisms of two different species. Generally, these relationships can be placed into three categories: **mutualism**, **commensalism** and **parasitism**. These relationships play an important role in shaping the community.

Mutualism

Mutualism is a symbiotic relationship where **both species benefit**. Some examples include:

- Sea anemones do not sting clownfish and provide them with shelter and protection from predators. In return, clownfish provide the sea anemone with nutrients and their bright colours attract their predators that the anemone can sting and ingest.
- Bees and flowering plants have a mutualistic relationship where bees obtain nutrition in the form of pollen or nectar, and the plants get their pollen dispersed by the bees to other plants of the same species.
- A lichen is an organism formed by the close association of an alga and a fungus. The alga provides food and oxygen through the process of photosynthesis and the fungus absorbs water and mineral nutrients. It is only by this close association that both species can survive in particular environments.
- In the stomach of a cow, bacteria exist that have a warm environment with a plentiful food supply and provide the necessary enzymes to break down cellulose, which is the main food type in the cow's diet. Both species benefit from this close relationship.

Figure 4.1.6: The clownfish and sea anemone (left) and bees and flowering plants (right) interactions are two examples of mutualistic relationships.

Commensalism

Commensalism is a symbiotic relationship where **one species benefits but the other is unaffected** (neither harmed nor benefitted). Some examples include:

- Barnacles are filter-feeders that benefit from attaching to some species of filter-feeding whales. Barnacles gain a habitat and access to food as whales travel to plankton blooms. The whales are not affected biologically by the attachment of barnacles.
- Some birds follow armies of ants. As large armies of ants travel, they can stir up insects causing them to fly away. The birds then catch and eat these insects. The birds benefit but the ants are unaffected.
- Remora fish attach themselves to larger animals such as whale sharks and detach when the whale shark feeds, so they can feed on the scraps left by sharks. The shark is unaffected by this.

Figure 4.1.7: The whale and barnacle (left) and remora fish and whale shark (right) interactions are two examples of commensal relationships.

Parasitism

Parasatism is a symbiotic relationship where **one species benefits but the other is harmed**. Parasatism involves an organism called a parasite that harms an organism called the host. Some examples include:

- Ticks, fleas and some species of lice can live on the skin of their animal hosts such as a dog, human or cattle, and consume their blood. The ticks get nutrition from the host animal, but their host loses blood.
- Tapeworms are parasites that live in the intestines of their host organism and can outcompete the host for specific nutrients.

Table 4.1.3: A comparison of the three main symbiotic relationships.

Type of relationship	Both benefit	One benefits, neither is harmed	One benefits, the other is harmed
Mutualism	✓		
Commensalism		✓	
Parasitism			✓

Helpful online resources

Mad Garden Science: Symbiosis - Mutualism, Commensalism, Parasitism

<https://www.youtube.com/watch?v=QHSHrunOvMo>

Types of nutrition

There are two types of nutrition that organisms use to obtain their essential requirements:

Autotrophs

Autotrophs are organisms that can convert inorganic materials into the organic molecules needed to sustain life. Plants are autotrophs and carry out the process of **photosynthesis** where light energy is trapped and converted into chemical energy. In some ecosystems where light is unavailable, such as thermal vents deep in the ocean, some organisms have developed the ability to produce organic energy rich compounds from chemicals. This process is called **chemosynthesis**. Organisms that carry out autotrophic nutrition are called producers and are the point of entry for energy into the food webs of their respective ecosystems. In a terrestrial environment, this could include the grasses, shrubs, herbaceous plants and forest trees. In an aquatic environment, the producers can include various species of algae and phytoplankton.

Heterotrophs

Heterotrophs are those organisms that need to feed on other organisms to obtain their organic molecules. In humans and many other animals, this will involve eating the organic material of other organisms, and digesting this food so that the essential nutrients are absorbed for use by cells. If a heterotroph feeds only on producers, it is called a **herbivore**. A **carnivore** feeds only on other heterotrophs, whereas omnivores, like most humans, feed on both autotrophs and other heterotrophs.

Decomposers

Decomposers are heterotrophs that extract energy from the remains or waste products of organisms from all trophic levels. These organisms play a critical role in ecosystems as they **break down dead matter and recycle nutrients** for producers to use to grow and reproduce. Without them, dead organisms and dead matter would build up all over Earth and nutrients would not be able to be recycled. Decomposers include some species of bacteria and fungi.

Food chains and food webs

Food chains and food webs show the **feeding relationships** in ecosystems. The arrows in food chains and food webs point in the direction that the energy and nutrients move. Every community of living organisms in an ecosystem has a **trophic structure**, which consists of tiers called **trophic levels**. A trophic level is the relative position of an organism in the food chain. The first trophic level is always a **producer** that can synthesise its own energy rich compounds. Heterotrophs make up the remaining trophic levels as they feed on producers and other animals that have consumed producers. These heterotrophs are called **consumers** and can be herbivores, omnivores or carnivores. The first consumer in a food chain or food web that consumes all or part of the producer is called a **primary consumer** and is positioned at the **second trophic level** (as the producer is always the first). A consumer that eats the primary consumer is therefore called a **secondary consumer** and is positioned at the **third trophic level** (see Figure 4.1.8). Most food chains do not contain any more than four trophic levels. A consumer that sits at the top of a food chain and does not have its own natural predator(s) is called an apex predator (see Figure 4.1.8). Some examples of apex predators include lions, tigers, polar bears, killer whales, grey wolves and eagles.

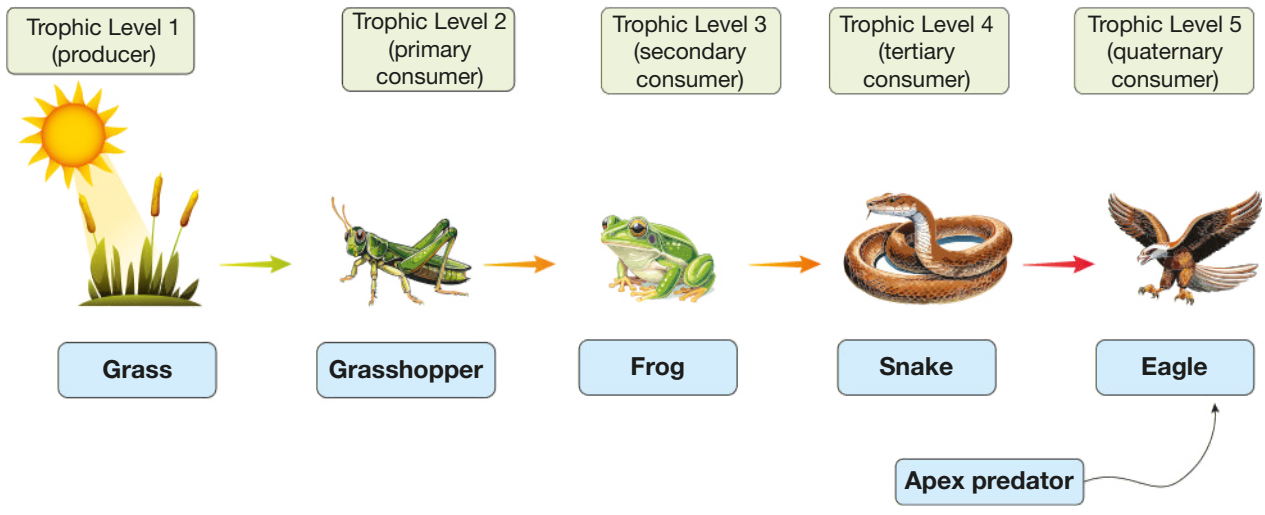


Figure 4.1.8: An example of a food chain with the organisms respective trophic levels and type of nutrition.

Most consumers in the community usually eat a range of foods and thus a food chain does not adequately represent the true feeding relationships. Many consumers will be represented at **several trophic levels**. A more realistic representation of the trophic structure of an ecosystem is a **food web**, which is constructed from many linked food chains (see Figure 4.1.9). **Decomposers** breakdown the remains of dead organisms at all trophic levels returning the nutrients they contain to the soil.

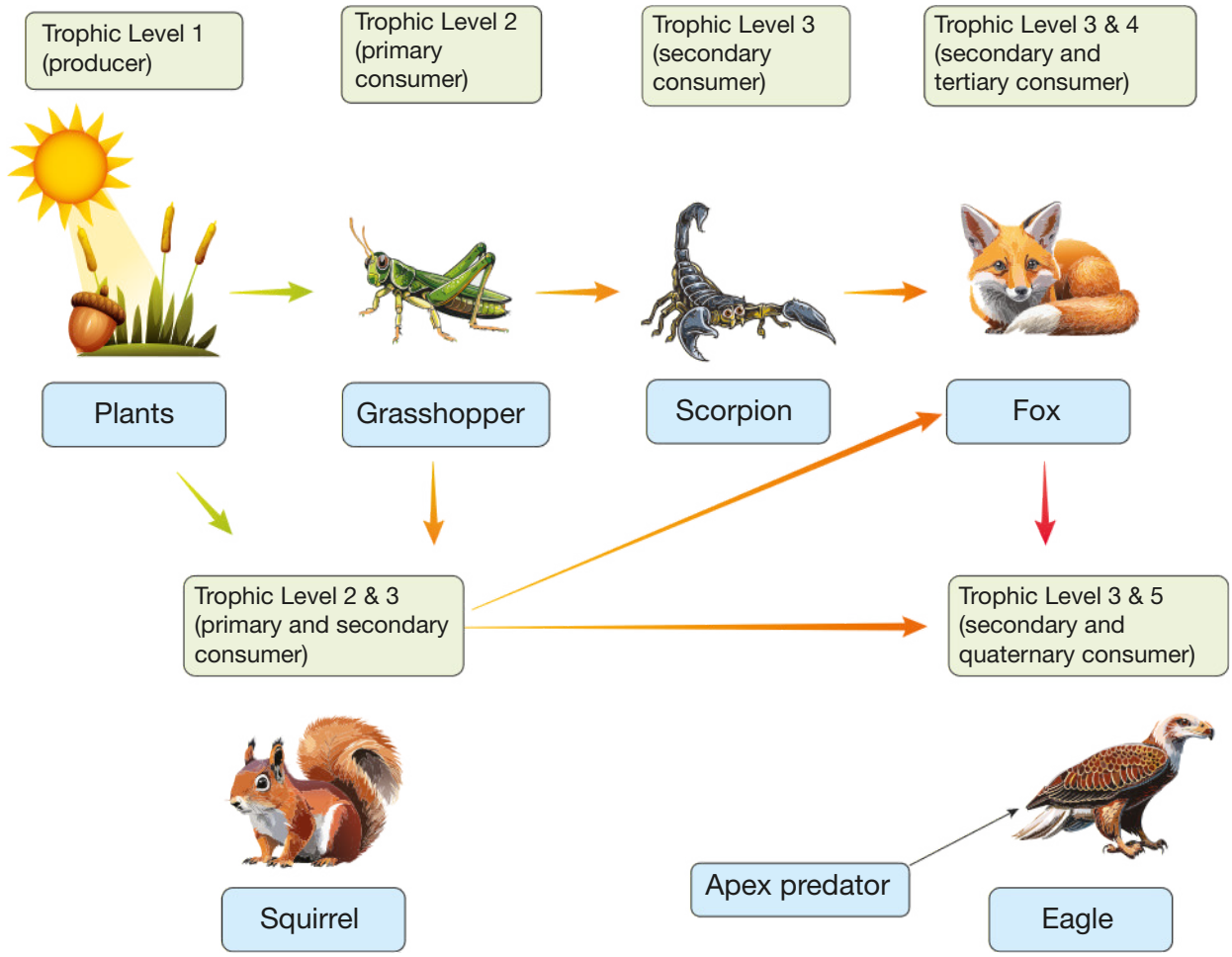


Figure 4.1.9: A simple example of a food web that shows that some organisms are represented at multiple trophic levels because they consume more than one type of organism.

Helpful online resources

Cognito: Trophic Levels - Producers, Consumers, Herbivores & Carnivores

<https://www.youtube.com/watch?v=D1In8W2qev4>

Biodiversity

The term biodiversity refers to the variety of living things on Earth. This includes the genetic information they consist of and the ecosystems that they form. The biodiversity of life is therefore generally expressed at three different levels: **genetic diversity, species diversity, and ecosystem diversity** (see Figure 4.1.10).

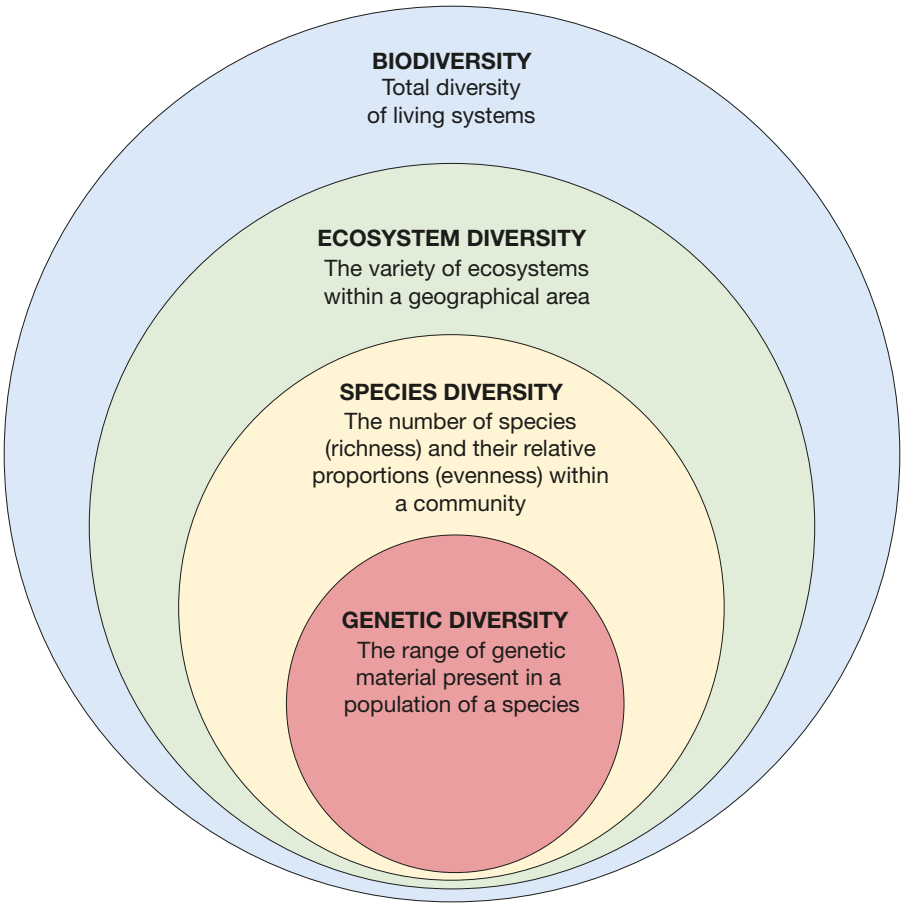


Figure 4.1.10: An overview of the three levels of biodiversity.

Helpful online resources

FuseSchool – Global Education: What Is Biodiversity?

<https://www.youtube.com/watch?v=_bk2nnDI68g>

Importance of biodiversity

Living things have evolved in ways that maintain the planet, so it is suitable for life to exist. Some examples include nutrient cycling, the regulation of climate, regulation of the water cycle, and maintaining atmospheric oxygen and carbon dioxide levels. **Biodiversity is therefore important for the continuity of life on Earth**. It is important to conserve biodiversity so that life can continue to flourish on Earth.

Ethically speaking, diversity of life has aesthetic value that should be preserved. The clearing of land and introduction of non-native species reduces biodiversity at all levels. Therefore, the best way to preserve biodiversity is to preserve the natural habitat of species.

Biodiversity is important for many reasons, including:

- the provision of oxygen, food and fresh water
- the provision of resources and raw materials
- it is a source of organic molecules for medicinal purposes
- the breakdown of waste materials
- provision of natural sites for recreation and appreciation of the beauty that exists in nature's ecosystems.

Helpful online resources

MinuteEarth: Why Biodiversity Is Good For The Economy

<https://www.youtube.com/watch?v=c80oLYvr9ck>

FuseSchool – Global Education: Why does biodiversity matter to me?

<https://www.youtube.com/watch?v=O7PPd_0a9Mw>

Genetic diversity

Genetic diversity can be described as **the diversity within species**. Species are made up of individuals with their own unique combination of genes. Species may also have different populations around the world that are genetically different from each other. Generally, the more individuals there are in a population, the greater the genetic diversity is and the greater the chance of a species surviving environmental changes.

Genes are sections of DNA on the chromosomes of organisms that code for specific proteins, and these become expressed as the features or characteristics of the organism. The appearance of an organism, its **phenotype**, is therefore a direct expression of its **genotype** (the genes it has), together with the effects of the environment.

Effect of the environment on genetic diversity

A population is a group of individuals of the same species that interbreed together in a particular living place. One species will consist of many populations that are geographically isolated from one another. As a result, they are exposed to different environmental conditions (biotic and abiotic factors) that act on the variation within these populations. Therefore, different populations generally have different genetic compositions, or **gene pools**. A gene pool is the sum of all genes of all the individuals in a population. Not all groups or species have the same degree of genetic diversity, but this diversity is important for the survival of the species.

If a population has a diverse set of genes, or **large gene pool**, then it is **more likely to survive** changing environmental conditions that may threaten the survival of individuals. This is because it increases the chance that some individuals will have genotypes that can survive the changing conditions. The individuals that are better adapted to the new environmental conditions, or selection pressures, are therefore more likely to reproduce and pass on the more suitable traits to their offspring. If all individuals were genetically identical, then one change in the environment, such as a new disease, could wipe out all individuals of the population. This mechanism or process is called **natural selection** which was first proposed by Charles Darwin in 1859. A prime example of the importance of variation for the survival of a species is seen in the peppered moth example (see Figure 4.1.11).

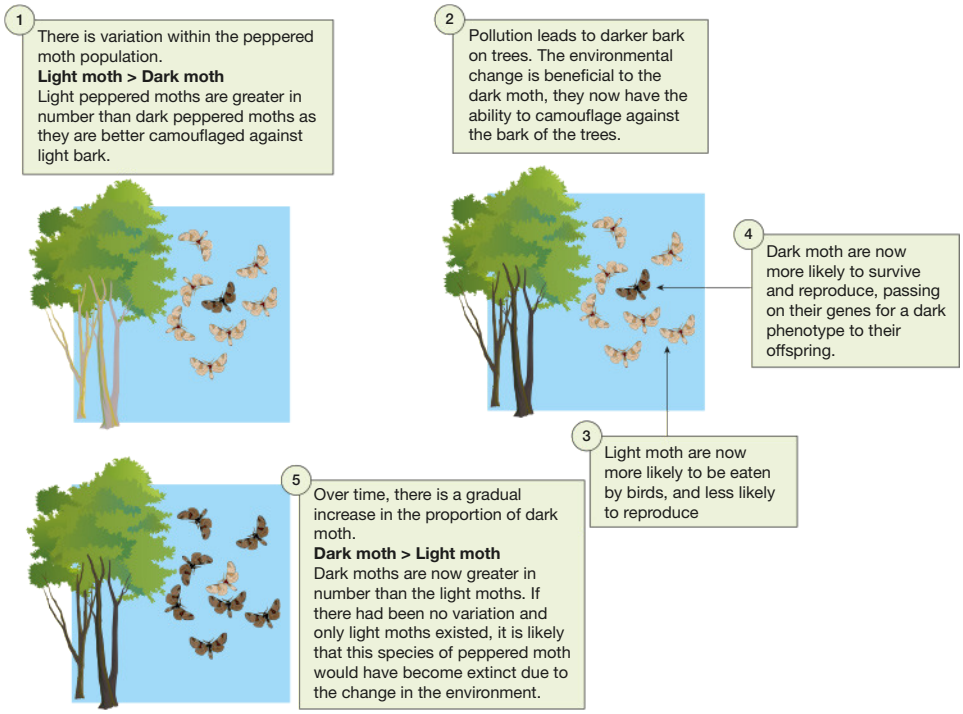


Figure 4.1.11: The effect of pollution on the population of peppered moths.

Another environmental factor that can affect genetic diversity is **genetic drift**. Genetic drift refers to **random changes** in the gene pool of a population and small populations are more susceptible to genetic drift. One example is the random loss of genes due to environmental events such as natural disasters. This is called the **bottleneck effect** (see Figure 4.1.12). If a bushfire rips through an ecosystem, there is large loss of life, but there is also a large reduction in genetic diversity due to the individuals within populations that are killed. The individuals that survive a bushfire are not necessarily better adapted to their environment, they were just in the right place at the right time. Any reduction in population sizes, such as by disease or hunting, results in a reduction in genetic diversity and an increased pressure of survival on the species. This has been noted with the population of platypus on King Island in Bass Strait, which has very low genetic biodiversity in the population rendering them highly susceptible to disease or other environmental pressures.

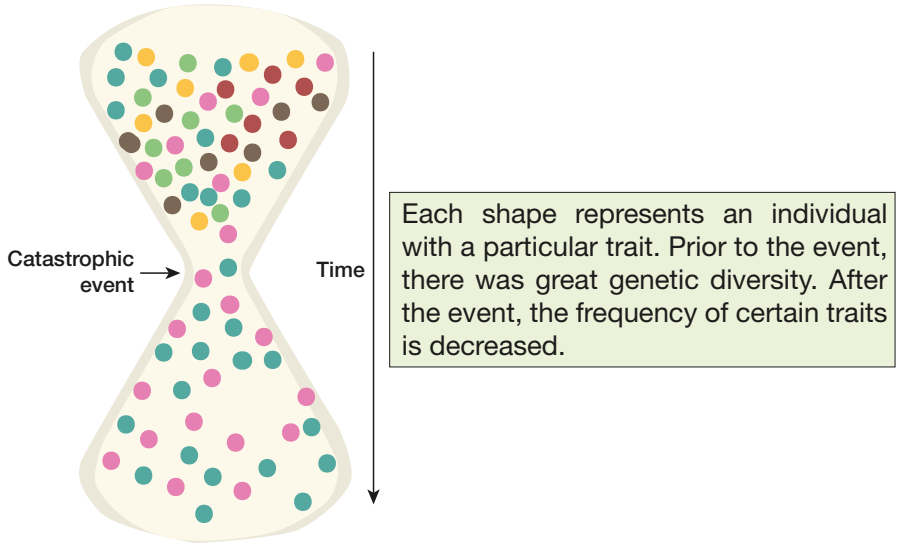


Figure 4.1.12: The effect of a genetic drift event such as volcanic eruption on the variation within a population.

Species diversity

Species diversity is what we are generally thinking of when we think of the richness of life on Earth. More specifically, species diversity is the **variety of species in a community** or geographical area. Some areas on Earth have a low species diversity, such as deserts, whereas others have a rich species diversity, such as rainforests. Species diversity generally increases in richness from the poles to the equator.

Currently, approximately 1.5 million species have been discovered on Earth. However, there are many species yet to be discovered especially in areas such as deep-sea trawls and subterranean ecosystems. It is estimated that there could be more than 11 million species on Earth, with many of these being species of microorganisms.

Species diversity is essential for perpetuation of the community. Delicate relationships exist between organisms in a healthy ecosystem. Adding or removing one species can change the entire ecosystem. Humans don't always fully understand all the interactions between species and the importance of one species to another in a community. An example of this is the redundant mutualistic relationship between the dodo and Calvaria tree. By 1681, the dodo of New Zealand was hunted to extinction. Following the extinction of the dodo, the numbers of Calvaria trees significantly declined. Further research discovered that the dodo was involved in the dispersal of Calvaria tree seeds. The dodo fed on the seeds, which involved breaking open the very hard-outer casing. The seeds passed through the digestive system of the dodo and was dispersed through its waste. Without the dodo, less of the hard-outer casings were broken and less seeds were being dispersed. These two species coevolved and they are one example of how animals and plants can rely on each other in a community.

Figure 4.1.13: Tropical rainforests (left) and the Great Barrier Reef (right) are two examples of ecosystems with a rich species diversity.

Ecosystem diversity

Ecosystem diversity refers to the **variety of ecosystems on earth**. Within ecosystems, communities interact with the physical factors such as light, water and soil to form ecosystems. There are many different ecosystems such as tropical rainforests, deserts, grasslands and freshwater river ecosystems (see Chapter 4.5 for more information). Ecosystem diversity helps regulate climatic conditions, recycle nutrients, maintain soil quality, and maintain balance in atmosphere. Humans could not live on Earth without these processes ecosystems naturally perform. **Ecosystem diversity is therefore essential for the perpetuation of life**. Unfortunately, humans are negatively impacting many ecosystems and the global processes they help regulate. This is explored further in Chapter 4.7 – Human impact on ecosystems.

4.1 Review questions

Multiple choice questions

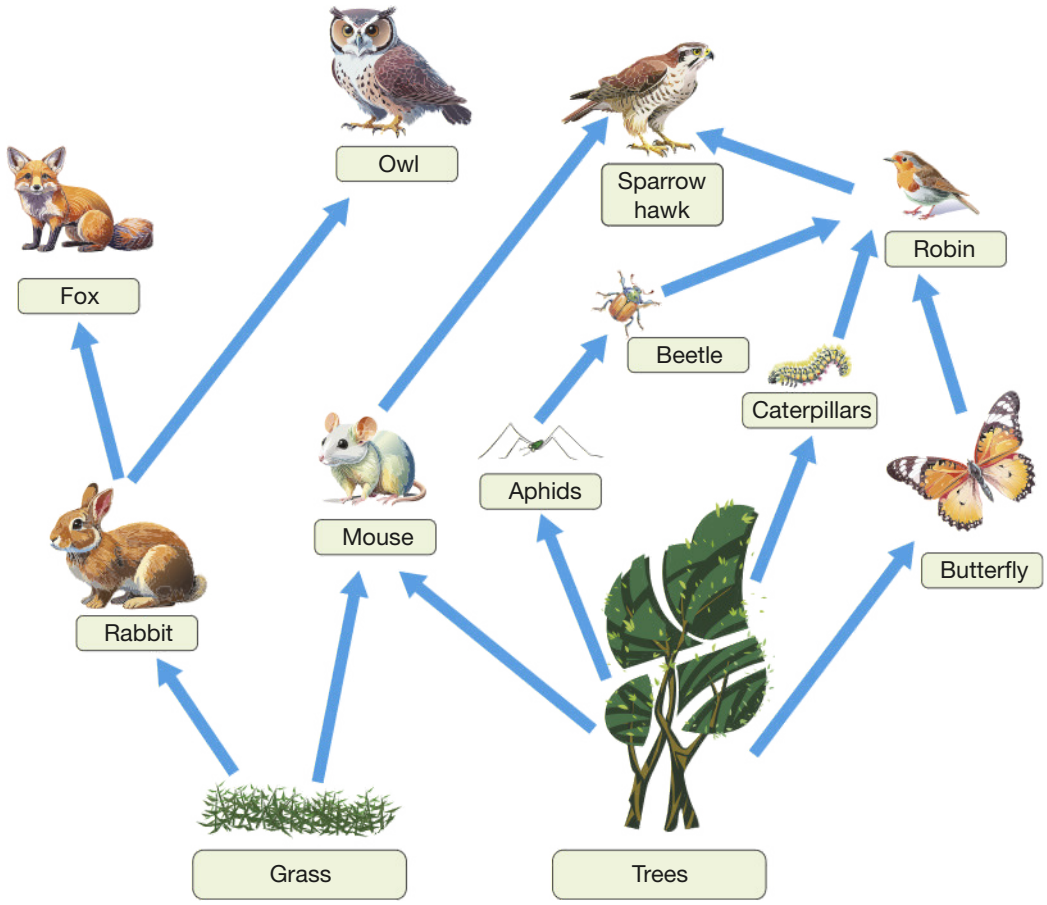
1. An ecosystem can be defined as
   - J all the interactions between organisms in a specific geographical area.
   - K a community and its interactions with its physical environment.
   - L the abiotic factors in a specific geographical area.
   - M all the populations of a species in the biosphere.
2. Which of the following options is **not** a biotic factor?
   - J The introduction of European wasps to Australian ecosystems.
   - K Competition for nesting sites in trees.
   - L Chlamydia disease killing koalas.
   - M Low phosphorus content in soil.
3. Decomposers
   - J are autotrophs.
   - K use inorganic molecules to make food.
   - L breakdown organic wastes into inorganic molecules.
   - M are always positioned at the first tropic level.
4. Maintaining biodiversity is important for many reasons. Which of the following options is **not** one of these reasons?
   - J It increases sources of possible medicinal chemicals.
   - K Maintains a suitable oxygen concentration in atmosphere.
   - L Provides a variety of resources.
   - M It decreases food sources.
5. Cattle egrets eat the insects stirred up by cattle when they are grazing. The cattle are unaffected, while the birds gain food.

   This type of interaction between cattle and cattle egrets is best categorised as a
   - J mutualistic relationship.
   - K competition interaction.
   - L commensal relationship.
   - M predator-prey interaction.
6. The trophic level that contains organisms that only consume plant material is
   - J primary producers.
   - K primary consumers.
   - L secondary consumers.
   - M tertiary consumers.

7. Genetic diversity in a species is important

J to increase the chance of a species surviving changes to the environment.
K to prevent genetic drift.
L to provide resources such as food and water to humans.
M because biodiversity has aesthetic value that should be preserved.

Refer to the diagram below which shows a food web to answer questions 8 and 9.



8. Select the option below that correctly identifies four organisms and their respective trophic levels.

	Primary consumer	Secondary consumer	Tertiary consumer	Quaternary consumer
J	Trees	Beetles	Sparrow hawk	Owl
K	Mouse	Owl	Fox	Sparrow hawk
L	Beetles	Butterfly	Sparrow hawk	Robin
M	Rabbit	Sparrow hawk	Robin	Sparrow hawk

9. If the beetle was removed from this food web, the most likely and direct effect on the food chain would be:

J the robin's population would increase.
K the caterpillar numbers would decrease.
L the number of trees would decrease.
M the aphid population would decrease.

10. Farmers generally spray their crops with herbicides to kill weeds.

They do this because

J weeds are a nuisance and must be killed.
K weeds are producers that can photosynthesise.
L weeds are parasites.
M weeds compete with the crops for mineral nutrients from the soil.

Free response questions

1. Distinguish between the following terms:
   a) Species and population

   b) Population and community

   c) Community and ecosystem

   d) Biotic and abiotic factors

2. List some typical natural resources that an ecosystem provides for the community.

3. Explain why typical ecosystems have a variety of different populations.

4. Australia has been described as 'mega-diverse' with many 'endemic' species. Explain what this means.

5. Identify the likely type of interaction involved in each of the following examples, choose from: *predation, competition, mutualism, commensalism and parasitism.*
   a) Brumbies and wallabies feeding together in an ecosystem
   b) A tick feeding on a kangaroo through its skin
   c) A remora fish attaching to a whale shark
   d) Cellulose-digestive bacteria feeding in a cow's stomach
   e) A platypus hunting a yabby
   f) A Venus fly-trap and an insect
6. Explain what it means when scientists state that members of different species are genetically isolated.

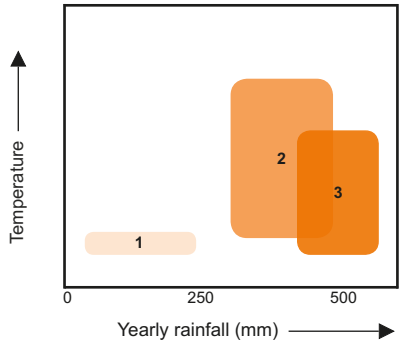
7. The cassowary is a bird that feeds on fruits and berries. When the birds eat the fruits, seeds are not digested but when passed from the bird's digestive system are able to germinate and grow into new plants.
   a) Identify **and** explain the type of symbiotic relationship that exists between the cassowary and these fruit bearing plants.

b) Explain how this relationship contributes to biodiversity in the ecosystem in which it is found.

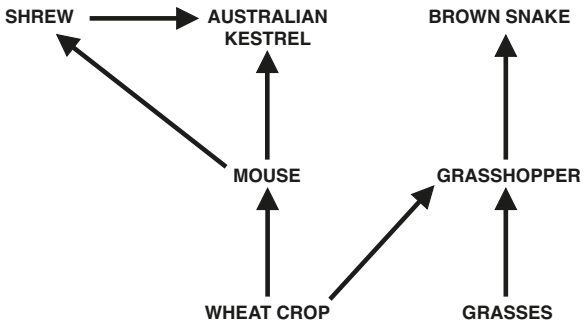
8. In the adjacent diagram the areas enclosed show the range of temperature and rainfall in which species 1, 2 and 3 can exist. On the basis of the information shown:

a) State the species that can survive over the greatest temperature range.

b) Explain why species 2 and species 3 are more likely to compete with each other than with species 1.



9. The food web below represents some of the feeding relationships in an agricultural ecosystem.



a) Identify the organisms in this food chain that consume at the:

Second trophic level:

Third trophic level:

Fourth trophic level:

Third and fourth trophic levels:

b) Explain **two** reasons why the shrew numbers might fall if the mouse population was effectively wiped out by a disease:

c) Explain the possible effects of the mouse population being wiped out by a disease on the grasses in this ecosystem.

10. The following account was recorded by some biologists observing the feeding relationships in a typical Australian woodland.

One of the most aggressive predators was the feral cat. It fed on invertebrates, reptiles, birds and several native animals up to the size of possums. Another high order consumer was the dingo that fed mainly on koalas, ring tail possums, and the yellow-footed antechinus. It was open woodland dominated by two species of eucalypt. There were some small shrubs, grasses and the occasional golden wattle. The koala and ring tail possums obtain their requirements feeding on the leaves of trees. Invertebrates like spiders, hunt for gnats and other insects, which feed on shrubs and grasses, and ants feed on nectar from the flowers of wattle and eucalypts. The birds like the grey fantail and willi-wagtail feed on a variety of invertebrates. The kookaburra had a varied diet consisting of insects and small birds. The yellow-footed antichinus feeds mainly on spiders and large insects. The main decomposers were bacteria and fungi.

a) Using the description above, construct a single food chain to include a producer, first, second and third order consumer.

b) Complete the table below, listing each organism in the correct column.

Producers	Primary consumers	Secondary and higher order consumers	Decomposers

c) Name an organism which is a:

- carnivore
- herbivore
- omnivore

d) From the information in the biologists account above, construct a food web to show the feeding relationships between the organisms mentioned.

11. Biodiversity is important for all life.

    a) Explain why the higher the level of species diversity, the more stable the ecosystem.

    b) State **four** examples to illustrate why ecosystem biodiversity is important to human populations.

    c) Predict why the species richness in an Australian sclerophyll forest would generally be higher than in an Australian grassland ecosystem.

Chapter 4.2 Biological classification

Science Understanding

Biological classification is hierarchical and indicates the relationship between organisms based on their physical structures and the similarities in shared molecular sequences.

There is an internationally agreed system of nomenclature of species which undergoes revision.

- Distinguish between scientific names and common names for species.
- Recognise that very closely related species have similar scientific names.
- Discuss the advantages of an internationally agreed system of nomenclature. Different species show different features that help maintain their reproductive isolation.

Reproductive isolating mechanisms may be pre-zygotic or post-zygotic.

Biological classification

Taxonomy is the science of classifying organisms and sets the criteria for classification of organisms. Classification is therefore the process of organising organisms into **taxonomic groups** using one or more criteria. Classification is an artificial process invented by humans and there is no single correct way to classify. Traditionally, organisms were classified based on their structural characteristics, but due to advances in technology, molecular (DNA and protein) sequencing is also used for a more accurate classification.

Purpose of classification

Classification enables scientists to organise, name and study the vast number of different types of living things. It is estimated that there could be more than 11 million species on Earth, of which approximately 1.5 million have currently been classified. Classification keys enable scientists to **organise, locate and identify species** and reduce the amount of information they need to sort through and remember, such as which plants are poisonous and should not be eaten.

There is an internationally agreed system of nomenclature of species that allows each organism to have a single **universally recognised scientific name**. This helps to avoid confusion that arises from organisms having two or more **common names**, which are used in everyday language. An example of this is *Echium plantagineum*, which is a plant with purple flowers native to parts of Europe, Africa and Asia. *Echium plantagineum* has also been introduced to Australia and the United States of America where it is an invasive weed and is poisonous to livestock. This purple weed has many common names across the world including Paterson's curse, Salvation Jane and purple viper's-bugloss (see Figure 4.2.1). Having a universally recognised scientific name avoids the situation of one species, like this plant, being classified as multiple species. Classification also gives scientists some insight to **evolutionary links** as it helps show how closely related organisms are.

Figure 4.2.1: Echium plantagineum has many common names globally but its scientific name ensures it is correctly classified as one species.

Hierarchical classification

Biological classification involves identifying organisms and placing them into groups. These groups are known as **taxonomic levels** or **taxa** (singular: taxon) and was designed by Carolus Linnaeus in the 18th century. These taxonomic groups form a hierarchical system where large groups contain smaller groups. The taxonomic groups in descending order are shown in Figure 4.2.2.

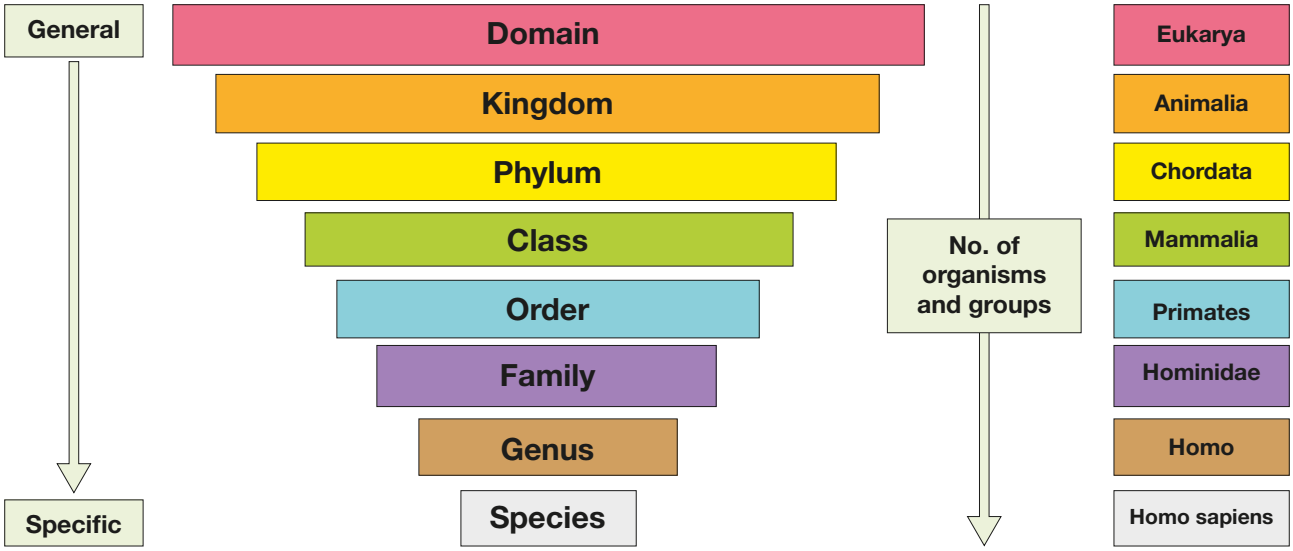


Figure 4.2.2: Linnaeus' hierarchical structure of biological classification allows species to be grouped and named, such as humans being classified as Homo sapiens. Species have more features in common the more subdivided they are.

This sorting is based on shared characteristics as well as molecular similarities. **Domains** are the highest and **most general** taxonomic level, whereas **species** are the lowest and **most specific** taxonomic level. As the taxonomic levels become more specific, they become smaller and contain less species. This is represented in Figure 4.2.2 but is more clearly presented in the example in Table 4.2.1. Additionally, species that are closely related will have a greater number of the same taxonomic levels in common.

Table 4.2.1: An example of how taxonomic levels increase in specificity from domain to species. It is also evident in this example that the bonobo and chimpanzee are the most closely related species in this example due to having the most taxonomic levels (seven) in common.

Common Name	Domain	Kingdom	Phylum	Class	Order	Family	Genus	Species
Lousiana live oak	Eukarya	Plantae	Tracheophyta	Angiospermae	Fagales	Fagaceae	*Quercus*	*Quercus virginiana*
Earthworm	Eukarya	Animalia	Annelida	Clitellata	Opisthopora	Lumbricidae	*Lumbricus*	*Lumbricus terrestris*
Goldfish	Eukarya	Animalia	Chordate	Actinopteri	Cypriniformes	Cyprinidae	*Carassius*	*Carassius auratus*
Killer whale (orca)	Eukarya	Animalia	Chordate	Mammalia	Artiodactyla	Delphinidae	*Orcinus*	*Orcinus orca*
RIng-tailed lemur	Eukarya	Animalia	Chordate	Mammalia	Primates	Lemuridae	*Lemur*	*Lemur catta*
Human	Eukarya	Animalia	Chordate	Mammalia	Primates	Hominidae	*Homo*	*Homo sapiens*
Bonobo	Eukarya	Animalia	Chordate	Mammalia	Primates	Hominidae	*Pan*	*Pan paniscus*
Chimpanzee	Eukarya	Animalia	Chordate	Mammalia	Primates	Hominidae	*Pan*	*Pan troglodytes*

Binomial system

The **binomial system of nomenclature** was also designed by Carolus Linnaeus, in the 18th century. The binomial system is used to give every species a **scientific name with two parts**, hence binomial. The first part is the **genus** (generic) name, which is capitalised (e.g. ***Homo***). The second part specifies the **species** (specific) name, which is written in lower case (e.g. ***sapiens***). Together, the genus and species names form the scientific name, which is ***Homo sapiens*** for humans, using the binomial system of nomenclature. These are the lowest two levels of the hierarchical structure of biological classification. The binomial names are Latin and are therefore typed in *italics* or underlined if handwritten to indicate that they are Latin. Sometimes the genus name is shortened to just an initial, so humans scientific name could be presented as ***H. sapiens***.

It is important to note that even though two organisms may have the same genus name, they are not the same species if the second part, the species name, is different. Having the same genus name but a different species name, indicates that the two species are closely related. An example of this is lions, ***Felis leo***, and wild cats, ***Felis sylvestris***.

The international system of nomenclature of species undergoes revision

Originally, only five kingdoms were recognised in Linnaeus' hierarchical structure of biological classification (see Figure 4.2.4). With emerging technologies of molecular sequencing of DNA and proteins, it became evident that there were problems with this system. The modern classification system now includes a more up to date version of the classification system with three domains, eukarya, archaea and bacteria (see Figure 4.2.5). The Eukarya domain consists of eukaryotic species, whereas Archaea and Bacteria domains both consist of prokaryotic species.

The main reason for this change is because archaea are very different from bacteria at both the structural and molecular levels. This resulted in the decision to split the monera kingdom into two kingdoms, bacteria and archaebacteria, changing the number of kingdoms to six (see Table 4.2.2 for some information on the six kingdoms). There is not universal agreement about the current system and the nomenclature system is **reviewed every 4 years** at a series of international congresses. Even though some taxonomists may not agree with the current system, it is the internationally agreed system of use to maintain consistency.

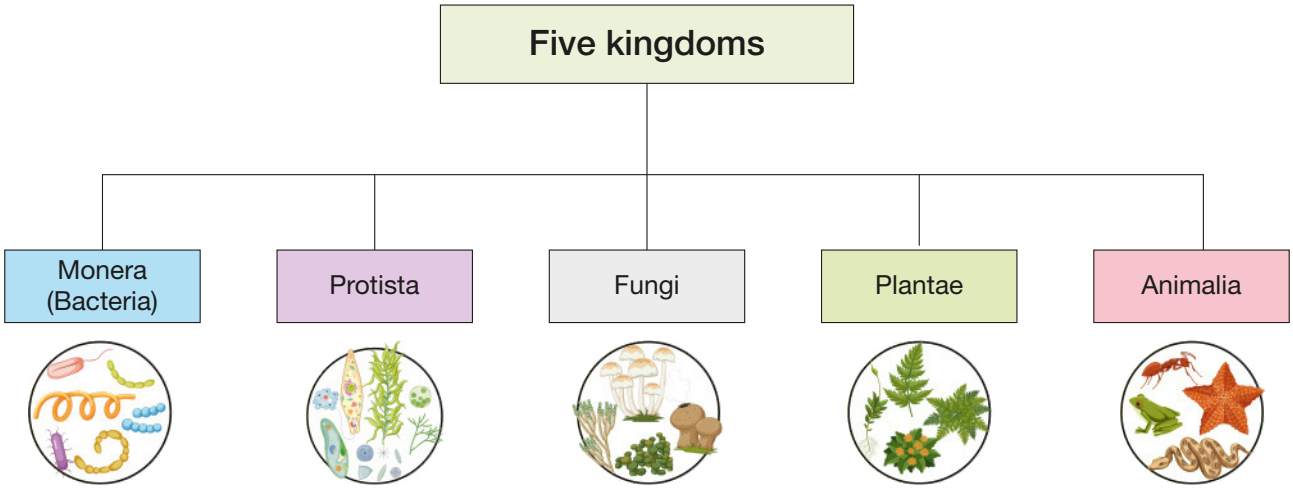


Figure 4.2.4: Linnaeus' original hierarchical structure of biological classification included five Kingdoms.

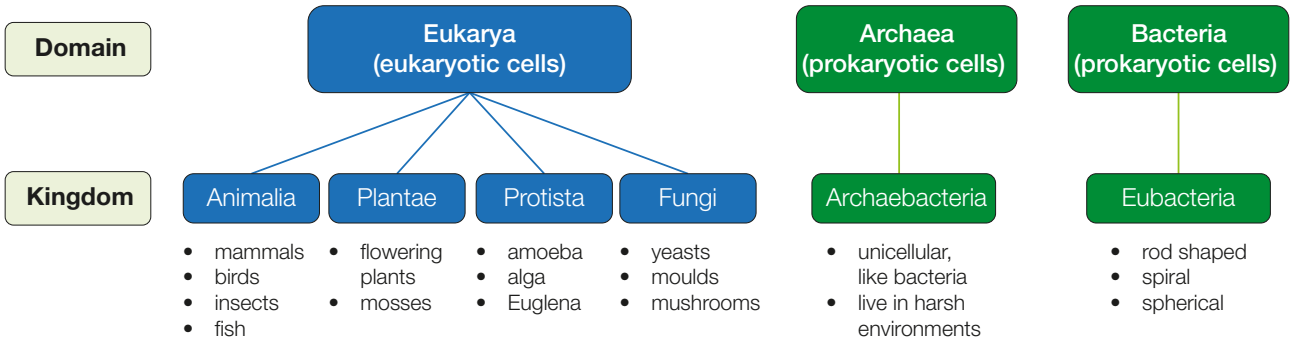


Figure 4.2.5: The modern hierarchical structure of biological classification which includes three Domains and six Kingdoms.

Table 4.2.2: The six kingdoms and some characteristics used to identify groups that are classified.

Kingdom	Prokaryotic or eukaryotic	Has a cell wall?	Type of nutrition	Other
Animalia	Eukaryotic	No	Heterotrophic	Mostly multicellular, mobile and specialised organs and systems
Plantae	Eukaryotic	Yes	Autotrophic	Mostly photosynthetic and non-mobile
Protista	Eukaryotic	No	Heterotrophic or Autotrophic	Extremely diverse group, some animal like (amoeba) and some plant like (alga)
Fungi	Eukaryotic	Yes	Heterotrophic	Reproduction by spores
Archaea	Prokaryotic	Yes	Heterotrophic or Autotrophic	Unicellular, live in harsh environments
Bacteria	Prokaryotic	Yes	Heterotrophic or Autotrophic	Unicellular with a variety of different shapes (rod, spiral, spherical)

Helpful online resources

Cognito: GCSE Biology - Classification

<https://www.youtube.com/watch?v=HLnaIJm5wM4>

Basis of classification

Recall that a species is defined as a group of organisms with similar anatomical characteristics that share a common gene pool. **Organisms of the same species can interbreed to produce fertile offspring** but those from different species cannot. This definition has its **limitations** though including:

- Reproductive isolation does not occur instantly and even though two populations may have different physical features, they may still be able to interbreed and produce fertile offspring.
- This species definition cannot be applied to asexually reproducing species.
- There could be a lack of data to apply this species definition to particular species. This could be because of a lack of funding for research or it could be because the species are extinct and their interbreeding behaviours have not been documented.

Therefore, when classifying organisms into their respective groupings multiple characteristics are often used to increase the accuracy of the classification including: physical features, reproductive strategies and molecular sequencing.

Physical features

As physical features are an expression of the genotype and the environment, it is logical that organisms with similar features are often closely related. As discussed earlier in this chapter, these physical features can be used in classifying a range of different organisms. An example for plants and animals is shown in Figure 4.2.6.

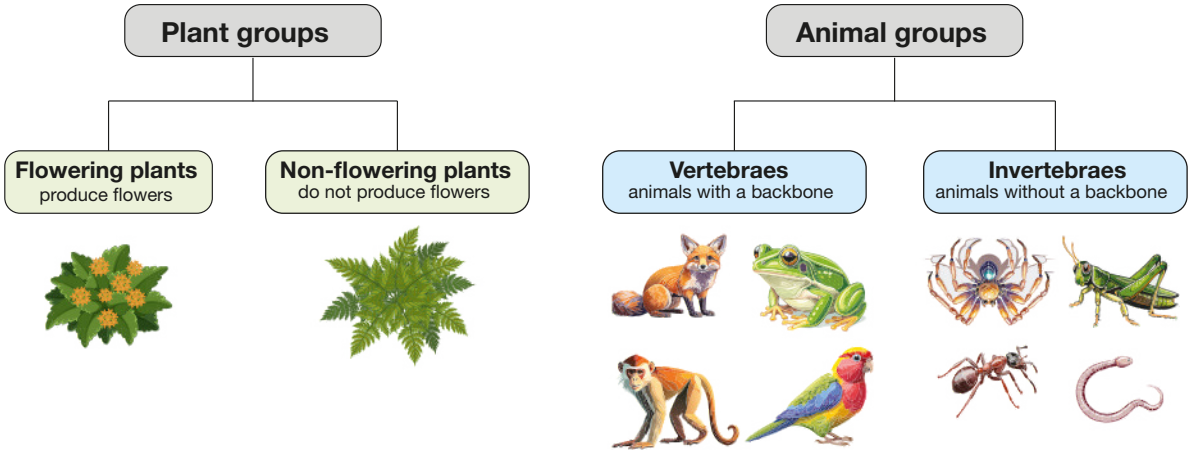


Figure 4.2.6: Plants can be grouped by their ability or inability to produce flowers, and animals can be grouped by the presence or absence of a backbone.

Reproductive strategies

Methods of reproduction are also used in classification. Some species reproduce by sexual means, which involves the fusion, or fertilisation, of gametes. Other species reproduce by asexual means, which does not involve gametes and instead involves the processes of binary fission or mitosis. An example of the use of reproductive strategies to group organisms are mammals. All mammals have fur, produce milk and are warm-blooded, but they can have one of three different reproductive strategies. Refer to Table 4.2.3 for more information.

Table 4.2.3: An example of how the reproductive strategies of mammals can be used to group them into three different groups.

Mammal grouping	Examples	Description of reproductive strategies
Placentals	• Humans • Cats	A placenta nourishes the foetus. Placentals give birth to live and well-developed offspring.
Marsupials	• Kangaroo • Wallaby	They give birth to small and poorly developed young that reside and develop in a mother's pouch.
Monotremes	• Platypus • Echidna	They lay eggs but the offspring still suckle on the mammary glands of their mother.

Molecular sequencing

In recent times, the practice of examining DNA sequences and protein sequences of organisms has been of great assistance in either helping to classify species or to support other evidence, such as physical features. Molecular sequencing has helped to **increase the accuracy** of biological classification.

DNA is made up a very long sequences of four bases: adenine, guanine, cytosine and thymine. By comparing DNA and known gene sequences, inferences can be drawn regarding common ancestors and henceforth, the degree of relatedness.

A common example of molecular sequencing is the use of the protein cytochrome c to compare the relatedness of species. Cytochrome c is a protein that is **necessary for aerobic respiration in virtually all living organisms**. This protein varies from one species to another, and the degree of similarity in its amino acid sequence between species indicates the closeness of the evolutionary relationships. The cytochrome c sequences for humans and chimpanzees match at all 104 amino acid positions for example indicating a very close evolutionary relationship. Human cytochrome c varies in nine amino acids from a rabbit, 13 amino acids from a turtle and 45 amino acids from yeast. Humans are therefore the least closely related to yeast from the organisms mentioned (see Table 4.2.4).

Data provides support for classifying some species as more closely related to a particular group when compared with other groups. It has been found that the evolutionary relationships based on this protein are generally in agreement with those based on physical features.

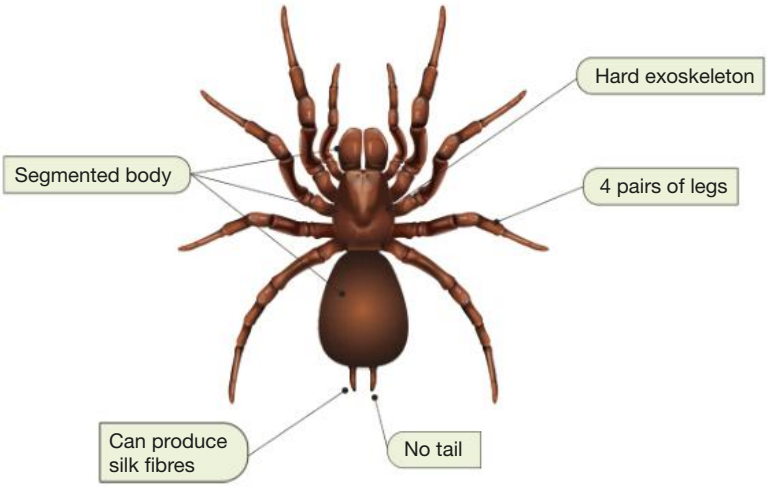
There are some **limitations** to this process though. Molecular sequencing cannot be used on extinct species where the DNA and proteins have degraded and cannot be sequenced reliably. Additionally, species that do not respire aerobically cannot be compared using the amino acid sequencing of the cytochrome c protein.

Table 4.2.4: The differences between cytochrome c amino acid sequences in six species. It is assumed that the first organisms had cytochrome c and that over billions of years there have been changes in the gene coding for the protein.

	Human	Monkey	Rabbit	Duck	Turtle	Yeast
Human	0					
Monkey	1	0				
Rabbit	9	8	0			
Duck	11	10	6	0		
Turtle	13	14	9	7	0	
Yeast	45	45	15	46	49	0

Using dichotomous keys

A dichotomous key is a reference tool that uses a series of alternative choices to clearly identify a given species. Dichotomous means 'divided into two parts.' A dichotomous key therefore presents a series of mutually exclusive choices based on particular characteristics. To identify a species, the **pair of statements** need to be applied to the unknown species. One statement will be applicable whereas the other will not. The applicable statements will then lead to another pair of statements, which will lead to another pair of statements. This will continue until a correct statement leads to the identity of the species (see Figure 4.2.7). Dichotomous keys can also be represented by means of branched diagrams (see Figure 4.2.8). **Branched diagrams** can be easier to understand, but they take up a lot of space and are therefore limited in the number of organisms they can include.



1	Hard exoskeleton absent . . . . . 2 Hard exoskeleton present 3
2	Hard shell absent . . . . . Slug Hard shell present . . . . . Snail
3	3 pairs of legs . . . . . 5 4 pairs of legs 4
4	Tail absent . . . . . .6 Tail present . . . . . Scorpion
5	Body color uniform . . . . . Ant Body striped black and yellow . . . Wasp
6	Silk producing organ present . . . Spider Silk producing organ absent . . . . .Mite

Figure 4.2.7: The features of the organism can be used to identify it using the dichotomous key. The organism is a spider as it has an exoskeleton, four legs, no tail and it can produce silk.

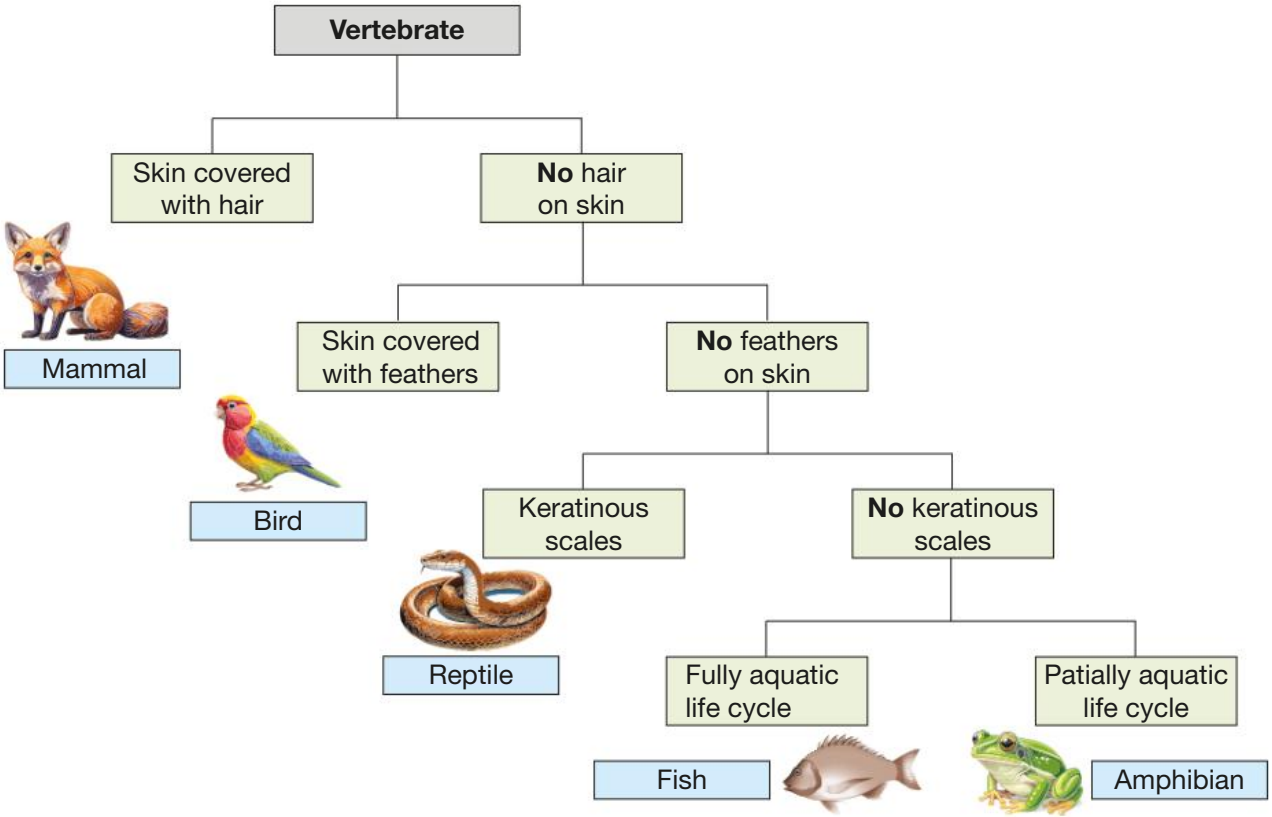


Figure 4.2.8: A branched diagram can also be used to provide a series of paired choices and represent a dichotomous key.

Reproductive isolation

In Chapter 4.1 it was noted that an important feature of a particular species is that, whilst they can interbreed with members of the same species, they are what is termed 'reproductively isolated' from members of another species. This effectively means that separate species cannot interbreed with each other to produce fertile offspring.

Many species have unique and quite involved courting rituals that are designed to attract only members of the opposite sex of the species. The time of flowering plays an important role in sexual isolation in flowering plants. Certain closely-related animal species are also reproductively isolated as their breeding seasons do not coincide. Differences in the shape of animal genitalia may prevent mating and differences in flower shape may prevent pollination.

A mechanism that maintains **reproductive isolation** between groups of closely related species is a biological feature that prevents gene flow between the groups, even though the groups' habitats may overlap. Barriers that prevent fertilisation will either prevent mating between individuals or will interfere with the actual fusion of ova and sperm in animals, or ova and pollen in plants.

