Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 01 – Cell Structure & Organisation

Name: **Class:**

A. Content

- Plant and animal cells
- Specialised cells, tissues and organs

B. Learning Outcomes

Students should be able to:

(a) identify cell structures (including organelles) of typical plant and animal cells from diagrams, photomicrographs and as seen under the light microscope using prepared slides and fresh material treated with an appropriate temporary staining technique:

- chloroplasts
- cell membrane
- cell wall
- cytoplasm
- cell vacuoles (large, sap-filled in plant cells, small, temporary in animal cells)
- nucleus

(b) identify the following membrane systems and organelles from diagrams and electron micrographs:

- endoplasmic reticulum
- mitochondria
- Golgi body
- ribosomes

(c) state the functions of the membrane systems and organelles identified above.

(d) compare the structure of typical animal and plant cells.

(e) state, in simple terms, the relationship between cell function and cell structure for the following:

- absorption – root hair cells
- conduction and support – xylem vessels
- transport of oxygen – red blood cells

(f) differentiate cell, tissue, organ and organ system.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
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D. Lecture Outline

1. Introduction
2. Historical perspectives
3. Cell structure
4. Cell differentiation

E. Practical Work

- Preparing, observing and drawing plant cells

1. INTRODUCTION

The cell is the basic unit of life from which organisms are made. Cells are microscopic and can only be seen through the magnifying lenses of a microscope. In 1665, Englishman Robert Hooke published his book *Micrographia*, which contains drawings of thin slices of cork seen through a microscope. Anthony Van Leeuwenhoek (pronounced 'Laywenhook') was one of the very first to produce detailed observations of plant and animal cells with his self-made microscope. The study of the structure of cells (cytology) is a major branch of cell biology.

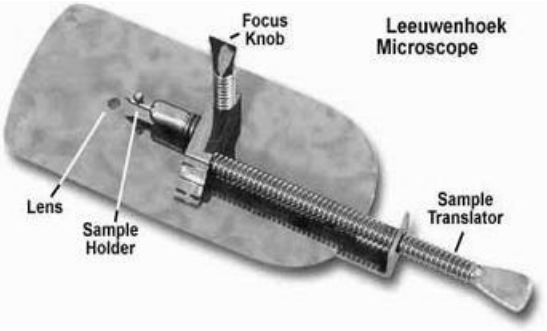
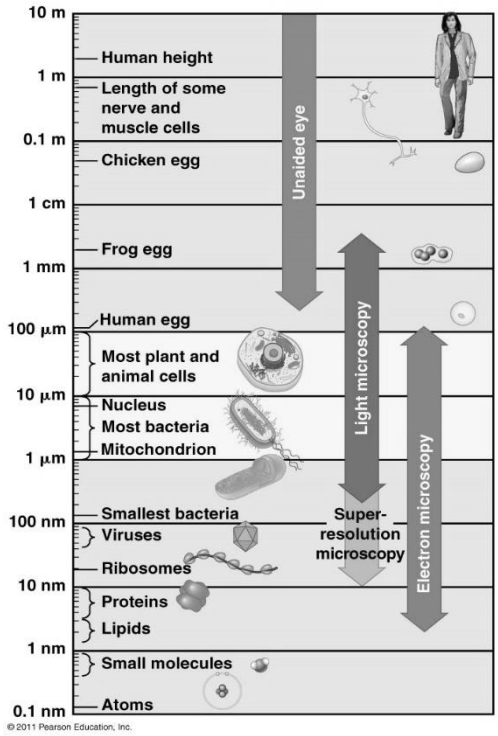


Figure 1.1 A Leeuwenhoek microscope can magnify x266
Source: http://sciencesanneehuit.wikispaces.com/Microscope+simple



1 centimeter (cm) = 10^{-2} meter (m)
1 millimeter (mm) = 10^{-3} meter (m)
1 micrometer (μm) = 10^{-3} mm = 10^{-6} m

Figure 1.2 The size range of cells
Source: Pearson Education

In the 1950s, all living organisms were placed in 5 kingdoms: **Monera**, **Protista**, **Fungi**, **Plantae** and **Animalia**. As recent as the 1990s, kingdom Monera was recognised as two different kingdoms (**Eubacteria** and **Archaebacteria**) as a result of accumulating molecular evidence. Today, as a result of molecular analyses, scientists recognise the classification of living organisms into three domains: **Eukarya** (composed of protists, fungi, plants and animals), **Bacteria** and **Archaea**.

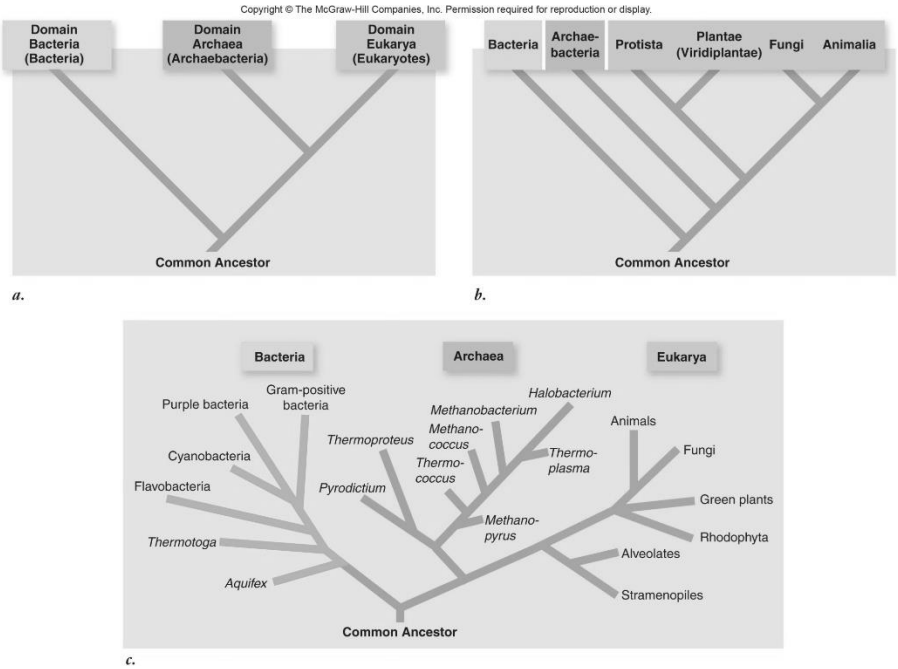


Figure 1.3 Phylogenetic tree supporting the grouping of organisms into three domains

Members of the domain Archaea live in some of the most extreme environments on the planet. These include thermophilic bacteria and halophilic bacteria. The members of the domain Bacteria are ecological diverse bacteria whose cell wall contains a substance known as peptidoglycan.

Table 1.1 Organisms are grouped into three domains

Classification of Living Things						
DOMAIN	**Bacteria**	**Archaea**	**Eukarya**			
KINGDOM	Eubacteria	Archaebacteria	Protista	Fungi	Plantae	Animalia
CELL TYPE	Prokaryote	Prokaryote	Eukaryote	Eukaryote	Eukaryote	Eukaryote
CELL STRUCTURES	Cell walls with peptidoglycan	Cell walls without peptidoglycan	Cell walls of cellulose in some, some have chloroplasts	Cell walls of chitin	Cell walls of cellulose; chloroplasts	No cell walls or chloroplasts
NUMBER OF CELLS	Unicellular	Unicellular	Most unicellular; some colonial; some multicellular	Most multicellular; some unicellular	Multicellular	Multicellular
MODE OF NUTRITION	Autotroph or heterotroph	Autotroph or heterotroph	Autotroph or heterotroph	Heterotroph	Autotroph	Heterotroph
EXAMPLES	*Streptococcus*, *Escherichia coli*	Methanogens, halophiles	*Amoeba*, *Paramecium*, slime molds, giant kelps	Mushrooms, yeasts	Mosses, ferns, flowering plants	Sponges, worms, insects, fishes, mammals

Miller and Levine

2. HISTORICAL PERSPECTIVES

Table 1.2 Key steps in the origins of cell biology

Since antiquity	Magnifying properties of convex lens known	1839 Purkinje	Realised that the contents of cells ('cytoplasm + nucleus') were important, not just the walls
Early 17th century	The use of two convex lenses to make near objects look larger was practised in Europe	1838 Matthias Schleiden	Explained the derivation of plant tissues from cells
1632–1723	Antony van Leeuwenwoek produced his own microscopes and made numerous observations of blood cells and protozoa	1839 Theodor Schwann	'Cells are organisms and entire animals and plants are aggregates of these organisms arranged according to definite laws'
1661 Marcello Malpighi	Used lenses, discovered capillaries, and may have described cells in writing of 'saccules' and 'globules'	1856 Rudolf Virchow	Established the idea that cells arise only by division of existing cells
1662 Robert Hooke	Introduced the term 'cell' in describing the structure of cork; believed cell walls to be the important part of otherwise empty structures	1862 Louis Pasteur	Disposed of the spontaneous generation theory of microbial appearance
1809 Jean de Monet de Lamarck	'No body can possess life if its containing parts are not of cellular tissue or formed by cellular tissues'	1897 Eduard Buchner	Confirmed that fermentation requires only a cell extract, not whole cells
1825–1945	With the invention of the immersion lens, the light microscope reached the limit of resolving power = 0.2 μm	1900	Rediscovery of work of Gregor Mendel, giving the theoretical basis of modern genetics

1828 Friedrich Wöhler	Synthesised urea, discrediting the view that organic compounds can be made only by living things	1930–46	Electron microscope developed, then used widely in cytology, revealing details of cell organelles (cell ultrastructures)
1831 Robert Brown	Reported his discovery of the cell nucleus	modern cell biology	Established that cells contain basic hereditary material (DNA) in the nucleus; roles of nucleic acid in the control of metabolism and of growth via protein synthesis understood

Clegg and Mackean

3. CELL STRUCTURE

A cell is a unit of life consisting of a mass of living matter called **protoplasm**. A cell functions just like a factory with many specialized organs known as **organelles**. A cell can be divided into 2 main regions: the **nucleus** and the **cytoplasm**. All cells have cytoplasm surrounded by a selectively permeable **cell membrane**. Most cells have a nucleus. An exception is the mature human red blood cell.

Traditionally, cells have been divided into animals and plants (Figure 1.4 and 1.5). However, with the use of more powerful microscopes, two types of cellular organisations are now recognized: **prokaryotes** and **eukaryotes**. Eukaryotes are essentially cells which possess a nucleus and membrane-bound organelles. Plants, animals and fungi are examples of eukaryotes. Prokaryotes are cells which do not possess a membrane-bound nucleus e.g. bacteria and they are usually smaller in size as compared to eukaryotes.

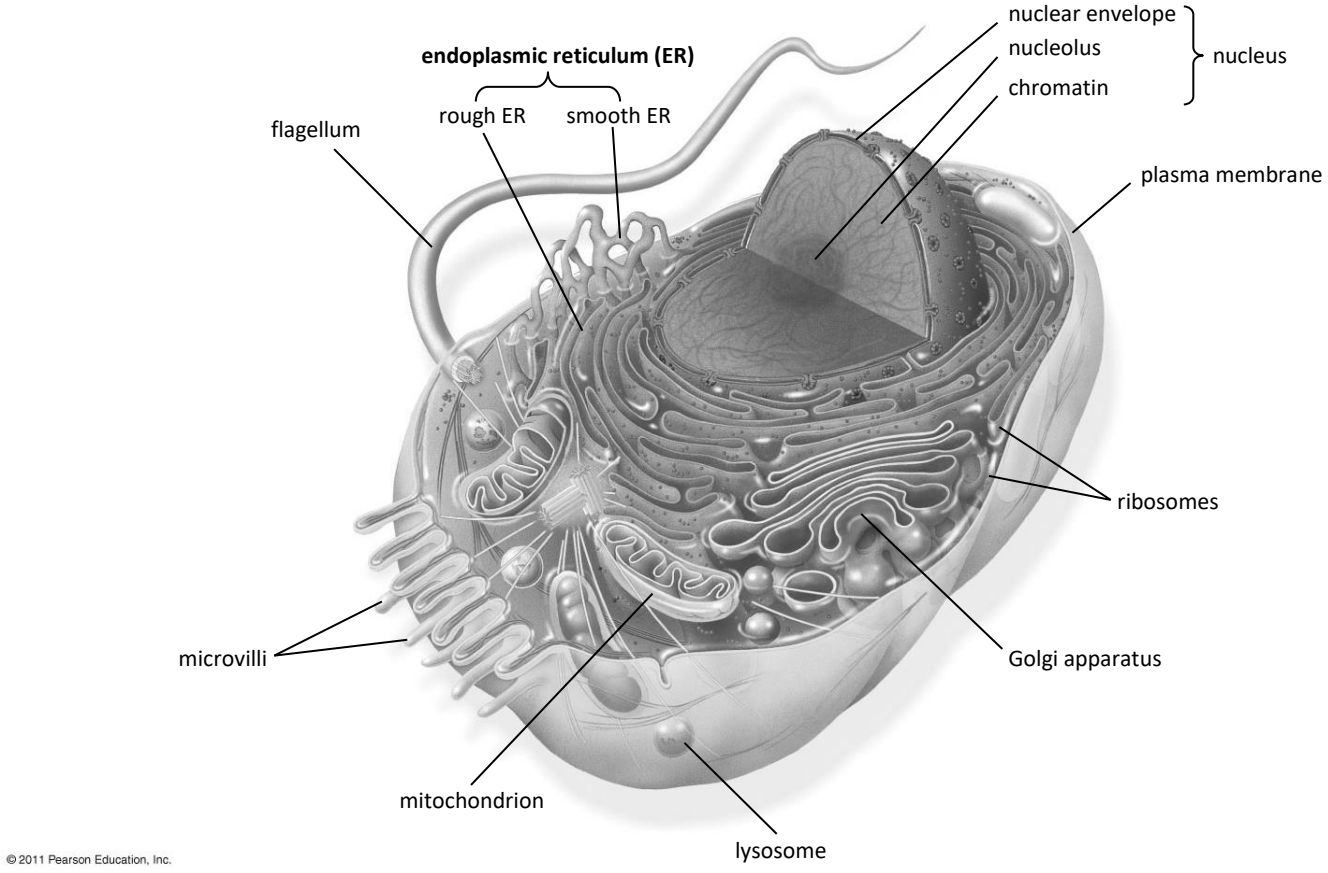


Figure 1.4 Schematic drawing of a generalized animal cell (under an electron microscope)
Source: Pearson Education

