SASTA South Australian Science Teachers Association

Supporting Teachers of Science
Advancing Science Education

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WORKBOOK Biology SASTA South Australian Science Teachers Association

SACE STAGE 1
Australian Curriculum

WORKBOOK

Biology

TOPICS
- Cells and microorganisms
- Infectious disease
- Multicellular organisms
- Biodiversity and ecosystem dynamics

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THIRD EDITION
Rhys Lewis

WORKBOOK

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SACE STAGE 1
Australian Curriculum

Biology

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Contents

About this book

The Third Edition of the popular SASTA Stage 1 Biology Workbook sets students on the path to success in their study of biology through its clear and engaging narrative, innovative use of art and photos, and superior contextual questions that enhance teaching and learning.

The Third Edition provides an unmatched comprehensive text fully mapped to the Stage 1 Biology Course in South Australia. The text is highly organised and emphasises essential biological concepts while keeping students engaged with learning outcomes that assess progress in understanding. The workbook has the concise, accessible, and engaging writing style of past editions while maintaining a clear emphasis on developing the reader's ability to apply their knowledge in new and familiar contexts rather than simply recalling it. Some major strengths of the text include its ability to develop critical thinking, problem-solving skills, comprehensive factual knowledge, and its aesthetically stunning artwork that represents complex topics clearly and succinctly.

The Third Edition provides hundreds of new Chapter Questions and four new Review Tests that assess student learning in the key areas of Science Understanding, Science Inquiry Skills and Science as a Human Endeavour. In addition, the workbook includes a comprehensive set of solutions to all Chapter Questions and Review Tests. Each chapter is written with a contextual-based approach accompanied by frequent assessment provides the intellectual challenge needed to promote critical thinking and ensure academic success. The engaging and challenging questions have made this a leading textbook of choice for biology students.

The Third Edition features an expanded text, providing students and teachers with greater content knowledge. In addition, the text has been supported with hundreds of new illustrations that engage students while simplifying complex concepts. Furthermore, the workbook has been updated to include recent contextual examples in all chapters that help students connect biology to the world around them. These are a few examples of the many changes in the Third Edition that provide students with scientifically accurate text, historical perspective, and relevant supporting details essential to a modern understanding of biology.

SASTA is excited about the Third Edition of this quality workbook. We are confident that the clarity of the text in combination with its assessment tasks will support students in building the mental models needed to understand biology. In addition, the book is written and reviewed by experienced biology teachers who use their teaching knowledge as a guide in producing an up-to-date text that is beautifully illustrated and pedagogically sound, helping students to learn faster, study efficiently, and retain more knowledge of key concepts.

This book will be updated as the curriculum changes. SASTA and the author wish to thank its members who have written to us to identify errors and offer suggestions for improvements. Your feedback has been invaluable and is deeply appreciated. SASTA and the author continue to welcome constructive feedback about the content and design of this book. We also wish to thank the readers and schools who use our physics, chemistry and biology workbooks. Your support is greatly appreciated.

Both SASTA and the author wish you all the best with your studies in Stage 1 Biology, and we remind you that our Stage 2 Biology workbook is available for purchase if you wish to pursue Biology at Stage 2.

CHAPTER 1

TOPIC 1: CELLS AND MICROORGANISMS

Eukaryotic Cells

Eukaryotes are more complex living things that likely evolved from prokaryotes in endosymbiotic events between 1.5 and 2.5 billion years ago. Eukaryotes comprise one of the three domains of living things, called **Eukarya** which includes the four kingdoms: protists, fungi, animals, and plants (Figure 1.26). Eukaryotic cells are much larger than prokaryotic cells, ranging from 10 to 100 micrometres in length. In addition, the basic shape of the eukaryotic cell is spherical; however, the shape is ultimately determined by the specific function of the cell. Thus, the cell's shape may be variable (i.e., frequently changing) or fixed. For example, variable or irregular shape occurs in Amoeba and white blood cells (leucocytes), and fixed shape occurs in almost all protists (e.g., *Euglena*, *Paramecium*), plants and animals. Furthermore, the number of cells varies from one in a unicellular eukaryote such as yeast and protozoa and protophyta (protists) to many cells in multicellular organisms such as fungi, plants and animals.

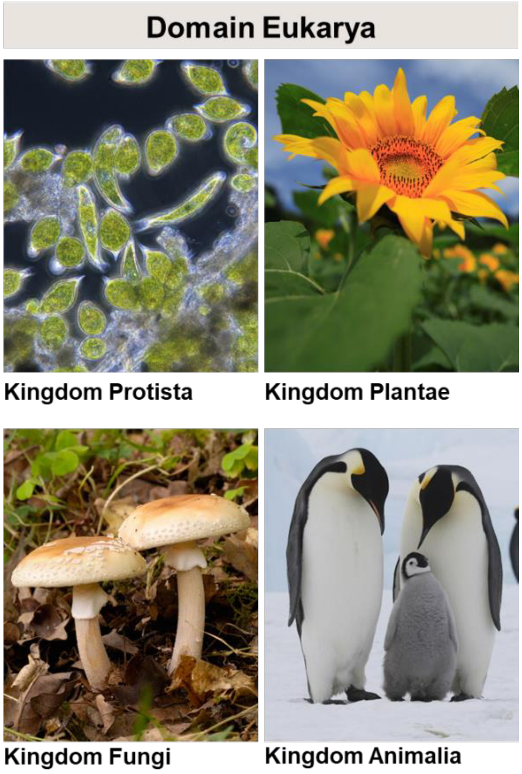


Figure 1.26: Eukaryotes

The defining feature of eukaryotic cells is a **nucleus** that stores the hereditary material. In fact, the term eukaryote is derived from the Greek meaning "nucleated." In eukaryotes, the hereditary material is on two or more linear chromosomes, each composed of a single DNA molecule wrapped tightly around globular proteins called **histones**. The chromosome number ranges in eukaryotes from two to more than a thousand. Figure 1.27 is TEM of a cell nucleus in a thyroid follicular cell from a mouse. The nucleus is seen at the left of the cell. The chromosomes are visible as a light blue mass.

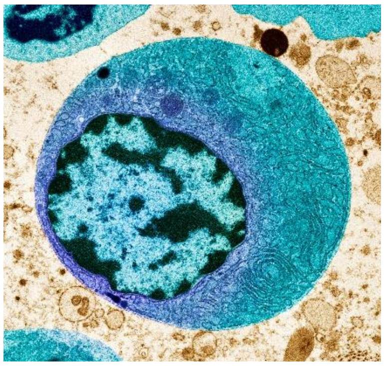


Figure 1.27: Thyroid cell

In addition to the nucleus, the cytoplasm of a eukaryotic cell contains many membrane-enclosed organelles, literally meaning "tiny organ". Each organelle in a eukaryotic cell is isolated from the cytosol by a lipid bilayer membrane similar to the cell membrane. Within an organelle is a specialised set of proteins and other molecules that facilitate one or more essential processes in the cell, including respiration, protein synthesis and cell division. Figure 1.28 is a TEM of a nerve cell showing several organelles, including the nucleus at the bottom right of the image.

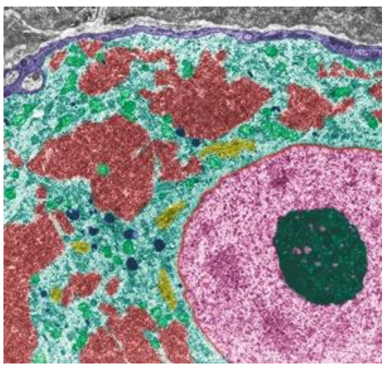


Figure 1.28: Organelles

Analysis of the cell structure of thousands of animal and plant species has revealed structural features common to all eukaryotes and others found in certain species only. Some of these features are illustrated in the generalised animal and plant cells shown in Figure 1.29.

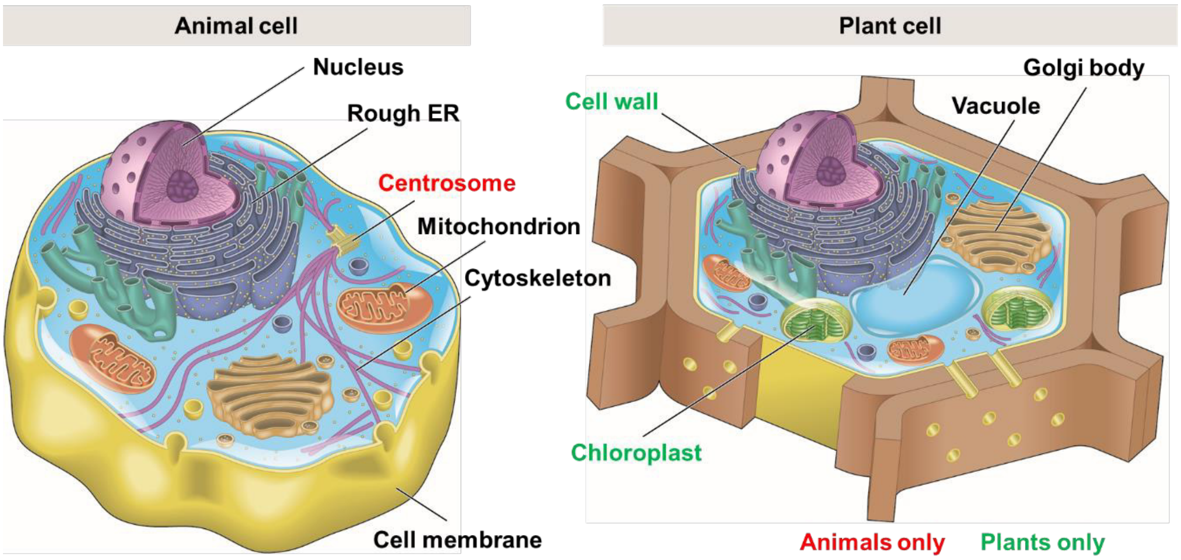


Figure 1.29: The general features of eukaryotic animal and plant cells.

The outer covering of a eukaryotic cell comprises one or two layers. The innermost layer is the cell membrane which has a similar structure and function to prokaryotes. The cell membrane is the outermost layer in animal cells, but plants, fungi and some protists contain a cell wall that encloses the membrane. The cell walls of eukaryotes differ in structure and composition, with plants containing cellulose and fungi containing chitin. Figure 1.30 is TEM showing several yeast cells with the cell walls coloured blue.

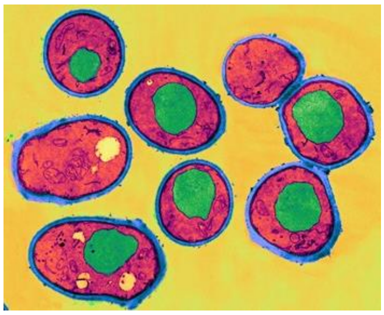


Figure 1.30: Cell walls in yeast

The cell membrane encloses the cytoplasm, which is filled with cytosol. The cytosol in eukaryotes dissolves a great variety of small molecules involved in metabolism. The cytosol also contains fibres that maintain cell shape, control mobility and provide anchoring points for other cellular structures, including organelles. Collectively, these fibres are called the **cytoskeleton**. The thickest fibres are the **microtubules** (20 nm in diameter) that transport water and nutrients, separate chromosomes during cell division, and are the primary structural proteins in motile organelles such as cilia and flagella. The thinnest fibres are the **microfilaments** (7 nm in diameter) that maintain cell shape and form the contractile component of cells, mainly muscle cells. The middle-order fibres are the **intermediate filaments** (10 nm in diameter) that facilitate cell cohesion and prevent cell damage under tension. Figure 1.31 is a fluorescent light micrograph of two fibroblast cells, showing their cytoskeletons composed of microtubules (yellow) and microfilaments (blue).

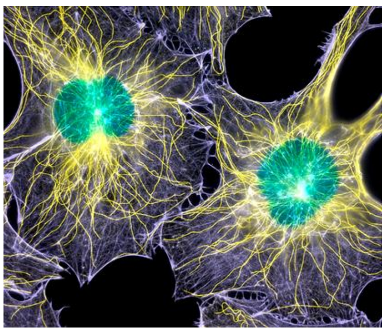


Figure 1.31: Cytoskeleton

Plant cells contain organelles called **plastids** that contain pigments and may synthesise and accumulate various substances. Examples of plastids include **amyloplasts** (Figure 1.37) that store starch, **proteinoplasts** that store protein, **elaioplasts** that store fats and oils and **chromoplasts** that contain coloured pigment molecules. Chromoplasts impart various colours to plant cells, including the colours of fleshy fruits and flower petals. The green-coloured chromoplasts in algae and plants are called **chloroplasts**. Chloroplasts (Figure 1.38) contain a green pigment called **chlorophyll** that facilitates photosynthesis, producing glucose for respiration. Like mitochondria, each chloroplast is bound by two membranes, both of which have no chlorophyll. However, unlike mitochondria, there is a third system of membranes within the inner membrane boundary, called **grana**. A chloroplast contains many interconnected grana on various photosynthetic enzymes and the molecules of green pigment chlorophyll and other photosynthetic pigments to absorb light. The grana are bathed in the fluid containing various photosynthetic enzymes, and starch grains called the **stroma**. The stroma also contains circular DNA molecules and ribosomes similar to those found in prokaryotes.

Animal cells have **centrosomes,** organelles that organise microtubules, including those comprising the spindle fibres produced in mitosis. A centrosome comprises two barrel-shaped clusters of microtubules called **centrioles** and a complex of proteins that help synthesise microtubules.

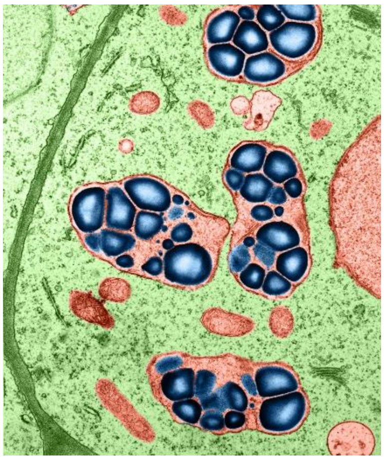


Figure 1.37: Amyloplasts

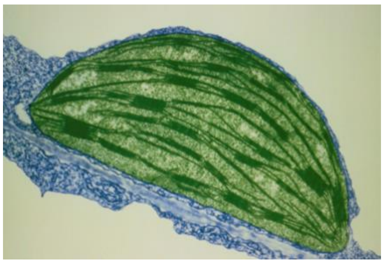


Figure 1.38: Chloroplast

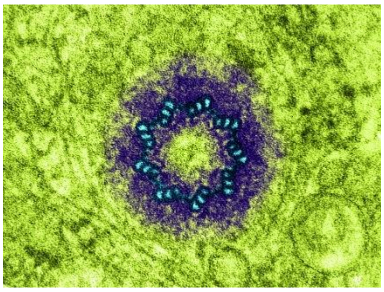


Figure 1.39: Centrosome

Comparing Prokaryotic and Eukaryotic Cells

Prokaryotic and eukaryotic cells have similarities and differences (Figure 1.40). Each contains a cytoplasm filled with cytosol that is enveloped by a cell membrane. In addition, both cells contain thousands of protein molecules that facilitate the chemical processes that give rise to the characteristics of living things. These proteins are assembled by ribosomes using the information stored on DNA molecules. Finally, both cells are powered using energy stored in adenosine triphosphate (ATP) molecules.

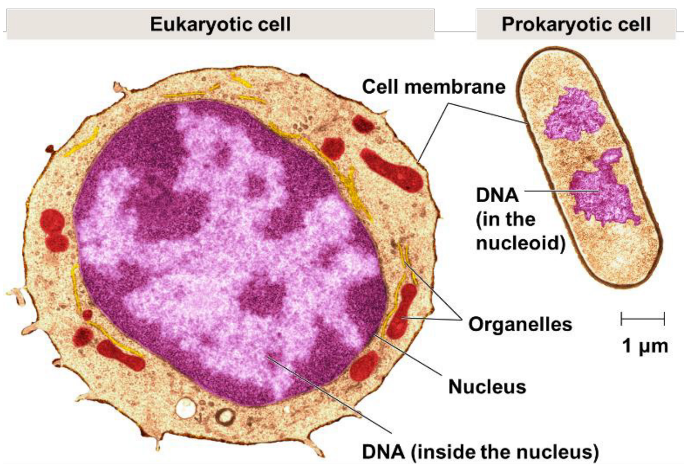


Figure 1.40: TEM showing the two cell types.

However, there are many significant differences in the structures of prokaryotic cells and eukaryotic cells. First, prokaryotic cells are much smaller than eukaryotic cells. Second, most of the DNA is in a membrane-bound organelle called the nucleus in a eukaryotic cell and is concentrated in a region of the cytoplasm called the nucleoid in a prokaryotic cell. Third, prokaryotes contain a single, circular chromosome, whereas eukaryotic cells contain multiple linear chromosomes (Figure 1.41). Finally, eukaryotes contain membrane-bound organelles that facilitate specialised functions that typically occur in the cytoplasm in prokaryotic cells.

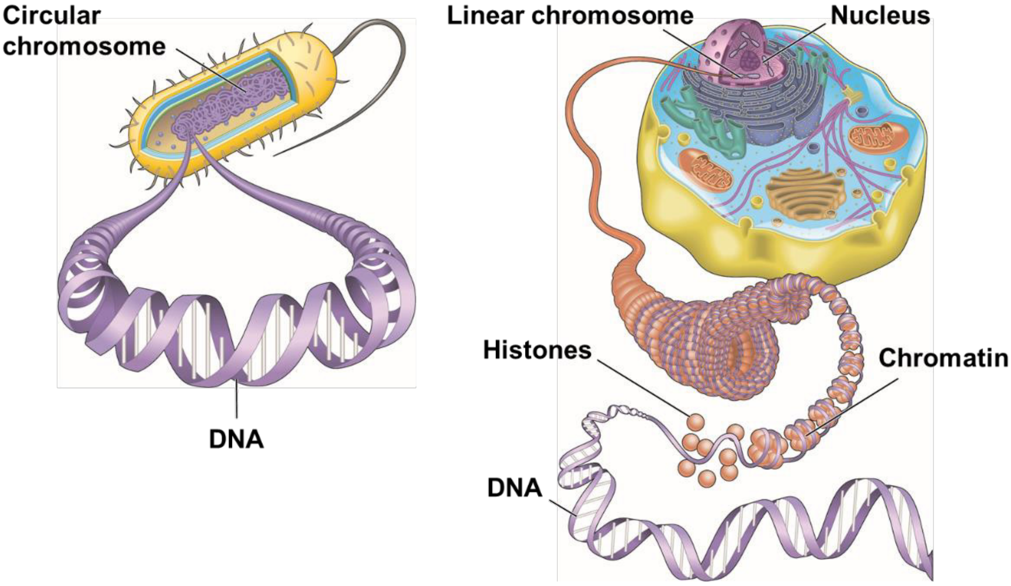
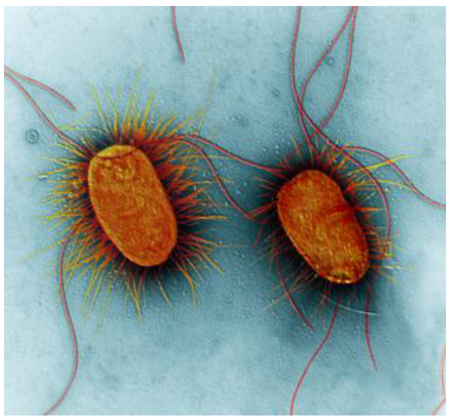


Figure 1.41: Chromosome structure in prokaryotes and eukaryotes.

Question 6

The TEM opposite shows two *Escherichia coli* bacteria.



(a) The long filaments are flagella.

(1) State the function of flagella in bacteria.

______________________ (1 mark) **KA1**

(2) Describe how flagella achieve this function.

____

____

______________________ (1 mark) **KA1**

(b) The diagram also shows a large number of spiky filaments on the surface of each bacterium.

(1) Name the spiky filaments.

______________________________ (1 mark) **KA1**

(2) State one function of the spiky filaments in bacteria.

____

______________________________ (1 mark) **KA1**

Cell Division in Eukaryotes

Eukaryotes contain multiple linear chromosomes, each composed of DNA molecules coiled tightly around globular proteins called **histones**. Before a eukaryotic cell can divide, it must copy each chromosome in the parent cell so that each daughter cell contains a complete set of chromosomes upon division. In most eukaryotes, cell division involves two steps, the division of the nucleus, called **mitosis** and the division of the cytoplasm, called **cytokinesis**. Collectively, this process is referred to as **mitotic cell division** and is common in most eukaryotes, including fungi, animals and plants. As a process, mitosis is remarkably similar in all eukaryotes and is divided arbitrarily into the stages or phases illustrated in Figure 1.43.

Before mitosis, the chromosomes occur in the form of long, decondensed fibres. In animals cells, the centrosome is replicated in preparation for mitosis, as in Figure 1.43 (1). The first phase of mitosis, called **prophase**, begins with thin-threadlike chromosomes condensing into X-shaped bodies visible under an optical microscope. Each X-shaped chromosome is composed of two identical DNA molecules, each called a **sister chromatid** held together by a DNA-containing region, called the **centromere**. During early prophase, the centrosomes migrate to opposite poles of the cell and begin synthesising long microtubules called **spindle fibres,** as in Figure 1.43 (2). In plants, this occurs in the absence of centrosomes. In late prophase, the nuclear membrane is broken down, and the spindle fibres attach to the centromeres and begin organising the chromosomes, as in Figure 1.43 (3). The second phase, called metaphase, begins with the spindle fibres arranging the chromosomes along the cell's equator, as in Figure 1.43 (4). The third phase, called **anaphase**, begins with breaking the centromeres and the separation of sister chromatids, each being pulled to opposite ends of the parent cell by contracting spindle fibres, as in Figure 1.43 (5). The final stage of mitosis, called **telophase**, is prophase in reverse and begins with the reformation of the nuclear membrane around each group of chromosomes to form daughter nuclei and concluding with the chromosomes decondensing, as in Figure 1.43 (6). Mitosis typically lasts one hour in animal and plant cells.

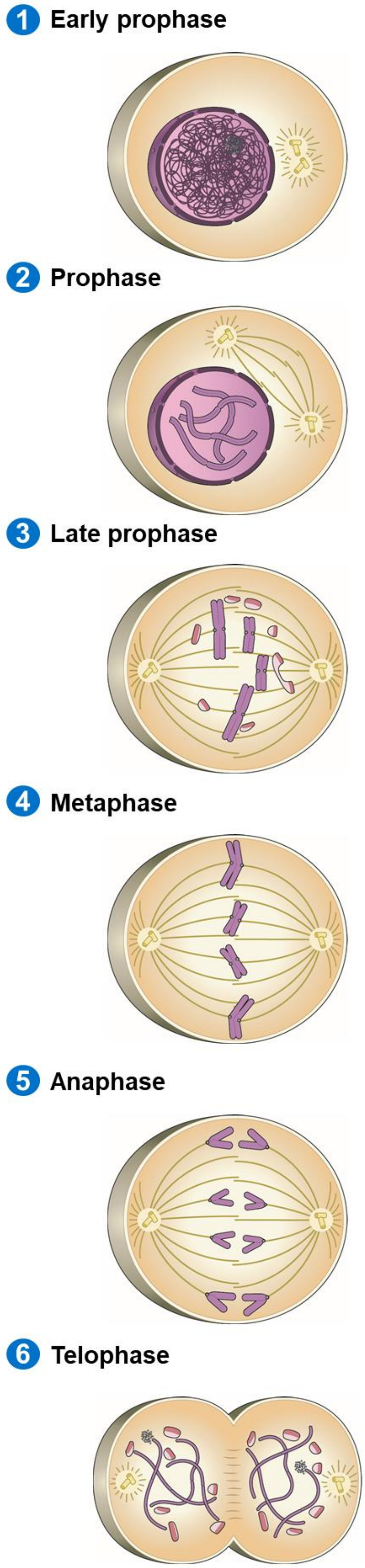


Figure 1.43: Mitosis in eukaryotes

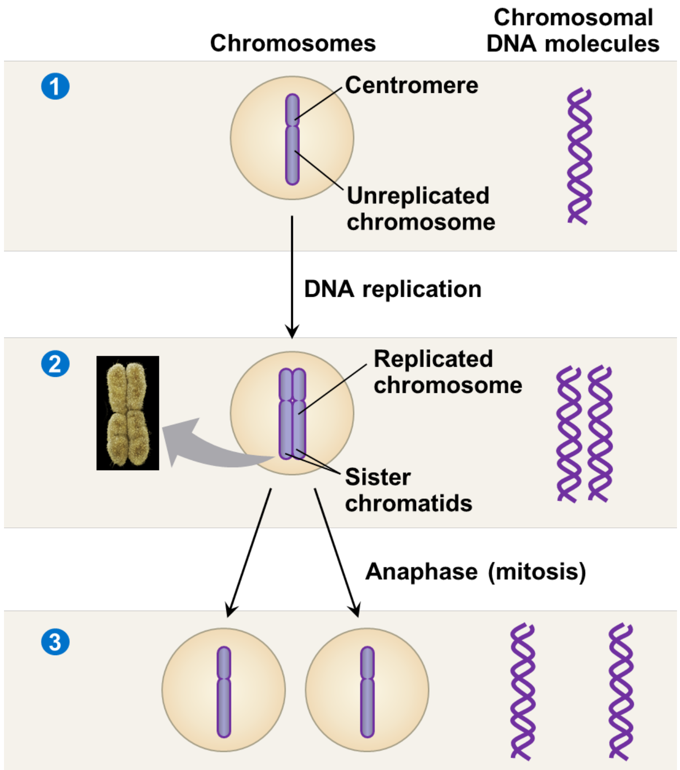


Figure 1.44: Chromosome changes in eukaryotes

The purpose of DNA replication and mitosis is to ensure that each daughter cell produced in cell division has the complete set of chromosomes required to carry out all life processes. Before DNA replication, each DNA molecule is arranged into a linear structure called an **unreplicated chromosome**, as shown in Figure 1.44 (1). During DNA replication, each unreplicated chromosome is copied, and the two copies are joined, forming a **replicated chromosome** (Figure 1.44 (2)). While bound as a replicated chromosome, the two chromosomes are referred to as **sister chromatids**. The two chromatids are separated during anaphase, and each daughter cell inherits one sister chromatid (Figure 1.44 (3)), producing genetically identical daughter nuclei.

DNA replication and mitosis are coupled to cytokinesis, the constriction of cytoplasm into two separate cells. During cytokinesis, the cytoplasm divides by a process called **cleavage**. Cytokinesis usually begins in anaphase and continues through telophase. The first sign of cleavage in animal cells is the furrowing of the cell membrane at the cell's equator during anaphase. Cleavage is accomplished by contracting a ring composed mainly of protein filaments. The **contractile ring** assembles in early anaphase; once assembled, it develops a force large enough to pull the cell membrane down into a furrow that physically cleaves the parent cell in two, as in Figure 1.45 (1). In plants, vesicles containing cell wall and membrane components are assembled along the equator of the cell. The vesicles fuse into a structure called the **cell plate** which, upon completion, separates the parent cell into two daughter cells, as in Figure 1.45 (2).

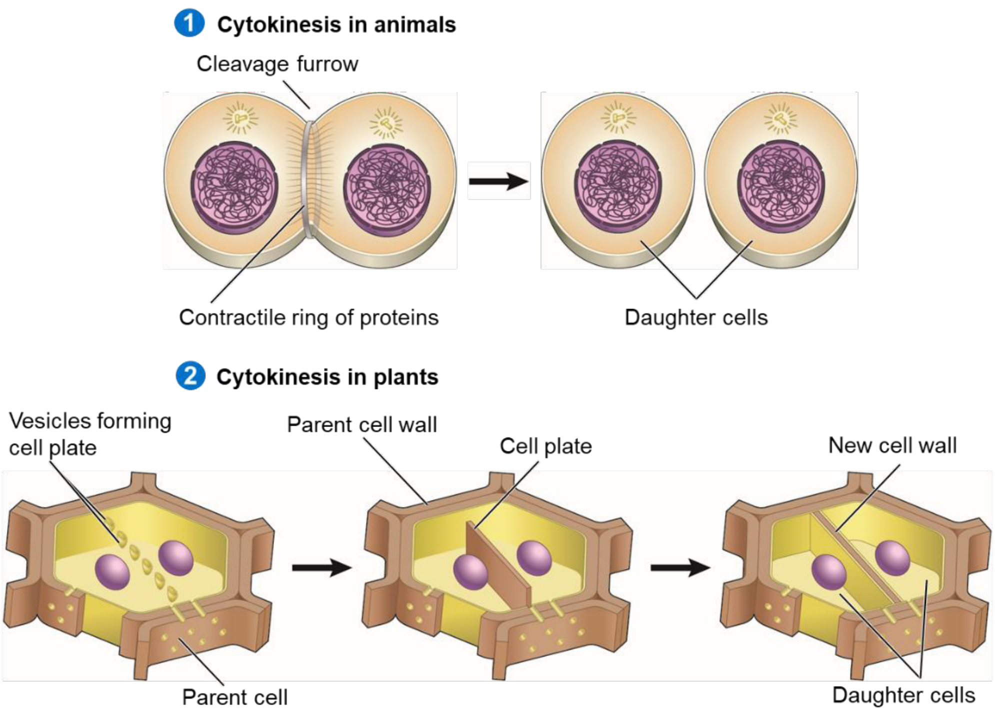


Figure 1.45: Cytokinesis in animals and plants.

1.4: Nutrition, respiration and excretion

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 the removal of wastes.

Living things require energy to maintain life processes, including growth, excretion and sensitivity. This energy is used in various processes at the cellular level, including active transport, DNA replication, and protein synthesis. Living things derive energy from their environment. Some living things absorb energy from sunlight, while others absorb the energy released in the chemical reactions of organic and inorganic molecules extracted from their environment. Living things are characterised into two broad categories based upon how they obtain energy and nutrients.

Autotrophs

Most living things derive energy from the breakdown of energy-rich nutrients such as carbohydrates and fats. These energy sources are defined as **food sources**. Living things that synthesise their food using energy and inorganic molecules in the environment are called **autotrophs**. For example, plants, phytoplankton and green algae are **photoautotrophs** that synthesise carbohydrates and other energy-rich molecules using light, carbon dioxide, and water in photosynthesis. In contrast, some prokaryotes are **chemoautotrophs** that synthesise energy-rich molecules using the energy released in the chemical reactions of inorganic molecules. Autotrophs play an essential role in ecosystems as **primary producers,** transforming sunlight into other energy forms that **consumers** may utilise. Examples of photoautotrophs and chemoautotrophs are shown in Figure 1.48.

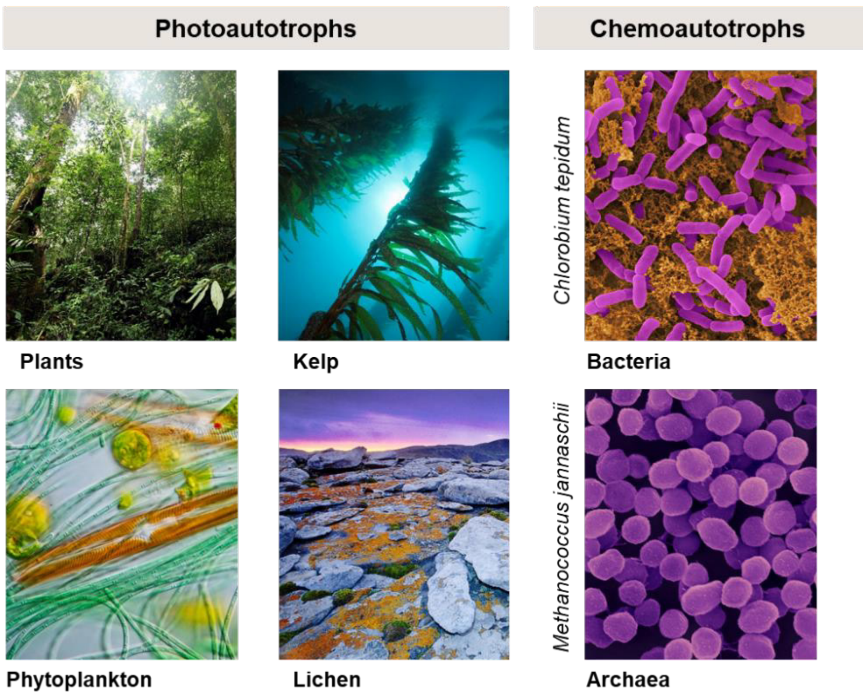


Figure 1.48: Autotrophs

Heterotrophs

Living things that derive their food from living or formerly living things are called **heterotrophs**. A heterotroph typically obtains energy and nutrients by eating and digesting other living things, usually plants and animals, for energy and nutrients. Thus, heterotrophs are consumers in ecosystems as they consume producers or other consumers.

Heterotrophs that eat plants exclusively are called **herbivores**, those that eat animals exclusively are called **carnivores**, and those eating plants and animals are called **omnivores**. Heterotrophs that consume dead and decaying matter are called **detritivores**. These organisms obtain food by feeding on the remains of plants and animals as well as faecal matter. Examples of heterotrophs are shown in Figure 1.49.

Figure 1.49: Heterotrophs

Photosynthesis

The Sun is the principal energy source in the majority of ecosystems on Earth. The Sun's light contains energy that photoautotrophs transform into chemical energy in **photosynthesis**. Photosynthesis is a complex chemical process that uses sunlight to transform carbon dioxide and water into oxygen and the nutrient glucose ($C_6H_{12}O_6$). Photoautotrophs contain light-absorbing molecules such as **chlorophyll** stored in **thylakoid membranes** in the cytoplasm of prokaryotes like bacteria and the chloroplasts of eukaryotes like plants, as shown in Figure 1.50. The absorption of light by chlorophyll molecules initiates the process of photosynthesis. The process concludes with the energy stored in chemical bonds between atoms in glucose molecules. Thus, photosynthesis is an essential chemical process that supplies photoautotrophs with the glucose required for respiration. The process of photosynthesis is summarised by the word and symbol equations below.