An important aspect of reproduction in animals is the attraction of mates. In nature this attraction is normally brought about by specific chemicals called **pheromones**, which are released by one of the sexes, or by specific mating calls and rituals. Frogs emit unique mating calls that attract only members of their own species and female moths release sex attractants (pheromones) that lure the male of the species for mating.

Even if mating does occur, there are instances where the sperm may not unite with the ova. This could occur as the sperm may be destroyed in the reproductive system, fail to be attracted to the ova, or be unable to penetrate the ova. On rare occasions when members of different species do succeed in mating, there are often other factors that will prevent the development of a fertile adult. The fertilised egg may have unequal numbers of chromosomes from the male and female and thus development does not proceed. The well documented case of a horse mating with a donkey and producing a strong, robust mule, that is none the less sterile, is a good example of how reproductive isolation is maintained between the two species of horse and donkey.

Reproductive barriers form isolating boundaries around closely related species and can be divided into two groups, **pre-zygotic** and **post-zygotic** isolating mechanisms (see Figure 4.2.9).

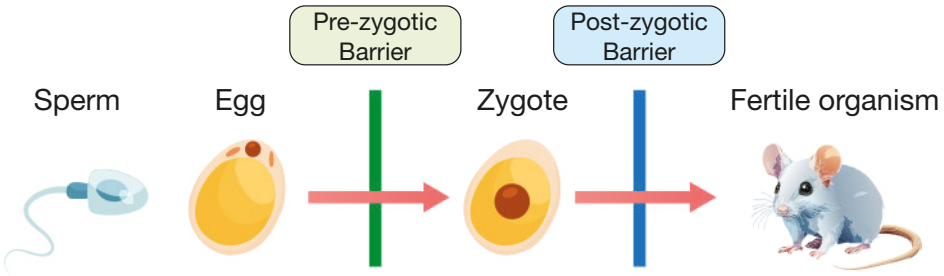


Figure 4.2.9: A pre-zygotic barrier prevents the zygote from forming, whereas a post-zygotic barrier occurs after the zygote has formed and prevents the organism from reaching sexual maturity or being fertile.

Pre-zygotic mechanisms

Pre-zygotic mechanisms refer to any mechanism that occurs **before** the gametes fuse to form a zygote (e.g. sperm and egg). Some examples include:

- Different mating calls and rituals
- The use of species specific chemicals to attract members of the opposite sex
- Differences in flower shape or genitalia
- Different seasons or times for reproduction
- Inability of sperm to survive in the female reproductive system
- Pollen tubes are unable to grow towards the ovules in a flower

Post-zygotic mechanisms

Post-zygotic mechanisms refer to any mechanism that occurs **after** the gametes fuse to form a zygote (e.g. sperm and egg). Some examples include:

- Zygotes fail to develop (miscarriage)
- Young fail to reach sexual maturity
- Offspring live but they are infertile

4.2 Review questions

Multiple choice questions

1. Which of the following is the correct order of taxonomic hierarchy, from largest to smallest?

   J Kingdom → phylum → class → order → family → genus → species
   K Phylum → class → kingdom → order →f family → genus → species
   L Kingdom → class → order → family → phylum → genus → species
   M Kingdom → family → genus → phylum → class → order → species

2. Which of the following options was **not** a kingdom in Linnaeus' original hierarchical structure of biological classification?

   J Monera
   K Protista
   L Archaea
   M Fungi

3. Which of the following options is incorrect regarding what classification keys enable scientists to do?

   J Organise species into groups.
   K Provide insights into how closely related species are.
   L Facilitates identification of organisms.
   M Establish common names for species.

4. As the taxonomic levels decrease from domain

   J the number of organisms represented in each group increase
   K the levels become less specific.
   L the relatedness of organisms increases.
   M the levels become more general.

5. Identify the two closest related species.

   J *Pinus glabra* and *Ilex glabra*
   K *Equus caballus* and *Equus quagga*
   L *Panthera leo* and *Felis leo*
   M *Canis lupus* and *Elephas maximus*

6. Linnaeus' original hierarchical structure of biological classification consisted of five kingdoms, but this has been revised to consist of six kingdoms.

   The most correct reason for this revision is

   J because technology has advanced and it has helped reveal that bacteria are prokaryotic, but archaea are not.
   K bacteria and archaea are just too similar.
   L because taxonomists review the classification system every four years.
   M molecular sequencing has increased the accuracy of classification.

7. *Refer to the diagram below which shows the hierarchy for a grey wolf to answer the following question.*

	X		Y			Z
Animalia →	Chordata →	Mammalia →	Carnivora →	Canidae →	*Canis* →	*C. lupus*

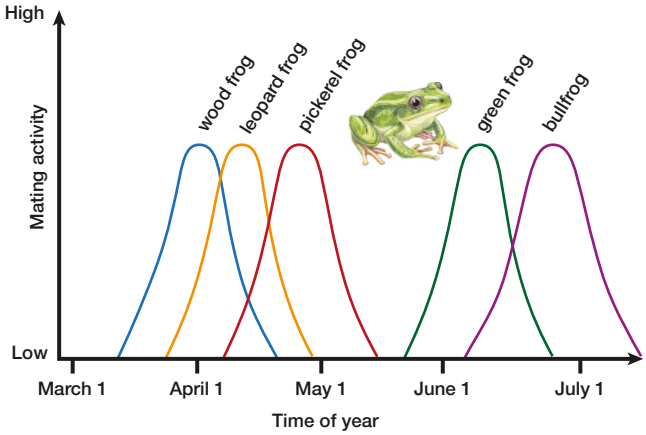
   Identify the taxonomic levels of X, Y and Z.

	X	Y	Z
J	Phylum	Class	Binomial name
K	Class	Order	Genus
L	Phylum	Order	Species
M	Order	Family	G. Species

8. An example of a pre-zygotic barrier is

   J the prevention of an egg being fertilised.
   K infertile offspring.
   L a zygote developing but the individual dies before reaching sexual maturity.
   M mating calls of two frogs being very similar.

9. *Refer to the graph below displaying the mating activity of frogs to answer the following question.*



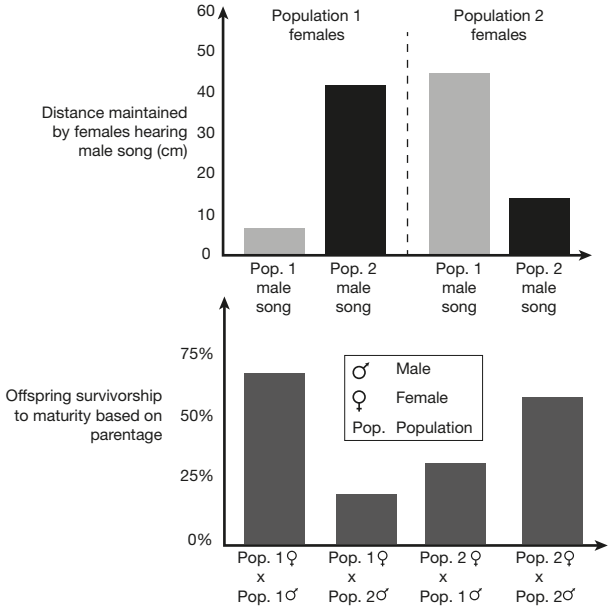
   Select the most correct statement regarding the data displayed in the above graph.

   J All five types of frogs in the graph are reproductively isolated because they mate at different time of the year.
   K The wood frogs and pickerel frogs have no overlap of mating activity between March and July and therefore reproductively isolated.
   L Green frogs and wood frogs live in different ecosystems and are therefore reproductively isolated.
   M The bullfrog and leopard frog are very likely to be reproductively isolated.

10. *Refer to the adjacent graphs displaying the outcomes of courtship and reproduction between two populations of crickets to answer the following question.*

    Male crickets rub their wings together to 'sing' and attract females. With reference to the information in the graphs, the two mechanisms shown to support reproductive isolation between these two populations are

    J different mating rituals and different seasons of mating.
    K reduced success of offspring surviving to sexual maturity and differences in mating calls.
    L all zygotes fail to develop and the two cricket populations deploy their mating calls at different times of the year.
    M the graphs infer geographical separation between the two populations and the two populations have the same mating call.



Free response questions

1. Explain what it means to say that the biological classification system used is hierarchical.

2. Name of the three domain levels of classification used to classify life on Earth **and** state the main identifying characteristic(s) for each one.

3. Describe the binomial system that is used to name organisms **and** state one example.

4. Species can have common names and scientific names.
   a) State the differences between the common names and the scientific names used for organisms.

   b) Describe an advantage for each method of naming organisms.

5. Describe **three** types of information that can be used to separate organisms into different groups.

6. Explain why the internationally agreed system of nomenclature of species undergoes revision every four years.

7. Describe the reproductive strategies used to classify mammals into three separate groups.

8. Explain what it means to say that the members of one species are genetically isolated from other species.

9. Explain how the use of molecular analysis of DNA and proteins has added to scientists' ability to place organisms correctly in the hierarchy of classification.

10. Explain **two** limitations of the definition of a species.

11. a) Compare the timing of the two types of reproductive barriers, pre-zygotic and post-zygotic mechanisms.

    b) State **two** examples of each type of reproductive barrier.

Pre-zygotic	
Pre-zygotic	
Post-zygotic	
Post-zygotic	

12. State **two** examples of reproductive isolating mechanisms that might prevent gene flow for each of the following examples:

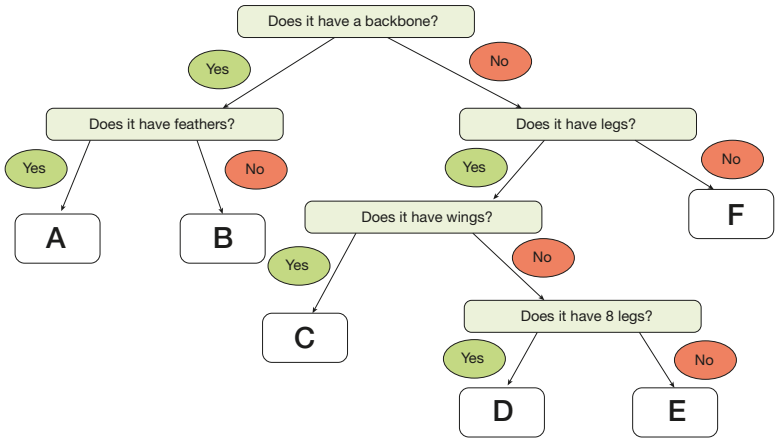
    a) Two groups of flowering plants

    b) Two groups of closely related frogs

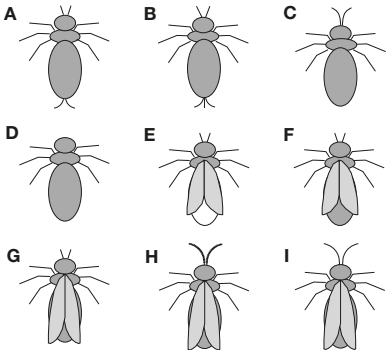
    c) A horse and a donkey

13. Use the branched dichotomous key below to match the animals below with its corresponding letter in the branched diagram.

A:
B:
C:
D:
E:
F:



14. Construct a dichotomous key to classify each of these insects into a separate group.



	Statement	Instruction
1 a		
1 b		
2 a		
2 b		
3 a		
3 b		
4 a		
4 b		
5 a		
5 b		
6 a		
6 b		
7 a		
7 b		
8 a		
8 b		
9 a		
9 b		

Chapter 4.3 Adaptations

Science Understanding

Organisms have adaptations that help them survive and reproduce.

- Discuss examples of adaptations (behavioural, structural and physiological) in plants and animals.

Adaptations

An adaptation is a feature of an organism that increases its **fitness**, which is the probability of the organism **surviving and reproducing** in its habitat. All organisms have adaptations that help them to survive and reproduce in their respective habitats, which are **inherited or learnt**. Generally, adaptations can be grouped into three types (see Figure 4.3.1):

- structural (or anatomical) adaptations
- physiological (or functional) adaptations
- behavioural adaptations

The species in one habitat are suited to live there and may not be suited to live in other habitats. Habitats can change for many reasons including the influence of humans and variations in climate. When species cannot adapt to the changes in their environments, they can die, and over time, become extinct. Therefore, an adaptation is a feature produced by natural selection for its current function in a specific habitat. Organisms adapt for many different reasons including:

- to find nutrients or food
- to adjust to the temperature of their habitat
- to defend themselves from herbivores or predators
- to increase chance of reproducing
- to escape from predators and other dangers
- to adjust to changes in their habitat

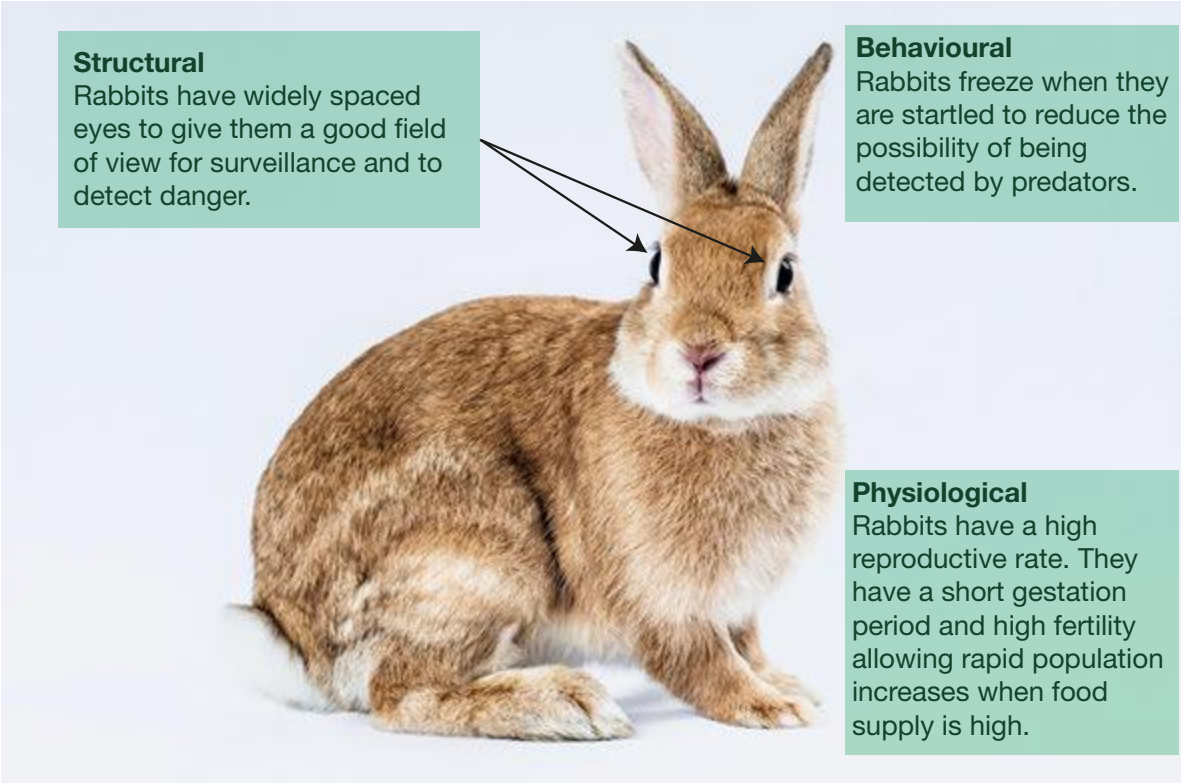


Figure 4.3.1: An example of a structural, physiological and behavioural adaptation of rabbits.

Structural adaptations

Structural adaptations, also called **anatomical** or **morphological** adaptations, are the physical body features of an organism that help them survive (see Figures 4.3.2 and 4.3.3). Structural adaptations are genetically inherited and have been shaped by natural selection, which acts on traits passed on to offspring. These adaptations increase the biological fitness of organisms and do not develop during one organism's life, but over many generations. Some examples of structural adaptations are:

- the large ears of the bilby and other desert animals such as the fennec fox, which increase surface area to emit more heat, cooling the animal down,
- in contrast the arctic fox has very small ears to reduce heat loss and stay warm in the colder climate,
- the streamlined shape of dolphins that assist their movement through the ocean,
- the long neck of a giraffe allows it to reach the leaves high in the treetops which contain the most nutrients and water.

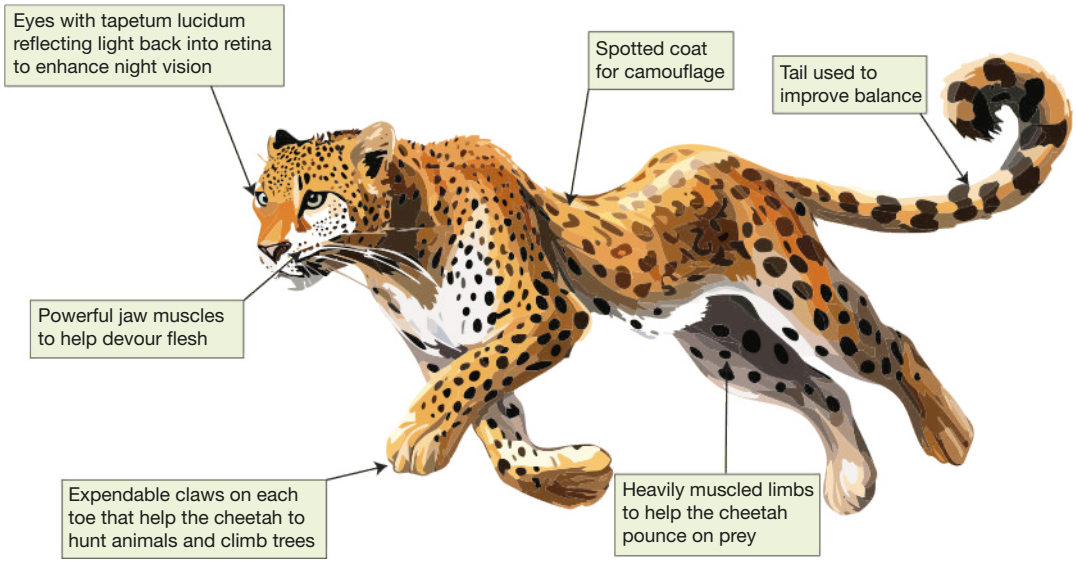


Figure 4.3.2: Some structural adaptations of a cheetah.

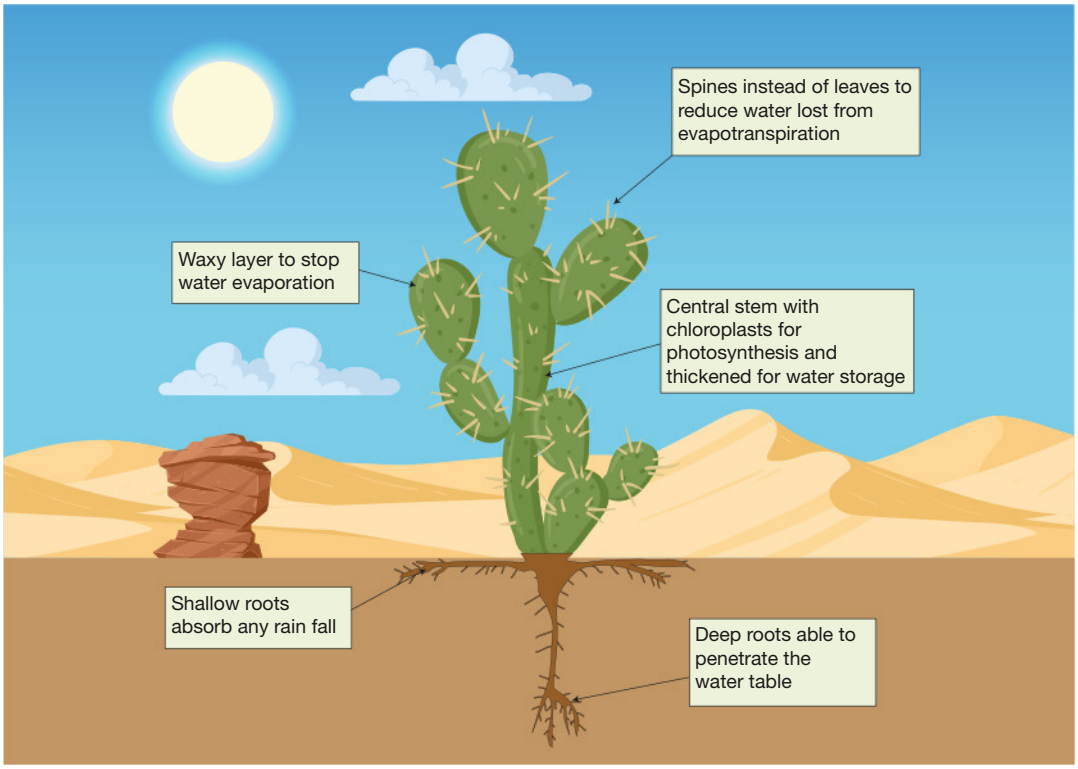


Figure 4.3.3: Some structural adaptations of a cactus.

Physiological adaptations

Physiological adaptations, also called **functional** adaptations, are generally based on features that are not visible. They are generally associated with **metabolic processes** and are usually based on body chemistry and other processes that enhance survival and reproduction (see Figure 4.3.4). Some examples of physiological adaptations are:

- the excretion of very concentrated urine by desert animals such as kangaroo rats that excrete a powder urine to conserve water,
- the presence or secretion of toxins by plants to assist in defending themselves against herbivores,
- a wolves' sense of smell is 100 times more sensitive than a human, which assists with hunting,
- hormones such as oxytocin in humans promote bonding, and breastfeeding increases oxytocin release in both the mother and the feeding baby, further increasing their bond,
- human milk contains all the essential nutrients for a baby to grow and survive and the proportions of the nutrients vary from the start of a feed to the end of the feed, such as the more filling fats being more concentrated towards the end of the feed so the baby can obtain additional essential nutrients before filling up and unlatching,
- harp seal milk is about 50% fat compared to the average 4% fat of human milk, providing extra sustenance for the baby harp seals keep warm in the cold Arctic temperatures.

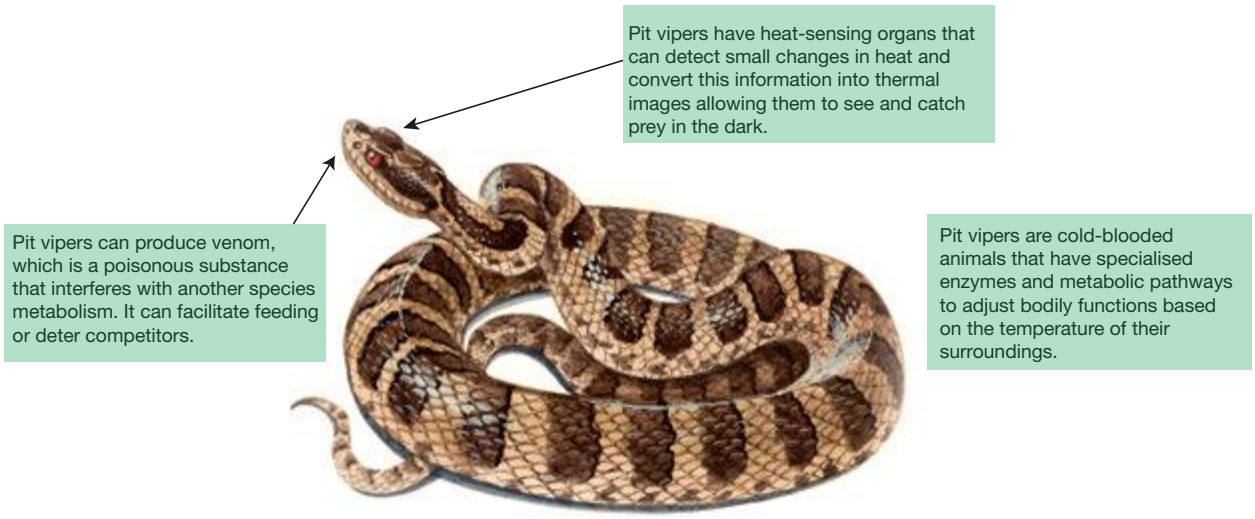


Figure 4.3.4: Some physiological adaptations of a pit viper.

Some structural and physiological adaptations of mangroves

The solute level in soil water is an important influence in determining the community. Plants and animals exposed to elevated solute concentrations need special adaptations to prevent tissue dehydration (see Figure 4.3.5). Mangroves are salt-tolerant trees and shrubs that live in coastal intertidal zones (the area between low and high tides). This means that they live in oxygen poor soil with their roots submerged in saline sea water. Their root system has adapted to provide additional support through prop roots, to prevent being washed away with the changing tides. They have also developed special structures called pneumatophores that stick out of the water at low tide to obtain oxygen for the plant. Mangroves have developed multiple adaptations to survive in the saline conditions such as roots preventing the absorption of salt, leaves excreting salt crystals on their underside, and transporting salt to specific leaves where it accumulates until the leaves die and fall to the ground taking the salt with them.

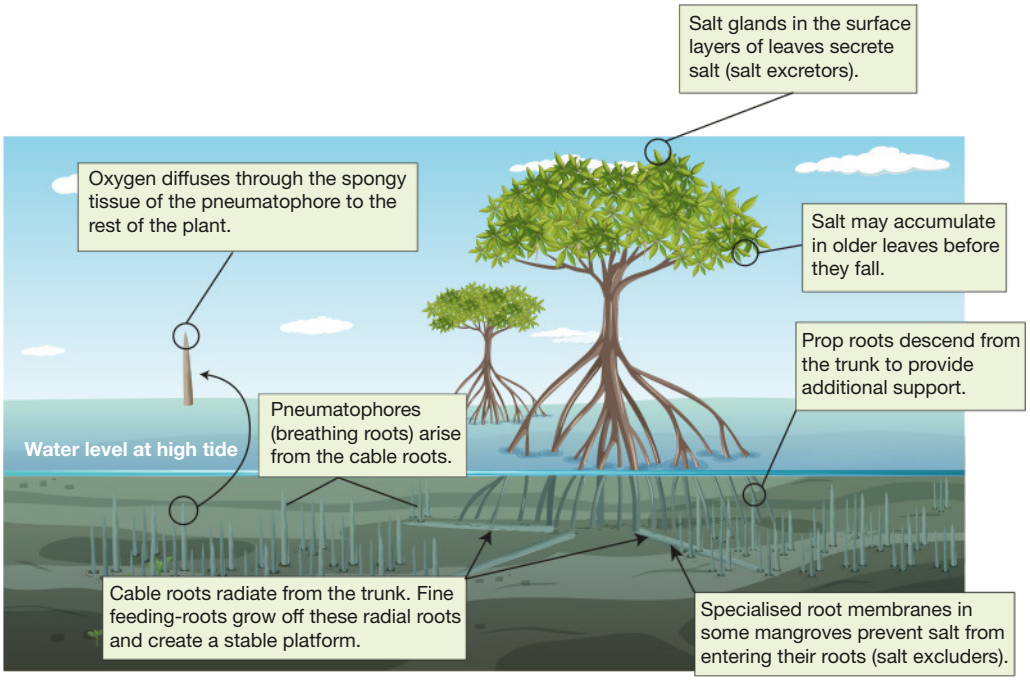


Figure 4.3.5: Some structural and physiological adaptations of mangroves.

Behavioural adaptations

Behavioural adaptations are those associated with patterns of activity or behaviour (see Figure 4.3.6). It is something an animal does in response to an external stimulus to increase its chance of survival and can be **innate or learnt**. An innate behaviour, also called instinctive behaviour, is an act that is performed naturally, the first time an organism is subjected to the stimulus. It is not learnt and is therefore pre-programmed into an organism's genome.

Some examples of behavioural adaptations are:

- some desert animals such as bilbies tend to be more active at night when conditions are cooler (nocturnal species),
- courtship rituals by birds or the mating calls of frogs are behavioural adaptations that help increase the chance of finding a mate and reproducing,
- the migration of humpback whales to colder waters to feed on krill, and migration to warmer waters to give birth,
- when confronted by a predator, opossums play dead to avoid being consumed, and as most predators prefer to eat live prey, so they don't get sick from dead and decaying matter, they do not eat the dead-looking opossum.

Figure 4.3.6: Some behavioural adaptations of emperor penguins.

Helpful online resources

HighSchoolScience101: Types of Adaptations

<https://www.youtube.com/watch?v=vnmPdHmRv9o>

BBC Earth: Top 5 Animal Adaptations

<https://www.youtube.com/watch?v=ZT8YswmQuAg>

4.3 Review questions

Multiple choice questions

1. Organisms are constantly adapting

   J to decrease their chance of reproducing.
   K to compete against other species to be the apex predator.
   L to increase chance of survival in their ecosystem.
   M so they can grow in number and expand into additional habitats.

2. Adaptations are a feature of

   J an individual organism's genes.
   K an organism's habitat.
   L an organism's behaviour.
   M both an organism's habitat and its genes.

3. A physiological adaptation is a

   J body process that helps an organism survive and reproduce.
   K body structure that helps an organism survive and reproduce.
   L body stimulus that helps an organism survive and reproduce.
   M body response that helps an organism survive and reproduce.

4. Nicotine is a potent chemical insecticide and occurs naturally in a variety of plants including tobacco plants. Some urban birds now collect used cigarette butts and line their nest with them to ward off mites, lice and fleas. The type of adaptation these birds have developed would be classified as a:

   J structural adaptation.
   K physical adaptation.
   L physiological adaptation.
   M behavioural adaptation.

5. *Refer to the diagram of a chameleon below to answer the following question.*

   Which of the following options is a physiological adaptation that enhances survival of the chameleon?

   J Each eye can move independently providing a 360° field of vision.
   K Chameleons have a long, sticky tongue that they rapidly extend to capture insects and other small prey.
   L Chameleons can change colour and blend seamlessly with their surroundings.
   M Chameleons have delicate skin and are sensitive to chemicals.

6. Mangroves and other salt tolerant plants have developed the ability to transport excess salt to specific leaves to concentrate and store the salt there until these leaves die and fall to the ground.

   This is an example of a

   J structural adaptation.
   K morphological adaptation.
   L physiological adaptation.
   M behavioural adaptation.

7. Which of the following is an example of an adaptation that some desert plants may exhibit to survive the hot and dry conditions.

   J the leaves are larger with an increased surface area to volume ratio.
   K they have a thick waxy layer to reduce water loss.
   L the leaves have an increased number of stomata to reduce the amount of water loss through evaporation.
   M they have thorns to deter herbivores from eating them.

8. When predators catch live prey they are used to it trying to fight for its life to free itself. However, predators of European grass snakes often experience something different. When a European grass snake is caught by a predator, the snake responds by relaxing all its muscles resulting in a lifeless appearance. It also releases a foul-smelling excretion. This generally results in the predator releasing the snake from its jaws and the snake drops to the ground where it continues to look like and smell dead. After the predator leaves, the snake slithers off.

   The two types of adaptations European grass snakes have developed and use to escape predators are

   J structural and behavioural.
   K structural and physiological.
   L functional and behavioural.
   M physical and behavioural.

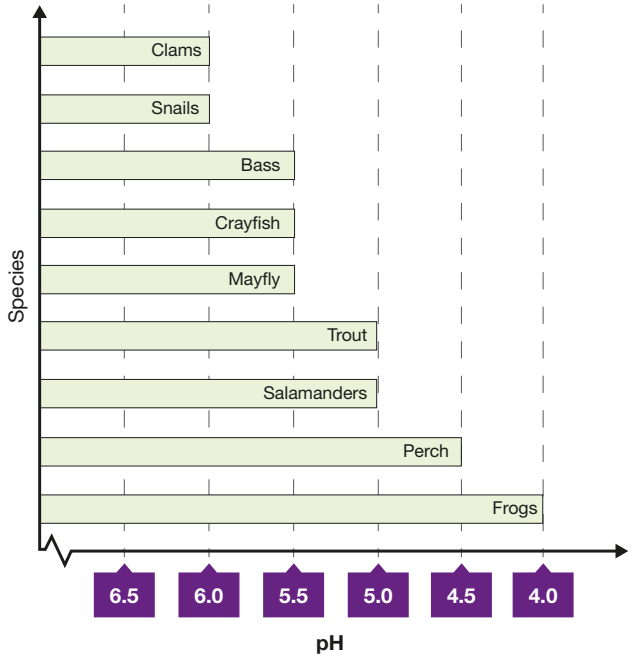
9. *Refer to the four adaptation examples (A to D) below to answer the following question.*

A: Seals divert more blood to its brain when diving deeper in the ocean.
B: Whales store additional oxygen in their muscle tissue.
C: Polar bears have white fur to blend into their surroundings.
D: Polar bears often slide across the ice to disperse their weight and decrease the chance of falling through thin ice sheets.

   Select the option that correctly identifies the four adaptations A to D.

	A	B	C	D
J	Structural	Behavioural	Functional	Physiological
K	Physiological	Structural	Behavioural	Functional
L	Behavioural	Functional	Physiological	Structural
M	Functional	Physiological	Structural	Behavioural

10. *Refer to the graph below showing the pH tolerance of some aquatic organisms to answer the following question.*



   With reference to the graph, which of the following statements is most correct?

   J Clams are the best adapted organism to an acidic environment.
   K The mayfly, crayfish, and bass all live in the same habitat.
   L Snails and clams are the least adapted to acidic environments.
   M Frogs are the most adapted to an alkaline environment.

Free response questions

1. Name the three different categories of adaptations **and** give an example of each to illustrate your understanding.

2. For each of the organisms listed below, state **one** adaptation they possess to assist in their survival:

   a) Rabbit

   b) Cheetah

   c) Cactus

   d) Snake

   e) Emperor penguin

3. Predation is an interaction between species in communities.

   a) Explain how predation influences the survival of individuals within prey populations.

   b) Complete the following table by identifying **and** explaining **one** example of each type of adaptation that organisms preyed on have evolved, to help them survive predation.

Type of adaptation	Example of adaptation prey have developed to survive predation	Explanation of how this adaptation increases the survival of prey against predation

4. Some adaptations can be inherited and some can be learnt.

   a) State one example of an inherited adaptation **and** one example of a learnt behaviour.

   Inherited

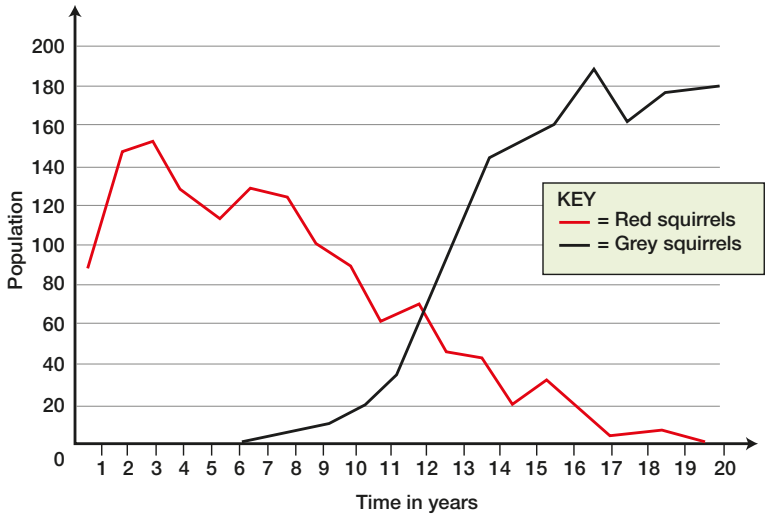
   Learnt

   b) Explain the difference between inherited and learnt adaptations.

5. Complete the following table by providing an explanation of how each adaptation to desert like conditions aids the survival of the organism **and** identify the type of adaptation and an organism that has the adaptation.

Major environmental factor involved	Adaptation	How the adaptation aids survival	Type of adaptation	Example of organism with adaptation
Water only available for a short period of time	A short life-cycle (germinate, grow, flower, set seed)			Sturt desert pea
High temperatures	Large ears with rich blood supply			Bilby, fox
High temperatures	Hopping			
Harsh temperatures and low water	Lays large numbers of eggs			
High temperatures	Nocturnal			

6. Refer to the graph below which shows the results of a study that tracked the amount of red and grey squirrels in a woodland habitat for 20 years. The grey squirrels were introduced to the community in the sixth year of the study.



With reference to the graph and your understanding of adaptations, discuss the impact of introducing grey squirrels to this woodland habitat on the population of red squirrels that were already established in this habitat.

Chapter 4.4 Energy and matter in an ecosystem

Science Understanding

The biotic and abiotic components of ecosystems interact with each other to capture, transform, and transfer energy.

Nutrients within an ecosystem are involved in biogeochemical cycles.

- Represent the water cycle and biogeochemical cycles, for elements such as nitrogen, phosphorous, and carbon.

Transforming energy

Life on Earth as we know it could not exist without **the Sun**. The Sun provides a suitable temperature for life to exist, but it is also the **primary source of energy** for most ecosystems. Energy is vital for all organisms as it is required by organisms to perform a variety of life processes. The Sun provides a constant source of **physical energy**, in the form of light, that photosynthetic organisms can capture and **transform** into **chemical energy**, in the form of glucose. During **photosynthesis**, the chemical bonds that hold carbon dioxide and water molecules together are broken and the atoms are rearranged to produce a glucose molecule and some oxygen molecules (see Figure 4.4.1). Effectively, the energy supplied by light has been used to produce the organic molecule glucose, which has **captured the energy** in the bonds that hold its atoms together. Glucose can then be broken down through cellular respiration to transform this captured energy into usable energy (ATP) allowing cells to do work.

The Earth receives far more energy in the form of sunlight than is ever trapped by the producers. Most of the energy is either absorbed or reflected by the surface of the Earth or the atmosphere. It is estimated that only around 1% of this energy striking the Earth is ever trapped and converted to chemical energy by plants.

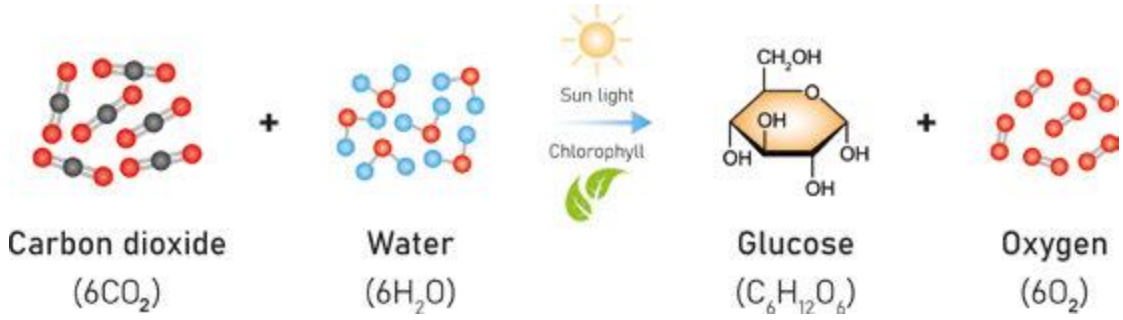


Figure 4.4.1: Photosynthesis transforms the light energy provided by the Sun into chemical energy in the form of glucose.

Transferring energy

The **primary producers** in a community are the starting point for all life on Earth. They are the producers of chemical energy that all other species in a food web rely on for their energy needs. Primary producers use the glucose they produce for their daily energy needs, but they can transport excess glucose produced into storage sinks, such as potatoes and carrots, that animals consume to obtain their chemical energy needs.

As discussed in Chapter 4.1, every community of living organisms in an ecosystem has a **trophic structure**, which consists of tiers called **trophic levels** (see Figure 4.4.2). A trophic level is the relative position of an organism in the food chain and most food chains do not contain more than four trophic levels. Energy is **transferred** from one trophic level to another, by **consumption**. The first trophic level is always the primary producer or autotroph, and the remaining trophic levels consist of consumers, or heterotrophs. Consumers can directly consume primary producers, consume other consumers that have already fed on primary producers, or a mixture of both.

Not all energy consumed is transferred to the next trophic level though. Approximately 90% of the obtained energy is lost as heat and waste at each trophic level. Only **approximately 10%** of the energy originally obtained by a trophic level is therefore available to the next trophic level through consumption (see figure 4.4.2).

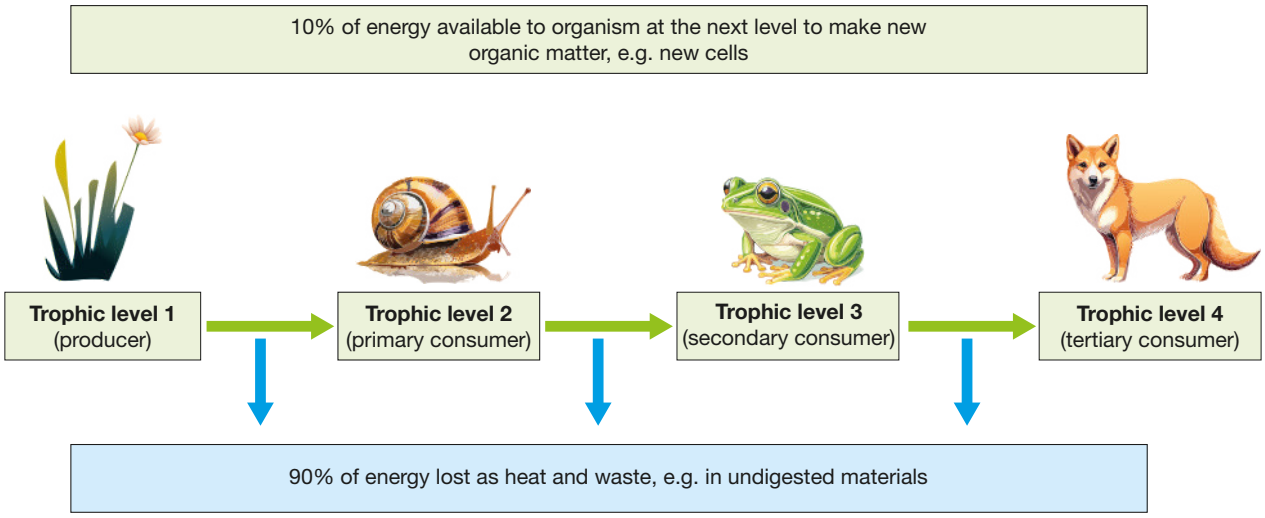


Figure 4.4.2: Energy is transferred from one trophic level to another by consumption, as indicated by the green arrows. Approximately 90% of energy obtained by a trophic level is lost as heat and waste, as indicated by the blue arrows.

Energy flow through an ecosystem

Energy cannot be recycled. It can only be transformed into another form of energy or transferred as the same form of energy. Not all energy produced by autotrophs is transferred to the next trophic level. Autotrophs, such as plants, use a considerable amount of the energy they capture in maintaining their own life processes. Additionally, energy is lost through the excretion of wastes. Only some of the energy produced by autotrophs is therefore used to make new cells that can be consumed, passing on the energy stored in these new cells. Consequently, there is considerably **less energy available for the next trophic level**.

This loss of energy continues through the food chain. Consumers also use the energy obtained from their food to maintain their own life processes such as grow, repair wounds, move and reproduce. Consumers don't always consume the whole organism and obtain all the available energy from its food source. Humans are notorious for this and tend to consume the muscles of animals but steer clear of major organs and bones. This is the same in the wild where bones and some parts of tissues of prey are not consumed, and the branches and roots of plants are often not consumed. Therefore, only the energy that is made into new cells and is consumed by an organism is transferred to the next trophic level. **This loss of energy is why food chains generally do not exceed more than four trophic levels**.

Approximately 90% of energy an organism obtains is lost through respiration in the form of **heat**, and the production of **waste products**, such as urine and faeces (see Figure 4.4.3). The efficiency of aerobic respiration is approximately 45%, which means the remaining 55% of energy is generally transformed into heat, which is a by-product of the reaction. This heat helps humans to maintain a constant body temperature of 37°C and is eventually **lost to the environment** through radiation. Additionally, consumers cannot digest all the materials they consume. Humans, for example, cannot digest insoluble fibre such as cellulose, that makes up the cell wall of plant cells, so it passes through the digestive system undigested and is later egested.

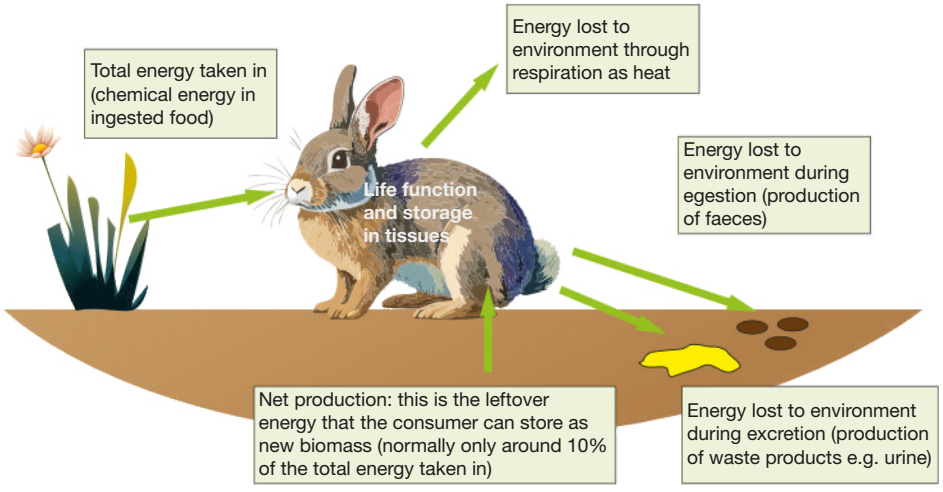


Figure 4.4.3: Energy consumed is mostly lost to the environment through heat and waste.

Dead organisms and waste products of all trophic levels, including dropped leaves, dead skin and faecal matter, are **broken down by decomposers**. In doing so, the decomposers extract energy from the remaining organic matter and respire, releasing heat back to the environment. Therefore, the waste and dead matter is eventually transformed to heat energy and **radiated back into the atmosphere**. Almost all the energy that enters the Earth's atmosphere returns to space as heat. However, some is trapped in fossil fuel stores. Also, due to the increase in greenhouse gas emissions, more of this radiated heat is being trapped in the Earth's atmosphere due to the enhanced greenhouse effect (see Chapter 4.7 for more information).

As most energy is lost to the environment, only a small percentage of the initial energy obtained is trapped by each trophic level. It is estimated that **approximately 10%** of the initial energy obtained is transferred to the next trophic level. This can be represented as an **energy pyramid** (see Figure 4.4.4).

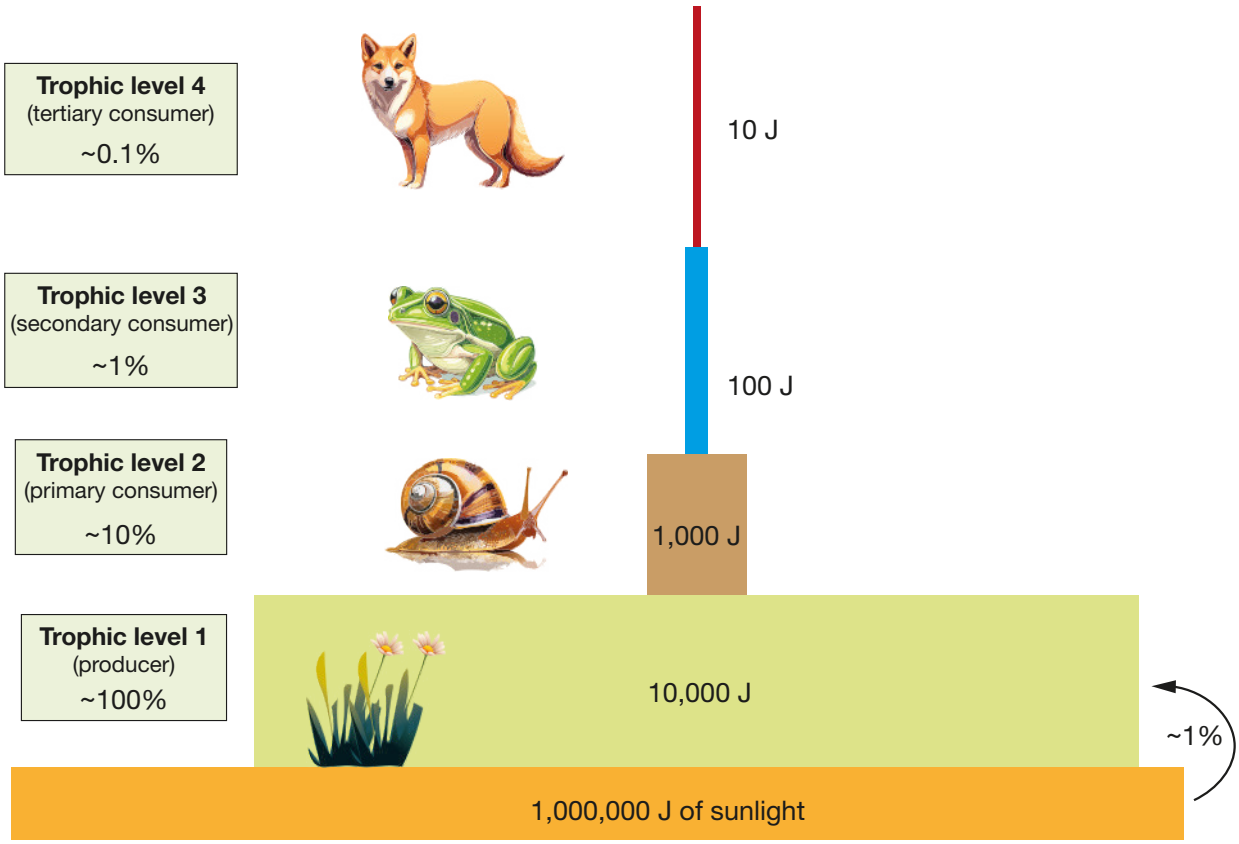


Figure 4.4.4: Approximately 1% of the sunlight is captured by photosynthetic autotrophs and only 10% of this initial energy captured by producers are passed on to each trophic level as energy is lost as heat and waste. This considerable energy loss through the trophic levels generally limits food chains to four or five trophic levels. A fifth trophic level would only receive approximately 0.01% of the original energy capture by the producers.

Helpful online resources

Cognito: GCSE Biology - Food Chains & Predator Prey Cycles

<https://www.youtube.com/watch?v=NFTSm3D2xrM>

Biogeochemical cycles

Chemical elements and simple nutrient molecules needed by organisms are cycled within ecosystems. The cycling of elements and inorganic compounds, like water, involves interactions between the biotic and abiotic components of an ecosystem and therefore **both biological and geochemical processes**. This type of cycling is called a biogeochemical cycle (see Figure 4.4.5).

The main elements that make up tissue are carbon, oxygen, nitrogen, sulfur, phosphorus, potassium and calcium. As **matter is neither created nor destroyed in the ecosystem**, it is important to cycle matter from the abiotic environment through living organisms and then back to the abiotic environment (see Figure 4.4.5).

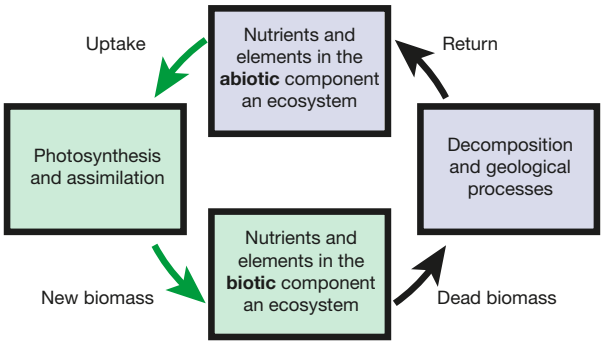


Figure 4.4.5: A general representation of biogeochemical cycles that involve the flow of matter from the abiotic components to the biotic components of an ecosystem and vice versa.

The process of cycling involves the action of the **decomposers** including bacteria and fungi. By feeding on dead and decomposing material, the metabolic action of decomposers breaks down the organic material like carbohydrate, protein, nucleic acids and lipids into inorganic substances. These are returned to the soil, increasing soil fertility (abiotic component) to be taken up by producers and incorporated back into new plant material (biotic component), and in turn to the bodies of consumers.

The water cycle

Only about 0.9% of the Earth's total water is easily accessible for human use. Most of the planet's water is in oceans (97.5%) and is saline, which means it is not potable (drinkable). The remaining 1.6% is locked away in glaciers, ice caps, and deep underground, leaving a small fraction available as freshwater in rivers, lakes, and shallow groundwater (see Figure 4.4.6).

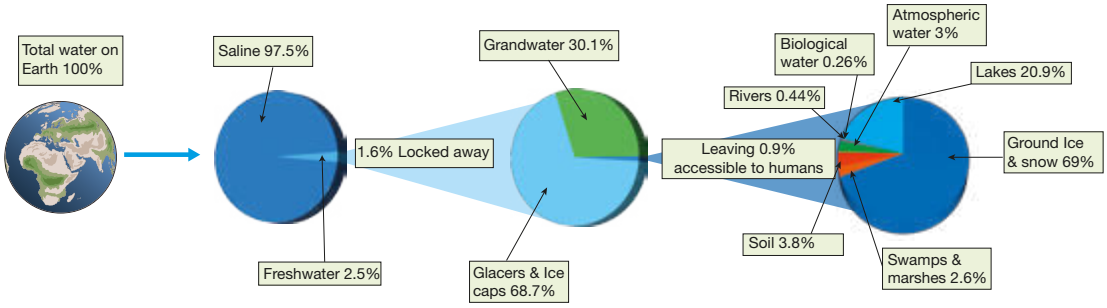


Figure 4.4.6: A breakdown of the inaccessible and accessible water to humans on Earth.

The biogeochemical cycling of water within an ecosystem is called the **water cycle**, or hydrologic cycle. It involves the continuous movement of water on, above, and below the Earth's surface. The cycle involves **evaporation**, where water from oceans, lakes, rivers and animals turns into **water vapour** and rises into the atmosphere. **Transpiration** from terrestrial plants also releases water vapour into the atmosphere. The vapour cools and condenses into clouds in a process called **condensation**. Eventually, water falls back to Earth as **precipitation** (rain, snow, sleet, or hail). Some of this water flows over the land as **runoff**, returning to bodies of water, while some **infiltrates** the ground, replenishing **groundwater**. Snow and ice can also **melt** forming liquid water and runoff into bodies of water and **percolate** into groundwater. Plants can absorb water through their roots and transport water to their tissues. Animals ingest water by drinking freshwater and through eating plants and animals. The cycle continues to repeat (see Figure 4.4.7).

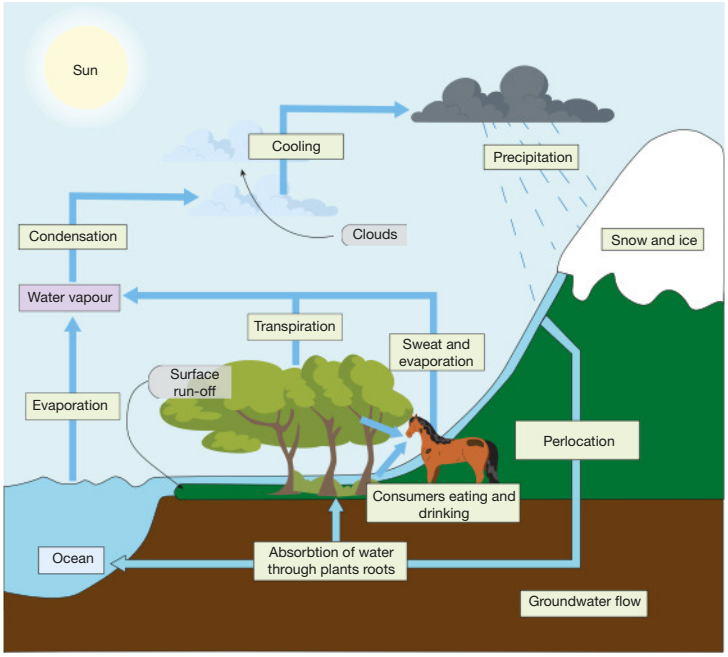


Figure 4.4.7: A summary of the events of the water cycle.

The carbon cycle

The carbon cycle describes the movement of carbon between Earth's major reservoirs or pools, including the atmosphere, oceans, terrestrial ecosystems, and fossil fuel reserves (see Figure 4.4.8). Carbon dioxide (CO_2) is absorbed from the atmosphere by plants through **photosynthesis** and converted into glucose. This energy rich carbohydrate can then be used as an energy source through **cellular respiration**, releasing carbon dioxide, or converted into other **organic matter**, such as proteins and lipids, and incorporated into the plant's tissues.

Animals then **consume** plants, or other animals that have consumed plants, transferring carbon through the food chain. The **decomposition** of dead organisms and waste products releases carbon back into the soil and atmosphere. Animals and decomposers also release carbon dioxide into the atmosphere through **respiration**.

Carbon can be **stored** for long periods in **carbon pools**, such as forests (biomass), soils, oceans, and fossil fuels. **Carbon fluxes** describe how carbon **moves** between these pools. For example, the ocean absorbs large quantities of carbon dioxide from the atmosphere in a process called **carbon sequestration**, while volcanic activity and the **combustion of organic matter**, such as wood or fossil fuels, release carbon back into the atmosphere. Human activities, particularly the burning of fossil fuels and deforestation, have increased atmospheric carbon dioxide levels, and significantly altered natural carbon fluxes which is contributing to global warming and climate change (see Chapter 4.7 for more information).

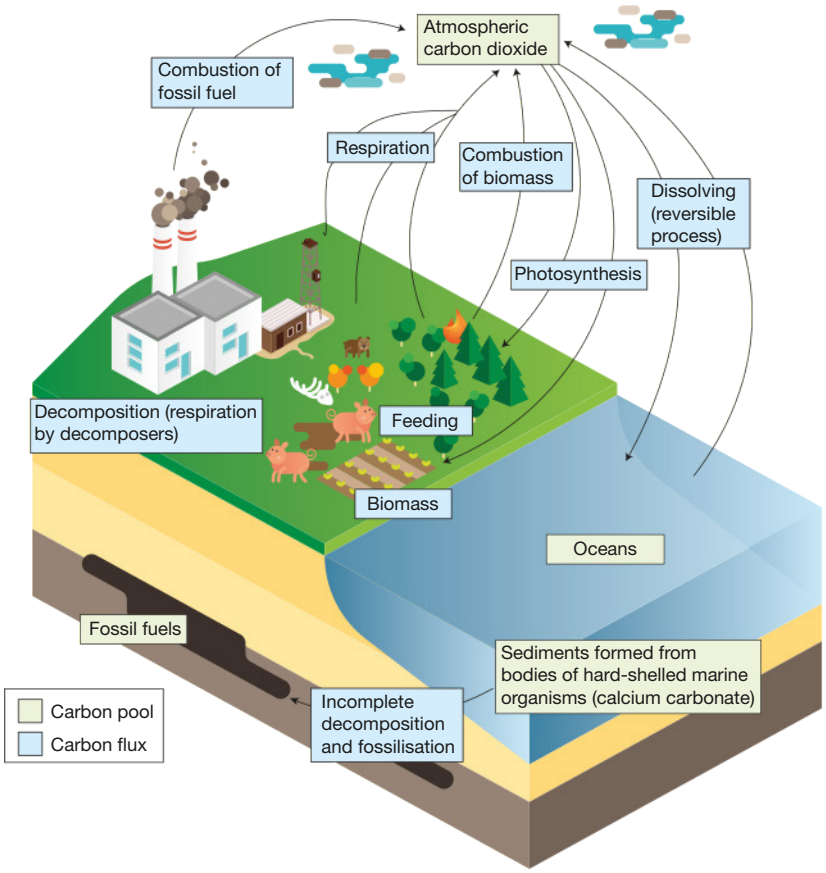


Figure 4.4.8: A summary of the events of the carbon cycle including some major carbon pools and fluxes.

The nitrogen cycle

Nitrogen is an important element found in the **proteins and nucleic acids** (DNA and RNA) of organisms. The nitrogen cycle describes how nitrogen moves between the atmosphere, soil, water, and living organisms (see Figure 4.4.9). Nitrogen in its gaseous form (N_2) makes up approximately 78% of Earth's atmosphere but is not directly usable by most organisms. The cycle involves **nitrogen fixation**, where certain bacteria in the soil or in the root nodules of legumes, convert atmospheric nitrogen (N_2) into ammonia (NH_3), which can then be taken up by plants. Nitrogen can also be fixed through **lightning** or industrial processes. Once in the soil, **nitrification** occurs, where other bacteria convert ammonia into nitrites (NO_2^-) and then into nitrates (NO_3^-), which plants absorb through their roots to build proteins and other essential molecules.