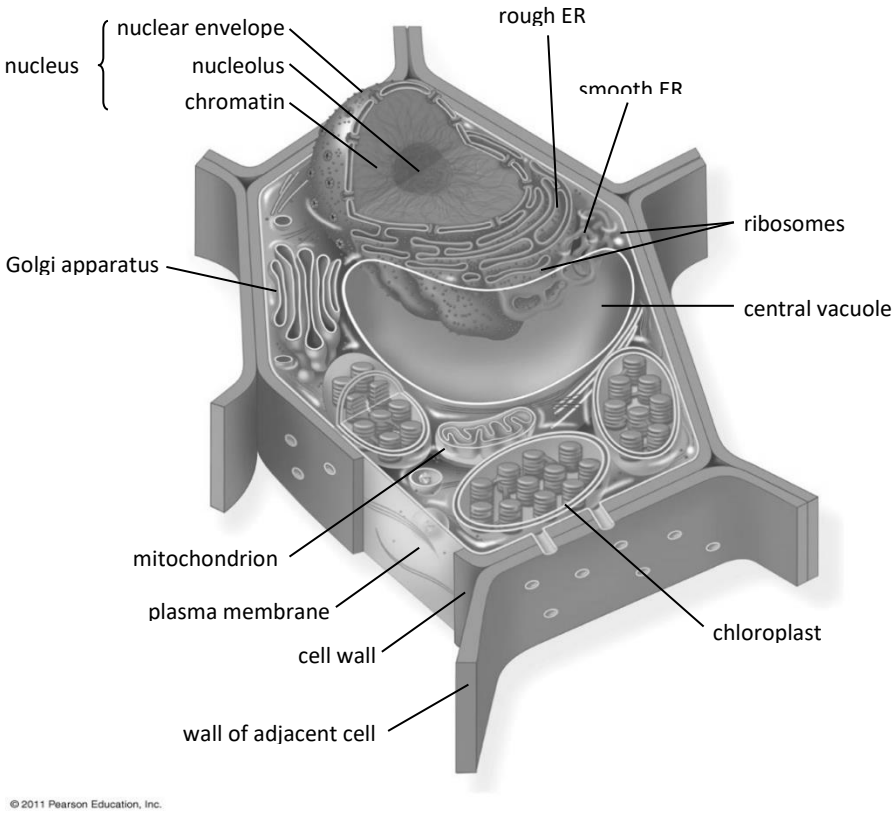


Figure 1.5 Schematic drawing of a generalized plant cell (under an electron microscope)
Source: Pearson Education

Cytoplasm

- Aqueous ground substance containing specialised structures called **organelles** e.g. nucleus, endoplasmic reticulum.
- Contains water (90%), essential ions such as sodium, sugars and enzymes.

Nucleus

- Largest organelle and easily seen with a light microscope.
- Contains hereditary material, DNA (in long thread-like structures called **chromatin** threads).
- When the cell is dividing, the thin chromatin threads condense and become highly coiled **chromosomes** which are visible under the light microscope.
- **Nuclear membrane** or envelope surrounds the dense **nucleoplasm**.
- Nuclear membrane composed of two membranes, of which the outer membrane is continuous with the endoplasmic reticulum.
- Nuclear membrane perforated by numerous **nuclear pores** that control passage of substances moving in and out of the nucleus.
- Function(s): Controls and directs activities e.g. cell growth, reproduction, repairing of cells

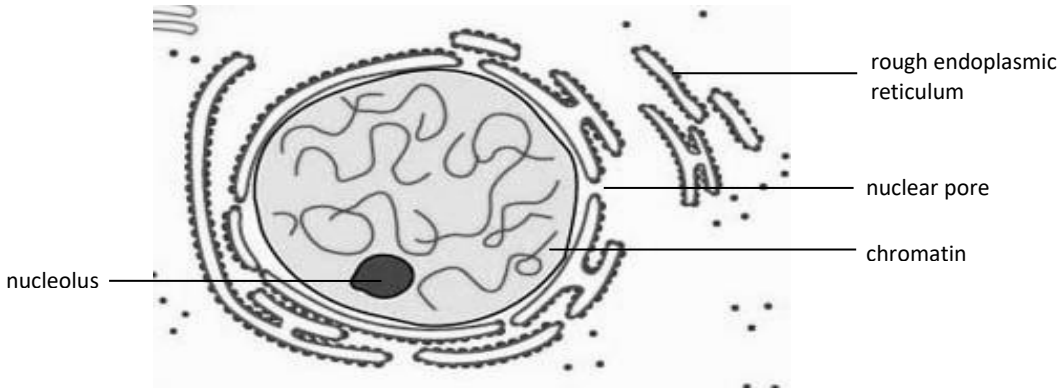


Figure 1.6 The nucleus as seen under an electron microscope

Nucleolus

- Sub-nuclear structure not surrounded by membrane and occupies about ¼ of the volume of nucleus.
- One or more nucleoli (singular: nucleolus) may be present within a nucleus.
- Function(s):
  (1) Involved in **protein synthesis**

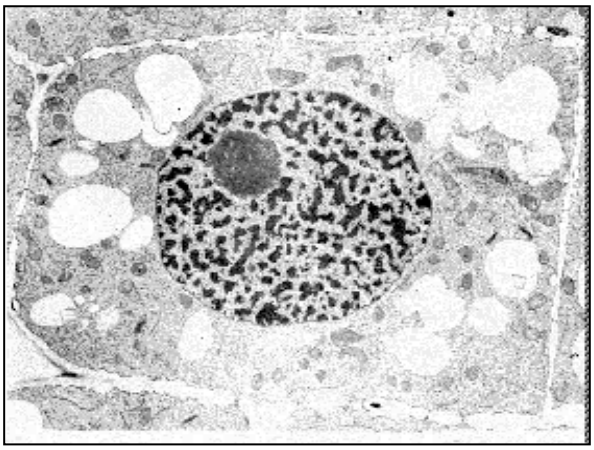


Figure 1.7 The nucleolus appearing as a dark sphere (under the electron microscope)
Source: http://www.daviddarling.info/encyclopedia/N/nucleolus.html

Cell membrane (or plasma membrane)

- **Selectively permeable**, allowing smaller substance e.g. water to pass through.
- Made up of mainly of proteins and lipids (lipids are in the form of phospholipids).
- Organic solvents such as alcohol penetrate membrane more rapidly than water.
- Function(s):
  (1) Controls substances entering or leaving cell
  (2) Act as receptor sites for recognising external stimuli and chemicals

Mitochondrion

- Bounded by double membrane and are mostly spherical or rod-shaped.
- Occur in most cells and actual number depends on metabolic activity of cells. Highly active cells may possess up to 1000 mitochondria (singular: mitochondrion).
- Function(s):
  (1) **Release** energy, in the form of **ATP** (adenosine triphosphate) during cellular **respiration** for activities such as growth, cell division, active transport

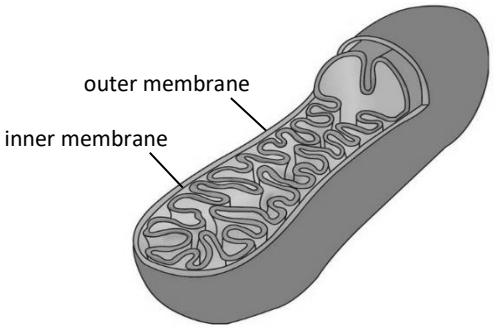


Figure 1.8 The mitochondrion (under an electron microscope)

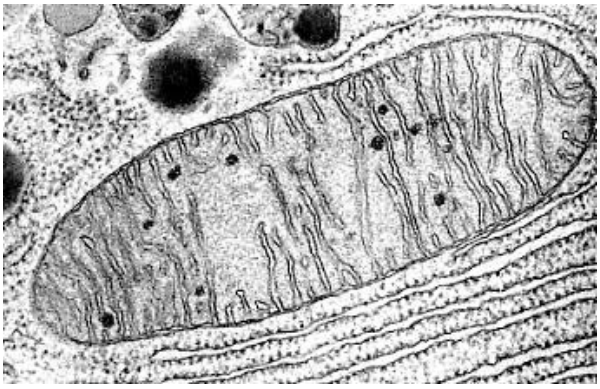


Figure 1.9 Electron micrograph of mitochondrion
Source: http://emp.byui.edu/wellerg/The%20Cell%20Lab/Eukaryotic%20Cells/the%20Eukaryotic%20Cell%2003%20Cell.html

Vacuoles

- Fluid-filled organelle surrounded by a selectively permeable membrane known as **tonoplast**.
- In plant cells, **a single large central vacuole** exists permanently. The plant vacuole contains a liquid known as **cell sap**.
- In animal cells, the vacuoles are smaller, numerous and often less permanent.
- Function(s):
  (1) Provides support for plants when it is filled with water by maintaining turgidity of cells
  (2) Temporarily stores waste products and food reserves

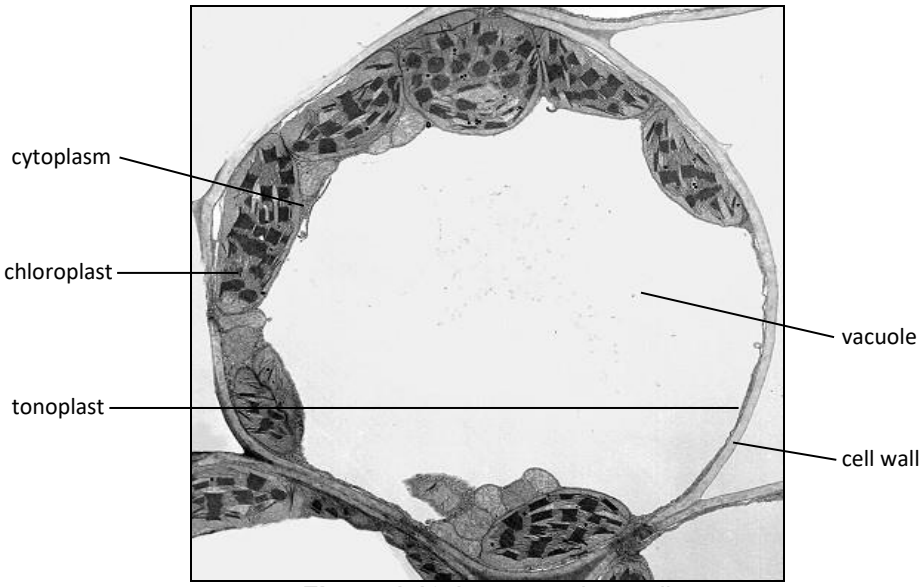


Figure 1.10 A mature plant cell
Source: http://www.biologie.uni-hamburg.de/b-online/library/webb/BOT410/anatweb/pages/Parenchyma-6.htm

Chloroplast

- Bounded by double membrane and visible with a light microscope (3.0-10.0 μm in diameter).
- Chloroplasts are found in green parts of plants and in algae.
- Chlorophyll is located in a series of membranes (called **thylakoids**) running through a matrix (called **stroma**). In some parts, thylakoids may be stacked up to form **granum**.
- May contain **starch grains** which are converted from glucose made during photosynthesis.
- Function(s):
  (1) Contains pigment **chlorophyll** to trap / absorb sunlight during **photosynthesis** producing glucose

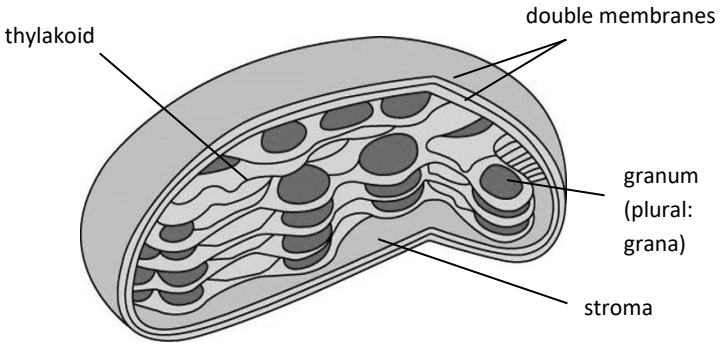


Figure 1.11 The chloroplast

Figure 1.12 Chloroplasts in algae *Spirogyra*
Source: http://www.microscopy-uk.org.uk

Cell wall

- Made up mainly of **cellulose**.
- Inelastic, inflexible and totally permeable.
- May undergo extensive lignification e.g. xylem vessels.
- Function(s):
  (1) Provides mechanical support
  (2) Protects cell from overexpansion (when water enters cell by osmosis) → turgor pressure

Table 1.3 Differences between cell wall and cell membrane

cell wall	cell membrane
made of cellulose (polysaccharide)	made of lipids and proteins
fully permeable	partially permeable
relatively thicker	relatively thinner
more rigid / less flexible	less rigid / more flexible

Ribosomes

- Made up of ribosomal RNA (ribonucleic acid) and proteins.
- Can be found either in the cytoplasm or attached to the endoplasmic reticulum (forming rough ER).
- Ribosomes on RER largely responsible for the synthesis of secretory proteins as compared to free ribosomes synthesising intracellular proteins.