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

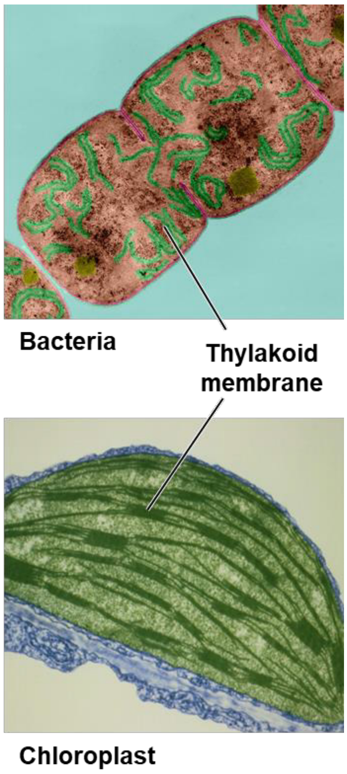


Figure 1.50: Thylakoid membranes in prokaryotes (top) and eukaryotes (bottom)

1.5: The cell membrane

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.

In Chapter 1.4, we explored some materials required for metabolism, including water, gases, nutrients, ions, and the waste products of metabolism. This chapter explores how materials move in and out of cells—a process controlled by the cell membrane.

The Cell Membrane

The **cell membrane**, also called the **plasma membrane**, is the boundary that separates a cell from its surroundings. A cell membrane encloses prokaryotic and eukaryotic cells and exhibits selective permeability, allowing some materials to cross it more readily than others. The selective permeability of a cell membrane is due to its chemical composition and structure. The cell membrane is composed of lipids, proteins and carbohydrates, with the relative proportions varying between prokaryotes and eukaryotes. The most abundant lipids in the cell membrane are **phospholipids**. Phospholipids are molecules containing **hydrophobic** ("water-hating") and **hydrophilic** ("water-loving") regions. When placed in water, phospholipid molecules assemble spontaneously into a bilayer with the hydrophobic tails directed to the centre of the bilayer and the hydrophilic heads directed to the surface, as in Figure 1.60. This arrangement allows the phospholipid bilayer to act as a stable boundary between two aqueous compartments, such as the cytoplasm and the cell's external environment.

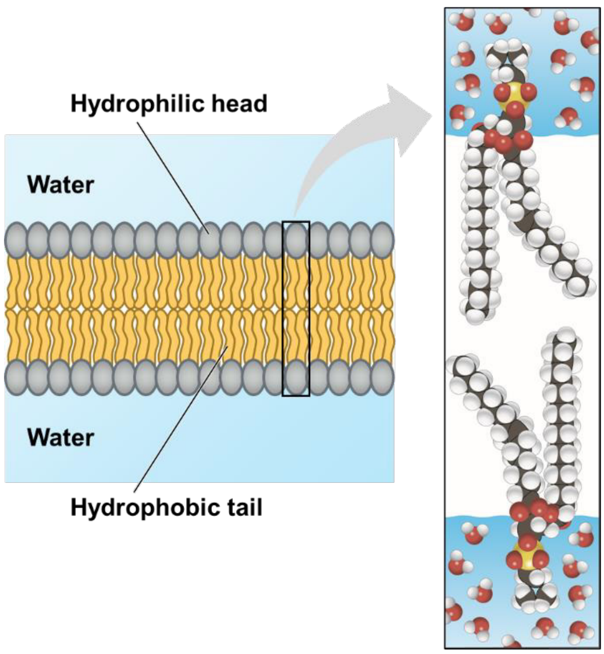


Figure 1.60: Phospholipid bilayer

The cell membrane is highly fluid as the phospholipids and other molecules move freely within the bilayer. Most phospholipids drift laterally, but some will occasionally flip-flop transversely across the membrane. Most membranes contain lipids called **sterols** that regulate fluidity. In animal cells, fluidity is regulated by **cholesterol,** a sterol embedded between phospholipid molecules in the bilayer, as in Figure 1.61. At warm temperatures, cholesterol restrains phospholipids, restricting their lateral movement. At cool temperatures, it prevents phospholipids from packing tightly.

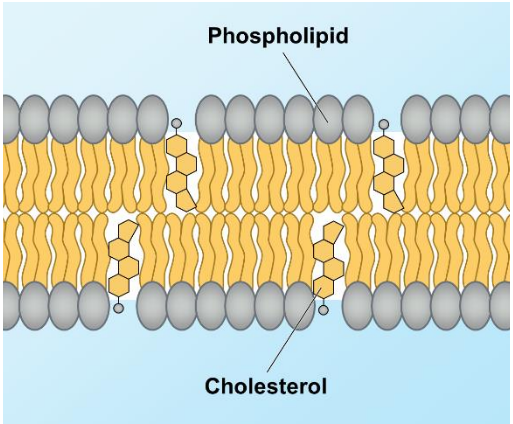


Figure 1.61: Cholesterol molecules

In addition to lipids, the cell membrane contains hundreds of different proteins. Proteins form the majority component of most membranes, averaging 50% of the total composition. Some of these proteins are bound to the hydrophilic surface of the membrane, and others penetrate the hydrophobic core. Proteins attached to the surface of the membrane are called **peripheral proteins**, and those penetrating the lipid bilayer are called **integral proteins**. In 1972, American biologists S.J. Singer and G.L. Nicolson suggested the widely accepted **fluid mosaic model**, which states that a biological membrane is a mosaic of different protein molecules attached to or embedded within the fluid matrix of the lipid bilayer. The fluid mosaic structure of the cell membrane is illustrated in Figure 1.62.

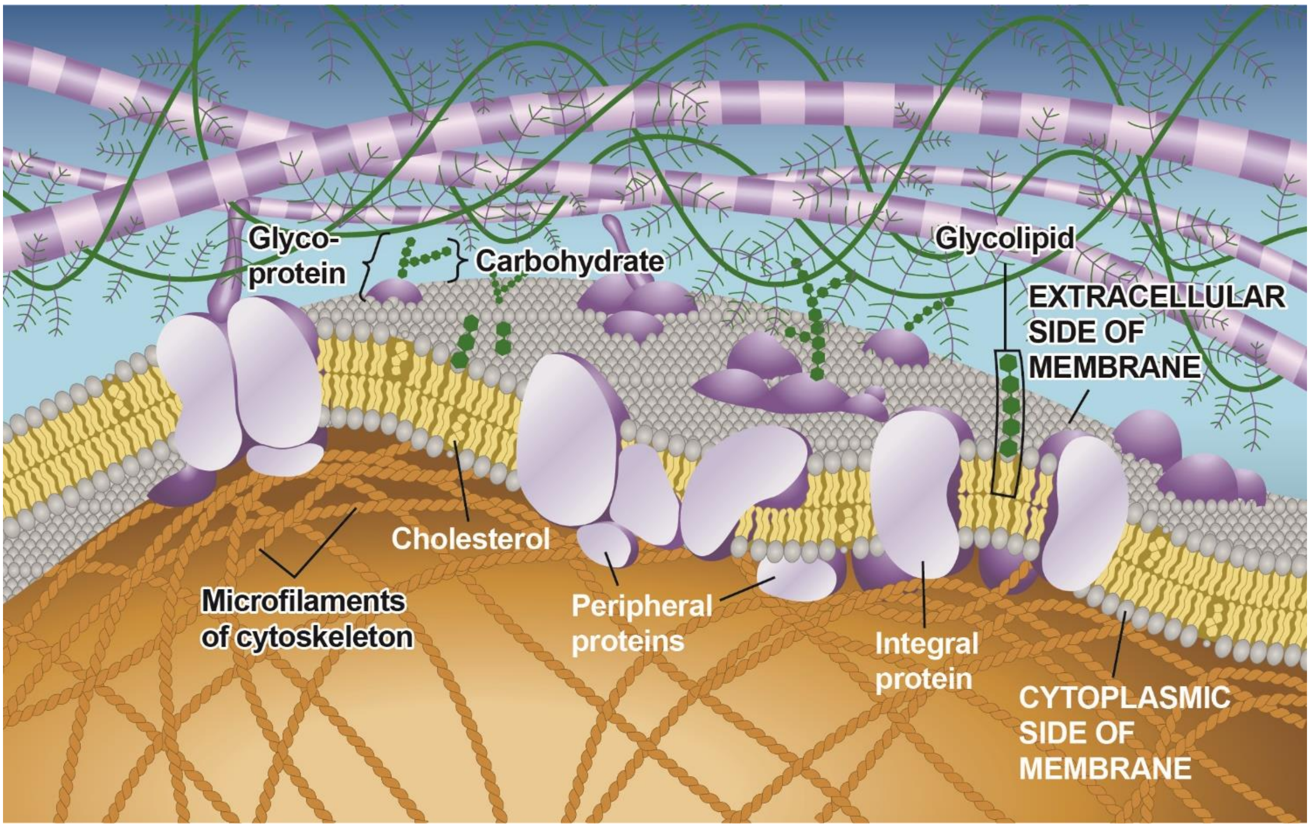


Figure 1.62: The fluid mosaic structure of the cell membrane.

The peripheral and integral proteins of the cell membrane are not randomly distributed. Instead, most proteins occupy a specific membrane region where they carry out various functions depicted in Figure 1.63. The most common function of membrane proteins is the transport of materials between the cell and its surroundings. In addition, many essential enzymes are embedded in the cell membrane, and these catalyse specific metabolic reactions. Furthermore, some membrane proteins act as receptors for signal molecules that cause changes in cellular activities, while others help cells recognise one another, which is essential in normal development and immunity. Finally, some membrane proteins anchor cells to each other and the **extracellular matrix (ECM)** in animals.

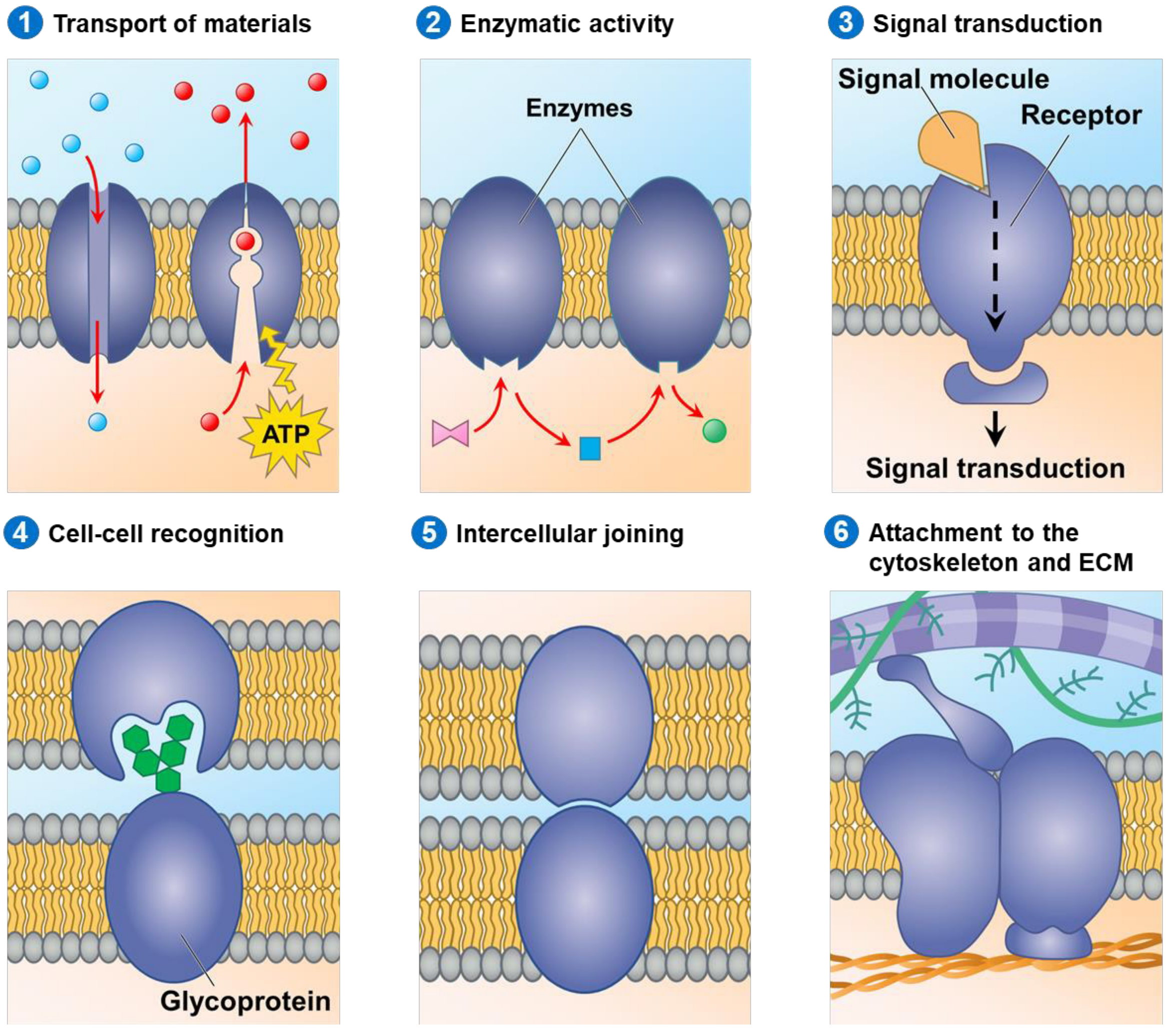


Figure 1.63: The fluid mosaic structure of the cell membrane.

In addition to lipids and proteins, the cell membrane contains a small percentage of carbohydrates. Carbohydrates may be covalently bonded to lipids (forming **glycolipids**) or more commonly to proteins (forming **glycoproteins**) on the external side of the cell membrane. The type of carbohydrate molecules that form glycoproteins and glycolipids vary among species, individuals, and even cell types in an individual. Both glycolipids and glycoproteins play an essential role in cell-cell recognition, a process in which different cells bind to each other using molecules, often containing carbohydrates, on the extracellular surface of the cell membrane. Cell-cell recognition typically triggers a response such as communication, cooperation, transport, defence, or growth.

Hydrophobic materials diffuse rapidly across a cell membrane as they dissolve readily in the hydrophobic interior of the lipid bilayer. However, hydrophilic materials do not readily dissolve in the hydrophobic interior and move across membranes with the help of specific transport proteins, a process called **facilitated diffusion**. For example, channel proteins transport hydrophilic solutes across the membrane through a hydrophilic tunnel (Figure 1.68), while carrier proteins bind their passenger, change shape, and release their passenger on the other side. In both cases, the transport is passive as the protein helps a specific substance diffuse across the membrane down its concentration gradient, requiring no energy input.

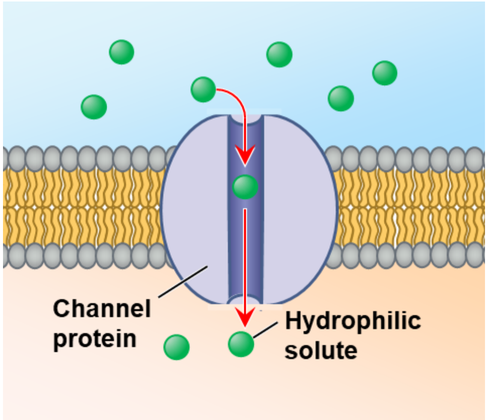


Figure 1.68: Facilitated diffusion

In contrast, some materials are transported against their concentration gradient, a process called **active transport** that requires ATP. In active transport, a substrate binds to a specific transport protein that changes shape using ATP (Figure 1.69). The change in shape causes the protein to transport the solute against its concentration gradient.

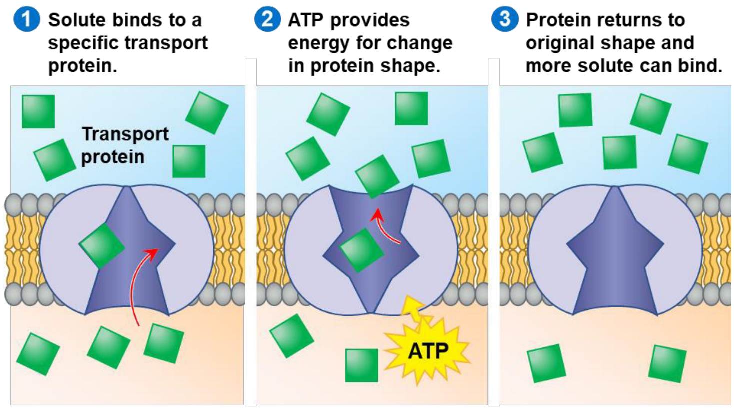


Figure 1.69: Active transport

Small molecules enter or leave the cell through the lipid bilayer or via transport proteins. In contrast, large molecules, such as proteins, cross the membrane in bulk via vesicles in an active process called **bulk transport**. A cell has two bulk transport mechanisms called **endocytosis** and **exocytosis.** Endocytosis moves large molecules into a cell, and exocytosis moves them out. In both cases, the material is packaged within a vesicle that fuses with the membrane. In endocytosis, the cell takes in large molecules by forming vesicles from the cell membrane. In exocytosis, transport vesicles migrate to the membrane, fuse with it, and release their contents outside the cell, as in Figure 1.70.

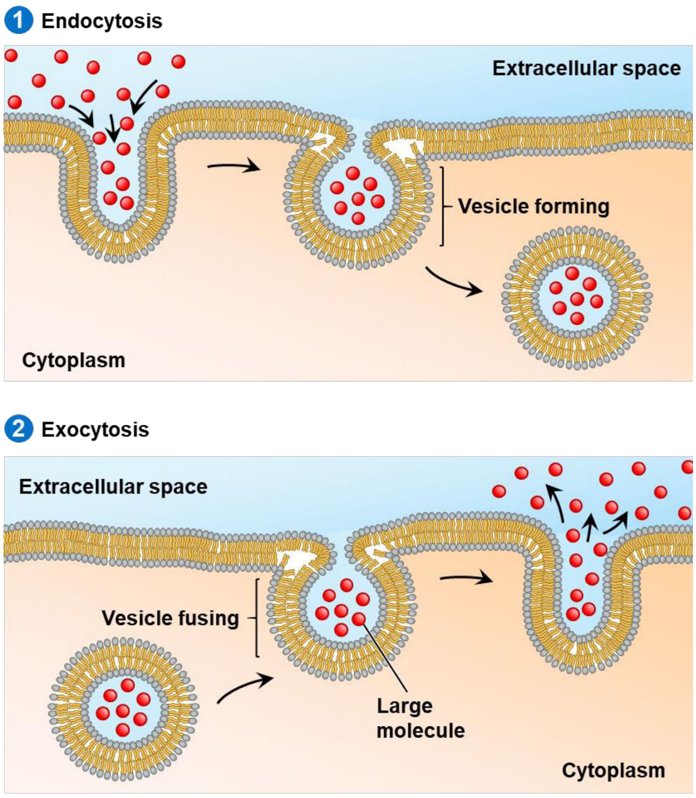


Figure 1.70: Bulk transport

pH

pH is a measure of the acidity, neutrality, or alkalinity of a solution. Microorganisms are highly sensitive to changes in pH inside their cytoplasm and outside the cell as acidic and alkaline environments alter the chemical structures of membranes, transport proteins and enzymes inside the cell, causing a cell to become metabolically inactive. For this reason, pH is a significant factor affecting the growth of microorganisms. Each species has a definite pH growth range and pH growth optimum. **Acidophiles** have their growth optimum between pH 0 and 5.5; **neutrophiles**, between pH 5.5 and 8.0; and **alkalophiles** prefer the pH range of 8.0 to 11.5 (Figure 1.87). In general, different microbial groups have characteristic pH preferences. Most bacteria and protists are neutrophiles, but some bacteria and photosynthetic protists prefer more acidic surroundings. In addition, fungi prefer a slightly acidic environment ranging from pH 4 to 6, and some archaea are extremophiles that grow in low pH environments. For example, *Sulfolobus acidocaldarius* inhabits hot springs and grows well between pH 1 and 3.

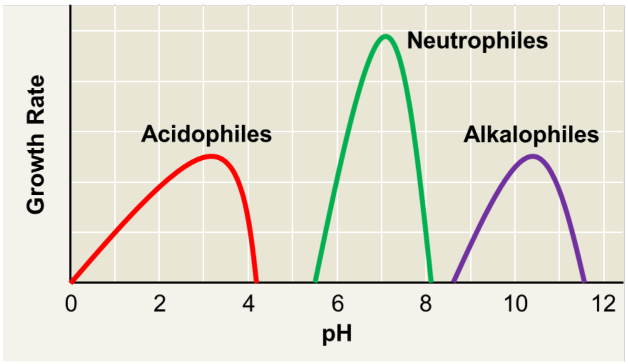


Figure 1.87: Effect of pH on microbial growth rate

Temperature

The growth rate of microorganisms is dependent on their environmental temperature. At higher temperatures, enzymes and transport proteins are denatured, and the lipid bilayer melts and disintegrates. At lower temperatures, water crystallises, and the rates of enzyme reactions and facilitated diffusion are reduced, effectively lowering the rate of metabolism in the cell. Microbial growth has a fairly characteristic temperature dependence with distinct **cardinal temperatures**, called the minimum, optimum, and maximum (Figure 1.88). Although the shape of the temperature dependence curve can vary, the temperature optimum is always closer to the maximum than to the minimum. The cardinal temperatures vary greatly between microorganisms, with **psychrophiles** preferring lower temperatures, **mesophiles** preferring moderate temperatures and **thermophiles** preferring higher temperatures.

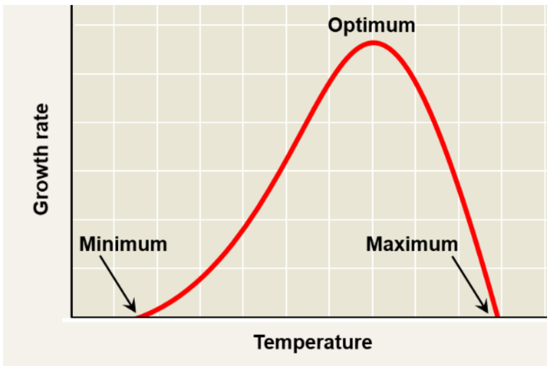


Figure 1.88: Effect of temperature on growth

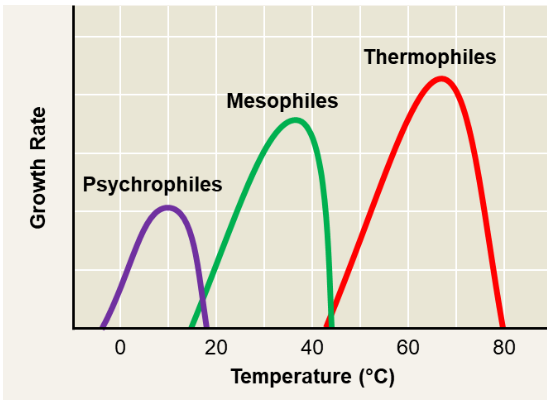


Figure 1.89: Temperature ranges for growth

Decomposers

Microorganisms play essential roles as **decomposers** in nearly every ecosystem on Earth. Decomposers are microorganisms, primarily bacteria and fungi, that decompose formerly living matter such as dead plants and animals and their components such as leaves. Decomposers produce and secrete enzymes that digest cells and macromolecules, releasing soluble nutrients that other living things may assimilate. Decomposers play a vital role in biogeochemical processes, including the carbon, nitrogen, and phosphorus cycles in ecosystems by recycling nutrients and making them available to other living things. For example, bacteria and fungi are essential decomposers in soils. Bacteria and fungi decompose formerly living matter, releasing nutrients that maintain soil structure and store water for plant use. Some of these nutrients are absorbed by plants through root hairs, as shown in Figure 1.90. The degradation of plant material by decomposers in soil occurs in three stages. Firstly, easily degraded compounds such as soluble carbohydrates and proteins are broken down. Secondly, complex carbohydrates, such as cellulose, are degraded by cellulase enzymes produced and secreted by fungi and bacteria of the genus *Streptomyces*, *Pseudomonas*, and *Bacillus*. Finally, lignin, the highly resistant structural component of woody plants, is broken down by *Basidiomycete* fungi and *Actinomycetes* bacteria. These organisms produce and secrete phenol oxidase enzymes needed for lignin degradation. The degradation of plant material produces soluble nutrients that plants and microorganisms utilise for metabolism and growth. Plants absorb these nutrients through root hairs.

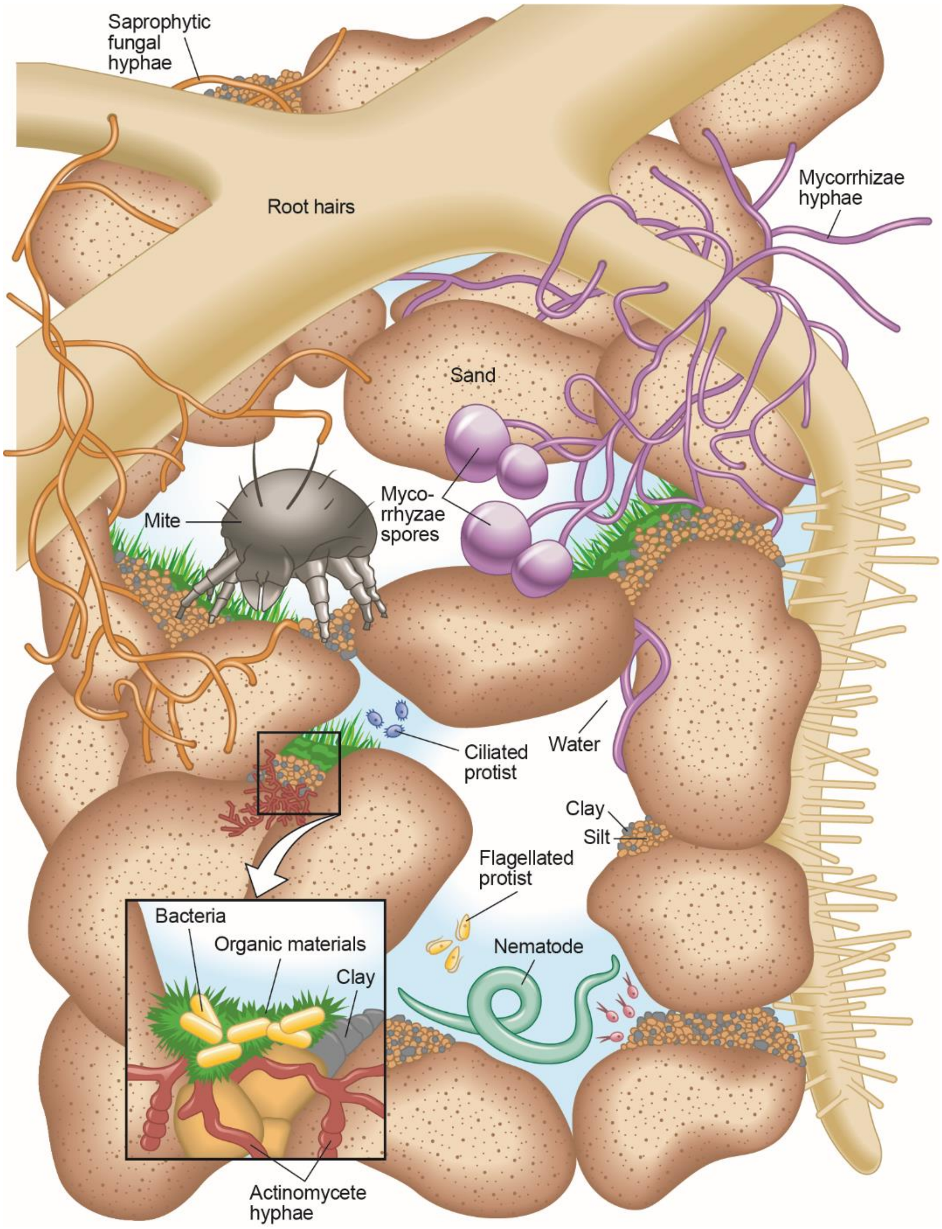


Figure 1.90: Soil habitat showing decomposers.

Preventing Microbial Food Spoilage

Around 10 000 years ago, humans began colonising land in groups and developing sustainable food sources through agriculture and farming. This transformation reduced the human dependence on hunting and gathering, but it introduced the need to preserve surplus food. Some of the first methods of **food preservation** occurred around 3000 B.C., including the use of salt and smoking to preserve meat, the production of cheeses and curds to preserve milk, and the use of sugar to preserve wines. However, despite efforts to minimise food spoilage, it was not until the nineteenth century that microbial food spoilage was understood. In 1857, French scientist Louis Pasteur (Figure 1.101) showed that microorganisms cause milk spoilage. Pasteur's work led to the development of techniques to control spoilage organisms in wines and beers.

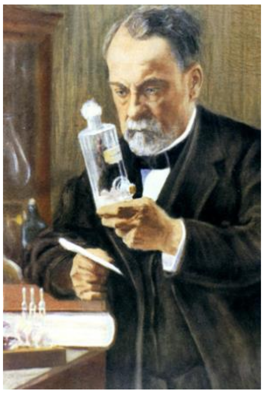


Figure 1.101: Louis Pasteur

A variety of methods are used in food preservation. **Filtration** removes microorganisms from liquids such as water, wine, beer, juices, and soft drinks. Several major beer brands are filtered to preserve the flavour and aroma of the original product. Figure 1.102 shows the filtration system at a large beer manufacturing plant.

Figure 1.102: Filtration system

Other methods of food preservation involve storing foods at low temperatures in a refrigerator or freezer, as in Figure 1.103. **Refrigeration** at 5°C or below slows microbial growth, although microorganisms eventually grow and produce spoilage with extended storage. Hence, although refrigeration slows the metabolic activity of most microbes, it does not lead to significant decreases in overall microbial populations. In contrast, controlling microbial populations in foods using high temperatures can significantly limit disease transmission and spoilage. **Canning** is a food preservation technique that involves heating food in special containers at 115°C for 25 to 150 minutes to kill food spoilage organisms before being sealed in cans, as in Figure 1.104. Canning effectively preserves foods for several years. Another technique, called **pasteurisation**, preserves liquids, including milk and beer. Pasteurisation involves heating foods above the maximum growth temperature for food-spoilage microbes for a fixed time interval. For example, milk is pasteurised by heating the raw material to 63°C for 30 minutes, 71°C for 15 seconds or 141°C for 2 seconds in the equipment shown in Figure 1.105. Shorter-term pasteurisation results in improved flavour and extended product shelf life.

Figure 1.103: Freezing food

Figure 1.104: Canning

Figure 1.105: Milk pasteurisation

Dehydration is a common technique of food preservation that inhibits microbial growth by removing water from food. Open-air drying using sunlight and wind has been practised since ancient times to preserve food and is commonly used to preserve fish, as in Figure 1.106. In addition, dehydration is achieved by adding salt and sugar to foods to produce a hypertonic environment that draws water out of microbes by osmosis. **Freeze drying** is a low-temperature dehydration process that involves freezing the food product, lowering pressure, then removing the ice by sublimation. Freeze drying is commonly used to preserve frozen foods.


Figure 1.106: Drying fish

Chemical-based preservation involves adding various chemical agents to foods, including simple organic acids, sulfites, nitrites, ethylene oxide, and ethyl formate. These chemical agents may inactivate microbial proteins, damage the cell membrane or damage DNA, preventing replication. For example, sorbic acid inhibits microbial growth by lowering the pH of microbial cells. For example, Figure 1.107 shows two bowls of cottage cheese; the bowl on the right contains sorbic acid and shows no microbial growth, whereas the bowl on the left has no sorbic acid and has visible mould growth.


Figure 1.107: Preserving cheese

Ionising radiation is also used in food preservation. For example, ultraviolet radiation is used to sterilise food handling equipment, and gamma radiation is used to sterilise moist food products, including seafood, fruits, and vegetables. Gamma radiation initiates the decomposition of water molecules into products that damage microbial DNA. For example, Figure 1.108 shows two groups of mushrooms. The group to the right was irradiated with gamma rays that inhibited microbial growth, whereas the mushrooms at the left were not irradiated and show microbial growth.


Figure 1.108: Irradiated food

Preventing Foodborne Disease

Foodborne diseases cause illness in more than 4 million Australians and 50 million people globally each year. Most foodborne diseases are transmitted by uncooked or contaminated food and are associated with poor food preparation or hygiene practices. A common mode of transmission is from unwashed hands to food. For this reason, hands must be washed thoroughly with soapy water (Figure 1.109) before, during and following food preparation. In addition, care must be taken to ensure food is cooked thoroughly and that utensils used to prepare one food are not used to prepare others to minimise the transfer of microorganisms between foods.


Figure 1.109: Washing hands

Quarantining carriers

When the risk of infection is high in a population, governments may choose to control the spread of disease by mandating that an infected or potentially infected individual be quarantined. **Quarantine** is the restriction of activities or separation of persons who may have been exposed to a pathogen and is considered to be a reasonable control in preventing the spread of contagious diseases like COVID-19, which are spread in airborne droplets. The term quarantine originally refers to self-quarantine or quarantine of selective individuals who are suspected to be carriers of the infection. However, a new term called **mass quarantine** is emerging nowadays, which primarily refers to the Government's enforced quarantine of a population to prevent the spread of a disease outbreak. A primary function of mass quarantine is to minimise the spread of the disease to allow hospitals to treat unwell patients (Figure 2.31) effectively. The curve refers to the projected number of people that a pathogen will infect over a certain period. The curve takes on different shapes, depending upon the rate of spread. A steep curve indicates the exponential spread of the disease in a shorter period, leading to the overloading of the health care system. This is particularly of importance in countries with a high population density and limited health care facilities. In contrast, a shallow curve represents a lower rate of spread, allowing health care providers to treat all infectious individuals effectively. The term **flattening the curve** means to slow down the rate of infection, which leads to lower stress on the health care system, and in this case, may also provide time to search for definitive treatments like a drug or vaccine. While quarantine has proven to be a successful technique in controlling the spread of infection, it is also argued that aggressive quarantine measures have severe economic, psychological, and social impacts on society.