Plants are consumed by animals, transferring nitrogen through the food chain. When plants and animals die, **decomposition** by bacteria and fungi breaks down organic nitrogen compounds, returning ammonia to the soil in a process called **ammonification**. Nitrification can then occur to convert ammonia to nitrate ions (NO_3^-), that can be absorbed by plants.

Additionally, **denitrification** occurs where specialised bacteria convert nitrates back into nitrogen gas (N_2), releasing it into the atmosphere and completing the cycle. Human activities, such as the use of nitrogen-based fertilisers and fossil fuel combustion, have increased the amount of reactive nitrogen in ecosystems, leading to environmental impacts like **eutrophication** and the disruption of natural nitrogen cycles (see Chapter 4.7 for more information).

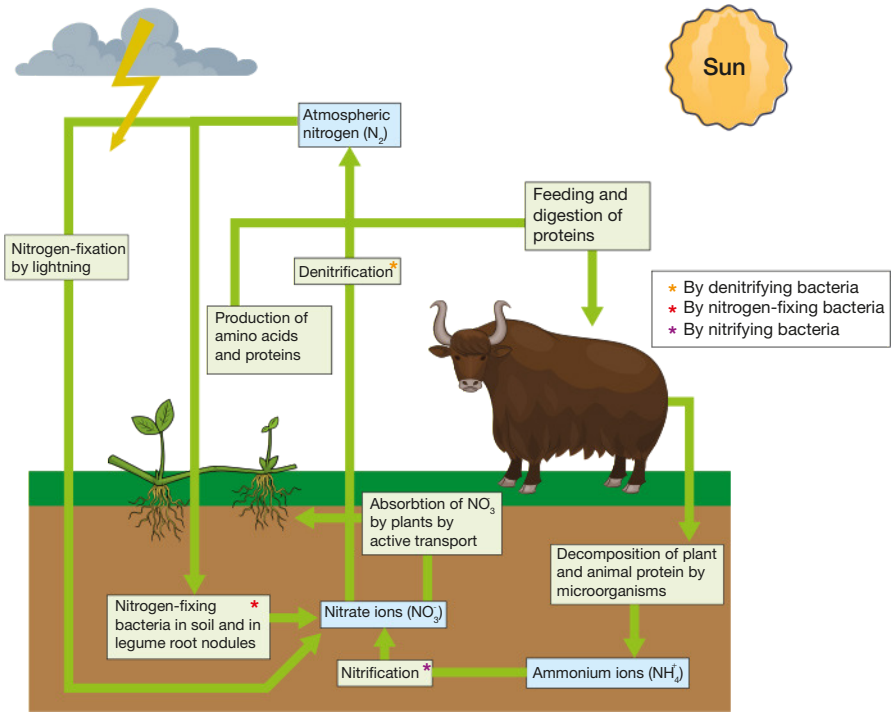


Figure 4.4.9: A summary of the events of the nitrogen cycle.

The phosphorus cycle

The phosphorus cycle describes the movement of phosphorus between the soil, water, and living organisms. Unlike carbon or nitrogen, phosphorus does not have a gaseous phase and is **mainly found in rocks and sediments** as phosphate minerals. The cycle begins with the **weathering** and **erosion** of rocks, which releases inorganic phosphate (PO_4^{3-}) into the soil and water. Plants absorb these phosphates through their roots to synthesise essential molecules like nucleic acids (DNA and RNA), ATP and phospholipids. Many plants have evolved mycorrhizae which are symbiotic relationships between fungi and plant roots, where the fungi enhance the plant's ability to absorb water and nutrients, especially phosphorus, from the soil (see Figure 4.4.10). In return the plant provides the fungi with carbohydrates produced through photosynthesis. This mutualistic relationship improves plant growth and resilience, particularly in nutrient-poor soils.

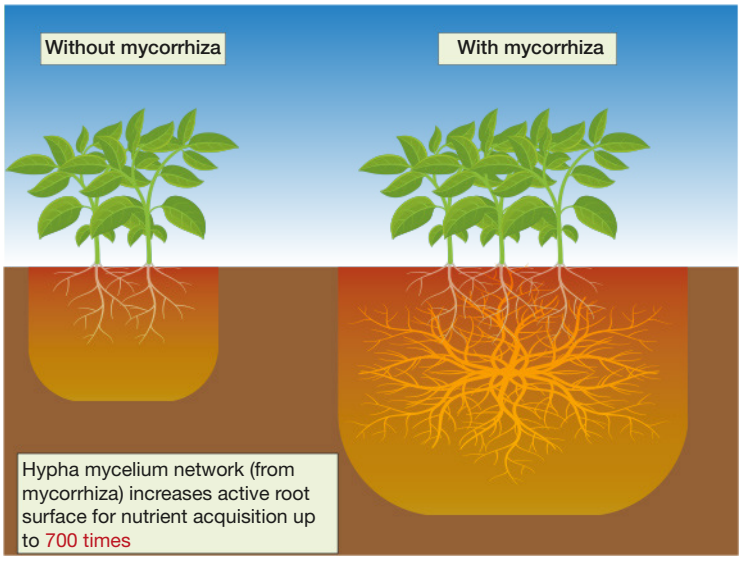


Figure 4.4.10: Mycorrhizae between fungi and plant roots increase the surface area of roots significantly and increase the chance of their ability to absorb sufficient nutrients and survive.

When animals **consume** plants, they obtain phosphorus containing molecules that are incorporated into their tissues. These molecules continue to move through the food chain. When plants and animals die, **decomposers** break down organic matter, returning phosphorus to the soil as inorganic phosphate. Some of this phosphorus is **leached** into water bodies, where it can settle and eventually form sedimentary rock, restarting the cycle over millions of years through **geological uplift**. Unlike other nutrient cycles, the phosphorus cycle is relatively slow (see Figure 4.4.11). Human activities, such as the use of phosphorus-rich fertilisers and detergents, can accelerate this cycle, leading to an excess of phosphorus in water bodies, which causes **eutrophication** and harms aquatic ecosystems (see Chapter 4.7 for more information).

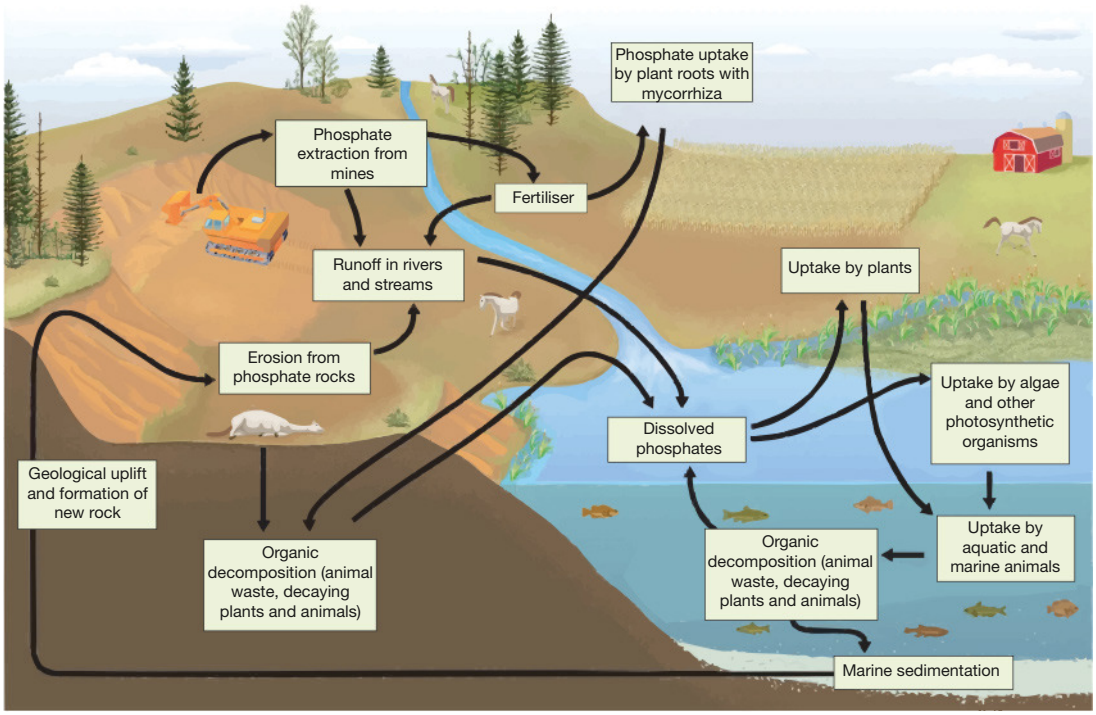


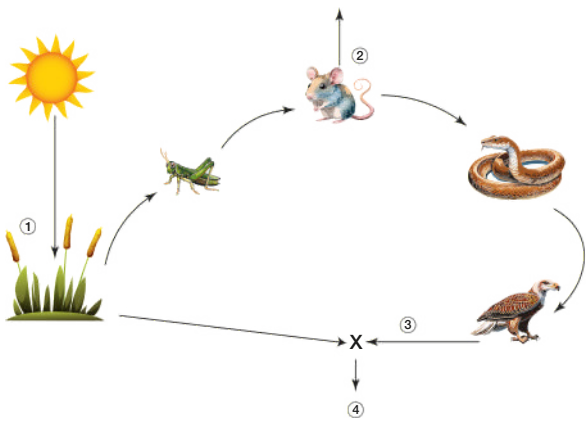
Figure 4.4.11: A summary of the events of the phosphorus cycle.

4.4 Review questions

Multiple choice questions

1. The primary source of energy on Earth is
   - J primary producers.
   - K primary consumers.
   - L photosynthesis.
   - M the Sun.
2. An example of a transfer of energy is
   - J the production of chemical energy during photosynthesis.
   - K the consumption of meat by a human.
   - L the production of heat energy during cellular respiration.
   - M the combustion of organic matter.

Refer to the image to the right showing a food chain to answer questions 3 and 4.



3. In a typical food chain, what percentage of the original energy that enters this food chain would generally reach the snake?
   - J 1.000%
   - K 0.100%
   - L 0.010%
   - M 0.001%

4. Which of the following options, represents the breakdown of organic matter in the food chain?

   J 1
   K 2
   L 3
   M 4

5. Which of the following options is **not** true regarding energy flow in ecosystems?

   J Ecosystems require a constant source of energy.
   K Energy is captured in ecosystems through the process of aerobic respiration.
   L Energy availability is higher in the lower trophic levels.
   M Energy can be recycled in an ecosystem by decomposers.

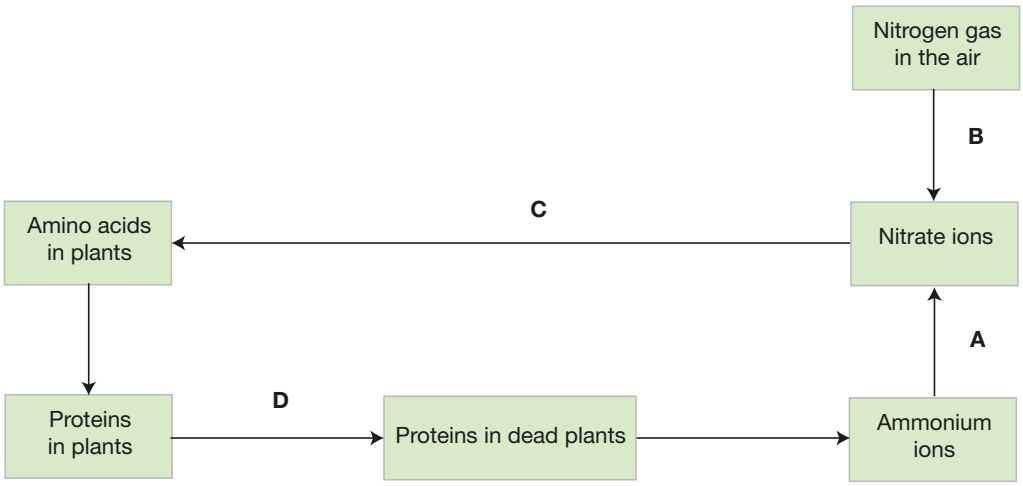
6. Which biogeochemical cycle does not have an atmospheric component?

   J Water cycle
   K Carbon cycle
   L Nitrogen cycle
   M Phosphorus cycle

7. Which of the following options is true regarding the water cycle?

   J Consumers only obtain their water through drinking.
   K Transpiration is the evaporation of water from plants.
   L Surface runoff always ends up in the groundwater.
   M Water vapour is absorbed by plant roots.

Refer to the flow diagram below showing a section of the nitrogen cycle to answer questions 8 and 9.



8. Identify the letter (A to D) in the flow diagram that represents nitrification.

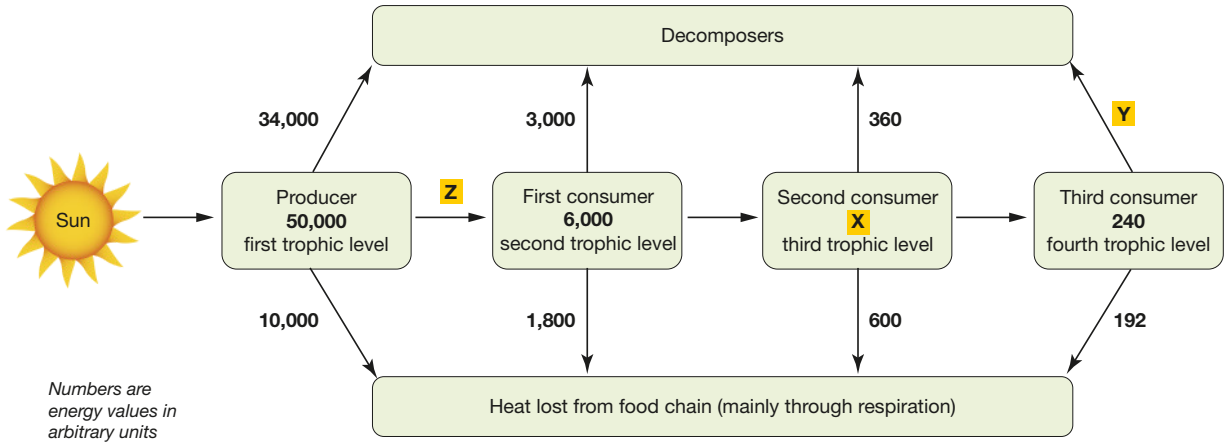
   J A
   K B
   L C
   M D

9. Some plants, known as legumes, like peas and beans, possess nitrogen-fixing bacteria inside nodules on their roots. Crops like these are used to increase the nitrogen content of soils in agriculture and are often in rotation with other crops like cereals.

   Which letter (A to D) in the flow diagram represents the process described above?

   J A
   K B
   L C
   M D

10. *Refer to the image below which shows energy flow through a food chain to answer the following question.*



Identify the energy values at X and Y and the percentage of the original energy transferred to the first consumer at Z in the energy flow diagram above.

	X	Y	Z
J	1200	240	6%
K	192	24	10%
L	2400	432	22%
M	1200	48	12%

Free response questions

1. Outline the role of producers in capturing energy from the Sun to make energy available to consumers.

2. Explain how energy is transferred from one trophic level to the next throughout a community.

3. Explain why only approximately 10% of the energy trapped by a trophic level is transferred to the next trophic level.

4. Explain what biogeochemical cycles are.

5. Explain why most food chains are limited to approximately four trophic levels.

6. Compare the movement of energy through an ecosystem with the cycling of matter.

7. Discuss the likely consequences to an ecosystem if the decomposers were removed.

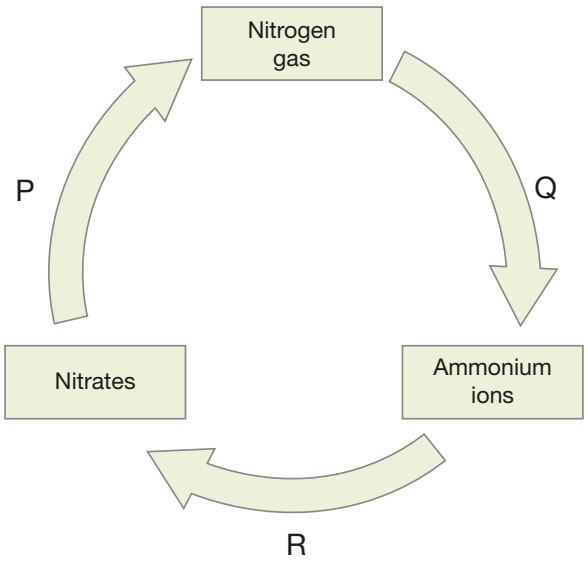
8. Outline the most likely impact on the carbon cycle of the following activities:
   a) Deforestation

   b) Burning of fossil fuels.

9. a) State **two** roles of nitrogen in living organisms.

   b) Name the form in which the element nitrogen is taken into producers.

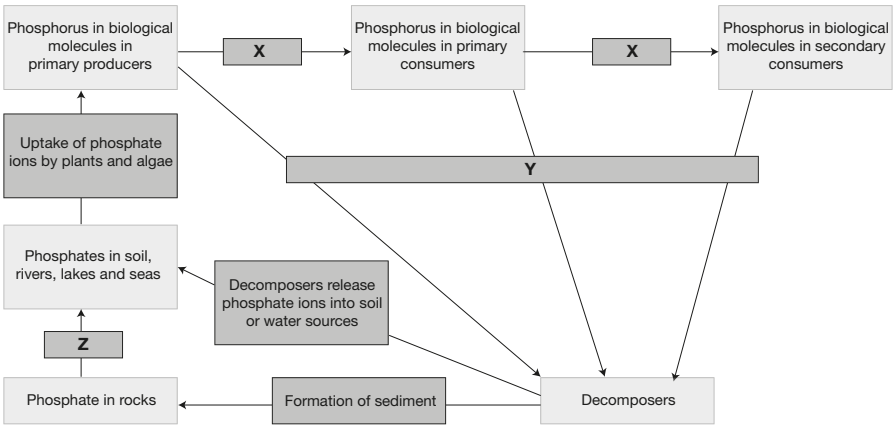
Refer to the flow diagram below showing part of the nitrogen cycle.



   c) Identify the letter that represent denitrification.

   d) Explain **two** different methods that bacteria can add usable forms of nitrogen to soils for plants to absorb.

10. *Refer to the flow diagram below of the phosphorus cycle to answer the following questions.*



a) State the original source of phosphorus for organisms.

b) State **two** roles of phosphorus in living organisms.

c) Identify the processes occurring at X, Y and Z in the flow diagram above.

X:

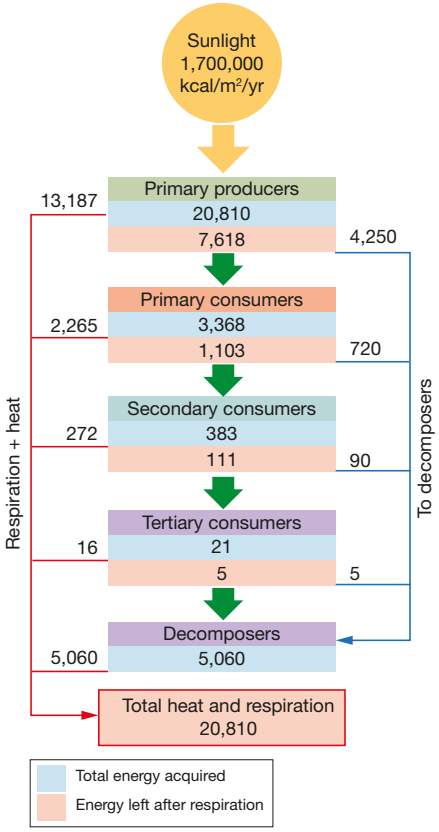
Y:

Z:

d) Explain why desert plants are likely to have developed mycorrhizae.

11. *Refer to the diagram below showing the flow of energy through an ecosystem to answer the following questions.*

a) Calculate the percentage of sunlight captured by primary producers.



b) (i) Calculate the percentage of energy transferred from the primary producer to the primary consumer.

(ii) Calculate the percentage of energy transferred from the secondary consumer to the tertiary consumer.

(iii) Discuss likely reasons why there is a difference in the percentage of energy transferred at the start of the food chain compared to towards the end of the food chain.

(iv) Calculate the average of your answers to questions (b)(i) and (b)(ii).

(v) Discuss what your answer to part (b)(iv) shows regarding the flow of energy through an ecosystem.

Chapter 4.5 Ecological niches and keystone species

Science Understanding

Ecosystems can be diverse, and can be defined by their biotic and abiotic components and the interactions between elements of these components.

- Compare the characteristics of at least two ecosystems.

Ecosystems include populations of organisms that each fills a specific ecological niche.

Describe a niche in terms of key indicators within the ecosystem, including habitat, feeding relationships, and interactions with other species.

Patterns within a community include zonation and stratification.

Keystone species play a critical role in the maintenance of their ecosystem.

- Explain the significance of keystone species in their ecosystem.

Environmental components determine the type of community

Most ecosystems have their own particular producers, consumers and decomposers. The actual composition of the community is primarily determined by the environmental conditions of the habitat. If regions with similar conditions on different continents are compared it can be seen that similar types of producers have evolved. Australia is a large island continent with a diversity of plant communities. It is typified by **habitats** that are arid, with variable water levels, subject to fire and high salinity, and have poor soil with low nutrient levels. With high temperatures, and wind accelerating evaporation, the organisms that can survive are those that can keep water loss to a minimum. Most organisms like trees, birds, reptiles and mammals are distributed throughout Australia on the basis of water availability and have adapted to their **niches** over long periods of time.

Most native plants are well adapted to survive these harsh conditions. A sclerophyll plant has leaves that are rigid with a thick waxy cuticle, helping to reduce loss of water from leaves through evaporation. Additionally, as fire is an integral part of Australian ecosystems, species have evolved adaptations to enable them to survive regular bushfires. Acacias are an example of this and are generally one of the first plant species to regenerate following a fire. This is because the acacia seeds have adapted to germinate more efficiently in the presence of heat and smoke.

Types of ecosystems

Ecosystems can be broadly categorised into different types based on their unique combinations of biotic (living) and abiotic (non-living) components (see Table 4.5.1). Biotic components include plants, animals, fungi, and microorganisms, while abiotic factors encompass climate, soil, water, sunlight, and temperature. Ecosystems like rainforests, deserts, oceans, tundras, and grasslands each have distinct interactions between these components that shape the biodiversity and ecological functions of each system. The specific balance of biotic and abiotic factors determines the species that can survive (see Tables 4.5.2 and 4.5.3), how energy flows through the ecosystem, and how nutrients are cycled within it. This diversity in ecosystems is crucial for maintaining the health of the planet and supporting various forms of life.

Table 4.5.1: A brief comparison of the seven major types of ecosystems.

Type of ecosystem	Description	Examples
Rainforests 	Rainforest ecosystems are dense, and biodiverse. They are found primarily in tropical regions, characterised by high rainfall and rich vegetation. These ecosystems support a vast array of plant and animal species including Brazil nut trees, fig trees, vines, ferns, macaws, flying foxes, anacondas, siamangs and tigers. Rainforests are a major carbon sink on Earth, helping regulate the atmosphere and climate.	• Tropical • Temperate • Deciduous • Mangroves • Montane • Mixed • Boreal
Tundra 	Tundra ecosystems are cold, treeless regions found in the Arctic and high mountain areas, characterised by permafrost and minimal vegetation. Despite the harsh climate, they support specialised plant and animal life adapted to extremely cold conditions. Some examples include Arctic moss, dry shrubs, Arctic foxes, caribou and polar bears. They also store frozen methane playing a crucial role in Earth's carbon cycle.	• Arctic • Antarctic • Alpine
Desert 	Desert ecosystems are arid regions with sparse rainfall, characterised by extreme temperature fluctuations and limited vegetation. Despite these harsh conditions, deserts support a variety of specially adapted plants and animals that thrive in the dry, nutrient-poor environment. Plants are well adapted to store and retain water, whereas animals are often nocturnal and active at night when it is colder, or burrowers, so they can escape the heat. Some examples include cacti, yuccas, camels, lizards, snakes and hopping mice.	• Hot and dry deserts • Semi-arid deserts • Coastal deserts • Cold deserts
Freshwater 	Freshwater ecosystems are marine ecosystems that are not salty like the ocean. They generally contain a diverse range of aquatic life such as pondweed, water lilies, reeds, freshwater frogs, turtles, otters and alligators. These ecosystems are vital for supporting biodiversity, regulating water cycles, and providing essential resources such as fresh drinking water for both wildlife and human populations.	• Rivers • Streams • Lakes • Ponds • Wetlands • Estuaries
Ocean 	Ocean ecosystems cover the majority of Earth's surface and encompass diverse habitats, from coral reefs to deep sea trenches. Coral reefs are one of the most biodiverse ecosystems on Earth. Ocean ecosystems consist of many aquatic species including lichens, seaweed, shellfish, tuna, sharks and whales. These ecosystems play a vital role in regulating global climate, supporting marine biodiversity, and providing resources such as oxygen, food, and livelihoods for millions of people.	• Open ocean • Coral reefs • Deep sea • Kelp forests
Grassland 	Grassland ecosystems are open, expansive regions dominated by grasses and few trees, typically found in both tropical and temperate zones. Some examples of species inhabiting grassland ecosystems are multiple species of grasses, zebras, African elephants, wildebeest, emus and foxes. These ecosystems support a wide range of wildlife and play a crucial role in carbon storage, soil health, and agriculture.	• Temperate • Savannas (grassy woodlands) • Steppes • Pampas
Alpine 	Alpine ecosystems are high-altitude environments characterised by cold temperatures, strong winds, and a short growing season, with vegetation primarily consisting of hardy grasses, shrubs, and mosses. These ecosystems also support specialised animal species adapted to the extremely cold alpine conditions such as mountain goats, marmots, ibex and wolves.	• Alps • Andes • Himalayas • Rocky Mountains

Table 4.5.2: A brief comparison of the abiotic and biotic components of four specific ecosystems.

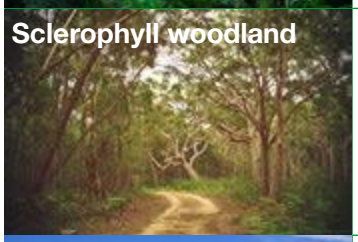
Ecosystem	Some key abiotic components determining the community	Examples of biotic components
 Tropical rainforest	Very high rainfall, high average temperatures, high humidity, nutrient poor soil	Trees, lichens, moss, palms, climbing species of plants
 Sclerophyll woodland	High temperatures, little water availability, high light intensity, low nutrient levels, high frequency of fire	Acacias, banksias, eucalypts, ants, termites, skinks, snakes, kangaroos, koalas, possums, rosellas, kookaburras
 Australian hot and dry desert	High light intensity, very poor nutrient levels, very low rainfall	Sturt Desert Pea, spinifex and saltbush, thorny dragon, red kangaroo, bilby, hopping mouse (see Figure 4.5.1)
 Freshwater pond	Low oxygen availability, variable light intensity, from the top of the pond to the bottom, low solute concentration	Reeds, duckweeds, waterlilies, pondweeds, mosquito larvae, ducks, water beetles, mosquito fish, frogs, turtles, snails

Figure 4.5.1: A thorny dragon (left) and Sturt Desert Pea (right) that reside in some Australian hot desert ecosystems.

Table 4.5.3: Ecosystems can be defined by their biotic and abiotic components and the interactions them. The abiotic components can shape an ecosystem as organism must adapt to survive in a particular ecosystem such a pond ecosystem.

Abiotic component affecting pond ecosystem	Adaptation and how it assists the organism	Category of adaptation	Example of organism
Low oxygen levels	Leaves with large airspaces for floating and gas storage and exchange	Structural	Waterlily
	Gills for efficient extraction of oxygen from water	Structural	Fish
	Air tube that extends to water surface to exchange gases	Structural	Mosquito larvae
	Wing cases to trap air bubbles for gas storage and exchange	Structural	Water beetle
	Holds breath whilst diving for gas storage and exchange	Behavioural	Duck
Low solute concentration	Contractile vacuoles to expel water that enters by osmosis	Physiological	*Paramecium* (protist)
	Leaves covered with a waxy cuticle to prevent water from entering	Structural	Duckweed
	Exoskeleton helps stop water entry into cells	Structural	Insects such as water beetles
	Efficient kidneys to excrete water and salts	Physiological	Fish
High viscosity of water	Streamlined body shape to reduce friction when moving	Structural	Fish
	Webbing between toes to help thrust and movement	Structural	Frogs
Low light intensity	Broadleaves that have a large surface area for light absorption	Structural	Waterlily

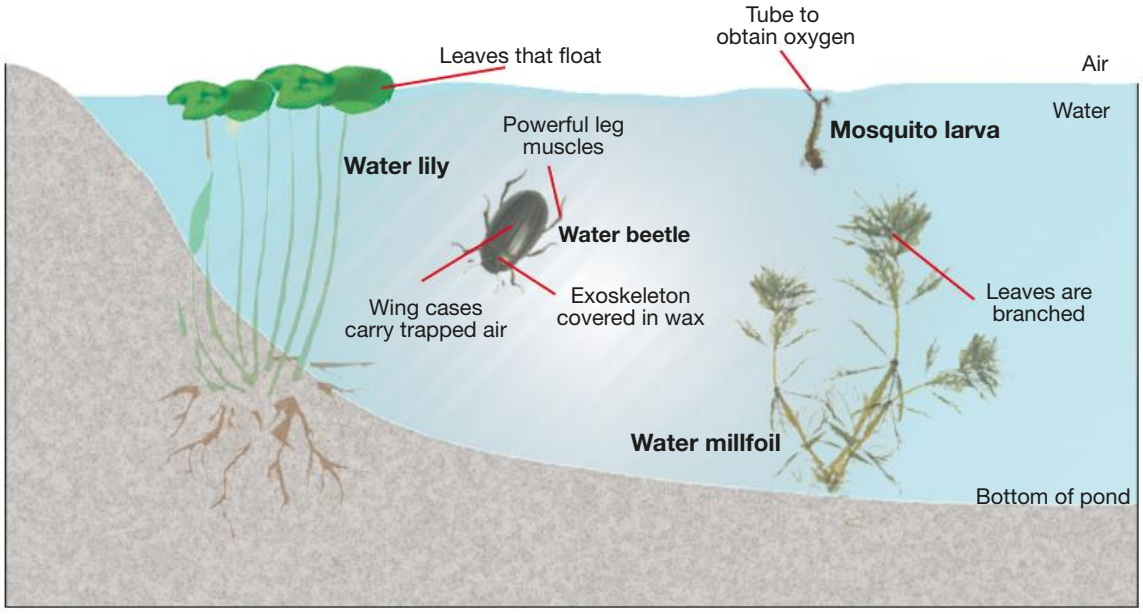


Figure 4.5.2: Some adaptations of some organisms living in a freshwater pond that assist them to survive the challenges that the abiotic components present.

Ecosystem stability

4.5

Ecosystems persist if they can capture, transform, and transfer energy, and cycle essential nutrients and chemical elements. All the species in an ecosystem play a role in helping ecosystems to complete these functions. As a rule, ecosystems with a rich diversity of species are most likely to resist change and remain intact. Ecosystems that are maintained over long periods of time are called **stable ecosystems**. Low species diversity ecosystems are not as resilient: these ecosystems that are more vulnerable to change are called **unstable ecosystems**.

Ecological niches

An ecological niche is the specific role or function that an organism plays within its ecosystem and is defined by living and non-living factors. This can include its:

- habitat,
- resources required from the environment,
- feeding relationships, and
- interactions with other species in the community.

Both abiotic and biotic factors shape the niche of an organism within an ecosystem (see Figure 4.5.3). These factors can act as selection pressures that ensure the most suitable individuals in a species survive to reproduce, shaping ecological niches.

It is important to recognise that a niche is not just where an organism lives, but how it survives and reproduces within its environment. A habitat is defined as where a species lives and is a geographical space, but its niche is how a species fits into its habitat and interacts with it. A habitat can therefore consist of many niches (see Figure 4.5.4).

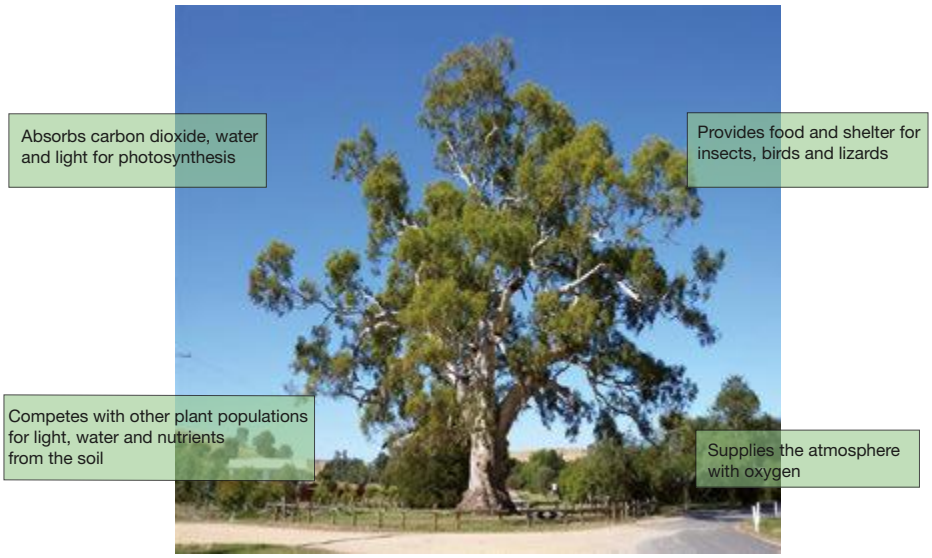


Figure 4.5.3: Some information about the niche of a River Red gum.

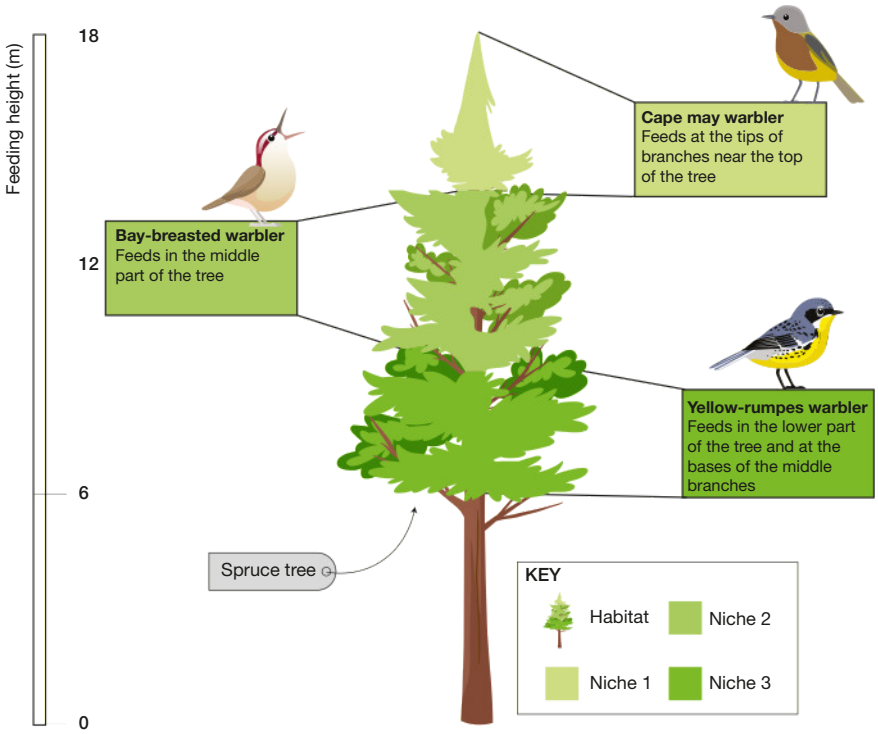


Figure 4.5.4: A spruce tree habitat consists of multiple niches where each species of warbler has a specific feeding relationship.

Helpful online resources

FuseSchool – Global Education: What is a Niche?

<https://www.youtube.com/watch?v=xIVixvcR4Jc>

Representing the niche of different species

If the populations of two species have a similar niche they will compete where parts of the niche overlap, for example, for the type of food eaten. One way to represent how much niche overlap exists is to draw a **niche overlap graph**. If the zone of overlap is small there is relatively little competition between the species. This means the species will probably co-exist in the ecosystem. The extent of niche overlap between populations of two species with identical niches, however, will be very high. As a result, the competition between the species will be intense throughout the ecosystem. The end result is usually the disappearance of populations of one of the species from the ecosystem. An example of a niche overlap graph of different species co-existing in an ecosystem is shown in *Figure 4.5.5*.

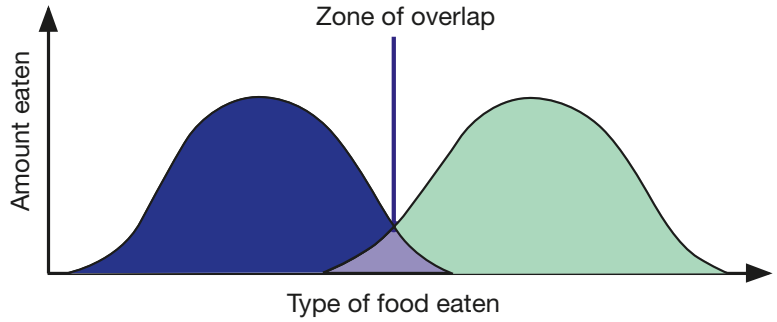


Figure 4.5.5: The niche of two species, showing the extent of overlap.

The fundamental versus the realised niche

A **fundamental niche** represents the full range of environmental conditions and resources an organism can theoretically use, while a **realised niche** is the portion of that range the organism actually occupies due to competition, predation, or other limiting factors. The classic example of this concept is observed in the barnacle species *Chthamalus dalli* and *Balanus glandula* on rocky intertidal shores. Chthamalus barnacles can survive across a broader range of the intertidal zone (their fundamental niche), but they are primarily found in the upper intertidal zone in nature (their realised niche). This is because Balanus barnacles, which dominate the lower intertidal zone, outcompete Chthamalus in that region. Thus, while Chthamalus could survive in both zones, competition from Balanus restricts them to a smaller, realised niche higher on the shore (see Figure 4.5.6). The establishment of realised niches in ecosystems reduces niche overlap that, in turn, facilitates co-existence and, over time, the diversity of species.

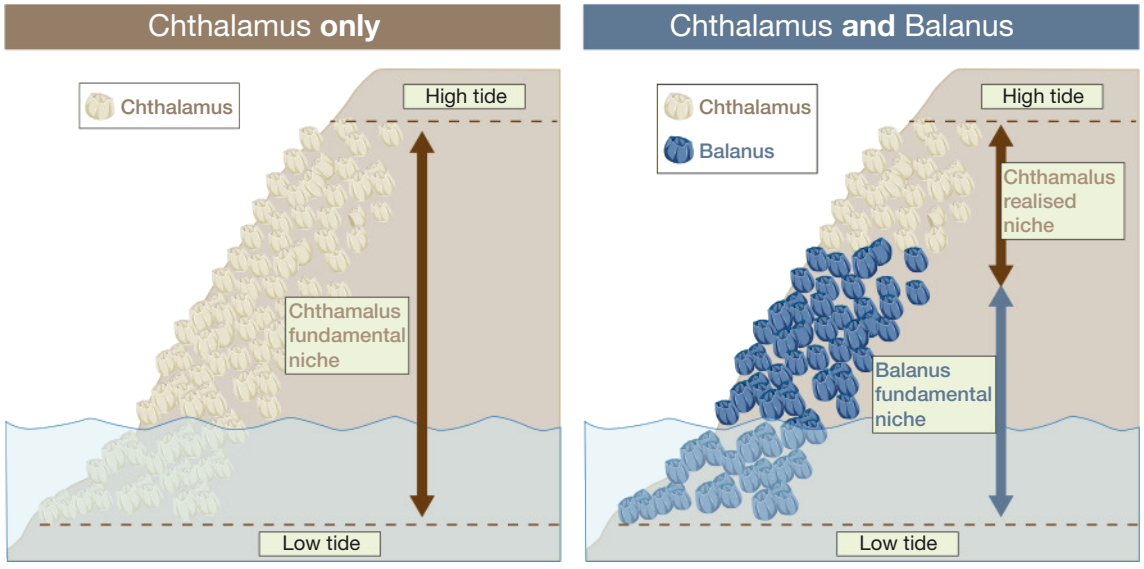


Figure 4.5.6: An example of the realised niche of the Chthamalus barnacle compared to its functional niche.

Zonation

Ecological zonation refers to the spatial distribution of species or communities across distinct environmental gradients, such as depth or tidal zones. This pattern of organisation is influenced by varying abiotic factors like temperature, moisture, light, and salinity, **which create different habitats across zones**. Species occupy specific zones based on their ability to survive and thrive within the environmental conditions of that area, forming unique habitats. **Within these zones, organisms fill their ecological niches**, interacting with available resources and other species. The concept of zonation illustrates how both habitat preferences and niche roles drive the distribution and structure of ecosystems, as seen in ecosystems like intertidal rock platforms, oceans and mountainsides.

Intertidal rock platforms

Rock platform ecosystems form when rock cliffs and rocky sections have been pounded by waves together with erosion caused by the boulders to form a platform that can host a great variety of life. Such ecosystems are called intertidal due to the actions of the rising and falling tides of the sea which provide a very unique set of environmental conditions that can pose specific issues for the organisms that live there.

Due to this phenomenon of high and low tidal movement, a very distinctive feature called zonation is evident. Zonation is described as the zones or regions from the sea to the upper reaches of the splash zone at high tide, where specific organisms form three main horizontal bands or zones, the splash zone, the intertidal zone and the low tide zone (see Table 4.5.3 and Figure 4.5.7 for more information).

Table 4.5.3: A summary of the three main zones of an intertidal rock platform.

Rock platform zone	Description and examples of abiotic components	Examples of biotic components
Splash zone (supratidal or supralittoral zone)	This is the zone where the high tide reaches and therefore often fully exposed. Organisms that live in this zone can be subjected to fluctuating temperatures, direct rainfall and human activity. Organisms that live here have an increased risk of dehydration due to less water supply than other zones, and exposure to the sun.	Mostly shelled organisms that possess strong muscular tissue enabling them to clamp down on the rock platform live in this zone such as limpets. Lichens are also common in the splash zone as they can survive in dry conditions. Lichens are producers that provide valuable food for the grazing sea animals.
Intertidal zone	This zone is the area between the high and low tides that is variable and can be fully submerged at high tide to fully exposed at low tide. Organisms that live here can be at risk of heat stress and dehydration at low tide. They can also be at risk of being washed away into the ocean due to the pounding nature of wave action and rainfall.	Mostly shelled organisms reside at the higher end of the intertidal zone such as limpets and periwinkles (sea snails). Periwinkles graze on various algae and have adapted to trap water inside the shell and seek shelter in cracks in the rocks. Some soft bodied organisms live at the lower end of the intertidal zone where they are less exposed to the pounding of wave action.
Subtidal zone (subtidal or sublittoral zone)	This zone is the zone below the intertidal zone and is permanently under water. This zone has much more stable environmental conditions due to being fully submerged, but the intensity of light generally decreases at greater depths.	Many soft bodied organisms such as algae, fish, sea sponges and sea stars live in this zone due to the more stable conditions associated with being permanently submerged.

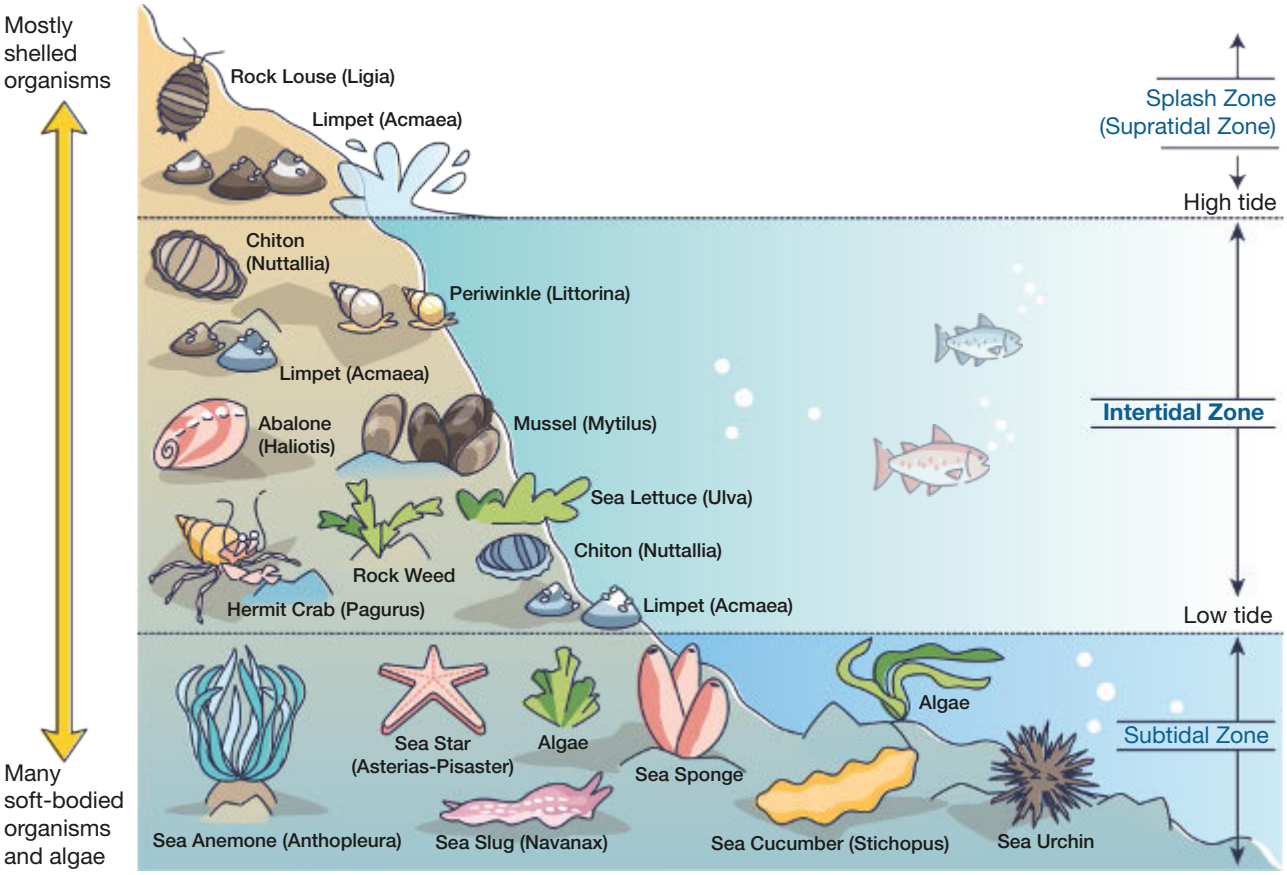


Figure 4.5.7: The zonation of an intertidal rock platform.

Figure 4.5.8: Lichens (left), sea snails which are also called periwinkles (middle), and a crab (right) on an intertidal rock platform.

Helpful online resources

UnderH2O: The Intertidal

<https://www.youtube.com/watch?v=DR1gP5S6Bsk>

Stratification

Stratification refers to the **vertical layering of habitats** within an ecosystem. This vertical structure creates distinct layers, each with its own set of abiotic conditions such as light intensity, temperature, and moisture, which influence the types of species that can inhabit each layer. A tropical rainforest, for example, consists of four main layers, the emergent, canopy, understory, and forest floor layers (see Figure 4.5.9). **Each layer provides different habitats that support specialised organisms adapted to those specific conditions**. The physical conditions at the uppermost emergent layer are very different to the lowermost forest floor layer. For example, the plant species at the emergent layer have access to high light intensity but the plants in the understory do not and often receive filtered light of low intensity, limiting the type of species that can grow in this layer (see Figure 4.5.9). **Within each layer, organisms occupy ecological niches**, where they play distinct roles based on the resources and interactions available.

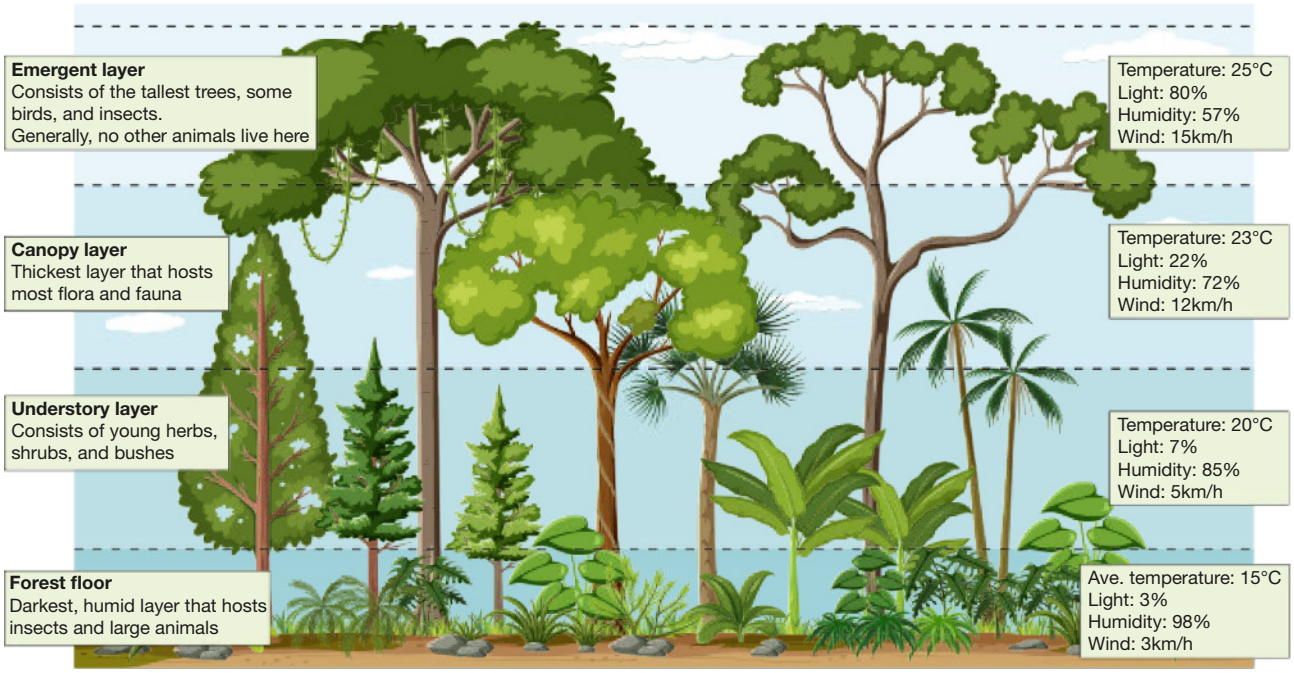


Figure 4.5.9: The stratification of a tropical rainforest

Helpful online resources

Inspire Education: The 4 Layers of the Rainforest

<https://www.youtube.com/watch?v=blh3Kq9xf_o>

Keystone species

The arches of stone buildings used to have a special stone at the top of the arch called a keystone. Although all the stones were needed, the keystone was the most important, its presence ensured the arch's stability would be maintained. Like the stones in an arch, all the species of an ecosystem contribute to its stability. The ecological niche of a few of them, however, affects the stability of the ecosystem much more greatly than the numbers or size of them would suggest. These organisms are called keystone species.

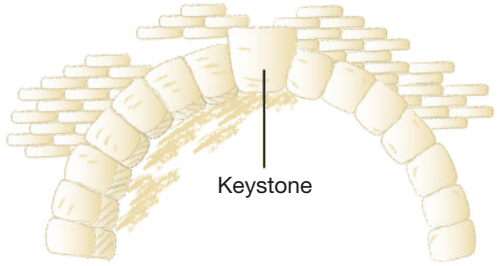


Figure 4.5.10: The keystone of a stone building arch ensures its stability. The term "keystone" is used to describe key species that provide ecosystems with great stability.

Keystone species play a critical role in maintaining the structure, balance, and health of ecosystems. Unlike other species, their presence or absence has a disproportionately large impact on the environment and the variety of species within it. By influencing factors like population control, resource availability, or habitat structure, keystone species help regulate the ecosystem's dynamics. For example, apex predators like sharks can control its prey population sizes, while ecosystem engineers like beavers create wetlands that benefit a wide range of species. **Without keystone species, ecosystems can become destabilised**, leading to a significant loss of biodiversity and ecological collapse. Some examples of Australian keystone species are highlighted in Table 4.5.4.

Table 4.5.4: Some examples of Australian keystone species.

Keystone species	Ecological niche and role in ecosystem maintenance
Grey-headed flying fox	East Coast rainforests; ranging from southern Queensland to Victoria. Pollination and seed dispersal. Facilitates the reproduction and thus survival of dozens of species of palms and other rainforest plants.
Grey nurse shark (Eastern states population)	Coastal waters; ranging from southern Queensland to Victoria. Consumer of fish, crustaceans, sharks, rays and squid. Keeps the population size of many species of these organisms in balance.

Loss of keystone species destabilises ecosystems

The extinction or loss of any species in the wild is regrettable and to some extent weakens the stability of its ecosystem. The prospect of keystone species going extinct is particularly serious. The existence of the East Coast rainforests are under threat, partly because Grey-headed flying foxes are a **vulnerable species** and face a high risk of going extinct in the wild. Furthermore, the grey nurse sharks are now a **critically endangered species** so the risk of them going extinct in the wild is extremely high. It is therefore likely that its prey population sizes along the east coast of Australia will progressively increase as their predator's population approaches extinction.

Decline in sea otters example

One of the best known studies about keystone species and the critical role they play in their ecosystem took place in California in the 1970s and concerned sea otters. Sea otters are a coastal marine species of mammal that consume invertebrates called sea urchins. Populations of sea urchins consume a type of seaweed called kelp. The kelp's niche includes providing marine organisms with a source of food and shelter and, via photosynthesis, oxygen for aerobic respiration. The study showed that large populations of sea otters kept the size of sea urchin populations relatively low. This allowed the kelp populations to be maintained as large, well-developed underwater forests. The species diversity of the kelp forest ecosystem was high as there was ample oxygen, food and shelter (see Figure 4.5.11).

A subsequent study showed that the decrease in the population size of sea otters along the Pacific North West coast in the 1990s, apparently mostly due to an increase in predation by killer whales, caused sea otter populations to sharply decline. This caused the size of sea urchin populations to radically increase which in turn led to much less kelp forest, and, very quickly, a catastrophic decrease in species diversity of the ecosystem (see Figure 4.5.11).

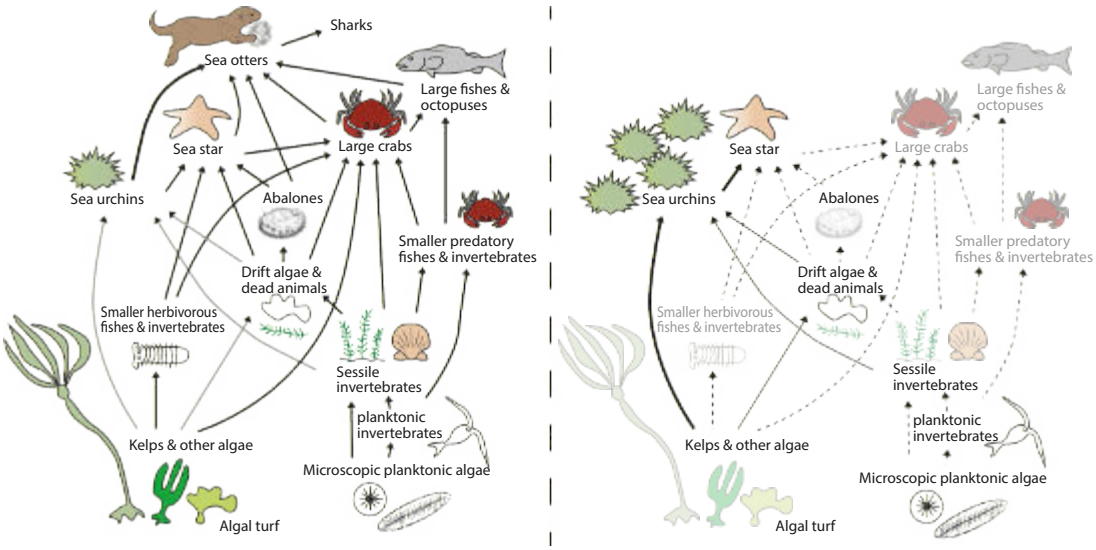


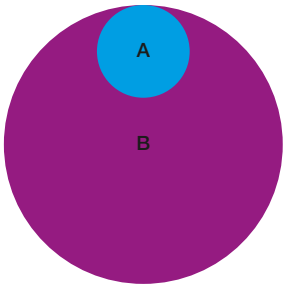
Figure 4.5.11: A stable kelp forest food web (left) and the same kelp forest food web following a decrease in the sea otter population (right). The changed relationships are shown with dotted lines and the affected species are shown greyed-out.

4.5 Review questions

Multiple choice questions

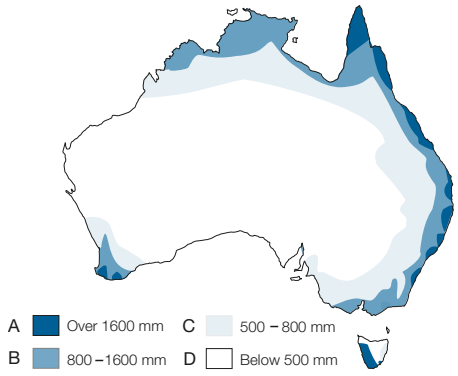
1. Ecosystems can be broadly categorised into different types
   - J by their biotic and abiotic components and the interactions between them.
   - K because they have similar features.
   - L to increase ecosystem diversity.
   - M because each ecosystem consists of the same abiotic components but different biotic components.
2. An ecological niche is
   - J a physical location where a species lives.
   - K the relationship between two communities.
   - L the specific role and position of an organism within an ecosystem.
   - M a highly specialised organism.
3. Identify the most correct definition of a keystone species from the following options.
   - J A species that migrates.
   - K A species whose habitat is rocks and stones.
   - L A species that is always an apex predator.
   - M A species that keeps balance in its ecosystem.
4. *Refer to the image to the right which represents the niche of a species to answer the following question.*

   Which of the following statements is most correct regarding the image representing niches?

   - J A and B represent the niches of different species.
   - K A represents the fundamental niche and B represents the realised niche of a species.
   - L B represents the fundamental niche and A represents the realised niche of a species.
   - M A and B together represent the realised niche of a species.

Refer to the image below which shows the average rainfall across Australia to answer questions 5 and 6.



5. The type of ecosystem that is most likely to be found in the areas represented by A is
   - J a tundra ecosystem.
   - K an ocean ecosystem.
   - L a grassland ecosystem.
   - M a rainforest ecosystem.
6. The type of animal that is most likely to be present in the areas represented by D is a
   - J bilby.
   - K elephant.
   - L jackrabbit.
   - M zebra.

7. When two or more species have a similar niche

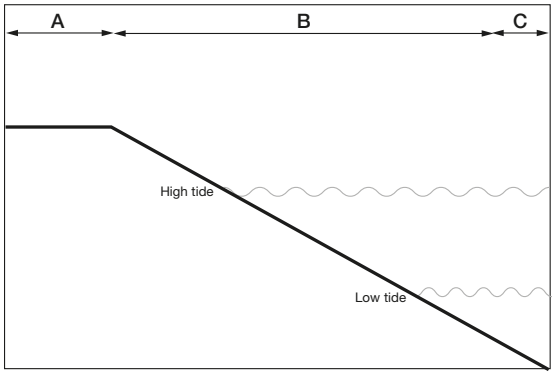
   J they compete for similar resources and the more competitive species will force the exclusion of the other species from the ecosystem.

   K they will both fill the niche without any competition.

   L a zone of overlap will be formed, and if it is a small overlap, they are likely to co-exist.