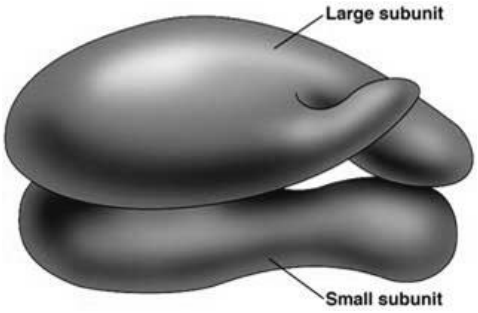


Figure 1.13 Structure of a ribosome

Endoplasmic reticulum (ER)

- A network of folded membranes forming sheets, tubes or flattened sacs called **cisternae** in cytoplasm.
- Originates from outer membrane of nuclear membrane.
- Two types of ER: **rough ER** and **smooth ER**

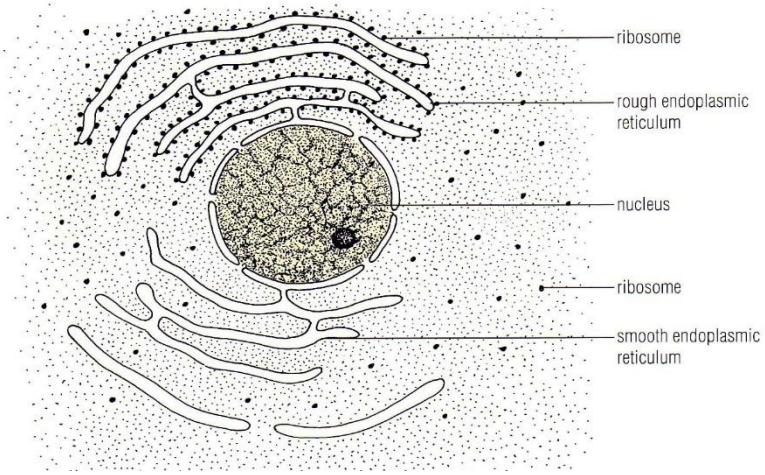


Figure 1.14 The endoplasmic reticulum
Source: Clegg, C. J. and Mackean

Rough ER (RER)

- Covered with ribosomes on the outer surface of the membrane.
- Granular appearance due to ribosomes and more sheet-like.
- Function(s):
  (1) **Transport** proteins which are manufactured by ribosomes on its surface (NOT protein synthesis). These proteins are then exported out of the cell e.g. digestive enzymes
- RER are numerous in enzyme secreting cells e.g. pancreas.

Smooth ER (SER)

- Lacks ribosomes on its membrane and more tubular.
- Function(s):
  (1) Synthesis of **fats** and **steroids**. Sex hormones in mammals are steroids.
  (2) **Detoxification** of harmful substances into harmless materials.
  (3) Give rise to Golgi body
- SER are numerous in liver, skin oil glands

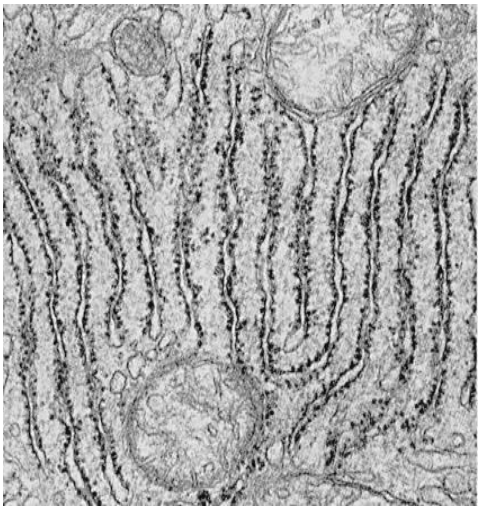


Figure 1.15 EM of RER
Source: bergenbiologytext.weebly.com

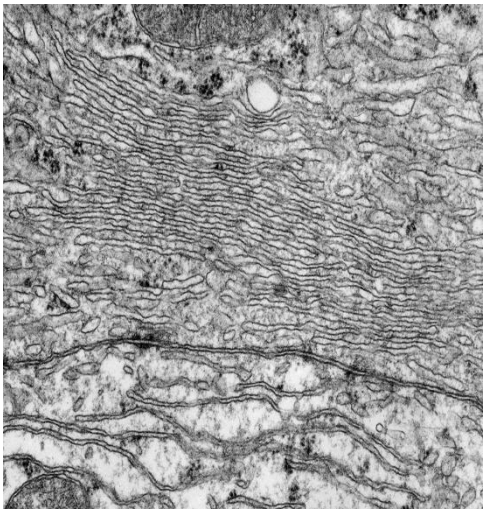


Figure 1.16 EM of SER
Source: medcell.med.yale.edu

Golgi apparatus/Golgi body

- Compact **stack** of membrane-bound sacs and associated vesicles called **Golgi vesicles**.
- The sacs are fluid-filled and pinch off into smaller sacs called Golgi vesicles at their end.
- Discovered and identified in 1897 by the Italian physician Camillo Golgi.
- Has a convex face (*cis* face) formed by fusion of vesicles derived from ER and a concave face (*trans* face) where vesicles are budded off.
- Normally only one Golgi apparatus is found in each animal cell but many may be found in plant cells.

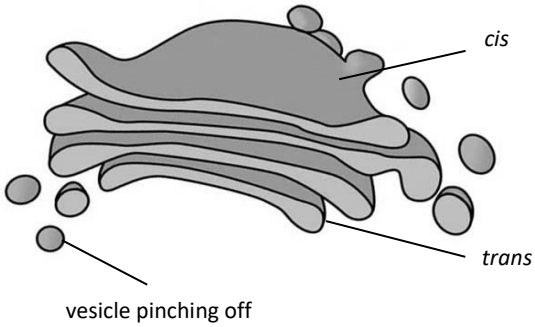


Figure 1.17 Golgi apparatus

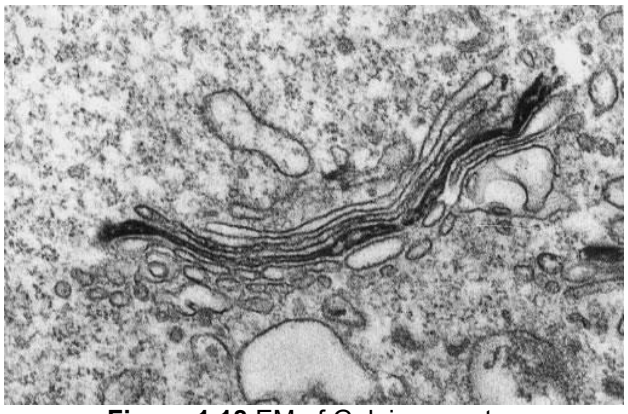


Figure 1.18 EM of Golgi apparatus
Source: www.zoology.ubc.ca

- Function(s):
  (1) Chemically **modifies** substances made by the ER
  (2) Stores and **packages** these substances in vesicles for secretion out of cells
  Example: Carbohydrate is added to protein during the formation of glycoproteins e.g. mucus

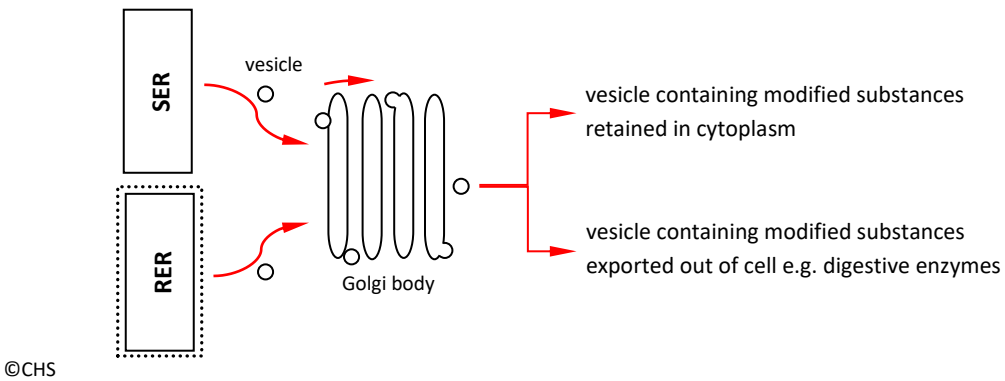


Figure 1.19 The role of Golgi apparatus

Lysosomes

- Spherical bodies bounded by a single membrane.
- Contains hydrolytic enzymes and are abundant in secretory cells and phagocytes.
- Function(s):
  (1) Digestion of food and foreign particles such as bacteria
  (2) **Autophagy** e.g. removal of unwanted structures, worn-out organelles within the cell
  (3) **Autolysis** e.g. self-destruction of a cell during metamorphosis. Lysosomes are sometimes known as 'suicide bags'

Table 1.4 Relative sizes of organelles

structure	average length/μm
nucleus	10 – 20
mitochondrion	3 – 10
chloroplast	4 – 10
lysosome	0.2 – 0.5
centriole	0.3 – 0.5
ribosome	0.02
cell membrane	0.0075

Table 1.5 Differences between plant and animal cell

	plant	animal
cell wall	present	absent
cytoplasm	normally confined to a thin layer at edge of cell	present throughout cell
nucleus	found at the edge of cell	found normally at the central of cell
chloroplasts	present (for most plant cells)	absent
vacuoles	single large central vacuole	many small vacuoles
tonoplast	present around vacuole	absent
centrioles	absent	present
food reserves	starch	glycogen

4. CELL DIFFERENTIATION

- Differentiation is the process whereby a cell become specialised for a specific function.
- Also known as **division of labour**
- Advantage: A specialised cell is able to carry out its tasks more effectively.
  Disadvantage: As a specialised cell normally loses the ability to carry out other functions, it is less able to change its function if an unusual need arises.

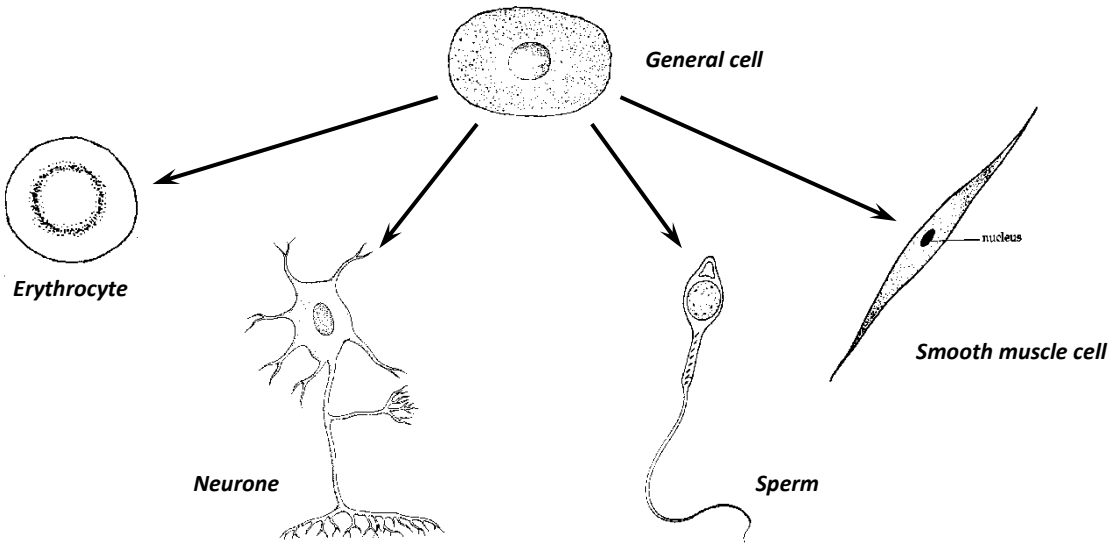


Figure 1.20 Some specialised cells found in the human body

Root hair cell

- Long and narrow to increase surface area to volume ratio for absorption of water and minerals