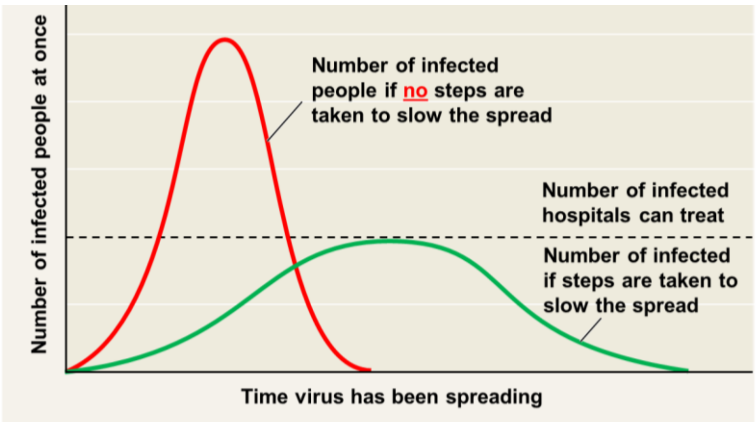


Figure 2.31: Disease curves

The immune response

The final method of disease control discussed in this section is the immune response of susceptible hosts in a population. The **immune response** refers to the process by which the host's immune system recognises a pathogen and defends itself. In general, a population with a high proportion of individuals with healthy immune systems are less susceptible to infection, causing the disease to spread at a lower rate. Conversely, a population containing a higher proportion of individuals with weakened immune systems is more susceptible to infection. For example, HIV-affected regions of Africa have higher instances of malaria and tuberculosis as HIV weakens the immune system, increasing the number of individuals susceptible to infection.

2.3: Infection

Pathogens have adaptations that facilitate their entry into cells and tissues, and 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 evade the immune system.

The first step in the infectious process is the attachment and entrance of a pathogen into a susceptible host and its cells. Entrance may be accomplished through one of the body surfaces such as the skin, respiratory system, gastrointestinal system, urogenital system, the conjunctiva of the eye or by sexual contact, needles, blood transfusions, organ transplants, or animal vectors. Regardless of the method of entry, the infection begins when the pathogen enters the body and alters the environment in such a way that causes disease in the host. In many cases, the pathogen enters host cells to reproduce while evading the host's immune system. This section describes the process by which pathogens enter host cells and cause infection.

Portals of Entry

An encounter with a potential pathogen is known as exposure or contact. The food we eat and the objects we handle are all ways to contact potential pathogens. Yet, not all contacts result in infection and disease. For a pathogen to cause disease, it needs to enter the body and access host tissue. A site on the host's body through which pathogens enter and pass into host tissue is called a **portal of entry**. Many of these sites are natural body openings such as the mouth, nose, ears, anus and genitals, but others are openings in the skin produced by wounds, bites and needles. The major portals of entry are identified in Figure 2.32.

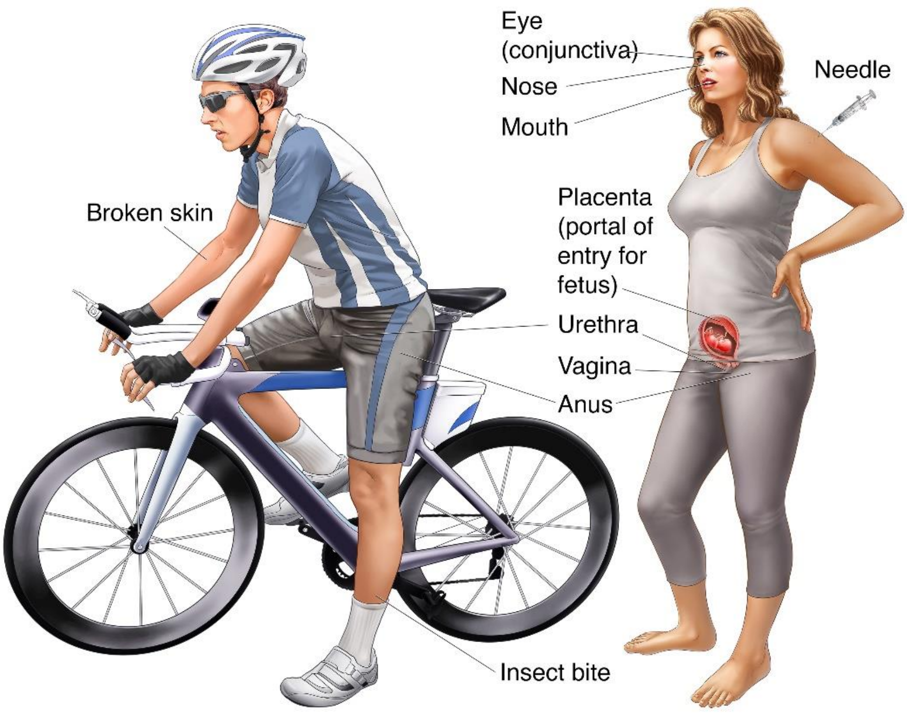


Figure 2.32: Portals of entry

Cellular Recognition

Many pathogens, including bacteria, viruses and protists, have adaptations that facilitate their attachment and entry to host cells and tissues. These organisms produce specific attachment proteins, usually glycoproteins, that bind to receptors embedded within host cell membranes. Attachment proteins are usually positioned on the pathogen's surface to maximise contact with host cells. Each attachment protein only binds to a complementary receptor on the host cell surface, as depicted in Figure 2.33. The binding of a pathogen to its receptor typically results in penetration of the pathogen or the delivery of its genetic material to the host cell's cytoplasm. In the case of human viruses, the genetic material enters the host cell, where it uses the host cell's replication machinery to produce copies of itself. The temperature, pH and nutrient availability of host cells provide an ideal environment for the growth and replication of a pathogen. In addition, pathogens utilise host cells as a means of evading host defences. By hiding inside host cells, a pathogen is protected from direct contact with immune cells and chemical factors such as complement proteins and antibodies.

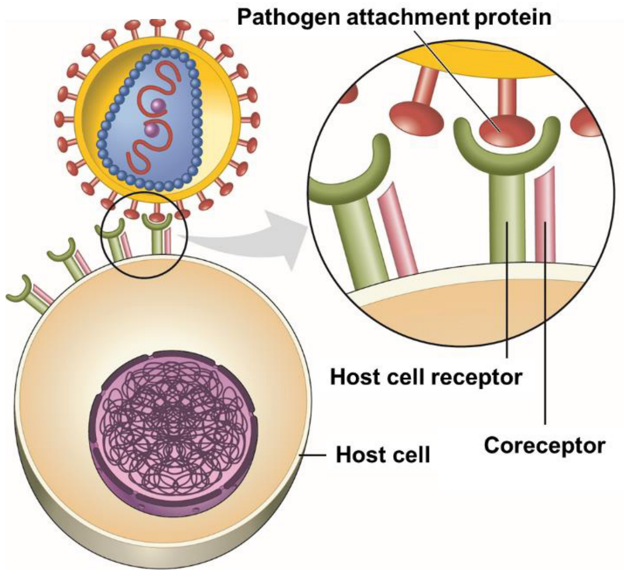


Figure 2.33: Host-pathogen binding

Question 71

Chickenpox is a highly contagious skin disease caused by the varicella-zoster virus (VZV). VZV enters the body in airborne droplets that are inhaled into the respiratory system.

(a) VZV produces glycoproteins that facilitate its attachment to respiratory epithelial cells.

Describe how VZV and respiratory epithelial cells recognise each other.

____

__________________________________ (1 mark) **KA2**

(b) VZV particles enter host respiratory epithelial cells where they replicate.

State why VSV replicates inside host cells.

____

__________________________________ (1 mark) **KA2**

(c) Following infection, VZV particles enter host nerve cells, where they hibernate for decades.

Suggest a reason why VZV hibernates inside nerve cells.

____

__________________________________ (1 mark) **KA2**

Physical Barriers

A pathogen invading a human host is immediately confronted with an array of **physical barriers** that act as the host's first line of defence against infection (Figure 2.35). The intact skin consists of thick, closely packed cells that form a very effective mechanical barrier to microbial invasion. Furthermore, secretions from sebaceous and sweat glands give human skin a pH ranging from 3 to 5, acidic enough to prevent microbial growth. Skin cells are frequently shed, removing pathogens from the body's surface. In addition, the **mucous membranes** of the eyes (conjunctiva) and the respiratory, digestive, reproductive and urinary systems withstand microbial invasion because the tightly bound epithelial cells form a protective covering that resists penetration. Furthermore, the cells in mucous membranes produce **mucus**, a viscous fluid that traps pathogens and other particles. In addition, many mucosal surfaces are bathed in specific antimicrobial secretions. For example, lacrimal glands bathe the eyes and skin in **tears** that are toxic to many bacteria. One antibacterial substance in these secretions is **lysozyme**, an enzyme that lyses bacteria by breaking down the cell wall. Mucus secretions also contain specific proteins that inhibit growth and prevent the attachment of microorganisms. Inhaled microbes are deposited on nasal hairs and mucous membranes lining the respiratory tract. Epithelial cells lining the respiratory tract have organelles called **cilia** (Figure 2.36) that trap and sweep microbes and mucus toward the mouth where they are expelled. In addition, microorganisms and mucus may be forcefully removed from the respiratory tract by **coughing and sneezing reflexes**. Pathogens entering the mouth are inactivated by saliva, and those reaching the stomach are inactivated by gastric juice, a mixture of acid, enzymes and mucus. Pathogens entering the ears are trapped by wax that protects against bacteria, fungi, and water-borne pathogens. Finally, urination removes pathogens in the bladder and urethra, and defecation removes those in the intestines and rectum.

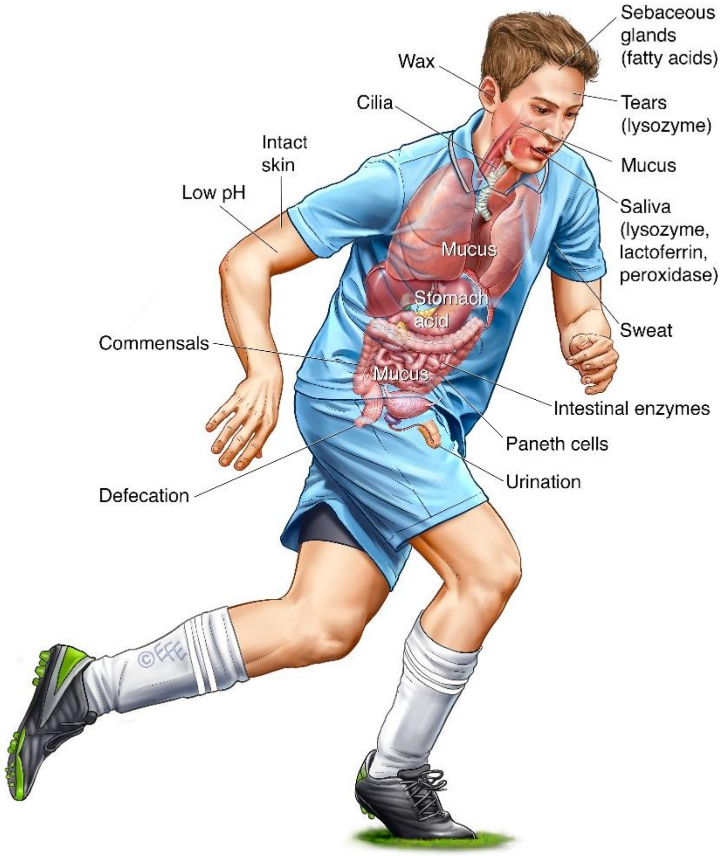


Figure 2.35: Physical barriers

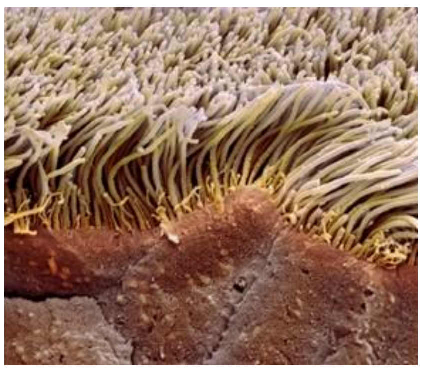


Figure 2.36: Respiratory cilia

Inflammation

So far, we have discussed the cellular components of the innate immune system and explained how these cells recognise and destroy pathogens before communicating their presence to the adaptive immune system. But how do the innate immune cells perceive an impending invasion by pathogens, and how do they defend the host? One part of the answer lies in the process known as inflammation.

Inflammation is an essential non-specific defence reaction to tissue injuries caused by pathogens or a wound. The **inflammatory response** begins when injured tissue cells release **chemokines**, chemical signals that activate nearby capillaries' inner lining (Figure 2.41). Within the capillaries, **selectins**, a family of cell adhesion molecules, are displayed on endothelial cells lining the capillaries near the tissue injury. These adhesion molecules attract and attach wandering neutrophils to the endothelial cells, causing them to stop flowing through blood. The neutrophils then squeeze through the endothelial wall of the blood capillary, migrate to the injury site, and phagocytose the pathogen. A local inflammatory response begins when neutrophils secrete signalling molecules that recruit phagocytes to the site of injury or infection. In addition, mast cells release the signalling molecule **histamine** at sites of damage. Histamine triggers nearby blood vessels to dilate and become more permeable. The resulting increase in local blood supply produces the classic symptoms of inflammation such as swelling, warmth and redness. White blood cells neutralise the pathogen and then remove waste material from the injured site, returning the body to a state of health.

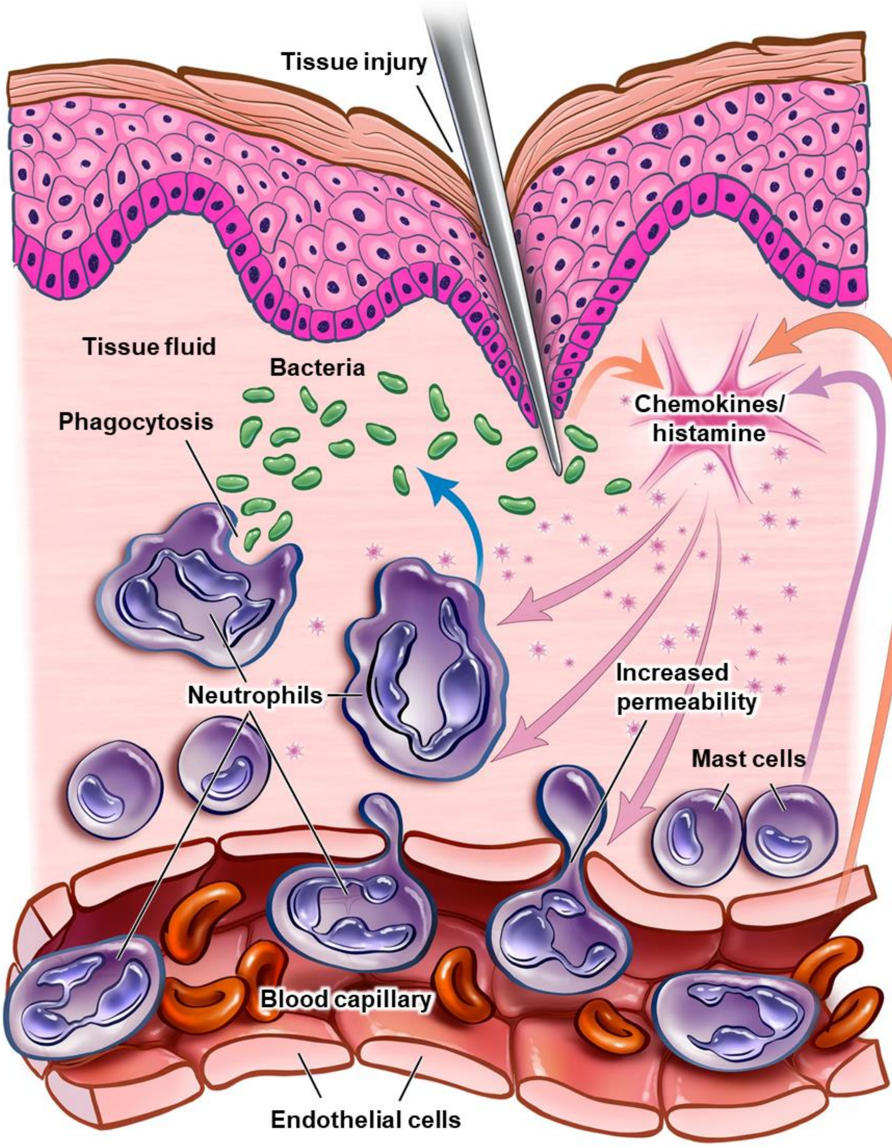


Figure 2.41: Inflammatory response

T cell Antigen Receptors

For a T cell, the antigen receptor consists of two chains, an α chain and a β chain with different structures (Figure 2.53). Near the base of the receptor is a transmembrane region that anchors the molecule in the T cell membrane. The variable regions of the α and β chains at the outer tip of the molecule form a single antigen-binding site while the remainder of the receptor molecule is made up of the constant regions.

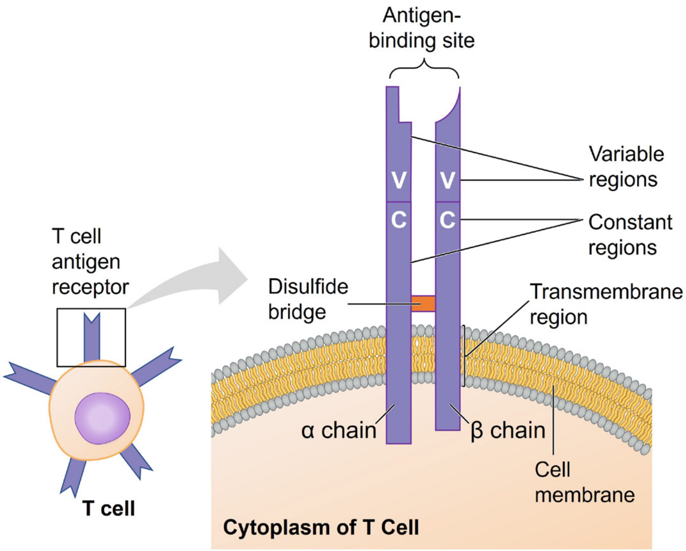


Figure 2.53: T cell antigen receptor

Recall that B cell antigen receptors bind to antigens protruding from pathogens or circulating free in body fluids. In contrast, the antigen receptors of T cells bind only to fragments of antigens displayed on the surface of host cells. The display of protein antigens occurs when a pathogen infects a host cell or when an immune cell engulfs antigens or a whole pathogen (Figure 2.54). Inside the host cell, enzymes digest each antigen into fragments that become bound to a protein of the **major histocompatibility complex (MHC).** These proteins transport the bound fragment to the host cell membrane. The result is **antigen presentation** (Figure 2.55), the display of the antigen fragment on the host cell surface is essential for antigen recognition by T cells. In effect, antigen presentation advertises the fact that a host cell contains a non-self antigen. If the cell displaying an antigen fragment encounters a T cell with the proper specificity, the antigen receptor on the T cell can bind to both the antigen fragment and the MHC molecule triggering the adaptive immune response.

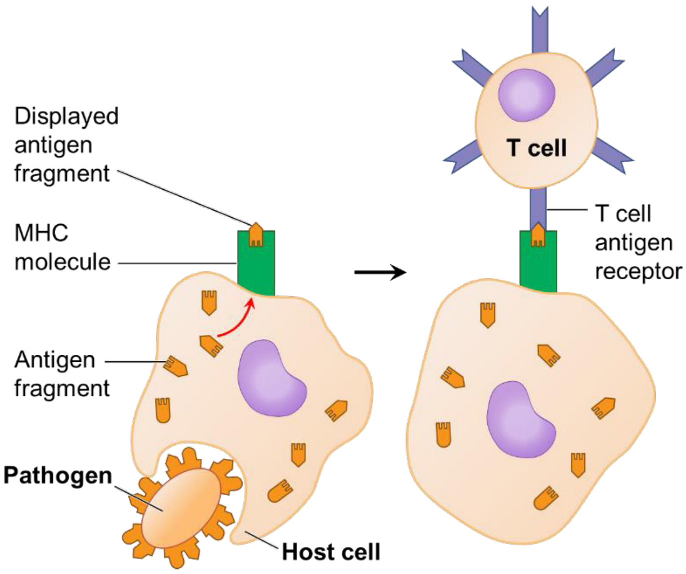


Figure 2.54: Antigen recognition by T cells

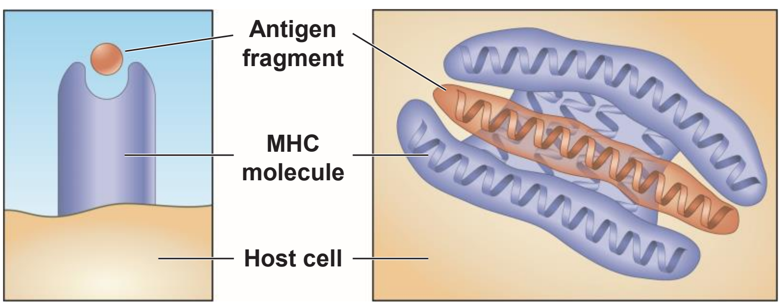


Figure 2.55: Antigen presentation

In the case of B cells, activation initiates a humoral immune response (Figure 2.60) in which a single activated B cell gives rise to thousands of plasma cells. These plasma cells produce and secrete antibodies into the blood at a rate of 2000 antibodies per second during its five-day life span.

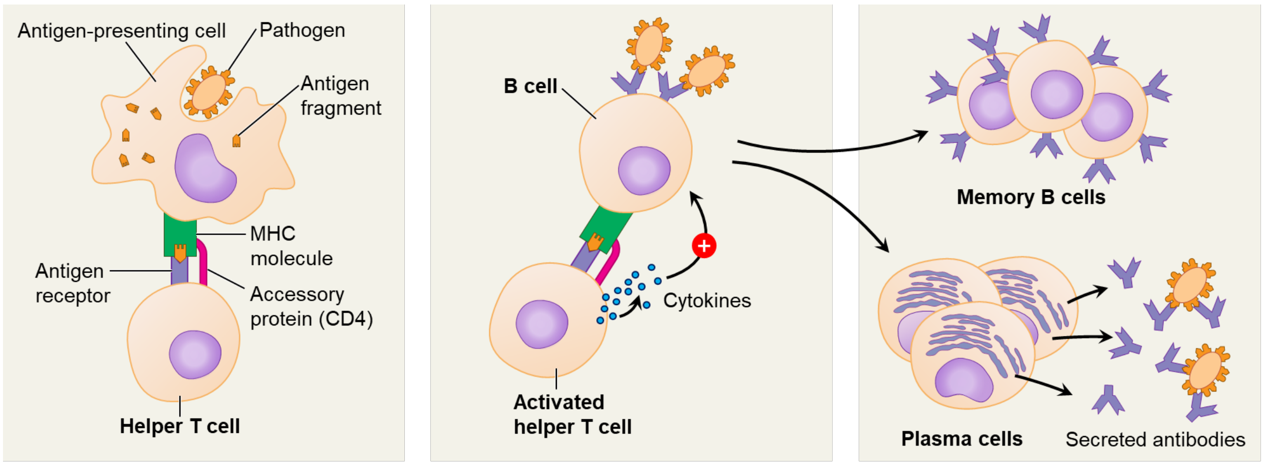


Figure 2.60: Role of helper T cells in humoral and cell-mediated immune responses

Antibodies do not directly kill pathogens, but they interfere with pathogen activity by binding to antigens, marking it for inactivation and destruction. For example, one process, called **neutralisation**, involves antibodies binding to proteins on the surface of a virus (Figure 2.61). The bound antibodies prevent the virus from binding to host cells. Similarly, antibodies sometimes bind to toxins released in body fluids, preventing the toxins from entering body cells. Another example is **opsonisation**, a process in which antibodies bound to antigens on bacteria present a readily recognised structure for macrophages or neutrophils, promoting phagocytosis (Figure 2.62). Because each antibody has two antigen-binding sites, antibodies can also facilitate phagocytosis by linking bacterial cells, viruses, or other foreign substances into aggregates that are too large to enter host cells.

Antibodies sometimes work together with the complement system (Figure 2.63) to destroy a foreign cell. Binding of a complement protein to an antigen-antibody complex triggers events leading to the formation of a pore in the lipid bilayer of the foreign cell or virus. The pore allows water and solutes to rush into the cell, causing it to swell and burst.

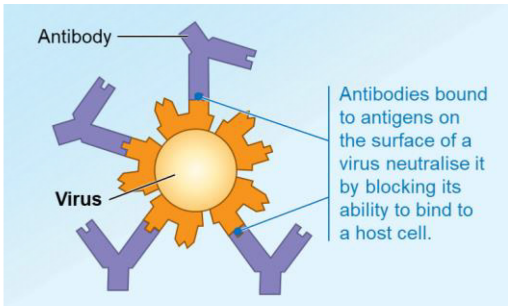


Figure 2.61: Neutralisation

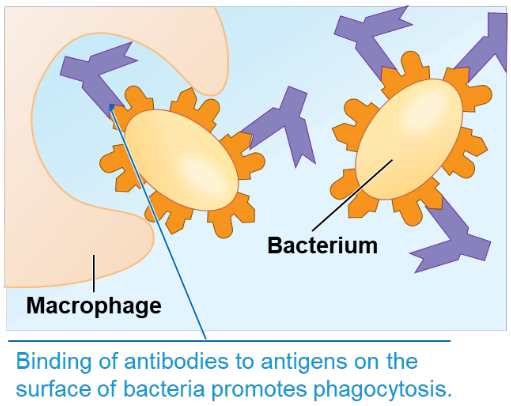


Figure 2.62: Opsonisation

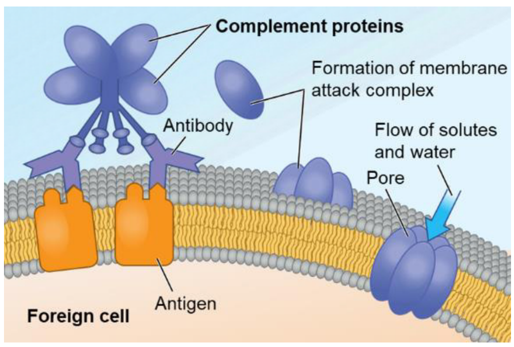


Figure 2.63: Complement system

3.1: Cell differentiation

Specific cell structures and functions develop through cell differentiation. Recognise that:

- cells in a multicellular organism are genetically identical
- gene expression is responsible for cell specialisation.

We have seen that living things are composed of one or more cells. For example, unicellular organisms, including bacteria, archaea, protists and some fungi, are composed of a single cell with a specialised structure that helps facilitate all life processes. In contrast, multicellular organisms, including plants and animals, are composed of many different cell types, each with a specialised structure and function allowing it to facilitate one or more life processes in the organism's body. Figure 3.01 shows the structure and function of different animal cells.

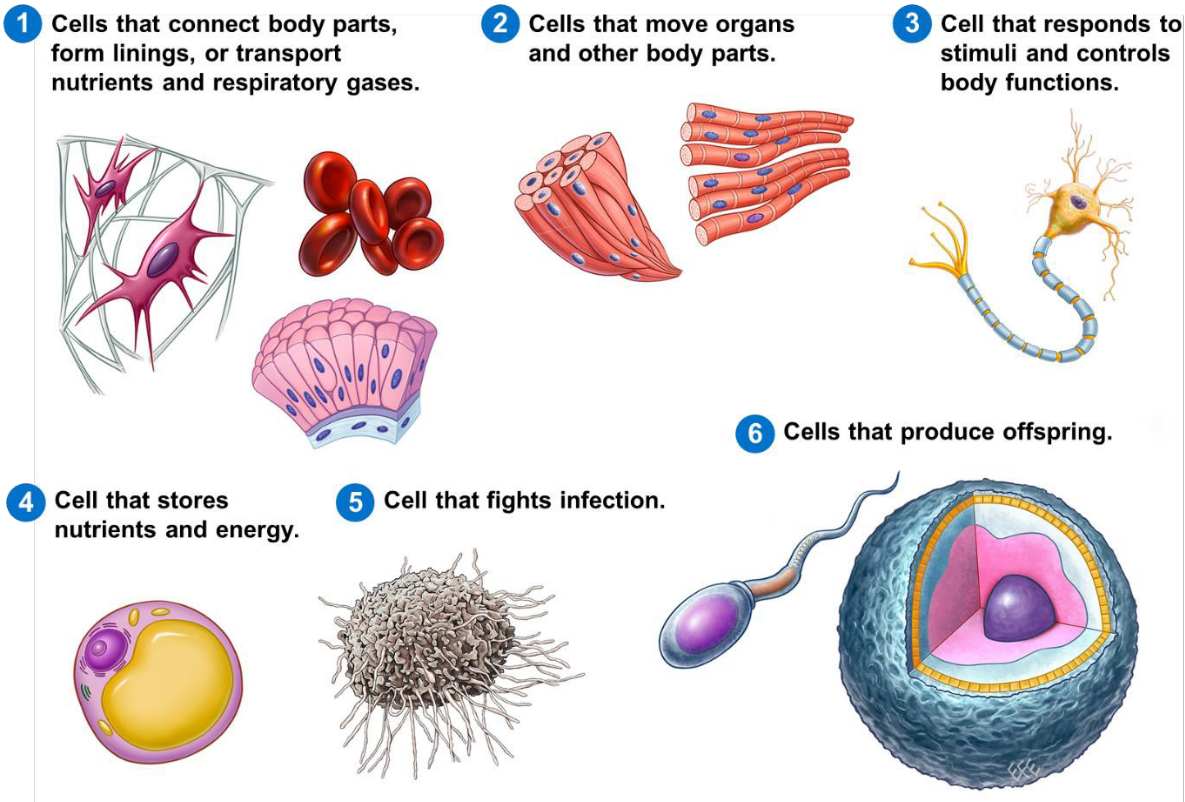


Figure 3.01: Structures and functions of different animal cells.

A cell's structure and function are determined by its genetic material, which is contained in one or more chromosomes. Each chromosome contains hundreds of genes encoding the production of protein molecules that give cells their unique structures and functions, as in Figure 3.01. Genes are switched on and off in response to signals from their external and internal environments. A switched-on gene is being expressed, and its protein is synthesised, whereas a switched-off gene is not expressed. Regulation of gene expression is essential for cell specialisation in multicellular organisms made up of different cells. To perform its distinct role, each cell type must maintain a specific gene expression program in which certain genes are expressed and others are not.

Cell Differentiation

Both unicellular and multicellular organisms produce offspring. Following reproduction, offspring undergo a process of development in which its cell or cells becomes specialised. For example, a multicellular organism such as a plant or animal begins as a fertilised egg or zygote that undergoes extensive cell division as it develops into an adult organism. These cells are produced primarily through mitotic cell division and are genetically identical. However, as plant and animal cells divide, they undergo cell differentiation in which gene expression becomes highly regulated, resulting in some genes being switched on and others off. This unique gene expression pattern results in a specialised set of proteins that give a cell its structure and functions. For example, beta cells in the animal pancreas express the INS gene that encodes the protein insulin. Furthermore, the INS gene is expressed exclusively in beta cells, giving them their function as insulin-secreting cells.

In differentiated cells, specific genes are expressed at particular times, but other genes may not be expressed at all. For example, a typical human epithelial cell expresses about a third to a half of its genes at any given time. In contrast, highly differentiated cells, such as muscle or nerve cells, express a smaller fraction of their genes. Therefore, the differences between cell types are not due to the presence of different genes but to differential gene expression, the expression of different genes by cells with identical genomes. In most cases, differentiated cells begin as undifferentiated cell types called stem cells that develop into differentiated cell types through differential gene expression. For example, skeletal muscle cells in animals arise from stem cells through differential gene expression. Stem cells respond to signals that trigger the expression of the gene myoD. The MyoD protein turns on genes encoding muscle cell proteins and turns off genes encoding cell division, as depicted in Figure 3.02. As a result, the stem cells become differentiated skeletal muscle cells with a different gene expression pattern shown below.

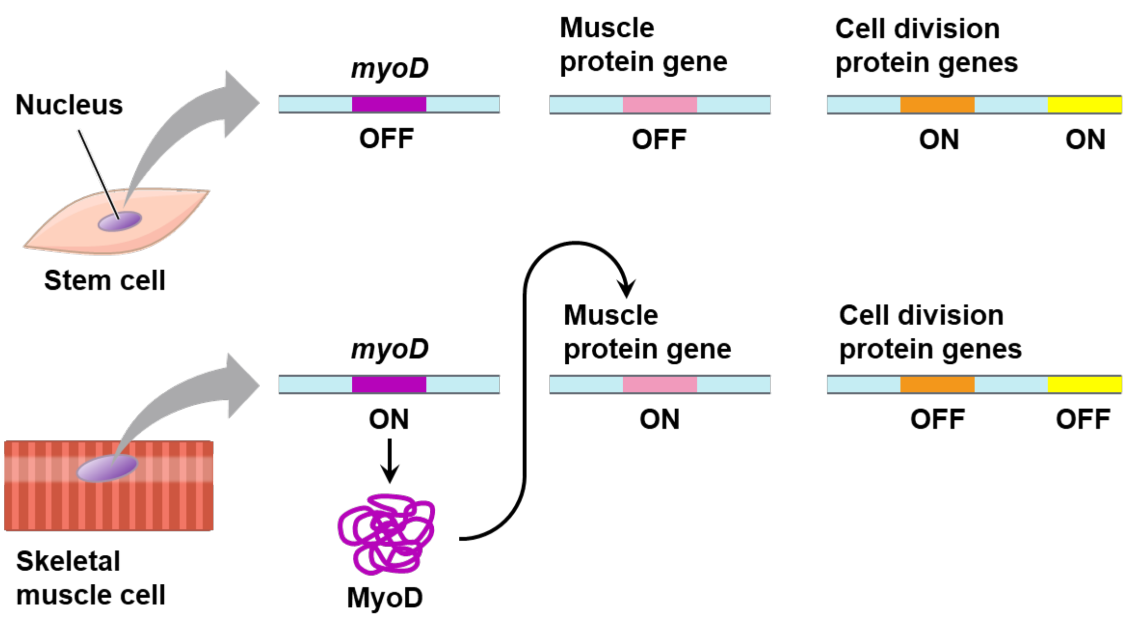


Figure 3.02: Formation of a skeletal muscle cell through cell differentiation.