   M one species will become extinct.

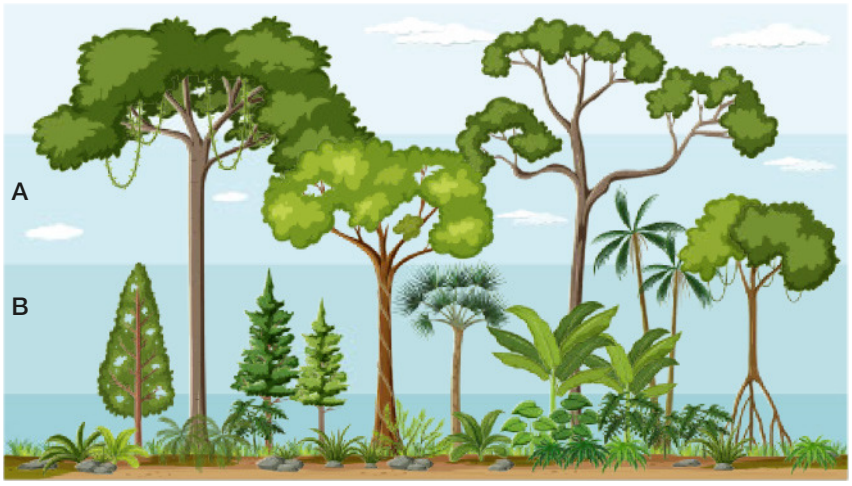
8. *Refer to the image below which shows an intertidal rock platform to answer the following question.*



Select the option that correctly identifies the two zones of the intertidal rock platform (B and C) and a species likely to inhabit each corresponding zone.

	Name of zone B	Species likely to be in zone B	Name of zone C	Species likely to be in zone C
J	Supratidal zone	Soft bodied organisms	Splash zone	Hard shelled organisms
K	Intertidal zone	Soft bodied organisms	Splash zone	Soft bodied organisms
L	Supratidal zone	Hard shelled organisms	Subtidal zone	Hard shelled organisms
M	Intertidal zone	Hard shelled organisms	Subtidal zone	Soft bodied organisms

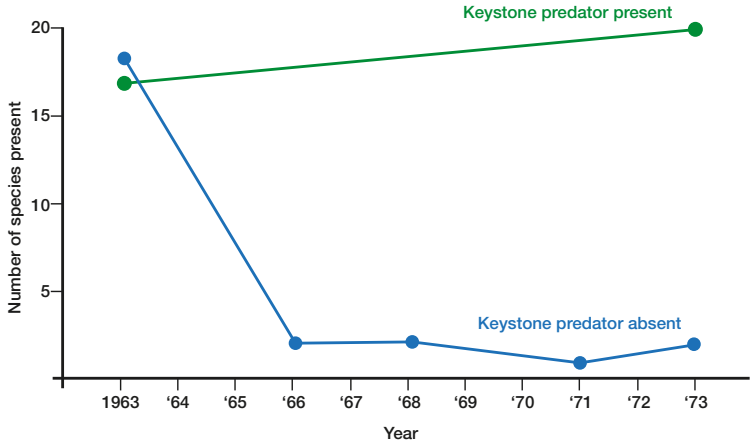
9. *Refer to the image below which shows the stratification of a rainforest to answer the following question.*



Select the option that correctly identifies the two layers of the rainforest (A and B) and a likely corresponding abiotic component at each layer.

	Name of layer A	Likely abiotic component at layer A	Name of layer B	Likely abiotic component at layer B
J	Emergent	High temperature	Understory	Low light intensity
K	Canopy	High temperature	Understory	High humidity
L	Emergent	High light intensity	Forest floor	Low light intensity
M	Canopy	High light intensity	Forest floor	High humidity

10. *Refer to the graph below which shows the number of species present in an ecosystem with and without a keystone species to answer the following question.*



Which of the following options is correct regarding the information shown in the graph?

J The absence of keystone predators increased the number or other predators present.

K The presence of keystone predators increased the total number of species present each year over the 10 recorded years.

L The absence of keystone predators decreased the total number of species present each year over the 10 recorded years.

M The presence of keystone species destabilised the ecosystem.

Free response questions

1. Ecosystems can be broadly categorised based on their unique combinations of abiotic and biotic components.

   Complete the following table by describing the likely abiotic and biotic factors of the four types of ecosystems listed.

Ecosystem	Description of likely abiotic and biotic components
Grassland	
Tundra	
Desert	
Freshwater	

2. Discuss how the abiotic factors can shape the biotic factors in an ecosystem.

3. Explain the difference between a habitat and a niche.

4. Describe the ecological niche of an Australian River Red gum by referring to both abiotic and biotic components of the ecosystem. Hint: refer to Figure 4.5.3.

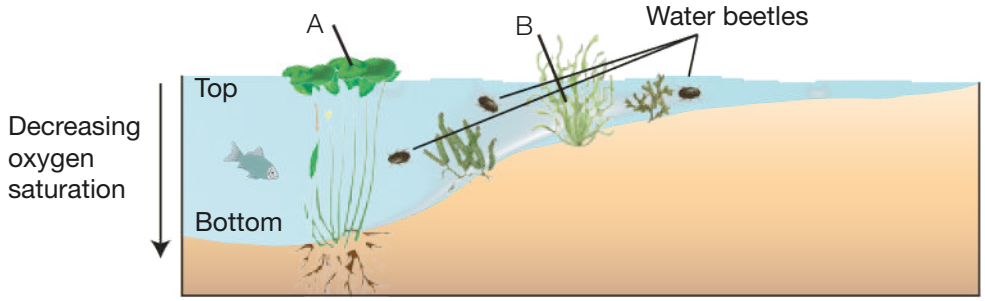
   a) Abiotic components

   b) Biotic components

5. Suggest **three** important factors that organisms generally need to fulfill their ecological niche to survive.

6. Explain why competition for resources is usually greater between members of the same species, compared to competition with different species.

7. *Refer to the diagram below of a simple pond ecosystem and Table 4.5.3 to answer the following questions.*



   a) Predict **three** ways that the abiotic factors may differ from the top of the pond compared to the bottom.

   b) Explain how having large floating leaves provides an adaptive advantage for the plant labelled A.

   c) The leaves labelled B are branched. Explain **one** way this type of adaptation assists in plant survival.

   d) Water beetles have adapted to trap bubbles under their wings when they dive deeper. Explain **one** likely reason for this adaptation.

Pond water is quite fresh, and therefore has a low solute concentration.

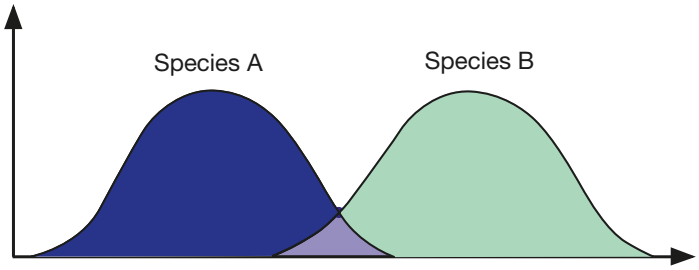
e) Describe **one** problem that this solute concentration could pose for organisms living in pond water.

f) (i) Name **one** organism that has developed an adaptation to overcome this problem identified in (e).

(ii) State **one** adaptation the organism identified in (f)(i) has developed to survive in the low solute concentration of pond water.

(iii) Explain how the adaptation identified in (f)(ii) helps the identified organism survive in the low solute concentration of pond water.

8. Refer to the graph of a niche overlap below to answer the following questions.



a) Briefly explain what is meant by the 'zone of overlap' and what it represents.

b) Discuss the likely outcome if species A and species B niches completely overlapped.

9. Sheep and kangaroos are found living together throughout southern Australia. The presence of sheep alters the fundamental niche of kangaroos, causing them to have a very different niche.

a) Use the example above to illustrate the difference between a 'fundamental niche' and a 'realised niche'.

b) Describe **two** other biotic factors that influence the realised niche of kangaroos.

10. Describe the characteristics of the zonation in an intertidal rock platform and select the main components giving rise to the zonation.

11. Refer to the table below showing some environmental factors of three rock pools (A, B and C) at various points from the sea to answer the following questions.

Environmental factor	Pool A (near high water mark)	Pool B (intertidal zone)	Pool C (close to sea)	Sea
Solute concentration (salinity) (g/L)	46	39	37	34
Average temperature (9am - 4pm) (°C)	31	30	27	16
Percentage O_2 dissolved (compared with sea water) (%)	17	53	67	100

a) Describe the gradient that exists in the rock platform, moving from the sea to Pool A for each of the **three** environmental factors.

b) The solute concentration is an important factor in determining the survival of organisms. Some rock pools in the supratidal zone are noted to have varying levels of salinity. Sometimes, the pool may have very saline conditions but at other times the same pool may be mainly freshwater with low solute concentrations.

(i) Explain **one** possible explanation for this wide fluctuation in salinity.

(ii) Outline some possible problems that this fluctuation in salinity poses for the organisms living in these pools **and** provide some adaptations that the organisms possess to overcome these problems.

c) Compare the average temperatures from the sea to Pool A with the percentage dissolved oxygen recorded.

d) Briefly outline how you could test the relationship identified in (c) above.

12. Stratification refers to the vertical layering of habitats within an ecosystem.

a) Complete the following table by describing the gradient that exists in rainforests for the four identified environmental factors **and** explain the most likely reason(s) for these gradients. Hint: Refer to Figure 4.5.9.

Environmental factor	Description of gradient through rainforest strata and likely explanation
Light intensity	
Temperature	
Humidity	
Wind	

b) (i) Compare the type of species present in the emergent layer to the forest floor layer.

(ii) Explain **one** reason why the species identified in (b)(i) above live in their respective habitats, the emergent and forest floor layers.

13. Hammerhead sharks are a keystone species. They feed on cownose stingrays, which in turn feed on scallops, clams and oysters.

a) Explain what a keystone species is.

Hammerhead shark populations are being decimated by humans in the shark finning industry, where sharks are caught and their fins are stripped for use in shark fin soup. The shark fin industry is the second most profitable industry behind illegal drugs.

b) Explain the impact of a major decline in the hammerhead shark population on this food web.

c) Using your understanding of the interaction between science and society, discuss how the shark finning industry has influenced society.

Chapter 4.6 Ecosystems change over time

Science Understanding

Ecosystems can change over time.

Ecological succession involves changes in biotic and abiotic components and their dynamic influence on each other.

- Describe examples of succession.

Evidence for longer term changes can be found in geological deposits including the fossil record.

Ecosystems change over time

The location and composition of an ecosystem is influenced by its abiotic and biotic components, and how these influence each other. For example, the air temperature and soil solution quality, influences the number and size of plant populations, which in turn affects, and is affected by, animal populations in the ecosystem. Unsurprisingly, changes to the abiotic and biotic components of an ecosystem can change the make-up of its community and may alter the range, or distribution, over which it is found. These changes can occur over the short term, such as the changing of seasons, or long term, such as **ecological succession**.

Short term ecological change

Daily change

The Earth rotates on its axis once every 24 hours causing day and night. The abiotic components of an ecosystem change during the day and as day passes into night. This includes changes to light intensity, temperature, and humidity of the air. These, and other short-term abiotic changes, exert a powerful influence on the presence and number of populations of animals. For example, populations of herbivores, and thus predators, may be present and quite active in a grassland ecosystem during the early and later part of the day, but less so at night.

Seasonal change

The **cyclic** changing of seasons throughout the year results in changing weather patterns for ecosystems. This is caused by the revolution of the Earth around the sun, which takes 365 and ¼ days (a year), and results in four distinct seasons, spring, summer, autumn and winter. Seasonal changes can affect abiotic factors such as temperature, rainfall levels, soil moisture levels, evaporation rates, the flowing of rivers, and snow cover. The changes in abiotic factors impact the biotic factors and affect the type and amount of food available for humans and other organisms. During winter, the days become shorter and the temperature decreases. In some areas, like polar regions, winter also brings snow. The animals in polar regions need to find alternative sources of food, move to warmer locations, or hibernate to survive the harsh winter periods. In contrast, the abiotic components of many terrestrial ecosystems in spring support the reproduction of most plant and animal species. The size of populations of many species may change so much that the community begins to visibly change (see Figure 4.6.1).

Figure 4.6.1: A woodland ecosystem in mid-winter (left) and early summer (right) highlighting the seasonal changes in this ecosystem.

Long-term ecological change

Not all ecosystem change is short-term and cyclic. Long-term change to ecosystems occurs if the abiotic and biotic components of the ecosystem are significantly altered, such as the colonisation of new species to an area, a natural disaster or some kind of human activity. Events like this **may change the abiotic and biotic components** so much that the conditions are **more suitable for other species** to thrive, instead of the earlier collections of species in the ecosystem. Over time, this slowly and permanently **changes the mix of species** in the ecosystem. This more **unidirectional** type of ecosystem change is called **ecological succession** (see Figure 4.6.2).

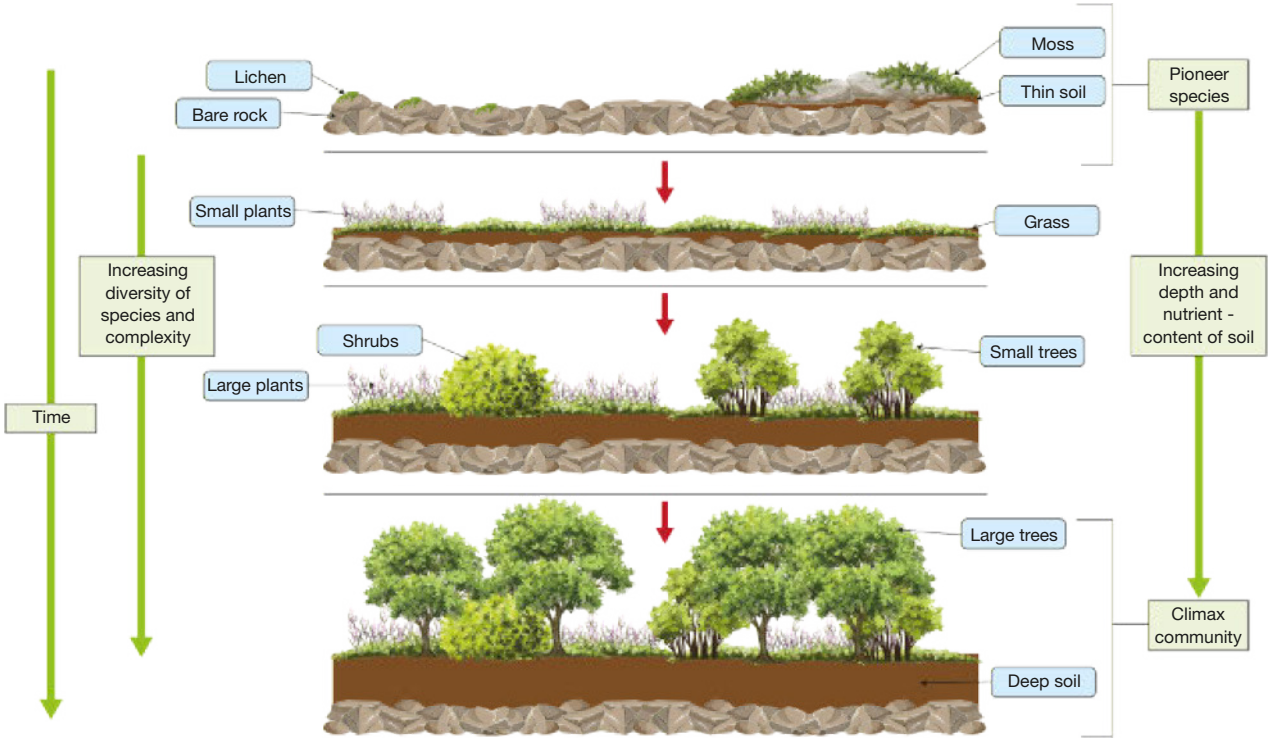


Figure 4.6.2: Ecological succession is the gradual process by which the species composition of a community changes and is often brought about by the modification of the habitat caused by the organisms that live there.

Primary succession

Ecological succession may start in a virtually lifeless area that lacks soil, such as bare rock that is uncovered by a gradual decrease in sea level, lake level or the retreat of a glacier. It also occurs after the formation of volcanic islands. A prime example of this is the thirteen Galapagos Islands off the coast of Ecuador, South America. This type of succession is called **primary succession** (see Figure 4.6.3).

Primary succession on bare rock begins when spores of autotrophic organisms blown by the wind settle in crevices in the rock produced by erosion. This includes the spores of lichens and mosses. Populations of these colonising species grow and eventually die. Their remains, together with tiny pieces of eroded rock, contribute to the formation of a **simple soil** (see Figure 4.6.4). Over time, this becomes more stable and nutrient-rich and thus more suited to supporting the germination of seeds of wind dispersed plants, such as grasses and small non-woody **herbaceous plants**. The growth of the root systems of these plants help hold the soil together but they can also penetrate the rock crevices at times and widen them, contributing to the weathering of the rock and deepening of the soil level. The eventual death and decomposition of these plants further increases the nutrient levels in the soil and adds more depth, which can become more suitable for small woody shrubs. Over time, populations of these shrubs and animals that colonise the developing ecosystem, seeking food and shelter, live and die and the rock continues to erode and break up due to weathering and the action of plant root systems. Eventually, this leads to the formation of a **mature soil** that permits seeds of trees, dispersed by animals travelling to the ecosystem (see Figure 4.6.4). After several hundred years the once almost lifeless and bare rock has been transformed into a living species-rich ecosystem (see Figure 4.6.3).

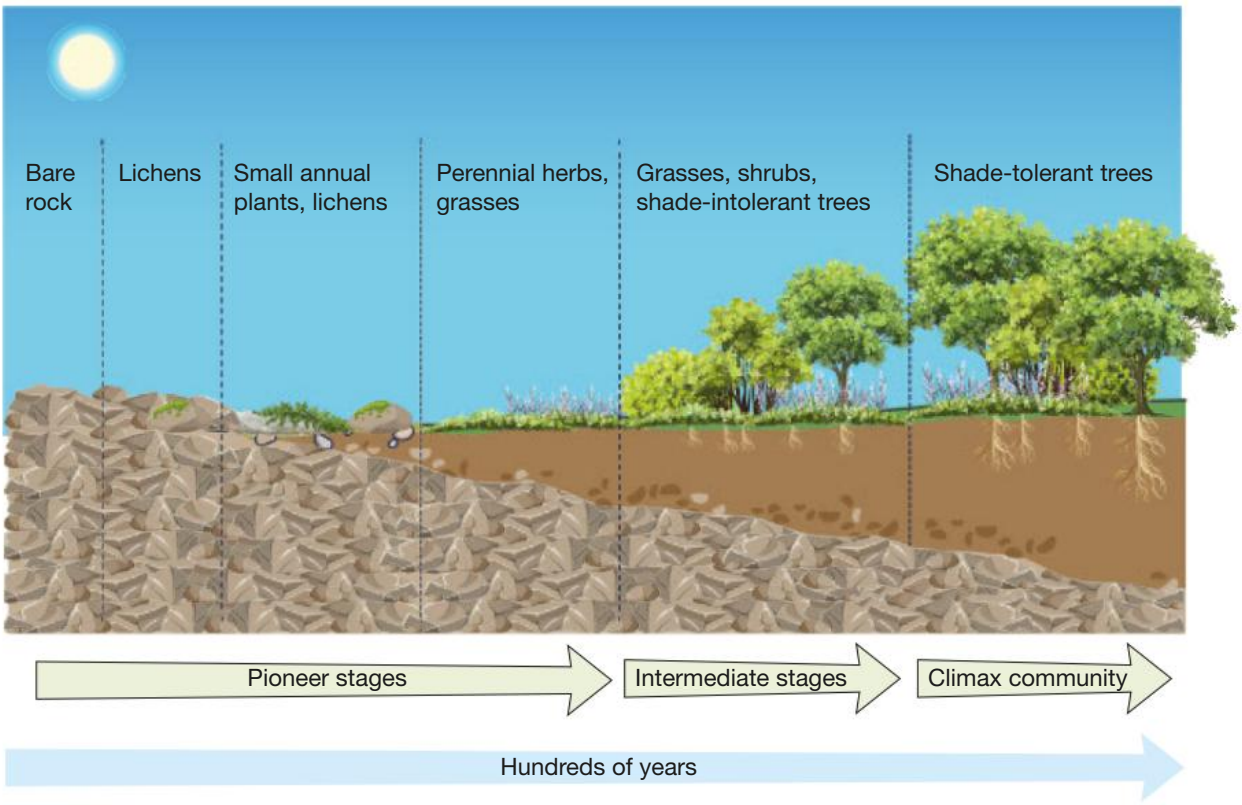


Figure 4.6.3: Primary succession starts from bare rock and over a long period of time progresses to a climax community with a high biodiversity.

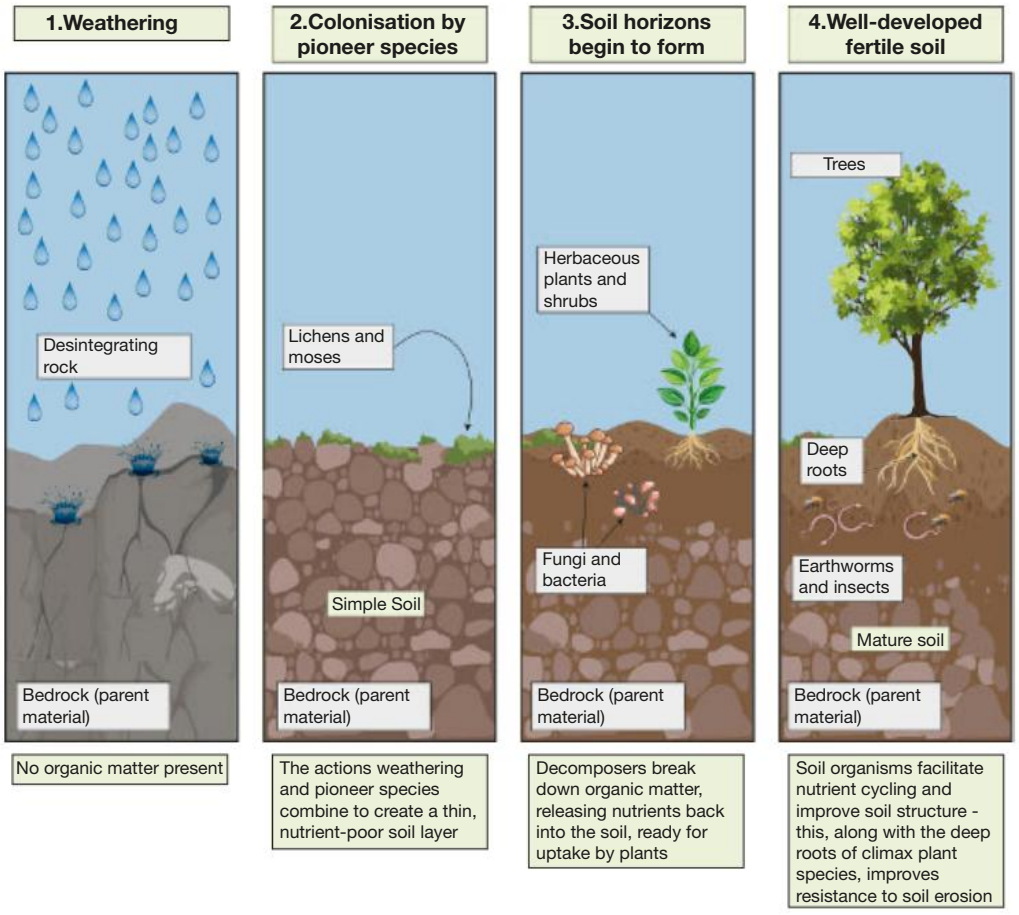


Figure 4.6.4: Until soil is formed, large amounts of vegetation are unable to be supported. Once soil is formed, plants can grow and modify the harsh environment present in the early stages of primary succession, leading to increased soil depth and quality, which supports the growth of more complex species.

Secondary succession

Ecological succession may also occur in an already mature ecosystem if it experiences a natural disaster or is subjected to a major human activity (see Table 4.6.1). This type of succession is called **secondary succession** (see Figures 4.6.5 and 4.6.6). One example of a natural disaster is a wildfire which results in a large loss of life. This loss of life is random and the species that survive are not necessarily better suited to the environment, they were in the right place at the right time (away from the wildfire). Secondary succession therefore generally occurs following a **genetic drift** event.

Secondary succession following a wildfire begins with the germination of the seeds of wind-blown herbaceous plants. Germination of the plants and the growth of seedlings is rapid because the soil is warm and nutrient rich due to the high ash content following a wildfire. The underground seeds of species present prior to the fire that are undamaged also germinate quickly and grow. As a result, **a new mixture of populations** of plant species soon becomes established. Populations of animals in the original ecosystem that escaped the fire may return seeking food and shelter, as do populations of new animal species. Competition between populations of colonising species of plants, and between returning and new species of animals, influences how many species become established, the size of their populations and ultimately how different the post-fire ecosystem is from the original ecosystem it replaces.

Generally, secondary succession occurs more quickly than primary succession although how long it takes is determined by factors including the size of the original disturbance and the stability of the original ecosystem. Refer to Table 4.6.2 for a comparison of primary and secondary succession.

Table 4.6.1: Some examples of natural and human-induced disturbances that could lead to secondary succession.

Type of disturbance	Example	Type of disturbance	Example
Natural	Wildfire	**Natural**	Landslide
Natural	Volcanic eruption	**Natural**	Avalanche
Natural	Floods	**Human-induced**	Deforestation
Natural	Sea-level rise or retreat	**Human-induced**	Mining
Natural	Tropical cyclones	**Human-induced**	Arson
Natural	Insect plague	**Human-induced**	Nuclear meltdown
Natural	Disease	**Human-induced**	War
Natural	Tsunami	**Human-induced**	Controlled burns

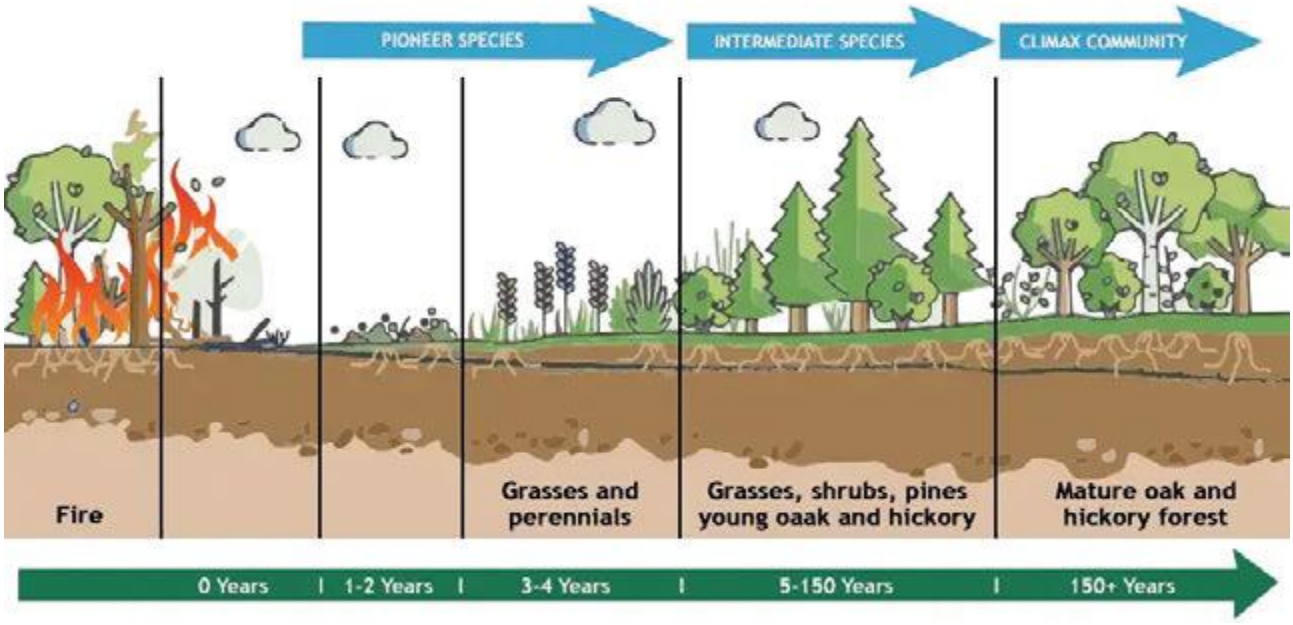


Figure 4.6.5: Secondary succession occurs in established areas that experience disturbances and generally results in a new mix of species.

Figure 4.6.6: A forest fire (top left) and recovery after 1 year (top right), 2 years (bottom left) and 9 years (bottom right).

Table 4.6.2: A comparison of primary and secondary succession.

Primary succession	Secondary succession
No life present to start with	Original life removed by disturbance
No soil present to start with	Existing soil is present
Starts in a new area	Established area
Lichens and mosses are the first colonising species	Plant seeds and roots are already present
Collective mass of species (biomass) is lower	Collective mass of species (biomass) is higher

Very long-term ecological change

Studies have shown that ecosystems can develop and change a great deal over just a few decades let alone centuries. It stands to reason that given much, much longer periods of time, tens or hundreds of millions of years, significant ecosystem changes should occur. If true, ecosystems today likely bear little or no resemblance to ancient ecosystems in the same location tens or hundreds of millions of years ago.

Ediacaran biota

One example of very long-term change concerns the discovery of an ecosystem that once existed in what is now the northern Flinders Ranges in South Australia. Today, ecosystems of the northern Flinders are very dry and hot for most of the year with sparse populations of arid shrub and woodland. These support a diversity of arid-adapted animals that includes species of insects, reptiles, birds and mammals. During the **Ediacaran Period** (600-543 million years ago), however, the region was at the bottom of a shallow sea. There was no life on land and no animals and plants in the sea. The multicellular forms of life were soft-bodied sponge-like organisms and plant-like algae that lived attached to the sea floor.

The existence of the Ediacaran biota, and thus of the abiotic components of the ecosystem at the time, is **supported by fossil evidence**. The fossils of these Ediacaran species are on display in the Museum of South Australia. Studies of the Ediacaran and Flinders ecosystems have gone on to improve our understanding of ecosystem change over very long periods of time.

Helpful online resources

JG Online: The Ediacaran Explosion ft. CambrianScience

<https://www.youtube.com/watch?v=7aofA9xgpD4>

Dinosaurs in Australia

Another example of very long-term ecosystem change that has taken place in Australia can be seen in central western Queensland near the town of Winton. Today the ecosystems in this part of Australia are semi-arid and mostly consist of vast flat grasslands and extensive river flats that flood with summer rains. There is a large diversity of animal species, many of which are threatened by the persistence of cattle farming that remains vital to the local economy. In the **Cretaceous Period**, 146-65 million years ago, the ecosystem was quite different. During this time, the ecosystem included rivers and mudflats that ran into large lakes. These were surrounded by lush rainforests that consisted of many species of plants. Species of small bi-pedal dinosaurs inhabited the rainforest and edges of the lakes and periodically wandered out onto the mudflats to drink water and to feed.

The existence of the Winton Cretaceous ecosystem is supported by the discovery of pollen and spores of the now extinct rainforest plants and fossils of the dinosaurs that lived with them at the time. Evidence for small bi-pedal dinosaurs in the ecosystem was demonstrated by the spectacular discovery of a complex series of fossilised footprints at nearby Lark Quarry that captured a **dinosaur stampede** that took place on a mudflat 95 million years ago. Refer to Figure 4.6.7 to see a photo of the preserved dinosaur prints from Lark Quarry in Queensland.

Helpful online resources

ABC iView: Dinosaur Stampede | Australia: The Time Traveller's Guide

<https://www.youtube.com/watch?v=jRWFXr60kUk>

Figure 4.6.7: Preserved dinosaur prints from Lark Quarry in Queensland.

Figure 4.6.8: A computer generated image showing a Thylacaleo attacking a DIprotodon.

Megafauna

A third case of a very long-term ecosystem change involves the ecosystem that existed in the **Pleistocene Period** (2 million-10,000 years ago) in the south-east corner of South Australia near Naracoorte. For most of that time the area was colder and drier than it is today, with only occasional periods that were warmer and wetter. Analysis of the soil shows that this supported a sparse mixture of species of tough-leafed grasses and shrubs. Large numbers of fossils discovered in the Naracoorte Caves confirm that these were consumed by **megafauna** that consisted of giant species of marsupials. Some examples of megafauna include the Diprotodon, a four wheel drive sized herbivore (see Figure 4.6.8), and *Procoptodon,* a short-faced giant kangaroo that stood 2.5 metres high and ate leaves. The main predator at the time was *Thylacoleo* or the marsupial lion that was the size of a leopard (see Figure 4.6.8).

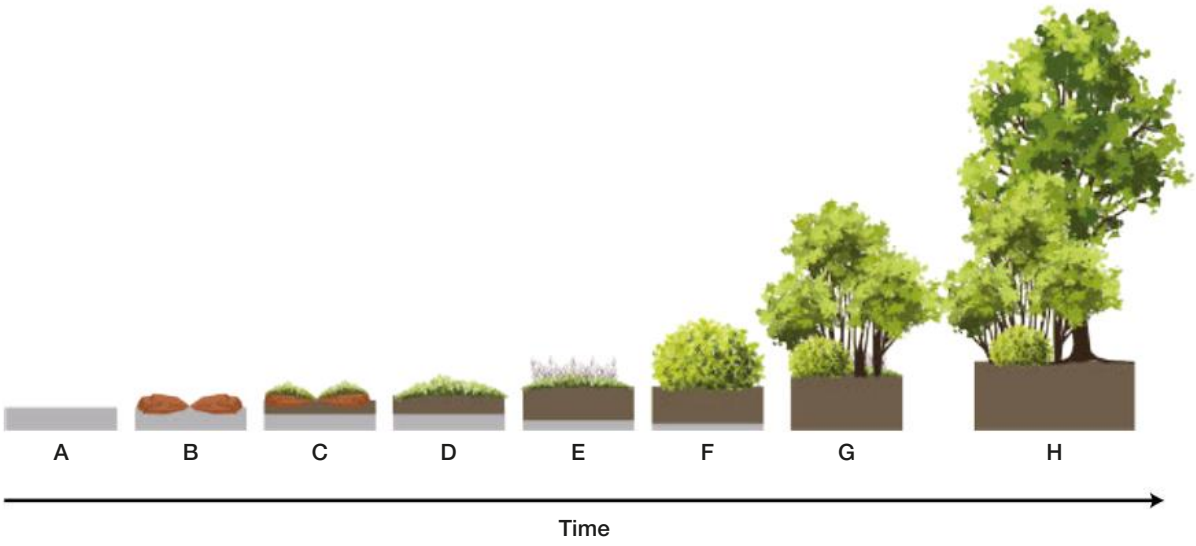
None of these plants and animals feature in ecosystems in the Naracoorte area today. **Fossil evidence** suggests that the megafauna had become extinct by about 35,000 years ago, either as a result of a warming environment, the arrival of the first humans, or both.

4.6 Review questions

Multiple choice questions

1. An example of a pioneer species is a
   - J bare rock.
   - K tree.
   - L shrub.
   - M moss.
2. A likely event preceding primary succession is
   - J a tsunami.
   - K a wildfire.
   - L the retreat of a glacier.
   - M deforestation.
3. Lichens
   - J are complex species that outcompete shrubs.
   - K help create fungi in soil.
   - L are basic species that are most common in climax communities.
   - M help create simple soil during primary succession.
4. Which of the following is **not** an example of a natural disaster leading to secondary succession?
   - J Wildfire
   - K Flooding
   - L Logging
   - M Landslide
5. A natural disaster such as a wildfire does **not** cause
   - J genetic drift in multiple species.
   - K a resulting period of ecological succession.
   - L short term ecological change.
   - M a loss of biodiversity.
6. Which of the following is a correct description of ecological succession?
   - J A forest is destroyed and replaced by a lake.
   - K One type of community replaces another over time.
   - L A series of natural changes leading from climax to pioneering community.
   - M A climax community is destroyed forever.
7. Which of the following options does **not** contribute to the formation of nutritious soil?
   - J Rain and wind weathering rock.
   - K Wind and rain eroding soil.
   - L The decomposition of dead shrubs.
   - M Plant roots penetrating crevasses of bedrock.
8. What is likely to occur following a disturbance to an established area that left no soil behind?
   - J Primary succession.
   - K Secondary succession.
   - L Pioneering community.
   - M No life remains in this area forever.

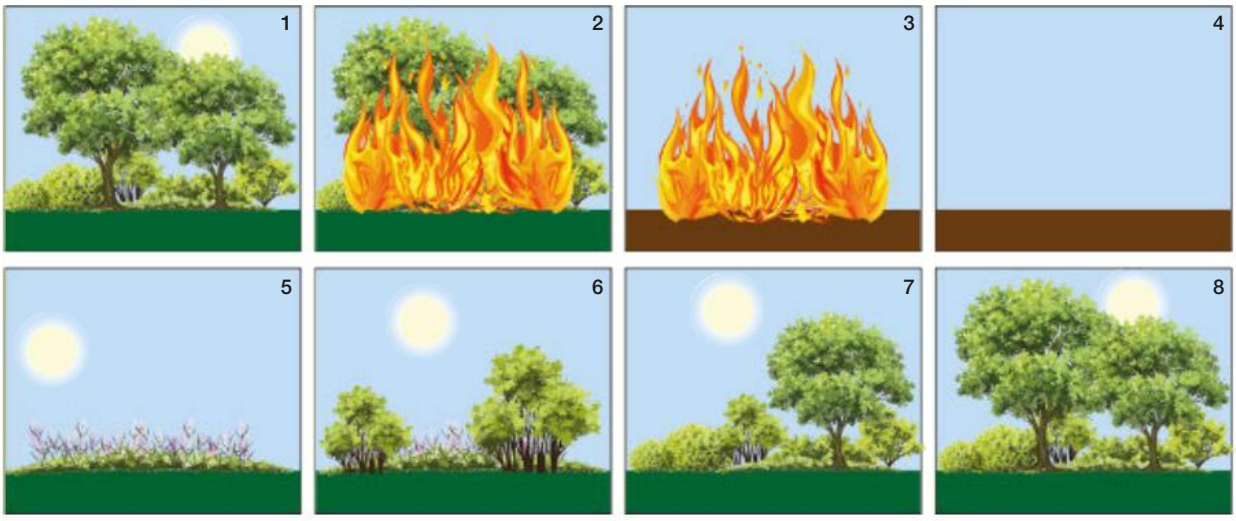
9. *Refer to the graph below which shows a change in the mix of species over time to answer the following question.*



Select the option below that correctly identifies the type of succession and the types of communities present in the three corresponding stages.

	Type of succession	Type of community present at B	Type of community present at E	Type of community present at H
J	Primary	Intermediate	Climax	Pioneering
K	Secondary	Intermediate	Climax	Pioneering
L	Primary	Pioneering	Intermediate	Climax
M	Secondary	Pioneering	Intermediate	Climax

10. *Refer to the diagram below showing some stages of an ecological succession event to answer the following question.*



With reference to the diagram above, which of the following statements is correct?

J The species in Stage 1 and Stage 8 of the diagram would be exactly the same.
K Stage 1 shows pioneer species at the start of ecological succession.
L Stage 4 shows that this is an example of primary succession.
M Stages 6 and 7 show intermediate communities.

Free response questions

1. Define succession.

2. State **three** differences between primary and secondary succession.

3. State **one** example of a short-term change to an ecosystem **and** describe the cause of the change.

4. Describe how fossil evidence provides support for succession in ecosystems over very long-time spans.

5. Suggest **two** reasons that might cause an established ecosystem to start to change.

6. Primary succession can occur on bare rock:
   a) State **two** examples of species that may live on bare rock at the start of a primary succession event.

   b) Outline the role played by autotrophic organisms in primary succession that takes place on bare rock.

   c) Suggest some possible adaptations that these autotrophs may possess.

7. North-east Queensland is home to wet tropical rainforest ecosystmes. In 2011, Mission Beach in far north-east Queensland was hit by Cyclone *Yasi*. Explain how this natural disaster led to secondary succession in the local wet tropical rainforest ecosystems **and** what changes may have occurred.

8. Fossilised Ediacaran biota is not endemic to Australia, and has been discovered in other areas, most notably in the south-east corner of Canada. Given that there is no evidence of Australia and Canada ever being connected to one another, what is the likely reason for parts of both countries having a similar biota in the Ediacara Period?

9. The Tasmanian World Heritage Wilderness Area in the south-west of the state contains cool wet rainforest that has remained virtually unchanged for the last 40 million years. Suggest why succession has had little impact on this region.

10. Predict how each of the following may make an ecosystem more suitable to new species:
    a) Spinifex grass taking hold in a sand dune.

    b) Insects moving into leaf litter which has accumulated.

11. Explain **two** reasons why secondary succession usually occurs more quickly than primary succession.

12. Explain the following observations regarding succession.
    a) There is greater level of biodiversity in mature, stable ecosystems compared to ecosystems in an early succession communities.

    b) Ecosystems late in succession recycle essential nutrients and chemical elements better than ecosystems early in succession.

    c) In mature ecosystems there are a greater number of heterotrophic species compared to autotrophic species.

Chapter 4.7 Human impact on ecosystems

Science Understanding

Humans can interfere with natural cycles.

Humans have significant impacts on ecosystems.

- Explain how the destruction of habitats as a result of human activity speeds changes in ecosystems and impacts on biodiversity.

By measuring key aspects of the biotic and abiotic components of the ecosystem, it is possible to make predictions relating to the impact of environmental change.

- Describe how these predictions can help to develop strategies to minimise the adverse effects of such change

Sustainability of the human population

According to the United Nations (UN), the human population is currently projected to reach 9 billion by 2037, 10 billion by 2057 and 11.2 billion by 2100. The **growth of human population** has not been gradual (see Figure 4.7.1). Most of the growth has been concentrated in a huge exponential increase in the last 500 years, which has put enormous strain on the Earth's natural resources, such as fresh water and fertile land. These **resources are finite** and are being used at a much faster rate than they can be replaced. Humans also hunt species for sport and have even **introduced foreign species** to new areas because they enjoy hunting them. This was the case with the European settlers to Australia who introduced rabbits and foxes to hunt. By measuring the human population, modelling can be completed to **predict the future population growth**. This can allow governments to make decisions surrounding population growth, such as the need for urban expansion and decisions surrounding **food and water security**.

In order to meet the growing urban planning and agricultural demands, large areas of **land and forests have been cleared**. As a result, many habitats have been destroyed, **decreasing biodiversity**. Also, a lack of education in efficient farming processes has resulted in excessive land clearance, especially in developing countries. This is because the crop yields decrease after a couple of years due to **soil erosion**, so more land is cleared to gain access to more fertile soils, and in turn greater yields. In addition, **toxins, wastes and other pollutants** are being produced by humans at a much faster rate than they are being broken down, which is polluting our environment.

The increased resources required by the growing human population, combined with the increased land clearance and waste production are also contributing to **global warming and climate change**. This further impacts ecosystems due to factors such as increased evaporation of fresh water supplies, and increased frequency of natural disasters such as droughts, floods and cyclones. This results in genetic drift and changes in selection pressures on species, often with reduced populations and hence reduced genetic diversity. Those species better adapted to the increased temperatures and other pressures associated with global warming have an increased chance of survival compared to those that are not.

Human impact also extends to aquatic ecosystems. **Overfishing** our oceans is contributing to the endangerment and extinction of many fish species. Our modern fishing practices such as long lining and bottom trawling are also very inefficient resulting in a lot of by-catch that is wasted. Additionally, **ocean acidification**, which is a result of increased carbon emissions, adds further pressure on oceanic food chains. The overuse of fertilisers, and poor animal and human waste management, can result in **eutrophication** and result in the death of many aquatic organisms.

In summary, human activity and the growing human population are having significant impacts on biodiversity and ecosystems.

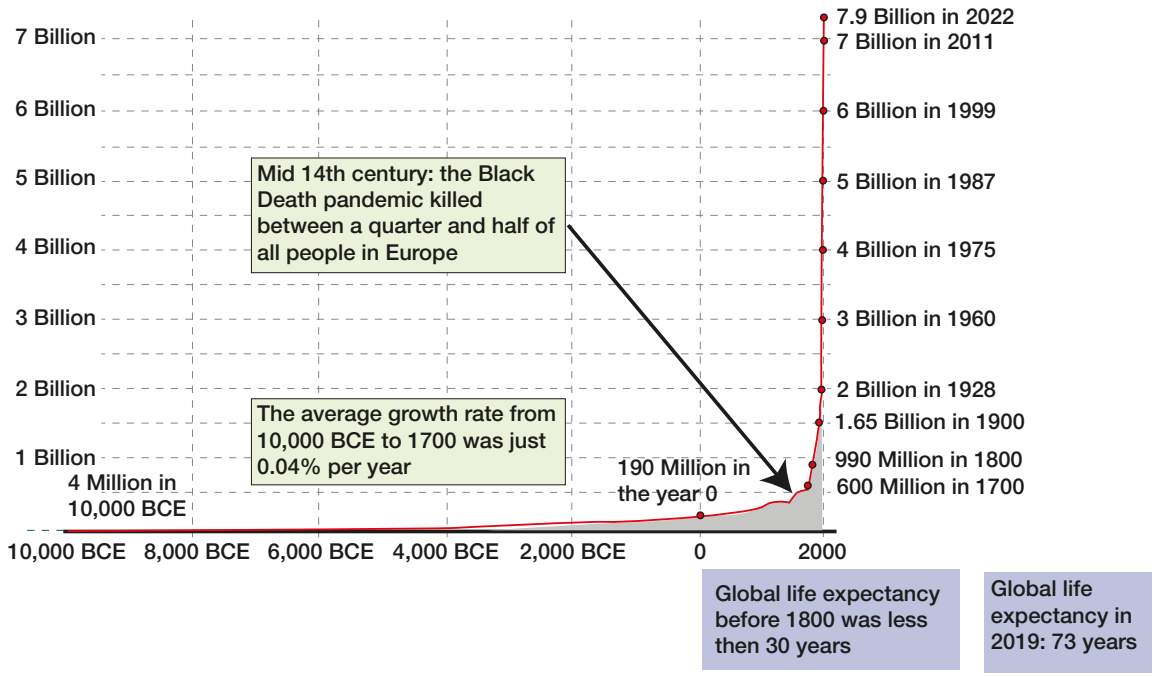


Figure 4.7.1: The size of the world population over the last 12,000 years.

Helpful online resources

FuseSchool: Global Education: Human Impact

<https://www.youtube.com/watch?v=Um-bo2MWDsQ>

Cognito: GCSE Biology - How Human Waste Reduces Biodiversity

<https://www.youtube.com/watch?v=0lUHnS-8kR4>

Land clearance

Land clearance involves the destruction of native vegetation and habitats to repurpose the land. This includes **deforestation** which is the permanent clearance of trees from forests. Land clearance results in **habitat destruction** which is the main contributing factor driving many species towards **endangerment or extinction**. It can also cause **habitat fragmentation** which occurs when natural forests are broken up into smaller, isolated patches of natural ecosystems that cannot adequately sustain communities of organisms and rich biodiversity. Some additional impacts of land clearance on the environment are highlighted in Figure 4.7.2).

In Australia, since European settlement, humans have cleared native vegetation for many reasons including agriculture and urban development (see Table 4.7.1 for some more examples). Prior to the 1860s most of the clearing was near urban settlements, but with the development of machinery and the economic and social policies put in place by governments of the day, clearing soon spread to fertile areas that enabled the wool and wheat industries to expand and flourish.

Globally, the world's forests continue to reduce in size as human population sizes increase. Approximately 129 million hectares of forest have been lost since around 1990. An increasing number of forests have recently been placed under protection and management practices are improving. Over the last 25 years the rate of net global deforestation has slowed considerably.

Some vital reasons to maintain natural vegetation include:

- to provide a range of habitats to help maintain species diversity
- to provide vegetation with deep roots which maintain water table levels and help prevent soil salinity
- to help maintain and protect the soil from erosion
- to absorb carbon dioxide, a greenhouse gas, and produce oxygen
- to help maintain regional rainfall patterns
- to help reduce the number of weeds and feral animals.

Table 4.7.1: Some reasons for human land clearance.

Purpose of land clearance	Explanation
Logging	Trees are felled for timber to use for a variety of purposes including building houses and furniture.
Agriculture	Large areas of land are cleared for plantations such as wheat, soy and rice. They are also cleared for pasture so that livestock can graze the pasture lands, such as cattle, sheep and horses.
Urban expansion	As the human population increases, the need for more housing and facilities to support the growing human communities require land to be cleared.
Mining	Land is cleared to construct mines and obtain valuable resources that lie in the earth below the natural vegetation.
Roads	Land is cleared to build roads for humans to commute to and from locations. Urban expansion and growing human population increases the need to build more roads to new developments and update existing roads to increase traffic efficiency.

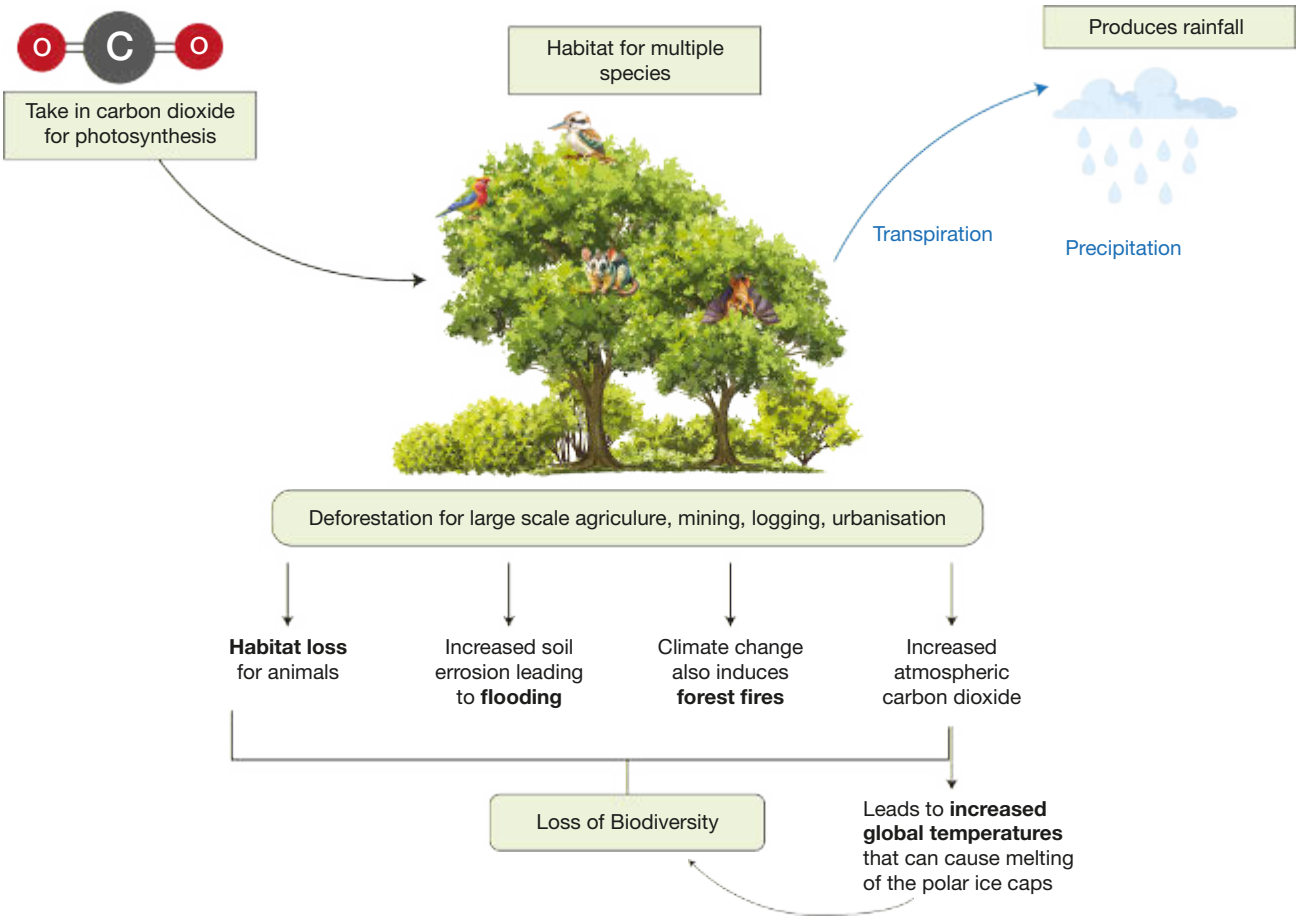


Figure 4.7.2: Some impacts of deforestation on the environment.

Helpful online resources

Cognito: Land Use - Deforestation & Peat Bogs

<https://www.youtube.com/watch?v=SROoINlp4VY>

Habitat fragmentation

In the woodlands of eastern Australia, some five million hectares of forest are logged commercially, with the forest being repeatedly cut and replanted. When the native vegetation is cleared, habitats for native species are destroyed, the diversity of habitats is reduced and there are major disruptions to ecological processes.

Temperate woodlands are one of the most threatened types of ecosystems in Australia. It has been estimated that around 80 per cent of these woodlands have been cleared. These woodlands now contain a very high number of threatened native animals and plants. These regions have had the largest numbers of birds that have become extinct of any habitat in Australia. When native vegetation is cleared there are a number of impacts on the environment, some that are not observed for considerable periods of time. The clearing of older trees is a major threat to native birds, as many of these species require the nesting sites and hollows that are only found in mature trees of 100-400 years of age. When individual species are threatened or destroyed there is often a 'chain reaction'. These 'chain reaction' effects could be related to biological processes such as predation, decomposition, pollination, seed dispersal, pest control or other relationships. Surviving woodlands are also placed under pressure by the action of introduced animals like rabbits and foxes, as well as any grazing by domestic stock, other significant changes can also occur.

The loss of native grasses and herbaceous plants destroys both a food source for native species and their natural habitat. The conditions of a disturbed ecosystem are ideal for different species to move in and colonise. Many introduced plants and weeds often take over, along with feral animals, further leading to a breakdown of the remaining woodland habitat. In Victoria it was found that small heavily grazed patches support fewer forest birds, but more farmland birds, who aggressively compete with native species, excluding them from nesting sites (see Figure 4.7.4).

Figure 4.7.4: Examples of aggressive birds: the noisy miner (left), galah (middle) and magpie (right).

Through clearing, **fragmented patches or islands of native vegetation** are created in between pasture land and paddocks. When these islands of native vegetation are relatively small, they cannot sustain important ecological processes like water and nutrient cycling as effectively as before. This **habitat fragmentation** will generally cause a **decline in species diversity**, and other more aggressive species of birds, will tend to increase in number at the exclusion of others. When the native species of deep-rooted plants are removed, there is often a rise in the water table and associated problems of soil salinity, which affect not only the remaining native vegetation but also agricultural crops.

Introduced species

Foreign species brought to Australia from other countries are known as **invasive or exotic species**. Since European settlement many species have been introduced into Australian ecosystems, often with devastating consequences. They compete with native species for habitat and resources or directly feed on them. Two species cannot occupy identical niches within a community, and generally one species will have a competitive advantage and survive at the expense of the other (see Figure 4.7.5). Some competitive advantages include possessing a larger fundamental niche, lacking predators and having faster reproduction rates. Terrestrial examples of such vertebrates include feral cats, dogs, foxes, rabbits, pigs, and goats, cane toads, camels and rats.

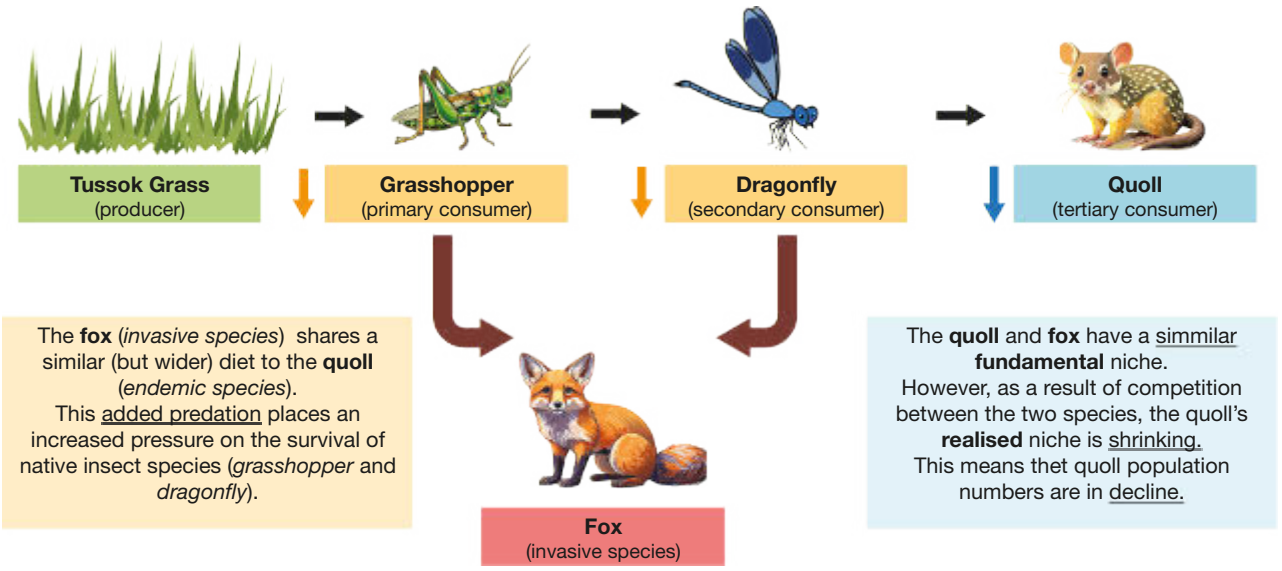


Figure 4.7.5: An example of the impact of introducing foxes on quolls and its community.

Helpful online resources

TED-Ed: The threat of invasive species - Jennifer Klos

<https://www.youtube.com/watch?v=spTWwqVP_2s>

Cane toads

Cane toads are native to countries in Central and South America. They were introduced to Hawaii, from where they were subsequently brought to far north Queensland in 1935 to act as biological control agents of cane beetles that were damaging sugar cane crops. The biological control program designed to use them was unsuccessful mainly because the introduced toads ate more than just cane beetles. Having **virtually no natural predators** has enabled them spread over huge areas of Australia in the intervening decades to the present day. The impact of the cane toads on biodiversity in Australia has been significant. Many of their predators die after ingesting a toad, due to the poisonous glands on their backs.

Feral cats

Feral cats are the same species as domestic cats, except they live and reproduce in the wild and survive by hunting or scavenging. They were introduced by European settlers who initially brought them across as pets. They can produce three litters of kittens a year, so their population numbers have been increasing rapidly. It is estimated that there is somewhere between 5 and 23 million feral cats in Australia. They inhabit 99.8% of Australian land including forests, woodlands, grasslands, wetlands and arid areas. Australian feral cats kill more than 2.6 billion animals including mammals, birds, reptiles, and insects every year. **Many scientists now believe the main threat to Australian biodiversity is the feral cat**, as they are a credible threat to over 200 native species and have contributed to the extinction of more than 20 mammal species already. By researching the number of feral cats and their threat to biodiversity, governments can allocatee funding accordingly and enact legislation to combat the damage caused by feral cats. One example is the culling of feral cats near Wilpena pound so that the Western bilby could be re-introduced to the area without the threat of predation by these feral cats.

Helpful online resources

9 News Australia: Australian government declares 'war' on feral cats

<https://www.youtube.com/watch?v=4iHJa7W7t94>

Global warming and climate change

Global warming and climate change are **not the same process**. Global warming refers to the increasing average temperature on Earth, but climate change is much broader. Climate change refers to the changing weather and climate patterns and includes the side effects of global warming, such as melting polar ice caps and drought. These side effects of global warming contribute to the changing weather and climates. For example, the cold freshwater released into the ocean's saltwater from **melting polar ice caps** can contribute to **changing ocean currents**. Ocean currents play a significant role in **global weather patterns**.