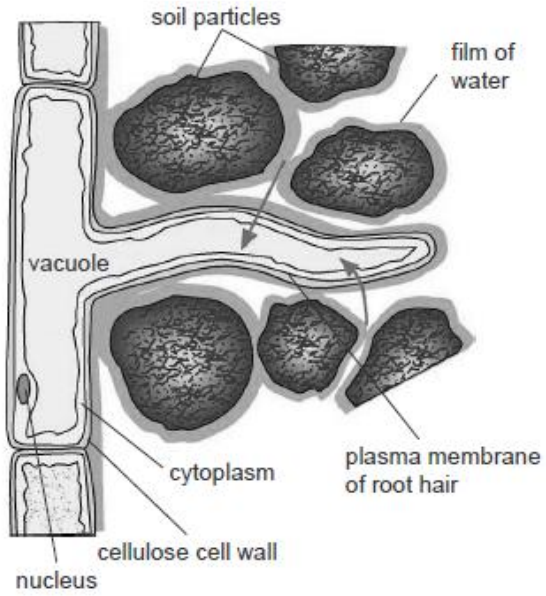


Figure 1.21 A root hair cell

Figure 1.22 Root hairs near tip of tomato root
Source: http://www.biotech.cornell.edu/brc/imaging-facility

Human red blood cell

- **Biconcave** shape to increase surface area to volume ratio and increase the rate of oxygen transport
- Contains red pigment **haemoglobin** which binds to oxygen
- Lacks nucleus so as to allow more haemoglobin to be packed in (NOT pack more oxygen)

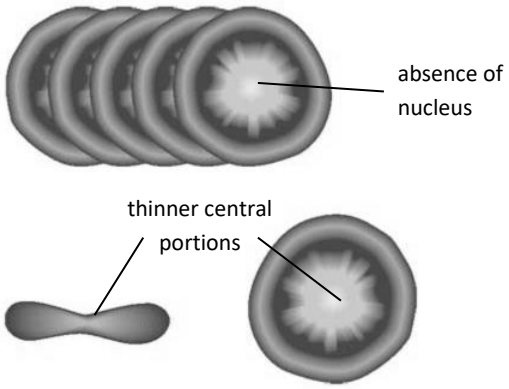


Figure 1.23 Human red blood cells

Xylem vessel

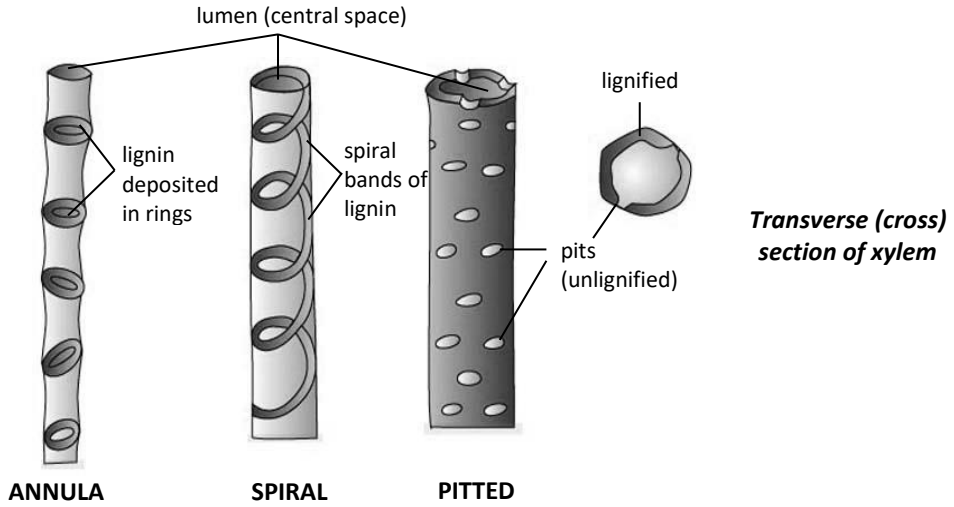


Figure 1.24 Xylem vessels with different ways of lignification

- Narrow and long tubes extending from roots to the leaves.
- Absence of cross walls (partition walls) and protoplasm → conduct water and mineral salts ~~to move~~ through the lumen easily without hindrance
- Lignified cell wall (contain **lignin**) → strengthened wall and prevent collapse of individual xylem vessel
- Lignified xylem vessels when bundled together provide mechanical support to the plant.

Different Levels of Organisation

- Most organisms are made up of many cells and are said to be **multicellular** e.g. human.
- A **tissue** is a group of cells of the same structure and origin which come together to perform a particular function. Tissues can be classified into simple tissue e.g. one type of cells or complex tissue e.g. more than one type of cells.
- Example of simple tissue: epidermis, muscles
- Example of complex tissue: blood, phloem, xylem
- An **organ** consists of different tissues being grouped together to perform a function.
- Example: Stomach consists of tissues such as
    (1) Epithelium tissue
    (2) Glandular tissue
    (3) Muscular tissue
    (4) Nervous tissue
    (5) Connective tissue
- An **organ system** consists of a group of different organs working together for a particular function.

- Example: Digestive system consists of organs such as:
    (1) Stomach
    (2) Gullet
    (3) Small intestines
    (4) Large intestines
    (5) Rectum
- Various organ systems together make up the entire living **organism**.

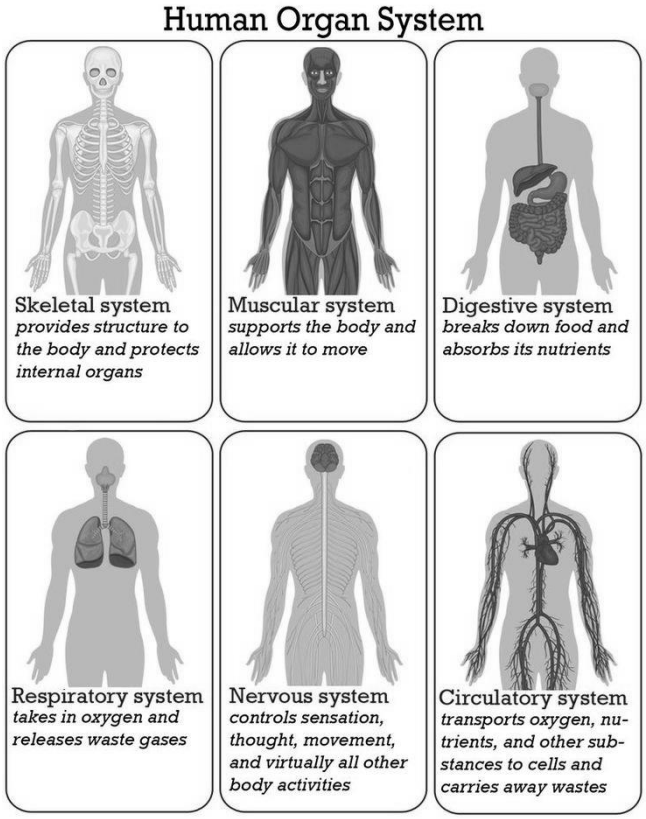


Figure 1.25 Examples of organ systems in human

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 02 – Movement of Substances

Name: **Class:**

A. Content

- Fluid Mosaic Model of Membrane Structure
- Membrane Proteins and Their Functions
- Diffusion, Facilitated Diffusion, Osmosis, Active Transport, Endocytosis, Exocytosis

B. Learning Outcomes

Students should be able to:
(a) define diffusion and describe its role in nutrient uptake and gaseous exchange in plants and humans
(b) define osmosis and describe the effects of osmosis on plant and animal tissues
(c) define active transport and discuss its importance as an energy-consuming process by which substances are transported against a concentration gradient, as in ion uptake by root hairs and uptake of glucose by cells in the villi.
(d) describe the fluid mosaic model of membrane structure as a phospholipid bilayer (Knowledge of the roles of phospholipids, cholesterol, glycolipids, proteins and glycoproteins is not required).
(e) outline the roles and functions of membranes within cells and at the surface of cells. (Knowledge of osmosis, facilitated diffusion, active transport, endocytosis and exocytosis is required.)
(f) list the functions of membrane proteins including channels for passive transport and pumps for active transport.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
4. Reece J.B., Urry L.A., Cain M.L., Wasserman S.A., Minorsky P.V. and Jackson R.B. Campbell Biology (9th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline

1. Introduction
2. Fluid Mosaic Model of Membrane Structure
3. Membrane Proteins & Their Functions
4. Diffusion, Facilitated Diffusion & Osmosis
5. Active Transport
6. Bulk Transport – Endocytosis and Exocytosis
7. Summary

E. Practical Work

- Preparing, observing and drawing plant specimens (e.g. potato, water spinach) in different solutions.
- Recording and calculating the changes and percentage changes in length or mass of plant specimens (e.g. potato, spinach) in different solutions.

1. INTRODUCTION

For the proper functioning of all living tissues, the movement of substances into and out of cells – across their plasma membranes, has to occur continuously.

These transport processes are important for the (i) entry of substances useful to the cell (e.g. oxygen, glucose), (ii) removal of excretory products (e.g. carbon dioxide), and (iii) secretion of substances out of the cell (e.g. hormones).

Substances move in and out of cells via the following transport systems: (i) passive transport – diffusion, facilitated diffusion and osmosis, (ii) active transport, and (iii) bulk transport.

2. FLUID MOSAIC MODEL OF MEMBRANE STRUCTURE

- The currently accepted model for the structure of the plasma membrane (and cellular membranes generally) is the fluid mosaic model.

- In this model, there is a bilayer (double layer) of **phospholipids** (lipids containing a phosphate group) which are arranged with their **hydrophobic tails** facing inwards. The phospholipids **move** within the bilayer. A "mosaic" of various immobile **proteins** are embedded in or attached to the bilayer of phospholipids.

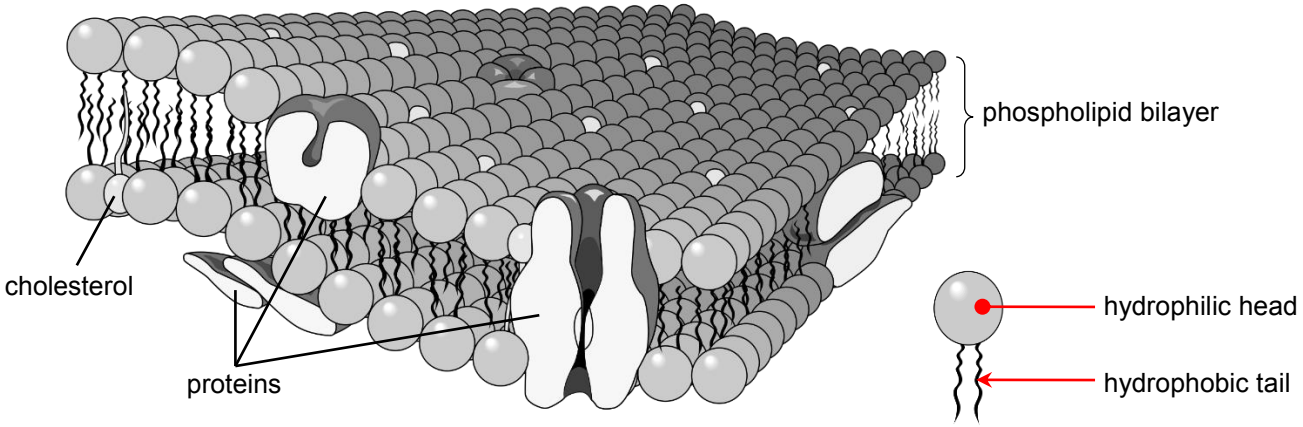


Figure 2.1 Membrane structure showing its components

- Evidence for fluid mosaic model:

  This model was supported by **freeze fracture technique**, whereby a cell is frozen and fractured with a knife such that the cell membrane can be split into its two layers to reveal the ultrastructure of the membrane's interior. The extracellular and cytoplasmic layers were viewed under an electron microscope, and the bumps seen demonstrated that the proteins were embedded in the phospholipid bilayer.

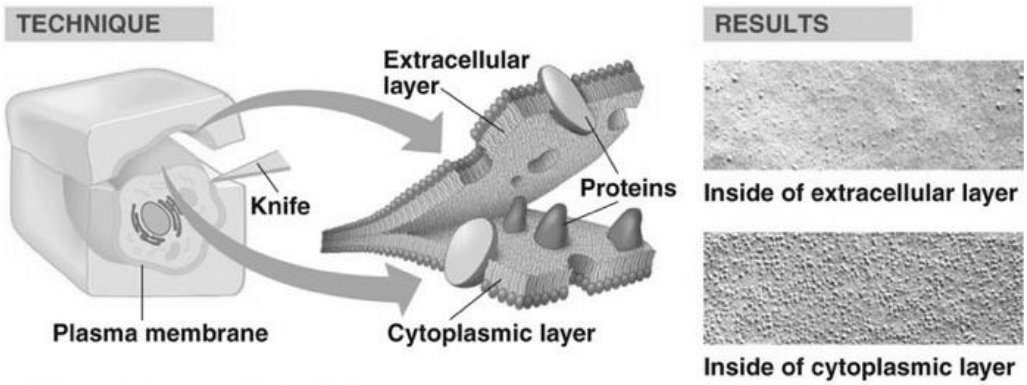


Figure 2.2 Electron micrographs show membrane proteins (seen as bumps) in both layers, demonstrating that proteins are embedded in the phospholipid bilayer.