3.2: The structural hierarchy

Multicellular organisms have a hierarchical structural organisation of cells, tissues, organs, and systems.

- Use examples from plants and animals to explain the 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.

Multicellular organisms, including plants, animals, and some fungi, are living things with bodies composed of more than one cell. In most cases, the bodies of multicellular organisms have four levels of organisation: cells, tissues, organs, and organ systems.

Tissues

We have seen that cells are the basic unit of structure and function in living things. Multicellular organisms are composed of specialised cell types that perform specific functions. Groups of cells that are similar in structure and function are organised into tissues. The cells in a tissue work together to accomplish a common function. For example, in animals, muscle tissue is composed of cells responsible for moving the body. Early in the development of the multicellular organism, the cells of the growing embryo differentiate into the three fundamental embryonic tissues: ectoderm, mesoderm and endoderm, collectively called **germ layers**. Each germ layer, in turn, differentiates into the many different cell types and tissues that are characteristic of the organism's body. In adult vertebrate animals, there are four principal kinds of tissues: epithelial, connective, muscle, and nerve tissue (Figure 3.03).

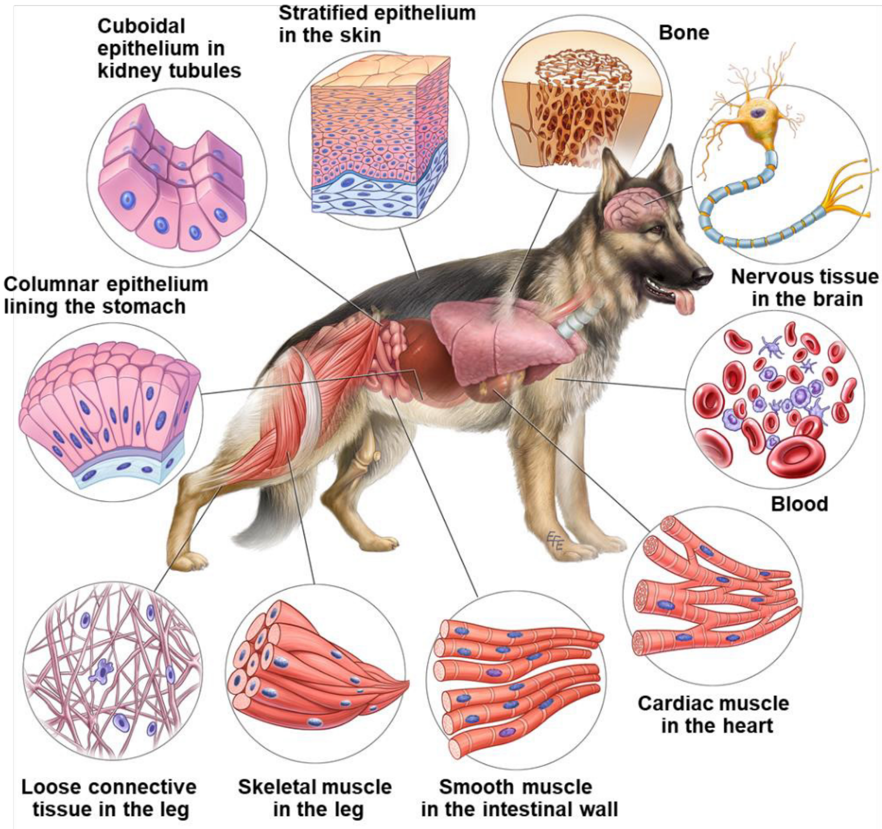


Figure 3.03: Animal tissues

Muscle Tissue

Muscle tissue is composed of specialised cells that facilitate movement. There are three types of muscle tissue: skeletal, cardiac and smooth, which vary in structure, location, and control mechanisms (Figure 3.06). **Skeletal muscles** are usually attached to bones by tendons so that their contraction causes the bones to move at their joints. A skeletal muscle contains numerous, very long muscle cells called muscle fibres with multiple nuclei. **Cardiac muscle** is found in the heart's walls and is responsible for the involuntary contractions that pump blood through the circulatory system. Cardiac muscle consists of smaller, interconnected cells, each with a single nucleus. The interconnections contain junctions that permit the movement of materials between cells. Finally, **smooth muscle** is found in the walls of hollow internal organs such as the intestines and tubes such as blood vessels and is responsible for involuntary movements such as contractions in the digestive system that move food along. Smooth muscle tissue is arranged into sheets of long, spindle-shaped cells, each containing a single nucleus.

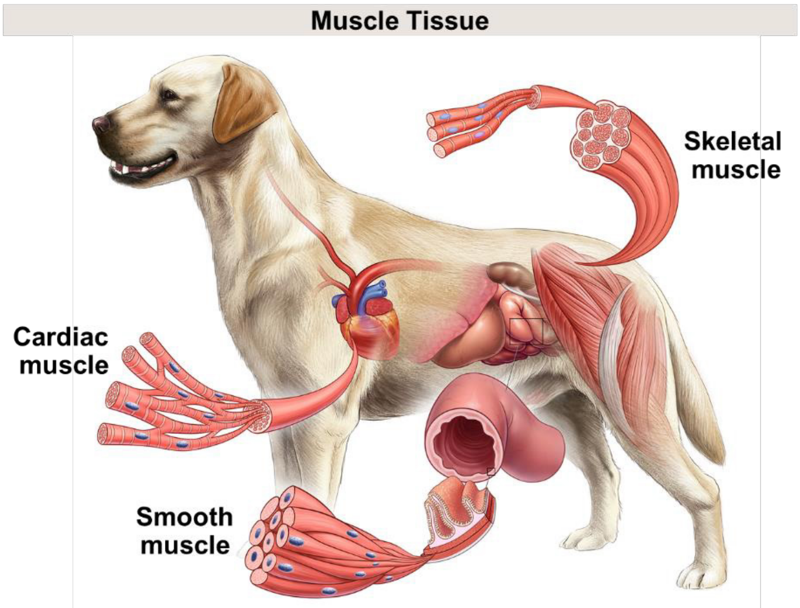


Figure 3.06: Muscle tissue types

Nervous Tissue

Nervous tissue makes up the brain, spinal cord, and nerves and is composed of specialised cells responsible for conducting messages throughout the body. Nervous tissue contains two groups of cells: **neurons** that transmit nerve impulses and **glia**, which help nourish, insulate, and replenish neurons (Figure 3.07). Neurons are specialised to produce and conduct electrochemical signals called **nerve impulses** around the body. Neurons coordinate various life processes, including sensitivity, the body's response to stimuli and movement. Glial cells do not conduct electrical impulses but instead support and insulate neurons and eliminate foreign materials in and around neurons.

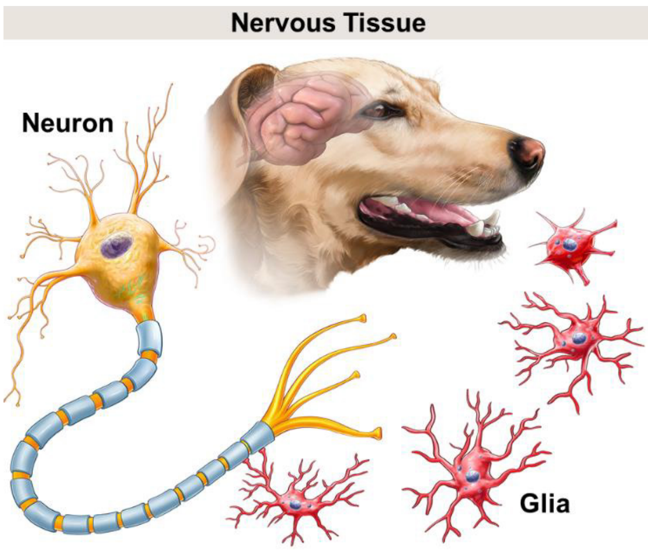


Figure 3.07: Nerve cell types

Organs

Organs are body structures composed of different tissues that work together to perform a specific function. Vertebrates contain more than 50 organs, each containing epithelial, connective, muscle and nervous tissues. One example is the stomach (Figure 3.09), which contains epithelial tissue that secretes acid to digest the food, nervous tissue that stimulates cells to release the acid, smooth muscle tissue that contracts to push food through the stomach, and connective tissue that supports other tissues by supplying nutrients and removing waste.

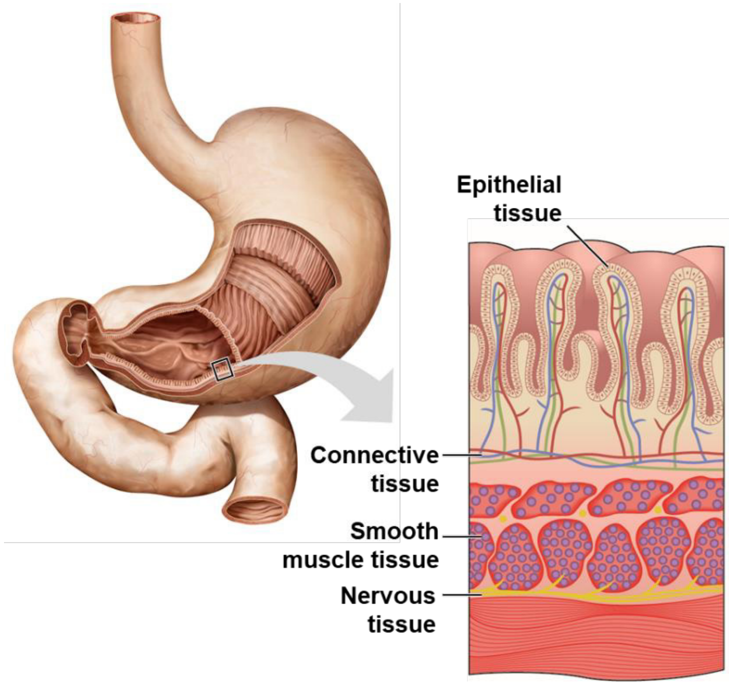


Figure 3.09: Tissues in the stomach.

Vascular plants contain three primary organs: roots, stem and leaves. A **root** is an organ that anchors a vascular plant into the soil, absorbs minerals and water, and stores nutrients. In most vascular plants, the **leaf** is the primary photosynthetic organ. In addition to absorbing light, leaves exchange gases with the atmosphere, dissipate heat, and defend themselves from pathogens and herbivores. A **stem** is an elongated organ that erects and orients the leaves in a way that maximises photosynthesis. Another function of stems is to elevate reproductive structures, thereby facilitating pollen and fruit dispersal. Green stems may also perform a limited amount of photosynthesis. All plant organs contain dermal, ground, and vascular tissues. For example, a leaf (Figure 3.10) contains dermal tissue that prevents water loss and facilitates gas exchange, ground tissue that absorbs sunlight and facilitates photosynthesis and vascular tissue that supplies water for photosynthesis and transports sugars from leaves to stems and roots. In this example, all three tissues are assembled into an organ that facilitates a common function: photosynthesis.

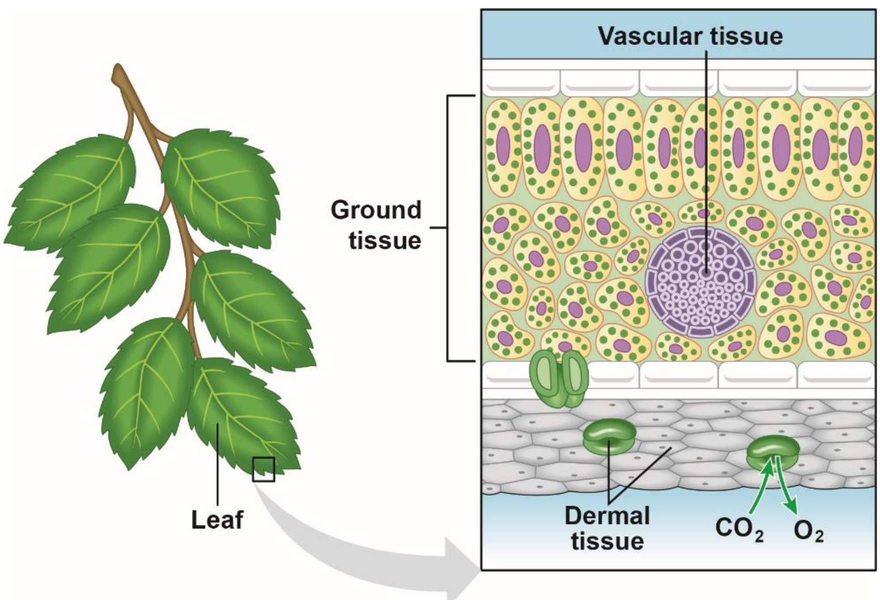


Figure 3.10: Tissues in a leaf.

Organ Systems

An **organ system** is a group of organs that cooperate to facilitate bodily functions. The vertebrate body contains 11 principal organ systems, two of which are illustrated in Figure 3.11. For example, the digestive system is composed of several organs, including the mouth, oesophagus, stomach, small intestine, large intestine, rectum and anus, which extract nutrients from food. Similarly, the circulatory system is composed of the heart and blood vessels, organs that cooperate in transporting blood and distributing nutrients, respiratory gases and wastes around the body. Organ systems in animals and plants are **interdependent**. For example, the digestive and circulatory systems are interdependent in animals. The digestive system has organs that break down food into soluble compounds that are absorbed into the blood from the intestines. The blood then vehicles nutrients to tissue cells for respiration.

Figure 3.11: Organ systems in animals

In contrast, vascular plants have two organ systems: the **root system** and a **shoot system**. The root system comprises all organs below the surface, and the shoot system comprises organs above it (Figure 3.12). The two organ systems are interdependent, and vascular plants rely on both systems for survival. For example, roots require energy to transport minerals against their concentration gradients in soil, and this energy is typically extracted from carbohydrates in respiration. However, roots are rarely photosynthetic and will starve unless the carbohydrates produced during photosynthesis are imported from the shoot system. Conversely, the shoot system contains organs that facilitate photosynthesis, but each requires water and minerals from the soil they cannot access without the root system. Hence, the shoot system depends on the water and minerals that roots absorb from the soil, and the root system depends on carbohydrates that the shoot system produces in photosynthesis.

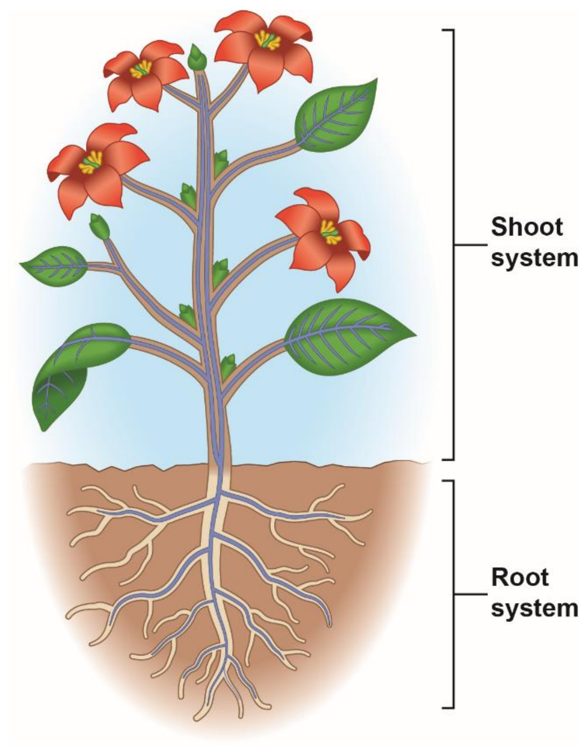


Figure 3.12: Organ systems in vascular plants

Gills in Aquatic Animals

The conditions for gas exchange vary considerably depending on the source of oxygen. For example, oxygen concentrations are about 21% in air and less than 1% in water. In addition, the air is less dense and viscous than water, allowing it to rush through narrow tubes and passageways. As a result, breathing air is relatively easy, reducing the need for efficient gas exchange. In contrast, water is a much more demanding gas exchange medium than air. The lower oxygen concentration, higher density, and higher viscosity cause aquatic animals to expend considerable energy facilitating gas exchange. In the face of these challenges, adaptations have evolved in aquatic animals that enable efficient gas exchange.

Gills are outfoldings of the body surface that are suspended in the water. The distribution of gills over the body varies considerably between aquatic animals, but each produces a total surface area much greater than the body's exterior. Figure 3.18 shows the structure and function of fish gills. Each gill arch has two rows of gill filaments, composed of flattened plates called **lamellae**, each lined with capillaries that pick up oxygen from the water. As water flows past gills, a process called **ventilation**, oxygen diffuses into gills, and carbon dioxide and water diffuse out. Most gill-bearing animals promote ventilation by either moving their gills through the water or move water over their gills. For example, fish use swimming and coordinated mouth movements to ventilate their gills. Furthermore, the gas exchange efficiency in fish is maximised by **countercurrent exchange**, the exchange of gases between blood and water flowing in opposite directions. Because the fluids flow in opposite directions, blood has a lower oxygen concentration than the water it meets, providing the large concentration gradient required for passive diffusion.

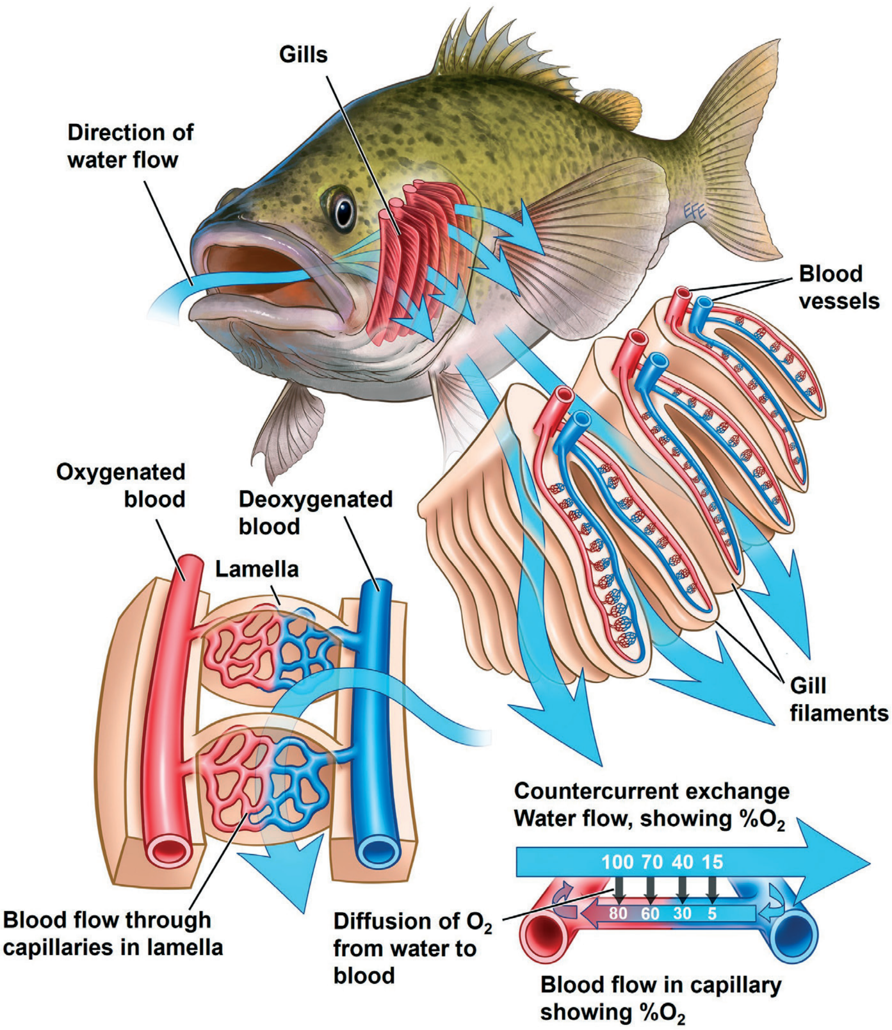


Figure 3.18: The structure and function of fish gills.

Tracheal Systems in Insects

In most terrestrial animals, respiratory surfaces are enclosed within the body, exposed to the atmosphere only through narrow tubes. The most familiar of these arrangements is the lung, but the most common is the insect **tracheal system**. Insects have a hard exoskeleton which is unsuitable for gas exchange. So instead, respiratory gases are exchanged between tissue cells and a network of internal air tubes that branch throughout the body. The largest tubes, called **tracheae**, connect to external openings called **spiracles** spaced along the insect's body surface. Air enters a spiracle and passes through the tracheae into smaller tubes called **tracheoles**. At the tips of the tracheoles is a moist epithelial lining that enables gas exchange by diffusion (Figure 3.19). The extensive network of tracheoles greatly increases the surface area to volume ratio for gas exchange with body tissues.

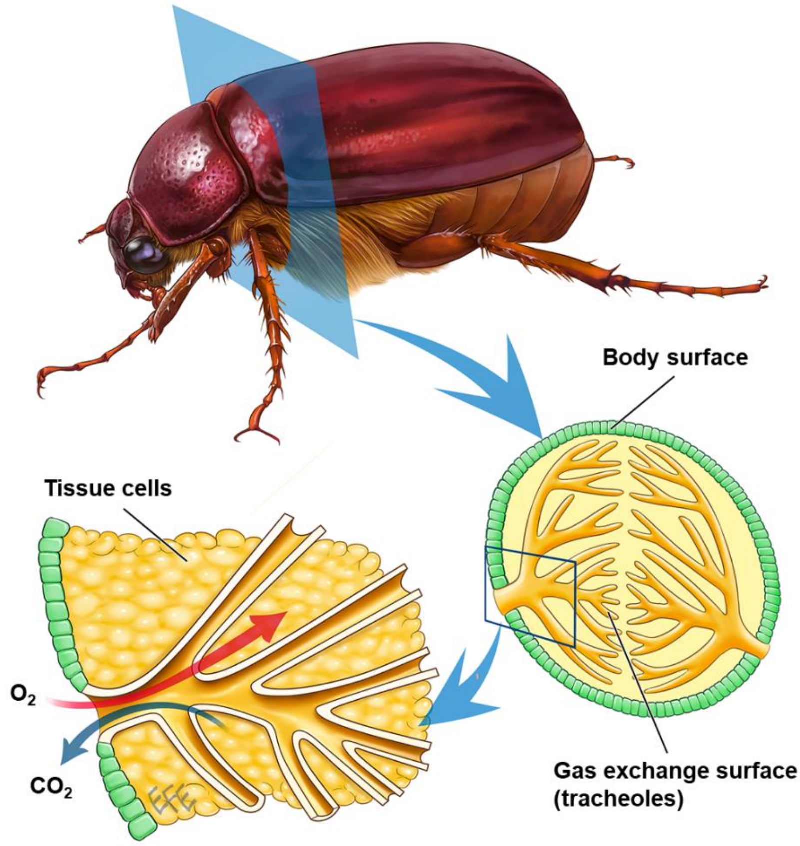


Figure 3.19: The structure of insect tracheoles

In addition, tracheoles have closed ends filled with fluid. When the animal is active and is consuming large quantities of oxygen for respiration, most of the fluid is withdrawn into the body, increasing the surface area of tracheoles in contact with tissue cells. Furthermore, the tracheae enlarge, forming **air sacs** (Figure 3.20) near organs requiring a large oxygen supply.

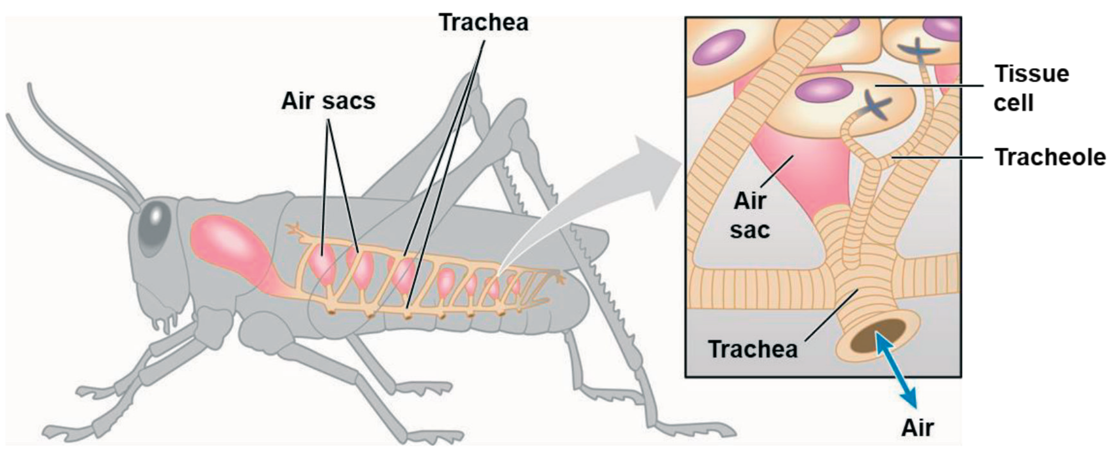


Figure 3.20: A tracheal system.

Lungs

Lungs are respiratory organs in vertebrates and some invertebrates. Unlike tracheal systems, which branch throughout the body, lungs have a fixed location inside the body. The respiratory surface of a lung is not in direct contact with all other parts of the body, so the gap must be bridged by the circulatory system, which transports gases between the lungs and the rest of the body. The use of lungs for gas exchange varies between vertebrates that lack gills. For example, some amphibians rarely use their lungs as gas exchange occurs primarily across external body surfaces. In contrast, most reptiles, all birds and all mammals depend entirely on lungs for gas exchange. In mammals, lungs are located in the thoracic cavity, enclosed by the ribs and diaphragm. Air enters the nostrils and mouth, flows through the nasal cavity and into the trachea, which branches into two **bronchi** (singular, **bronchus**) leading to each lung. The bronchi repeatedly branch into thinner tubes called **bronchioles,** increasing the surface area for gas exchange. At the tips of bronchioles are **alveoli** (singular, **alveolus**; Figure 3.21), tiny air sacs that facilitate gas exchange.

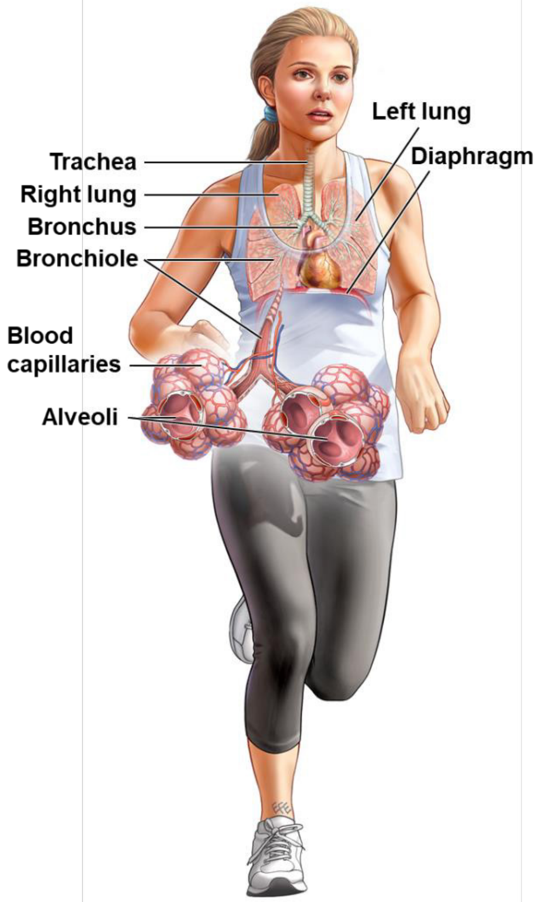


Figure 3.21: Mammalian lungs.

Each lung contains millions of alveoli, providing a large surface area to volume ratio for efficient gas exchange. Oxygen in the air dissolves in the moist film lining the epithelial tissue in alveoli and rapidly diffuses across the epithelium into blood capillaries surrounding an alveolus. Carbon dioxide diffuses in the opposite direction, as shown in Figure 3.22. The epithelial tissue lining the alveolus and capillary is one cell thick, reducing the diffusion path and enabling the rapid diffusion of oxygen and carbon dioxide. In addition, the constant blood flow through capillaries maintains the oxygen and carbon dioxide concentration gradients required for passive diffusion.

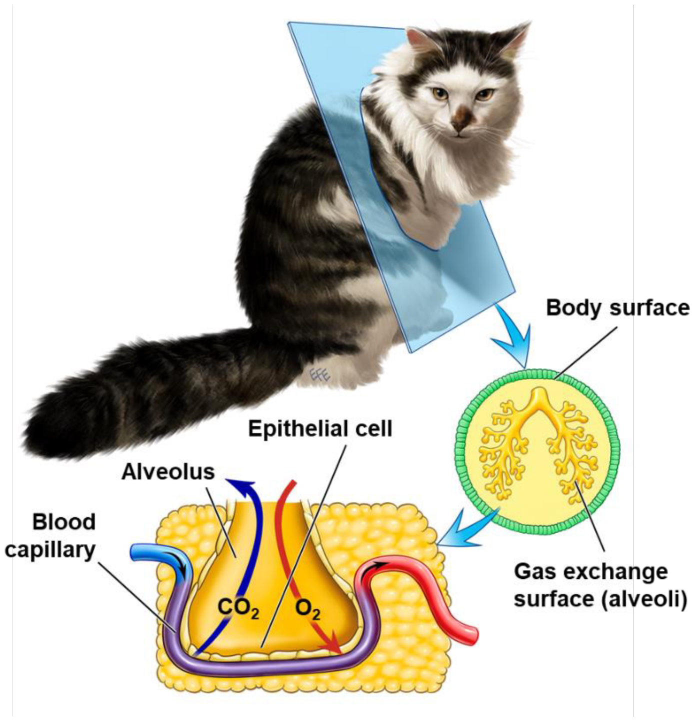


Figure 3.22: Gas exchange in an alveolus.

3.4: Gas exchange in plants

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.

Like animals, plants exchange gases with their environment, including carbon dioxide, oxygen and water vapour. In vascular plants, gas exchange is facilitated by the structure of the leaf (Figure 3.24). The dermal tissue contains tiny pores called **stomata** (singular, **stoma**) that facilitate the exchange of carbon dioxide and oxygen between the surrounding air and the photosynthetic cells inside the leaf. The ground tissue, called **mesophyll**, is sandwiched between the upper and lower dermal tissue layers. Mesophyll has two distinct layers of cells: palisade and spongy. **Palisade mesophyll**, located beneath the upper dermal tissue, consists of one or more layers of elongated, chloroplast-rich cells specialised for light absorption. **Spongy mesophyll**, located inward from the lower dermal tissue, consists of irregularly shaped cells with fewer chloroplasts, each surrounded by air spaces that permit the circulation of gases. The air spaces are particularly large near stomata, where carbon dioxide is taken up from the outside air and oxygen is released. The vascular tissue brings the xylem and phloem into close contact with the photosynthetic tissue, which obtains water and minerals from the xylem and loads its sugars into the phloem for transport to the roots and stem.

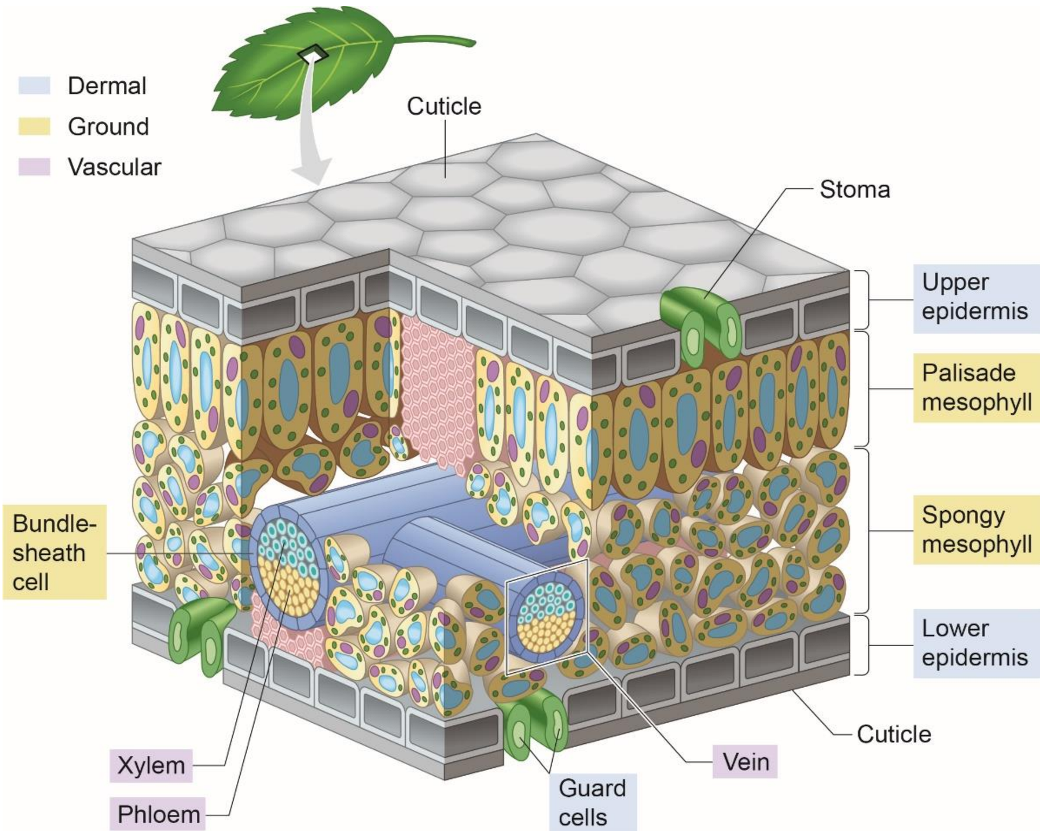


Figure 3.24: Leaf structure in vascular plants.

Gas Exchange in Plants

The diffusion of carbon dioxide and oxygen into leaves for photosynthesis and respiration occurs through stomata. Each stoma consists of two **guard cells** that regulate the opening and closing of the pore (Figure 3.25). The cell membranes contain channel proteins that open in sunlight, facilitating the diffusion of potassium ions (K^+) from neighbouring cells into guard cells. The increase in solute concentration causes water to diffuse into guard cells from neighbouring cells by osmosis. Increased water absorption causes guard cells to become turgid and bow outwards, increasing the pore size between cells. Thus, the open pore enables the rapid exchange of gases. Conversely, the outflow of potassium ions causes guard cells to lose water, become flaccid and less bowed, closing the pore, as shown in Figure 3.25.