Climate change can be seen as perhaps the single greatest threat to global biodiversity which, if left unchecked, will almost certainly cause the extinction of thousands of species over the next couple of hundred years or so, and may even threaten the long-term survival of the human species. Some additional potential impacts of climate change are:

- More frequent and intense storms
- More frequent and damaging floods and droughts
- Melting glaciers causing rising sea levels
- Increased evaporation of water which is changing rainfall patterns
- Decreased food and water security due to loss of land to rising sea levels, and more intense storms and natural disasters
- Increased pests and diseases in some parts of the world
- Human and animal migration due to rising sea levels, drought and floods
- Decreased biodiversity due to habitat loss.

Helpful online resources

Cognito: GCSE Biology - Global Warming & Climate Change #91

<https://www.youtube.com/watch?v=lkqobb34oLI>

Kurzgesagt - In a Nutshell: Is It Too Late To Stop Climate Change? Well, it's Complicated.

<https://www.youtube.com/watch?v=wbR-5mHl6bo>

Greenhouse gases

The overwhelming majority of scientists agree that global warming is leading to climate change and, as a consequence, significant and irreversible changes in physical and biological systems.

Greenhouse gases are the gases in the atmosphere that can absorb heat radiation and re-radiate them back towards the Earth's surface. Some examples include **carbon dioxide** (CO_2), **methane** (CH_4), **water vapour** (H_2O) and **nitrous oxide** (N_2O). Atmospheric concentrations of carbon dioxide and methane, began to rise around 200 years ago, after having changed little since the end of the last ice age. This coincides with modern human life and the industrial revolution.

Carbon dioxide is the most emitted greenhouse gas accounting for approximately 80% of greenhouse gas emissions. The concentration of carbon dioxide has increased from 280 parts per million (ppm) prior to 1800 to more than 400 ppm today, which is an increase of more than 40%. Human-induced carbon dioxide emissions are released from the combustion of fossil fuels and waste, cement production and other chemical reactions. Furthermore, land clearance reduces the amount of carbon dioxide sequestered (removed) from the atmosphere by plants through photosynthesis. Humans have significantly disrupted the carbon cycle, adding carbon dioxide to the atmosphere faster than it can be removed. Methane is 28 times greater than carbon dioxide at trapping heat in the atmosphere over a 100-year period. Methane is released through natural gas leakage, livestock and the decomposition of landfill (waste).

The greenhouse effect

The sun radiates ultraviolet (UV) radiation towards Earth. About half of the UV radiation is absorbed by the Earth and re-emitted as infra-red (IR), or heat radiation. Some of the heat radiation will leave the atmosphere, but some is absorbed by greenhouse gases, such as carbon dioxide. The heat radiation is re-emitted by greenhouse gases and some is directed back towards Earth, warming the planet. The warming of the Earth by the heat radiation emitted by greenhouse gases is called the **greenhouse effect** (see Figure 4.7.6). Without the greenhouse effect, the average temperature of the Earth's surface would be too low to support living things.

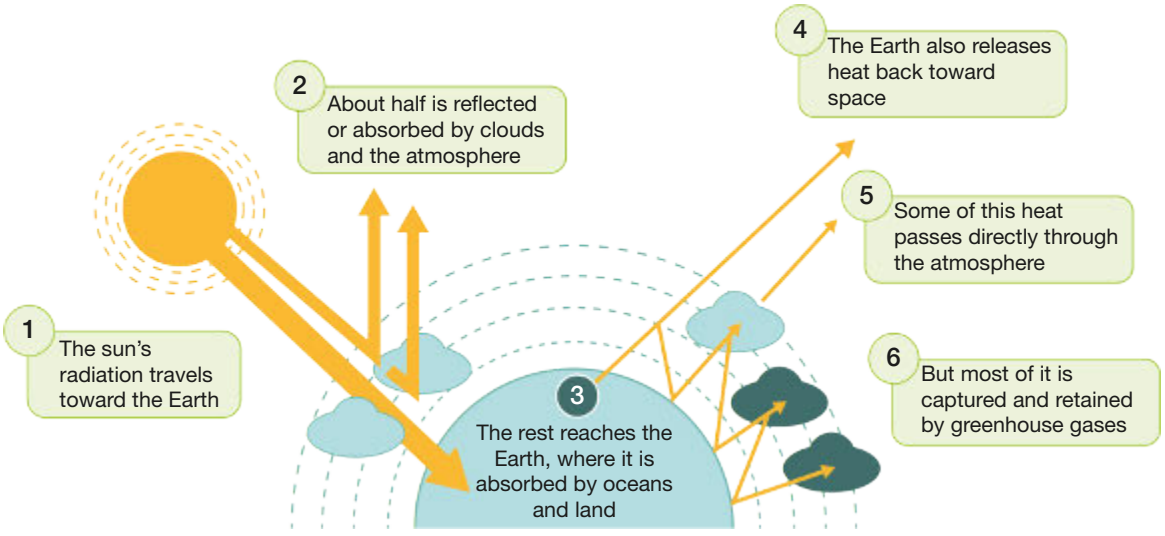


Figure 4.7.6: An explanation of the greenhouse effect.

The enhanced greenhouse effect

As the concentration of greenhouse gases increase in the atmosphere, so too does the warming of the Earth. This is because there is a greater number of greenhouse gases that the heat radiation leaving the Earth's atmosphere must avoid to successfully leave the atmosphere. As a result, more heat radiation continues to remain in the atmosphere as it continues to 'bounce' between the Earth's surface and greenhouse gases in the atmosphere. This is called the **enhanced greenhouse effect**, which leads to global warming.

Helpful online resources

MinuteEarth: How Do Greenhouse Gases Actually Work?

<https://www.youtube.com/watch?v=sTvqlijqvTg>

Impacts of global warming on oceans

Disruption of the global carbon cycle is not only impacting the atmosphere but also the Earth's oceans. Approximately 93% of the heat from the sun is absorbed by the oceans, 4% by the continents (including Antarctica) and only about 2% by the atmosphere. Additionally, the oceans absorb approximately 30% of the carbon dioxide emissions released due to human activity. These factors have significant impacts on the oceans as displayed in Table 4.7.2.

Table 4.7.2: Some impacts of global warming on the oceans.

Ocean impact	Explanation
Rising sea levels	Increased global temperatures are increasing the melting of the polar ice caps and permafrost, which releases more water into the oceans. Additionally, the increased absorption of heat from the sun increases the temperature of the water and consequently its volume (thermal expansion).
Increasing water temperatures	The increased absorption of heat from the sun increases the temperature of the water and consequently its volume (thermal expansion). There is evidence that as the oceans warm, marine plants and animals will relocate changing food webs and impacting on these ecosystems.
Decreasing water temperatures	As the polar ice caps melt into water, this water is very cold and parts of the ocean that the ice melts into can therefore become colder. This can then lead to changes in ocean currents and contribute to increased frequency and intensity of natural disasters associated with climate change.
Ocean acidification	When carbon dioxide dissolves in water, carbonic acid is produced. As significant amounts of carbon dioxide are being produced by human activity, the ocean is absorbing much more carbon dioxide and more carbonic acid is being produced in oceans. This is increasing the acidity of the oceans (lowering the pH). There are many impacts of ocean acidification but a major one is its interference with corals and shellfish. Corals and shellfish cannot build their shells and existing calcium carbonate shells can dissolve in the lower pH environment (see Figure 4.7.7).

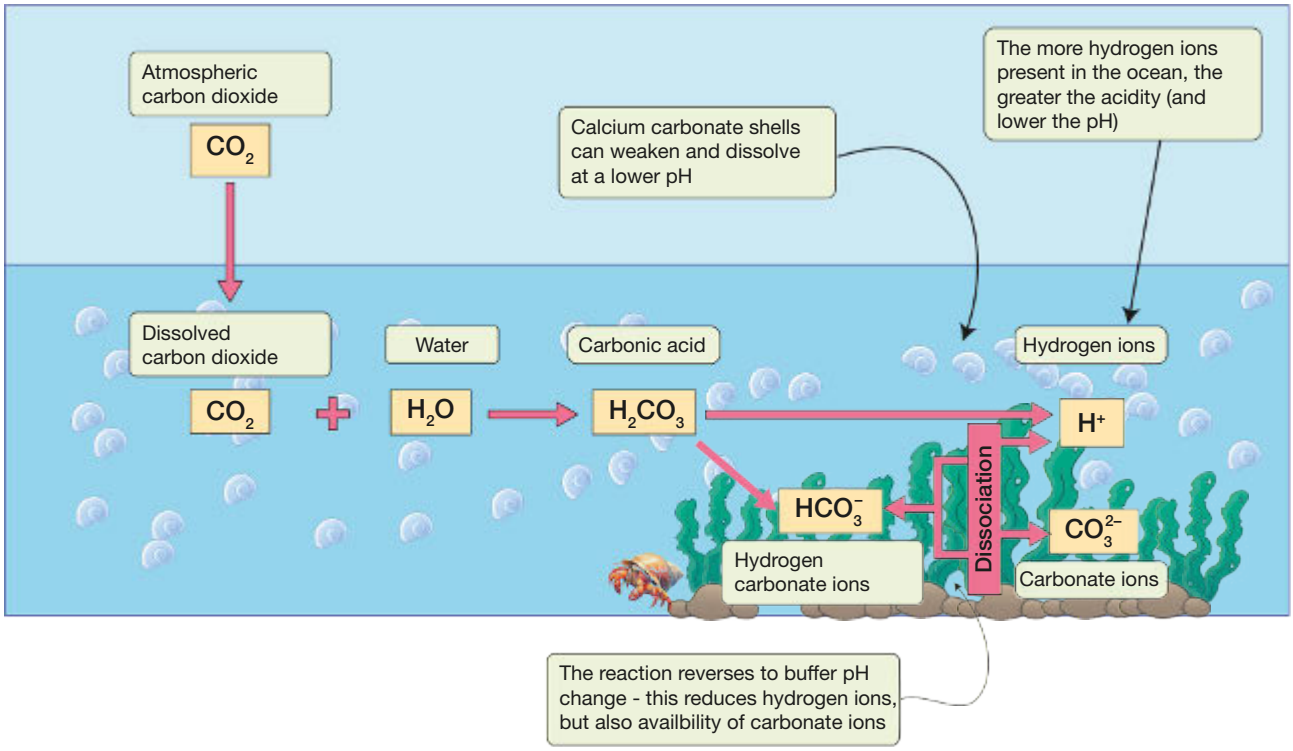


Figure 4.7.7: How atmospheric carbon dioxide can reduce the pH of oceans.

Measuring the impact

Environmental scientists use data to study trends or patterns in biotic and abiotic components of ecosystems and thus make predictions regarding the potential impact on ecosystems. Australia has warmed by approximately 1.1°C since records began (about 100 years ago) and current modelling suggests that as this continues the impact on biodiversity will be immense (see Figure 4.7.8). This rising in temperature correlates with the rise in carbon dioxide and methane emissions (see Figure 4.7.9). As there are causative effects that explain this correlation, scientists can model emissions and make predictions on global temperature rises (see Figure 4.7.10). This modelling can help with researching effects on biodiversity and food production in the future, as well as other predictions. Governments around the world can then make educated decisions about limiting greenhouse gas emissions to limit the effects on humans and the biosphere.

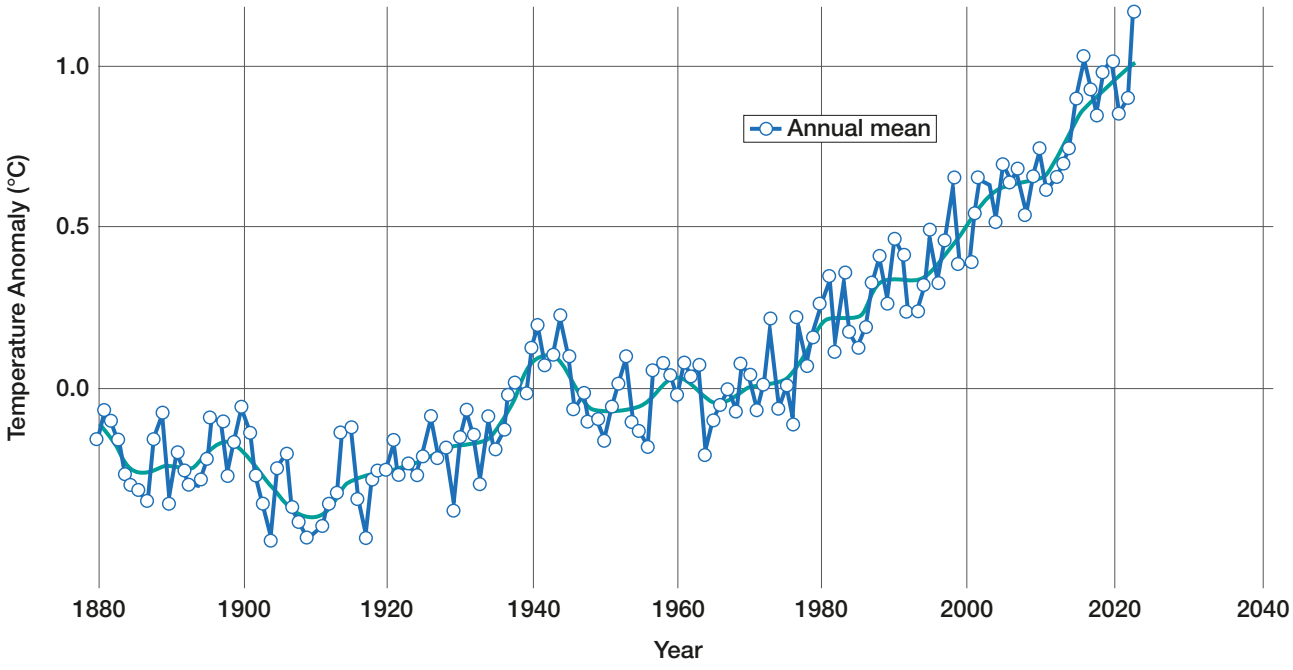


Figure 4.7.8: The mean annual global surface temperatures for the last 143 years shows that the last 10 years are the hottest on record (based on NASAs data).

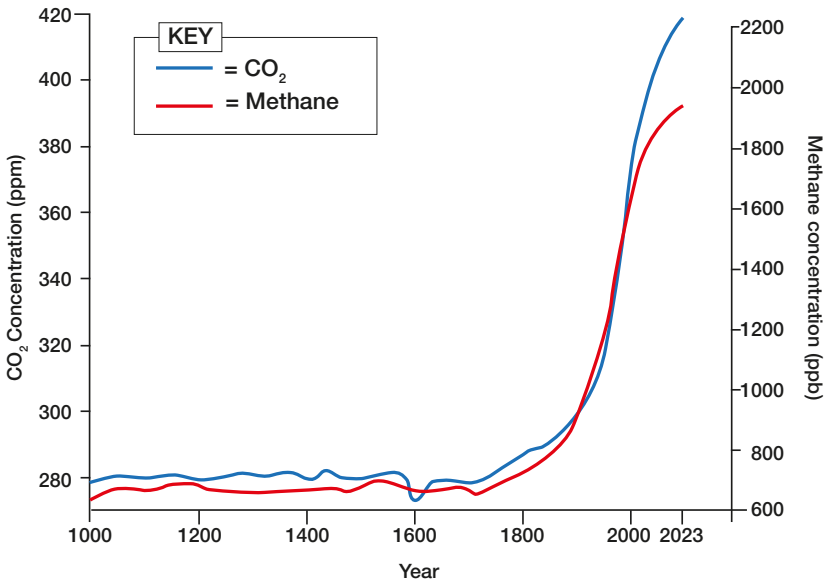


Figure 4.7.9: The modelling of global temperature changes based on humans reducing their greenhouse gas emissions to varying degrees.

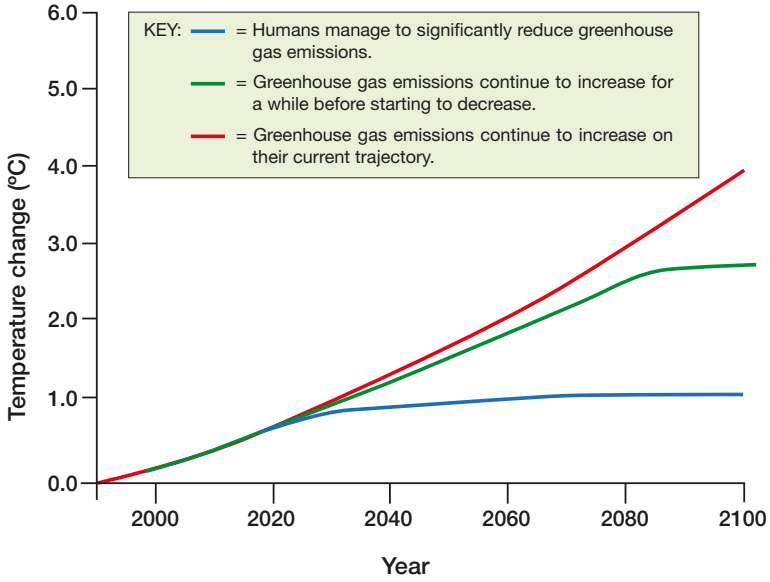


Figure 4.7.10: The atmospheric concentrations of carbon dioxide and methane gases between the years 1000 and 2023.

Pollution

As a direct result of the modern-day human lifestyle, pollution is a major problem for the Earth's biodiversity. One source of pollution is **air pollution**. The combustion of fossil fuels by power plants and internal combustion engines in vehicles, incineration of waste, spraying chemicals such as pesticides for agricultural purposes and many other human activities can contribute to air pollution. Air pollution is a public health threat and is attributed to the premature death of more than 8 million people annually. It also impacts other animal and plant life in the biosphere. The World Health Organisation (WHO) monitors and regularly updates the **air quality standards** so governments can develop achievable and time appropriate policies to reduce air pollution.

Another type of pollution is **plastic pollution**, generally through human littering. Accumulation of plastic waste in waterways and the oceans can kill animals. Some aquatic life can get trapped in plastic waste and suffocate, while others consume it and it gets stuck in their digestive system where it cannot be digested contributing to their death.

Additionally, plastics degrade into **microplastics and nanoplastics** that can enter food chains through **biomagnification**. The health effects of this for humans and other species are not well understood, but some of these microplastics are endocrine disruptors that can interfere with hormonal pathways.

Another example of pollution is **water pollution**. Water is essential for life and all animals need a safe water supply to survive. Chemical spills, such as oil spills, can contaminate bodies of water. Furthermore, the runoff of excess fertilisers and manure into waterways can lead to **algae blooms**.

Helpful online resources

Kurzgesagt - In a Nutshell: Plastic Pollution: How Humans are Turning the World into Plastic

<https://www.youtube.com/watch?v=RS7IzU2VJIQ>

Algae blooms

Nitrogen is an important component of the pigment chlorophyll in plants, which traps light for photosynthesis, and in amino acids, which are used to synthesise new proteins. Nitrogen, therefore, is an essential nutrient required for crops to produce a high yield. Phosphorus is also essential for plants. It is required to synthesise nucleic acids (DNA and RNA), ATP (for energy) and phospholipids to make cell membranes. Farmers often interfere with the natural cycles and apply **fertilisers**, which generally contain a source of nitrogen and phosphorus, to their fields to increase available nutrients and produce a greater yield. Fertilisers can increase available nutrients to crops but they can also runoff into waterways leading to **eutrophication**, which is the build-up of nutrients in a body of water. Eutrophication can result in the increased growth of microorganisms such as algae, which is known as **algae blooms**. Please refer to Figure 4.7.11 for further explanation.

It is important to consider **monitoring eutrophication**. Eutrophication can be measured chemically, for example, by measuring oxygen levels. The rate of oxygen depletion by organisms is the 'biochemical oxygen demand' (BOD). It reflects the activity of microorganisms in decomposing organic material. Therefore, algae can be used as an **indicator species** to measure the health of the water body.

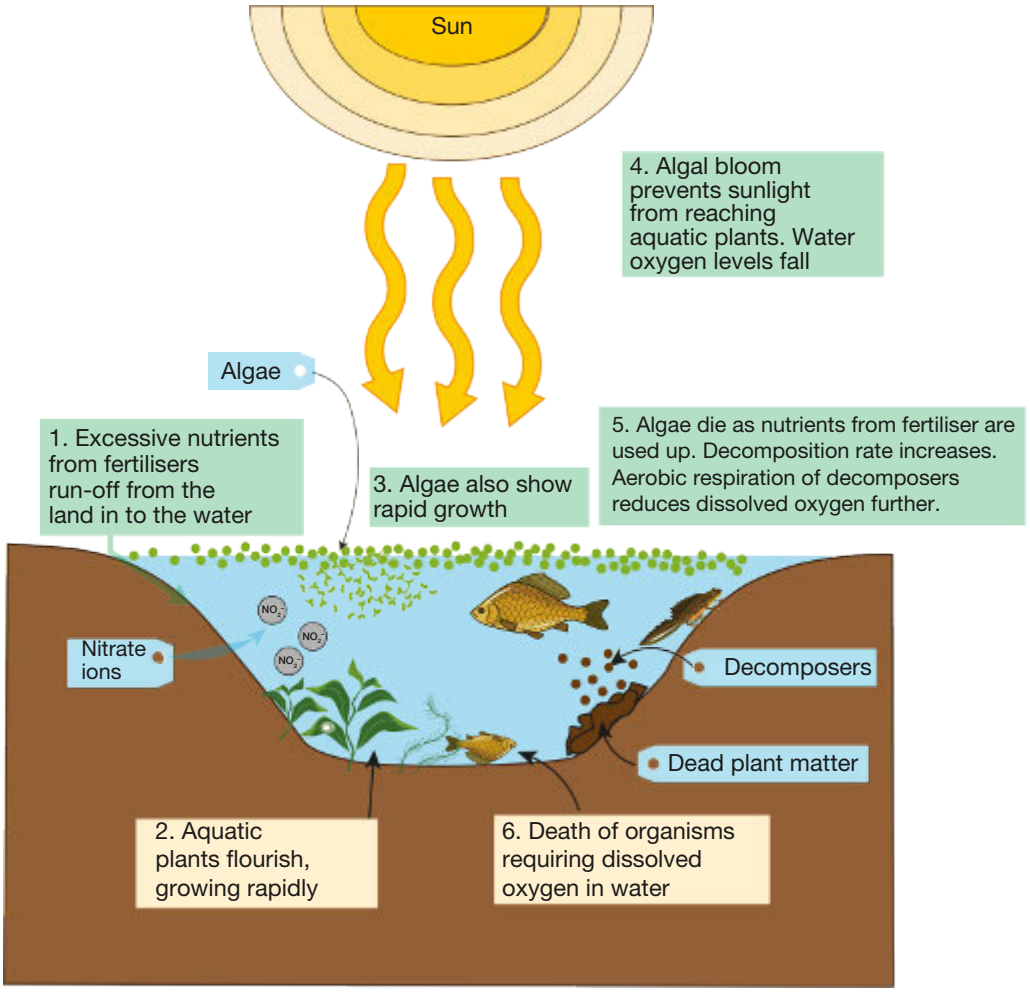


Figure 4.7.11: An explanation of how the excessive use of fertiliser can lead to algae blooms and loss of biodiversity in marine ecosystems.

Helpful online resources

Oxford Mastering Biology: Animation E2, 1.1 Consequences of algal blooms

<https://www.youtube.com/watch?v=JNoLNQ3ojE4>

FuseSchool - Global Education: What Are Fertilisers?

<https://www.youtube.com/watch?v=jJSUN-r3ZXo>

Bioaccumulation and biomagnification

Bioaccumulation is a process where a particular chemical(s) accumulates in an organism because they cannot be broken down or excreted faster than they are being taken in through ingestion. This can lead to biomagnification, where organisms at higher trophic (feeding) levels accumulate higher and higher levels as they feed on other organisms.

DDT is a pesticide that is banned in most countries due to its toxicity. It is still used in some poorer developing countries though. DDT biomagnifies through food chains (see Figure 4.7.12). Methyl mercury and microplastics are other examples that can undergo biomagnification and enter the human food chain. For example, it is strongly recommended that pregnant women eat deep sea fish sparingly (i.e. battered flake can only be consumed once every 2 weeks, with no other fish in between). This is because the biomagnification of methyl mercury is detrimental to the developing brain of the foetus.

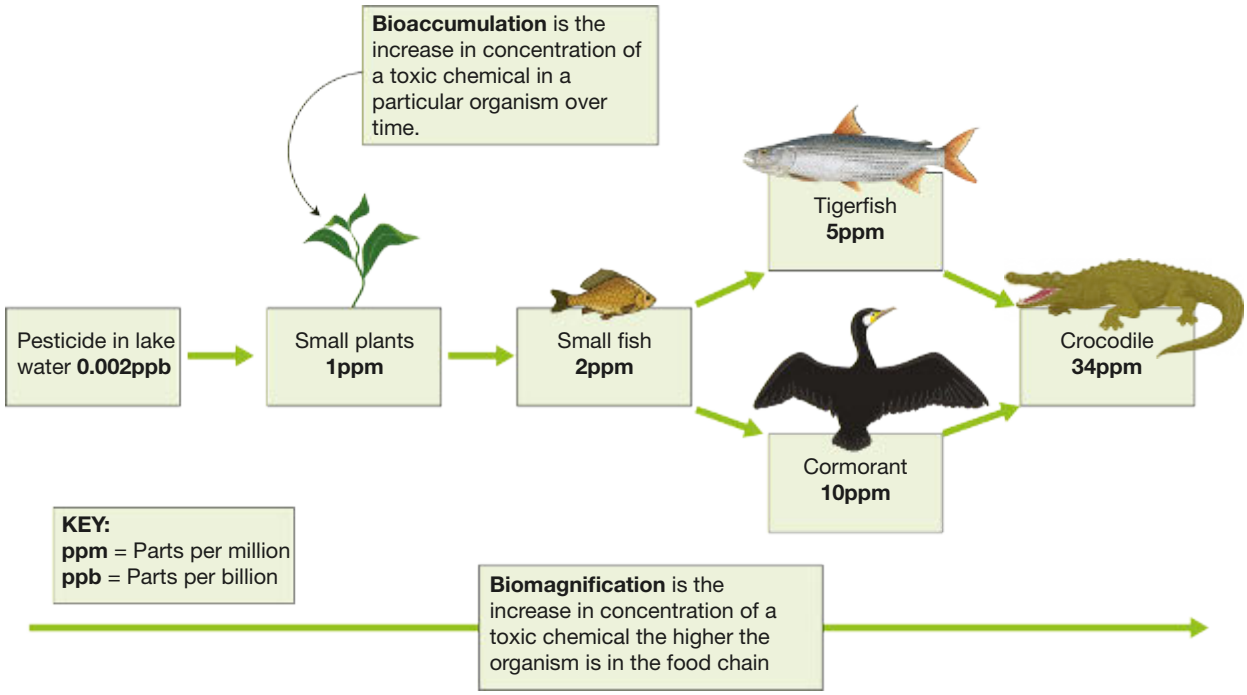


Figure 4.7.12: The bioaccumulation of a pesticide in a small plant its biomagnification up the food chain.

Strategies to reduce human impact

Humans have the power to make change. Humans can be creative and think critically to overcome problems that once seemed impossible. By collaborating with colleagues locally and internationally, humans have already overcome many problems, such as banning chlorofluorocarbons (CFCs) globally to reduce their impact on the hole in the ozone layer. There are many other challenges still to overcome that rely on global collaboration and buy-in to achieve. One such example is the **Paris Agreement**, where just under 200 countries drew up a series of goals with the aim of cutting greenhouse gas emissions over the coming decades.

The Paris Agreement

The key features of the Paris Agreement include the following:

- to keep global temperatures below 2°C above pre-industrial times
- to limit greenhouse gases emitted by humans to the same level that ecosystems can absorb naturally beginning between 2050 and 2100
- to review each country's contribution to cutting emissions every five years
- developed (rich) countries are required to help developing (poorer) countries by providing 'climate finance' to adapt to climate change with an emphasis of moving to renewable energy.

Practices that can reduce our impact on carbon dioxide levels

Ultimately, it is up to individuals to make lifestyle changes to help reduce carbon dioxide levels. One of the biggest contributions of carbon dioxide is the burning of fossil fuels for the power use for homes, air conditioners, cars, mobile phones and so on. Some strategies that individuals can implement to reduce carbon dioxide emissions are:

- reduce the need for heating and cooling; dress sensibly, insulate homes
- use energy-efficient household appliances; look for the 'Energy Star' label to purchase the most efficient refrigerators and washing machines
- don't waste food and consider reducing meat consumption
- use LED lighting which is more efficient
- drive a smaller car and/or walk or ride a bicycle where practical
- reuse and recycle materials
- develop sustainable gardening and farming practices
- overall, reduce our **carbon footprint**.

Helpful online resources

Cognito: GCSE Biology - Maintaining Biodiversity

<https://www.youtube.com/watch?v=bs9e6ovISbs>

4.7 Review questions

Multiple choice questions

1. Which animal has had the greatest negative impact on world ecosystems?
   - J Shark
   - K Cane toads
   - L Mosquitoes
   - M Humans
2. An irreversible effect of deforestation is
   - J the extinction of some species.
   - K the reduction of atmospheric carbon dioxide levels.
   - L the hole is the ozone layer.
   - M amount of available farming land.
3. Which of the following options is most likely to lead to soil erosion?
   - J The clearance of native flora.
   - K A long period without rain.
   - L Adding vegetation to a specific area.
   - M Eutrophication.

4. Deforestation contributes to global warming because it

   J decreases the Earth's surface reflectivity.
   K enhances the Earth's natural cooling processes.
   L increases the amount of greenhouse gases absorbed by trees.
   M reduces the number of trees that can absorb carbon dioxide.

5. Eutrophication of a lake is generally the result of

   J an increase of oxygen concentration in the body of water.
   K a decrease in oxygen concentration in the body of water.
   L an increase in nitrogen concentration in the body of water.
   M a decrease in nitrogen concentration in the body of water.

6. An invasive species generally

   J occupies different niches to native organisms.
   K has a competitive disadvantage to native organisms.
   L evolve quicker than native species and outcompete them.
   M add pressure on the survival of native species.

7. One way to mitigate global warming is to

   J continue researching and developing crops that can grow in drought like conditions.
   K reduce the carbon emissions from motor vehicles.
   L invest in water sources that do not depend on climate.
   M develop strategies to alleviate the impacts of climate change.

8. A study showed that populations of some bird species have decreased in number by as much as 50% since 1966. Natural cycles and food and water shortages were eliminated as causes of the decreased bird numbers by the study.

   A contributing factor to the declining populations of some bird species would likely be:

   J consuming an energy dense diet.
   K the destruction of natural habitats.
   L the overproduction of bird offspring.
   M decline in predator populations.

9. Willow trees are native to the northern hemisphere and were introduced to Australia in the 19th century as garden plants. They have since been planted on riverbanks in Australia to help stabilise them and have spread along waterways in temperate Australia. They have interrupted some natural processes in aquatic ecosystems including outcompeting native plants from re-colonising.

   This is an example of

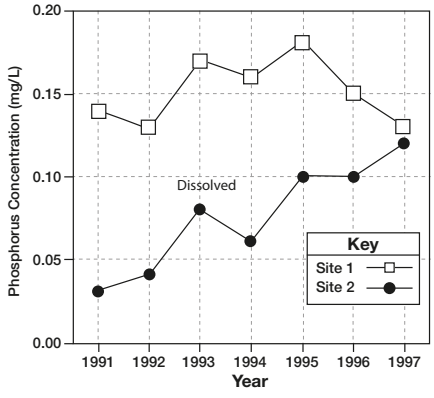
   J the flow of energy in ecosystems.
   K how planting willow trees can increase soil erosion.
   L how all garden plants prefer to live near riverbanks.
   M the unintended effects of adding a species to an ecosystem.

10. *Refer to the graph to the right which shows measurements of phosphorus concentrations taken annually at two different sites from 1991 to 1997.*

    Compounds containing phosphorus can act as fertiliser and interfere with the natural processes in ecosystems.

    Which of the following statements represents a valid inference based on information in the graph?

    J Site 2 was more polluted than site 1 from 1991 to 1997.
    K The amount of compounds containing phosphorus at site 2 increased year on year during the period from 1991 to 1997.
    L It is likely that some strategies were implemented to control pollution at site 1 in 1995.
    M It is likely that site 2 contained no plant life from 1993 to 1994.



Free response questions

1. Humans are accelerating the destruction of habitats.
   a) State **four** ways humans are negatively impacting the natural habitats of other species.

   b) Explain why the loss of habitat often reduces biodiversity.

2. a) State **three** reasons for land clearance by humans.

   b) Explain how land clearance can contribute to reduced soil fertility.

3. Extinction is a normal occurrence in ecosystems.
   a) Describe the link between the trend in human population and the number of species extinctions.

   b) Describe the most likely reason why scientists are so concerned about the current trend of species extinctions.

4. a) Name **three** greenhouse gases.

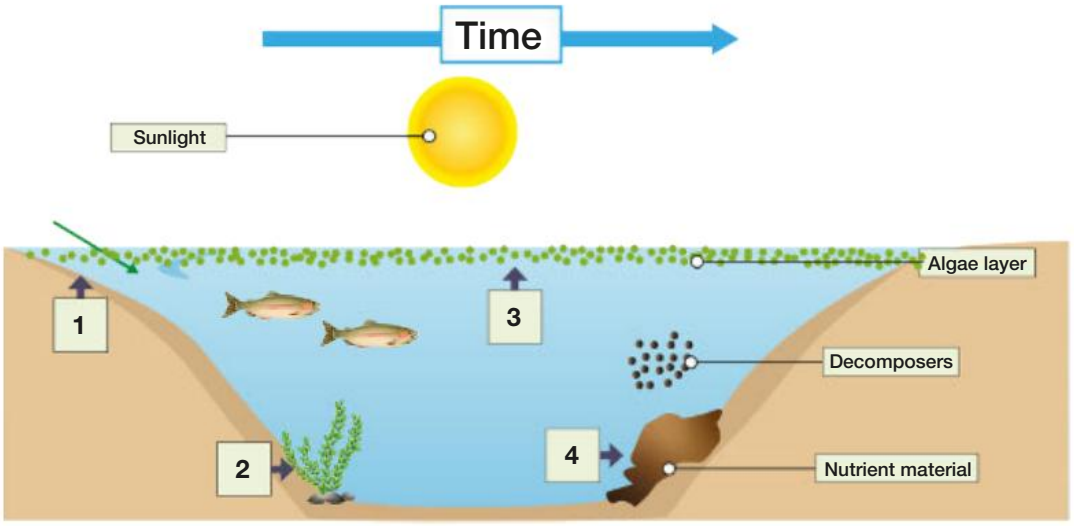
   b) Explain the difference between the greenhouse gas effect and enhanced greenhouse gas effect.

   c) Describe **two** possible effects of global warming on communities of organisms.

   d) Explain how waste disposal in landfill contributes to the enhanced greenhouse gas effect.

5. Discuss how data on greenhouse gas emissions can be used to predict future temperatures.

6. *Refer to the diagram below that shows a body of water near an agriculture farm to answer the following questions.*



a) Outline what the green arrow at '1' represents in the diagram.

b) Describe what happens to the aquatic plants at '2' and the algae at '3' following the event at '1' in the diagram.

c) Explain the likely penetration of sunlight into the body of water following the events that occurred from '1 to 3' in the diagram.

d) Explain the presence of decomposers and nutrient material at '4' in the diagram.

e) Explain the likely outcome for the fish that live in this body of water following the events that occurred from '1 to 4' in the diagram.

f) Identify the 'indicator species' in the diagram.

7. It was recently discovered that the permafrost holds double the amount of mercury than the rest of Earth, approximately 1.8 million tons. The permafrost also holds significant amounts of trapped methane. As the global temperatures increase due to human induced global warming, the permafrost continues to melt, releasing its trapped contents.

   a) Explain the impact that the release of significant stores of methane from the permafrost would have on the remaining permafrost.

Mercury is a poisonous chemical to humans and animals and bioaccumulates in living tissue affecting the brain and reproductive system.

b) Explain the biomagnification of mercury in ocean food chains.

c) Explain why pregnant women are advised against consuming deep-sea fish.

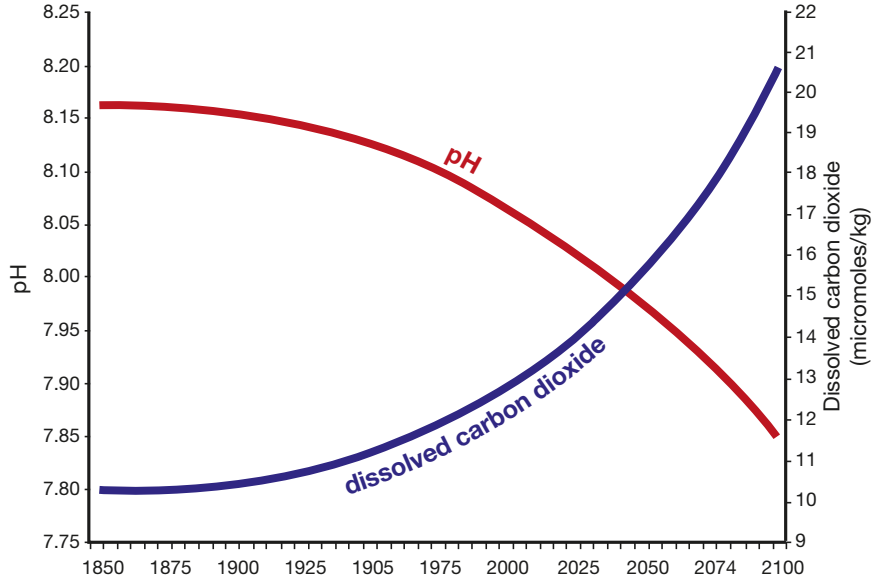
There are many other chemicals and biological concerns trapped deep within the polar ice caps. One biological concern is dormant viruses. Scientists have drilled deep into the ice and discovered viruses up to 50,000 years old. These dormant viruses can reactivate when thawed. Humans have not been living side by side with these viruses so their ability to infect humans, their virility and contagiousness are currently largely unknown.

Use your understanding of the interaction between science and society to answer the following question.

d) (i) Discuss how society has influenced this research.

(ii) Discuss how this research could influence society.

8. *Refer to the graph below which shows the correlation between dissolved carbon dioxide concentrations and acidity of the oceans over time to help answer the questions that follow:*



a) Describe the trend shown in the graph.

b) Explain how greenhouse gas emissions can increase ocean acidification.

c) Explain why the acidification of the oceans is threatening coral reef organisms.

d) Using evidence from the graph, explain why this graph is a prediction.

e) Discuss how these predictions can help to develop strategies to minimise the adverse effects of ocean acidification.

f) Discuss **two** different impacts that damage to the coral ecosystems of the Great Barrier Reef would likely have to Australian society.

g) Jellyfish, which have existed for over 500 million years, are thriving due to human activities such as overfishing, which removes their predators, and global warming, which creates oxygen-deprived waters where they flourish. This rapid increase in jellyfish populations is disrupting ecosystems, and harming salmon and caviar farms. Additionally, they are shutting down nuclear power plants because the ocean water used to cool many nuclear reactors is now infested with jellyfish.

Furthermore, it is expected that rising ocean acidity, driven by carbon emissions, will exacerbate the issue. Scientists exposed jellyfish to water with the current ocean pH and water with the predicted pH for 2100. Each treatment also contained the same amount and type of zooplankton (food), which are a critical foundation of ocean food webs. The results showed that the jellyfish ate 37% of the zooplankton in today's conditions, but this increased to 83% of the zooplankton in the predicted ocean pH conditions of 2100. Scientists are unsure if this is because the zooplankton took advantage of weakened zooplankton, or if perhaps the jellyfish were negatively affected and required additional nutrition for survival.

Discuss how this example demonstrates one, or more, concepts of Science as a Human Endeavour.

9. In the 1960s, the 'Green Revolution' attempted to introduce new varieties of cereal crops that yielded more seed into developing countries. These varieties did not have an extensive stem and root system and therefore farmers depended heavily on fertilisers and irrigation. This approach ultimately failed to achieve its original high expectations of feeding more of the world's population.

   Discuss the most likely reasons why the 'Green Revolution' failed to achieve its goals.

10. Scientific research has indicated that some species of plants compete more effectively when atmospheric carbon dioxide concentrations are raised. It has also been demonstrated that under these conditions some plants produce significantly lower quantities of seed. Explain how these observations provide support for the argument that increasing atmospheric carbon dioxide levels may lead to a loss of biodiversity.

11. Outline **five** strategies an individual could implement to reduce their carbon footprint.

Topic 4 Review Test: Biodiversity and Ecosystem dynamics

It is recommended that 85 minutes is allocated to complete this test. Indicate your choice for each multiple choice question (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks allocated for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (10 marks)

1. Organisms within a community interact with one another. One type of interaction involves one species benefitting whilst the other is unharmed.

   This type of interaction is called

   J parasitism.
   K commensalism.
   L mutualism.
   M predation.

2. Which one of the following options correctly matches a type of reproductive isolating mechanism and an example that illustrates this particular type?

	Isolating mechanism	Example
J	Pre-zygotic	Different courtship rituals
K	Post-zygotic	Differences in the shape of flowers
L	Pre-zygotic	Infertile offspring
M	Post-zygotic	The inability of sperm to survive in the female reproductive tract

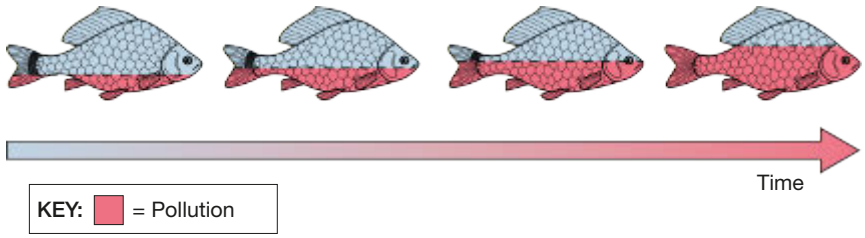
3. Which of the following options is incorrect regarding the importance of biodiversity?

   J It is important for the provision of oxygen, food and fresh water.
   K It is important for genetic drift.
   L It is important for the provision of resources and raw materials.
   M It provides natural sites for recreation.

4. Which of the following options is incorrect regarding the biological classification of species?

   J It gives scientists some insights into evolutionary relationships between species.
   K It allows species to be recognised universally with one scientific name.
   L It enables species to have multiple common names.
   M It enables scientists to organise, locate and identify species.

5. *Refer to the diagram below showing the pollution in an individual fish over time to answer the following question.*



   This diagram represents

   J Pollution
   K Biomagnification
   L Bioaccumulation
   M Biotechnology

TEST

6. A community is

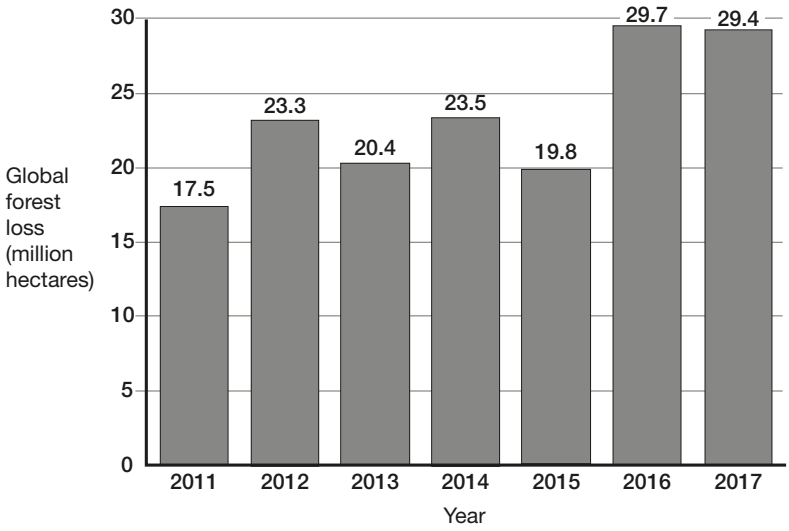
J a group of organisms of the same species in a particular geographical area at a particular time.
K the interactions of the living and physical components in a particular geographical area.
L a group of organisms with similar characteristics.
M the biotic factors in a common geographical area.

7. *Refer to the diagram below to answer the following question.*

This diagram indicates

J a healthy aquatic ecosystem.
K a healthy penetration of light to lower levels of the body of water.
L a mutualistic relationship between plants and water.
M likely eutrophication.

8. *Refer to the graph below to answer the following question.*



The average global forest loss from 2011 to 2017 is

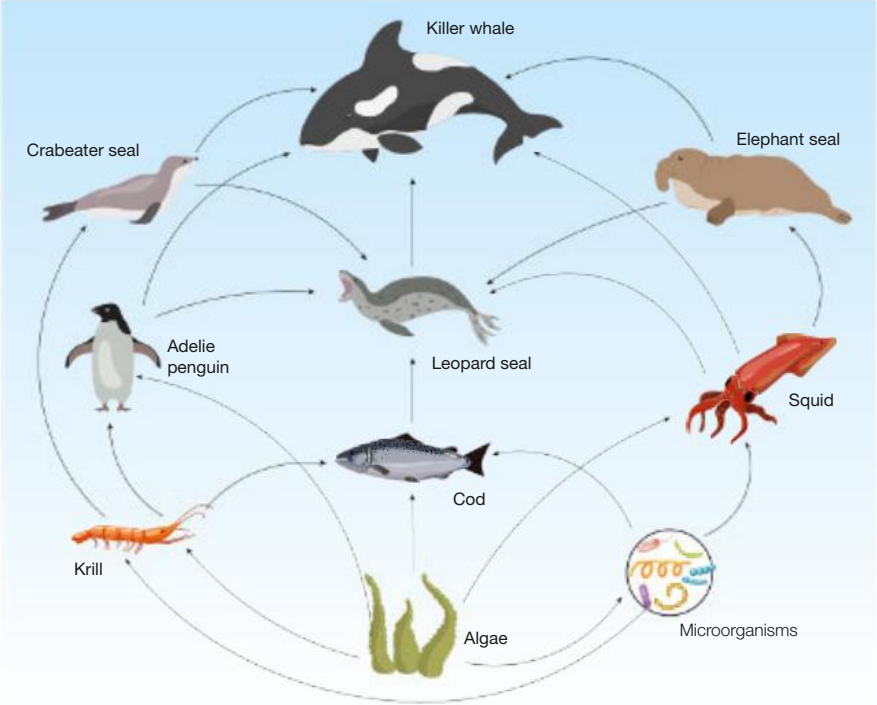
J 23.4 million hectares.
K 138.4 million hectares.
L 23.3 million hectares.
M 23.5 million hectares

9. Zonation is observed at an intertidal rock platform.

Which one of the following options is most likely to represent the abiotic conditions influencing the type of community found in the subtidal zone of an intertidal rock platform in comparison to the supratidal zone during the day?

	Temperature	Dissolved oxygen	Light intensity
J	Relatively stable	Higher	Lower
K	Fluctuating	Lower	Lower
L	Fluctuating	Higher	Higher
M	Relatively stable	Lower	Higher

10. *Refer to the diagram below showing some feeding relationships in a marine ecosystem to answer the following question.*

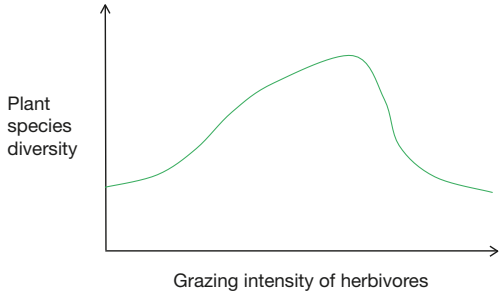


The killer whale is a consumer

J at the fourth trophic level only.
K at the fourth and fifth trophic levels only.
L at the third, fourth and fifth trophic levels only.
M at the third, fourth, fifth and sixth trophic levels.

Section 2: Free response questions (70 marks)

11. *Refer to the graph below to answer parts (a) and (b).*



a) Describe the pattern of results as indicated in the graph.

(2 marks)

b) Explain **one** possible reason why herbivore grazing may lead to a change in the plant species diversity.

(2 marks)

12. *Refer to Table 1 below to answer parts (a), (b) and (c).*

Table 1: Some of the hierarchy of classification information of five different species of plant.

Species	Class	Family	Genus	Species
A	Angiospermae	Proteaceae	Grevillea	robusta
B	Angiospermae	Myrtaceae	Eucalyptus	robusta
C	Angiospermae		Callistemon	citrinus
D			Callistemon	pallidus
E			Adiantum	cunninghamii

a) Using the binomial system of naming and correct conventions, state the scientific name for species B.

(2 marks)

b) Using only the information in the table, identify the two plants that are the most closely related.

(1 mark)

There are three higher levels of classification missing from Table 1, including Kingdom and Phylum.

c) State the name of the other level of classification missing from the table.

(1 mark)

Different species of plant remain reproductively isolated.

d) Describe **one** method that is used by plants to remain reproductively isolated from other plant species.

(2 marks)

13. *Refer to Table 2 below showing data collected from two animals living in their natural habitat to answer parts (a) and (b).*

Table 2: The amount of water gained and lost through a variety of methods by two animals.

Method of water gain	Amount of water gained by Animal A (mL/day)	Amount of water gained by Animal B (mL/day)
Drinking	0	750
Food	10	225
Metabolic reactions	42	72
Method of water loss	**Amount of water lost by Animal A (mL/day)**	**Amount of water lost by Animal B (mL/day)**
Evaporation	35	250
Urine	14	629
Faeces	3	166

a) (i) Identify which animal is most likely to live in a dry habitat.

(1 mark)

(ii) Use evidence from Table 2 to justify your answer to part (a)(i).

(2 marks)

b) (i) Calculate the net water balance (total water gained – total water lost) for the two animals.

(2 marks)

(ii) Explain the likely reason for the net water balance observed for the two animals in part (b)(i).

(2 marks)

Organisms have adaptations that enable them to survive dry environments.

c) Outline **one** example of the three types of adaptations that species have developed to survive in dry environments.

Structural:

(1 mark)

Behavioural:

(1 mark)

Physiological:

(1 mark)

TEST

14. *Refer to Table 3 below to answer parts (a) to (c).*

Table 3: The results of an investigation into the effect of varying nutrient levels on the density of a cereal crop.

Treatment	Mineral nutrient levels (arbitrary units)		Cereal crop density kg/m²
	Nitrate	Sulfate	
1	50	25	0.37
2	50	50	0.43
3	100	25	0.62
4	100	50	0.70
5	100	100	0.72
6	200	25	0.47

In deconstructing the problem, scientists decided to investigate the effect of varying both nitrate and sulfate levels.

a) Write an investigable question that might have been used to guide this investigation.

(1 mark)

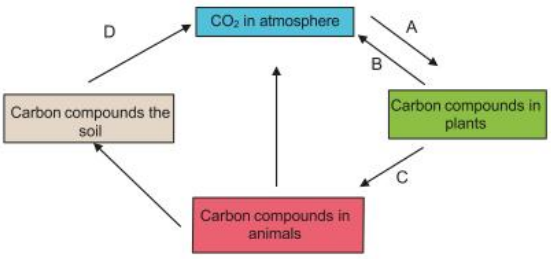
b) Identify **and** explain a limitation of this investigation.

(2 marks)

c) Identify and explain the impact of **one** biotic component that can affect the growth of the cereal crop.

(2 marks)

15. *Refer to the adjacent flow diagram which shows part of the carbon cycle.*



a) Name the chemical reaction or metabolic process labelled:

A

(1 mark)

B

(1 mark)

C

(1 mark)

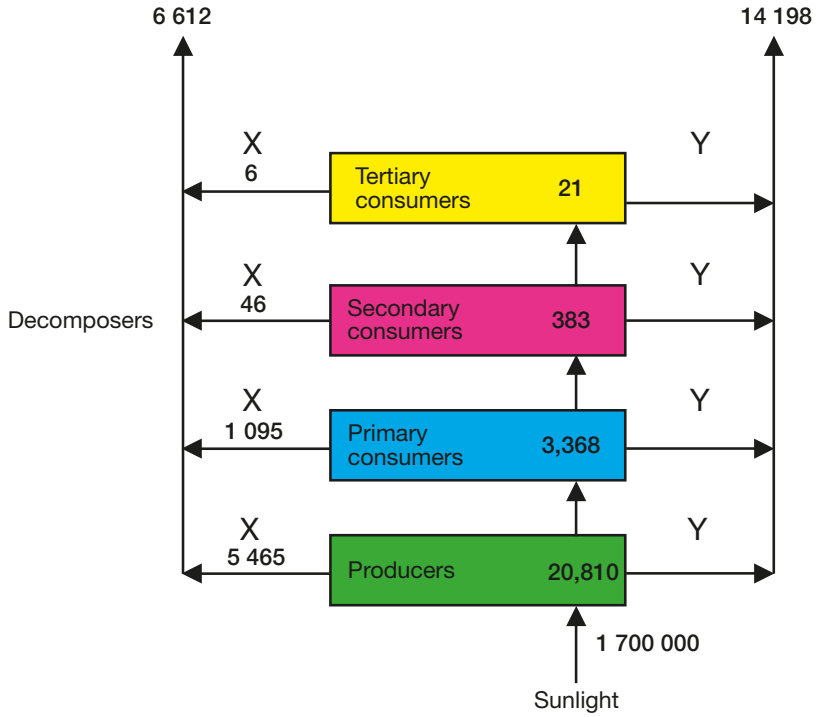
b) Name the group of organisms responsible for the process labelled D.

(1 mark)

c) Discuss how the combustion of fossil fuels by humans is interfering with the natural carbon cycle.

(4 marks)

16. *Refer to the diagram below showing energy flow (in kJ/m²/year) through an ecosystem.*



There is energy loss at 'X' and 'Y' as indicated in the energy flow diagram.

a) Identify how energy is lost at X and Y respectively:

X:

Y:

(2 marks)

b) (i) Calculate the amount of energy lost by producers in kJ/m²/year through method 'Y'.

(1 mark)

(ii) Calculate the total percentage energy lost by producers.

(2 marks)

c) Explain why most natural ecosystems cannot support any more than about three or four trophic levels.

(3 marks)

TEST

17. The Tasmanian bettong is a native marsupial that plays a very important role in its ecosystem. The animals are noted for their foraging and digging, activities which have very beneficial effects on the soil, water and dissolved mineral nutrients. The actions of the bettong increase the soil's capacity to hold and absorb water and disperse the spores of fungi. The fungal spores are a main food source for the bettong and the actions of the marsupial release and dispense spores throughout the habitat. Plants such as eucalypts and acacias form mutualistic relationships with the fungi which are essential for these plants in obtaining mineral nutrients from the soil in a form that they can use.

a) Explain what a keystone species is.

(2 marks)

b) Using evidence from the information above, determine whether the Tasmanian bettong would be considered a keystone species or not.

(2 marks)

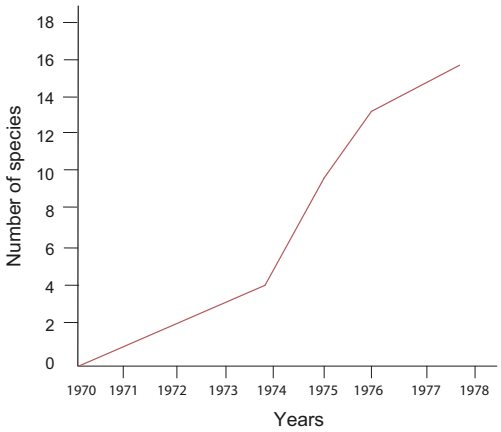
c) The Tasmanian bettong is considered extinct on the mainland of Australia. In attempts to re-colonise the bettong on the mainland, individuals were sourced from a range of different areas in Tasmania. Explain how sourcing the bettongs from different areas may increase the ability of the relocated population to survive on the mainland.

(2 marks)

18. *Refer to the adjacent graph showing the number of species found on an island immediately following, and for eight years after, a volcanic eruption in 1970.*

a) State the name of the process occurring on the island ecosystem over this nine year period.

(1 mark)



b) Explain the process identified in part (a).

(2 marks)

c) Explain the effect of natural disasters on the genetic diversity of a species.

(2 marks)

19. *Refer to the table below comparing several components in two lakes to answer parts (a) and (b).*

Component being compared	Lake 1	Lake 2
Nitrate concentration (mg/L)	0.05	0.25
Chlorophyll concentration (µg/L)	3.6	9.4
Light penetration (metres)	4.2	1.8
Oxygen used in lower levels (mg/L/day)	3.8	5.6

a) Explain the difference in chlorophyll concentration between the two lakes.

(4 marks)

b) Explain why more oxygen has been used in the lower levels of Lake 2 compared to Lake 1.

(3 marks)

20. The Felixer is an innovative tool developed to help control feral cats and foxes. This automated device is designed to identify feral cats and foxes using sensors and then spray them with a toxic gel. This toxic gel remains on the coat of the animal until they clean themselves and ingest it. The gel is lethal to cats and foxes but harmless to other wildlife. The Felixer is solar powered and can play audio to attract its target species.

a) Explain the effect of introduced species like feral cats on species diversity.

(2 marks)

b) Explain the effect of an introduced species on established species with similar niches.

(3 marks)

Use your understanding of science as a human endeavour to answer the following questions.

c) (i) Discuss how society has influenced the development of the Felixer.

(2 marks)

(ii) Discuss how the Felixer could influence society.

(4 marks)

Total: /80

Suggested Answers

Chapter 1.1 Suggested answers

Multiple choice questions

1. M 2. J 3.K 4. L 5. J 6. K 7. J 8. J 9. L 10. K

Free response questions

1. Some possible answers include:
   - Maintaining a stable internal environment
   - Controlled exchange of materials
   - Response to stimuli
   - Obtaining energy and chemical elements
   - Transport of materials
   - Removal of waste
   - Cell division
   - Growth and development
   - Independent movement
   - Reproduction
2. Unicellular organisms consist of only one cell such as bacteria or Euglena, whereas multicellular organisms are made up of many cells such as cats and humans.
3. The three features of the original cell theory are:
   - all organisms are made of cells
   - cells are the basic units of life
   - cells come from pre-existing cells that have multiplied
4. Some examples include:
   a) red blood cell, cheek cell, etc.
   b) nerve cell, ovum, etc.
5. Cells are not visible to the naked eye and in most cases a microscope is needed to see them. The invention of the light microscope allowed observation of the cells and development of the cell theory.
6. A cell membrane defines the boundary of a cell, encloses its contents and controls the entry and exit of materials into and out of the cell.
7. Sections need to be very thin to allow light to pass through the specimen and then through the lenses of the microscope to your eye.
8. Properties include:
   - it possesses a genetic code that carries information to make protein molecules.
   - It possesses the ability to self-replicate (make identical copies of itself).
9. Reasons include:
   Structure: all cells consist of cells and the products of cells.
   Function: cells carry out all vital functions of organisms.
10. Some possible pieces of evidence would include:
    - looking for evidence of cells (likely using a light microscope to observe a thin specimen)
    - observing whether the structure responds to stimuli such as exposure to light
11. The plant is responding to the light stimulus and its leaves have grown towards the window so that more light can be acquired for photosynthesis.
12. With a light microscope the internal details such as smaller cell organelles like mitochondria, Golgi bodies and endoplasmic reticulum cannot be seen.
13. a) An ovum is 120µm which is bigger than an amoeba at 50µm.
    b) An ovum (120µm) is about 2.4 times bigger than a 50µm skin cell (120/50 = 2.4).
    c) Approximately 25 E. coli cells would fit across a cheek cell (50/2 = 25).
14. The longest cell is the banana cell at approximately 90µm. It is twice the size of moss cells which are 45µm long. Liver cells are the smallest of the three cells with a length of approximately 25µm.
15. a) The length of the cell is 40mm. The scale bar shows that 5mm = 5µm.
    Therefore, the actual size of the cell (A) = 5µm × 8 = 40µm.
    b) A = 40µm
    I = 4cm = 40000µm
    M = I/A = 40000/40µm = x1000

Chapter 1.2 Suggested answers

Multiple choice questions

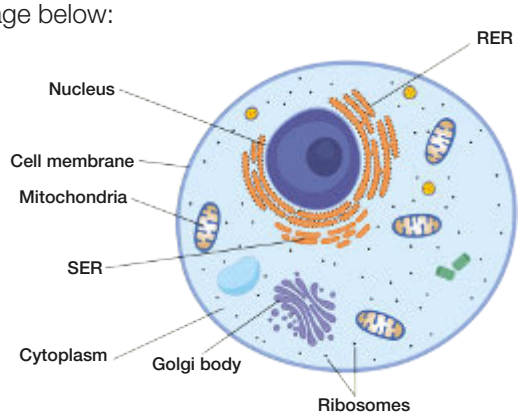
1. L 2. K 3. K 4. M 5. J 6. M 7. L 8. K 9. J 10. L

Free response questions

1. Refer to the suggested answers in the table below:

Organelle	Present in bacterial, plant and/or animal cells	Structural features	Special functions
Cell wall	Bacterial and plant cells (not in animal cells).	Bacterial cell walls consist of the carbohydrate peptidoglycan whereas plant cell walls consist of the carbohydrate cellulose.	Protects the cell and helps maintain cell shape.
Nucleus	Both plant and animal cells (not in bacterial cells).	Consists of DNA in the form of linear chromosomes surrounded by a membrane, which contains nuclear pores.	Stores and protects the genetic information of the cell and coordinates all activities of the cell.
Nucleoid	Only in bacterial cells.	Consists of one circular chromosome.	Stores genetic information and coordinates all activities of the bacterial cell.
Mitochondria	Both plant and animal cells (not in bacterial cells).	Consists of a double membrane and a network of folded inner membrane extensions called cristae that contain many enzymes.	Site of aerobic respiration.
Chloroplasts	Some plant cells only.	Contains the pigment chlorophyll in stacks of membrane called grana.	Site of photosynthesis.
Ribosomes	Found in all three cell types.	They are smaller and free floating in the cytoplasm in bacteria. The larger ribosomes in plant/animal cells are usually attached to the RER.	Synthesise proteins for the cell.
Smooth endoplasmic reticulum	Both plant and animal cells (not in bacterial cells).	Is a network of interconnected membrane sacs that do not contain ribosomes.	Synthesis of lipids and metabolism of carbohydrates.