- Functions of membranes:
  1. The cell membrane is **selectively permeable** and it **controls the movement** of substances moving in and out of the cell.
  2. The cell membrane forms a **boundary** between the contents of the cell and the external environment, ensuring that a constant internal environment within the cell is maintained.
  3. The cell membrane is responsible for cell-to-cell **communication**. Cell membranes are equipped with receptor proteins that receive chemical messenger molecules from other cells, allowing the cell to sense changes in the external environment and respond to them.

3. MEMBRANE PROTEINS AND THEIR FUNCTIONS

- Although phospholipids form the main fabric of the membrane, membrane **proteins** (the "**mosaic**" aspect of the model) determine most of the membrane's specific functions. Different types of cells or organelles contain different sets of membrane proteins.

- There are 2 major populations of membrane proteins:
  i. **Integral** (or intrinsic) proteins are tightly bound within the bilayer. The hydrophobic amino acids will be in contact with the hydrophobic lipid bilayer, while the hydrophilic portions will be exposed to the aqueous medium on either side of the membrane.

  ii. **Peripheral** (or extrinsic proteins) are loosely attached to the surface of the membrane, often to the exposed portions of the integral proteins.

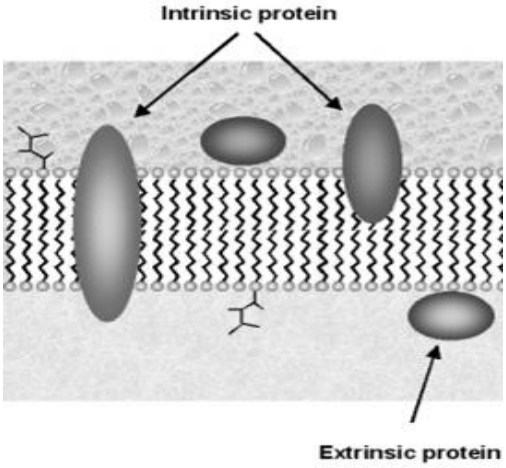


Figure 2.3 Intrinsic and extrinsic membrane proteins
Source: http://www.mikeblaber.org/

- Some functions of membrane proteins are listed below. In many cases, a single protein performs a combination of these tasks:
  i. Transport: **Transport proteins** are involved in the movement of specific molecules across the membrane by acting as **channel** or **carrier** proteins.

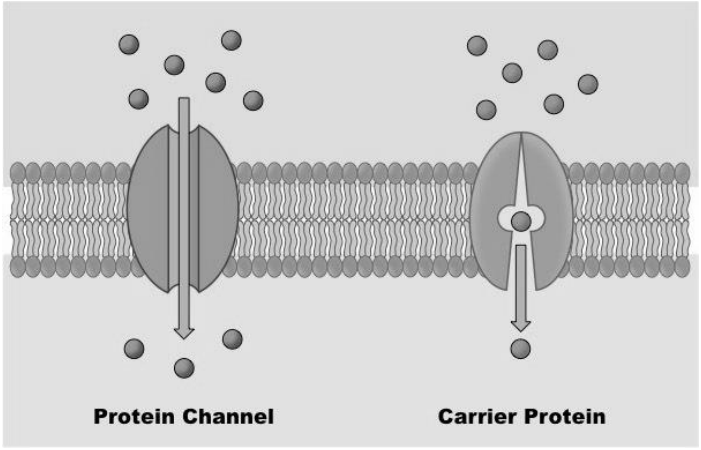


Figure 2.4 Types of transport proteins

ii. Enzymatic reactions: Some proteins are **enzymes** which have their active sites exposed to substances on either side of the membrane. In some cases, the enzymes are organised together as part of a metabolic pathway.

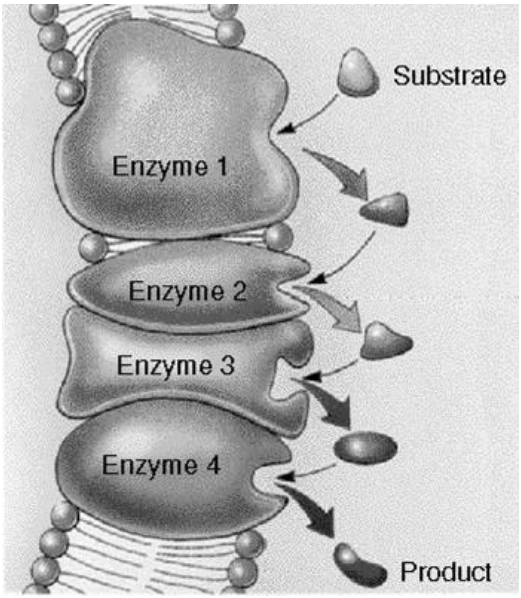


Figure 2.5 Series of enzymes involved in same metabolic pathway

iii. Signal transduction: Some proteins act as receptors to receive chemical messenger, e.g. a hormone. Upon binding and receiving the signal, the protein will undergo a conformational change to **relay the message** to the inside of the cell.

iv. Cell to cell recognition: Cells are able to determine if other cells it encounters are alike or different from itself. Some proteins have identification tags exposed so that they can be specifically recognised by other cells.

v. Intercellular joining / adhesion: Some proteins may attach with other proteins of adjacent cells.

4. DIFFUSION, FACILITATED DIFFUSION & OSMOSIS

4.1 Diffusion

Definition: Diffusion is the **net movement of particles** (atoms, ions or molecules) from a region of **higher** concentration to a region of **lower** concentration, **down a concentration gradient**.

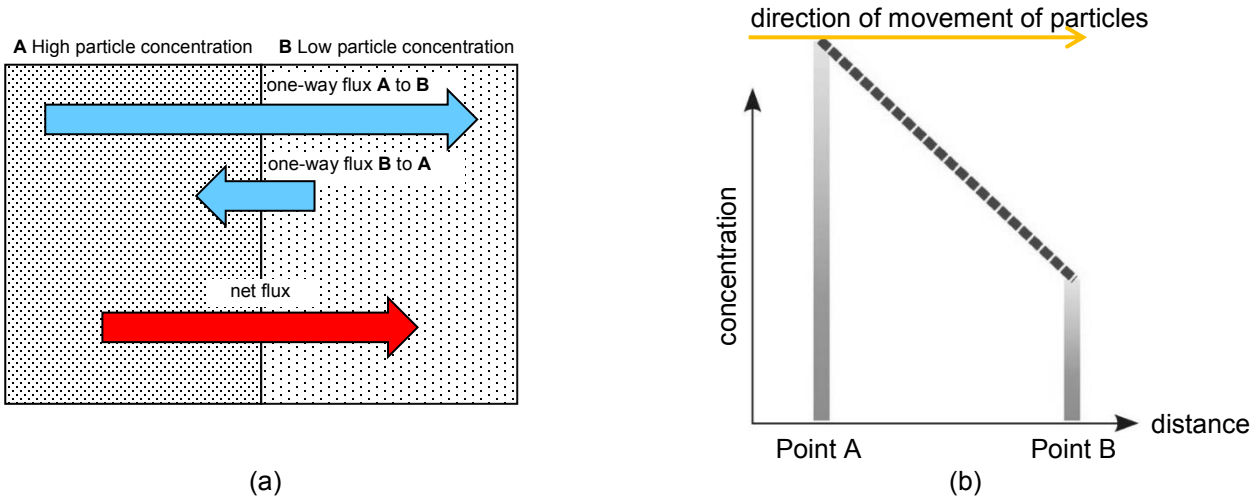


Figure 2.6 (a) Diffusion involves net flow of particles from point A to B **(b)** down a concentration gradient

Features of Diffusion:

- It is a **passive** process – it does not require the expenditure of energy; it relies on the kinetic energy of the particles.
- It is a slow process.

- It will occur wherever a **concentration gradient** exists. An equilibrium is reached when the net concentration of particles on each side are equal. At this point, net movement stops.
- If there is more than one type of particles, diffusion of the particles will occur independently of one another.

Examples of diffusion in living systems:
(i) Exchange of oxygen and carbon dioxide into and out of plant leaf epidermal cells.
(ii) Exchange of oxygen and carbon dioxide between lungs and red blood cells in humans.

Examples of diffusion in non-living systems:

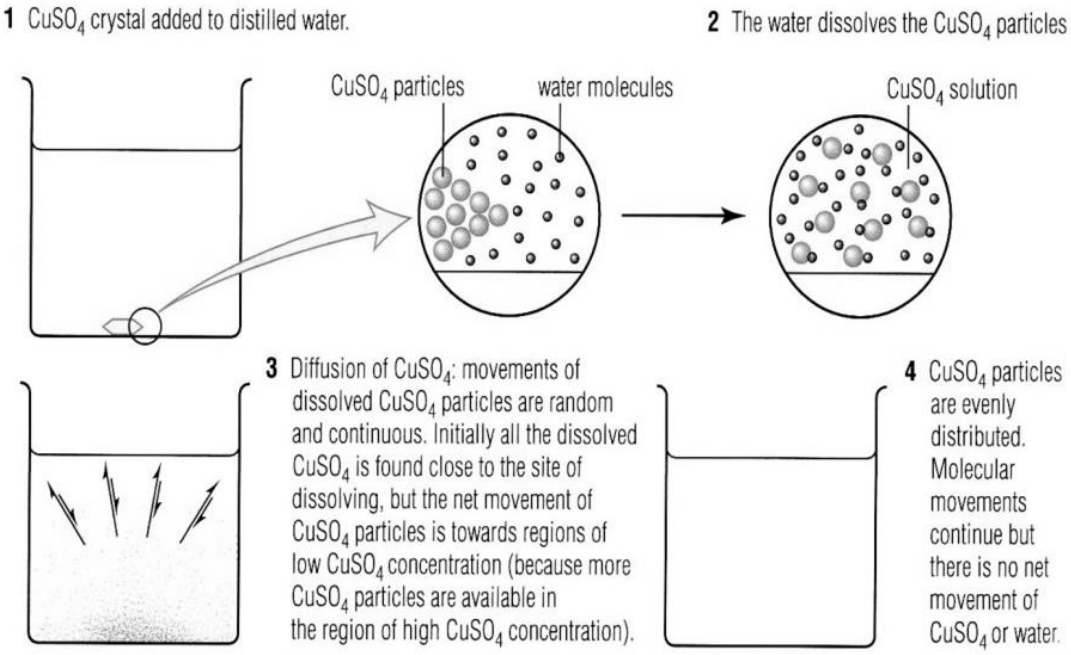
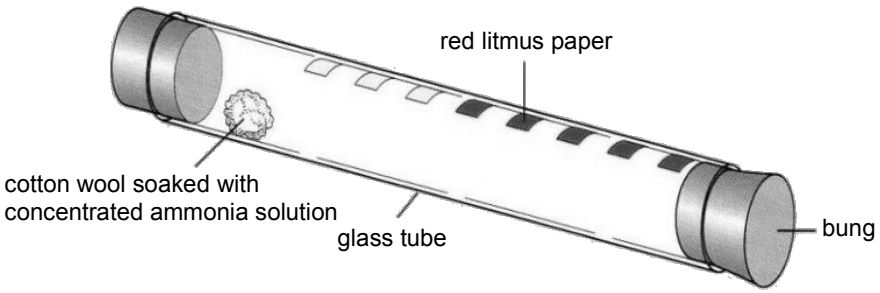


Figure 2.7 An experiment depicting the diffusion of solute particles in liquids
Source: Clegg, C. J. and Mackean



The red litmus papers changed colour from red to blue in the sequence shown. That is, ammonia diffused from a region of high concentration to regions of lower concentrations.

Figure 2.8 An experiment depicting the diffusion of gases
Source: Clegg, C. J. and Mackean

4.2 Facilitated Diffusion
Facilitated diffusion occurs when a substance is aided across a membrane by **transport protein**. **Charged** particles (e.g. ions like Na^+, Ca^{2+}) and relatively **large** polar molecules (e.g. amino acids, sugars, fatty acids and glycerol), cannot diffuse across the plasma membrane directly by diffusion because they are insoluble in lipids or are repelled by the hydrophobic region of the membrane.

What are the similarities between diffusion and facilitated diffusion?
Both are passive processes and involves the movement of substances down a concentration gradient.

There are two types of transport proteins involved in facilitated diffusion:
• **Channel proteins** - they provide a hydrophilic passage for small polar molecules to flow very quickly from one side of the membrane to the other by shielding the molecules from the hydrophobic phospholipid bilayer.