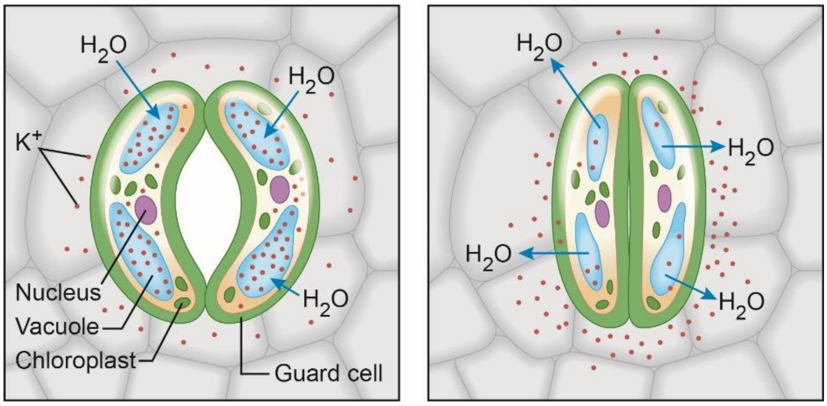


Figure 3.25: Opening (left) and closing (right) of a stoma.

Leaves generally have large surface areas that enhance light absorption for photosynthesis. In addition, the interior mesophyll has a very high surface-area-to-volume ratio for gas exchange. Upon diffusing through the stomata, carbon dioxide enters the air spaces surrounding spongy mesophyll cells, where gas exchange occurs. Mesophyll cells are in direct contact with the air spaces, as shown in Figure 3.26, which shortens the diffusion path and increases the diffusion rate of carbon dioxide. In addition, mesophyll cells have thin cell walls, which shortens the diffusion path and a layer of moisture that increases diffusion efficiency. Furthermore, the irregular shapes of spongy mesophyll cells increase the leaf's internal surface area for gas exchange by 10 to 30 times, which helps increase the diffusion rate of carbon dioxide into mesophyll cells. In addition, the process of photosynthesis produces oxygen. Some of this oxygen is used in mesophyll cells for respiration, and the rest exits a leaf through open stomata.

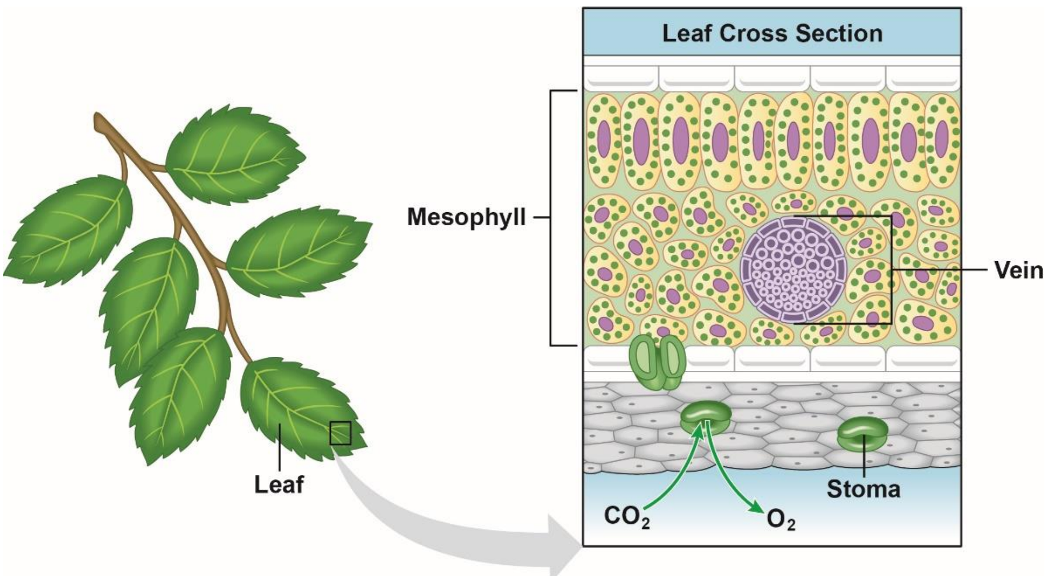


Figure 3.26: Gas exchange surface in leaves.

The Mammalian Digestive System

Food processing in mammals is facilitated by **the digestive system,** which consists of the organs of the digestive tract and several accessory glands such as salivary glands, the pancreas, the liver, and the gallbladder. We shall consider the role of each organ and accessory gland by considering the steps in food processing as a meal travels along the human digestive tract (Figure 3.32).

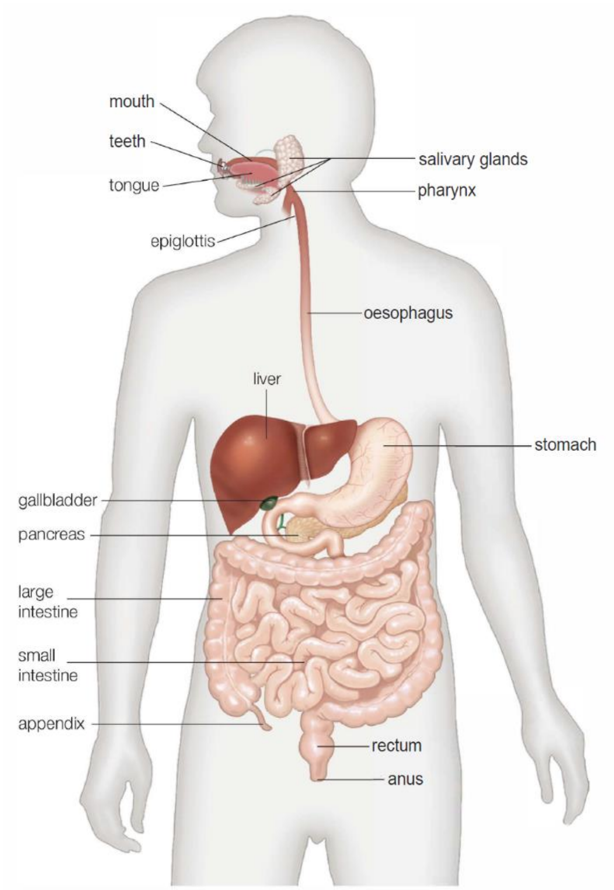


Figure 3.32: The human digestive system

Food enters the mouth and is mechanically mashed and ground into smaller pieces by **teeth**. Meanwhile, the arrival of food in the mouth triggers the release of **saliva** by the salivary glands. Saliva contains digestive enzymes that begin breaking down food particles into smaller molecules for absorption. The mechanical breakdown of food by teeth increases the surface area available for chemical breakdown by saliva. Once chewing begins, **tongue** movements manipulate the mixture of saliva and food into a ball called a **bolus**. During swallowing, the tongue provides further assistance, pushing the bolus to the back of the mouth and into the **pharynx**, or throat region, which leads to the oesophagus. The **oesophagus** is a muscular tube that connects to the stomach. Food is pushed along the oesophagus by **peristalsis**, alternating waves of smooth muscle contraction and relaxation (Figure 3.33).

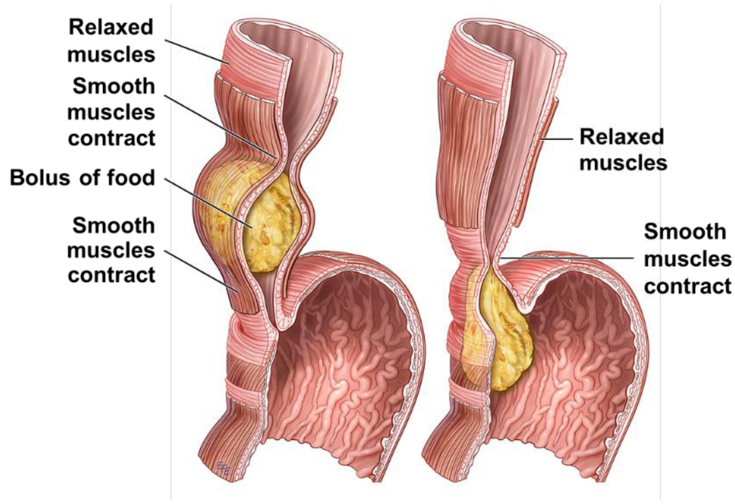


Figure 3.33: Peristalsis

Upon reaching the stomach, food is stored and processed over two to six hours. The stomach secretes a mixture of hydrochloric acid and digestive enzymes called **gastric juice** and mixes it with the food through a churning action facilitated by smooth muscle tissue. Churning brings all of the food into contact with the gastric juice, increasing the rate of chemical digestion. Churning produces a nutrient-rich broth called **chyme** (Figure 3.34) that enters the small intestine.

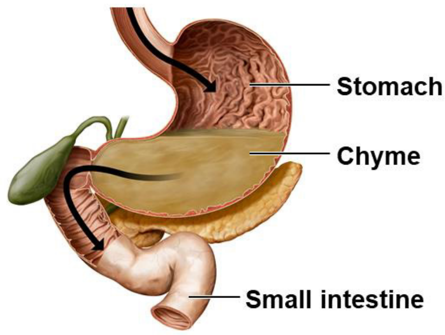


Figure 3.34: Food processing in the stomach.

Although digestive enzymes facilitate some chemical digestion in the mouth and stomach, most chemical digestion occurs in the **small intestine,** an organ whose diameter is smaller than the large intestine. The small intestine is the digestive tract's longest compartment and is over six metres long in humans. The first component of the small intestine is the **duodenum,** where chyme mixes with digestive juices from the intestinal walls, pancreas, liver, and gallbladder. The arrival of chyme stimulates the pancreas to secrete bicarbonate into the duodenum that neutralises chyme's acidity. In addition, the pancreas secretes digestive enzymes into the duodenum that break down fats, carbohydrates and proteins. Fats present a challenge for digestion as they do not dissolve in water and instead form large globules that digestive enzymes cannot effectively attack. In humans and other vertebrates, fat digestion is facilitated by **bile salts** that break apart fat globules. Bile salts are a liver secretion stored and concentrated in the **gallbladder**.

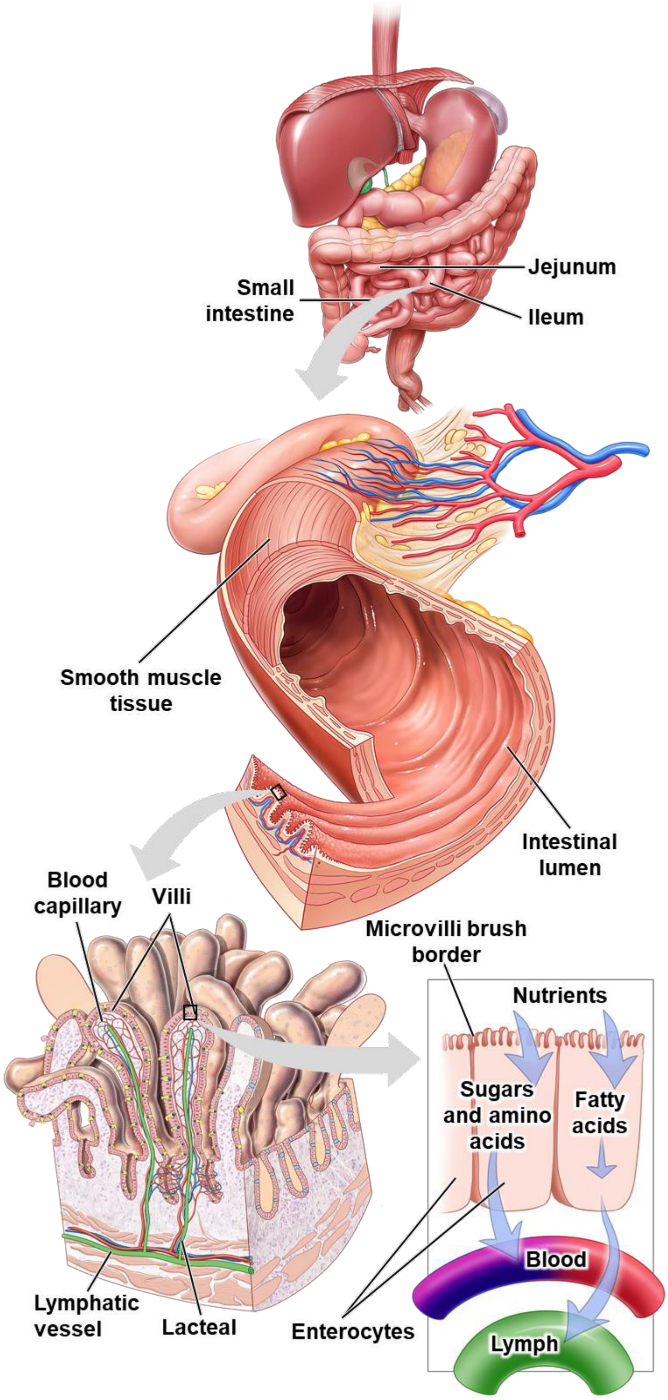


Figure 3.35: The small intestine.

With digestion essentially complete, the contents of the duodenum move by peristalsis into the **jejunum** and **ileum**, where nutrient absorption occurs across the lining of the intestine (Figure 3.35), Large folds in the lining encircle the intestine and are studded with finger-shaped projections called **villi** (singular, **villus**). Each villus is lined with absorptive epithelial cells called **enterocytes**, each with a cell membrane folded into many microscopic projections, or **microvilli**, facing the intestinal lumen within the villi. The enterocyte microvilli have a brush-like appearance which is referred to as the **brush border**. Together, villi and microvilli produce a nutrient exchange surface with a vast surface area. In addition, the cell membranes of enterocytes contain digestive enzymes that break down macromolecules and transport proteins that transport nutrients into the blood capillaries of the circulatory system located within each villus. Blood flow through the capillaries is essential to maintain a large concentration gradient for rapid diffusion.

3.7: Excretion in animals

In animals, the excretory system is responsible for the removal of wastes.

- Describe the structure and function of nephrons in the kidney in the excretory system.
- Explain the importance of filtration and reabsorption.

Animal cells produce a variety of waste products in metabolism. Among the most common are **nitrogenous wastes**, including ammonia, urea and uric acid produced in the breakdown of proteins and nucleic acids (Figure 3.39). Metabolic waste products are often highly toxic and are removed from animals through a process called **excretion**. For example, fish produce ammonia, a highly toxic waste product that dissolves easily in water and is excreted across the whole body surface or through gills. In contrast, insects, reptiles and birds, convert ammonia to uric acid, which is excreted in urine or faeces, whereas mammals and amphibians convert ammonia to urea, which is transported to the kidneys, and excreted in urine.

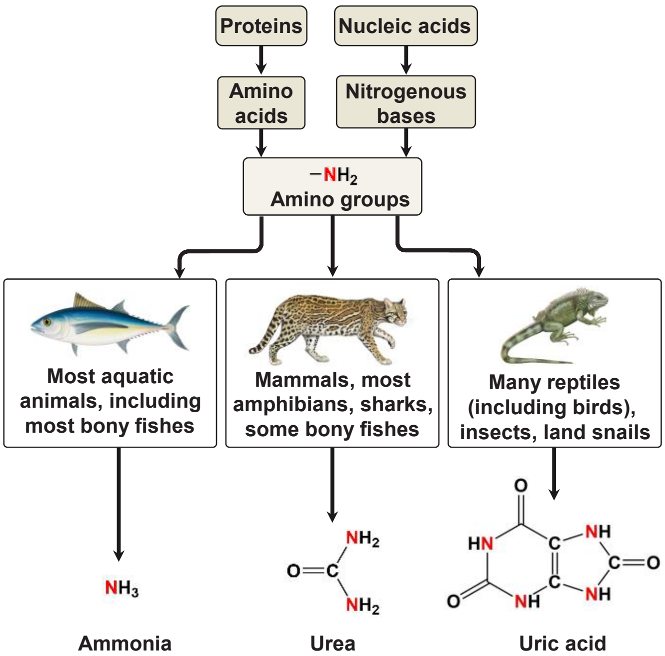


Figure 3.39: Nitrogenous waste in animals

In most animals, the excretion process begins when blood containing metabolic waste is brought in contact with the selectively permeable membrane of epithelial cells in excretory organs (Figure 3.40). In most cases, blood pressure drives the process of **filtration** in which water and small solutes, such as salts, sugars, amino acids, and nitrogenous wastes, cross the membrane, forming a solution called **filtrate**. In contrast, cells and large molecules such as proteins remain in the blood. Next, valuable solutes, including glucose, certain salts, vitamins, hormones, amino acids and water, are **selectively reabsorbed** from the filtrate and returned to the body fluid, while non-essential solutes and wastes remain in the filtrate. Finally, the processed filtrate containing nitrogenous wastes is excreted from the body as **urine**.

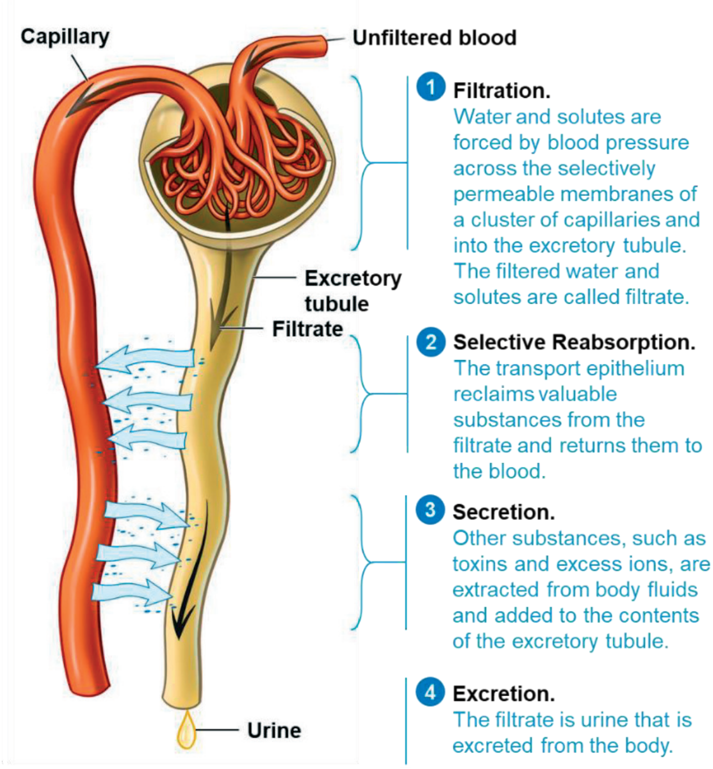


Figure 3.40: Excretion process in animals

Kidneys

In vertebrates, excretion is facilitated by a compact organ called the **kidney**. Like the excretory organs of most animals, kidneys consist of tubules arranged in a highly organised manner and are closely associated with a network of blood capillaries. The vertebrate excretory system also includes ducts and other structures that carry urine from the kidney tubules out of the body. Humans have two kidneys, each a bean-shaped organ approximately 10 cm long, located on each side of the spine just below the rib cage (Figure 3.41). Urine produced by each kidney exits through a duct called the **ureter**, which drains into the **urinary bladder**. Urine is expelled from the bladder through a tube called the urethra during urination, emptying through the genitals.

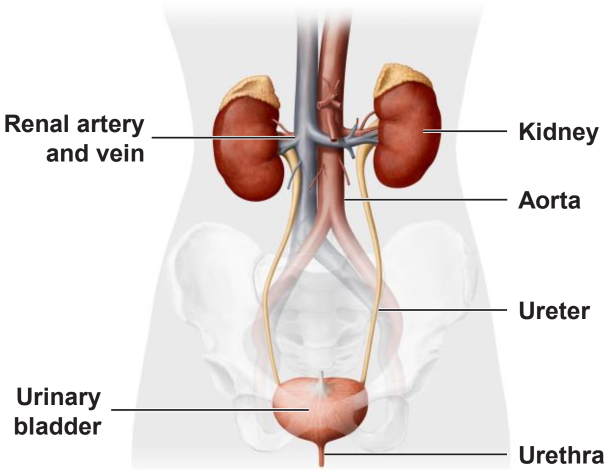


Figure 3.41: Kidney location

Each kidney has an inner **renal medulla** and an outer **renal cortex**, each supplied with blood by a **renal artery** and drained by a **renal vein** (Figure 3.42). Within the cortex and medulla lie tightly packed excretory tubules and associated blood capillaries. The tubules carry and process a filtrate produced from the blood entering the kidney. Nearly all of the fluid in the filtrate is reabsorbed into the surrounding blood vessels and exits the kidney in the renal vein. The remaining fluid leaves the excretory tubules as urine and exits the kidney via the ureter.

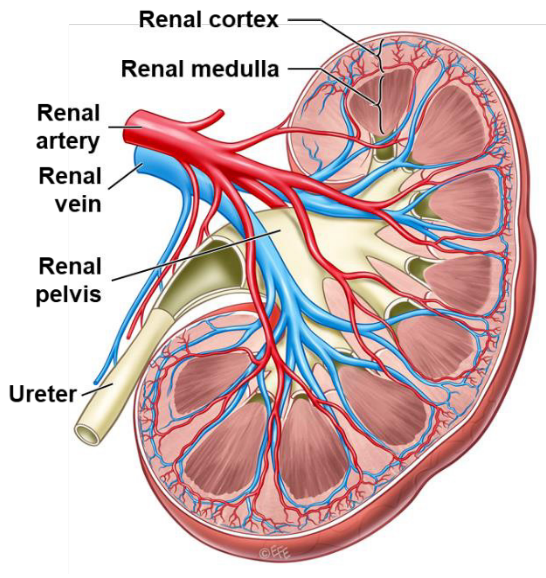


Figure 3.42: Kidney

Positioned along the border of the renal cortex and medulla are **nephrons**, the functional units of the vertebrate kidney (Figure 3.43). A human kidney contains approximately one million nephrons, 85% of which are **cortical nephrons** that reach a short distance into the medulla and perform excretory and regulatory functions. The remainder are **juxtamedullary nephrons** that reach deep into the medulla and produce concentrated or dilute urine by regulating the concentrations of solutes and water in the blood. Each nephron is 3-5 cm long and consists of

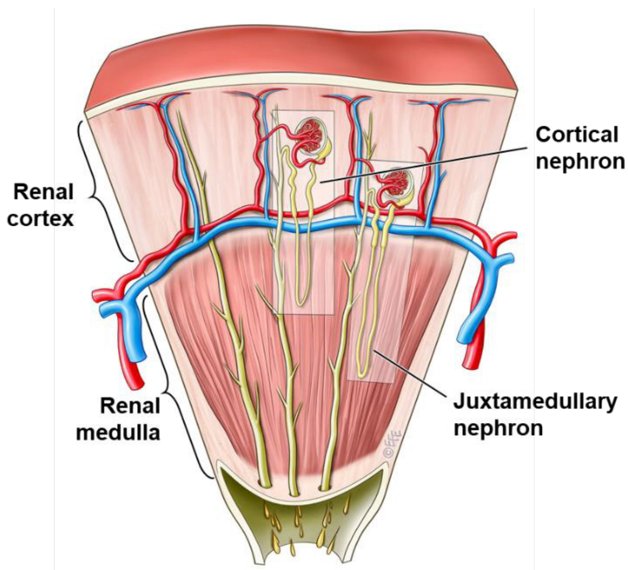


Figure 3.43: Nephron arrangement

a single long tubule, and a ball of capillaries called the **glomerulus**. The glomerulus is surrounded by a cup-shaped swelling of the tubule called **Bowman's capsule** (Figure 3.44). A filtrate is formed when blood pressure forces fluid from the blood in the glomerulus into the lumen of Bowman's capsule. The filtrate is then processed in the three major regions of the nephron: the **proximal tubule**, the **Loop of Henle,** and the **distal tubule**. Finally, a **collecting duct** receives processed filtrate (urine) from many nephrons and transports it to the **renal pelvis,** where it drains into the ureters.

In the human kidney, filtrate forms when fluid passes from blood in the glomerulus to the lumen of Bowman's capsule. The glomerular capillaries and epithelial cells of Bowman's capsule permit the diffusion of small solutes, including salts, glucose, amino acids, vitamins, and nitrogenous waste, while retaining cells and large molecules. The filtrate composition is then altered as specific solutes, including glucose, amino acids and water, are selectively reabsorbed into the **peritubular capillaries**, tiny blood vessels surrounding the proximal tubule (Figure 3.45). The epithelial tissue lining the proximal tubule is an exchange surface that facilitates the selective reabsorption of materials. The exchange surface is adapted to increase the filtration rate. For example, the epithelium is one cell thick, shortening the diffusion path, and each epithelial cell contains microvilli, forming a brush border that greatly increases the surface area for selective reabsorption.

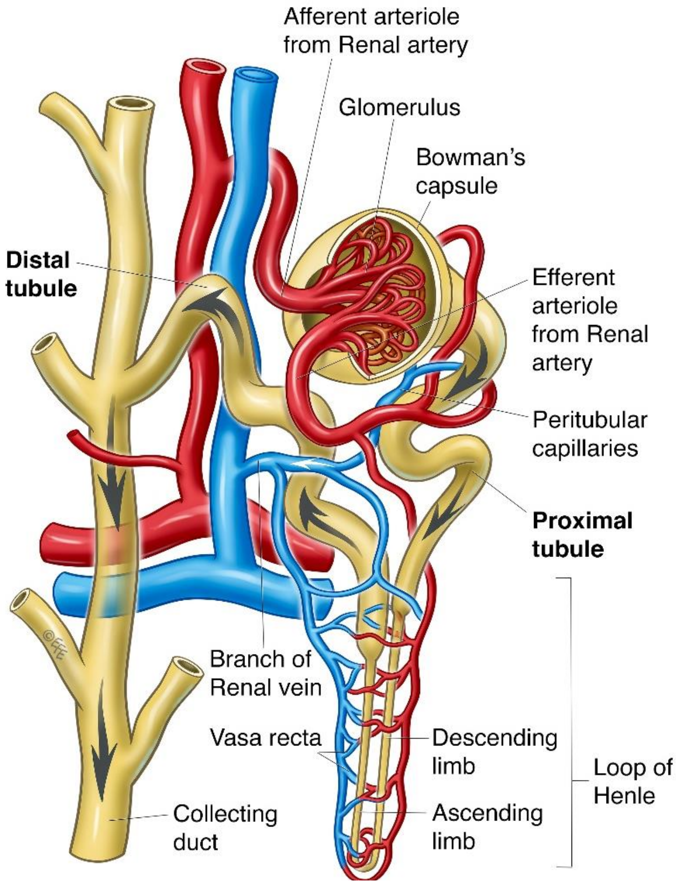


Figure 3.44: Nephron structure

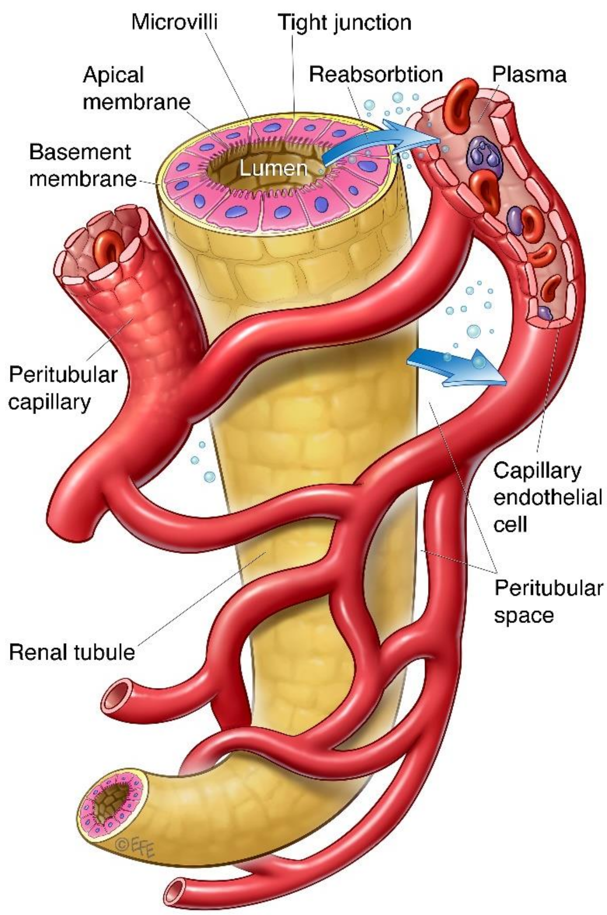


Figure 3.45: Selective reabsorption in the primal tubule

Reabsorption in the proximal tubule retains valuable nutrients, ions, and water from the filtrate. Salt, glucose, amino acids and other essential solutes diffuse into the epithelial cells and tissue fluid, causing water to follow by osmosis (Figure 3.46). The salt and water exiting the filtrate diffuse from the tissue fluid into the peritubular capillaries. Upon leaving the proximal tubule, filtrate enters the **descending limb** of the Loop of Henle. The epithelial cell membranes lining the descending limb contain numerous **aquaporins** for water transport but no channel proteins to transport salt and other small solutes. Consequently, water diffuses out of the filtrate along the descending limb by osmosis into the hypertonic tissue fluid in the renal medulla. The filtrate then returns to the renal cortex in the **ascending limb,** which contains epithelial cells with membranes that lack aquaporins. Consequently, water remains in the filtrate along the length of ascending limb. However, salt, which became highly concentrated in the descending limb, diffuses out of the filtrate into the tissue fluid. This salt diffusion maintains the hypertonic environment of the tissue fluid in the renal medulla needed for water reabsorption in the descending limb. Next, filtrate moves through the distal tubule, where its composition is modified further before entering the collecting duct. When the body is dehydrated, the **hypothalamus** in the brain secretes **antidiuretic hormone (ADH)**, which causes epithelial cells lining the collecting duct to produce more aquaporins, stimulating water reabsorption. In contrast, less ADH is present when hydrated and epithelial cells produce fewer aquaporins, reducing water reabsorption. As water diffuses out of the collecting duct, the remaining solutes become concentrated, causing some, including salt and urea, to diffuse down their concentration gradients into the surrounding tissue fluid, maintaining the hypertonic environment. The remaining filtrate is urine which is transported to the urinary bladder before excretion.

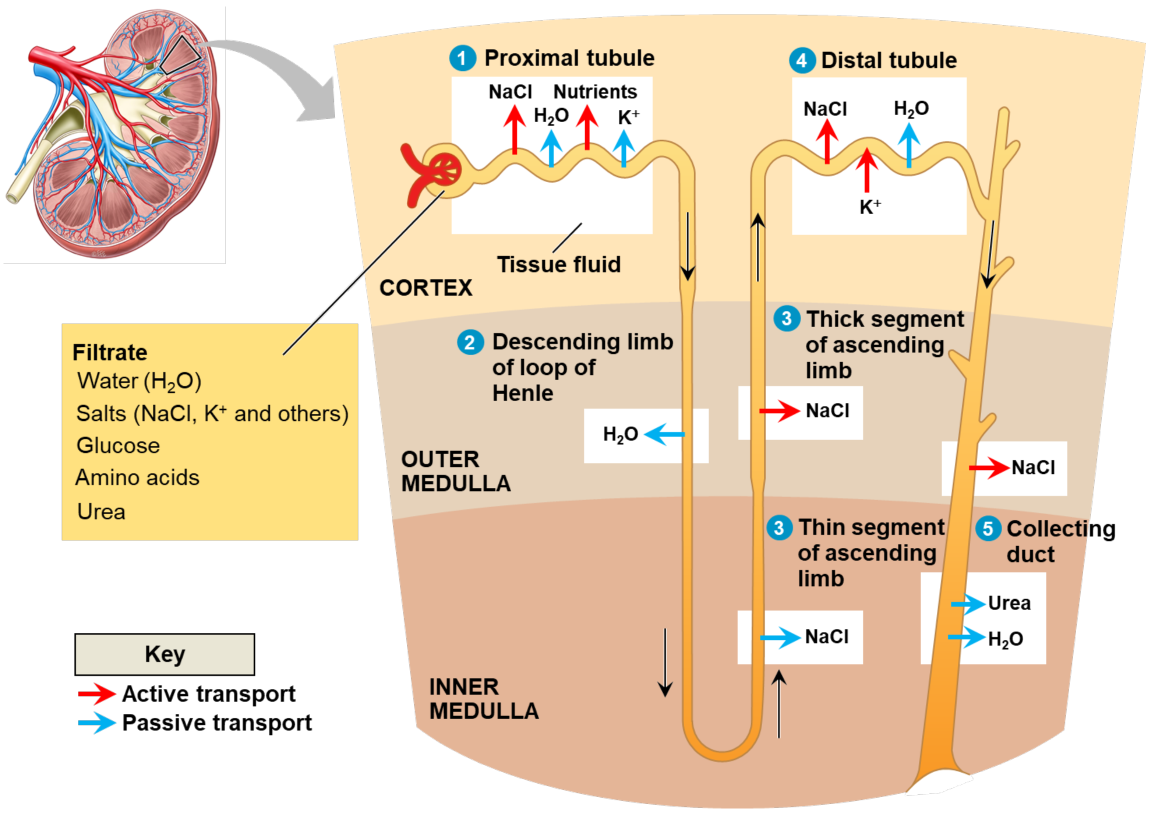
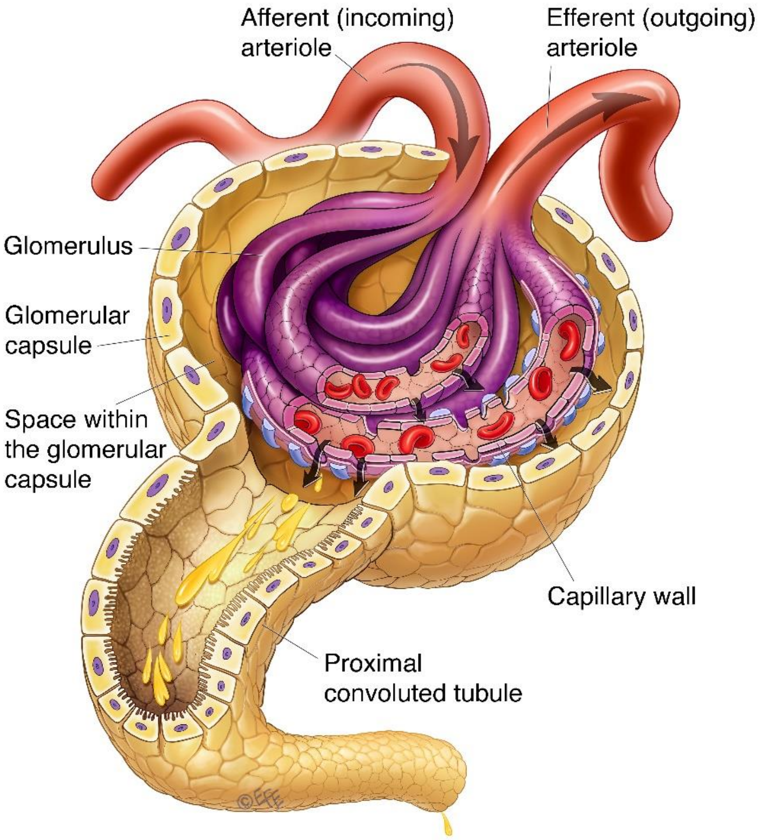


Figure 3.46: Urine formation

Question 112

The diagram below illustrates the structure of the glomerulus and Bowman's capsule.