2. Some possible answers include: both have cell membranes, both contain DNA/chromosomes, both contain ribosomes, prokaryotic and some eukaryotic have cell walls, both have a cytoplasm, both transform energy and carry out chemical reactions.
3. Some possible answers include: eukaryotic cells are bigger than prokaryotic cells, there are no membrane-bound organelles in prokaryotic cells, chromosomes are circular in prokaryotic cells and are linear in eukaryotic cells, ribosomes are bigger and generally attached to an RER in eukaryotic cells whereas they are smaller in prokaryotic cells and free floating in the cytoplasm.
4. a) Refer to the labels in the image below:



b) Ribosomes, cell membrane and the cytoplasm.

5. Prokaryotic cells can grow, divide and make energy available because they contain their own DNA in the form of a circular chromosome. This allows them to produce proteins required for growth, cellular division and the metabolism of organic molecules to release cellular energy. They may only have one chromosome, but it contains the code necessary for the proteins involved in all the life processes required to survive.
6. Some possible answers include:
   a) Any cell requiring a lot of energy such as skeletal muscle cells, cardiac muscle cells, kidney cells, sperm cells, etc.
   b) Any cell involved in the secretion of proteins such as cells of the salivary glands, pancreatic cells, etc.
7. a) Any two of the following:
   - storage of water in plant cells
   - provides structural support and regulates plant cell shape
   - nutrient storage
   - storage and disposal of waste products

   b) These cells are likely to be in leaves because it contains chloroplasts, which are found in leaf cells and use light to produce glucose through the process of photosynthesis.
8. a) It is a eukaryotic cell.
   b) Because the cell has a nucleus and prokaryotic cells do not contain a nucleus.
9. a) Cell 1 is a plant cell. It is clear that it contains chloroplasts within the cell.
   b) Cell 2 is an animal cell. The cell does not contain a large central vacuole, a cell wall or any chloroplasts.
   c) (i) Organelle A is a cell wall. Its function is to protect the cell and help to maintain its shape.
   (ii) Organelle B is a chloroplast. Its function is to produce glucose molecules through the process of photosynthesis.
   (iii) Organelle D is a mitochondrion. Its function is to provide energy to the cell by aerobic respiration.
   (iv) Organelle E is a cell membrane. Its function is to separate the cells intracellular environment from the extracellular environment and control the entry/exit of substance into and out of the cell.
   d) Organelles C and F are both nuclei. They both have the same function which is to store and protect genetic information and coordinate all activities of the cell. Both C and E will contain a nuclear membrane and pairs of linear chromosomes inside them, but they are likely to differ in the number of pairs of chromosomes as each cell belongs to a different organism (one is plant and another is from an animal cell).

Chapter 1.3 Suggested answers

Multiple choice questions

1. M 2.M 3.J 4. L 5. L 6. K 7. K 8. J 9. L 10. M

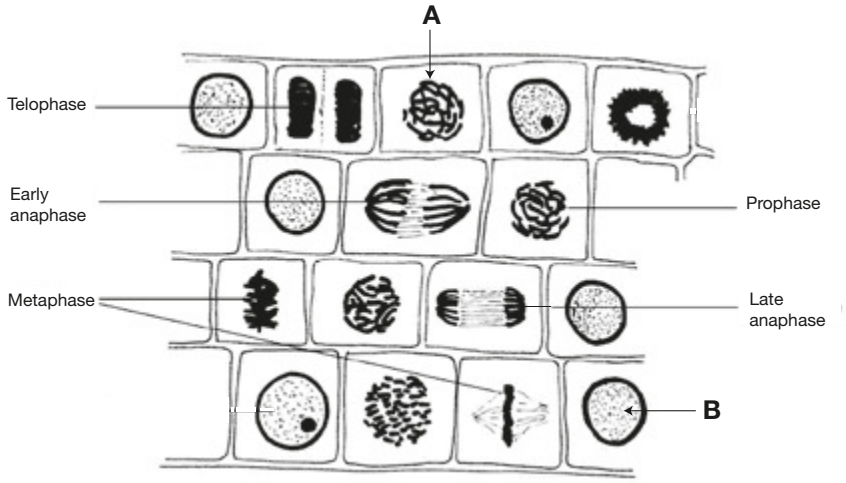
Free response questions

1. Because DNA replication occurs prior to both forms of cell division. This enables each parent to provide each daughter cell with an identical set of their genetic information.
2. Some possible answers include:
   a) **Prophase:** the nucleus breaks down and centrioles move to the poles of the cell.
   b) **Metaphase:** spindle fibres attach to centromeres of doubled chromosomes and align them along the equator of the cell.
   c) **Anaphase:** the sister chromatids are pulled apart by spindle fibres and pulled to opposite poles of the cell.
   d) **Telophase:** a nucleus begins to form around each set of chromosomes which are decondensing back into chromatin form.
3. Mitosis is defined as division of the nucleus, whereas cytokinesis is the division of the cytoplasm (i.e. the splitting into two identical new daughter cells).

4. See table below:

Type of division	Type of organism	Type of chromosome	Number of cells formed	Spindle fibres involved?	DNA replication involved?
Binary fission	Prokaryote	Circular	2	No	Yes
Mitotic division	Eukaryote	Linear	2	Yes	Yes

5. a) 4
   b) B, C, E, D, A
6. The student's statement is not entirely true. Binary fission is used by prokaryotic cells to reproduce but not all eukaryotes use mitotic division to reproduce. Many eukaryotic organisms use meiosis and fertilisation to reproduce sexually. Some eukaryotic organisms can reproduce asexually and sexually, but many can only reproduce one way or the other.
7. With reference to the graph:
   a) DNA replication occurs in the section B-C because during this time the amount of DNA per cell doubles.
   b) The sister chromatids are being pulled apart towards the poles in Anaphase. Telophase occurs where nuclei re-form around the two sets of identical genetic information and cytokinesis occurs. As cytokinesis is finalised, the DNA content of each daughter cell is the same as the original parent cell prior to DNA replication (i.e. at A to B).
8. a) Refer to the labels on the image below:



   b) Cell A shows the genetic information in condensed chromosome form whereas cell B shows it in decondensed chromatin form. The individual chromosomes are visible in cell A under a light microscope suggesting that the chromatin has condensed around histone proteins. As chromatin is decondensed it cannot be seen as individual structures under a light microscope, as in cell B.
   c) Chromatin must condense into chromosomes prior to mitotic division because this allows the DNA to be moved around the cell easily during mitosis and helps to protect the long DNA molecules from getting tangled during the division of the nucleus.
9. a) Because the loss of control could lead to uncontrolled cell division and the formation of a mass of cells known as a tumour or cancer.
   b) The mistake is that the spindle fibres have not attached to both sides of the centromere of one duplicated chromosome. As the spindle fibres are only attached to one side of the centromere, it is highly likely that the two sister chromatids will not be separated, and both will be dragged to the left pole of this cell. This would not result in identical sets of genetic information at opposite poles of the cell. There would be 5 units of DNA at the left pole and 3 units of DNA at the right pole. As the goal of mitotic division is to produce genetically identical cells, this could be detrimental to the organism. *Note: it is likely that the cell would pick up the mistake prior to the division and if it could not be fixed, the cell would be terminated to prevent any detrimental effects*.

Chapter 1.4 Suggested answers

Multiple choice questions

1. K 2. M 3. K 4. J 5. M 6. M 7. J 8. M 9. K 10. L

Free response questions

1. Any **three** different processes that occur at the **cellular level**. Some examples include:
   - DNA is replicated to form sister chromatids prior to cellular division.
   - The sister chromatids are pulled apart by the spindle fibres during mitosis.
   - Muscle cell contraction.
   - Active transport of material against concentration gradient.
   - Endocytosis/exocytosis, which involves the movement of the cell membrane to import/export materials into the cell.
   - The synthesis of proteins in the cytoplasm (prokaryotic cell) or ribosomes (eukaryotic cell).
   - The rapid movement of a sperm's tail.
2. See table below:

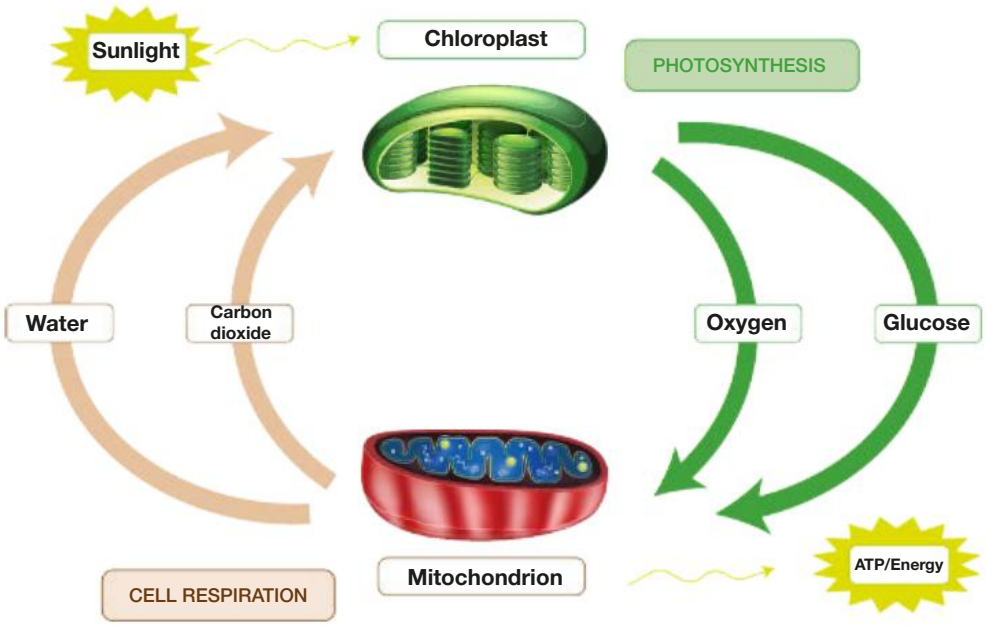
Organism	Type of nutrition	Process by which carbon is obtained	Initial energy input
A fern	Autotrophic	Through photosynthesis (CO_2)	Light
A human	Heterotrophic	Through consumption (glucose)	Chemical energy (glucose)

3. The word equations are:
   a) carbon dioxide + water → glucose + oxygen
   b) glucose + oxygen → carbon dioxide + water
   c) glucose → lactic acid
   d) glucose → ethanol + carbon dioxide
4. Some possible answers include: carbon dioxide, urea, water, lactic acid and ethanol.
5. Carbon dioxide is a by-product from aerobic respiration, which occurs in both plants and animals. Carbon dioxide in plants is a raw material (reactant) required for photosynthesis and if sunlight is available can be used by some plant cells to produce glucose. However, human cells must excrete it because high levels inside cells can lower pH (increase acidity), making conditions less suitable for chemical reactions to occur in cells.
6. Referring to the graph:
   a) Violet/indigo light (~420 nm) and orange/red light (~680 nm) are the colours/wavelengths most likely to increase the growth rate of a typical flowering plant. This is because the rate of photosynthesis is the highest for these wavelengths/colours of light, providing a higher rate of glucose production to fuel the plants growth.
   b) As the rate of photosynthesis for green light (~550 nm) is low, it shows that green light is not absorbed well by this typical plant. Therefore, it suggests that green light is reflected by leaves to our eyes and we perceive the leaves as green.
7. Some factors that may affect the rate of photosynthesis include:
   - Light intensity is important because light provides energy for photosynthesis.
   - Carbon dioxide concentration (%) is important since it is a raw material (reactant) for the process.
   - Temperature will affect the rate at which the chemical reactions involved in photosynthesis occur within the cells.
8. a) Refer to answers in the table below:

Element	Number of atoms	
	Reactants	Products
Carbon	6	6
Oxygen	18	18
Hydrogen	12	12

   b) (i) The number of carbon , oxygen and hydrogen atoms in the reactants and products of photosynthesis are the same.
   (ii) The inorganic source of carbon is carbon dioxide (CO_2) which plants mainly source from the air (by diffusion). Note CO_2 can also be obtained from respiration, but the main source is from the air.

c) Refer to the answers in the flow diagram below:



d) Photosynthesis provides plants with an energy-rich molecule in glucose, but the energy is trapped within the bonds of glucose and is not in a usable form for plant cells. Plant cells must also be able to respire to break down the glucose molecules releasing usable energy (through ATP) so the cell can use it to perform cellular processes.

9. a) Refer to calculation below:

Start = 5.5cm (55mm)

End = 1.2cm (12mm)

Total distance moved = 55 – 12

= 33 mm

b) Refer to calculation below:

Total distance moved = 33 mm

Time elapsed = 30 minutes

Rate of movement = 33/30

= 1.1 mm/min

c) The air in the respirometer contains oxygen, which takes up space. When the woodlouse respires aerobically, oxygen is consumed, drawing the droplet of water towards the woodlouse. The greater the amount of oxygen consumed, the less space oxygen will take up in the respirator and the further the droplet will move towards the woodlouse. In addition, the carbon dioxide released through aerobic respiration is absorbed by the potassium hydroxide and is not replacing the oxygen in the test-tube chamber that the woodlouse is enclosed in.

d) The average estimated respiration rate for each of the four animals are:

A = (1.4+1.6+1.5)/3 = 1.50 mm/min

B = (0.5+0.9+0.9)/3 = 0.77 mm/min

C = (1.7+2.3+2.0)/3 = 2.00 mm/min

D = (1.3+1.1+1.4)/3 = 1.27 mm/min

e) (i) C

(ii) The dataset for animal C has the largest range of 0.6 mm/min (i.e. 2.3 – 1.7) and is therefore the least precise and most affected by random error.

f) Some possible limitations include:

- This method doesn't consider that animals are different sizes and therefore consist of different numbers of respiring cells when calculating the respiration rate. The respiration rate per gram of each animal could be calculated instead and compared.
- The respirometer used is basic and only provides a rough estimate of respiration rate by measuring the distance a coloured drop of liquid moves in 30 minutes (mm/min). A more advanced respirometer with a greater resolution, would provide greater validity when comparing the respiration of the four animals.

Chapter 1.5 Suggested answers

Multiple choice questions

1. K 2.J 3.K 4. M 5. L 6. J 7. M 8. J 9. K 10. L

Free response questions

1. Lipids, proteins and carbohydrates.
2. Some possible answers include:
   - Glucose–substrate for aerobic respiration, which provides useable energy.
   - Oxygen–substrate for aerobic respiration, which provides useable energy
   - Amino acids–building blocks for polypeptides and protein molecules.
   - Salts – can help with maintaining water/solute balance.
3. The cell membrane consists of a double layer of phospholipids that have a range of proteins embedded in it. The membrane also consists of carbohydrates bound to lipids (glycolipids) and proteins (glycoproteins).
4. Some possible answers include:
   - Protecting the intracellular environment.
   - Providing support and helping to maintain cell shape through adhesion proteins that can stick out and bind to specific protein molecules on adjacent cells.
   - Selectively controlling the exchange of molecules between the cell and its external environment through transport proteins.
   - Allows communication through receptor proteins and complementary hormones.
   - Involved in cell recognition through glycoproteins and glycolipids that act as cell identity markers and allow the immune system to distinguish between the organism's cells and foreign cells (e.g. bacteria).
5. The word 'fluid' in the name of the model refers to the ability of both lipids and proteins to continually move in the membrane. This characteristic is critical for membrane permeability, or ease of movement of molecules across the membrane. The term 'mosaic' refers to the pattern formed by the variety of proteins embedded within the phospholipid bilayer. These proteins are fundamental to the function of the cell membrane. Therefore, this is a very suitable name for the model.
6. Because some molecules can pass through the phospholipid bilayers of the cell membrane easily, but others cannot.
7. Because the membrane consists of a double layer of phospholipid molecules. The external heads of the phospholipids are water-loving (hydrophilic) but the internalised tails are water-hating (hydrophobic). Therefore, the water-loving glucose molecules that dissolve in water have a low permeability across the lipid bi-layer and may need assistance to cross the membrane through transport proteins.
8. Some of the molecules that cannot pass through the membrane bilayer easily can be important for cell survival, such as amino acids and nucleic acids. These molecules rely on transport proteins to be transported across the cell membrane. The transport proteins for these molecules are specific and therefore selective for the molecules that can move across them, hence selectively permeable.
9. See table below:

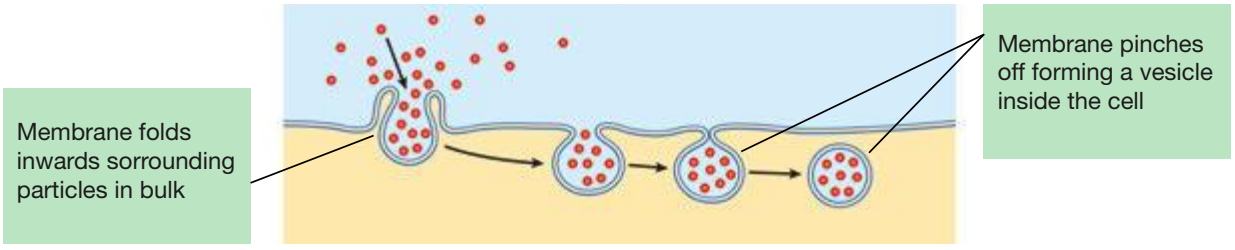
Transport process	Are proteins in the lipid bilayer required?	What is the concentration gradient?	Is an energy input required?
Simple diffusion	No	High to low	No
Facilitated diffusion	Yes	High to low	No
Active transport	Yes	Low to high	Yes
Osmosis	No, but can be used to increase osmosis (aquaporins)	• High water to low water • Low solute to high solute • Hypotonic to hypertonic	No

10. a) Facilitated diffusion
    b) Because the molecules are moving through a transport protein in the membrane and there is no indication of energy being required. Additionally, there is a high concentration of molecules outside the cell and a lower concentration inside the cell further indicating that energy is not required for this process.

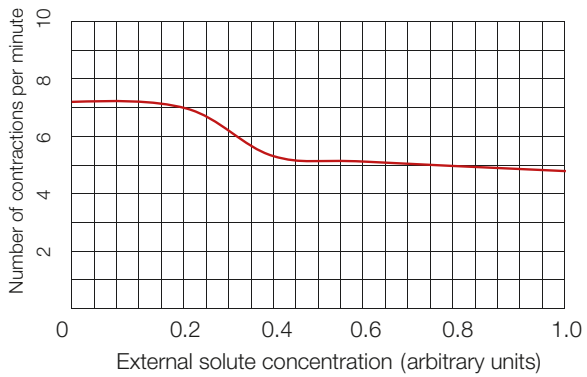
11. a) osmosis
    b) mineral ions move by active transport
    c) epithelial cells absorb droplets by endocytosis (pinocytosis)
    d) endocytosis (phagocyctosis)
    e) oxygen moves by diffusion
12. a) See table below:

Edge length (cm)	Total surface area SA = l × w × 6 (cm^2)	Volume V= l × w × h (cm^3)	SA:V	SA:V (simplified to compare more easily)
1	1 × 1 × 6 = 6	1 × 1 × 1 = 1	6 : 1	6 : 1
2	2 × 2 × 6 = 24	2 × 2 × 2 = 8	24 : 8	3 : 1
3	3 × 3 × 6 = 54	3 × 3 × 3 = 27	54 : 27	2 : 1
4	**4 × 4 × 6 = 96**	**4 × 4 × 4 = 64**	**96 : 64**	**1.5 : 1**
5	5 × 5 × 6 = 150	5 × 5 × 5 = 125	150 : 125	1.2 : 1
6	6 × 6 × 6 = 216	6 × 6 × 6 = 216	216 : 216	1 : 1

    b) As the edge length of the cube increases from 1 cm to 6cm, the SA:V decreases from 6:1 to 1:1.
    c) Because as the cube size increases, the volume increases more than the surface area resulting in the observed decreasing SA:V.
    d) As the size of a cell increases, its surface area to volume ratio decreases and this results in a decreased efficiency in exchanging materials with its external environment.
13. a) Hypertonic
    b) These red blood cells show evidence of shrinking and becoming dehydrated following placement in the hypertonic solution.
    c) Osmosis. Water has moved out of the cells by osmosis from a hypotonic solution (high water concentration) inside the cells to a hypertonic solution (low water concentration) outside the cells.
    d) Because chemical reactions occur in cells, and they require the cell to maintain a narrow range of conditions to maintain efficiency and function normally. For example, cells require waste products such as carbon dioxide and urea, to be excreted from the cells because if they build up, they can increase acidity, which reduces the efficiency of chemical reactions inside they cell.
14. a) They are both considered active transport processes because they both involve the movement of the cell membrane, which requires energy expenditure.
    b) See diagram below:



15. a) Your graph should look like this.



b) As the external solute concentration increases the rate of contractions per minute slowly decreases.

c) If the paramecium did not have contractile vacuoles, water would rush into the paramecium when exposed to a 0% external solute concentration environment. This could result in the paramecium bursting and dying.

d) The graph indicates that the cell membrane is permeable to water because at lower solute concentrations, more water moves into the cell and has to be pumped out by faster contractions of the contractile vacuole. This is evident as there was 7.1 contractions per minute at 0% external solute concentration which decreased to 4.9 contractions per minute at 1.0% external solute concentration. In conclusion, as the external solute concentration increases, less water moves into the paramecium by osmosis, so less rapid contractions of the vacuole are needed to pump the excess out water of the cell.

e) Some possible answers include:

- There is no evidence of replication in the dataset and therefore the reliability of any conclusions made would be limited.
- The results are limited to the one species of Paramecium tested.
- The reduced rates of contraction of the vacuole may be due to another factor such as fatigue.
- The conclusions are limited to the external solute concentrations tested in the experiment and as such cannot be extrapolated to others.

Chapter 1.6 Suggested answers

Multiple choice questions

1. M 2.L 3.K 4. K 5. J 6. M 7. K 8. J 9. M 10. L

Free response questions

1. Bacteria, archaea, fungi, protists and viruses.
2. a) Binary fission. When environmental conditions are optimal, many types of bacteria can double every 20 minutes, resulting in rapid exponential growth.

   b) Resources will eventually run out and the waste materials produced by the bacteria may be toxic to them.
3. a) Bacterial cell walls are composed of peptidoglycan, but Archaean cell walls are not. Archaean cell walls contain unique lipids.

   b) The structure of the cell wall protects them and allows them to survive in extreme environmental conditions.
4. The three main ways that fungi absorb their nutrients are:
   - decomposers obtain their nutrients from decaying and dead matter,
   - symbionts obtain their nutrients through symbiotic relationships with plants, and
   - parasites obtain theirs through harmful relationships with host organisms.
5. Decomposers are heterotrophic and feed on dead/decaying organic matter. As they do this, they release organic compounds to the environment (e.g. soil) and carbon dioxide to the atmosphere (through cellular respiration).
6. a) Yeast. Yeast breaks down the starch in flour and respires anaerobically producing carbon dioxide which rises the dough.

   b) Lactic acid bacteria. These bacteria ferment the lactose sugars in milk producing lactic acid which decreases the pH and results in the milk clotting (forming a soft gel).
7. a) Because all eukaryotic organisms that are not classified as fungi, plants or animals are classified as protists. This leaves a diverse range of organisms with a diverse range of characteristics all being classified as protists.

   b) Algae are photosynthetic autotrophs that convert carbon dioxide into oxygen and glucose in the presence of sunlight. It is estimated that they produce 50% of the earth's oxygen. They are also the primary producers of ocean food chains which ultimately all humans rely on as a food source.
8. Some possible answers include:
   - there are very few ethical issues.
   - they are very small, containing little genetic material that is relatively easy to manipulate.
   - they have a very short life-cycle and produce products quickly.

9. a) Fungal cell walls are composed of chitin, but fungi-like protist cell walls are composed of cellulose.
   b) A gene that confers resistance to the 'late blight' disease could be isolated from the host organism and inserted into a bacterial plasmid. This recombinant plasmid could then be inserted back into bacteria and cultured, cloning the target gene. The target gene can then be incorporated into the first cell of a potato plant to produce a GM late blight resistant potato plant.
10. a) The collection of all microorganisms (bacteria, fungi, archaea, viruses) in the gut.
    b) Some possible answers include:
       - Antibiotics – this individual could have required antibiotics to treat a pathogenic infection, but the antibiotics could have also wiped out multiple bacterial species in the gut microbiome.
       - Food poisoning (illness) – pathogenic bacteria could have been consumed releasing toxins and killing/outcompeting many native bacterial species that were once established. This could have caused a dip in the range of species and population sizes during this time.
    c) he lactic acid is acidic lowering the pH of the gut (increasing acidity). This makes the gut environment less favourable for pathogenic microorganisms to survive and reduces the risk of pathogenic infections to the host organism.
11. a) Yeast/moulds and *S. aureus*.
    b) Bacteria require water to perform many chemical reactions and they obtain this from their environment. However, water molecules bind to salts/sugars/soil too and can be unavailable for bacteria to use. A high water activity means there is lots of free water for bacteria to use, but as the water activity is lowered, more water becomes unavailable to use (bound to salts, etc.) making conditions less favourable for bacterial growth.

Chapter 1.7 Suggested answers

Multiple choice questions

1. L 2.J 3.K 4. L 5. M 6. J 7. M 8. L 9. M 10. J

Free response questions

1. Food spoilage is any undesirable change to a food. It can result from physical, chemical or microbiological changes.
2. Food poisoning occurs when pathogenic (disease causing) microorganisms and their toxins and are consumed, causing symptoms such as fatigue, vomiting, diarrhoea and dehydration. This is generally undetectable as the toxins do not give off sensory cues. Food spoilage however is any undesirable change to a food and sensory cues are generally observed, such as growth of mould or physical damage and associated browning.
3. Some possible answers include:
   - wash hands frequently, especially after touching digital devices, changing a nappy, etc.
   - avoid coughing or sneezing over food or the area where it is being prepared
   - wear clean protective clothing, such as an apron
   - tie back long hair and wear hair nets
   - completely cover all cuts and wounds with a band-aid or wear gloves to cover them
   - if an individual has diarrhoea and/or vomiting they should not prepare food for others and should arrange for someone else to do it.
4. Some possible answers include:
   - Preservation increases the shelf life of foods.
   - Preservation can help reduce the amount of food waste because if shelf life is increased then there is a greater chance of it being purchased and consumed.
   - Preservation of foods can decrease the rate of spoilage and help maintain the quality and nutrient retention in some foods.
   - Preservation decreases the risk of food poisoning occurring.
   - Preservation can increase the convenience of some foods.

5. See table below:

Food	Method(s) of preservation	Description of preservation method(s)
	Pickling	Pickling exposes microorganisms to lower pH (more acidic) environment which can kill them by deactivating enzymes essential for survival. The majority of microorganisms (and their spores) that are subjected to a pH lower than 4.5, cannot survive.
	Vacuum sealing	Vacuum packaging removes the atmospheric gases from the product and is sealed tightly to reduce the amount of oxygen in the packaging. Aerobic microorganisms require oxygen to produce energy, therefore less oxygen reduces their growth and ability to divide efficiently. Reducing oxygen does not kill bacteria, it makes them dormant.
	Freezing	Freezing food slows microbial growth by exposing them to temperatures below -18°C (below the 'danger zone'), which converts the water in foods to ice, reducing available free water molecules and hence, water activity. Reducing water activity does not kill microbes, it prevents them from reproducing.
	Dehydrating	Fruits can be dehydrated by air drying or using commercial food dehydrators. Dehydration removes moisture from microbes and the food itself. This slows microbial growth by reducing available water required for chemical reactions and growth, and they can become dormant (enter resting phase).
	Canning	This involves placing foods into cans and heating them to temperatures above 100°C (above danger zone) killing them. The canning process also drives oxygen out and is vacuum sealed preventing air exposure and microorganisms from entering.
	UHT	UHT pasteurisation involves heating the product to 138°C for 2 seconds killing microorganisms and deactivating enzymes involved in food spoilage.

6. Washing hands destroy many different microorganisms that contain a cell membrane. The cell membrane is made of lipids that soap molecules bind to ripping the cells apart. Rubbing hands against each other rigorously creates greater friction, destroying and removing more microorganisms from hands.
7. If placed in the same bag the heat from the hot foods can be transferred to the cold foods (e.g. milk) that need to be kept cold. This can increase the temperature of the food that needs to remain cold into the 'danger zone' where bacteria thrive and increases their rate of reproduction. Keeping them separate decreases the chance of this happening, increasing the shelf life of the colder foods and the potential risk of food poisoning.
8. Cross-contamination. Placing cooked chicken on the cutting board it was prepared on can transfer bacteria from when the raw chicken was placed on it. If consumed, there is a higher risk of food poisoning occurring.
9. Freezers are set at -18°C whereas fridges are set between 1 and 5°C (generally 3°C). Therefore, freezers are much colder than fridges and remove foods further from the 'danger zone' slowing growth more. Additionally, freezing foods freezes the water in the food and microbes, reducing water activity, making bacteria dormant.
10. Adding salts to foods increases the amount of salt that can bind to free water molecules, reducing water availability for microorganisms. This increases the extracellular solute concentration, which can result in water moving by osmosis from microbes to the extracellular environment further dehydrating them.
11. Cooking the mince above 75°C would have killed almost all of the microorganisms in the mince but it the toxins they released in the food prior to being cooked cannot be destroyed by cooking it. Therefore, by consuming the mince that was well past its use-by-date the individual consumed the toxins in the mince, contracting food poisoning.

Topic 1 Review Test: Suggested answers

Multiple choice questions

1. L 2.J 3.K 4. L 5. M 6. J 7. L 8. J 9. M 10. M

Free response questions

11. a) A ribosome

b) Some possible answers include:

- A is prokaryotic and therefore DNA is located in the cytoplasm. B is eukaryotic with the DNA contained in a nucleus.
- A has a circular chromosome, whereas B has linear chromosomes.
- A has a single chromosome but B has many pairs of linear chromosomes.

c) Some possible answers include:

- Cell B contains a cell wall but cell A does not.
- Cell B contains chloroplasts but cell A does not.
- Cell B contains a large central vacuole but cell A does not.

d) Any two of the following points of the cell theory included in the answer:

- all organisms are made of cells
- cells are the basic units of life
- cells come from pre-existing cells that have multiplied.
- DNA is passed between cells during cell division
- the cells of all organisms within a similar species are mostly the same, both structurally and chemically
- energy flow occurs within cells.

e) Cell A is a prokaryotic, unicellular organism consisting of a single cell. Tissues exist in multicellular organisms and consist of many cells combined that have similar structures and functions.

12. a) Stage A is prophase. During prophase, the nucleus disintegrates and the chromosomes move into the cytoplasm. The centriole duplicates and each one moves to opposite poles of the cell. Spindle apparatus starts to form.

b) Stage B is Anaphase. During anaphase, the sister chromatids are separated by the spindle fibres that pull the chromatids to the opposite poles of the cell.

c) One of the following:

- DNA replication. The chromosomes must be replicated prior to cell division (forming sister chromatids), so that each daughter cell receives an identical copy of each chromosome.
- Chromatin condensing into chromosomes. The chromatin must condense into tightly packed chromosomes to protect the genetic code as each chromosome is moved around the cell and chromatids are split.

d) Mitotic division occurs in eukaryotic cells, it is a division of the nucleus. Binary fission occurs in prokaryotic cells, as no nuclei are present the circular chromosome replicates and then divides into two.

13. a) A = chloroplast, B = mitochondrion

b) W and Z = glucose and oxygen, X and Y = water and carbon dioxide

c) Chlorophyll. Chlorophyll traps light energy required for photosynthesis to occur.

d) Plants absorb nitrogen and phosphorus minerals from the soil, through their roots. Animals consume plants, or animals that have eaten plants, and therefore the molecules containing these mineral nutrients too.

Nitrogen is required to synthesise chlorophyll, DNA, RNA and amino acids/proteins. Phosphorus is required in the synthesis of DNA, RNA, ATP and the phospholipids for membranes.

e) Some waste products can be toxic, especially if they build up to high concentrations. These waste products therefore need to be excreted from cells to prevent damage to cell structures such as proteins and organelles.

14. a) For 1 cm^3 cube: SA = (1 × 1) × 6 = 6 cm^2 `V = 1 × 1 × 1 = 1cm^3 SA:V = 6:1

For 2 cm^3 cube: SA = (2 × 2) × 6 = 24 cm^2 `V = 2 × 2 × 2 = 8cm^3 SA:V = 3:1

b) (i) The two cubes lost mass.

(ii) Osmosis is the nett movement of water molecules from low solute concentration to high solute concentration. As the two potato cubes have a low solute concentration (0.9%) and the external glucose solution has a high solute concentration (5%), water will move from the potato cubes to the external solution by osmosis. This movement of water out of the potato cubes would reduce that mass of the two potato cubes.

(iii) Any two of the following in answer:
- the potato cells would become dehydrated
- plasmolysis would have occurred (i.e. the cell membrane would have pulled away from the cell wall).
- large central vacuole would have shrunk

c) As cube X is smaller than cube Y, it has a greater SA:V and it exchanges materials more efficiently (cube X has a SA:V of 6:1 which is greater than cube Y that has a SA:V of 3:1). This would result in cube X having a greater percentage change of its mass than cube Y (a greater percentage loss of mass as water moves out of cubes by osmosis).

15. a) Lactic acid bacteria are required to make yoghurt. They ferment the lactose sugars in milk producing lactic acid which decreases the pH and results in the milk to clot. This results in the soft gel mouthfeel associated with yoghurt and the sour taste (before more sugar is added to give it additional flavour).

b) Cellular division requires energy. Aerobic bacteria require oxygen to perform aerobic respiration and produce energy in the form of ATP. Without sufficient oxygen, the rate of cellular division would be reduced significantly as fermentation supplies significantly less energy than aerobic respiration.

c) Two possible answers include:
- Freezing foods at -18°C removes them from the danger zone (5-60°C) which is the ideal temperature range for bacterial growth and division. The very cold temperatures slow down microbial growth significantly (to an almost dormant state), preserving the food.
- Freezing foods also freezes the water in the foods which reduces water activity of the foods. Bacteria require liquid water to perform chemical reactions and grow. With no (or very little) liquid water available, the bacteria become dormant and cannot grow and divide, preserving the food.

d) Fungi such as yeast. Under anaerobic conditions (without oxygen), yeast can perform ethanol fermentation, which could be harvested to be used in biofuel.

e) Plasmid

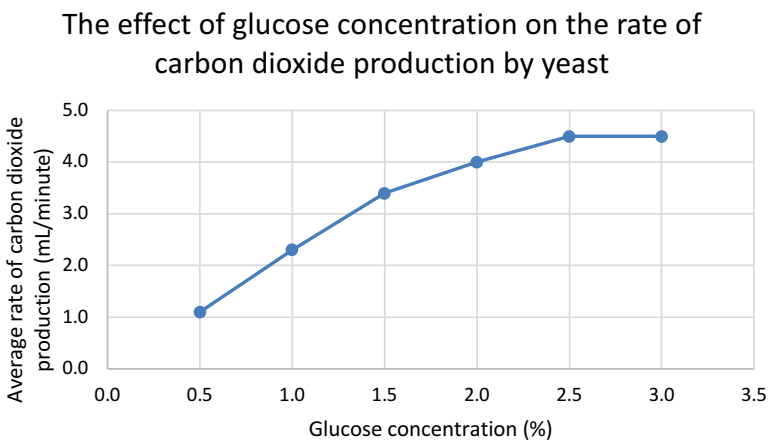
f) Some possible answers include:
- This development could result in government and private funding to build new plastic recycling plants that incorporate this new multi-plastic digesting bacteria. The construction and manning of this plant creates many new jobs, positively impacting the economy.
- This development could allow plastic waste to be recycled more efficiently and possibly produce by-products that can be used to synthesise other products. This could be beneficial to the economy by creating new products with cheaper sources resources whist being environmentally friendly.
- If the synthesis of multi-plastic digesting bacteria is successful, they could be applied to areas of the environment littered with plastic waste, such as oceans. This could save the lives of many animals that get stuck in plastic waste and suffocate or consume plastic waste that gets stuck in their digestive system and results in death.
- If multi-plastic digesting bacteria was applied to oceans to digest the plastic waste, it could have unexpected consequences as a result of adding another species of bacteria to the oceans. It is unknown how this bacterial species would impact ocean food webs.

16. a) (i) 32.6/3 = 10.9 mL per 4 minutes

(ii) 10.9/4 minutes = 2.725 (or 2.73) mL/min

b) Conducting multiple trials and averaging the results reduces the effect of random errors and increases the reliability of the data.

c) See graph below:



d) Approximately 1.2%

e) (i) Some possible answers include:
- Use the same mass of yeast cells such as 5g.
- Use the same volume of yeast suspended in solution such as 5mL.

(ii) If the number of yeast cells significantly differed between trials then this would result in increased scatter of the data and reduce the validity of the results/conclusion.

f) As glucose concentration increased from 0.5% to 2.5% so did the average rate of carbon dioxide production, but the rate of carbon dioxide production then plateaued as the glucose concentration increased to 3.0%.

Chapter 2.1 Suggested answers

Multiple choice questions

1. J 2.L 3.L 4. K 5. M 6. L 7. L 8. L 9. M 10. K

Free response questions

1. An infectious disease can be transmitted from one organism to another either directly or by a vector. A non-infectious disease is unable to be transmitted.
2. A pathogen is a disease-causing microbe. A parasite is an organism that lives inside or on a host and relies on its host to complete its life cycle. They can be considered pathogenic if they cause disease.
3. Ring worm refers to the appearance of circular red patches, or rings, that are associated with an infection caused by a fungal species.
4. a) Two of: Bacteria, fungi or protists (protozoa).
   b) Spores can allow these organisms to become dormant and survive less favourable environmental conditions. They can then germinate when conditions are more favourable and survive. Spores can enable a species to spread very easily as the spores are microscopic and can travel significant distances in the wind.
5. These are our natural microflora. They live in and on us in a mutually beneficial relationship, generally not causing harm as they have evolved with humans over time.
6. Some possible answers include:

Pathogen	Example of disease	Characteristic that assists survival and/or transmission
Bacteria	Cholera	Can divide rapidly through binary fission when conditions are suitable
Fungi	Toenail infection	Can produce spores that spread remarkably easily
Protozoa (Protist)	Malaria	Uses mosquitoes as a vector to spread
Virus	Influenza	Uses host cell's machinery to replicate
Parasitic worm	Tapeworm infection	Lays many eggs in faeces of host to infect others.
Prion	Creutzfeldt-Jakob Disease (CJD)	Are highly resistant to heat radiation and sterilisation

7. Because they do not display characteristics associated with life such as responding to stimuli and using energy. They also do not contain DNA as they are proteins and reproduce by converting 'normal' proteins into 'abnormal'.
8. a) A toxin is a poisonous substance secreted by a range of pathogens and other organisms.
   b) If a steak has passed its use-by-date, then there has been a lot of time for bacteria to grow and divide. Even though the steak has been cooked, killing the bacteria on it, cooking cannot destroy the toxins that have already been released in the steak by the vast number of bacteria.

9. See table below:

Disease	Bacterium	Fungus	Virus	Protist	Worm	Prion
Common cold			✓			
Diarrhoea	✓		✓	✓		
Malaria				✓		
Sinusitis	✓ (rare)	✓ (rare)	✓			
Tapeworm infections					✓	
Pneumonia	✓	✓	✓			
Mad cow disease						✓
Genital herpes			✓			

10. a) Africa, Southeast Asia
    b) Low income, poor health facilities, ability to identify isolate and treat infected individuals, poor education, low vaccination rates and poor sanitation.
    c) More people in developing countries die from infectious disease due to the reasons listed above. Non-infectious diseases are more common in developed countries than non-infectious diseases because these countries generally have good infectious disease practices in place, or the money to do so when an outbreak occurs. Therefore, there is a higher chance of them succumbing to a non-infectious disease due to poor diet and lifestyle choices, such as cardiovascular disease and some types of cancer.

Chapter 2.2 Suggested answers

Multiple choice questions

1. M 2.J 3.L 4. K 5. M 6. K 7. J 8. K 9. J 10. M

Free response questions

1. Some possible examples include:

Method	Examples of pathogens
Droplet transmission (cough or sneeze)	Flu virus, cold virus
Direct contact	Fungal spores infection, herpes virus
Faeces	Cholera bacteria, hepatitis A virus
Contaminated food	Salmonella bacteria, E.coli bacteria

2. Measles can be spread through aerosols that travel further and linger in the air for longer than larger droplets that contain influenza, which travel much shorter distances in the air.
3. Some possible methods of transmission include:
   - exchanging needles for drug use
   - unprotected sex
   - blood transfusion
   - breast milk
4. a) Some possible answers include:
      - The dog licking a child's face.
      - A child sharing some food with their pet dog such as an ice-cream.
      - A child touching a surface contaminated by the dogs saliva or faeces and then consuming some food without washing their hands.
   b) A rat is an intermediate host of tapeworm. The eggs of the tapeworm can be released in cat faeces, which can be ingested by rats. The life cycle of the worm completes itself inside the rat and if its tissue is consumed by another cat, it can become infected with the tapeworm parasite.
5. Salmonella bacteria are very common in poultry. If the chicken is not cooked properly, some bacteria can survive and be transmitted to humans when ingested. Salmonella from chicken can also be transmitted to humans through cross-contamination, for example when the cooked chicken is cut on the same cutting board that the raw chicken was cut on.

6. Two possible answers are:
   - In freshwater streams, creeks and lakes that may have been polluted by human waste.
   - Poor hand hygiene following egestion of faeces and transmission through contact of faecal matter from an infected individual to another.
7. Rabies is spread through the saliva of cats, dogs, bats and livestock. This is often transmitted through a bite or scratch of an infected individual.
8. A lot of these insects that are vectors of disease live in tropical areas. With global warming, new zones with higher temperatures enable the vectors to spread. This can increase the spread of disease. Additionally, some pathogens may adapt better to the warmer environmental conditions which could make them more resistant to human defences such as fever, spreading more easily between hosts.
9. a) The *Plasmodium* parasite reproduces inside the mosquito vector and the mosquito spreads the disease to humans when they bite them to feed on human blood.
   b) Destroying red blood cells and interfering with liver function due to an increase in the inflammatory response.
   c) The *Plasmodium* parasite enters the human host through the bite of a mosquito. It requires the human host to produce thousands of copies of male and female gametes that then spread to mosquitoes when they feed on the blood of an infected human. The two gametes fuse in the stomach of the mosquito to complete its sexual reproduction cycle.
   d) Some methods include spraying insecticides to kill the mosquitoes and reducing the amount of stagnant freshwater which is ideal for their breeding.

Chapter 2.3 Suggested answers

Multiple choice questions

1. K 2.L 3.J 4. L 5. J 6. M 7. K 8. K 9. L 10. M

Free response questions

1. a) An epidemic is localised and is an active outbreak of an infectious disease that affects a large number of people in a specific region or country. A pandemic however is the spread of an infectious disease on more of a global scale.
   b) Some possible answers include:
      - transmission of a pathogen to a new group of individuals not previously exposed
      - the development of a new strain of a pathogen
      - a new pathogen crossing the species barrier to humans from an animal
      - decreased herd immunity
2. a) Some possible answers include:
      - There was very poor sanitation at the time.
      - There was a lack of understanding of pathogens at the time and how they transmitted.
      - There was a low natural herd immunity to the bubonic plague.
      - Humans were mobile and travelled to other regions unknowingly spreading the plague.
      - The population of London was living in a high density environment fuellling its transmission.
   b) There is a better understanding of the cause of disease (bacteria) and how it is spread (lice/fleas). This allows us to treat infected carriers for to eliminate the fleas/lice that spread the bubonic plague. Antibiotics can also be used to treat infected individuals reducing the likeliness of death and its transmission.
3. Because there has been a significant increase in global travel by humans. This is largely due to increased accessibility to air travel and flights becoming significantly more affordable. Humans often cross international borders before symptoms develop and therefore infect others upon arrival. There has also been an increased migration.
4. a) Poor sanitation
   b) The spread of waterborne diseases such as cholera are more common in developing countries that do not have adequate access to fresh clean water. This is due to a variety of factors such as not having enough money to develop efficient waste disposal infrastructure and water treatment plants to all communities. This can result in waste ending up in water sources contaminating the water body and creating environments where pathogens like cholera can thrive and easily transmit. Unlike developed nations that have enough money to ensure adequate infrastructure, policies and procedures to provide clean and safe water to their populations.

5. Urban expansion generally involves land clearance, which can expose humans to new human-wildlife interactions. If the wildlife bites or scratches a human, a pathogen(s) could be transmitted. If the pathogen has adapted to infect humans, it could cross the species barrier. The greater the urban expansion, the more chance there is for new human-wildlife interactions and the transmission of a pathogen across the species barrier.
6. A mutation changes the genetic sequence (DNA/RNA sequence), which may result in a change to the structure of a protein in a pathogen. If the shape of surface proteins are changed, the immune system of an infected host may no longer recognise the pathogen resulting in the pathogen persisting within the host for longer, increasing its contagiousness. Alternatively, mutations could result in new physical structures in the pathogen that increase the severity of symptoms and/or death rate (i.e. increased virulence).
7. a) Population B had herd immunity prior to the exposure to the pathogen. Even though one member of population B is infected, the chain of transmission starts and ends with this individual as the majority of the herd is immune to this pathogen. Population A however, did not have herd immunity and the infectious disease was able to spread more easily, infecting many of its members.
   b) Herd immunity can protect the vulnerable and those unable to be vaccinated against a pathogen. This could be infants, pregnant women, the elderly or any other immunocompromised individual. As their immune systems are compromised, they cannot combat infections easily. By the herd being immune the transmission of disease into a community is stopped and these vulnerable people within the community are also protected from being infected.
8. High biodiversity keeps the numbers of rodents down meaning there are fewer reservoirs for the bubonic plague bacteria. This can result in less ticks to transmit the bubonic plague to humans and less bubonic plague bacteria in ticks reducing the likeliness of transmission to humans. Overall, high biodiversity can reduce the number of infected humans and vice versa.
9. a) Blood borne transmission
   b) The number of people living with HIV infections increased significantly from 1981 to 1991, where there was a short plateauing until 1997 when the numbers continued to increase significantly. The number of deaths of individuals who are HIV positive increased rapidly from 1981 to 1995 and then sharply decreased until 1997. From here the number of deaths continued into a very gradual decline to 2009.
   c) A likely reason is a new effective medication could have become available to HIV infected individuals that allowed them to manage their symptoms and increase their chance of surviving.
   d) Some possible answers include:
      - Because there was a greater education and a greater community understanding, there could also have been a greater number of people getting tested and diagnosed with the disease. Therefore, there were less unreported cases, and this could account for some of the increase in cases observed post 1995.
      - As less people were dying from 1995, more were living with HIV which could have resulted in more cases of accidental transmission through exposure to their blood and accidents with broken condoms.
10. Some possible answers include:
    - Governments could be influenced to learn from the way they managed the COVID-19 pandemic to improve health outcomes in the future. This could include investing in local manufacturing facilities to ensure vaccinations can be manufactured locally and not have to be imported. It could involve reviewing their quarantining policies etc.
    - There could be an increased number of community members who are now influenced to take extra measures to prepare for the next pandemic. This could include stocking up on essential supplies including toilet paper and cans of foods.
    - This could influence further research into the most likely pathogens to cause the next pandemic and into treatments to try and prevent it from occurring. This would require extra funding from government and private donors, but could also result in the creation of some new research positions.

Chapter 2.4 Suggested answers

Multiple choice questions

1. L 2.M 3.L 4. L 5. K 6. L 7. M 8. L 9. J 10. L

Free response questions

1. The Swiss Cheese Model for infectious disease prevention illustrates how multiple layers of defence, each with its own limitations or "holes," work together to reduce the risk of outbreaks. Layers include both individual and systemic layers that are all important because no individual layer is perfect.
2. Some possible answers include:
   - Insecticides – chemicals that kill mosquitoes can be used to reduce the number of carriers/vectors able to transmit malaria.
   - Insect repellent – chemicals that can be applied to the skin of individuals to prevent mosquitoes from biting and transmitting malaria.
   - Larvicides – chemicals that kill mosquito larvae can be used to reduce the number of carriers/vectors able to transmit malaria.
3. The Sterile Insect Technique involves producing and releasing sterilised male mosquitoes, which reduces the reproduction rates of mosquitoes as males still have their sexual drive and seek out female partners but cannot impregnate them. This results in infertile eggs being produced and a reduced population size over time.
4. Antiseptics are chemicals that can be applied to living tissues, such as skin, whereas disinfectants are harsher chemicals that are designed to treat non-living surfaces such as toilets and floors. Both kill a range of microbes including bacteria, viruses and fungi. An example of an antiseptic is hand sanitiser and an example of a disinfectant is a household cleaning product like bleach.
5. Quarantining involves **isolating** individuals who are infected, exposed, or potentially exposed to a contagious pathogen. However, contact tracing is the **identification** of individuals who have been in close contact with an infected person and taking steps to prevent further transmission. They are often used together to stop the spread of infectious disease.
6. Some reasons displaced populations such as refugees can be more vulnerable to infectious disease are the conditions that they are forced to live in including poor sanitation, overcrowding leading to easy spread of disease, poor early detection and treatment and lack of medical facilities.
7. a) Antibiotics are classified as chemicals produced by microorganisms, such as bacteria and fungi, that either kill bacteria (bactericidal) or slow the growth and division of bacteria (bacteriostatic).

   b) (i) Bacteria

   (ii) The investigation used 4 discs coated in antibiotics to test if they were effective. Antibiotics only work on bacteria and there is evidence of them working on the agar plate. Although all 4 antibiotics had varying effects on the growth of both microorganisms A and B, it is evident that the antibiotics inhibited growth due to the presence of zones of inhibition. Therefore, both microorganisms are types of bacteria.

   c) Microorganism B. This is because it is resistant to multiple antibiotics as is evident by the very small zones of inhibition surrounding discs 3 and 4. This shows that the antibiotics on discs 3 and 4 are ineffective to treat microorganism B infections. In contrast, Microorganism A is also showing resistance to one antibiotic on disc 1 but it is not multi-resistant so is it has more treatment options than microorganism B at this time.

   d) Two of the following answers:

Mechanism of action	Description
Inhibits synthesis of bacterial cell walls	Inhibit the strengthening of bacterial cell walls which results in their death through the cell bursting as it can no longer hold the contents of the cell.
Inhibits bacterial protein synthesis	Bacteria have smaller ribosomes to humans. These antibiotics inhibit the bacterial ribosomes from making proteins but do not interfere with human ribosomes.
Inhibits bacterial DNA synthesis	These antibiotics kill bacteria by inhibiting DNA synthesis resulting in DNA damage and bacterial death. They also inhibit the division of bacteria as DNA synthesis is required for binary fission.
Inhibits RNA synthesis	Bacteria require RNA molecules to produce proteins essential to their survival. This slows their growth, inhibits their ability to divide and results in their death.
Inhibits the synthesis of folate	Folate (vitamin B9) is essential for the synthesis of DNA and therefore cell division. These antibiotics do not kill bacteria but prevent them from dividing allowing the host's immune system to fight the infection more easily.

e) Disc 5 was soaked in water and acts as a control. As there is no antibiotic on this disc, it would be expected for no zone of inhibition to develop around this disc for both microorganism A and B. As can be seen in the results, there is no zone of inhibtion, which shows that bacteria can grow all the way up to and over the disc. This means that any zones of inhibition forming around discs 1 to 4 are not due to the water but due to the antibiotic.

f) (i) and (ii) See possible answers below:

(i) Factor controlled	(ii) Explanation
Temperature of incubator (37ºC)	Temperature can affect bacterial growth and division. Both microorganisms require the same temperature to achieve valid results and ensure one microorganism does not have the ability to show more growth than the other due to being exposed to a more optimum temperature than the other. Effect on growth should be from the antibiotic not lack of growth due to sub-optimal temperature.
Time incubated (36 hours)	The validity of the results would be reduced if one microorganism had more time to show growth compared to the other.
Concentration of antibiotics	The concentration of antibiotics can also affect growth of bacteria. Therefore, the concentration of the 4 antibiotics on the discs also needs to be held constant to ensure valid results can be achieved.
Number (five) and separation of antibiotics on agar plate	There were 5 same sized discs that were used in this experiment for both microorganism A and B. They were both evenly spaced out too as is evident in the results. This ensures that the bacteria on both plates have the same amount of space for growth and that zones of inhibition do not overlap.
Type of agar and concentration of nutrients supplied	Bacteria require nutrients such as glucose and water to grow. It is therefore important that they are supplied with the same concentration of nutrients. If one microorganism was supplied with more nutrients than the other, that microorganism is likely to show more growth than the other and reduce the validity of the results and conclusion(s).

g) Some possible answers include:

- This new knowledge could be applied to research the effect of other prescription medications to determine if any others are contributing to the development of antibiotic resistance. The new knowledge could also be applied to the wastewater treatment process, which may require additional steps to remove fluoxetine and other chemicals from the wastewater.
- This new research development could result in the modification of current prescription of antidepressant models/processes. This could involve stricter rules surrounding antidepressants containing fluoxetine including limiting the prescription periods to short term use or preferencing other antidepressants over those containing fluoxetine when appropriate.

8. a) The number of measles cases remained high during this period and fluctuated around the 400,000 per year mark.

b) The number of cases started to decrease towards zero, and from 1990 to 2010 there were significantly less reported cases, approximately in the hundreds to low thousands.

c) Vaccinations stimulate the immune system to recognise and fight specific infectious diseases without causing the illness. They do this by triggering the body to produce specific antibodies and memory cells. Vaccinations control the spread of infectious diseases by reducing the number of susceptible individuals in a population, thereby achieving herd immunity, which protects even those who cannot be vaccinated.

d) Some possible answers include:

- The spread of misinformation. The fraudulent study by Andrew Wakefield, published but now retracted, that falsely linked autism to the MMR. Even though this is not true and hundreds of follow up studies have confirmed no link between the two, the misinformation still persists within the community and has affected vaccination rates. With lower vaccination rates, herd immunity is reduced, allowing measles to spread through those not vaccinated and unable to be vaccinated.
- Measles is highly contagious and therefore requires a very large proportion of the community to be immunised against the virus to achieve an effective herd immunity. If not enough people are vaccinated/immune, the virus can take hold on communities, especially given the increased mobility of the human population nowadays.
- A lack of education of communities about the importance of vaccinations and how herd immunity is a collective effort to protect the vulnerable. As many pathogens have been eliminated or significantly reduced, through widespread vaccination and other medical advances, communities do not see the devastation that was once caused by pathogens prior to widespread vaccination, such as smallpox and the bubonic plague outbreaks/pandemics.

Chapter 2.5 Suggested answers

Multiple choice questions

1. K 2.J 3.M 4. M 5. J 6. K 7. K 8. L 9. M 10. L

Free response questions

1. The four key portals of entry points are:
   - respiratory surfaces (e.g. lungs)
   - wounds or breaks in the skin surface
   - gastrointestinal tract (e.g. mouth, lining of intestines)
   - urogenital tract (e.g. urethra)
2. a) Contagiousness refers to how easily a pathogen spreads, whereas pathogenicity and virulence refer to the disease-causing ability of a pathogen. Pathogenicity is a simple measure of whether a pathogen can penetrate a host and cause disease, whereas virulence is the degree to which the pathogen causes disease.
   b) High virulence means that the pathogen brings about a high level of disease. If the virulence is too high and kills its host too quickly, this can impair its ability to spread and multiply.
3. a) Through molecular recognition. Pathogens often express unique structures on their surface with specific shapes/patterns that are not found in hosts. They can be recognised by host immune cells through complementary binding with specialized receptors.
   b) The ability of hosts to recognise foreign pathogens is important for hosts to eliminate pathogens before they spread and cause disease. Alternatively, many pathogens like influenza require host cell recognition to enter the cell and replicate using its nutrients and machinery.
4. a) A high replication rate can produce so many viral particles that overwhelm and exhaust the host's immune system weakening the host organism's ability to combat the viral infection.
   b) Some viruses can integrate their genetic material into the host's DNA enabling it to avoid immune detection. This provides them with a stable and long-term reservoir for viral replication ensuring its persistence in the host.
   c) Latency is the ability to remain dormant in host cells allowing viruses like HSV in this case to evade immune detection and to reactivate later when the environment is more suitable to do so.
   d) If the cell bursts open (lyses), the host's immune system is triggered. Therefore, by not causing the cell to bust the HSV virus can exit the host cell undetected and avoid triggering the host's immune system.
5. Diarrhoea can be advantageous to the host organism because it can enable the host to expel some of the pathogen and assist the immune response. However, expelling the pathogen can help it spread and infect other hosts via contaminated water or food.
6. a) Some possible answers include:
      - Most spores are resistant to harsh conditions allowing the species to survive until conditions become more favourable when they germinate.
      - Spores are light, easily dispersed and some will end up in favourable environments allowing the spores to reactivate.

   b) Random mutations can occur to the genetic code (DNA) of the fungus that can result in the physical change in its structure, such as its antigens. The accumulation of these random mutations changed the TR3 strain enough to consider it a new strain, the TR4 strain.
   c) Some possible answers include:
      - Considering that its spores can remain dormant in the soil for up to 30 years and that fungicides do not work to kill them, the communication of this information to all banana farmers is very important. By communicating this information and keeping them informed, they can take preventative measures to protect their crops and their livelihood, such as monitoring outbreaks and avoiding sharing equipment with other farmers.
      - It is important for banana farmers to communicate this information with their employees and make sure they are informed about Panama disease and how it spreads. This information, especially ensuring their shoes are clean and free of soil, also needs to be communicated to any visitors to the farm such as delivery drivers.
7. a) Free-floating bacteria adhere to a surface such as teeth and divide increasing the population size. The attached bacteria secrete polysaccharides that form a protective sticky layer. Collectively, the attached bacteria in the slime-like matrix are called a biofilm.

b) Using dental floss is important because the plaque biofilm that forms between teeth is highly resistant to removal and cannot be easily dislodged by rinsing or brushing alone. The mechanical action of flossing physically disrupts and removes the tightly adhered bacterial biofilm, helping to maintain oral hygiene.

c) Most bacteria live in communities called biofilms, which allow thousands of bacteria to work together to survive, and often provides protection from antibiotics. Because the tests are not conducted on bacteria in their biofilm state, the results are limited to bacteria growing in their free-floating state and may not have the same effect against biofilm-forming bacteria.

d) Some possible answers include:

- This plaque detecting AI system could be applied to assist dentists to improve diagnostic efficiency and accuracy. It could also help them identify plaque build-up at an early stage, allowing dentists to intervene before oral health complications develop.
- This deep learning AI model could be applied to mobile apps to allow individuals to monitor plaque at home. This could make dental care more accessible and reduce the frequency of in-person visits to dentists for minor issues.
- The plaque detecting AI system could also be applied at universities. Dental students and professionals could use AI tools as training aids to learn and improve their diagnostic skills and plaque assessment accuracy.

e) Some possible answers include:

- The deep learning system could be limited by the dataset used to train it. It requires a large, diverse, and highly accurate dataset for training. The AI's performance may therefore be limited if its training data is biased or inaccurate.
- Dentists may become overly reliant on AI, potentially limiting their confidence to trust their own expertise. This could lead to possible misdiagnoses and unnecessary dental treatments for patients.