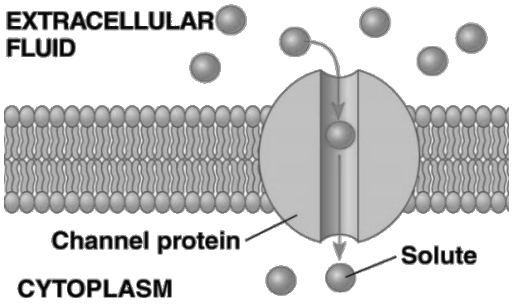


Figure 2.9 How channel proteins work
Source: Campbell Biology

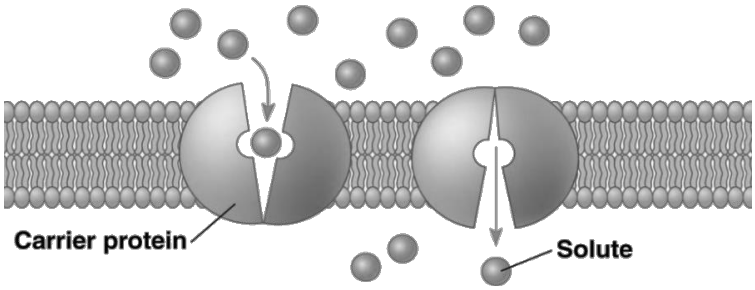


Figure 2.10 How carrier proteins work
Source: Campbell Biology

• **Carrier proteins** - the ion or molecule that needs to be transported binds to a binding site on the carrier protein. This causes a change in the shape of the carrier protein such that a hydrophilic channel forms in the centre. Once the molecule reaches the other side of the membrane, the carrier protein releases the molecule and resumes its original shape.

4.3 Osmosis
Definition: Osmosis is the net movement of **water** molecules from a solution of **higher water potential** to a solution of **lower water potential**, **down a water potential gradient**, through a **selectively permeable membrane**.

Water potential is defined as the tendency for water to leave that particular solution via osmosis. Water and all solutions have a water potential value. Pure water has the highest water potential, set at zero.

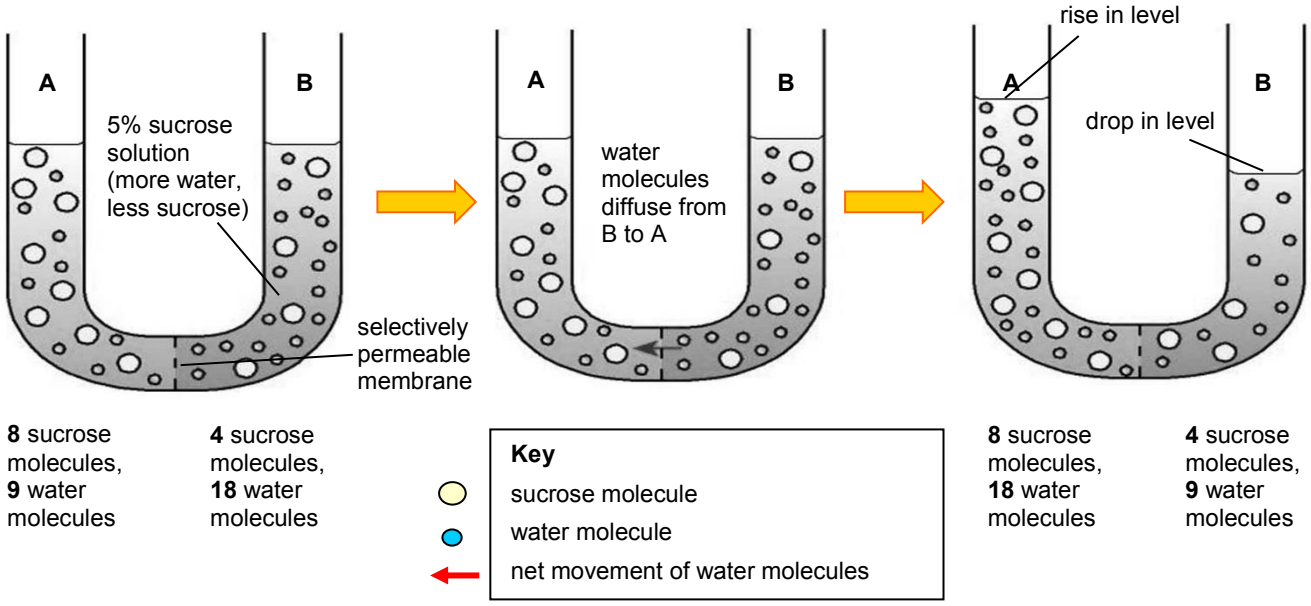


Figure 2.11 Movement of water via osmosis

- There are channel proteins, called **aquaporins**, on the plasma membrane that facilitate the movement of water molecules across the membranes of plant and animal cells.
- When comparing 2 solutions, a more dilute solution will have a higher water potential value, while a more concentrated solution has a lower water potential value.
- When comparing the water potentials of 2 solutions, one solution can be described as **hypertonic**, **isotonic** or **hypotonic** to another one.

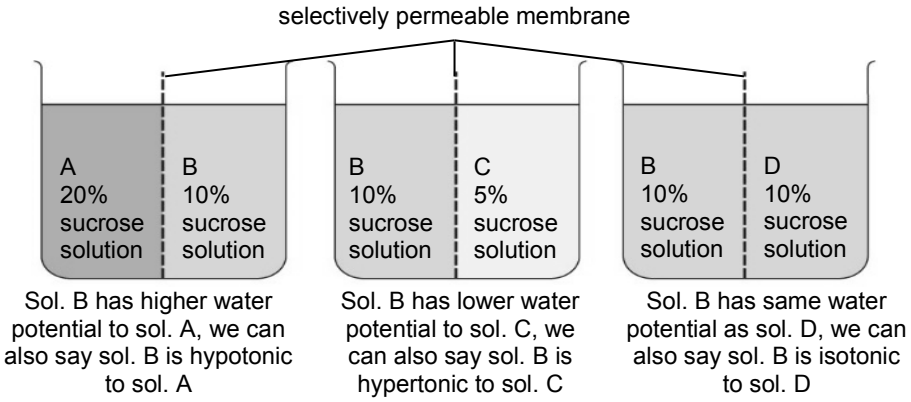
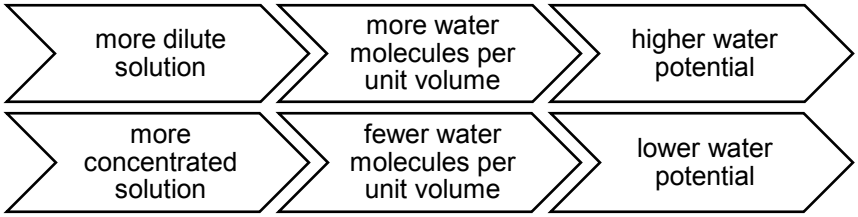


Figure 2.12 Solution can be described as hypertonic, isotonic or hypotonic relative to another one.



Features of Osmosis:
- It is a passive process; it does not require the expenditure of energy.
- As a result of osmosis, cells behave differently when exposed to solutions of different water potentials.

What happens to a cell in a solution with higher water potential?

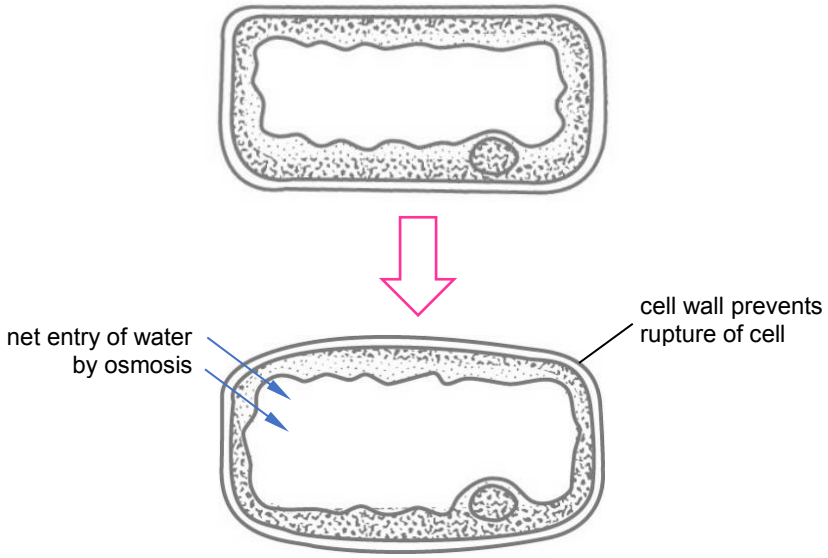


Figure 2.13 A plant cell in a solution with higher water potential

- Cell sap has a **lower water potential** than its surrounding solution.
- **Water** enters cell by **osmosis** through **selectively permeable cell membrane**.
- Large central vacuole **increases** in size.
- Cytoplasm gets pushed against cell wall, resulting in **turgor pressure**.
- The cell is said to be **turgid**.

Turgor / turgidity in plant cell helps:
- to keep stems upright
- to keep leaves flat so they can better absorb sunlight

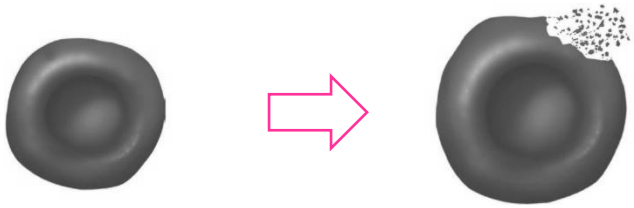


Figure 2.14 An animal cell in a solution with higher water potential

- Cell has a **lower water potential** than its surrounding solution.
- **Water** enters cell by **osmosis** through **selectively permeable cell membrane**.
- Cell **expands and bursts** as cell membrane ruptures and absence of cell wall.
- The cell has lysed. This process is termed **lysis**.

What happens to a cell in a solution with lower water potential?

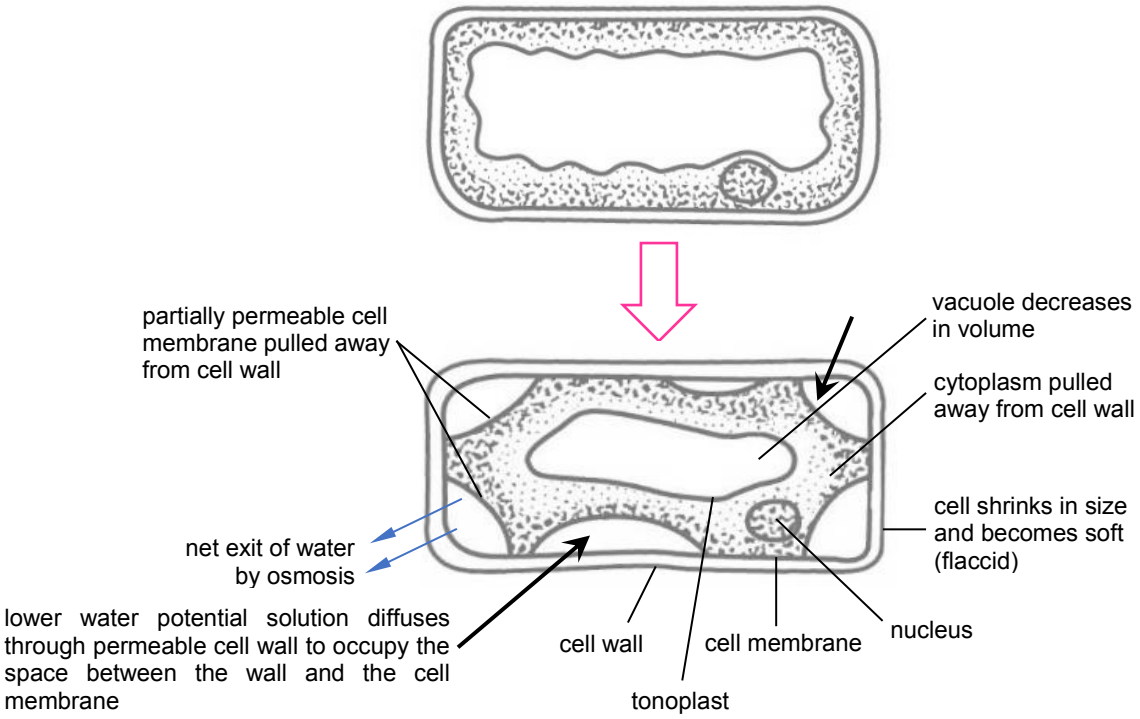


Figure 2.15 A plant cell in a solution with lower water potential

- Cell sap has a **higher water potential** than its surrounding solution.
- **Water** leaves cell by **osmosis** through **selectively permeable cell membrane**.
- Large central vacuole **decreases** in size.
- Cytoplasm and cell membrane shrink away from cell wall. This is termed **plasmolysis**.
- The cell is said to be **plasmolysed** and **flaccid**.
- Plasmolysed cells can return to original state by placing them in solution of higher water potential.