(a) The glomerulus is a network of blood capillaries that filters blood into Bowman's capsule.

(1) State two features of the glomerulus that support its function.

____

______________________________ (2 marks) **KA2**

(2) Describe the process of filtration and explain its importance in animals.

____

____

____

______________________________ (2 marks) **KA2**

(b) State why cells and proteins cells do not pass from the glomerulus into Bowman's capsule.

____

______________________________ (1 mark) **KA2**

(c) In people with diabetes, the epithelium of the glomerulus is damaged.

Suggest a chemical test to identify damaged epithelial tissue in people with diabetes.

____

______________________________ (1 mark) **KA2**

The hearts of vertebrates contain two or more muscular chambers. The chambers that receive the blood entering the heart are called **atria** (singular, **atrium**), and the chambers responsible for pumping blood out of the heart are called **ventricles**. The number of chambers and the extent to which they are separated differ substantially among groups of vertebrates. For example, blood travels through the body in sharks, rays, and bony fish and returns to its starting point in a single circuit (loop), an arrangement called **single circulation** (Figure 3.53). These animals have a heart that consists of two chambers: one atrium and one ventricle. Blood entering the heart collects in the atrium before transfer to the ventricle. Contraction of the ventricle pumps blood to a capillary bed in the gills, where oxygen diffuses into the blood and carbon dioxide diffuses out. As blood leaves the gills, the capillaries converge into a vessel that carries oxygen-rich blood to capillary beds throughout the body. Inside body capillaries, respiratory gases, nutrients, and waste products are exchanged with tissue cells before the blood returns to the heart in veins. When blood flows through each capillary bed, it experiences a pressure drop which reduces blood flow to the rest of the body. However, as the animal swims, the contraction and relaxation of muscles help accelerate blood flow, ensuring that circulation effectively supplies tissue cells with oxygen, nutrients and waste removal.

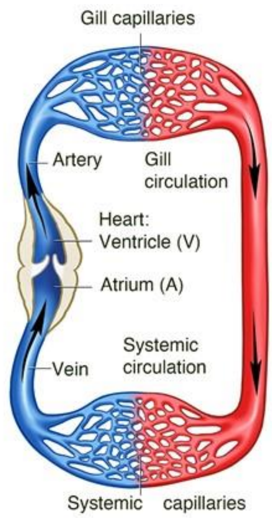


Figure 3.53: Single circulation.

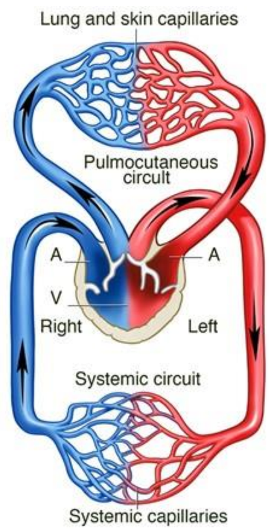


Figure 3.54: Double circulation in amphibians.

In contrast, the circulatory systems of amphibians, reptiles, and mammals have two circuits of blood flow; an arrangement called **double circulation** (Figures 3.54 and 3.55). In one circuit, called the **pulmocutaneous circuit** in amphibians and the **pulmonary circuit** in mammals, the right side of the heart pumps oxygen-poor blood to the capillary beds of the gas exchange tissues, where there is a net diffusion of oxygen into the blood and carbon dioxide out of the blood. The other circuit, called the **systemic circuit**, begins with the left side of the heart pumping oxygen-rich blood from the gas exchange tissues to capillary beds in organs and tissues throughout the body. Then, following the exchange of respiratory gases, nutrients and waste products, the oxygen-poor blood returns to the heart, completing the circuit. Thus, double circulation ensures rapid blood flow to the body as the heart repressurises the blood after flowing through capillaries.

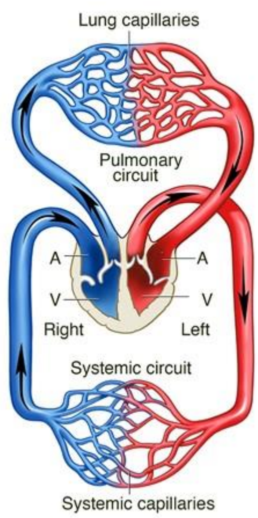


Figure 3.55: Double circulation in mammals.

The Human Circulatory System

Humans have double circulation, including pulmonary and systemic circuits (Figure 3.56). Within the pulmonary circuit, the right ventricle contracts and pumps blood through the pulmonary arteries to the lungs. As the blood flows through capillary beds in the left and right lungs, oxygen diffuses into the blood and carbon dioxide diffuses out. Oxygen-rich blood returns from the lungs through the pulmonary veins to the left atrium of the heart. The oxygen-rich blood then flows into the left ventricle, which pumps the oxygen-rich blood through the systemic circuit to tissue cells. Blood then leaves the left ventricle through the aorta, which branches into arteries that transport blood throughout the body. One branch transports blood to capillary beds in the abdomen and legs, and another transports blood to capillary beds in the head and arms. Within the capillary beds, there is a net diffusion of oxygen from the blood to the tissues and of carbon dioxide into the blood. Oxygen-poor blood from the abdomen, legs, head and arms is transported back to the heart by large veins called the **inferior vena cava** and **superior vena cava**. The vena cavae empty oxygen-poor blood into the right atrium before flowing into the right ventricle.

The human heart is located behind the sternum (breast bone) and consists primarily of cardiac muscle tissue. The two atria have relatively thin walls and serve as collection chambers for blood returning to the heart from body tissues. In contrast, the ventricles have thicker walls and contract more forcefully than the atria, especially the left ventricle, which pumps blood to the body through the systemic circuit. Although the left ventricle contracts with greater force than the right ventricle, it pumps the same volume of blood (70-80 mL) as the right ventricle during each contraction.

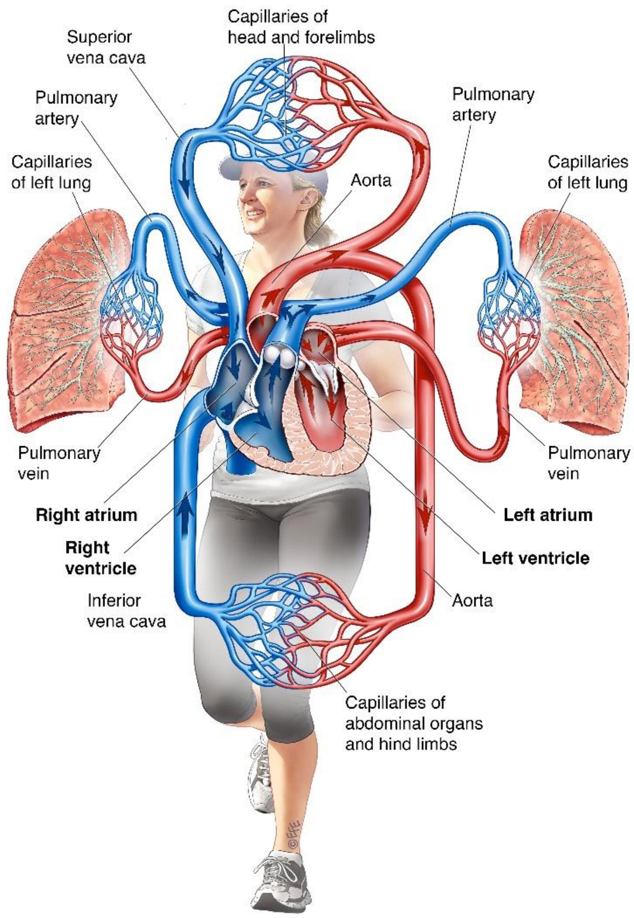


Figure 3.56: The human circulatory system

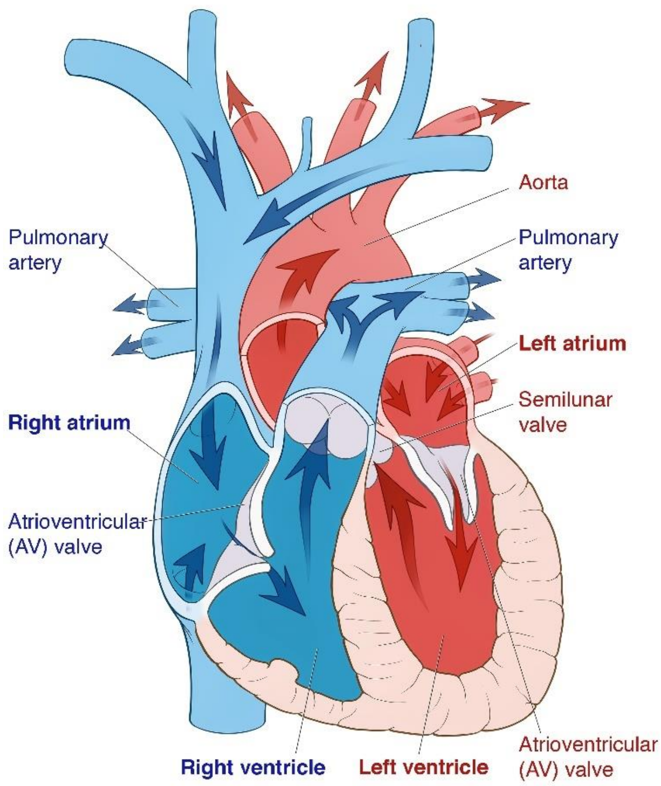


Figure 3.57: The human heart.

Fluid Exchange

The critical exchange of substances between the blood and tissue fluid occurs across the thin endothelial walls of blood capillaries. Small molecules, such as oxygen, and carbon dioxide, diffuse across the endothelial cells, while large molecules are transported by endocytosis and exocytosis. In addition, the capillary walls contain microscopic pores that permit the diffusion of small solutes such as sugars, salts, and urea. Two opposing forces control the movement of fluid between the capillaries and the surrounding tissues: Blood pressure tends to drive fluid out of the capillaries, and the presence of blood proteins tends to pull fluid back (Figure 3.60). Many blood proteins and all blood cells are too large to pass readily through the endothelium, so they remain in the capillaries. Blood proteins are responsible for much of the blood's **osmotic pressure**, produced by the difference in solute concentration across the capillary wall. The difference in osmotic pressure between the blood and the tissue fluid opposes fluid movement out of the capillaries. On average, blood pressure is higher than osmotic pressure, leading to a net loss of fluid from capillaries. There is also some leakage of blood proteins, even though the capillary wall is not very permeable to large molecules. The lost fluid and the proteins within it are recovered and returned to the blood via the **lymphatic system** (Figure 3.61). The fluid diffuses into the lymphatic system via a network of **lymphatic vessels**. The recovered fluid, called **lymph**, circulates within the lymphatic system before draining into a pair of large veins of the circulatory system at the base of the neck. Lymphatic capillaries have a greater diameter than blood capillaries, and the endothelial cells overlap, allowing tissue fluid to diffuse into the lymphatic capillary but not out. When pressure is higher in the tissue fluid than in lymph, the endothelial cells separate, and tissue fluid enters the lymphatic capillary. When pressure is higher inside the lymphatic capillary, the endothelial cells adhere more closely, preventing lymph from escaping back into tissue fluid.

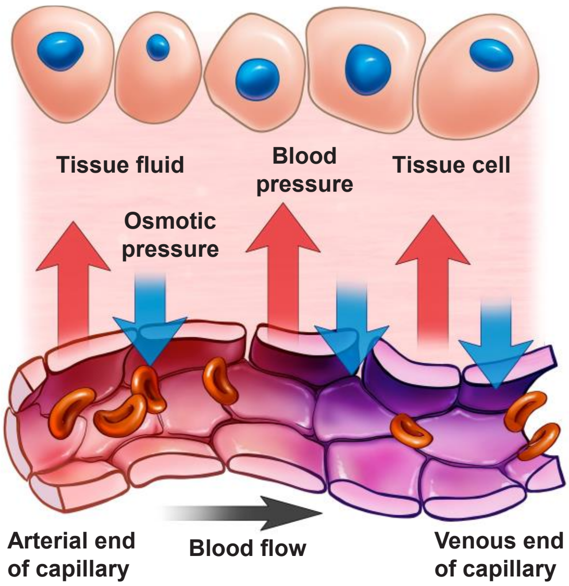


Figure 3.60: Fluid exchange across capillaries

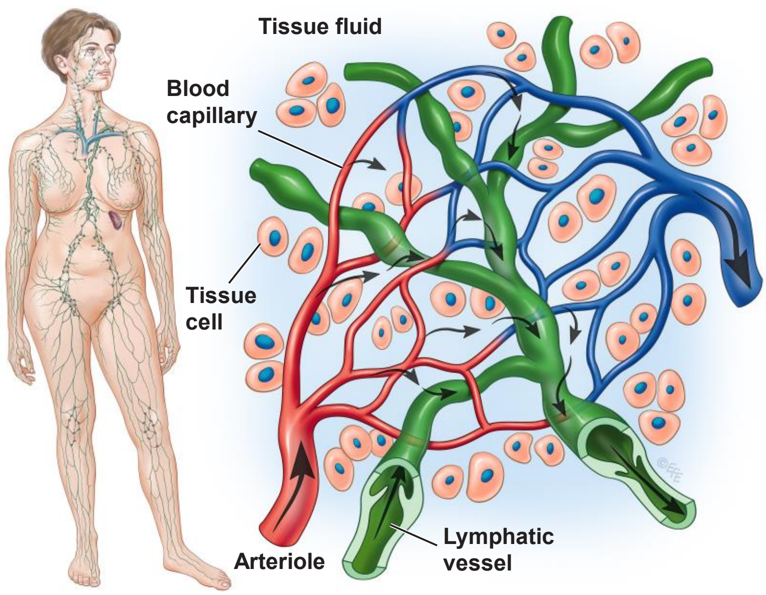


Figure 3.61: Fluid exchange across capillaries

3.10: Transport in plants

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.

Plants require water for photosynthesis, minerals for metabolism and nutrients for respiration. These materials and many more are transported between the root and shoot systems in vascular tissue. In the final part of this chapter, we explore the movement of materials in plants, beginning with the transport of water and minerals and concluding with the transport of nutrients.

Transport of Water and Minerals

Recall from Chapter 3.6 that plants absorb water and minerals from the soil solution surrounding roots. The soil solution is drawn into the root epidermal cells, crosses the **root cortex**, and passes into **xylem vessels** (Figure 3.62). From there the water, and dissolved minerals, called **xylem sap**, is transported long distances at velocities ranging from 15 to 45 metres per hour to the veins that branch throughout each leaf. As it travels upwards in xylem vessels, water diffuses into tissues, supplying cells with water and minerals.

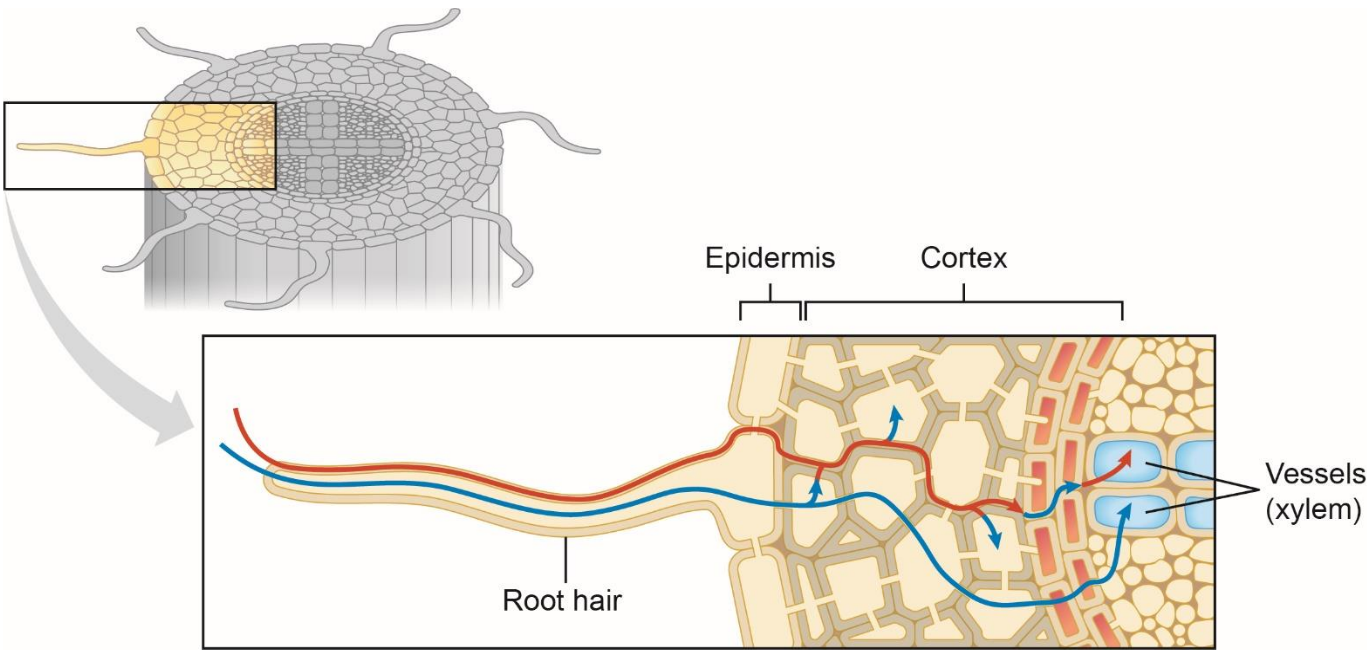


Figure 3.62: Transport of water and minerals from root hairs to the xylem

Transport of Xylem Sap

Different physical processes facilitate the transport of xylem sap from the root system to the shoot system. Firstly, root cells actively transport mineral ions into the xylem throughout the day, and the resulting accumulation increases the solute concentration inside xylem vessels, causing water to follow by osmosis. Second, the accumulation of water in xylem vessels generates **root pressure**, a force that pushes xylem sap upwards. However, in most plants, root pressure is a minor mechanism driving the ascent of xylem sap, pushing water only a few metres at most as the upwards force is smaller than the downwards gravitational force on the water column. It was soon discovered that transpiration, the loss of water from the shoot system, was the driving force behind the upwards flow of xylem sap. Recall from Chapter 3.4 that the air spaces within leaves are saturated with water vapour. On most days, the air outside a leaf has less water than the air inside it, causing water to diffuse down its concentration gradient and exit the leaf by diffusion and evaporation. The current leading hypothesis explaining the ascent of xylem sap, called the **cohesion-tension hypothesis**, suggests that transpiration produces an upward pulling force or **tension** on xylem sap, and the **cohesion** of water molecules transmits this **transpirational pull** from shoots to roots (Figure 3.63). The hypothesis states that the transpiration of water from leaves induces a tension or **negative pressure** that pulls water molecules from the xylem vessels into the air spaces down the pressure gradient. Furthermore, transpirational pull on xylem sap is transmitted from the leaves to the roots and even into the soil solution as each water molecule is cohesively bound to the next by attractive forces called **hydrogen bonds**. Hydrogen bonding forms a **transpiration stream**, an unbroken chain of water molecules extending from leaves to the soil. Water molecules exiting the xylem in the leaf pull on adjacent water molecules, and this pull is relayed, molecule by molecule, down the transpiration stream. Meanwhile, the strong adhesion of water molecules by hydrogen bonding to the hydrophilic walls of xylem cells helps offset the downward gravitational force.

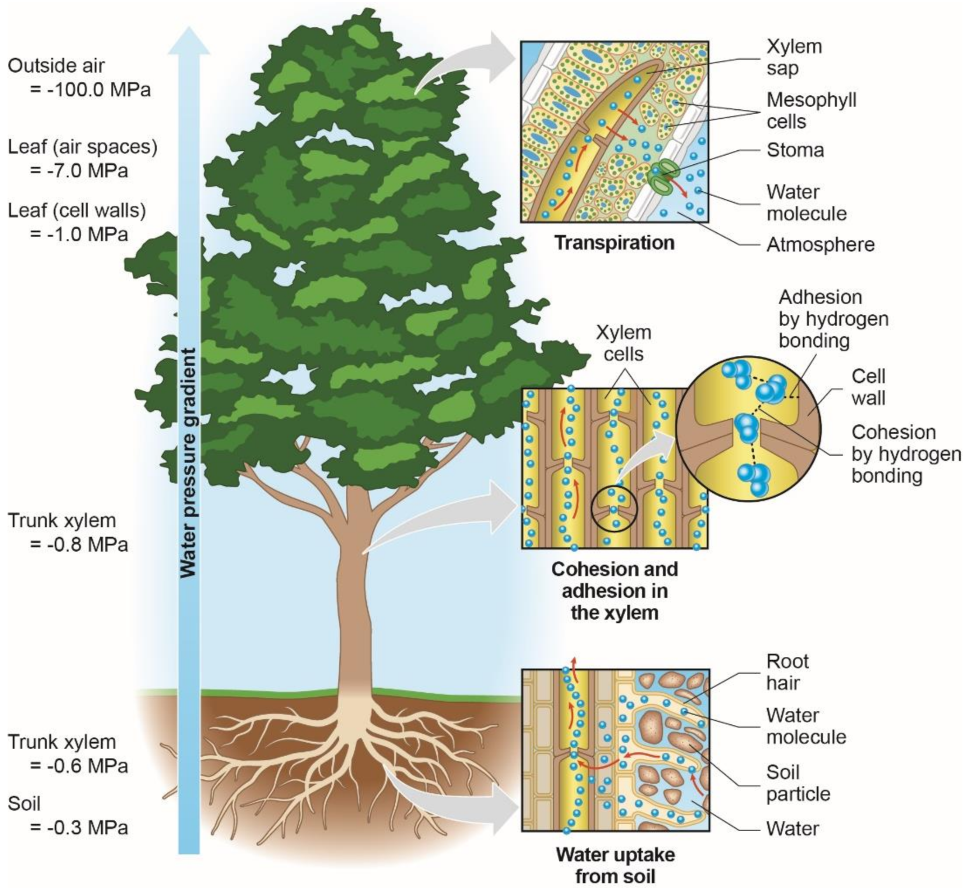


Figure 3.63: Transpirational pull by cohesion and tension.

Transport of Phloem Sap

The flow of water and minerals in xylem vessels is unidirectional and occurs from roots to shoots. In contrast, the flow of nutrients produced in photosynthesis often occurs in the opposite direction, transporting sugars from mature leaves to lower parts of the plant. The transport of photosynthetic products, called **translocation**, is facilitated by another vascular tissue called **phloem**. Like xylem, phloem is composed of specialised cells arranged end to end in long tubes that serve as vessels for translocation. However, the fluid that flows through phloem vessels, called **phloem sap**, differs significantly from xylem sap. The most prevalent solute in phloem sap is carbohydrate (sugar), typically sucrose, as well as amino acids, hormones, and minerals. In contrast to the unidirectional transport of xylem sap from roots to leaves, phloem sap moves from sugar production sites to sugar use or storage sites. A **sugar source** is a plant organ such as a mature leaf that is a net producer of sugar, and a **sugar sink** is an organ such as a growing root, stem, fruit, tuber or bulb that is a net consumer or depository of sugar. Sugar is transported in phloem sap from sources to the nearest sinks. For example, the upper leaves may export sugar to a growing branch, whereas the lower leaves may export sugar to the roots. Once produced inside a leaf, sugar diffuses down its concentration gradient from source cells, such as leaf mesophyll cells, to phloem vessels, as in Figure 3.64. Sugar transport into phloem often requires active transport because sucrose is more concentrated in phloem vessels than in mesophyll. The transport of sugar into phloem causes water to follow by osmosis, generating **positive pressure** at the source end of the vessel. As a result, phloem flows under pressure to sinks, where sucrose diffuses down its concentration gradient into sink cells, as depicted in Figure 3.65. Phloem sap flows from source to sink at rates as great as one metre per hour, driven by the pressure gradient generated by the building of pressure at the source-end and the reduction of that pressure at the sink-end.

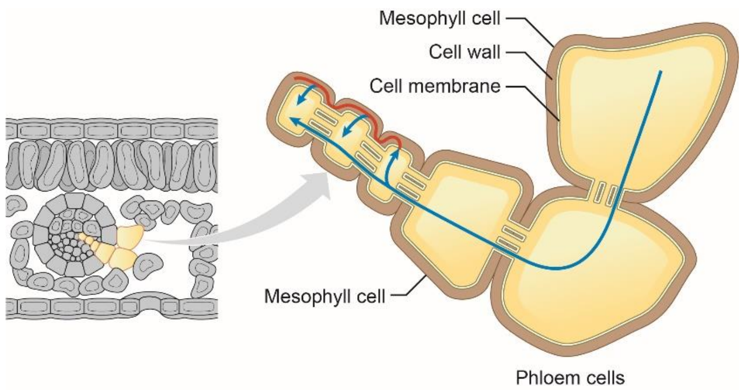


Figure 3.64: Loading sucrose into phloem vessels

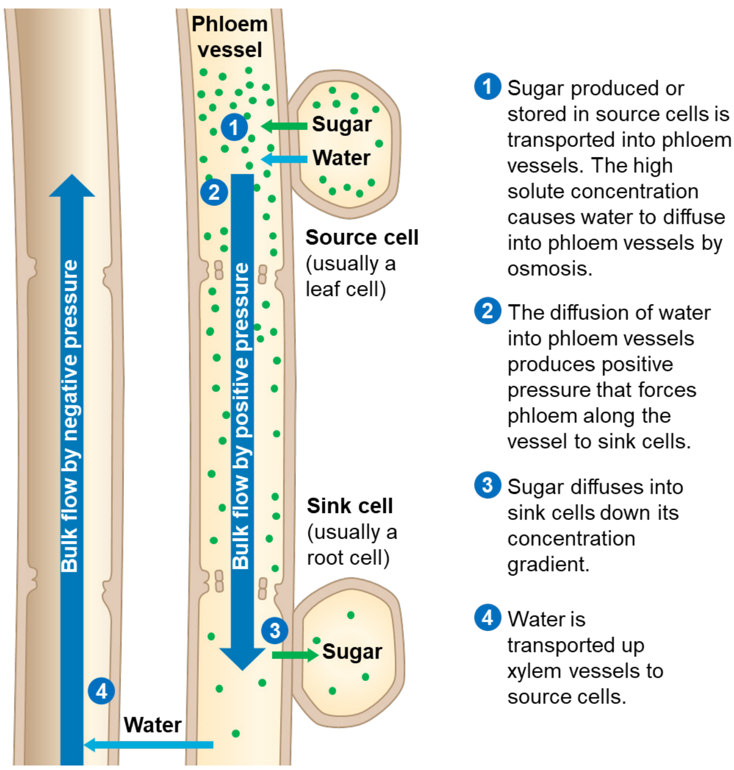


Figure 3.65: Pressure flow phloem vessels

Review Test 3

Questions 1 to 10

Questions 1 to 10 are **multiple-choice questions.** For each multiple-choice question, indicate the best answer to the question by shading in the bubble [O] beside it.

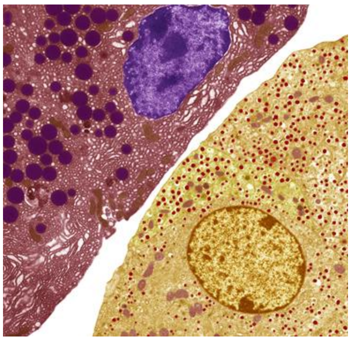
1. Multicellular organisms have a hierarchical structural organisation.

   Which of the following is a hierarchical structure of organisation in plants?

○ J Ground tissue → palisade mesophyll cell → shoot system → leaf
○ K Palisade mesophyll cell → ground tissue → leaf → shoot system
○ L Ground tissue → palisade mesophyll cell → leaf → shoot system
○ M Palisade mesophyll cell → ground tissue → shoot system → leaf

(1 mark) KA2

2. The TEM below shows two differentiated cell types in the human pancreas.



   The acinar cell (red) produces and secretes digestive enzymes, and the beta cell (yellow) produces and secretes the hormone insulin.

   Which of the following statements is accurate?

○ J The two cells have identical genes and different functions.
○ K The two cells have identical genes but the same function.
○ L The two cells have different genes and different functions.
○ M The two cells have different genes but the same function.

(1 mark) KA2

3. Coeliac disease is an immune disease that damages an organ in the digestive system.

   Organ damage results in a significant decrease in the absorption of nutrients from food.

   Which of the following organs is damaged by Coeliac disease?

○ J Mouth
○ K Stomach
○ L Small intestine
○ M Large intestine

(1 mark) KA2

Question 12

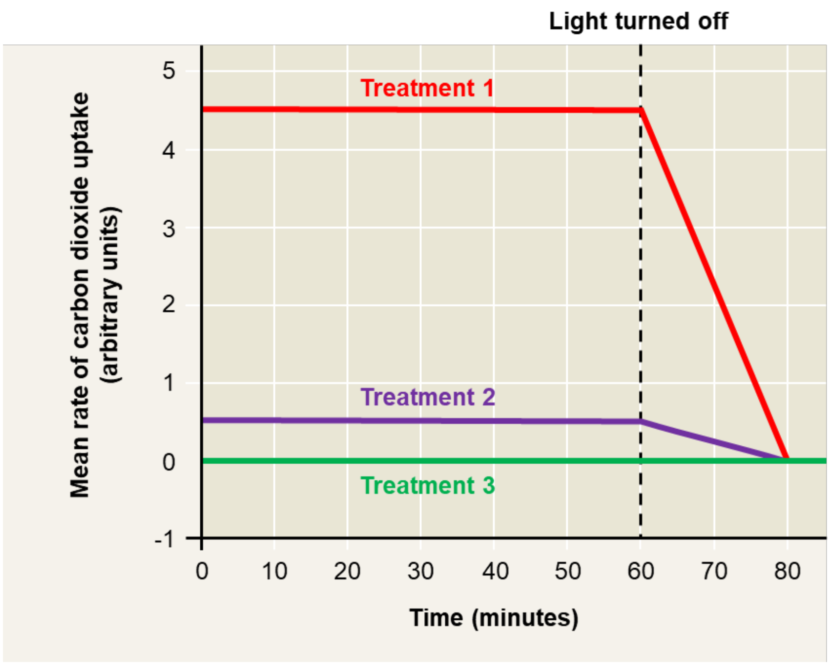
An investigation was conducted to study the rate of carbon dioxide uptake by grape plant leaves.

Grape leaves have stomata on the lower surface but no stomata on the upper surface.

The rate of carbon dioxide uptake by grape leaves was measured with three different treatments that used air-sealing grease to prevent gas exchange.

Treatment	Description
1	No air-sealing grease was applied to either surface of the leaf.
2	Air sealing grease is applied to the lower surface of the leaf.
3	Air sealing grease is applied to the upper and lower surfaces of the leaf.

The rate of carbon dioxide uptake by each leaf was measured for 60 minutes in light and then for 20 minutes in the dark. The results are shown below.



(a) Suggest the purpose of each treatment in the investigation.

(3 marks) **IAE1**

(b) State the independent variable in the investigation and give a reason.

(2 marks) **IAE1**

(c) State two variables held constant in the investigation.

(2 marks) IAE1

(d) Describe and explain the results shown for Treatment 1.

(2 marks) IAE3

(e) Treatment 2 shows an uptake of carbon dioxide when the lower surface of the leaf is sealed.

Suggest how the uptake of carbon dioxide continues when the lower surface is sealed.

(1 mark) IAE3

(f) Explain why the uptake of carbon dioxide falls to zero when the light is turned off in Treatments 1 and 2.

(2 marks) IAE3

(g) The grape leaves consumed water during the investigation.

(1) Explain how water moves in, through, and out of a grape plant rooted in soil.

(3 marks) KA1

(2) State two factors that increase the transpiration rate in grape plants rooted in soil.

(2 marks) KA1

Question 13

In animals, gas exchange is facilitated by the respiratory and circulatory systems.

(a) The heart, blood vessels and lungs contain cells with specialised structures and functions.

(1) Describe the process that produces cells with specialised structures and functions.

(1 mark) **KA1**

(2) State the advantage to animals of having cells with specialised structures and functions.

(1 mark) **KA1**

(b) The respiratory and circulatory systems in animals are interdependent.

Describe how these systems function together to ensure the survival of animals.

(2 marks) **KA2**

(c) Emphysema is a lung disease that develops in cigarette smokers, causing shortness of breath.

In people with emphysema, the inner walls of the alveoli weaken and rupture, creating larger air spaces instead of many small ones.

(1) State one way that emphysema causes shortness of breath.

(1 mark) **KA1**

(2) Discuss one economic and one social impact of lung diseases such as emphysema.

(4 marks) **KA3**

4.1: Biodiversity

Biodiversity is the variety of all living things and includes diversity in genetics, species, and ecosystems.

- Distinguish between a species, population, community, and ecosystem.
- Describe diversity in examples of:
    - species
    - ecosystems.