Chapter 2.6 Suggested answers

Multiple choice questions

1. L 2.M 3.K 4. L 5. K 6. J 7. L 8. M 9. M 10. L

Free response questions

1. a) The innate and adaptive immune systems.

   b) The innate immune system is non-specific whereas the adaptive immune system is highly specific. Humans are born with the innate immune system whereas the adaptive immune system 'adapts' over time and develops memory cells to each specific pathogen encountered.

2. The physical barriers are the body's primary protection and consist of structures that block or trap pathogens and other barriers that physically expel or flush away pathogens such as sneezing and tears. The chemical barriers are often secretions that help by neutralising or destroying pathogens before they can cause harm.

3. See table below:

First line defence mechanism	Type of barrier	First line defence mechanism	Type of barrier
Sebum secretion	Chemical	**Vaginal microbiota**	Biological
Mucous membranes	Physical	**Secretion of stomach acid**	Chemical
The shedding of dead skin cells	Physical	**Blinking**	Physical
Nasal hairs	Physical	**Urinating**	Physical

4. Some possible answers include:

- Consists of outer layer of dead cells that is very hard to penetrate.
- Contains sebaceous glands that secrete sebum.
- Skin generally lacks moisture which makes the skin quite waterproof and less hospitable to pathogens.
- Secretes sweat that can inhibit bacterial growth.
- Secretes antimicrobial chemicals such as dermcidin that inhibits some bacterial growth.

5. Cells lining the stomach secrete hydrochloric acid creating a highly acidic environment that can kill ingested pathogens by denaturing proteins and disrupting their cell membranes.

6. Sneezing is a forceful protective reflex that helps expel pathogens and irritants from the respiratory tract preventing pathogens from traveling further into the respiratory system and reducing the risk of infection.

7. a) Two of tears, saliva, mucus, sweat and breast milk.
   b) Lysozymes are antimicrobial enzymes that kill bacteria by digesting their cell walls
8. a) Mucus is a thick sticky secreted by mucous membranes that traps microbes preventing them from penetrating further into the body and attaching to epithelial cells.
   b) The epithelial cells of the mucous membranes in the respiratory tract contain cilia that move in a wave-like motion to transport mucus and any trapped particles and microbes to the throat to be expelled.
   c) Some possible answers include:
      - During the start of a common cold infection, the number of virus particles increase significantly. Mucus production can increase as a protective mechanism to help trap and remove the common cold virus particles from the respiratory tract and help prevent any additional pathogens from invading.
      - Increased mucus secretion can work in favour of the pathogen as it can increase the chance of its transmission to another host (e.g. runny nose). Therefore, some pathogens have adapted to cause the host to increase mucus production to aid the virus's transmission mechanism.
9. The skin is an effective first line of defence. Burns victims have suffered damage to this layer allowing pathogens to enter into underlying tissues and the bloodstream causing infection.
10. Some possible answers include:
    - Earwax is a normal, essential barrier containing antimicrobial chemicals necessary to prevent pathogen entry into the inner ear and should therefore remain intact.
    - People may cause damage or a wound to the ear, allowing pathogen entry if they use a cotton bud to clean their ears.
    - Cotton buds can irritate the skin lining the ear and push earwax further back into the ear canal. This can then turn into a vicious cycle whereby a cotton bud is used to manage the irritable ear, causing further damage.
11. The normal skin microbiome is a biological barrier of the first line of defence against pathogens. The skin microbiome is indigenous to the host's skin and can outcompete many invading pathogens for space and nutrients as they have adapted to living on human skin. This helps prevent the growth and colonisation of pathogens on the skin.

Chapter 2.7 Suggested answers

Multiple choice questions

1. M 2.L 3.L 4. K 5. L 6. J 7. L 8. M 9. K 10. M

Free response questions

1. a) **Non-specific:** the innate immune system recognises non-self antigens using special pattern recognition receptors that detect common patterns found on pathogens, which are not found on host cells. They cannot identify specific antigens/pathogens.
   b) **Broad:** The innate immune response is the same for all non-self-antigens identified and can therefore defend against a wide range of pathogens.
   c) **Rapid:** The innate immune response is immediate such as the inflammatory response which is an immediate reaction to infection or injury to help isolate the damage.
2. See table below:

Leukocyte	Role(s)
Neutrophils	Neutrophils are phagocytic cells that migrate to sites of infection/injury to engulf and destroy invading pathogens.
Mast cells	Mast cells help initiate inflammation by releasing histamines that dilate blood vessels and increase their permeability4
Macrophages	Macrophages are phagocytic cells that migrate to sites of infection/injury to engulf and destroy invading pathogens. Furthermore, they are antigen presenting cells that can activate the adaptive immune system.
Dendritic cells	Dendritic cells are phagocytic cells that migrate to sites of infection/injury to engulf and destroy invading pathogens. Furthermore, they are antigen presenting cells that can activate the adaptive immune system.
Natural killer cells	Natural killer cells destroy cancerous or virus-infected host cells, stopping the spread of infection. They do not directly attack invading pathogens.

3. a) Cytokines, or more specifically, chemokines.
   b) Neutrophils
   c) Phagocytic cells contain pattern recognition receptors that detect foreign non-self patterns on pathogens. Once identified through binding, the phagocyte surrounds the pathogen and engulfs it, forming an internal phagocytic vesicle (phagosome).
   d) The phagocytic vesicle (phagosome) fuses with a lysosome that contains digestive enzymes. The digestive enzymes destroy the pathogen. The digested materials can then be removed from the phagocyte through exocytosis.
4. a) Fever is an innate response that involves an increase the core body temperature to above 38°C.
   b) Fever enhances the immune response by creating an environment less favorable for pathogens and boosting the body's defense mechanisms. The elevated temperature inhibits the growth of many bacteria and viruses, often killing them, and accelerates immune cell activity.
5. a) Interferons (a cytokine)
   b) Some possible answers include:
      - Signalling uninfected cells to destroy RNA so viruses cannot replicate.
      - Signalling uninfected cells to reduce protein synthesis so viruses cannot replicate.
6. a) The roles of inflammation are to contain infection to the site of injury, eliminate pathogens, and start the healing process.
   b) Redness, pain, swelling and heat.
   c) When infection or damaged cells are detected, some host cells and immune cells release signalling molecules like cytokines and histamines. These signalling molecules attract immune cells to the site of injury/infection and dilate blood vessels, increasing their permeability for the immune cells to squeeze through. Phagocytic cells engulf and destroy pathogens and other foreign material. Many neutrophils die and contribute to pus. Immune cells release blood clotting factors that help seal the wound forming a scab.
7. a) The complement system is a group of over 30 different proteins that mainly reside in the blood plasma and circulate the body in an inactive form waiting to be activated by an infection or tissue damage.
   b) Upon activation, complement proteins bind to the surface of pathogens. This binding of the first complement protein to a pathogen brings about the binding of a specific sequence of complement proteins in what is termed a cascade effect (a chain of events). This results in an amplification loop and the pathogen being coated in complement proteins.
   c) The three main responses of the complement system are:
      - They bind to surface molecules on pathogens to attract phagocytes to the site of infections and enhance their identification for phagocytosis.
      - They bind to and puncture holes in the pathogen's cell membrane causing it to rupture.
      - They bind to mast cells and stimulate them to release histamine, which intensifies the inflammatory response by dilating blood vessels and helping recruit more leukocytes to the site of infection.
8. a) An exoskeleton made of chitin.
   b) Bark, waxy cuticles, cell walls, hairs, etc.
   c) (i) and (ii) Some possible answers include:
      - Caffeine, which is widely consumed by humans as a stimulant.
      - Cocoa, which is widely used in the food manufacturing industry to make chocolate and other chocolate-based products.
      - Nicotine, which is used in some insecticides and is a very addictive drug in tobacco and vapes.
      - Quinine, which is used as an antimalarial drug and in tonic water.
      - Pyrethrins, which are plant-based insecticides that are widely used to control pests.
   d) They both use pattern recognition molecules to detect non-self antigens in a non-specific fashion, just like vertebrates.
   e) (i) Antibiotics, such as penicillin.
      (ii) Antibiotics are antimicrobial chemicals that can inhibit or kill competing bacteria.
   f) Some possible answers include:
      - Produce and secrete antibiotics to defend against competing bacteria in their environment.
      - Bacteria can form biofilms that can protect them from antibiotics produced by competing microorganisms as these chemicals often cannot penetrate the biofilm
      - Bacteria can use restriction enzymes to recognise and cut viral DNA preventing the virus from using the bacterial cell to replicate.
      - Bacteria can use CRISPR to remember past viral infections and Cas proteins to cut viral DNA when encountered again to prevent the virus from replicating.

Chapter 2.8 Suggested answers

Multiple choice questions

1. L 2.K 3.M 4. L 5. J 6. M 7. M 8. K 9. L 10. M

Free response questions

1. The two main differences are that the adaptive response is specific in that the cells only target one type of antigen and are able to remember the antigens to which they have been exposed previously.
2. B lymphocytes target extracellular infections whereas T lymphocytes target infected host cells. Therefore both cell types are required for widespread protection.
3. a) The lymphatic system is a network of vessels, lymph nodes, and specialised organs that circulates lymph, a fluid containing lymphocytes.
   b) See table below:

Type of lymphocyte	Primary organ of lymphatic system where they develop	Primary organ of lymphatic system where they mature
B lymphocytes	Bone marrow	Bone marrow
T lymphocytes	Bone marrow	Thymus

4. a) The major histocompatibility complex (MHC) proteins are cell-surface markers that play a critical role in the immune system by distinguishing between self and non-self.
   b) MHC Class I molecules are found on the surface of nearly all cells with a nucleus, which present peptide fragments from intracellular proteins. Healthy cells display normal self peptides, while infected or abnormal cells present foreign or altered peptides (non-self), signalling the immune system to destroy them. MHC Class II molecules are expressed primarily on antigen-presenting cells and present peptides from extracellular pathogens that are recognised as non-self.
5. See table below:

First line of defence	Second line of defence	Third line of defence
earwax	macrophages	antibodies
skin	cytokines	B cells
lysozymes	neutrophils	MHC
	inflammation	T-cytotoxic cells

6. The correct order is: e, c, g, f, b, a, d, h.
7. a) B lymphocyte (or B cell)
   b) Some possible answers include:
      - By directly recognising specific antigens through their surface antibodies.
      - By antigens being presented to them by T-helper cells.
      - By signals from cytokines released by T-helper cells.
   c) At stage X, the B lymphocytes are dividing my mitosis and differentiating (changing into) B-plasma cells.
   d) (i) Antibodies
      (ii) Some possible answers include:
         - Neutralising pathogens and their toxins by blocking their ability to infect or damage cells.
         - Acting as anti-toxins by binding to harmful toxins and rendering them harmless.
         - Marking pathogens for easier identification and engulfment by phagocytes.
         - Immobilising bacteria by binding to their flagella.
         - Reducing the spread of pathogens by clumping them together (agglutination) making it easier for phagocytic cells to engulf them.
         - Activating the complement system, which results in pore formation in the pathogens cell wall/membrane and the pathogen bursting open.
   e) (i) B-memory cells.
      (ii) B-memory cells persist in the body and provide immunity by enabling a faster and stronger response upon subsequent exposure to the same antigen

8. a) Active immunity develops when an individual's adaptive immune system is responsible for the protection and B and T lymphocytes are activated, whereas passive immunity is when immunity is gained from someone else and the lymphocytes are not activated, such as a transfer of antibodies to an individual.
   b) Natural immunity occurs when immunity is acquired through natural exposure to a pathogen or transfer of antibodies, such as breastfeeding, while artificial immunity is gained through medical interventions, such as vaccinations.
9. The actions of the second and third lines of defence complement each other in managing infections. The innate response is quick acting but non-specific, whereas the adaptive response is specific and retains memory. Communication is also involved between the two lines of defence. When an injury or infection is detected by cells of the innate immune signals, such as cytokines, are immediately sent to the adaptive response for assistance. Additionally, phagocytic cells present antigen fragments to T-helper cells activating the adaptive immune response. The T-helper cells then activate the other T cells and B cells involved with mounting a specific response to the invading pathogen. The antibodies released by B-plasma cells help to slow down and mark pathogens for phagocytosis by cells of the innate system. Additionally, they act as a marker for complement proteins of the innate system to bind to complementing the role of antibodies of the adaptive immune system.
10. a) A vaccination is the deliberate injection of a dead or weakened version of a pathogen to develop immunity to a specific pathogen. It is a form of artificial active immunity.
    b) (i) Because this is a primary exposure and no antibodies have been developed yet. Additionally, the B cells have not been activated in the current adaptive immune response to the vaccination yet.
    (ii) Following the vaccination, the antigen is detected by phagocytic cells of the innate immune system, which engulf them and present antigen fragments to a specific T-helper cell, activating it. The T-helper cell multiplies into many copies. Some migrate to the site of vaccination where they change into T-cytotoxic cells if required. Others mobilise to locate the corresponding specific B cell so they can activate it.
    c) The B cells have been activated which multiply and differentiate into B-plasma cells, which migrate to the site of vaccination and start secreting specific antibodies. This accounts for the small increase in antibody concentration between days 5 and 14. Between days 14 and 20, a decrease in antibody concentration in the blood is observed. This is likely because the antibodies have helped the immune system overcome the antigen and less antibody is secreted as the immune response decreases.
    d) (i) A secondary exposure to the antigen, likely a natural exposure.
    (ii) There is a significant increase in antibody concentration between days 23 and 35. Then a small decrease is observed from days 35 to 40.
    (iii) Given the antibody increase was delayed and only showed a small increase in concentration in the blood following the vaccination at day 0, it is likely this was a primary exposure to the antigen. As memory cells, were developed from this primary exposure, there were more B memory cells when the individual encountered the pathogen for the second time at day 23. As more B memory cells were available to divide and change into B-plasma cells which secrete antibodies much faster and in greater quantity than the primary response.
11. a) This would be too slow. By the time the lymphocytes are stimulated and B and T cell action begins, the venom is likely to have spread and brought about its effects which can include death.
    b) Using artificial passive immunity. This involves injecting the anti-venom to the poison, which is a preparation of ready-made antibodies to combine with the antigen (venom) and de-activate it.

Topic 2 Review Test: Suggested answers

Multiple choice questions

1. M 2.J 3.K 4. M 5. L 6. L 7. K 8. L 9. L 10. M

Free response questions

11. a) Droplet infection is when a pathogen is transmitted from one person to another by droplets of moisture from the upper respiratory tract. The pathogens are present in large numbers, trapped inside the bubbles or droplets of moisture which are expelled by a cough or sneeze. Colds can be spread in this manner.
    b) Several possibilities including airborne (influenza), direct contact (sexually-transmitted HIV), dust-borne contact (hantavirus), indirect contact (athlete's foot), faeces/vehcle transmission (cholera), contaminated food (salmonella).
12. a) An epidemic is localised and is an active outbreak of an infectious disease that affects a large number of people in a specific region or country. A pandemic however is the spread of an infectious disease on more of a global scale.

b) The SARS-CoV-2 virus spread worldwide rapidly which provided lots of opportunities to replicate. With the increased replication there is an increased chance of random mutations occurring to the virus' genetic code. Random mutations can result in the physical change in its structure, such as its antigens. The accumulation of these random mutations changed the original SARS-CoV-2 enough to be considered a new strain. The continuation of this process over multiple years led to many different strains.

c) When the original SARS-CoV-2 strain infected people, their immune systems mounted an immune response which developed memory cells that remained circulating in their body awaiting future infections. However, the antigens of future strains had changed enough that the memory cells could not recognise it and combat it efficiently resulting in these individual's having to mount another immune response to these future strains and develop new memory cells….and the cycle continues.

13. a) Pili are hair-like structures that help bacteria adhere to host tissues, such as the urinary tract, preventing them from being flushed out when the host urinates.

b) Antibiotic resistant bacteria can reproduce by binary fission spreading the resistance to their offspring, also known as vertical gene transfer. Bacteria can also spread resistance to other bacteria through the process of conjugation (horizontal gene transfer) where a single strand of the genetic code containing the resistance gene(s) is donated to it.

c) This biofilm is a community of bacteria that stick to a surface and produce a protective slimy layer made of substances like polysaccharides and proteins. This slime-like matrix protects the bacteria within because the antibiotics often cannot penetrate it.

d) Because this type of antibiotic prevents the bacteria from replicating their genetic code (DNA) and therefore they cannot make more copies of itself and spread further throughout the host. This type of antibiotic does not kill the bacteria though and is therefore not considered bactericidal.

e) Some possible answers include:

Mechanism of action	Description
Inhibits synthesis of bacterial cell walls	Inhibit the strengthening of bacterial cell walls which results in their death through the cell bursting as it can no longer hold the contents of the cell.
Inhibits bacterial protein synthesis	Bacteria have smaller ribosomes to humans. These antibiotics inhibit the bacterial ribosomes from making proteins but do not interfere with human ribosomes.
Inhibits bacterial DNA synthesis	These antibiotics kill bacteria by inhibiting DNA synthesis resulting in DNA damage and bacterial death. They also inhibit the division of bacteria as DNA synthesis is required for binary fission.
Inhibits RNA synthesis	Bacteria require RNA molecules to produce proteins essential to their survival. This slows their growth, inhibits their ability to divide and results in their death.

f) Some possible answers include:

- The findings of this investigation focused on one species of bacteria: Group A Streptococcus. Therefore, this understanding can now be applied to other bacterial species to determine how many other species are exhibiting this adaptation. The results can then be shared with the medical community so that their procedures for prescribing antibiotics can be updated and individuals contracting these infections can be treated appropriately saving time, resources and lives.
- The findings of this investigation need to be applied to current processes in pathology labs. This study determined that the lab test was not sufficient to correctly determine the effectiveness of an antibiotic in a host. Testing guidelines need to factor this in going forward and ideally, these procedural updates should be formed collaboratively and applied universally.
- This study highlights the limitations of our ability to continue combatting the ever-adapting bacterial pathogens. It highlights the growing complexity of antibiotic resistance, and emphasizes the urgent need for new diagnostic tools, and further research into resistance mechanisms to combat the escalating threat of superbugs.

g) The diameter of the zone of inhibition (mm)

h) (i) Ciprofloxacin

(ii) This is because ciprofloxacin had the largest zone of inhibition of the eight tested, which means that this type of bacteria were very sensitive to this antibitiotic and could not grow close to the disc containing it – i.e. this bacteria demonstrated the least resistance to this antibiotic.

i) (i) Some possible answers include:

- Mis-calibrated incubator (set at 37°C but it was actually 36.5°C)
- Ruler/measuring tape used to measure the zones of inhibtion could have been mis-calibrated
- Mis-calibrated stopwatch/watch used for timing the 48 hours

(ii) If a systematic error occurred then the accuracy of the dataset would be decreased. In addition, the validity of the data would also have been reduced.

j) Antiseptics are chemical agents applied to living tissues, such as skin, to kill or inhibit the growth of microorganisms and prevent infection. Unlike antibiotics, which only target bacteria and are typically taken internally, antiseptics are used externally and have a broad spectrum of activity against bacteria, viruses, and fungi.

k) If this factor was not controlled and another species of bacteria was discovered on the plate, the validity of the results would be reduced. This is because it would not be fair to make a conclusion based on results where the zones of inhibition could have been influenced by the growth of another bacterial species (i.e. was the lack of a zone of inhibition due to the species being tested or the contaminated species?).

14. a) Mucous membranes secrete mucus which traps foreign particles and microorganisms in the inhaled air. The cilia move in a wave-like motion to transport the mucus and trapped particles to the throat where they can then be expelled from the body. Additionally, mucus contains antimicrobial proteins, such as lysozymes, and antibodies which neutralise or destroy pathogens.

b) A virus attaches itself to a host cell and injects its genetic code (RNA/DNA). The virus replicates itself inside the host cell using the host cell's machinery, making many copies of itself. The virus particles then exit the cell through a method such as budding, exocytosis or by bursting the cell (cell lysis).

c) A phagocytic cell (macrophage or dendritic cell).

d) At step 2, phagocytosis is occurring where the virus is engulfed by the phagocytic cell and enclosed in a phagocytic vesicle (phagosome). A lysosome containing digestive enzymes then fuses with the phagocytic vesicle, digesting the virus into fragments, which is shown in step 3.

e) T-helper cell. The phagocytic cell displays the antigen fragment using an MHC Class II protein to the unique T-helper cell with a specific complementary receptor, activating it.

f) Humoral immune response (adaptive immune response).

g) Antibodies + two of the following functions:

- Neutralising pathogens and their toxins by blocking their ability to infect or damage cells.
- Acting as anti-toxins by binding to harmful toxins and rendering them harmless.
- Marking pathogens for easier identification and engulfment by phagocytes.
- Immobilising bacteria by binding to their flagella.
- Reducing the spread of pathogens by clumping them together (agglutination) making it easier for phagocytic cells to engulf them.
- Activating the complement system, which results in pore formation in the pathogens cell

h) The antibodies released from the B-plasma cells can only target the viruses in the extracellular environment, they cannot target the cells that have already been infected. The cell-mediated response Is required for this. More specifically T-cytotoxic cells are required to target already infected cells and kill them before the new virus particles can spread to other cells. Both the humoral and cell-mediated immune responses are required for an effective immune response, covering both extracellular and intracellular environments.

i) Natural active immunity

Chapter 3.1 Suggested answers

Multiple choice questions

1. L 2.L 3.M 4. J 5. L 6. L 7. J 8. K 9. K 10. J

Free response questions

1. A DNA molecule is made up of DNA nucleotides and consists of two strands with complementary base pairs (A-T and C-G). The strands of DNA are twisted around each other to form a double helix. The DNA molecule consists of coding and non-coding regions.

2. a) A chromosome is a structure consisting of a DNA molecule wrapped tightly around histone proteins. A gene is a short coding section of the DNA molecule within a chromosome. It consists of a sequence of nucleotides that are arranged in a specific order.

b) A gene code for a polypeptide chain, protein or an RNA molecule.

c) When a DNA molecule is tightly coiled around the histone proteins (condensed) it is called a chromosome. However, when the DNA molecule is loosely packed around histone proteins (decondensed) it is not called a chromosome and is called chromatin.

3. a) A polypeptide is a sequence or chain of amino acids joined together by peptide bonds. A protein is a polypeptide chain or combination of multiple polypeptide chains bonded together that have folded in a precise way and therefore has a specific 3-D shape.

   b) **Process 1: Transcription**

   In this process a gene is used to make a molecule called mRNA, which is a 'working copy' of the gene that can exit the nucleus to a ribosome to be translated. An enzyme called RNA polymerase unwinds the DNA molecule and synthesizes the mRNA molecule.

   Process 2: Translation

   In this process mRNA is used to make a polypeptide. Ribosomes movie along the mRNA strand and assemble amino acids in a specific order with the help of transfer RNA (tRNA) molecules, forming a polypeptide chain.

4. a) See possible answers below:

   X: Base

   Y: Sugar

   Z: Phosphate

   W and X: Base-pair or C and G base pair.

   X, Y and Z: A nucleotide

   b) W and X (base pairs) are held together by weak hydrogen bonds. W and X are complementary forming three weak hydrogen bonds whereas the other two nitrogenous bases (A and T) form two weak hydrogen bonds.

5. A specialised cell is a cell that has differentiated and has specific structures required to perform a specific function, such as skeletal muscle cells. Unspecialised cells, also known as stem cells, are cells that have not yet differentiated and can divide an unlimited number of times. They have the potential to remain as stem cells or change into specialised cells through the process of differentiation.

6. Embryonic stem cells have the potential to differentiate into any of the approximate 230 human cell types, whereas adult stem cells cannot differentiate into all cell types and can only differentiate into a limited range of closely related cell types.

7. a) Mitosis

   b) The zygote divides by mitosis ensuring all cells are genetically identical in the organism. The genetically identical cells are represented by the 'same script' used by all the actors in the movie. The embryonic stem cells can differentiate to become specialised cells. These specialised cells only 'read' the sections of DNA that are relevant to its own function. Similarly, an actor only reads his/her lines in the movie script. This means that each cell has unique genetic expression and even though they are all genetically identical they can still play different roles within a multicellular organism.

8. Activators and repressors are transcription factors that both play roles in the regulation of transcription and therefore the expression of genes. Activators 'switch on' genes by making them more accessible to RNA polymerase, the enzyme that is involved in transcription. Repressors 'switch off' genes by blocking RNA polymerase from transcribing the gene.

9. a) Epigenetics is the study of how the environment influences gene expression.

   b) Structure A is closed chromatin and structure B is open chromatin. These structures are influenced by histone modification. Deacetylation of histone proteins causes the chromatin to condense resulting in the more tightly packed histone proteins seen at 'A'. As a result, the gene becomes inaccessible and RNA polymerase is unable to bind to the DNA and transcribe the gene. Alternatively, increased acetylation of histone proteins causes the chromatin to decondense resulting in the loose packing of the histone proteins seen at 'B'. This allows RNA polymerase to access the gene and express it.

   c) Increased methylation of cytosine bases inhibits RNA polymerase from binding to the promoter region, and hence transcription of the gene(s). In this case, RNA polymerase is inhibited from binding to and transcribing genes that code for suppressing the growth of tumours. This increases the chance of tumours, and possible cancer, developing in the organism.

10. Even though twins are genetically identical they are epigenetically different due to the different environmental factors they experience throughout their life. Different environmental impacts such as diet, lifestyle, trauma, friends, etc. between identical twins can result in the expression of different genes in the two individuals. The different genes that are switched on/off effect the organism's phenotype (its structure and physiology). These differences become more apparent in older organisms because the switching on/off of genes has been occurring for longer resulting in more changes to the phenotype.

Chapter 3.2 Suggested answers

Multiple choice questions

1. M 2.M 3.J 4. M 5. K 6. J 7. L 8. M 9. K 10. L

Free response questions

1. Cells make up tissues. Tissues make up organs. Organs make up organ systems, which in turn make up organisms.
2. 3: Organelle
   4: Cell
   5: Tissue
   6: Organ
   7: Organ system
3. a) Because it is a collection of similar specialised cells that are grouped together to perform a specific function.
   b) Because blood is a tissue that connects all organ systems in the body and supplies them with the nutrients they require for survival. Note: they also derive from the type of stem cell that other connective tissues derive from.
4. Some possible answers include:
   a) Any two of the four main types: epithelial, smooth muscle, nerve, and connective.
   b) Digestive system.
   c) Some possible answers include:
      - Kill bacteria on food and prevent food poisoning.
      - Secrete pepsin (protease) to chemically digest protein.
      - Mechanically digest food and mix partially digested food with gastric juices.
      - Secrete hydrochloric acid to denature protein (unravel them) making it easier for pepsin to chemically digest protein.
5. Some possible answers include: poor intake of calcium-rich foods, lack of exposure to sunlight, sedentary lifestyle (lack of weight bearing exercise).
6. Organs generally consist of all 4 types of tissue (2 or more) because each tissue type performs a specific function within the organ. An organ with one tissue in isolation is unlikely to survive because organs are dependent on other organs and their systems to survive. For example, how could an organ receive and transmit messages without any nervous tissue. Additionally, how could an organ survive if there was no connective blood tissue to deliver oxygen, glucose and other nutrients to it?
7. The respiratory system supplies oxygen, and the digestive system supplies nutrients (e.g. glucose) that all organ systems require. The system required to deliver these nutrients to other organ systems is the circulatory system. The circulatory system also collects and delivers waste products to the respiratory system (CO_2) and urea to the excretory organ system. None of these organ systems can work and survive in isolation, they all rely on each other.
8. a) From 1990 to 2000 the mean body mass of the population increased from 72.6 kg to 77.2kg. At the same time the percentage of the population with type 2 diabetes increased from 4.9% to 7.3%.
   b) Some possible answers include:
      - The data is only up to the year 2000 but it is currently 2024. The data is outdated and does not necessarily reflect the current situation.
      - The investigation is using the mean body mass of the population, and this does not factor in the cause of weight gain for all individuals within the population. Is the mass gain from increased muscle or increased fat tissue?
   c) Some possible answers include:
      - A diet high in sugar can overwork the insulin producing pancreas. Over a long period of time this can cause the death of the insulin producing cells in the pancreas as they 'tire'. This results in a reduced ability to produce insulin in response to glucose in the blood.
      - A diet high in 'bad' saturated/trans fats can result in increased weight gain in the abdomen area (where pancreas is located) and contribute to increased inflammation, which can result in the death of insulin producing pancreas cells. This reduces the ability to produce insulin in response to glucose in the blood.
      - A diet high in 'bad' saturated/trans fats can result in increased 'bad' cholesterol levels, which can build-up in the insulin receptors of body cells, reducing the ability of insulin to bind to it and the body cells' ability to respond to insulin and take up glucose (i.e. increased insulin resistance).

d) Exercise is energy intensive. It lowers blood glucose levels and burns fat resulting in weight loss and a reduced risk of developing type 2 diabetes. It also increases insulin sensitivity.

9. a) Some possible answers include:
   - The discovery of one lifestyle-related disorder being linked to or caused by microplastics fuels concern and some anxiousness surrounding the use of plastics in society. This concern and push from groups of society for more answers can influence further research into the effects of microplastics on organ systems and other disorders/diseases they could be contributing to.
   - Lifestyle-related disorders are also referred to as preventable diseases and the percentage of the population developing many of these disorders is increasing. The increased number of cases can influence greater research into the disorder(s) to look for causes of the increase. As microplastics are being found in many organs, this knowledge and need for answers of increased cases can influence researchers to investigate this microplastics avenue further.

   b) Some possible answers include:
   - This new discovery could influence governments to increase funding into further research into the impacts of microplastic on the male reproductive system and how medical practitioners assess male fertility. This could also influence the creation of more research positions being created in this field.
   - This discovery could influence the development of new diagnostic procedures that assess the extent to which a male's reproductive system is damaged by microplastics and in turn new treatment options to minimise further damage. As a result, male fertility and treatment options could be more efficient positively impacting the reproductive health industry.
   - The understanding that microplastics are negatively impacting male reproductive health on a global scale could influence governing bodies to introduce legislation to phase out the use of some types of plastics that are commonly found building up in the organs of the male reproductive system. This could also influence further research into other plastic packaging alternatives.

Chapter 3.3 Suggested answers

Multiple choice questions

1. K 2.J 3.M 4. L 5. J 6. J 7. L 8. K 9. L 10. J

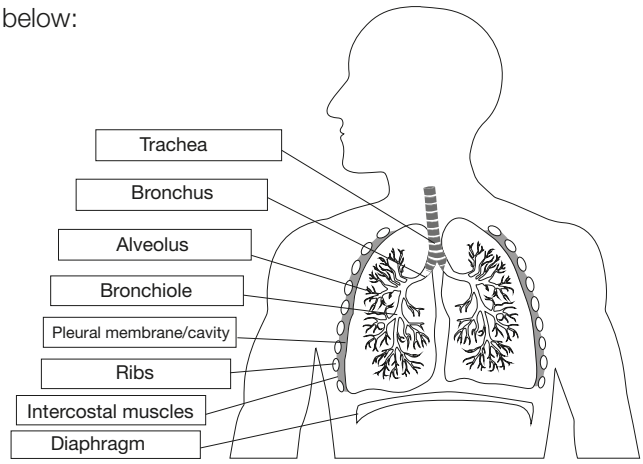
Free response questions

1. Smaller cells have a much greater surface area compared to their volume (SA:V) than larger cells. Therefore, smaller cells are more efficient at exchanging materials with their environment than larger cells.
2. Examples are shown below:

Organ	Materials exchanged	How surface area is maximised
Lungs	Oxygen and carbon dioxide	Large numbers of alveoli
Intestine	Products of digestion such as glucose, amino acids, fatty acids and glycerol	Large numbers of villi
Kidney	Urea, water, salts	Large numbers of nephrons

3. Regarding characteristics of exchange surfaces:
   a) Thin surfaces reduce the distances materials must move across.
   b) Moist surfaces allow substances to dissolve in the water, assisting the transport of materials across the surface.
   c) Large surface area provides more surface for exchange of substances to occur.

4. Refer to answers in the image below:



5. Refer to table below:

Feature	Inhalation	Exhalation
Diaphragm muscle	Contracts	Relaxes
Diaphragm shape	Flattens	Dome shaped
Intercostal muscles	Contracts	Relaxes
Ribs	Moves up and out	Moves down and in
Lungs	Inflates	Deflates
Volume of chest cavity	Increases	Decreases
Air pressure in lungs	Decreases	Increases

6. a) The tidal volume is how much air a person breathes in and out, whereas the residual volume is how much air remains in the lungs regardless of how hard a person exhales.
   b) The more air an athlete can breathe in and out, or the larger their vital capacity and the more oxygen and carbon dioxide can enter and leave the blood during gas exchange respectively. Training designed to increase vital capacity of athletes will help to boost performance and recovery.
7. The trunk of the tree can be likened to the trachea which then branches off into two main branches called the bronchi. The bronchi then branch off into many smaller branches called bronchioles. At the end of the bronchioles are bundles of alveoli where gas exchange takes place, just like there are many leaves at the end of smaller branches on trees. The respiratory tract extends from the top of the body down into the chest cavity and is not upright like a tree though.
8. a) Narrowing of bronchioles would cause difficulty breathing, shortness of breath and wheezing.
   b) The usual treatment is to inhale a medication that dilates or widens the diameter of the bronchioles.
9. An example is shown below:
   a) % Oxygen not exhaled = (20-16) / 20 × 100% = 0.2 × 100% = 20%. Therefore only ⅕ of the air inhaled diffuses into the blood.
   b) There is much less carbon dioxide in the alveoli when air is inhaled than in the blood, so the concentration of carbon dioxide in the alveoli is much lower than it is the blood. As a result, carbon dioxide diffuses rapidly out of the blood down the concentration gradient and into the alveoli. Additionally, the air in the alveoli is higher in oxygen concentration than the blood, so oxygen diffuses along its gradient into the blood. As there is less oxygen and more carbon dioxide in the alveolar air following gas exchange, carbon dioxide takes up a greater percentage of the alveolar air.
10. a) Refer to table below:

Structure	Order
Bronchus	3
Alveolus	1
Nasal cavity	5
Bronchiole	2
Nose	6
Trachea	4

b) The air is filtered, warmed and moistened by the structures of the respiratory tract.

c) The goblet cells release mucous that traps foreign matter. The epithelial lining of the trachea contains cilia that move in a wave like motion back towards the pharynx where it can be swallowed and exposed to highly acidic conditions of the stomach or discharged from the body through spitting.

d) Spirometer

e) 3.55 – 2.4 = 1.15 L (at approximately 40 seconds)

f) 13 breaths per minute

g) 4.7 – 0.2 = 4.5 L (Note that the question asks for vital capacity and not total lung capacity)

Chapter 3.4 Suggested answers

Multiple choice questions

1. M 2.J 3.M 4. J 5. J 6. L 7. K 8. L 9. K 10. M

Free response questions

1. Plasma mostly consists of water but it also consists of plasma proteins and other solutes such as salts, sugars and amino acids.
2. **Red blood cells:** To transport oxygen to all body cells from the lungs.
   White blood cells: To defend the body from pathogenic infections.
   Platelets: To assist the body in blood clotting and prevent bleeding out.
3. Some possible answers include:
   - Red blood cells are small (7.5mm in diameter) and biconcave in shape which increases their surface area to volume ratio significantly and increases their efficiency at exchanging oxygen with the lungs and body's cells.
   - They contain haemoglobin which is a protein containing iron (haem) that oxygen binds to reversibly so it can still be exchanged.
   - They do not contain a nucleus which allows them to contain more haemoglobin and carry more oxygen per unit cell.
4. A white blood cell count that is 6000 per mL above the normal range indicates that this individual is likely fighting off an infection. The white blood cells have been dividing and increasing in number to launch a quick and effective response to reduce the chance of the infection overcoming the organism's body.
5. Refer to the table below:

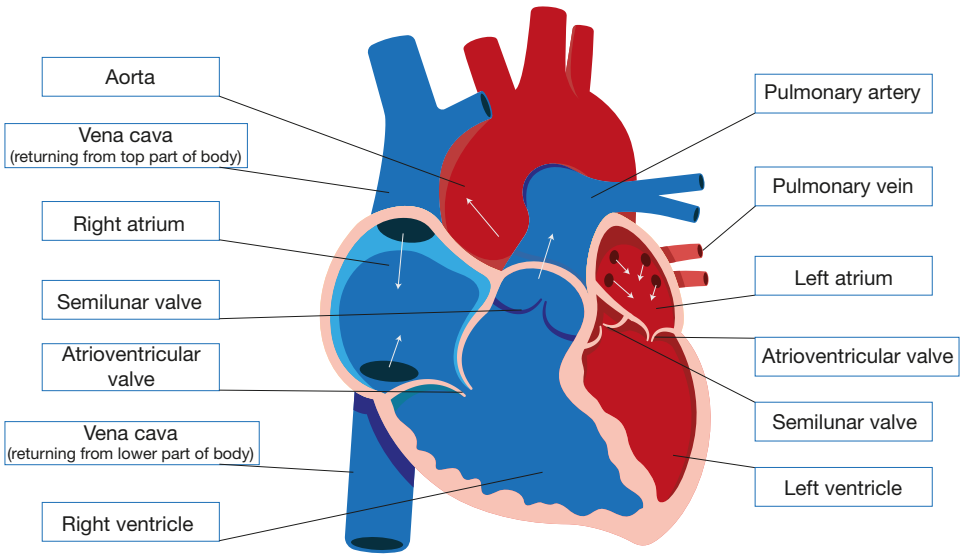
	Blood vessel		
Feature	**Artery**	**Capillary**	**Vein**
Oxygen concentration	High	Starts high as it enters capillary bed but due diffusion into body cells it becomes low at venule end.	Low
Carbon dioxide concentration	Low	Starts low as it enters capillary bed but due to diffusion from body cells it becomes high at venule end.	High
Direction of blood flow	Away from the heart	From arteries to veins	Towards the heart
Amount of muscle and elastic tissue	Thick layer	Generally, none	Thin layer
Blood pressure	High	Medium to low	Very low
Size of lumen	Thin	Very thin	Wide
Presence of valves	None	None	Present

6. a) A double circulation means that blood travels through the heart twice to complete one full circulation of the body.

   b) The double circulation consists of the pulmonary circulation and systemic circulation. The pulmonary circulation starts from the right side of the heart where deoxygenated blood travels to the lungs to be oxygenated and back to the left side of the heart. The systemic circulation then starts from the left side of the heart where it pups the oxygenated blood to all the body's cells at high pressure and concludes when the deoxygenated blood returns to the right side of the heart. This is one full circulation of the body.

   c) Blood loses pressure at it passes thought the lungs' capillaries and if blood travelled directly from the lungs to the body's cells, it would be doing so at a low blood pressure and it would not be able to deliver oxygen and other nutrients fast and frequently. By travelling back to the left side of the heart, the oxygenated blood can be pumped at high pressure so that all body cells receive their blood supply quickly and frequently.

7. Refer to labelled diagram below:



8. a) Plasma

   b) Tissue fluid/interstitial fluid

   c) Fluid F (plasma) has a much higher concentration of plasma proteins than Fluid G (tissue fluid).

   d) Glucose diffuses from high concentration in the plasma to the tissue fluid (Fluid G) which has a lower concentration as the blood flows through the capillary.

   e) The blood has a high concentration of oxygen and low concentration at A (compared to tissue fluid/body cells). Therefore, oxygen moves into the tissue fluid/body cells and carbon dioxide moves into the blood. As blood moved from point A towards the venule end the oxygen concentration becomes progressively lower and the carbon dioxide becomes progressively higher.

9. a) The lymphatic system consists of lymph capillaries that drain into lymphatic vessels. These vessels contain a fluid called lymph which flows through lymph nodes and back into veins through thoracic ducts. The lymphatic system also includes other organs such as the thymus and spleen.

   b) Plasma is forced out of capillaries at the arteriole end of capillary beds into the tissue fluid. Most of the water (90%) moves back into the capillaries as it approaches the venule end of the bed but about 10% is not reabsorbed here and remains in the tissue fluid. The lymphatic system collects this excess fluid from the tissue fluid and returns it to the circulatory system through thoracic ducts that pool into veins.

   c) Absorbing the excess tissue fluid is vital for preventing fluid accumulation in tissues, which can lead to swelling or oedema.

10. Regarding the blood pressure graph:

- Location 1 is likely to be in an artery. This is because arteries transport blood at high pressure.
- Location 2 is likely to be at the venule end of a capillary network because the blood pressure has decreased (due to plasma being forced out of the blood at the arteriole end).
- Location 3 is likely to be in a vein as the blood pressure is very low.

Chapter 3.5 Suggested answers

Multiple choice questions

1. M 2.L 3.K 4. J 5. M 6. L 7. K 8. M 9. M 10. J

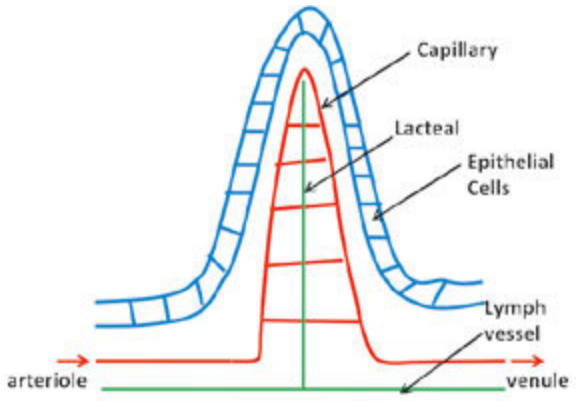
Free response questions

1. Refer to answers in the table below:

Organ	Organ name	Functions
A	Mouth	Food enters the digestive system through the mouth and chewing physically digests the food.
B	Oesophagus	Transports the food bolus from the mouth to the stomach by peristalsis.
C	Liver	Produces and secretes bile directly into the small intestine but also to the gall bladder.
D	Gall bladder	Stores bile and releases it into the small intestine.
E	Small intestine	Finishes the chemical digestion of all macronutrients and absorbs the digested nutrients through the villi.
F	Anus	Sphincter that faeces is eliminated through.
G	Rectum	Stores faeces in preparation for elimination.
H	Large intestine	Absorbs water and salts from remaining indigested material.
I	Pancreas	Produces and secretes pancreatic enzymes into the small intestine.
J	Stomach	Churns the food and starts the chemical digestion of protein by pepsin. Stores food and slowly releases into the small intestine.
K	Pharynx	Aids in the process of swallowing. Food passes through and into the oesophagus.
L	Salivary glands	Releases saliva into the mouth to lubricate food for swallowing and starts the chemical digestion of carbohydrates through action of salivary amylase.

2. Some possible answers include:
   - It has walls that are folded and elastic to maximise the storage of food.
   - It has smooth muscle that permits it to perform peristalsis and churn the partially digested food with gastric juices.
   - It contains glandular tissue, permitting it to secrete gastric juices into the stomach.

3. a)



   b) Some possible answers include:
   - The epithelium is very thin to reduce the distance substances to be absorbed need to travel.
   - The capillaries are located very close to the epithelium to facilitate the absorption of glucose and amino acids and their transport out of the villus.
   - The lacteal extends into the villus to maximise the transport of absorbed fatty acids and glycerol out of the villus.
   - The villi have a rich blood supply (especially in the jejunum (second section), which is the main section that absorbs nutrients.

4. Some possible answers include:
   - To moisten and lubricate food.
   - To bring food into contact with the enzyme salivary amylase, starting the chemical digestion of starch.
   - Enable us to taste the foods we eat.
5. Mechanical digestion involves physically breaking food into smaller pieces, increasing the surface area of the food, such as teeth physically chewing food or the stomach physically churning food and gastric juices. Chemical digestion involves enzymes that chemically break down large nutrients into smaller nutrients by facilitating the breaking of chemical bonds between subunits, such as salivary amylase that breaks starch into smaller polysaccharides and maltose sugars.
6. Some possible answers include:
   - There appears to be an alimentary canal – opening just before the oesophagus and just after the rectum. An alimentary canal of some kind is found in many animals.
   - The presence of an oesophagus and a rectum is consistent with a digestive system typical of many animals.
   - There are different compartments throughout this digestive system that are reminiscent of the animal organs and their compartmentalised functions.
   - This digestive system is long to maximise the efficiency of digestion just like other animal digestive systems.
7. Some possible answers include:
   - The duodenum permits chemical digestion of carbohydrates, proteins and lipids.
   - The duodenum contain villi that can start to absorb small quantities of selective nutrients.
   - The colon permits minerals and water to be absorbed into the bloodstream.
8. a) As the villi become flattened/destroyed, the amount of surface area the villi provide for absorption is greatly decreased.
   b) If villi are destroyed, this means there is less surface area for nutrients to be absorbed across and the individual could develop a nutrient deficiency related-disorder.
   c) Fatigue and weight loss could develop due to less absorption of the energy-providing nutrients, such as glucose across the reduced surface area of the flattened (damaged) villi.
9. The digestive system and circulatory system are co-dependent. The circulatory system provides the oxygen and glucose to all the cells of the digestive system required for aerobic respiration (energy production). The digestive system is responsible for processing carbohydrates into the simple sugars like glucose and absorbing them into the blood supply at villi. The transport of these digested nutrients relies on the circulatory system to do so. Additionally, the circulatory system carries waste products away from the cells of the small intestine.
10. a) The meal consumed contained high levels of starch and very little glucose, hence the relative amounts found in the mouth. Starch is chemically digested by enzymes to sugars like glucose. This is completed in the first section of the small intestine (duodenum), so no starch should be present in the jejunum or colon. The levels of glucose in the jejunum should be high because as soon as it is produced in the duodenum glucose is moved to the jejunum by peristalsis. All the glucose is absorbed through the villi in the ileum, so none is present in the colon.
    b) Both glucose and amino acids are the products of chemical digestion that is completed in the duodenum. As soon as they are produced, they are transported to the jejunum where they accumulate for a short period of time before being absorbed through the villi into the blood.
    c) Although fibre is a carbohydrate, the human digestive system cannot chemically digest it. Humans do cannot synthesise the enzymes required to digest and extract energy from it. Some bacteria can digest some types of fibre, but not all. Therefore, the amount of fibre in the colon is high.
11. a) From the age of about 15, stomach acid secretions gradually decrease from about 180 mg/hr to 45 mg/hr at the age of 65.
    b) Decreased secretion of stomach acid could result in a decreased ability to chemically digest protein in the diet. This is because pepsin is activated by a low pH set by the secretion of stomach acid (i.e. pepsinogen into pepsin). Reduced acid secretion could therefore mean reduced pepsin activation.
    c) Some possible answers include:
       - Storing chyme in the stomach and gradually releasing it allows more time for the gastric juices to mix with the partially digested food and for pepsin to digest protein into shorter peptides more efficiently.
       - Releasing small amounts of chyme into the small intestine, increases the efficiency of chemical digestion. Pancreatic juice and bile are secreted into the small intestine (duodenum) to help with the digestion of macromolecules. Releasing small amounts of chyme bit by bit, reduces the amount of nutrients in the small intestine at a given time to be digested. This increases the surface area of chyme that can be digested and allows for a greater ratio of enzymes to substrates.

Chapter 3.6 Suggested answers

Multiple choice questions

1. M 2.L 3.M 4. L 5. L 6. L 7. J 8. M 9. M 10. J

Free response questions

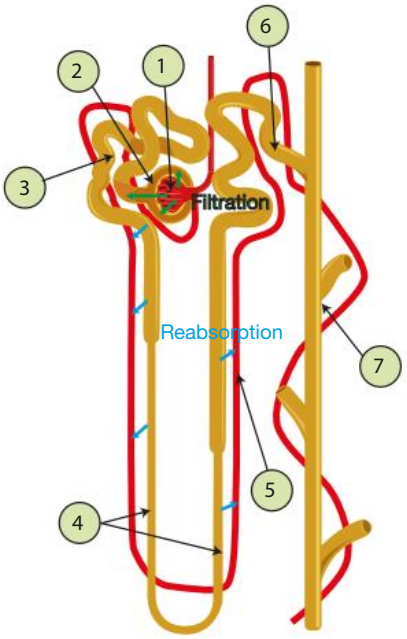
1. Excretion is the removal of toxic metabolic waste products and substances in excess from an organism.
2. See table below:

Organ	Name of organ	Function of organ
A	Kidney	To filter blood to remove metabolic waste products and to maintain water/solute balance in the blood.
B	Ureter	Transports urine from the kidneys to the bladder.
C	Bladder	Stores urine.
D	Urethra	Transports urine out of the bladder during urination.

3. a) See table below:

Structure	Name of structure
1	Glomerulus
2	Bowman's capsule
3	Proximal tubule
4	Loop of Henle
5	Capillary (blood vessel)
6	Distal tubule
7	Collecting duct

b)



c) See table below:

Structure	Function of organ
1	To filter the blood, which allows small molecules to pass through the capillary walls and into the tubule.
2	To collect the filtered substances (or glomerular filtrate) and allow it to pass into the proximal tubule.
3	To permit selective reabsorption of substances in the glomerular filtrate i.e. some are returned to the blood.

d) 7, which is the collecting duct. An increased ADH in the blood results in an increased permeability of the cell membranes of the collecting ducts to water. This increases the reabsorption of water back into the capillaries from the filtrate. As a result, a lower volume of urine is produced that will be more concentrated.

4. a) Blood is transported into the glomerulus of nephrons under high pressure, which causes water and other small substances to pass through the capillary walls and enter the Bowman's capsule; for example, glucose, amino acids, salts and the nitrogen-containing waste products.

   b) The filtrate in the Bowman's capsule flows into the tubule, where useful substances are reabsorbed back into the blood. Reabsorption occurs across the length of the tubule and some substances are also reabsorbed across the collecting duct, such as water.

5. The purpose of the blood being filtered at the kidneys is to remove waste products and excess metabolic products. If the process of reabsorbing the substances was not selective, it is likely that this purpose would not be achieved. The waste products could build up to toxic levels and the useful products could be excreted in the urine. Water loss in urine could also be significant. This would reduce the available useful products to an animal and reduce the efficiency of chemical reactions required to keep the animal alive.

6. a) The solute concentration in blood plasma is greater than it is in the glomerular filtrate since not all solutes are filtered.

   b) The solute concentration of urine is greater than it is in the filtrate since water is reabsorbed.

7. Some possible answers include:
   - Contains many mitochondria to supply energy for proximal tubule to reabsorb useful substances against the concentration gradient.
   - Has villi (and likely micro-villi – not shown in diagram) to increase the surface area of the cell(s) in the proximal tubule for increased efficiency in selective reabsorption.
   - The cell has a cytoplasm and the moisture in the cell/cytoplasm increases the permeability of substances across cells.
   - The cell contains many ribosomes to make proteins required for the cell to reabsorb the useful substances (e.g. transporter proteins in the cell membrane).

8. a) More blood would be filtered per unit time. This is because the pressure of blood flowing into the glomerulus would be even higher than is usually the case.

   b) Initially a greater volume of urine would be produced. This is because more water will be filtered by the glomerulus–most will pass along nephrons before it can be re-absorbed.

9. The cortex section of the kidneys contains the glomerulus and Bowman's capsule of the nephrons, the site of filtration. If physical damage occurred to the cortex, it is possible that the filtration process could be disrupted. Under normal circumstances, only small substances are forced out of the glomerulus and into the Bowman's capsule under high pressure. Damage to the glomerulus and Bowman's capsule could allow larger molecules like proteins and red blood cells into the tubule and then into the urine.

10. Some possible answers include:
    - It is more convenient as there is no need to travel to medical centres for dialysis multiple times per week.
    - It is more convenient as there is no need to follow a restricted diet required whilst having dialysis.
    - Having the kidney transplant is generally more cost effective for individuals in the long run.
    - Kidney transplant improves quality of life as it is a cure.

11. a) Some possible answers include:
    - Energy conservation. Glucose is an important molecule for energy in animals and excreting it in the urine would be wasteful.
    - Efficient kidney function. Under normal circumstances, 100% of glucose is reabsorbed. The presence of glucose in the urine could indicate a reduced efficiency of kidney function and possible kidney damage/disease.
    - Preventing dehydration. Glucose attracts water molecules and is therefore removed from the body in the presence of water. Excreting glucose in the urine could also lead to dehydration which would reduce the efficiency of cellular activity in the organism.
    - Blood glucose levels are regulated by the pancreas. If blood glucose levels remain under control through the action of the pancreas and the hormones it produces, then there is no excess glucose in the blood to be excreted in the urine.

    b) They could have diabetes. If the cells of an organism cannot produce enough insulin or cannot respond to insulin, the body must excrete the excess glucose in the urine to maintain water/solute balance in the blood. If it is not excreted, the presence of excess glucose in the blood would increase blood volume (by attracting water into blood) and in turn the blood pressure.

12. a) Protein is made up of amino acids. Animals cannot store amino acids and therefore any excess consumed is broken down and nitrogenous waste products such as urea are produced. An individual who consumes a high protein diet would have an excess supply of amino acids and therefore their body would produce a greater mass of urea than someone consuming a 'normal' amount of protein.

    b) A high protein diet results in a large amount of urea produced in the body, which must be excreted in the urine. Urea attracts water molecules and is therefore removed from the body in the presence of water. The more urea produced the greater the potential for water loss from the body in the urine, and dehydration if the required amount of water for the high protein diet is not consumed.

13. Some possible answers include:
    - The significant amount of humans with kidney disease and the ever-growing kidney transplant list has influenced researchers to seek solutions, such as the development of lab-grown kidneys.
    - This new development could influence research into kidney disease. As this is the first time mini kidneys have been developed with blood vessels, it is unlikely that kidney diseases involving the blood vessels could have been studied using mini kidneys. These lab-grown kidneys may therefore influence researchers to utilise them in their future studies on respective kidney diseases.

Chapter 3.7 Suggested answers

Multiple choice questions

1. K 2.L 3.M 4. J 5. L 6. L 7. M 8. L 9. M 10. K

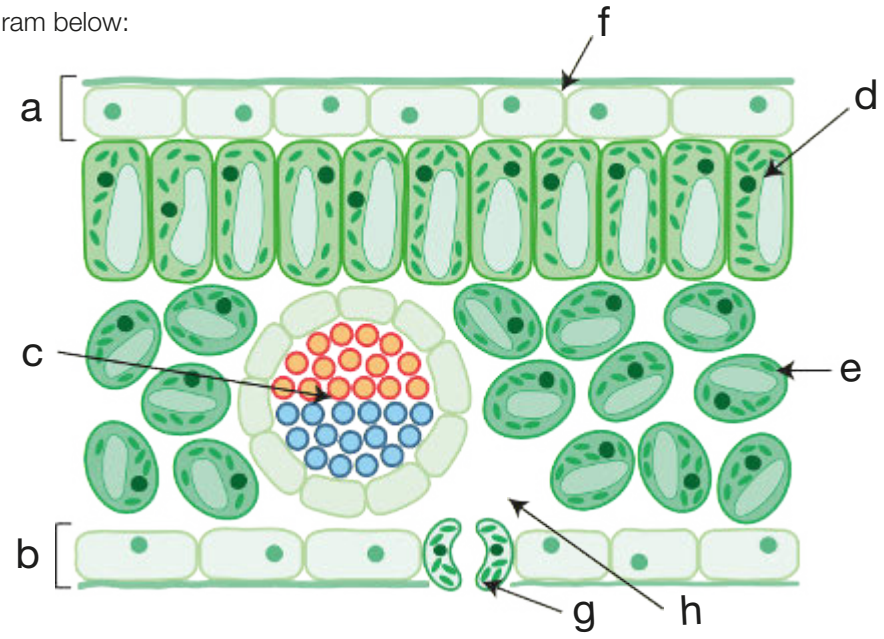
Free response questions

1. See the table below:

Tissue	Function(s)
Dermal	Covers and protects the plant.
Vascular	Transports nutrients such as water, glucose and salts throughout the plant.
Ground	Provides a site for photosynthesis to occur, supports vascular tissue, and helps with water and nutrient storage.

2. a) Leaf
   b) Fruit/chilli
   c) Stem
   d) Secondary root or lateral root
   e) Primary root
   f) Shoot system
   g) Root system

3. See the diagram below:



4. a) Palisade mesophyll cells, spongy mesophyll cells and guard cells.

b) Water and carbon dioxide are the reactants required for photosynthesis. Carbon dioxide is obtained by plants through gas exchange at stomata or through aerobic respiration, whereas water is obtained by the roots from the soil and delivered to leaf cells by vascular tissue, more specifically the xylem.

5. Some possible answers include:
   - Palisade cells are packed vertically directly under the upper epidermis to fit more in and maximise light absorption.
   - Palisade cells contain a large number of chloroplasts for photosynthesis (are abundant in chlorophyll).
   - They have a large central vacuole which keeps chloroplasts closer to the surface to maximise light absorption.
   - Carbon dioxide is produced by aerobic respiration, so it diffuses out of leaves.
6. a) Photosynthesis and gas exchange.
   b) During the day, photosynthesis is occurring at a faster rate than aerobic respiration. This results in plants taking up carbon dioxide and producing more oxygen by photosynthesis than is needed for aerobic respiration. As a result, the excess oxygen diffuses out of leaves. At night, plants cannot photosynthesise because there is no sunlight, but they still require energy from aerobic respiration. This results in the plant requiring additional oxygen from the atmosphere for aerobic respiration. Also, carbon dioxide is produced as a by-product of aerobic respiration and is excreted because it cannot be used for photosynthesis at this time.
7. Temperatures are generally the hottest in summer, which can result in the greatest evaporation of water vapour from leaves through stomata and from their surface. By dropping some leaves, these Eucalyptus species can reduce the rate of transpiration significantly, live off their stores and wait for the hot weather to pass, increasing their chance of survival.
8. The leaves of plants in tropical rainforests growing at ground level receive very little light because the light gets blocked by the tall trees. Having a very large surface area maximises the amount of space available to absorb of light that makes it through the canopy to the ground level for photosynthesis. Additionally, having very dark green leaves is evidence of the mesophyll cells containing a very high number of chloroplasts (that are green) improving the absorption of light for photosynthesis.
9. a) Stomata open during the day to allow gas exchange required for photosynthesis. Carbon dioxide moves into leaves and oxygen is excreted from leaves through stomata during the day. Stomata can also close to prevent the loss of water vapour from leaves.
   b) 4
   c) 8
   d) 80%
   e) See table below:

	Water moves into guard cells	Water moves out of guard cells	Cell becomes flaccid	Cell becomes turgid
Stomata open	**Yes**	**No**	**No**	**Yes**
Stomata closed	**No**	**Yes**	**Yes**	**No**

   f) Plant leaves have adapted to position their stomata on the underside of leaves to prevent the loss of water vapour through transpiration. As the top of leaves (upper epidermis) are exposed to the sunlight required for photosynthesis, the top of the leaves would experience a greater loss of water vapour if the stomata were positioned on the top of the leaves. Having the stomata positioned at the bottom of leaves reduces the rate of transpiration and increases the chance of survival.
   g) Guard cells have thick cell walls facing the stoma and thin walls facing adjacent epidermal cells. Guard cells open when they gain water and become turgid. The thin outer walls of the guard cells bend more easily than the thick outer cells causing them to curve and open the stoma.
10. a) See table below:

Type of cell	Surface area (mm^2)	Volume (mm^3)	Surface area to volume ratio (SA:V)
Root surface cell	4000	204,000	0.02:1
Root hair cell	37,000	222,000	0.17:1

    b) Root hairs have extensions that increase the surface area of the cells significantly. As root hairs absorb water and mineral salts from the soil, this increased surface area increases their efficiency at performing this function. This is evident by their SA:V being approximately 8.5x greater than the SA:V of root surface cells.
    c) As roots are generally underground, they are not exposed to sunlight and cannot perform photosynthesis. Therefore, photosynthesising mesophyll cells are not located in root hair cells because they cannot perform their function there. Additionally, the function of roots are to absorb water and nutrients from the soil, which mesophyll cells are not adapted to perform.