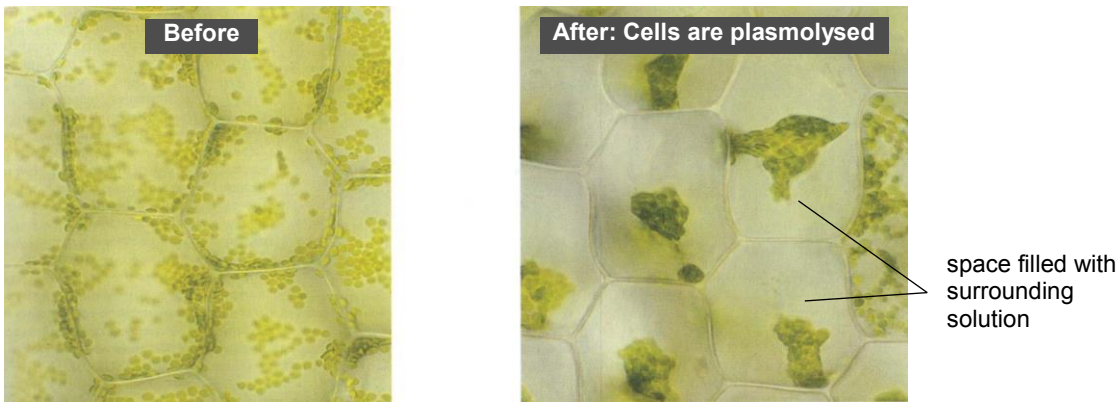


Figure 2.16 Plant cells before and after they were placed in a hypertonic solution

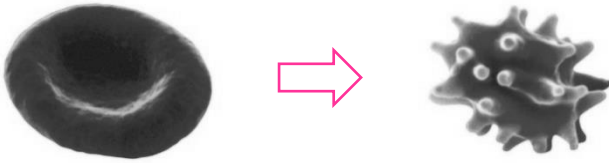
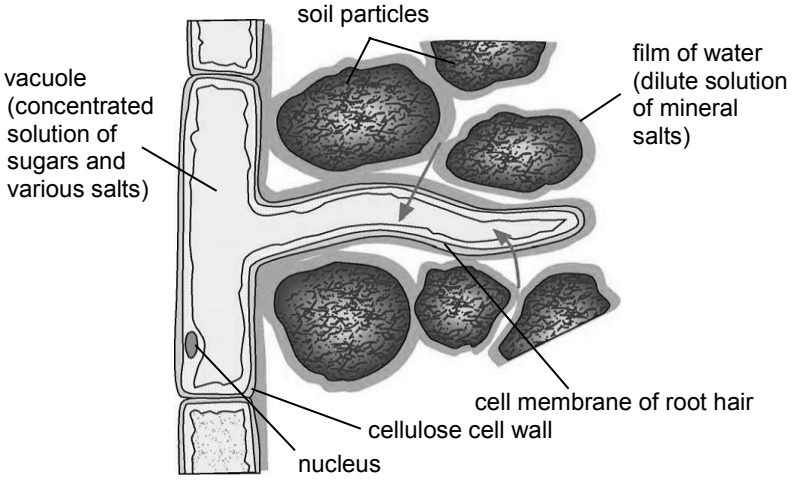


Figure 2.17 An animal cell in a solution with lower water potential

- Cell has a **higher water potential** than its surrounding solution.
- **Water** leaves cell by **osmosis** through **selectively permeable cell membrane**.
- Cell shrinks and little spikes appear on the cell membrane.
- The cell is crenated. The process is termed **crenation**.

Examples of osmosis in living systems:



Entry of water into plant
- Cell sap of root hair cells have lower water potential than soil water.
- Water moves into large central vacuoles of root hairs by osmosis through a selectively permeable cell membrane.

Figure 2.18 A section of a root hair cell

Factors affecting rate of passive transport:
- Concentration gradient: The steeper the concentration gradient, the faster the passive transport.
- Surface area: volume ratio: The greater the surface area: volume ratio, the faster the passive transport.
- Temperature: The higher the temperature, the faster the passive transport.
- Distance: The greater the distance travelled by the molecules (e.g. thickness of membrane), the slower the passive transport.

5. SURFACE AREA TO VOLUME RATIO

- The smaller the organism e.g. mouse, the larger is its surface area : volume ratio. The bigger the organism e.g. elephant, the smaller is its surface area: volume ratio.
- Implication of surface area: volume ratio?
  - Smaller organisms/cells (large SA : volume ratio) have the advantage of a relatively large absorbing surface for substances like oxygen.
  - The oxygen absorbed is able to reach the interior of the small organism fast enough.
  - For large organisms/cells (small SA : volume ratio), the oxygen absorbed will not be able to reach the interior of the organism fast enough.

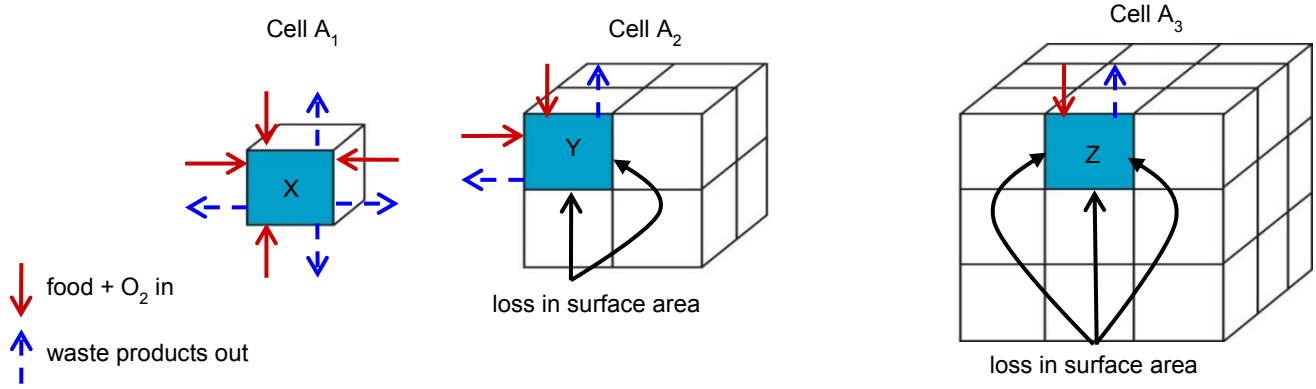
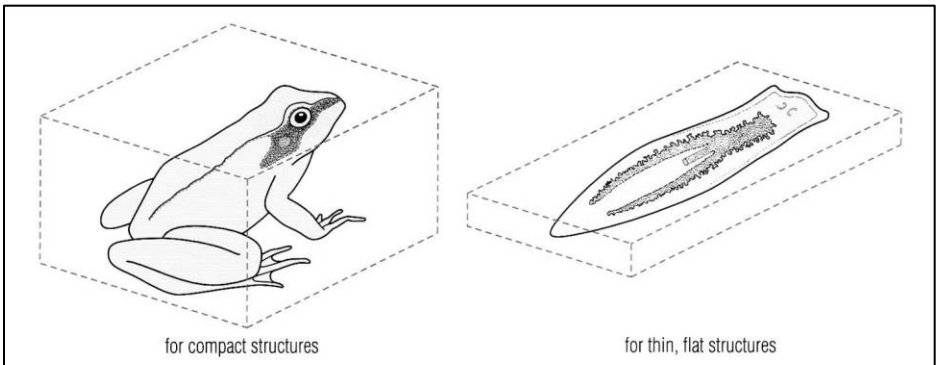


Figure 2.19 Diagrammatic models to explain what surface area to volume ratio means to a cell



'Organism'	Compact			Flat and thin		
	small	medium	large	small	medium	large
Dimensions/cm	1 × 1 × 1	2 × 2 × 2	4 × 4 × 4	2 × 1 × 0.5	8 × 2 × 0.5	16 × 8 × 0.5
Volume/cm^3	1	8	64	1	8	64
Surface area/cm^2	6	24	96	7	42	280
Surface area:volume ratio	6.0	3.0	1.5	7.0	5.25	4.4

Figure 2.20 Smaller organisms/cells which are also flat and thin have the largest SA: volume ratio, and therefore substances are able to diffuse into the organism the fastest than larger and/or compact organisms/cells with smaller SA: volume ratio.
Source: Clegg, C. J. and Mackean

6. ACTIVE TRANSPORT

Definition: Active transport is **energy-consuming** (released during cellular respiration) process of moving substances from a region of **lower concentration** to a region of **higher concentration**, **against a concentration gradient**.

Features of Active Transport:

- Active transport is performed by specific **carrier proteins** in the membrane.
- Active transport enables a cell to maintain internal concentrations of small molecules that differ from concentrations in its environment. For example, compared to its surroundings, an animal cell has a much higher concentration of K^+ ions and lower concentration of Na^+ ions. The carrier protein known as sodium-potassium pump therefore is maintaining these steep gradients by pumping Na^+ out of the cells and K^+ into the cells.

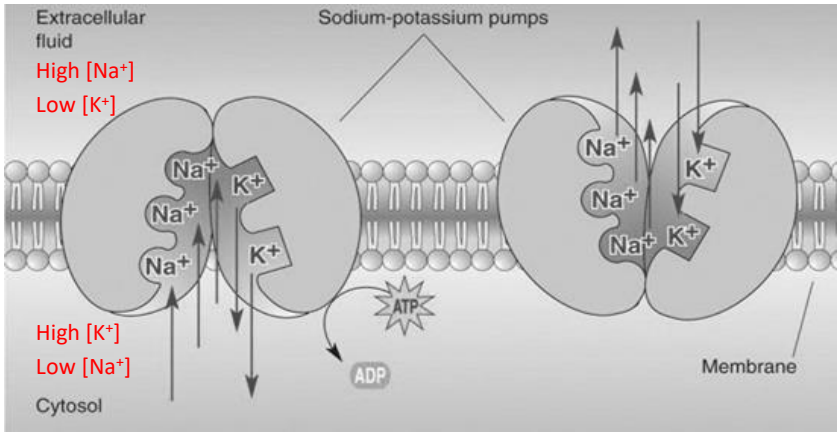


Figure 2.21 Energy is used by the carrier proteins to pump ions through the plasma membrane against their concentration gradient. The Na-K pump oscillates between 2 conformational states in a cycle that transfers 3 Na^+ out of the cell for every 2 K^+ pumped into the cell.

Examples of active transport include:

(i) Absorption of dissolved mineral salts / ions by root hair cells
(ii) Absorption of glucose and amino acids by small intestine cells
(iii) Selective reabsorption of glucose in kidney tubules

7. BULK TRANSPORT – EXOCYTOSIS AND ENDOCYTOSIS

For very large molecules such as proteins and polysaccharides, they cross the cell surface membrane in bulk by mechanisms that **involve packaging in vesicles**. Like active transport, bulk transport **requires energy**.

There are 2 types of bulk transport:
(i) **Exocytosis** where large molecules are released from cells.
(ii) **Endocytosis** where large molecules are taken into the cells.

Exocytosis

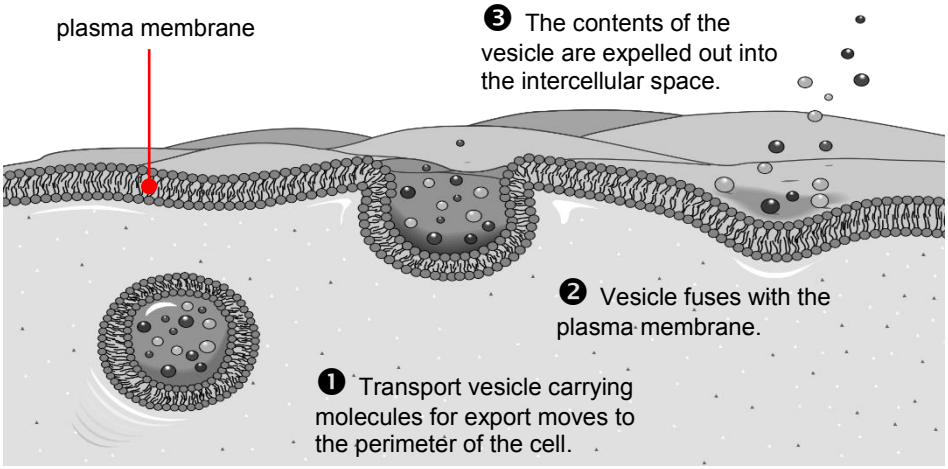


Figure 2.22 How substances are secreted out of the cell via exocytosis

- Examples of exocytosis include:
  - Secretion of enzymes by intestinal cells
  - Secretion of hormones by endocrine cells
  - Secretion of mucus by cells lining air passages
  - Release of neurotransmitters by neurons