In general, the higher the biodiversity of an ecosystem, the more stable it is.

Ecology is the scientific study of the interactions between organisms and the environment. When studying living things in nature, scientists often determine the environmental factors limiting their distribution and population sizes, including their variety of habitats, food sources and interactions with other species, such as predators. The interactions studied by ecologists are organised into a hierarchy that ranges in scale from single species to populations, communities, and ecosystems.

A **species** is a group of related living things that share common characteristics. In the context of plants and animals, the term species refers to a group of living things capable of producing fertile offspring through sexual reproduction. Two groups may share characteristics but are classified as separate species as they cannot interbreed or produce fertile offspring. For example, emperor penguins (*Aptenodytes forsteri*) and king penguins (*Aptenodytes patagonicus*) share similar physical features (Figure 4.01) but are separate species as they cannot interbreed and produce fertile offspring.

Figure 4.01: Penguin species

A **population** is a group of individuals of a single species living in the same general area. Members of a population rely on the same resources, are influenced by similar environmental factors, and are likely to interact and breed with one another. For example, Figure 4.02 shows a population of Grey reef sharks (*Carcharhinus amblyrhynchos*) in the Great Barrier Reef, Queensland, Australia.

Figure 4.02: Grey reef sharks

A **community** is a group of populations of different species in an area. For example, the Grasslands of Masai Mara in Kenya, Africa (Figure 4.03), are home to various animals, including lions, elephants, rhinoceros, cheetah, buffalo leopard, giraffe, hippo, zebra, and more than 500 bird species. The interactions of populations affect community structure and organisation.

Figure 4.03: Masai Mara community

An **ecosystem** is a community of organisms in an area that interact with each other and the physical environment. Ecosystems are described by their living components, including microorganisms, plants, animals, and non-living components such as light intensity, ambient temperature, water availability, soil type and pH and nutrient availability. For example, mangrove forests (Figure 4.04) are ecosystems located in the intertidal zones of tropical coastal rivers. Mangrove forests contain a community of mangroves, insects, migratory birds, fish, molluscs and crustaceans. Mangrove forests are characterised by low light intensity, warm ambient temperatures, sandy soil and a low dissolved oxygen concentration. An ecosystem can encompass a large area, such as a forest, ocean, sea, grassland, desert, tundra, reef, mountains, or a small area, such as a creek, pond, desert spring, or tree.

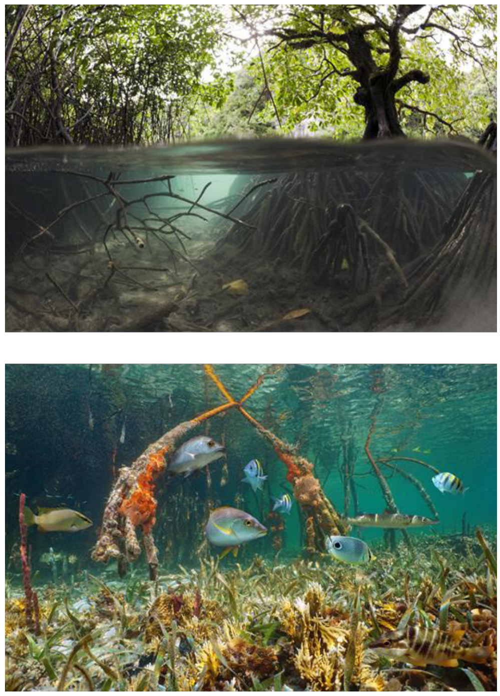


Figure 4.04: Mangrove forest

Biodiversity

Biodiversity refers to the variety of living things found in an area and is considered at three levels: genetic diversity, species diversity, and ecosystem diversity. Genes are nucleotide sequences on chromosomes that encode protein molecules that give rise to an organism's observable characteristics, called **phenotypes**. Individuals in a population contain the same number of genes that code for phenotypes, including physical features, behavioural traits, and disease or drought resistance. Most genes have **alleles**, variants that give rise to multiple phenotypes for a given gene, such as those encoding flower colour in pea plants (Figure 4.05). **Genetic diversity** refers to individual genetic variation within a population and genetic differences between populations resulting from adaptations to local conditions. Genetic diversity is inferred from the size of a **gene pool**, the total number of alleles for each gene in a population. A large gene pool is associated with many alleles for each gene, and a small gene pool is associated with very few alleles for each gene. In general, populations with large gene pools are more likely to adapt to environmental change, whereas those with low genetic diversity are less likely to adapt to environmental change and are more likely to become extinct. When a population becomes extinct, the species may lose some of the genetic diversity. For example, Asian rice (*Oryza sativa*) is a plant species that grows throughout Asia. Asian rice has high genetic diversity with thousands of alleles for specific genes, ensuring that the plant can survive certain environmental changes.

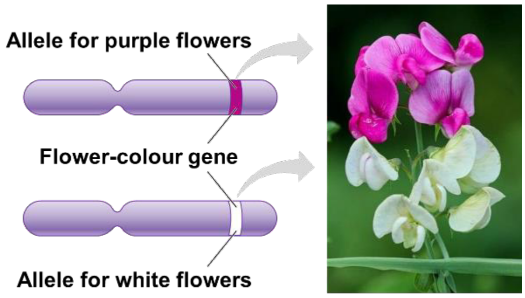
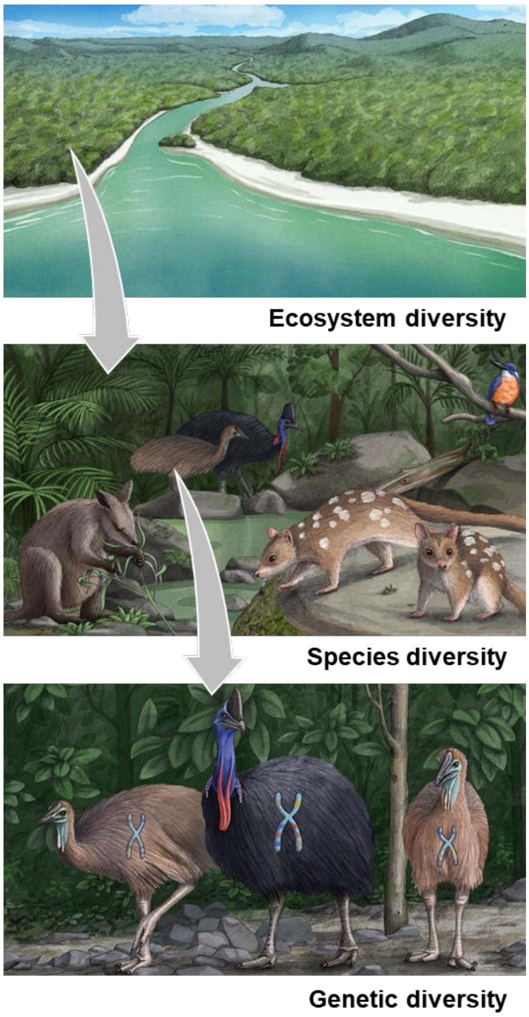


Figure 4.05: Pea flowers

Question 128

The diagram opposite shows the three levels of biodiversity.



(a) Describe the three levels of biodiversity shown.

(3 marks) KA1

(b) Human activity is decreasing biodiversity.

(1) Describe one human activity that decreases biodiversity.

(1 mark) KA2

(2) Describe and explain one environmental consequence of a decrease in biodiversity.

(2 marks) KA3

(3) Describe and explain one economic consequence of a decrease in biodiversity.

(2 marks) KA3

The Biological Species Concept

The word species is Latin for "kind" or "appearance." The word species has many definitions in biology, but the primary definition used in this workbook is the **biological species concept.** According to this concept, a species is one or more populations whose members interbreed in nature and produce viable, fertile offspring but are incapable of interbreeding or producing viable, fertile offspring with members from other species. For example, the mountain gorilla (*Gorilla beringei)* is classified as a species distinct from other primates as when their members meet and mate, they can produce viable babies who develop into fertile adults. In contrast, mountain gorillas and chimpanzees (*Pan troglodytes*) remain distinct biological species because many factors keep them from interbreeding and producing fertile offspring.

Figure 4.14: Mountain gorilla

Reproductive Isolation

The biological species concept suggests that each species has a gene pool consisting of all genes and alleles in a population at a given time. Genes cannot flow between the gene pools of two different species as members cannot exchange genes through interbreeding. For this reason, members of a species are said to be **reproductively isolated** as there exists one or more biological barriers that impede members from interbreeding and producing viable, fertile offspring with members of other species. Such barriers prevent gene flow between the species and limit the formation of **hybrids**, offspring that result from an interspecific mating, such as a zorse (Figure 4.15), the offspring of a zebra (*Equus zebra*) and a horse (*Equus caballus*). In many cases, a single barrier is sufficient to prevent gene flow, and in other cases, a combination of several barriers is necessary. These barriers are classified according to whether they contribute to reproductive isolation before or after fertilisation. **Pre-zygotic barriers** block fertilisation from occurring by impeding members of different species from mating. One example is **habitat isolation**, whereby two closely related species within the same area are prevented from mating as they occupy different habitats and rarely encounter one another. For example, the apple maggot fly (*Rhagoletis pomonella*) (Figure 4.16) feeds and mates on apples while its close relative, the blueberry maggot fly (*Rhagoletis mendax*), mates and lays its eggs only on blueberries. The different habitats used by each species for mating keeps the species reproductively isolated.


Figure 4.15: Zorse


Figure 4.16: Apple maggot fly

4.3: Adaptation

Organisms have adaptations that help them survive and reproduce.

- Discuss examples of adaptations (behavioural, structural, and physiological) in plants and animals.

An **adaptation** is a feature that helps an organism survive and reproduce in its environment. All living things have **general adaptations** that help them survive and reproduce, including eyes for seeing, legs for walking, wings for flying, fins for swimming or leaves for photosynthesising. In addition, living things also have **specific adaptations**, features that have evolved to make an organism more suited to its local environment. For example, the giraffe's (*Giraffa camelopardalis*) long neck helps it access vegetation unavailable to its competitors (Figure 4.22). In general, the better adapted an organism is to its habitat, the more successful it will be when competing for resources such as food and mates, increasing its chances of surviving and passing on its genes through reproduction. An organism's adaptations are a result of the genes inherited from its parents. Adaptations evolve over many generations as individuals with features best suited to their environments have greater reproductive success and pass their traits to offspring.

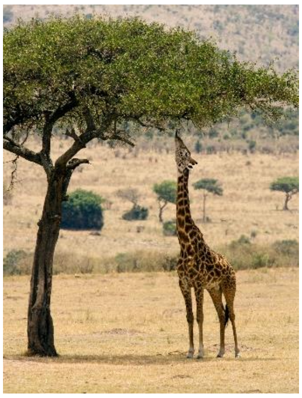


Figure 4.22: Giraffe

Behavioural Adaptations

Behavioural adaptations are actions or activities that improve an organism's survival and reproductive success in its environment. One example is **nocturnality**, a behavioural adaptation characterised by being active at night rather than in daylight hours. Nocturnality helps animals avoid hunting in intense sunlight, reduce competition for resources and avoid predation by using the cover of darkness. For example, the tawny frogmouth (*Podargus strigoides*) (Figure 4.23) is a nocturnal animal that hunts insects at night when there is less competition from other animals. A second example is **burrowing**, a behavioural adaptation in which the animal spends all or part of its time below ground. Animals use burrowing to protect themselves from extreme ambient temperatures and move around and feed without fear of predation. For example, the Southern Hairy-nosed wombat (*Lasiorhinus latifrons*) (Figure 4.24) lives in underground burrows that protect it from predators and ambient temperature extremes in winter and summer.

Figure 4.23: Tawny frogmouth

Figure 4.24: Southern Hairy-nosed wombat

A third example is **hibernation**, a behavioural adaptation in which an animal conserves energy by lowering its body temperature and metabolic rate to just a fraction of its normal levels and enters a deep sleep for extended periods. Hibernating species typically build up large fat reserves before hibernation and may wake to eat and defecate as required. For example, the eastern pygmy possum (*Cercartetus nanus*) (Figure 4.25) can spend a whole year in hibernation.

Figure 4.25: Eastern pygmy possum

A fourth example is **migration**, a behavioural adaptation in which one or more animal species travel from one habitat to another in search of food, shelter or mates. Migrating animals travel by land, sea, or air to reach their destination, often crossing vast distances and in large numbers. For example, migratory waterbirds (Figure 4.26), including plovers, sandpipers, and snipes, migrate tens of thousands of kilometres each year between their summer breeding grounds in the northern hemisphere and their feeding areas in Australia.

Figure 4.26: Migrating waterbirds

Plants exhibit a range of behavioural adaptations. One example is **climbing,** a behavioural adaptation in which a plant utilises natural and human-made structures for support and growth. For example, the Banksia rose (*Rosa banksiae*) has a flexible and robust stem, allowing it to use buildings (Figure 4.27) and natural structures for growth and support.

Figure 4.27: Banksia rose

A second example is **tumbling**, a behavioural adaptation of plants in dry climates that lack water for growth. Tumbling plants (Figure 4.28) break away from roots when the soil becomes dry and use the wind for tumbling to a new location. When the plant senses that moisture is available, it unrolls, projects its roots into the soil and resumes life processes.

Figure 4.28: Tumbling plant

A third example is **night-blooming**, a behavioural adaptation of plants in which flowers are opened at night. Several plant species inhabiting arid habitats have opted to bloom at night to prevent excessive water loss through transpiration, protect pollen from heat stress and attract nocturnal animal pollinators, including bats (Figure 4.29) and insects. In some cases, the flowers are short-lived, and some of these species bloom only once a year, for a single night.

Figure 4.29: Night-blooming

4.4: 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.
- Compare the characteristics of at least two ecosystems.

Patterns within a community include zonation and stratification.

An ecosystem is a community of organisms in an area that interact with each other and the physical environment. Earth is home to a diverse range of ecosystems, each exhibiting small-scale differences in its non-living or **abiotic factors,** including temperature, sunlight intensity, water availability and nutrient availability. These abiotic factors influence the type, distribution and abundance of living or **biotic factors** such as microorganisms, plants and animals adapted to that environment. One of the most critical biotic factors in any ecosystem are plant species, as they provide food and shelter for different animal species. The most significant influence on the distribution of plant species on land is **climate**, the long-term weather conditions in a given area. The climate factors of an ecosystem, including temperature, light intensity, wind speed, and the amount and type of precipitation, are primarily determined by its solar energy input. The sun warms the atmosphere, land, and water, establishing temperature variations that drive the movement of air (wind) and the evaporation of water, which drives rainfall and other types of precipitation. As a result, the climate varies both latitudinally and seasonally and is modified by factors, such as large bodies of water, mountain ranges and the type of vegetation. Most **terrestrial ecosystems** are named for their major climatic features and predominant vegetation (Figure 4.42). For example, temperate grasslands are generally found in middle latitudes, where the climate is moderate and various grass species dominate.

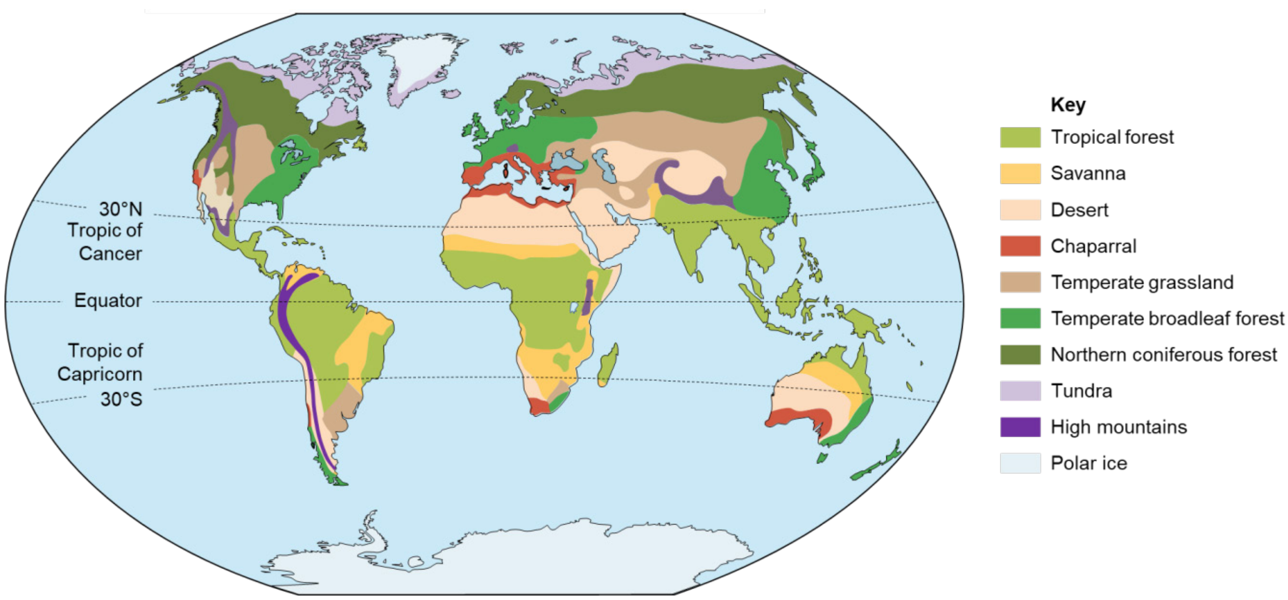


Figure 4.42: The major terrestrial ecosystems.

Tropical Forests

Tropical forests are ecosystems found in equatorial and subequatorial regions (Figure 4.43). These ecosystems are found in middle latitudes that face the sun and receive a high solar input that results in high temperatures, averaging 25-29°C with little seasonal variation and consistent rainfall ranging from one to four metres annually. Tropical forests contain vertical layers of different plant species, ranging from layers of shrubs and herbs on the forest floor to taller trees extending up to 60 metres. The diversity of plant life in Earth's tropical forests provides a habitat for millions of animal species, including arthropods, amphibians, reptiles, birds and mammals. In fact, tropical forests have the highest animal species diversity of all terrestrial ecosystems on Earth.

Figure 4.43: Tropical forest

Savanna

Savanna ecosystems also occur in equatorial and subequatorial regions (Figure 4.44). The high solar input yields warm temperatures year-round, averaging 24-29°C, but with more seasonal variation than tropical forests. As a result, savanna has wet and dry seasons causing variations in annual rainfall. For example, the wet season in the Australian savanna lasts from May to October and averages up to one metre of rainfall, whereas the dry season from December to March is often without rainfall. Savanna ecosystems contain a mixture of grasses and woody plants. The scattered woody plants are typically thorny, have small leaves and are drought and fire-tolerant, adaptations to the relatively dry conditions. The ground is covered with grasses and small nonwoody plants that grow rapidly in response to seasonal rains. The low-lying vegetation attracts small and large herbivores, such as insects and grazing mammals. These animals attract predatory birds and mammals. During seasonal droughts, grazing mammals often migrate to parts of the savanna with more vegetation and water.

Figure 4.44: Savanna

Desert

Deserts are ecosystems occurring in bands near 30° north and south latitude (Figure 4.45) or at other latitudes in the interior of continents, such as the Great Victoria Desert in Southern Australia. The air temperature varies seasonally and daily, with maximums exceeding 50°C in lower latitude hot deserts and –30°C in higher latitude cold deserts. Precipitation is very low, generally less than 30 centimetres annually, as cool, dry air from the equator descends over deserts, hindering the formation of rainclouds. The lack of precipitation causes deserts to be dominated by low-lying, widely scattered vegetation, including succulents, shrubs, and herbs, with structural adaptations enabling water conservation and heat tolerance. Common desert animals include lizards, snakes, ants, beetles, scorpions, birds, and seed-eating rodents, many of which are nocturnal. Desert animals typically have adaptations enabling water conservation and rapid heat loss.

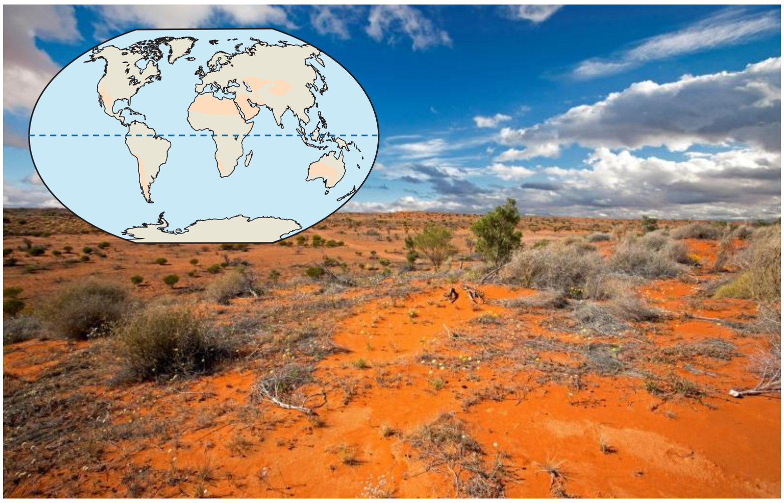


Figure 4.45: Desert

Chaparral

Chaparral (pronounced sha-puh-ral) are ecosystems occurring in mid-latitude coastal regions on several continents, including Australia, North and South America, Europe and Africa (Figure 4.46). Chaparral ecosystems are located at the continents' western end and are exposed to westerly winds. The average air temperature ranges from 10-12°C between autumn and spring and 30-40°C in summer. Precipitation is highly seasonal, with rainy winters averaging 30 to 50 centimetres annually and dry summers. The dominant plant species are grasses, shrubs, bushes, herbs and small trees, each with adaptations that help resist the effects of drought and fire. For example, some shrubs and trees, such as eucalypts, produce seeds that will germinate only after a fire. The vegetation in chaparral supports a diverse range of animal species, including insects, amphibians, reptiles, birds and small mammals.

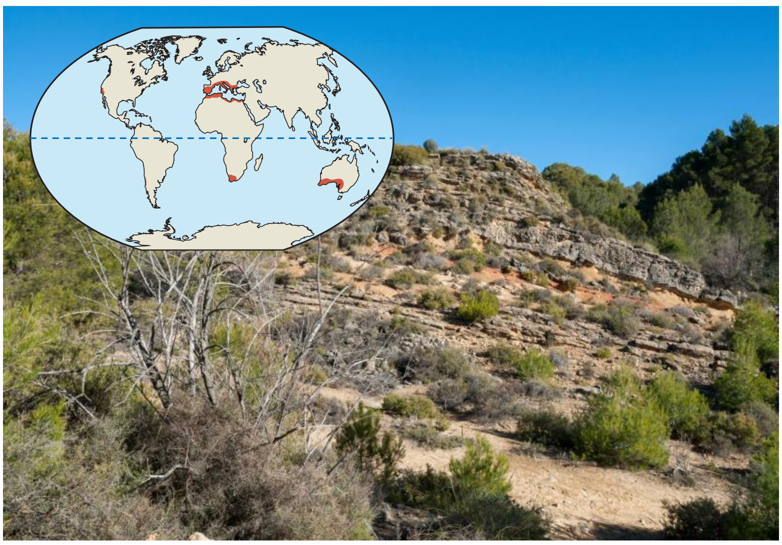


Figure 4.46: Chaparral

Temperate Grassland

Temperate grasslands are ecosystems occurring in the middle latitudes (25-55°) of the northern and southern hemispheres, specifically in Australia, New Zealand, North America, Argentina, South Africa, Uruguay, Hungary, and Russia (Figure 4.47). The average air temperature falls below −10°C in winter and approaches 30°C in summer. Precipitation is seasonal, with dry winters and wet summers averaging between 30 and 100 centimetres annually. Temperate grasslands are known for their rich soil that supports plant growth. The dominant plant species are grasses and herbs, which vary in height from a few centimetres to two metres. Many grassland plants have adapted to cold temperatures, drought, and occasional fires. For example, grasses sprout quickly after a fire. Temperate grasslands are home to many large herbivores, including kangaroos, deer, zebras, rhinoceroses, and gazelles, as well as carnivorous mammals and birds. Temperate grasslands are also home to a variety of burrowing animals.

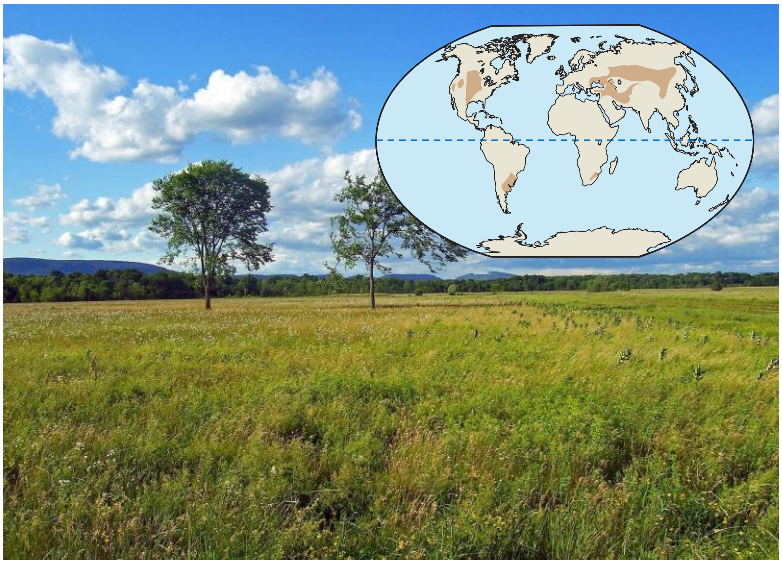


Figure 4.47: Temperate grassland

Temperate Broadleaf Forest

Temperate broadleaf forests are ecosystems occurring at midlatitudes in the Northern Hemisphere, with smaller areas in Australia, New Zealand. Chile and South Africa (Figure 4.48). The air temperature varies widely in these regions, with winter temperatures averaging 0°C and summer temperatures reaching 40°C. Precipitation averages from 70 to over 200 centimetres annually, with significant rainfall during all seasons, including summer rain and winter snow. A mature temperate broadleaf forest has distinct vertical layers, including a closed canopy, understory trees, shrubs, and herbs. The dominant plant species varies by region, with eucalypts in Australia and deciduous trees in the northern hemisphere. Insects, birds and mammals make use of all the vertical layers of the forest.

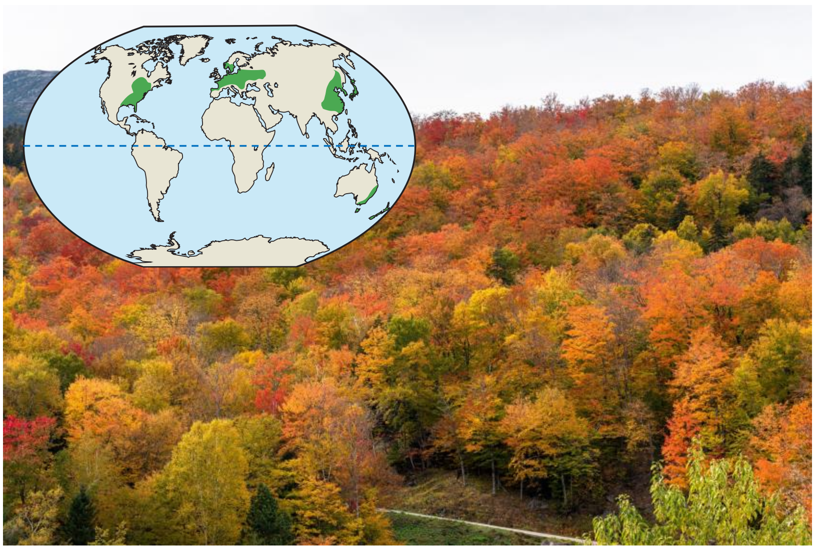


Figure 4.48: Temperate broadleaf forest

Zonation in Terrestrial Ecosystems

The climate of an ecosystem is determined by its average temperature and precipitation. Most organisms are adapted to live within a particular temperature range and will not survive outside their tolerance limits. Precipitation also limits the species found in an ecosystem, with larger organisms requiring more water than smaller organisms for survival. For example, Figure 4.51 shows that vegetation becomes taller and denser in hotter and wetter ecosystems and becomes smaller and sparser in colder and drier ecosystems.

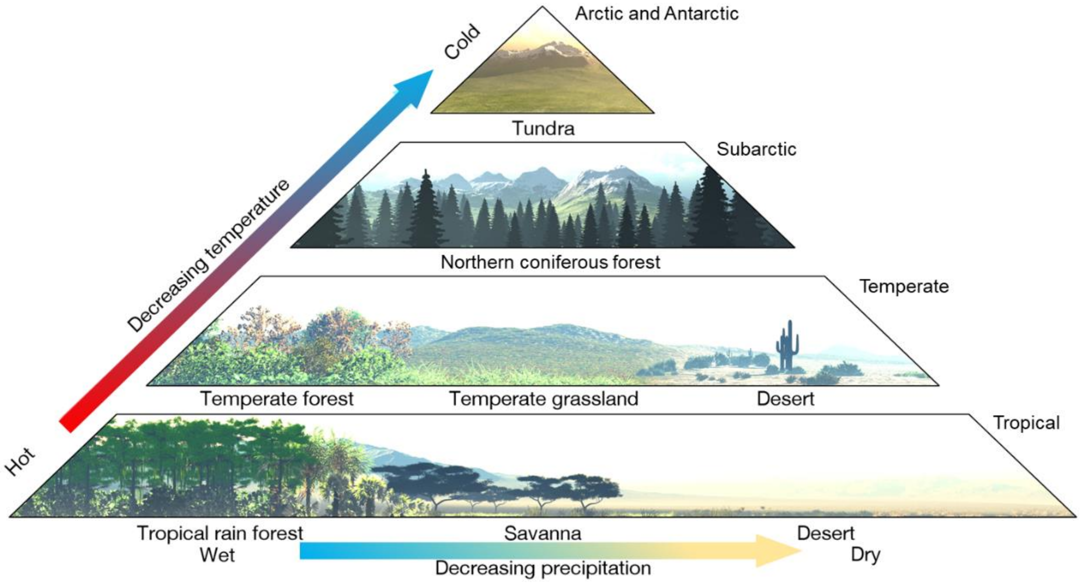


Figure 4.51: Effect of climate on vegetation.

The climate varies with **latitude**, the distance north or south of the equator and **altitude**, the height above sea level. In general, temperature and precipitation decrease with increasing latitude and altitude, resulting in distinctive vegetation zones. This **zonation** is depicted in Figure 4.52. Notice that the vines, palm trees, orchids and ferns of tropical forests usually grow closer to the equator, where temperature and precipitation are higher, while the mosses and lichens of tundra usually grow closer to the poles where temperature and precipitation are low.

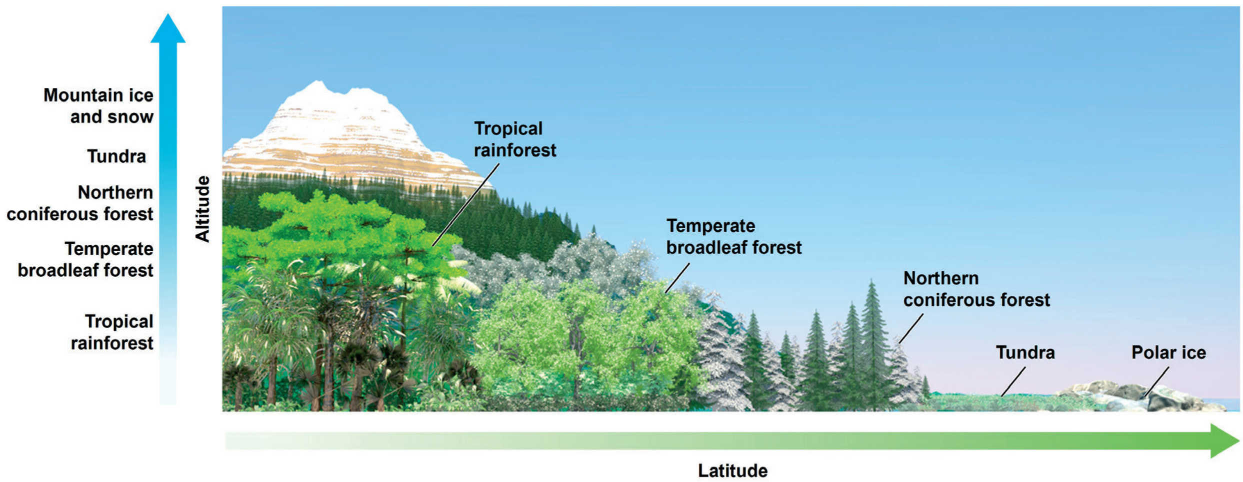


Figure 4.52: Zonation of terrestrial ecosystems.

Stratification in Terrestrial Ecosystems

Ecosystems with higher temperatures and precipitation contain dense canopies of vegetation arranged into distinct vertical layers or **strata** that experience similar abiotic conditions. Forests typically contain two or more strata, including the forest floor, herbaceous, shrub, understory, canopy and emergent layers, each characterised by the height range of plants and the amount of sunlight received. For example, tropical rainforests have four distinct strata. The lowest stratum, called the **forest floor**, has very few plants as the sunlight intensity is too low to support photosynthesis. The second stratum, called the **understory**, contains smaller trees, shrubs, ferns, vines and palms, requiring little water and sunlight for growth. The third stratum, called the **canopy**, contains taller trees and thick, woody vines, and the fourth stratum, called the **emergent layer**, has the tallest trees with the greatest foliage for absorbing sunlight. Different animal species inhabit each layer, each with adaptations that enhance their survival in that stratum. For example, low mass animals, including birds, bats, and butterflies, inhabit the emergent layer, where the tops of tall trees protect from predators. Monkeys, flying squirrels, and toucans inhabit the canopy where they swing, climb, glide, and leap between trees seeking various food sources. Birds, frogs, lizards and snakes occupy the understory, feeding on countless insects. Many animals in the understory use camouflage to stalk prey and hide from predators. Insects, spiders, amphibians, reptiles, and mammals inhabit the forest floor. The mammals, repriles and flightless birds in this stratum, including rhinoceroses, chimpanzees, gorillas, deer, cassowary, and jungle cats, are adapted to walking and climbing short distances. The layering of vegetation provides many different habitats for animals, thereby minimising competition for resources. Figure 4.53 shows stratification in the Daintree Rainforest is a region on the northeast coast of Queensland, Australia.