Chapter 3.8 Suggested answers

Multiple choice questions

1. M 2.M 3.K 4. L 5. L 6. L 7. J 8. J 9. M 10. L

Free response questions

1. See table below:

Material	Process used to take up material by roots	Explanation of why this process is used by roots
Mineral nutrients	Active transport	Concentration of mineral nutrients in soil solution is less than in root hair cells
Oxygen	Diffusion	Concentration of oxygen in the soil air spaces is greater than in root hair cells
Water	Osmosis	Solute concentration is the soil solution is less than in root hair cells.

2. See table below:

Transport vessel	Substances transported	Process that occurs in transport vessel	Direction of flow	Status of cells that tubes consist of
Xylem	Water, mineral nutrients	Transpiration stream	One way from roots to leaves through the stem	Non-living
Phloem	Sucrose and amino acids	Translocation	Two-way	Living

3. a) Sucrose.
   b) Starch.
   c) Tubers, bulbs and fruits.
   d) This is dependent on the time of the year, weather and stage of the plant's development. Generally, starch is broken down into sucrose in tubers and bulbs in periods of growth and times of the year when less photosynthesis occurs (e.g. when some trees drop their leaves). For flowering plants, extra energy is required to create new flowers, seeds and fruits (sinks) during spring. This extra energy is generally provided by other sinks such as tubers or bulbs.
4. a) Stem.
   b) Y: Xylem
   Z: Phloem
   c) Some possible answers include:
   - Xylem have thick walls which is evident in the image as Y has thicker walls than Z.
   - Xylem have continuous hollow tubes with no end walls this is evident for Y in the image.
   - Xylem are dead cells and have no cytoplasm. The cells making up Z have a cytoplasm, but Y do not (it is a continuous hollow tube).

   d) Some possible answers include:
   - Phloem have sieve plates with pores separating cells and these are evident in Z but not Y.
   - Phloem consist of companion cells, which is evident in Z but not in Y.
   - The cells making up Z have a cytoplasm, but Y do not (it is a continuous hollow tube) and therefore, Z must be phloem.
5. Water moves from the soil solution into root cells by osmosis. This inward movement results in an upward force called root pressure that causes water to be pushed towards the xylem vessels.
6. As water evaporates from mesophyll cells a region of low pressure is generated inside them. This causes water in nearby xylem vessels, now at a higher pressure, to experience a transpiration pull and move towards the mesophyll cells. There are also weak forces of attraction, called cohesion, between water molecules in the xylem. These cohesive forces of attraction between water molecules help to form long unbroken chains of water in xylem vessels. As a result of these weak cohesion forces and the evaporation of water through the stomata in leaves, water in xylem vessels is pulled up the xylem in a transpiration stream.

7. Carnivorous plants can consume small animals such as insects. The bodies of insects are rich in nitrates and other mineral nutrients. By consuming and digesting these insects, carnivorous plants can still absorb these nutrients required for growth and maintenance of the plant. This means they can still grow in nutrient poor soils like this.
8. a) Increasing the air temperature will increase the rate of fall of water level (or rate of uptake of water by the plant).
   b) Temperature of the air.
   c) Water uptake by the plant or rate of fall of water level.
   d) As the temperature of the air increased from 30°C to 50°C the rate of water uptake by the plant (or rate of fall of water level) increased significantly.
   e) The heat energy provided by the hair dryer evaporated water from the stomata in the leaves. This resulted in a force, called transpiration pull, that pulled water molecules up the xylem to the leaves. As a result, water moved into the roots from the solution surrounding the roots. As the temperature increased, the rate of evaporation increased and the rate of water uptake by the plant also increased. This is why the rate of fall of water level increased from 30°C to 50°C.
   f) Some possible answer include:
      - There is evidence of factors that were not controlled in the investigation reducing the validity of the data. Using a hair dryer could have applied direct heat to the plant increasing evaporation of water through the stomata. The temperature of the environment was not controlled.
      - The conclusion is only based on one type of plant and cannot be applied to all plants as some plants are better adapted to hot environments.
      - There are no indications that the measurement of water uptake was replicated, so the conclusion could be based on unreliable data.
      - There is no information to suggest the method was repeated, so the conclusion could be based on data with low or unknown accuracy.
9. Some possible answers include:
   - The elevated temperatures and dryer conditions are likely to reduce the availability of soil solution for plants to grow and increase soil salinity. As these conditions eventuate for crop farmers, it is going to provide some challenges to maintain crop growth for the growing population. This could influence the way crop farmers see their livelihood and they could decide to sell their land and move to a city for another job. Furthermore, the children of farmers may see the struggles associated with maintaining a farm and growing crops with the harsher conditions and decide not to continue with the family line of work and instead study and/or move into another line of work.
   - Communication and collaboration between farming communities and governments at all levels is likely to be required to establish policies that support famers to supply the necessary water at low costs to assist farmers in maintaining crop production for the growing population. This could include governments building new pipelines/infrastructure and supplying more fresh water to farming communities.
   - This could influence further investment into new developments such as vertical farms that require less water and require less space than traditional farms. Vertical farms can be built in old warehouses in towns and cities utilising spaces that have been abandoned. Increased investment from governments into this type of farming would provide new study and job opportunities and could provide sustainable sources of many crops. It could also contribute less carbon emissions than traditional farming as vertical farms rely on solar energy, there is less farming machinery required and less transport miles for harvested crops.

Topic 3 Review Test Part 1 – Animals: Suggested answers

Multiple choice questions

1. L 2.K 3.M 4. K 5. J 6. M 7. M 8. K 9. M 10. L

Free response questions

11. a) A nucleotide consists of a phosphate molecule bound to a sugar molecule, which is bound to one of the four DNA bases (A, T, C or G).

    b) A gene is a sequence of DNA nucleotides that are arranged in a specific order.

    c) A gene codes for a specific polypeptide chain, protein or RNA molecule.

    d) They are genetically identical.

    e) Some possible answers include:

    - Increased binding of epigenetic factors (methyl groups) to cytosine bases can decrease the expression of a gene and 'switch it off' and vice versa. Increased epigenetic factors on cytosine bases blocks the protein (RNA polymerase) required to translate the genetic code into proteins.
    - Increased binding of epigenetic factors (acetyl groups) to the histone proteins causes the chromatin to unwind (decondense) making the gene more accessible to be translated and therefore expressed. Decreased binding of epigenetic tags to histones causes the chromatin to wind up making the gene inaccessible and switching it off.

    f) (i) An embryonic stem cell is an unspecialised cell that can divide an unlimited number of times and has the potential to remain as stem cells or change into specialised cells.

    (ii) Embryonic stem cells can differentiate into specialised cells. To form different specialised cells, only specific genes are switched on in specific cells resulting in the expression of different genes in different cells. Additionally, different genes are switched off in different specialised cells. The structure and function of specialised cells are therefore determined by the specific genes that are expressed within that cell.

    g) (i) Some possible answers include:

    - Many people in society are overweight or obese and find it hard to lose weight. This can be due to multiple factors including busy lifestyles and being too tired to exercise. As a result, many people in the overweight/obese community are looking for a quick fix to lose weight. As this is seen as profitable by pharmaceutical companies, they have an incentive to continue spending money on researching treatments for losing weight.
    - There are many people in society that are overweight or obese and they can experience many health complications. This adds extra pressure on the health system and when governments experience backlash over the crowded hospitals they are more likely to provide funding for research to combat disorders like obesity.

    (ii) Some possible answers include:

    - The specific nutrients that could reverse epigenetic changes and improve obesity outcomes could be developed into a supplement for sale. This production, marketing and selling of this supplement could create many more jobs and have a positive impact on the economy.
    - The specific nutrients that could reverse epigenetic changes and improve obesity outcomes could be developed into a supplement for sale. This supplement could give the overweight/obese community a somewhat affordable option for losing weight when compared to expensive operations and medications. This could free up money for these people to spend more freely on other things like more expensive healthy foods and gym memberships to further lose weight.

12. a) A group of similar specialised cells that perform a specific function.

    b) Any two of the 4 options below:

    - very thin
    - have a very large surface area
    - are moist
    - have a rich blood supply

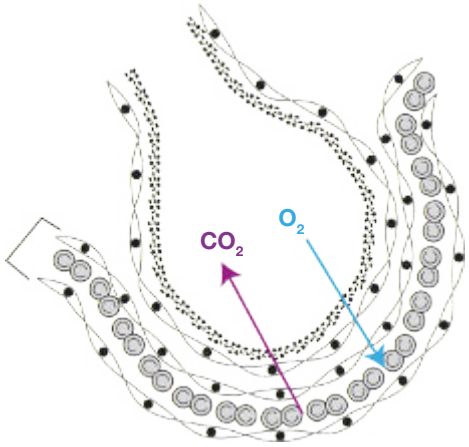
    c) Alveolus in the lungs.

d) See table below:

	Name of structure
A	Epithelial cell
B	Red blood cell
C	Blood plasma
D	Capillary

e) i) See arrows on image of alveolus and capillary:

(ii) The carbon dioxide concentration is higher in the capillary than the alveolus so carbon dioxide passively diffuses into the alveolus. Conversely, the oxygen concentration is higher in the alveolar air than the capillary and diffuses from the alveolus to the red blood cells in the capillary.



f) Emphysema is the destruction of the alveoli resulting in the permanent loss of surface area for gas exchange to occur across.

13. a) (i) B

(ii) Smooth muscle. Smooth muscle periodically contracts and is involved in the process of peristalsis. Peristalsis is an involuntary wave of sequential smooth muscle contractions that pushes food down the oesophagus and into the stomach.

b) Some possible answers are:

- To absorb water and dissolved salts from the undigested material.
- For bacteria to ferment soluble fibre and extract nutrients such as short chain fatty acids and vitamin K.
- To transport waste materials (stools) through peristaltic movements to the rectum.

c) (i) Bile

(ii) Small intestine

(iii) Fats. Bile physically digests fats (or lipids) by emulsifying the large fat droplets into many smaller fat droplets in the small intestine. This increases the surface area of fats allowing lipases to chemically digest them more efficiently.

14. a) Because veins contain valves that prevent the backflow of blood. If the vein was positioned in the opposite direction, blood from the aorta would get blocked by the valves in the vein and blood would not reach the heart tissue.

b) It is likely that the coronary artery could become completely blocked and this would result in the death of the tissue that the coronary artery is supplying blood to and a heart attack (or myocardial infarction).

c) Some possible answers include:

- High saturated and trans-fat diet, which raises blood cholesterol levels, increasing the chance of plaque development in blood vessels such as the coronary artery obstruction.
- A sedentary lifestyle. Exercise can increase the production of good cholesterol levels, which in turn lowers the bad cholesterol levels in the blood, decreasing the risk of obstructions like atherosclerosis. A lack of exercise can therefore increase the risk of atherosclerosis.
- A sedentary lifestyle. Exercise can make the heart stronger and increase the flow of blood through blood vessels, which can help to clear some obstructions. Exercise also helps to reduce high blood pressure, which is a risk factor for obstructions like atherosclerosis. A lack of exercise can therefore increase the risk of atherosclerosis.

d) Lymph capillaries

e) Tissue fluid is a product of blood flowing into the capillary network at high pressure. This causes plasma to be pushed out of the capillaries into the spaces between cells, except for the proteins and blood cells that are too big.

f) Lymph capillaries remove excess water from tissue fluid. Therefore, if they could not perform this function, the tissue fluid would build-up resulting in swelling or an oedema.

15. The answer should discuss matters such as humans endeavouring to:
- use a wide range of evidence from different sources
- use new technologies collecting data and analysing it with new knowledge
- use knowledge that can be influenced by social, ethical and cultural considerations
- use new evidence and techniques should enable medical professionals to make reliable predictions
- recognise there are limitations to the full understanding of how these genes determine health and well-being

Topic 3 Review Test Part 2 – Plants: Suggested answers

Multiple choice questions

1. L 2.M 3.J 4. L 5. K

Free response questions

6. a) Root hair cell

b) A structural adaptation of the root hair cell is the extension that sticks out into the soil. This extension increases the surface area of the cell significantly allowing the cell to exchange materials with the soil solution more efficiently.

c) Material A is water. Water moves into the root hair cells through the passive process of osmosis and continues into the xylem vessels in the roots. This movement of water into the xylem vessels from the roots creates an upwards force on the fluid in the xylem known as root pressure. The water molecules form weak forces of attractions called cohesion that results in long unbroken chains of water in the xylem. As transpiration occurs at the open stomata and water vapour diffuses out of the leaf, a region of low pressure is generated inside the mesophyll cells. This causes water in nearby xylem vessels, now at a higher pressure, to move towards the mesophyll cells. This upwards movement of water through the xylem is called the transpiration stream.

d) (i) Species A had a greater transpiration rate than species B. Species A lost 5mL of water per 100g of tissue (or 0.25mL of water per 100g of tissue per minute) compared to the 2.4 mL of water per 100g of tissue across the 20 minutes (or 0.12 mL per 100g of tissue per minute) that species B lost.

(ii) Some possible answers include:
- Species B may contain less stomata than species A and therefore there are less pores for transpiration to occur through decreasing its transpiration rate.
- Species B may have developed mechanisms to close stomata more efficiently than species B and less transpiration can occur through closed stomata than open ones.
- Species B could have a thicker waxy cuticle than species A. The waxy cuticle helps prevent evaporation of water and therefore a thicker waxy cuticle would prevent more water loss than a thinner one.
- Species B could have thinner leaves or less leaves than species A. Both of these scenarios would reduce the surface area for water to evaporate from.

7. a) The palisade mesophyll cells produce approximately 12 mg more glucose per hour than spongy mesophyll cells.

b) Some possible answers include:
- Palisade mesophyll cells contain more chloroplasts than spongy mesophyll cells and guard cells (in the lower epidermis). They can therefore trap more light and conduct photosynthesis and produce glucose at a greater rate than the other two types of cells.
- Palisade cells are located just under the upper epidermis and are therefore exposed to more sunlight that reaches the top of the leaves. This maximises the absorption of light for palisade mesophyll cells but less light reaches the spongy mesophyll cell below, and the guard cells located in the lower epidermis (underside of leaf). As a result, the palisade mesophyll cells can conduct photosynthesis and produce glucose at a greater rate than the other two types of cells.

c) The excess glucose is converted to sucrose and actively transported into the phloem. As the sucrose is transported into the phloem, the solute concentration gradient in the phloem increases attracting water to move into the phloem too. This raises the pressure of the phloem sap in the phloem sieve tube and the sap moves towards an area of lower phloem sap pressure, such as the roots. The sucrose is offloaded into the sink cells, such as the cells of a tuber, and the excess water moves back into the xylem.

Chapter 4.1 Suggested answers

Multiple choice questions

1. K 2.M 3.L 4. M 5. L 6. K 7. J 8. M 9. K 10. M

Free response questions

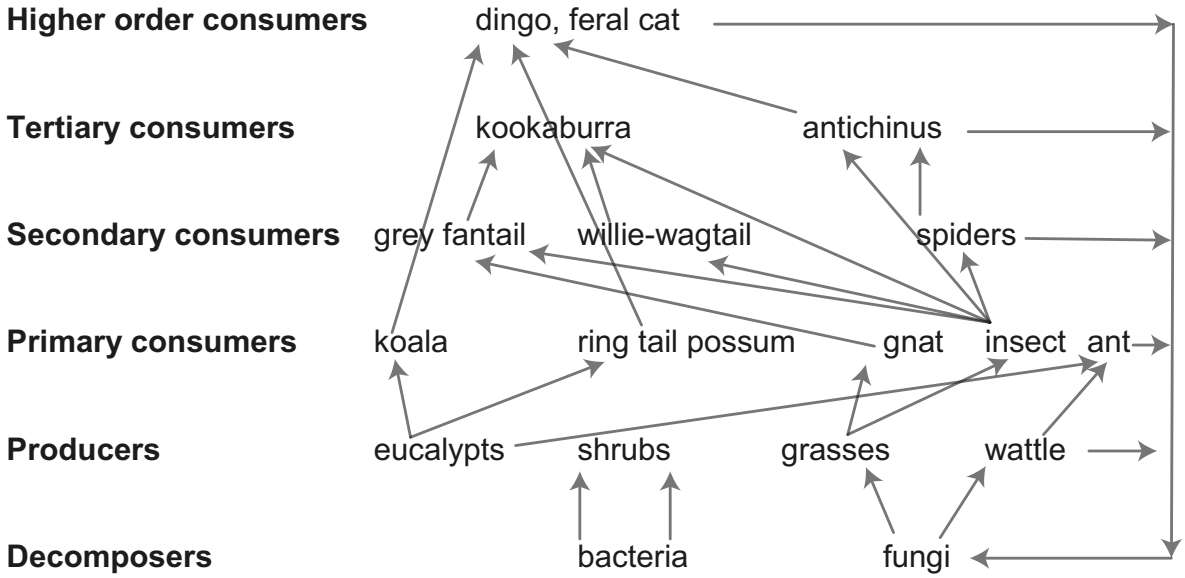
1. a) Members of one population are members of one species. One species can consist of several populations in different geographical areas.
   b) A community consists of several interacting populations. A population consists of organisms that are all the same species.
   c) An ecosystem consists of a community and the abiotic factors. A community only consists of the biotic factors.
   d) Biotic factors are the living components of ecosystems, whereas abiotic factors are the non-living components of ecosystems.
2. Resources include suitable temperature, oxygen, water, shelter, breeding sites.
3. Stable ecosystems have a diversity of species. Some are producers, trapping the Sun's energy to provide food, others are consumers that feed on the producers and other consumers that have already fed on producers. Ecosystems also require decomposers to breakdown waste and dead matter so nutrients can be recycled.
4. Mega-diverse refers to a region or country with an exceptionally high level of species diversity (lots of different species). Endemic species are those that are found naturally in only one region or country.
5. a) Competition
   b) Parasitism
   c) Commensalism
   d) Mutualism
   e) Predation
   f) Predation
6. Different species are unable to breed together and have fertile offspring. Therefore the two groups genes do not interact and there are separate gene pools.
7. a) Mutualism because both species benefit. Cassowaries obtain food from the fruit and the plants benefit with seed dispersal and reproduction.
   b) This fosters or encourages both species to thrive and other species that interact with them. Other species also rely on the plants for shelter, nutrition and safety. By the cassowary aiding in its seed dispersal, new trees can grow in different areas to help sustain new life increasing biodiversity.
8. a) Species 2
   b) Water is an important resource and greatly influences the ecosystem and its community. Species 2 and 3 overlap with their requirements for yearly rainfall and are therefore more likely to live in the same ecosystem or environment and compete for this water.
9. a) Second trophic level: mouse and grasshopper
      Third trophic level: shrew, Australian kestrel and brown snake
      Fourth trophic level: Australian kestrel
      Third and fourth trophic levels: Australian kestrel
   b) Some possible answers include:
      - Shrews feed on mice and will therefore lose a food source.
      - The Australian kestrel loses mice as a food source and will therefore eat more of the shrews.
   c) With a fall in mice numbers the wheat crop would likely increase. This would provide more food for grasshoppers and in doing so, the grasshopper numbers would in turn increase. If grasshoppers preferred the wheat crop, the grasses could increase in number due to less consumption by grasshoppers. Alternatively, the increase in grasshopper numbers consumes the wheat crop decreasing availability or eliminating the wheat crop. The increased population of grasshoppers will likely consume the grasses if wheat crop is not available and the grasses would also decrease in number.

10. Suggestions include:
    a) Shrubs and grasses → Insects → Spiders → Antichinus
    b) See table below:

Producers	Primary consumers	Secondary and higher order consumers	Decomposers
Eucalypt	Koala	Feral cat	Bacteria
Shrubs	Possum	Dingo	Fungi
Grasses	Insects	Spiders	
Golden wattle	Antichinus	Fantail	
	Ants	Willie wagtail	
	Gnats	Kookaburra	
		Antichinus	

    c) Examples include:
    - feral cat
    - koala
    - birds

    d)



11. a) The stability of an ecosystem is a reflection of its ability to respond to and recover quickly from challenges or disasters and will last over time. A well-established ecosystem with lots of species can function in this manner, trapping energy to make food, recycling nutrients with the populations interacting.
    b) Humans rely on ecosystems for food, oxygen, water, resources, recreation and more. Healthy ecosystems need to be biodiverse.
    c) Generally, the sclerophyll forest has more resources and hence a larger number of producers which can maintain more species hence 'species-richness'.

Chapter 4.2 Suggested answers

Multiple choice questions

1. J 2.L 3.M 4. L 5. K 6. M 7. L 8. J 9. M 10. K

Free response questions

1. It implies there are levels, or taxa, and each level is a part of the next higher level. At the top level all species are grouped into three domains and specificity increases as levels decrease towards species.
2. The three domains are:
   - Eukarya: organisms that are unicellular or multicellular made up of eukaryotic cells.
   - Bacteria: prokaryotic and unicellular with a variety of shapes including rod shaped, spiral and spherical.
   - Archaea: prokaryotes and unicellular but are structurally and chemically different to bacteria.
3. The binomial system consists of two names to form the scientific name for each species. The first is the genus and the second is the species: for example, Homo sapiens.
4. Regarding common and scientific names:
   a) Common names are not strictly bound by convention, the same animal may have more than one common name whereas scientific names always consist of two names that represent the genus and species names (the binomial name). Common names are usually in the native language (e.g. English) whereas scientific names are in Latin (which is an ancient Roman language).
   b) The common name can be easily recognised by all people and is usually easy to remember. The scientific name however, is more precise, it indicates much more to scientists about their characteristics and classification and prevents one species being counted as two different species as this name is universally recognised.
5. Three types of information are:
   - Physical features or morphology: some examples include the presence or absence of a spinal cord, appendages (e.g. wings or legs) and body covering (e.g. hair or feathers).
   - Reproductive strategies: sexual or asexual, egg laying or live birth.
   - Molecular sequencing: comparing the base sequences of DNA or amino acid sequences of proteins.
6. Because this system is a man-made system and is not perfect. It is the most accepted and widely used system for classifying species but it has its limitations. As technology advances and new species are discovered, the system requires international agreement to maintain a universal approach ongoing.
7. The three main groups of mammals are:
   - Placentals: the unborn are nourished in the uterus and are attached to a placenta.
   - Monotremes: mammals that lay eggs.
   - Marsupials: the young are born at a very early stage of development and develop in a pouch.
8. Members of one species can interbreed with each other under natural conditions to produce fertile offspring but cannot do so with members of another species. If they cannot interbreed then they are genetically isolated which means they have separate genetic material and separate gene pools.
9. It has allowed form more accurate classification of species. Members of closely related species share common sequences of DNA, more so than members of species that are distantly related. This comparison of DNA base sequences and amino acid sequences when comparing proteins is used, along with other data to understand common ancestry and relatedness.
10. Some possible answers include:
    - Reproductive isolation does not occur instantly and even though two populations may have different physical features, they may still be able to interbreed and produce fertile offspring.
    - This species definition cannot be applied to asexually reproducing species.
    - There could be a lack of data to apply this species definition to particular species. This could be because of a lack of funding for research or it could be because the species are extinct and their interbreeding behaviours have not been documented.
11. a) They differ in when the reproductive isolation occurs. Pre-zygotic mechanisms occur before the zygote is formed and post-zygotic mechanisms occur after the zygote is formed.
    b) Some possible answers include:

    Pre-zygotic examples: Different mating calls and rituals, the use of species specific chemicals to attract members of the opposite sex, differences in flower shape or genitalia, different seasons or times for reproduction, inability of sperm to survive in the female reproductive system, pollen tubes are unable to grow towards the ovules in a flower.

Post-zygotic examples: Zygotes fail to develop (miscarriage), young fail to reach sexual maturity, offspring live but they are infertile.

12. Some examples include:
    a) Flowering at different times and different flower shapes.
    b) Different mating calls and different mating seasons.
    c) Different shaped genitalia and sterile offspring that are unable to sexually reproduce.
13. A: Bird
    B: Monkey
    C: Bee
    D: Spider
    E: Ant
    F: Worm
14. A possible dichotomous key is :

	Statement	Instruction
1 a	Has wings	Go to 2
1 b	Does not have wings	Go to 6
2 a	Has long antennae	Go to 3
2 b	Has short antennae	Go to 4
3 a	Antennae have numerous fine hairs	H
3 b	Antennae does not have numerous fine hairs	I
4 a	Has long wings	G
4 b	Has short wings	Go to 5
5 a	Abdomen is white	E
5 b	Abdomen is dark grey	F
6 a	Has antennae	Go to 7
6 b	Does not have antennae	D
7 a	Has long antennae	C
7 b	Has short antennae	Go to 8
8 a	Has two extensions from its abdomen	A
8 b	Has three extensions from its abdomen	B

Chapter 4.3 Suggested answers

Multiple choice questions

1. L 2.M 3.J 4. M 5. L 6. L 7. K 8. L 9. M 10. L

Free response questions

1. The three different categories are structural, physiological and behavioural. There are many possible examples for each category. An example of each is:
    a) Structural: thick, waxy leaves on a gum tree prevent water loss.
    b) Physiological; excretion of concentrated urine by desert mammals reduces water loss.
    c) Behavioural; wombats burrow to avoid extremes of heat.
2. Some possible answers include:
    a) **Rabbit:** Structural – they have widely spaced eyes for increased field of vision to detect danger.
    b) **Cheetah:** Structural – long strong tail to help counterbalance when changing direction at high speeds.
    c) **Cactus:** Structural – thick layer of wax to prevent water loss.
    d) **Snake:** Physiological – produces venom to help catch prey and deter predators.
    e) **Emperor penguin:** Behavioural – huddle together to conserve heat loss and stay warm.

3. a) Predation can result in the individuals within the prey population that are less suited to avoiding a predator to be caught and eaten more easily. Those individuals within the prey population that are better suited or adapted to avoid predation are more likely to survive. Predation therefore adds selection pressure on the species to become better adapted.

   b) See table below for some example answers:

Type of adaptation	Example of adaptation prey have developed to survive predation	Explanation of how this adaptation increases the survival of prey against predation
Structural	Camouflage	Prey blend into surrounding making it harder for predator to see and consume them.
Physiological	Produce poisons	Predators are deterred to try and attack prey due to the risk of dying from poisonous sting or bite.
Behavioural	Dig and live in burrows	Hard for predator to find prey and prey can run to burrow for safety as predators are often too big to follow.

4. a) **Inherited:** the imprinting of a duckling to its mother after hatching.

   Learnt: monkeys learning to use rocks and other 'tools' to open shellfish to consume them.

   b) Inherited adaptations are passed on from parents to their offspring in their genes and can be structural, physiological or behavioural. Some behavioural adaptations that increase the chance of survival can be learnt throughout life by some organisms. These adaptations are not coded for by genes.

5. Suggestions include:

Major environmental factor involved	Adaptation	How the adaptation aids survival	Type of adaptation	Example of organism with adaptation
Water only available for a short period of time	**A short life-cycle (germinate, grow, flower, set seed)**	Enables full cycle of reproduction to occur quickly so the species can survive	Physiological	**Sturt desert pea**
High temperatures	**Large ears with rich blood supply**	Increases surface area for increased radiant heat loss	Structural and physiological	**Bilby, fox**
High temperatures	**Hopping**	Quickly move long distances to find water and shade and reduce burns to feet on hot surfaces	Behavioural	Red kangaroo, hopping mice
Harsh temperatures and low water	**Lays large numbers of eggs**	Increases the chance that some new offspring hatch from eggs and survive to reproduce	Physiological	Lizards like the bearded dragon, shield shrimps
High temperatures	**Nocturnal**	Avoid the heat of the day	Behavioural	Possum, bats

6. The introduction of grey squirrels resulted in the decline of the red squirrel population. This could have occurred because the grey squirrel population were better adapted to the habitat and outcompeted the red squirrels for resources. There could have also been a change in selection pressures or another human induced change in the habitat that the grey squirrels were better adapted to than the red squirrels. Eventually, the red squirrel's population died out in the woodland habitat and the grey squirrel population flourished.

Chapter 4.4 Suggested answers

Multiple choice questions

1. M 2.K 3.K 4. L 5. K 6. M 7. K 8. J 9. K 10. M

Free response questions

1. Producers convert light energy into chemical energy through the process of photosynthesis. Consumers can feed on the organic matter.
2. Through consumption. Energy is transferred by heterotrophs feeding on organisms from lower trophic levels.
3. Because energy is lost as heat during cellular respiration that all organisms need to perform to maintain life processes. This used energy cannot be passed on to the next trophic level. Also, organisms produce waste that has organic matter such as faces with undigested organic matter that is not passed on to the next trophic level.
4. Biogeochemical cycles involve the cycling of essential nutrients and water in ecosystems. They involve biological (biotic) and geochemical (abiotic) interactions to complete the cycles.
5. As only about 10% of the energy is passed on to the next trophic level there is less and less energy available at high trophic levels. With less energy these trophic levels cannot be sustained.
6. Energy is not recycled in an ecosystem whereas matter is. Energy is trapped and moves through the trophic levels, matter cycles between biotic and abiotic components.
7. Decomposers such as bacteria and fungi are important in the biogeochemical cycles as they consume waste and dead organic matter, and recycle the essential nutrients back into the environment. As decomposers are essential for nutrient and water recycling the consequences of their removal from an ecosystem would be severe. Essential inorganic elements and water, necessary to sustain organisms would not be available and many organisms would suffer or die.
8. a) The removal of trees would result in less photosynthesis and an increased carbon dioxide concentration in the atmosphere.
   b) Combustion of fossil fuels releases CO_2 into the atmosphere again leading to increased CO_2 levels.
9. a) Some possible answers include protein, nucleic acids and chlorophyll.
   b) Nitrate.
   c) P
   d) Some possible answers include:
      - Nitrogen fixing bacteria that can convert atmospheric nitrogen gas into usable forms such as nitrates.
      - Decomposing bacteria that breakdown dead and waste matter releasing inorganic matter such as nitrates.
10. a) Rocks
    b) Some possible answers include ATP, nucleic acids (DNA and RNA) and phospholipid membrane.
    c) Some possible answers are:

       X – consumption, feeding, eating.

       Y – waste, death, excretion, death and excretion.

       Z – erosion, weathering, weathering and erosion, breakdown of rocks.
    d) Desert plants live in dry and often nutrient poor soil. By developing mycorrhizae, desert plants increase the depth and width of their root structure, increasing the root systems surface area, to increase their chance of absorbing sufficient nutrients and therefore their chance of survival.
11. a) 20,810/1,700,000 × 1 00 = 1.22%
    b) (i) 3,368/20,810 × 1 00 = 16.2%
       (ii) 21/383 × 1 00 = 5.48%
       (iii) The consumers towards the end of the food chain have a lower transfer of energy (5.48%) compared to the transfer of energy from a primary producer to the primary consumer (16.2%). This is likely due to the greater activity of consumers compared to producers. Consumers expend lots of energy to survive including escaping predators, hunting prey and maintaining a constant body temperature.
       (iv) (16.2+5.48)/2 = 10.84%
       (v) 10% as the average conversion efficiency throughout a food chain/web. The percentage energy of transfer from one trophic level to another is not always the same and can depend on many different factors, including the efficiency of digestion and activity levels of the organism.

Chapter 4.5 Suggested answers

Multiple choice questions

1. J 2.L 3.M 4. K 5. M 6. J 7. L 8. M 9. K 10. K

Free response questions

1. See table below:

Ecosystem	Description of likely abiotic and biotic components
Grassland	Grassland ecosystems are open, expansive regions dominated by grasses and few trees, typically found in both tropical and temperate zones. Some examples of species inhabiting grassland ecosystems are multiple species of grasses, zebras, African elephants, wildebeest, emus and foxes.
Tundra	Tundra ecosystems are cold, treeless regions consisting of permafrost and minimal vegetation. Some specialised plant and animal life have adapted to extremely cold conditions, such as Arctic moss, dry shrubs, Arctic foxes, caribou and polar bears.
Desert	Desert ecosystems are arid regions with sparse rainfall, characterised by extreme temperature fluctuations and limited vegetation. Some examples of species that reside in deserts include cacti, yuccas, camels, lizards, snakes and hopping mice.
Freshwater	Freshwater ecosystems are marine ecosystems that are not salty like the ocean. They generally contain a diverse range of aquatic life such as pondweed, water lilies, reeds, freshwater frogs, turtles, otters and alligators.

2. The abiotic components can shape biotic factors in an ecosystem as organisms must adapt to survive in a particular ecosystem. Abiotic factors can act as selection pressures that ensure the most suitable individuals in a species survive to reproduce and fill specific niches in specific ecosystems.
3. An ecological niche is the specific role or function that an organism plays within its ecosystem and is defined by living and non-living factors. A habitat is defined as where a species lives and can therefore consist of many niches. An organism's niche is how a species fits into its habitat and interacts with it.
4. a) Examples include absorbing carbon dioxide, water and light for photosynthesis, supplies the atmosphere with oxygen, and absorbs light as well as water and nutrients from soil.
   b) Examples include provides food and shelter for insects, birds and lizards as well as competes with other plant populations for light, water and nutrients.
5. Some possible answers include:
   - An energy source – food or light for photosynthesis
   - Shelter – to provide protection from predators and warmth.
   - Inorganic materials – depending on whether the organisms is an autotroph or heterotroph they may acquire these through the soil or through consumption.
6. Members of the same species require the same or very similar resources, and therefore compete for those same resources. Individuals from different species are likely to have somewhat different resources that they require.
7. a) Some possible answers include:
      - Light: higher intensity at the top and decreases in intensity towards the bottom of the pond.
      - Pressure: lower at the top and increases with depth.
      - Oxygen: is higher near the surface and decreases with depth.
   b) The greater surface area of the broad floating leaves will facilitate a more efficient absorption of light for photosynthesis and may also include large airspaces to assist flotation and gas storage for photosynthesis.
   c) Some possible answers include:
      - Branching increases the surface area of the leaves which in turn increases the surface area for light and gas absorption for photosynthesis.
      - Branching allows for the plant to survive plant damage more easily. If one smaller branch is removed, there are still many others to cover its loss regarding photosynthesis and gas exchange. However, the loss of one big broad leaf takes a lot of time and energy to grow and replace.
   d) There are low oxygen levels deeper in the lake and the bubbles which contain oxygen can be used by beetles for aerobic respiration when they dive.
   e) In water with low solute concentration, water tends to move by osmosis into the cells of the organisms who have a higher solute concentration in their tissues. This poses problems for organisms as their cells begin to swell.

f) (i) A paramecium (a small protist).

(ii) Contractile vacuole

(iii) Contractile vacuoles collect the excess water and expels this from the cell through contraction, allowing paramecia to survive in low solute concentration environments such as this pond water.

8. a) The zone of overlap is where the niche of species is the same; for example, they compete for the same food.

b) As the niches of two species are not sufficiently different, competition between them for resources will be so intense that one of them will end up being excluded from the habitat or become extinct.

9. a) The fundamental niche of kangaroos is the range or distribution of them prior to the introduction of sheep. The realised niche of kangaroos is where they are located today.

b) Some examples include the introduction of rabbits, human activities like clearing native vegetation to graze sheep, and shooting the kangaroos.

10. Three separate zones can be observed, the supratidal (splash zone), intertidal and subtidal. The varying abiotic components give rise to zonation, with the tides determining the water coverage of each zone. The wave action on the rock platform can have a significant impact on the species that can survive in the intertidal zone. Shelled organisms are adapted to combat the pounding from wave action and the soft bodied organisms fill niches in the subtidal zone where they are submerged in water.

11. a) Some possible answers include:

- A gradual increase in salinity from the sea (34g/L) to Pool A (46g/L).
- The temperature sharply increases from the sea (16°C) to Pool C (27°C), then gradually increases to Pool A (31°C)
- The percentage of oxygen dissolved in water sharply decreases from the sea (100%) to Pool A (17%).

b) (i) At high tide and with wave action, sea water splashes into the pools of the supratidal zone (solute is 34 g/L). At lower tide and with high temperatures, water evaporates from the pools increasing the solute concentration.

(ii) The organisms need to cope with vast ranges of solute concentrations. An example is a barnacle that has strong valves that can close to prevent dehydration and keep out the water when it is too salty. Other organisms secrete salts.

c) The pattern is that at high temperatures there is less oxygen. This is expected since the solubility of gases in water decreases as the temperature increases.

d) Design an experiment where the independent variable is temperature and is controlled. An oxygen probe connected to a computer can then be used to measure the oxygen concentration at different temperatures and the data recorded in a table and possibly presented in a graph.

12. a) See table below:

Environmental factor	Description of gradient through rainforest strata and likely explanation
Light intensity	Light intensity decreases from the higher emergent and canopy levels to the lowest level of the forest floor. This is because the upper layers block light from reaching the lower levels. Light that reaches the lower levels filters through these upper layers.
Temperature	Temperature decreases from the emergent layer to forest floor. This is because little light penetrates the upper layers providing less light and heat to the lower layers.
Humidity	Humidity increases from the emergent layer to the forest floor. This is because it is cooler at the forest floor and wetter with less evaporation. Additionally, there is more wind in the upper levels to increase evaporation and vice versa.
Wind	Wind decreases from the upper emergent layer to the forest floor. The upper emergent layer is more exposed and there are less plant structures to block the wind. As the levels decrease the density of plant life increases making it harder for wind to penetrate.

b) (i) Very tall trees and some birds/insects live in the emergent layer. In contrast, broad leafed plants like ferns, and many organisms such as insects and big animals live on the forest floor.

(ii) It is relatively easy for many organisms living on the forest floor to obtain the resources they require due to a high availability of food, water and variety of habitats that provides them with shelter. Plants like ferns can survive here because their leaves spread over a large distance to trap the light that filters through the upper layers. Producers living in the canopy up higher have ample light and warmer temperatures for photosynthesis. Only animals like birds and insects that can fly that high can readily access this upper layer.

13. a) Some species, known as keystone species, are linked to the survival and structure of the whole ecosystem as they interact with many other species and these interactions determine the stability of most species.
    b) A decrease in hammerhead sharks would result in an increase in cownose stingrays. This in turn would result in a decrease in the populations of the cownose stingray's prey, scallops, clams and oysters.
    c) Some possible answers are:
    - The decimation of shark populations due to illegal shark finning is likely to have negatively influenced legal fishing businesses. As the flow on effect decreased the scallop, oyster and clam populations, fishing industries focusing on these species are likely to have decreased activity or shut down all together. This is likely to have reduced available jobs and negatively affected some countries' economies who can no longer sell these products both locally and internationally.
    - The shark finning industry has influenced the increased illegal fishing of sharks. This has resulted in 'illegal' incomes for many people and groups. As this illegal industry is very profitable, the income brought in from the shark fins is likely to have influenced more people to enter this industry, further decimating shark populations.

Chapter 4.6 Suggested answers

Multiple choice questions

1. M 2.L 3.M 4. L 5. L 6. K 7. K 8. J 9. L 10. M

Free response questions

1. Succession is a change in the mix of species in an ecosystem over time. As new species appear, they change the environment making it more suitable for other new species.
2. Some possible answers include:
    - Primary succession starts with some life but secondary succession has had the original life removed through a disturbance (there can be some life remaining too).
    - There is no soil to start primary succession, but the remaining soil is present for secondary succession.
    - Primary succession starts in a new area compared to secondary succession which starts in an established area.
    - Lichens and mosses are the first species in primary succession, whereas seeds and roots of plants are already present for secondary succession so it is much quicker.
3. Some possible answers include:
    - Daily change–This is mostly due to changes in light intensity and temperature that themselves are caused by the rotation of the Earth. Changes to abiotic factors bring about changes in biotic factors, such as the increased activity of predators during the day who hunt grazing herbivores.
    - Seasonal change – This is caused by the Earth revolving around the sun and results in changing weather patterns (abiotic factors) for ecosystems throughout the year. Winter can bring cold, short and often rainy/snowy days. These conditions are less favourable for many species that migrate for the winter or hibernate.
4. Succession is the change in the mix of species in an ecosystem. Fossil evidence collected from the same location shows this can and does happen over very long periods of time. The fossil evidence specifically shows that the types of species present during different time periods are different, and they are not the same as the mix of species currently inhabiting the same land.
5. Established ecosystems start to change if something significantly alters their abiotic components, such as a natural disaster like a wildfire or some kind of human activity like clearing of land for agriculture.
6. a) Lichens and mosses.
    b) Autotrophic organisms colonise bare rock. They can contribute to the weathering of bare rock and over time the remains of dead autotrophs contribute to the formation of a simple soil.
    c) Adaptations of autotrophs involved in primary succession might include spores resistant to high temperatures and very low amounts of water. It would be reasonable to expect germinated autotrophs to have small, tough leaves and very short to no stems.
7. Cyclone Yasi triggered secondary succession in far north-east Queensland by blowing down a lot of mature rainforest trees. This increased the intensity of light that could reach the rainforest floor and reduced competition between plants that survived. This allowed different populations of plants to grow in the area and changed to the mix of animal populations.
8. During the Ediacara period in parts of what is now Australia and Canada the abiotic components of marine ecosystems would have been very similar. As a result, they supported similar species of biota, such as similar species of soft-bodied sponge-like organisms.

9. In the Tasmanian World Heritage Wilderness Area, the abiotic and biotic components of the ecosystems have remained largely unchanged for the last 40 million years. For succession to commence these must be significantly changed through disturbance(s) first.
10. a) Spinifex grasses grow in a sand dune. Their roots stabilise the upper surface of the sand dune and dead remains of them contributes to the production of richer, deeper soil. The presence of them while alive provides food and shelter for colonising animal species.
    b) Insects may burrow in the soil and thereby mix organic material with sand and gravel and build up the soil. They may also eat some of the leaves in the litter and assist in the recycling of nutrients. Furthermore, they may be prey for other organisms.
11. Secondary succession is generally faster than primary succession due to multiple reasons including:
    - Secondary succession communities already have established soils whereas primary succession requires the development of a mature soil from bare rock.
    - Certain populations of plants species generally survive the initial ecosystem change, whereas there are no plant species at the beginning of primary succession.
    - Rapid emergence of new plant species in secondary succession (due to established soils) permits a speedy arrival of new animal species too.
    - Wildfires burn organic matter into nutrient rich ash, which increases the quality of the soil allowing Herbaceous plant seeds to germinate and grow quickly during secondary succession, whereas there is only bare rock in primary succession.
    - Some species of plants have fire-resistant seeds that permit rapid post-fire recovery, which is again not possible during primary succession.
12. a) Mature, stable ecosystems are long-lived. This means the mix of species they have has had a long period of time to emerge. Therefore, it is likely that a rich diversity of many different species and plant and animals will have become established.
    b) Ecosystems at a late stage of succession have a much greater biodiversity of species. This means they have many more species that are present to permit the ecosystem to function; in this case, to cycle essential nutrients and chemical elements.
    c) Autotrophs tend to be the first species to inhabit immature ecosystems – they trap the Sun's energy and provide food for the heterotrophs. As the ecosystem matures there is now sufficient food and shelter for the heterotrophs who will appear and start to occupy their various niches.

Chapter 4.7 Suggested answers

Multiple choice questions

1. M 2.J 3.J 4. M 5. L 6. M 7. K 8. K 9. M 10. L

Free response questions

1. a) Some possible answers include land clearance, deforestation, pollution, hunting, introducing species, increasing soil erosion, increased greenhouse gas release, increasing ocean acidification, increasing eutrophication and algae blooms.
   b) Habitats are the living spaces for all other organisms and if destroyed, many species are negatively impacted by loss of food, shelter and interactions, which can lead to reduced biodiversity.
2. a) Some possible answers include agriculture, logging, urban and industrial expansion, building roads and mining.
   b) Roots hold soil together and when cleared the most nutritious topsoil can be blown away by wind and rain (soil erosion). Additionally, the organic matter living in the area is often cleared and removed or incinerated, meaning nutrients aren't recycled into soil through decomposition.
3. a) As the human population increases so does the number of species extinctions (exponentially).
   b) The rate of species extinctions is so high compared to past history (and natural background extinction rate), and therefore, there is a greater loss of biodiversity and impacts on many natural ecosystems.
4. a) Some possible answers include carbon dioxide (CO_2), methane (CH_4), water vapour (H_2O) and nitrous oxide (N_2O).
   b) The sun radiates ultraviolet (UV) radiation towards Earth. About half of the UV radiation is absorbed by the Earth and re-emitted as heat radiation. Some of the heat radiation will leave the atmosphere, but some is absorbed by greenhouse gases and re-emitted back towards Earth, warming the planet. As the concentration of greenhouse gases increase in the atmosphere, it becomes harder for the heat radiation to leave the Earth's atmosphere. As a result, more heat radiation continues to remain in the atmosphere as it continues to 'bounce' between the Earth's surface and atmospheric greenhouse gases. This is called the enhanced greenhouse effect, which leads to global warming.

c) Some possible answers include:
- the relocation of animals because of changing abiotic conditions such as water temperature,
- a change in breeding patterns and/or behaviour, for example, flowering time for plants and egg laying for animals.
- changing growth rates of producers such as phytoplankton, which impacts food chains.

d) Waste disposal contains organic matter that decomposers can break down. When this organic matter is decomposed in anaerobic conditions, the decomposition process produces and releases methane which is a potent greenhouse gas. As the human population and their associated landfill waste increases, the amount of methane produced due to landfill also increases. This raises the atmospheric methane concentration, which in turn increases the enhanced greenhouse effect.

5. The atmospheric concentrations of greenhouse gases such as carbon dioxide and methane can be tracked and compared to the average global temperatures for an extended period of time. In doing so, a correlation can be observed and future modelling can be achieved to predict the average future temperatures based on future greenhouse gas emissions and atmospheric concentrations.

6. a) The runoff of fertliser into the body of water (containing nitrogen and/or phosphorus compounds).

b) The plants and algae require these nutrients to grow and due to the plentiful supply flourish.

c) There is likely to be little sunlight penetration into deeper waters due to the excess growth of algae on the surface that block and absorb the sunlight.

d) After the algae take advantage of the optimum nutrients from the fertiliser runoff, there is generally not enough nutrients to sustain the population explosion and they start to die off, reducing their population size quickly. The decomposers break down the dead algae as they sink into the depths of the water body recycling the nutrients, hence the nutrient material in the diagram.

e) As the algae bloom blocks light to the lower levels, the aquatic plants cannot photosynthesise efficiently and release oxygen into the water. Additionally, the decomposers use up lots of dissolved oxygen through aerobic respiration required for the decomposition of the dead algae that sinks to the bottom of the water body. Overall, the dissolved oxygen concentration is likely to be lowered and the fish in the diagram may not have enough to survive and could therefore die.

f) Algae

7. a) Methane is a powerful greenhouse gas that traps significant amounts of heat in the atmosphere. The release of significant stores from melting permafrost would further exacerbate the enhanced greenhouse gas effect and increase the average global temperatures. This would likely result in further melting of permafrost and further release of any methane stores trapped within.

b) As mercury cannot be broken down or excreted faster than it is being ingested, it is passed on to organisms higher in the food chain through consumption. Therefore, organisms at higher trophic levels in ocean food chains accumulate higher and higher levels as they feed on other organisms.

c) Deep-sea fish are often higher in the food chain and therefore are more likely to contain higher concentrations of mercury due to biomagnification. As mercury is poisonous to humans and can affect the brain, high levels of mercury in the mother could affect the brain development of the growing foetus and have lifelong consequences.

d) Some example answers are:

(i) As more than 99% of climate scientists agree that human induced global warming is occurring, society is anxious about the future consequences this could incur. Due to this societal pressure, government and non-government bodies have responded by funding research into the effects of global warming including the effects of melting permafrost to raise more awareness in the hope of accelerated change to reduce greenhouse gas emissions.

(ii) This research could make society more anxious about the effects of human induced global warming. It could influence a greater movement for change such as the reduction of carbon emissions and expediate the will of society to transition to renewable sources of energy.

8. a) As dissolved carbon dioxide increases, the pH decreases.

b) When carbon dioxide dissolves in water, carbonic acid is produced. Increased carbon emissions results in increased carbonic acid forming in oceans, increasing their acidity.

c) Acidification can weaken the shell or protective coating of many organisms such as corals and shellfish by dissolving the calcium carbonate they are made of. Additionally, shells for offspring cannot be built in low pH environments.

d) Because the graph extends beyond the present time and all the way to the year 2100 (x-axis). The graph is therefore based on previous data and provides predictions based on current projections.

e) Scientists can use the data to predict what this lower pH would do to oceans and their organisms. This data can be used to project economic loss and other impacts on society. All data-based predictions can

then be presented to government and non-government bodies to develop realistic strategies to lower atmospheric carbon dioxide levels and slow the acidification process.

f) See table below for some possible answers:

Factor	Explanation
Environmental	There are many impacts of ocean acidification but a major one is its interference with corals and shellfish. Corals and shellfish cannot build their shells and existing calcium carbonate shells can dissolve in the lower pH environment. This can interrupt food webs and result in a loss of biodiversity.
Ethical	Humans have an ethical responsibility to maintain habitats and the aesthetic appeal of ecosystems on Earth and the further loss of life at the Great Barrier Reef would be an ethical problem for humanity.
Economical	The loss of life at the Great Barrier Reef could impact food chains resulting in less seafood availability and impact global food chains. Some seafood could become less available and therefore more expensive.
	The Great Barrier Reef tourism numbers could decline significantly. This would reduce the number of overseas travelers to the area, reducing council, state and federal government economies. Many people working in the tourism industry would likely lose their jobs and may have to relocate from the area to find new work.

g) Some possible answers include:

- This prediction could influence governing bodies around the world to implement measures to limit the human impact on the number of predators of jellyfish. This could include applying catch limits on some species for fishing, increasing funding into the monitoring of illegal fishing and implementing new policies regarding combating ocean acidification.
- Communication and collaboration between governing bodies and leadership at nuclear power plants is likely to be required regarding the monitoring of ocean water for jellyfish used for cooling nuclear power plants. It is also likely that new procedures and technologies will need to be developed to filter the jellyfish efficiently from the water used to cool the nuclear power plants that depend on this water. The impacts of constant blackouts for those supplied electricity from these plants is more than an inconvenience as the current human lifestyle depends on electricity being available, such as for freezing food, making payments etc.
- If the findings of the study eventuates, it could have a negative influence on the lifestyle of many beach goers. Many people love to go to the beach to play, walk, swim, surf and cool down, but they may not want to if the water and beach are infested with jellyfish in the future. Some species of jellyfish can sting and/or be poisonous to humans. If the number of visitors and tourists to beaches decrease, this could also negatively impact local businesses, enforcing closures.
- There are limitations to this study, preventing its full application. Firstly, the study only subjected the jellyfish to changing ocean acidification with its prey, this doesn't replicate the full situation and pressures of the jellyfish ocean ecosystem, such as the lack of presence of jellyfish predators. Secondly, the scientists have only hypothesised possible reasons for the increased predation by jellyfish in increased acidification conditions. Therefore, this could impact government funding for further research to confirm/refute these hypotheses and increase the reliability and validity of any conclusions of this study.

9. Ultimately with more fertilisers and irrigation required, the costs associated rose dramatically and could not be easily financed by many developing countries. Without sufficient fertiliser and irrigation the crop yields would have been low and therefore the goal of producing more food for the growing population would not have been achieved.
10. If some plants compete more effectively than others, they will increase in number. This may cause some plants to thrive and others to die, thereby decreasing biodiversity. Additionally, the plants that produce less seeds in higher atmospheric carbon dioxide concentrations are less likely to reproduce and compete against species of plants that can produce plentiful seeds in the new atmospheric conditions.
11. Some possible answers include:
    - Walking or cycling to school or shops rather than using a bus or car.
    - Eating less beef.
    - Turning off lights and appliances when not using them.
    - Wearing more clothes in winter instead of burning fuels (directly or indirectly) to keep warm.
    - Using LED light bulbs instead of incandescent.
    - Using less devices with batteries and/or use rechargeable batteries.
    - Hang clothes on a clothesline instead of using an energy draining dryer.

Topic 4 Review Test: Suggested answers

Multiple choice questions

1. K 2.J 3.K 4. L 5. L 6. M 7. M 8. J 9. J 10. M

Free response questions

11. a) Plant species diversity increases as the grazing intensity increases from a low to moderate level. At high levels of grazing, plant species diversity falls rapidly.

    b) Some possible answers include:

    - Very low levels of herbivore grazing could mean that one competitive plant species outcompetes many other plant species and they are excluded from the ecosystem, reducing biodiversity.
    - At moderate levels of grazing, it is possible that the population size of an aggressive plant species are reduced, allowing more plant species to compete for resources and thrive.
    - At high levels of grazing it is more likely that the herbivores are feeding on more and varied species, drastically reducing diversity. Perhaps the population size of grazers is not being controlled by predators, leading to overgrazing and reduced plant species diversity.

12. a) Eucalyptus robusta – underlined if written in physical version of the Workbook

    Eucalyptus robusta – in *italics* if typed in digital version of the Workbook

    b) C and D

    c) Order

    d) Some possible answers include:

    - The two separate species may flower in different seasons or at different times of the year. This would ensure that cross-pollination could not occur and therefore reproductive isolation would be maintained.
    - The two separate species may have incompatible reproductive cells that cannot fuse to form a zygote and therefore remain reproductively isolated.

13. a) (i) Animal A

    (ii) Some possible answers include:

    - Animal A loses considerably less water by all methods compared to animal B. This may suggest animal A lives in a drier environment and has evolved strategies to minimise water loss.
    - Animal A gains significantly less water by all methods than animal B. This suggests that there is less water available and that animal A lives in a drier environment.

    b) (i) Animal A = [(10+42) – (35+14+3)] = 0 mL/day

    Animal B = [(750+225+72) – (250+629+166)] = +2 mL/day

    (ii) The net water balance is basically 0 mL/day for both animals. This is necessary because if one value exceeded the other for an extended period of time, the animal would either gain too much water and overhydrate or lose too much water and dehydrate. Water balance is critical for survival and transport of solvents throughout the body.

    c) Some possible answers include:

    - **Structural:** Large ears help radiate more heat away from the body to help cool the animal down.
    - **Behavioural:** Nocturnal species only feed at night avoiding the hot sun during the day.
    - **Physiological:** Excreting very little moisture in waste products to conserve water.

14. a) The levels of nitrate and sulfate are both equally as important in determining cereal crop density.

    b) Due to the limited treatments tested, it cannot be concluded that one nutrient is more important to cereal crop growth than the other. A greater range of concentrations need to be tested. The same concentration ratios for each nutrient needs to be tested to make valid conclusions. For example, 25 units of nitrogen was not tested and there is little data on 100 units of sulfate with different concentrations of nitrogen in this experiment.

    c) A biotic component could be weeds or grasses competing for water and other nutrients. This competition would reduce the size of the cereal crop and yield.

15. a) The reactions and processes are:

    A: Photosynthesis

    B: Aerobic respiration or anaerobic respiration

    C: Feeding/eating by herbivores.

    b) Decomposers such as bacteria and fungi)

c) Burning fossil fuels, such as coal and oil, releases large amounts of carbon dioxide into the atmosphere. This increased carbon dioxide enhances the natural greenhouse effect, trapping more heat in the Earth's atmosphere, causing global warming and contributing to climate change.

16. a) X: Waste

Y: Respiration (heat)

b) (i) 20810 – 5465 – 3368 = 11,977 kJ/m^2/year

(ii) (11,977 + 5,465)/20810 × 100 = 83.8% (84%)

c) Higher trophic levels require energy to survive, they obtain this energy from the trophic level below them which they feed on. As only about 10% of the energy trapped by the prior trophic level is passed on, there is not enough energy to support more trophic levels. The third and fourth trophic levels obtain 1% and 0.1% of the original energy trapped by producers respectively. A fifth trophic level would therefore only obtain 0.01% of this original energy which generally limits the number of trophic levels to 3 or 4.

17. a) A keystone species is one which is a very important species for the ecosystem, without which, many of the other species may perish. Keystone species play a critical role in maintaining the structure, balance, and health of ecosystems. Unlike other species, their presence or absence has a disproportionately large impact on the environment and the variety of species within it.

b) Yes, it would. As indicated, the actions of the bettong are fundamental in providing nutrients for the producers, which are the first trophic level. They facilitate this through feeding on fungal spores, resulting in their dispersal. These spores can then develop into mature fungi that form symbiotic relationships with the producers and provide them with these essential nutrients.

c) Sourcing from different areas is likely to introduce individuals with different genetic make-up. This adds genetic diversity to the gene pool and populations that possess this diversity are more robust and likely to survive a range of environmental challenges.

18. a) Succession (assuming no human intervention)

b) During succession established species alter the environment making it more suitable for other species to live in. An example of this is the decomposition of waste matter and dead established organisms that makes the soil more fertile and suitable for more complex plant species to grow in.

c) Natural disasters can reduce the genetic diversity of species. This is a random event and therefore the diversity lost is also random so individuals near the natural disaster are more likely to die whereas those positioned further away are less likely to die. This random loss of life is called genetic drift (or more specifically the bottleneck effect). A reduced genetic diversity can increase the risk of a species becoming endangered or extinct.

19. a) There are higher levels of nitrate and chlorophyll in lake 2 compared to lake 1. Nitrate is a mineral nutrient required and used by algae, which are photosynthetic organisms growing in the lake. Algae use nitrate to grow and make chlorophyll. Therefore, with increased nitrate availability for algae, they are able to grow and divide readily, leading to an algae bloom and a higher concentration of chlorophyll in lake 2.

b) Oxygen is used by organisms that are carrying out the process of aerobic respiration. In the lower levels of the lake these organisms are most likely to be decomposers, feeding on the increased numbers of plants, algae and phytoplankton which die and provide organic matter for them to decompose in lake 2.

20. a) Species diversity is generally reduced when foreign species are introduced to established ecosystems. This is because they can kill and eat native species that have not adapted to it as a predator. The introduced species may also not have a natural predator itself.

b) Species with similar niches have a large niche overlap and strong competition for the same resources. Generally, only one species can fill a specific niche, therefore the better competitor tends to survive and fill the niche whilst the other species is excluded. This can result in the other species moving to another ecosystem or becoming extinct.

c) (i) Some possible answers include:

- Farming communities have influenced the development of the Felixer. Foxes and some feral cats prey on animals such as chickens and if they penetrate chicken pens, they generally kill and consume the farmer's chickens. Any loss of livestock has an accompanied economic loss to replace the chickens and fix the chicken pen, so farming communities have been asking for help regarding fox and feral cat numbers.
- Environmentalists have been lobbying for help regarding the ever-growing number of feral cats that are consuming considerable numbers of native species every day. This lobbying has been heard by some branches of government that have supplied funding for research into developments that can help reduce feral cat numbers in a humane manner, influencing the development of the Felixer.

(ii) Some possible answers include:

- The Fleixer could have a positive influence on the environment and species biodiversity. As the Fleixer sprays the feral cats with a toxic gel and doesn't kill them immediately, the feral cats could make it back to their colony before cleaning themselves, increasing the chance of other cats from the colony also cleaning it and ingesting the toxic gel. This development could help to wipe out colonies of feral cats, reducing the number of native species they feed on.
- The Felixer could influence further research into using the technology to target other introduced species in a similar fashion around the world. The research would likely be focused on toxins that only affect the target species and effective audio to attract these invasive species to the Felixer.
- The Felixer could have a positive economic influence. A large workforce would be required to find and cull feral cat and fox populations across Australia, which is very expensive and would be ongoing. Instead, a once off fee to purchase the Felixers and the salaries of a much smaller workforce required to deploy and service the Felixers can be paid by government bodies. The money saved over time could then be used for other government needs.