Figure 4.53: Stratification in the Daintree Rainforest

Aquatic Ecosystems

Aquatic ecosystems are freshwater or marine environments distributed globally. Aquatic ecosystems show far less latitudinal variation when compared with terrestrial ecosystems, with freshwater ecosystems having a salt concentration of less than 0.1% and marine ecosystems having a salt concentration of around 3%. Both marine and freshwater ecosystems support terrestrial ecosystems. For example, the water evaporated from the oceans provides most of the planet's rainfall. In addition, the carbon dioxide absorbed by photosynthetic marine algae and bacteria helps moderate climate, and the oxygen produced supplies respiratory oxygen for terrestrial organisms. Furthermore, the water supplied by freshwater ecosystems seeps through soil, solubilising nutrients for plant growth.

Zonation in Aquatic Ecosystems

Many aquatic ecosystems are vertically and horizontally layered (Figure 4.54) into well-defined zones based on three physical criteria: light penetration (photic and aphotic), distance from shore and water depth (littoral, limnetic, neritic and oceanic zones), and whether the environment is open water (pelagic zone) or on the bottom (benthic and abyssal zones). Sunlight is absorbed by photosynthetic organisms and water, so its intensity decreases rapidly with depth. Thus, the upper **photic zone** is the only region with sufficient light intensity for photosynthesis, while the lower **aphotic zone** receives very little light. The photic and aphotic zones together make up the **pelagic zone**, an open water column filled with communities of aquatic organisms. Plankton and fish occupy the photic zone, while the aphotic zone harbours very little life. At the bottom of all aquatic zones, deep or shallow, is the **benthic zone**, made up of sand and organic and inorganic sediments. The benthic zone is occupied by communities of organisms collectively called **benthos** that obtain much of their nutrients and energy from dead organic matter called **detritus**, which sinks from the productive surface waters of the photic zone.

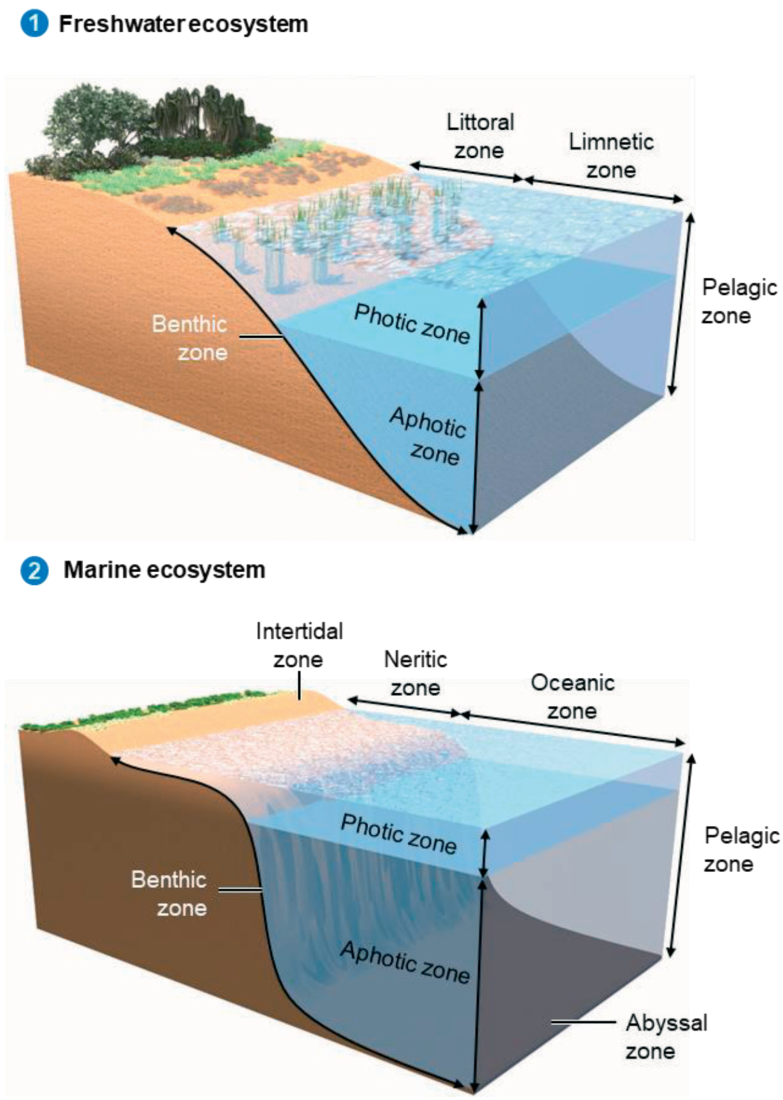
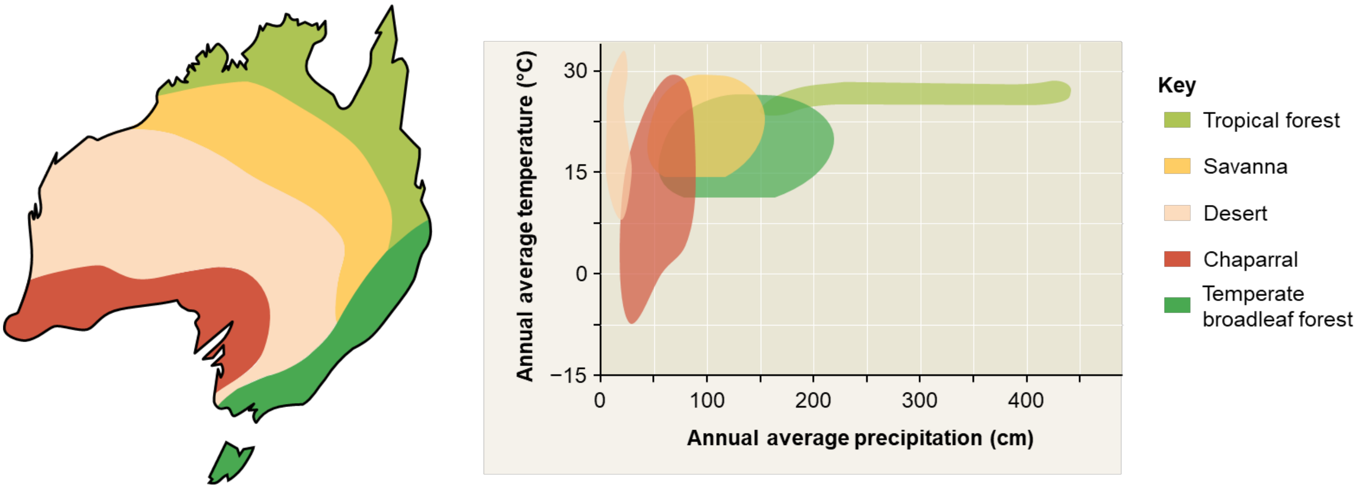


Figure 4.54: Zonation in aquatic ecosystems

Question 146

The diagram shows the distribution, annual average temperature and precipitation in five Australian terrestrial ecosystems.



(a) Describe the climate in the Australian chaparral.

(2 marks) KA2

(b) State why the type of vegetation varies between northern and southern Australia.

(1 mark) KA2

(c) Identify the ecosystem with the smallest plants and animals in Australia and give a reason.

(2 marks) KA2

(d) State why temperate broadleaf forest species are rarely found in other Australian ecosystems.

(1 mark) KA2

(e) Describe and explain why the tropical forest has the highest species diversity in Australia.

(2 marks) KA2

Question 149

The diagram below shows an African Savanna ecosystem.

(a) Describe the biotic components of the African Savanna ecosystem.

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____ (3 marks) **KA2**

(b) The African Savanna has warm temperatures year-round, with wet and dry seasons causing variations in annual rainfall.

Explain a consequence to herbivores of having wet and dry seasons.

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____

____

____ (2 marks) **KA2**

4.5: Energy transfers and nutrient cycles

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, phosphorus, and carbon.

Humans can interfere with natural cycles.

A community is a group of populations of different species in an area. The structure and dynamics of a community depend on the feeding relationships between organisms. In general, each community has a **trophic structure** that describes the passage of energy and nutrients from plants and other photosynthetic organisms to herbivores and carnivores. Each organism in a community occupies one or more **trophic levels** referring to its position in a food chain. The first trophic level is occupied by **primary producers**: autotrophs that produce nutrients from abiotic factors in their environment. For example, plants are the primary producers in terrestrial ecosystems, while phytoplankton are the most abundant producers in aquatic ecosystems. These organisms use sunlight, water and carbon dioxide to produce organic compounds, including carbohydrates, amino acids and lipids. The second trophic level are **primary consumers**, herbivorous animals that feed exclusively on primary producers. For example, insects and herbivorous mammals are primary consumers in terrestrial ecosystems, while zooplankton are the most abundant primary consumer in aquatic ecosystems. The third trophic level are **secondary consumers**, predatory animals that feed on primary consumers. For example, birds, amphibians, reptiles and small mammals are secondary consumers in terrestrial ecosystems, while fish and crustaceans are abundant secondary consumers in aquatic ecosystems. Above the secondary consumers are successively higher levels of predatory animals, including **tertiary consumers** and **quaternary consumers**. The transfer of chemical energy from its source in primary producers through primary consumers to secondary, tertiary and quaternary consumers is referred to as a **food chain** (Figure 4.63).

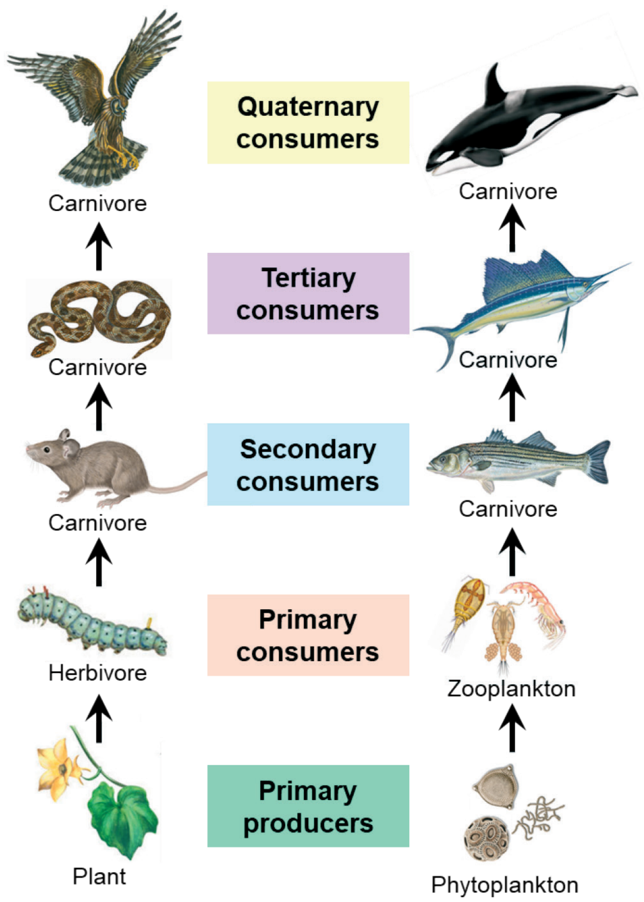


Figure 4.63: Terrestrial and marine food chains

Primary and Secondary Production in Ecosystems

In most ecosystems, primary producers carry out photosynthesis, transforming light energy into chemical energy stored in organic molecules (nutrients), and consumers then acquire these nutrients through food webs. Therefore, the total energy available to an ecosystem depends on photosynthetic production by primary producers. Each day, Earth's atmosphere receives approximately 10^{22} joules of energy from the Sun. However, 50% of this energy is absorbed or reflected by clouds and dust in the atmosphere, and much of the transmitted radiation strikes non-photosynthetic materials such as ice and soil. Furthermore, of the radiation reaching photoautotrophs, only specific wavelengths are absorbed by photosynthetic pigments such as chlorophyll; the rest is transmitted, reflected, or lost as heat. As a result, only 1% of the light striking photoautotrophs is converted to chemical energy. The total energy transformed by photoautotrophs per unit area and time in an ecosystem is called its **primary production** and is expressed as energy per unit area per unit time or as the mass of vegetation, called **biomass** added per unit area per unit time. Ecosystems vary considerably in their primary production, as in Figure 4.66. Tropical rainforests, estuaries, and coral reefs are among the most productive ecosystems per unit area.

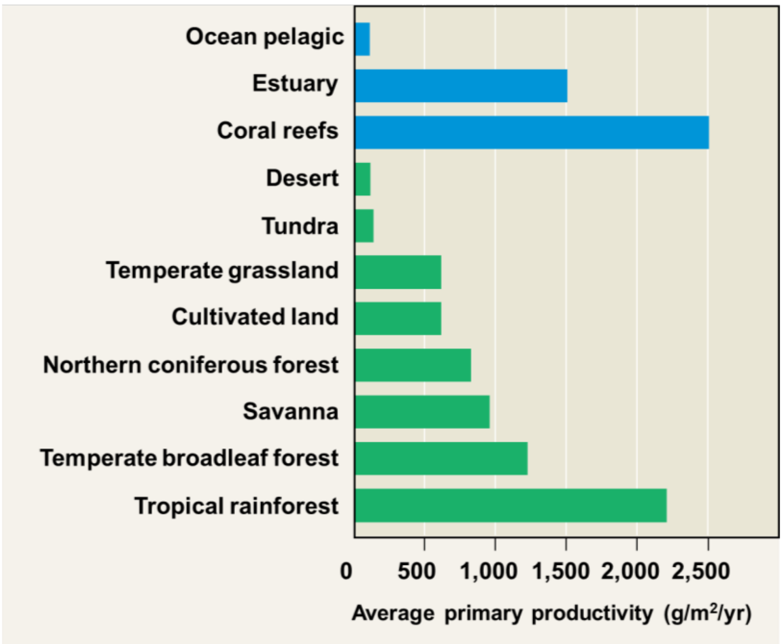


Figure 4.66: Primary production in different ecosystems.

Consumers obtain chemical energy for growth by consuming producers or each other. The amount of chemical energy in a consumer's food converted to new biomass is called **secondary production**. For example, when an insect feeds on a leaf, about one-sixth of the chemical energy is used for secondary production (Figure 4.67). The insect stores some of the remaining energy in organic compounds used for respiration and passes the rest in its faeces. The energy used in respiration is eventually lost from the ecosystem as heat. The energy in the faeces remains in the ecosystem temporarily, but most of it is lost as heat after decomposition. Thus, only the chemical energy stored by herbivores as biomass is available as food to secondary consumers.

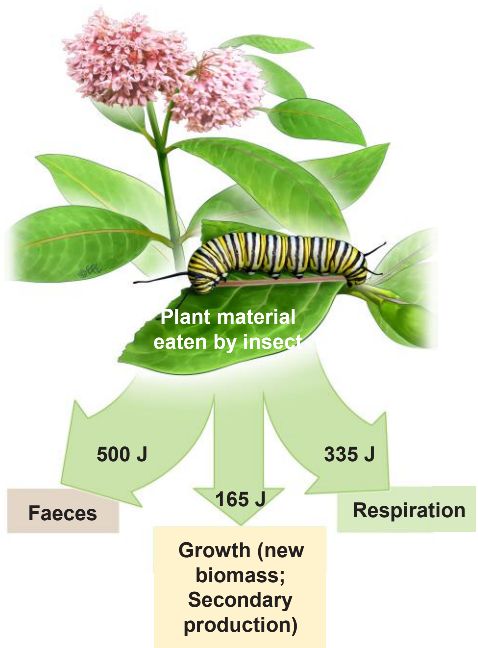


Figure 4.67: Energy partitioning in primary consumers.

4.7: Ecological Succession

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.

During the 20th century, ecologists debated whether ecosystems changed over time or reached equilibrium, a state of balance where the species composition of communities became more or less constant. Proponents of the **equilibrium model** thought an area had only one stable equilibrium, called a **climax community**, determined primarily by climate. However, other ecologists challenged the concept of a single climax community, suggesting that differences in soil type, topography and other abiotic factors created many stable communities in an area. Furthermore, opponents of the equilibrium model also questioned whether communities could ever reach a state of equilibrium in species diversity or composition as they were susceptible to **disturbances**, events such as a fire, flood, drought, storm or human activity that changes a community by removing organisms from it or altering resource availability. This emphasis on change in communities led to the formulation of the **nonequilibrium model**, which describes communities as constantly changing following disturbances. Mounting evidence suggests that the nonequilibrium model is the norm for most communities.

Ecological Succession

Changes in the species compositions of terrestrial communities are most apparent after a severe disturbance, such as a volcanic eruption producing bare land or retreating glacier stripping away all existing vegetation. The disturbed area may be colonised by various species, which are gradually replaced by other species, a process called **ecological succession**. When the process begins in a virtually lifeless area, such as on the bare rock produced by cooled lava or a retreating glacier, it is called **primary succession**. A recent example of primary succession is Muir Glacier, Alaska (Figure 4.84). The retreating expanse of ice and snow retreated over time, exposing bare rock that plants and animals soon colonised. During primary succession, the colonising species, called **pioneer species**, are often prokaryotes, lichens and mosses, small plants that grow from windblown spores. These organisms secrete acid that weather rocks, forming a thin soil with nutrients supporting lichens and mosses, which produce organic matter in photosynthesis. Soil develops gradually as rocks weather, and

1 Muir Glacier, 1941

2 Muir Glacier, 2004

Figure 4.84: Primary succession.

organic matter accumulates from the decomposed remains of the early colonisers. Once the soil is present, the lichens and mosses are usually overgrown by **intermediate species,** including grasses, shrubs, and trees that sprout from seeds blown in from nearby areas or carried in by insects and birds. Eventually, an area is colonised by plants that become the community's dominant vegetation. Producing such a **climax community** through primary succession may take hundreds or thousands of years. The process of primary succession from bare rock is described in Figure 4.85.

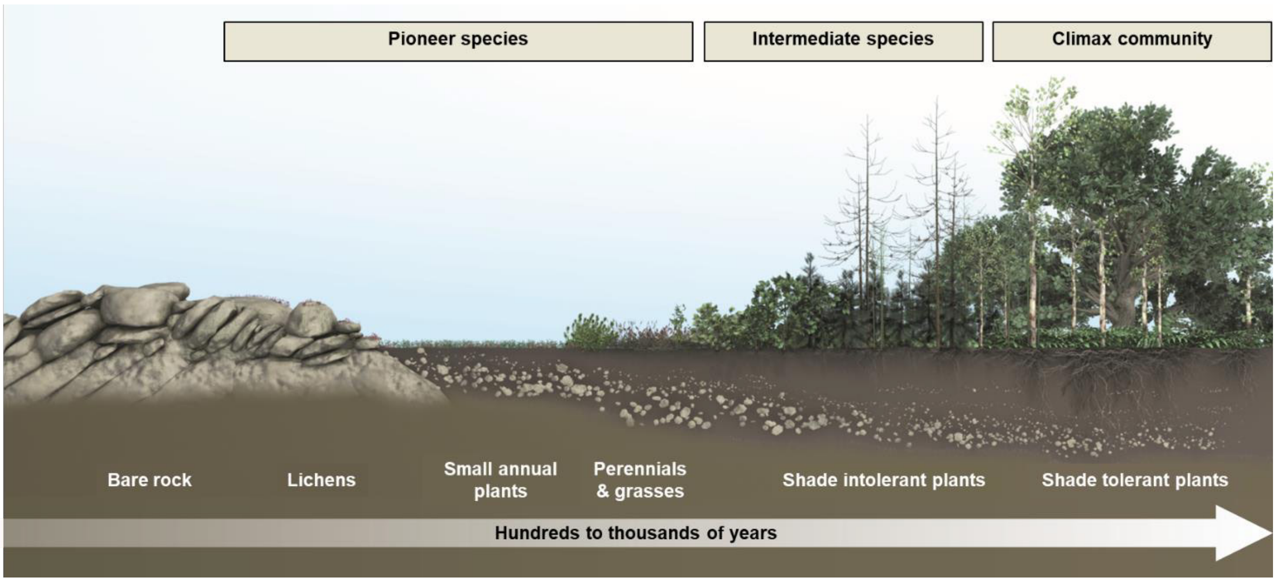


Figure 4.85: Primary succession

Primary succession occurs following volcanic eruptions that eject massive quantities of lava into the ocean. After the eruption, the lava cools and hardens into bare rock (Figure 4.86 (1)). Lichens carried on the wind settle and colonise the bare rock. Lichens secrete acids that weather the rock, forming thin soil, and their decomposition adds nutrients that fertilise the soil. Airborne spores from mosses and ferns settle onto the thin soil and add to it when decomposed (Figure 4.86 (2)). Gradually the soil becomes deep enough to store water, enabling colonisation by larger plant species whose seeds are brought into the community by insects and birds that migrate into the area (Figure 4.86 (3)). After many years, the soil is deep enough and has enough nutrients and water to support grasses, wildflowers, shrubs and trees that provide an ecological niche for various animal species (Figure 4.86 (4)).

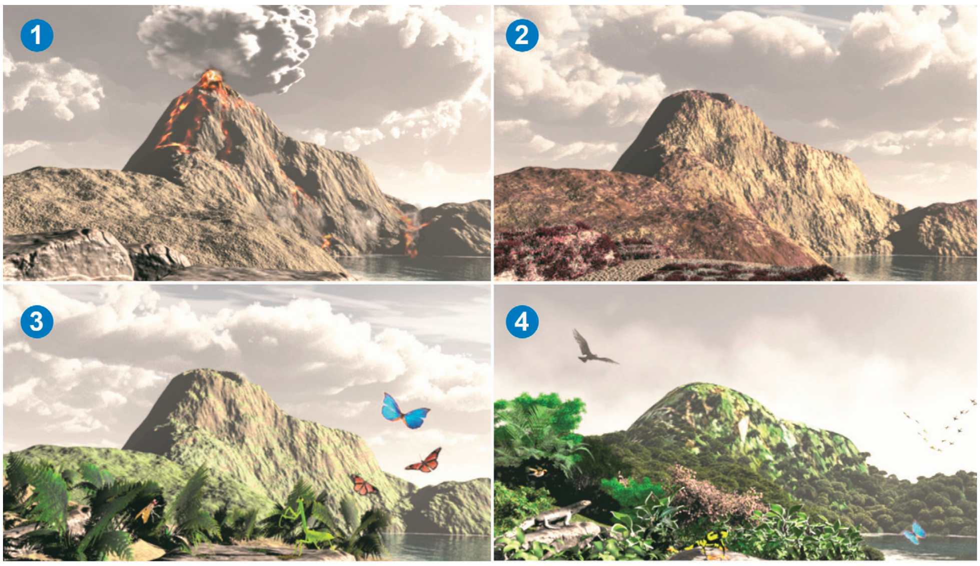


Figure 4.86: Primary succession on a volcanic island.

Primary succession changes the soil nutrient content and other abiotic factors caused by transitions in the vegetation. Most pioneer plant species have poor growth because the bare rock is low in nitrogen after an eruption or glacial retreat. The exceptions are plant species whose roots host nitrogen-fixing bacteria. These plant species rapidly increase the soil nitrogen content, facilitate colonisation by new plant species during succession. For example, Figure 4.87 shows the change in soil nitrogen during succession at Muir Glacier, Alaska. The exposed rock was first colonised by pioneering species that included liverworts, mosses, and willows. Then, after about three decades, *Dryas*, a nitrogen-fixing species, dominated the plant community. A few decades later, the area was invaded by Alder, another nitrogen-fixing plant that forms dense bushes up to nine metres tall. Soil nitrogen increased rapidly during the *Dryas* and Alder stages, permitting colonisation by larger hemlock and Spruce trees which add more nitrogen over time.

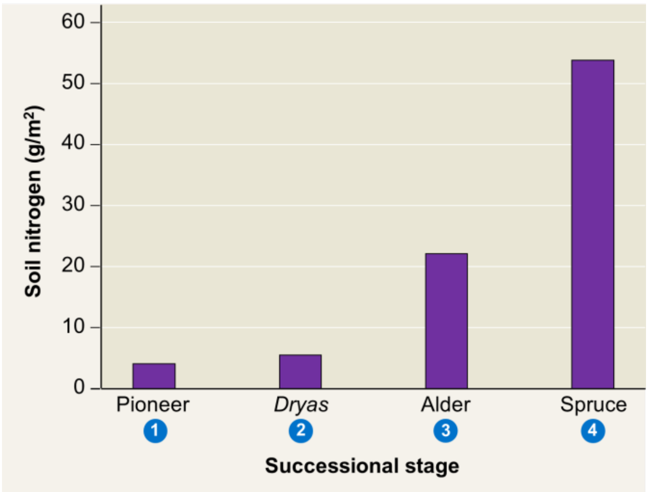


Figure 4.87: Soil nitrogen changes during succession

In contrast to primary succession, **secondary succession** involves recolonising an area after a significant disturbance has removed most of the organisms in a community, but the soil remains fertile. Following the disturbance, the area may return to its original state as the earliest plants to recolonise are often species that grow from windblown or vector-borne seeds. For example, in the temperate broadleaf forests in Australia, bushfires (Figure 4.88) create patches of forest with a high nutrient content that are colonised by pioneer species germinating from seeds that lay dormant in the soil. Pioneer plant species grow rapidly in the fertile soil, and their increasing abundance is paralleled with a return of herbivores and lower-order consumers. The high soil nutrient content ensures that a climax community is formed over hundreds rather than thousands of years.

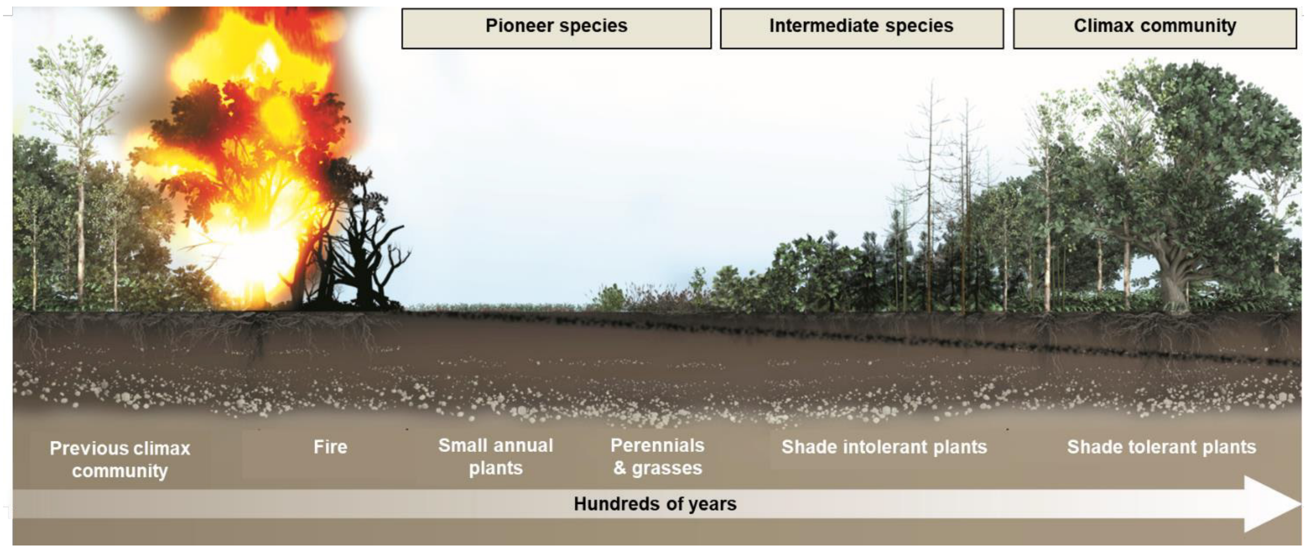
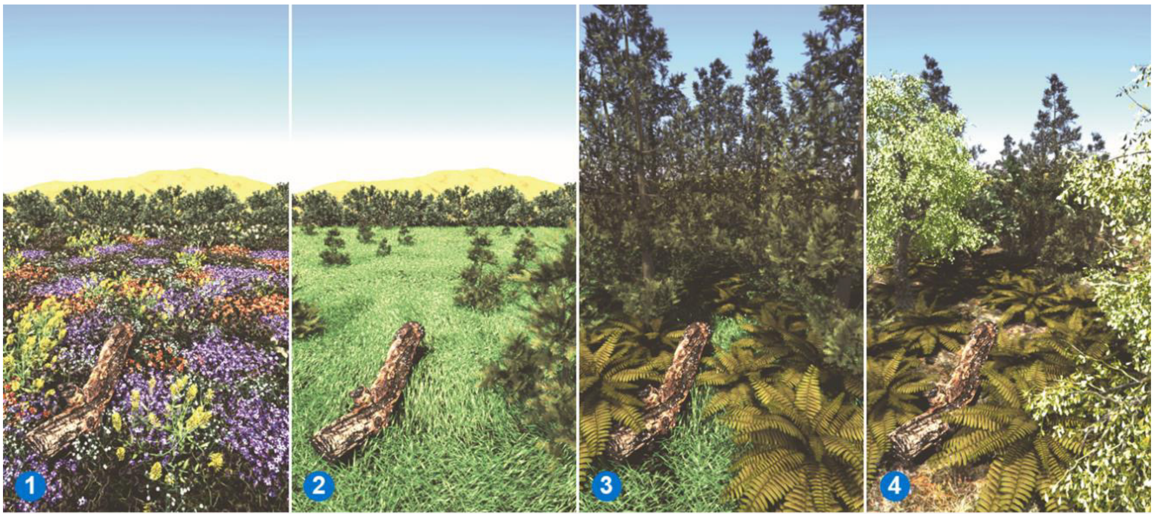


Figure 4.88: Secondary succession following a fire.

Question 164

The diagram below illustrates the process of secondary succession on abandoned farmland.



Weeds and wildflowers colonise abandoned farmland	Pine seedlings and other plants begin growing	Pine forest grows	A coniferous forest develops

(a) The farmland was produced by clearing an area of coniferous forest.

Suggest two reasons why the same community re-established in the area over time.

(2 marks) KA2

(b) The re-establishment of the coniferous forest took 75 years.

The same process can take up to 300 years during primary succession.

Explain why secondary succession occurs over a shorter period than primary succession.

(2 marks) KA2

(c) Scientists studying the area noted that the species diversity of Hemiptera, an insect order, increased from 45 to 80 during the first ten years of succession.

Explain the increase in species diversity of Hemiptera.

(2 marks) KA2

SOLUTIONS TO CHAPTER QUESTIONS AND REVIEW TESTS

Question	Part		Author's response	Marks
1	(a)	(1)	Movement	1
		(2)	Homeostasis	1
		(3)	Reproduction	1
		(4)	Respiration	1
		(5)	Evolution	1
		(6)	Excretion	1
		(7)	Nutrition	1
		(8)	Excretion	1
		(9)	Sensitivity	1
		(10)	Movement	1
		(11)	Respiration	1
		(12)	Growth	1
	(b)		The robot does not display all characteristics of life, including respiration, nutrition, excretion, growth, homeostasis and evolution.	1
2	(a)		Reproduction	1
	(b)		Growth	1
3	(a)	(1)	Human body temperature never increases above 37.5°C and never decreases below 36.5°C, which is evidence of regulation.	1
		(2)	Homeostasis	1
	(b)		Respiration	1
4	(a)		Sensitivity/responding to stimuli	1
	(b)		Movement	1
	(c)		Nutrition	1
5	(a)		Evolution	1
	(b)		Excretion	1
6	(a)	(1)	Flagella facilitate movement in bacteria.	1
		(2)	The flagella filament is rotated rapidly, propelling a bacterium through a liquid.	1
	(b)	(1)	Fimbriae	1
		(2)	**Any one:**	1
			Allow bacteria to stick firmly to structures. Facilitate attachment to other bacteria. Facilitate attachment to eukaryotic cells such as mould, plant and animal cells,	
7	(a)		Approximately 4 μm	1
	(b)		**Any one:**	1
			Presence of a nucleoid; No nucleus; No membrane-bound organelles;	
	(c)		Provides rigidity and structural support to the cell.	1

171	(a)		Genetic diversity measures genetic variation within the gene pool of a population, such as body length in grey nurse sharks.	1
	(b)		There is significant variation in the body lengths of individuals within the population of sharks.	1
	(c)		To obtain data that can be used to make predictions relating to the impact of environmental change caused by changes in the abundance of grey nurse sharks.	1
			These predictions can help scientists and governments to develop strategies to minimise the adverse effects of such change.	1
	(d)		Reduces genetic diversity.	1
			Each grey nurse shark has a unique set of alleles that are removed from the gene pool as individual sharks are caught or killed.	1
172	(a)		The remaining population of Gilbert's potoroo has low genetic diversity due to the low species abundance.	1
			The low genetic diversity makes the individuals highly susceptible to environmental change, such as introducing new pathogens, predators, and competitors.	1
	(b)	(1)	**Any one:**	1
			Small islands lack mainland predators, allowing Gilbert's potoroo to forage without predation by feral cats and foxes. Small islands are unaffected by mainland bushfires.	
		(2)	The abundance of species may increase on both islands.	1
			Scientists can then take individuals from the two populations and breed them and produce a population with greater genetic diversity than either parent population.	1
		(3)	The small number of founders may possess genes that make them susceptible to disease and other environmental pressures.	1
			These genes are then shared among subsequent generations producing a population of individuals that are susceptible to these pressures.	1
173	(a)		A bottleneck effect is an example of genetic drift that occurs when the population size of a species is significantly reduced;	1
			Human activity (hunting) caused a significant reduction in population size, which reduced the gene pool of the surviving population of the northern elephant seal.	1
	(b)		A bottleneck effect has reduced the genetic diversity of the current population of northern elephant seals;	1
			The current population is at greater risk from changing environmental factors, including disease, predation, competition and climate change.	1
	(c)		Natural predation does not cause a significant reduction in the population size of northern elephant seals, which is a requirement for the bottleneck effect.	1
	(d)		Humans do not hunt these animals for commercial purposes, resulting in a stable food supply for the northern elephant seal.	1
			The stable food supply provides energy for survival and reproduction, increasing the northern elephant seal population.	1