Endocytosis

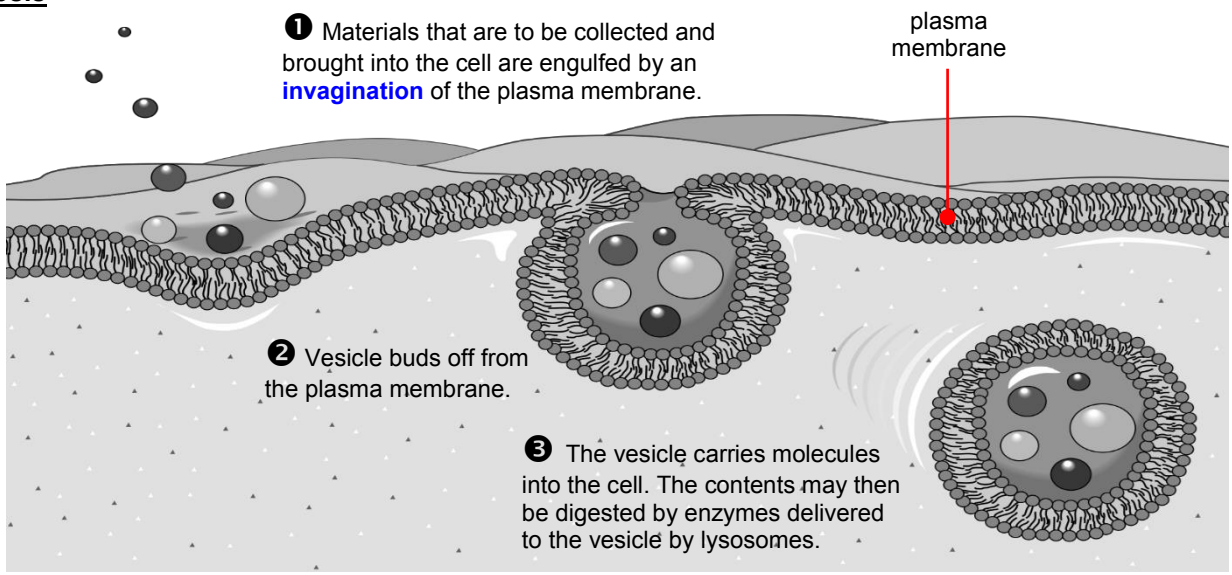


Figure 2.23 How substances are taken into the cell via endocytosis

- There are 3 kinds of endocytosis:

i. **Phagocytosis**: material taken up is in **solid** form (e.g. bacteria or cells). The particles within the formed vesicle usually get digested by the enzymes in the cell. Phagocytosis is **selective** and the cells will only take up specific particles. An example of phagocytosis is how certain white blood cells engulf bacteria.

ii. **Pinocytosis**: material taken up is in **liquid** form. The process is **non-selective**.

iii. **Receptor-mediated endocytosis**: material to be taken up **binds to the receptor proteins** on the cell membrane. The process is **selective**.

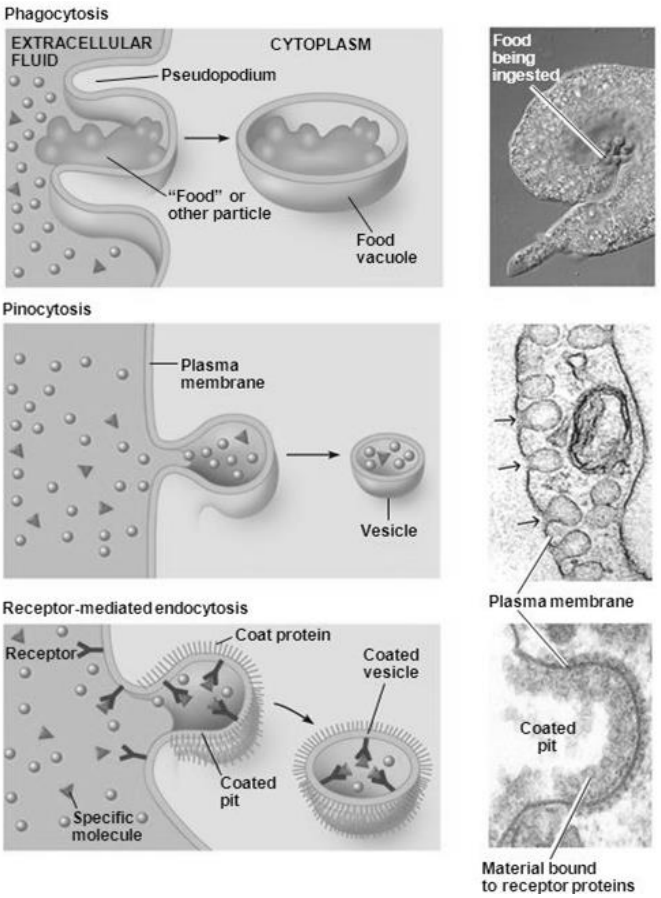


Figure 2.24 Summary of three different types of endocytosis

8. SUMMARY

Table 2.1 Comparison between diffusion, osmosis and active transport

	Diffusion	Osmosis	Active Transport
definition	Net movement of particles from a region of higher concentration to a region of lower concentration.	Movement of water molecules across a selectively permeable membrane, from a solution of higher water potential to a solution of lower water potential.	Movement of substances against a concentration gradient. Energy is required for this process.
importance/ examples	Gaseous exchange in lung cells and root hair cells.	Turgor pressure is important for the opening and closing of the stomata.	For ion uptake by root hair cells and uptake of glucose by small intestinal cells.
	Similarities		
	• Both are passive processes. • Both involve movement of substances down a concentration gradient.		
	Differences		
	• Any substance. • Membrane not required.	• Only water molecules. • Only across a selectively permeable membrane.	• Not an example of passive transport. • Requires selectively permeable membrane.

Table 2.2 Comparison between diffusion and facilitated diffusion

Diffusion	Facilitated Diffusion
Similarities	
• Both are passive processes. • Both involve movement of substances down a concentration gradient.	
Differences	
Occurs directly across the cell membrane	Requires transport proteins to facilitate the movement of substances across the cell membrane

Table 2.3 Comparison between facilitated diffusion and active transport

	Facilitated Diffusion	Active Transport
concentration gradient	Movement of molecules down a concentration gradient	Movement of molecules against a concentration gradient
transport proteins	Molecules can bind on either sides of membrane	Molecules only bind on one side of the membrane
expenditure of energy	Does not require expenditure of energy	Conformational change in carrier protein requires expenditure of energy (from the hydrolysis of ATP)

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 03 – Biological Molecules – Nutrients

Name: **Class:**

A. Content

- Chemistry of water, carbohydrates, fats and proteins
- Tests for starch, reducing sugars, protein, and fats

B. Learning Outcomes

Students should be able to:
(a) state the roles of water in living organisms.
(b) list the chemical elements which make up
    - carbohydrates
    - fats
    - proteins
    - nucleic acids

(c) describe and carry out tests for
    - starch (iodine in potassium iodide solution)
    - (Benedict's solution)
    - protein (biuret test)
    - fats (ethanol emulsion)

(d) state that large molecules are synthesised from smaller basic units
    - glycogen from glucose
    - polypeptides and proteins from amino acids
    - lipids such as fats from glycerol and fatty acids

Use the knowledge gained in this section in new situations or to solve related problems.

C. References

1. Lam PK, Lam EYK. 2013. Biology Matters. 2nd ed. Singapore: Marshall Cavendish.
2. Campbell NA, Reece JB. 2008. Biology. 7th ed. San Francisco: Pearson Education.

D. Lecture Outline

1. Introduction
2. Water
3. Biological Molecules:
    3.1 Carbohydrates
    3.2 Fats (Lipids)
    3.3 Proteins
4. Food Tests
    4.1 Iodine Test
    4.2 Benedict's Test
    4.3 Biuret Test
    4.4 Ethanol Emulsion Test

E. Practical Work

- Standard Food Tests

1 INTRODUCTION

Water is the universal medium for life on Earth. All organisms are made of mostly water and live in an environment dominated by water.

Apart from water, living organisms are made up of chemicals based mostly on the element **carbon**. Carbon enters the biosphere through the photosynthesis, where carbon dioxide in the atmosphere is converted to carbohydrates. As water lack carbon, it is considered an inorganic nutrient.

Of all chemical elements, carbon accounts for the large diversity of biological molecules. **Carbohydrates**, **Fats** (**Lipids**), **Proteins** and **Nucleic Acids** (e.g. DNA) that distinguish living matter from inanimate materials, are composed of carbon atoms bonded to one another and to atoms of other elements. **Hydrogen** (H), **Oxygen** (O), **Nitrogen** (N), **Sulfur** (S) and **Phosphorus** (P) are some of the other elements of biological molecules.

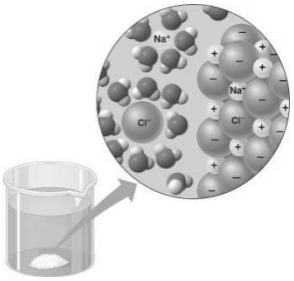
Within living matter of all cells, small organic molecules are joined together to form larger molecules. All living organisms are made up of four main classes of macromolecules: **carbohydrates**, **lipids**, **proteins** and **nucleic acids**.

STATE the roles of water in living organisms.

2 WATER

The roles of water in living organisms include

a) As a **solvent** of **chemical reactions**
Water is an effective solvent because it readily forms hydrogen bonds with charged and polar covalent molecules. Solvent is a dissolving agent and the substance that is dissolved is the solute. In an aqueous solution, water is the solvent. When we dissolved sodium chloride in water, water is the solvent and sodium chloride is the solute.
   - Water is a solvent for many chemical reactions in living cells.
   - Water is also a reactant in many of the chemical reactions (e.g. photosynthesis) in living organisms.



b) As a component of **protoplasm**, **tissue fluid**, **lubricants**, **digestive juices**, **blood**
   - Cells are 70-95% water.
   - Most cells are surrounded by water (in tissue fluid).

c) **Controlling body temperature**
Evaporation of water in sweat in mammals or evaporation of water from mesophyll cells in leaves of plants removes excess latent heat and prevents terrestrial organisms from overheating.

d) **Transporting dissolved substances**
Many substances are dissolved and transported in water. For example
   - Digested products such as glucose and amino acids are transported from the small intestine to other parts of the body, and
   - Waste products from cells are transported from the cells for removal from the body.

What are the functions of water in plants?

- Water is necessary for the light-dependent reactions of **photosynthesis**.
- Water keeps cells **turgid**.
- Mineral salts dissolve in water and are transported up the **xylem** of plants (see Figure 3.1).
- Sucrose and amino acids are transported in water through the **phloem**, from the photosynthetic parts to all parts of the plants (see Figure 3.1).

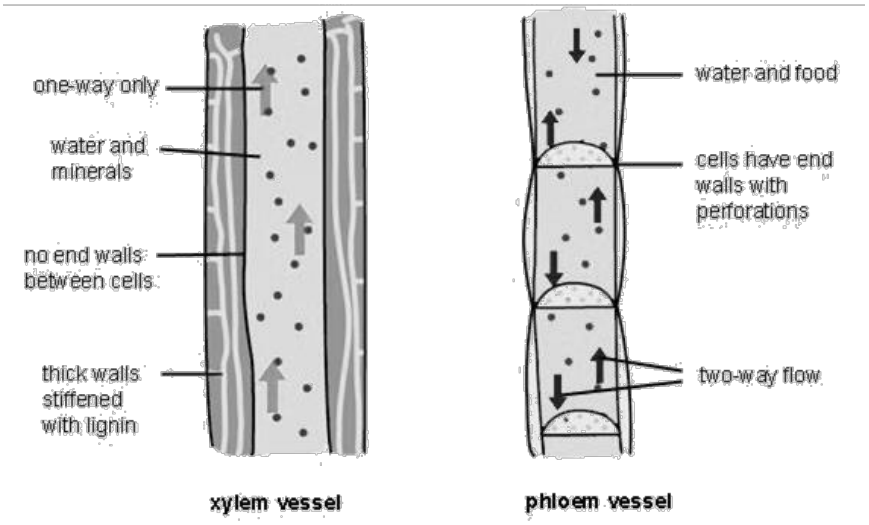


Figure 3.1 Xylem sap contains water and ions. Phloem sap contains water and sugars.
Source: http://www.diffen.com/difference/Phloem_vs_Xylem

LIST the chemical elements which make up carbohydrates, fats and proteins.

STATE that large molecules are synthesised from smaller basic unit:
- *glycogen from glucose*
- *polypeptides and proteins from amino acids*
- *lipids such as fats from glycerol and fatty acids*

3.1 CARBOHYDRATES

a) Carbohydrates are made up of the elements **Carbon** (C), **Hydrogen** (H) and **Oxygen** (O), with the general formula $C_nH_{2m}O_m$. (ratio of H:O always 2:1)

b) Carbohydrates include
- **Monosaccharides** (or simple sugars)
- **Disaccharides** (or double sugars)
- **Polysaccharides** (polymers of many monosaccharides)

Most names for sugars end in -ose.

c) Monosaccharides

- Monosaccharides generally have molecular formulas that are multiple of the unit CH_2O. Common monosaccharides include **glucose**, **galactose** and **fructose**. They all have the formula $C_6H_{12}O_6$.
- Glucose is the substrate in **cellular respiration**. Oxidation of glucose releases **energy**.
- Simple sugars also function as the raw material for the synthesis of other biological molecules, such as amino acids and fatty acids.

d) Disaccharides

- Two monosaccharides can join with a glycosidic linkage to form a disaccharide in the process known as **condensation**. Condensation reaction is the chemical reaction in which two simple molecules are joined together to form a larger molecule with the removal of one water molecule.
  - **Maltose** (malt sugar) is formed by joining two glucose molecules.
  - **Sucrose** (table sugar) is formed by joining glucose and fructose (see Figure 3.2). Sucrose is the transport form of sugars in plants.
  - **Lactose** (milk sugar) is formed by joining glucose and galactose.

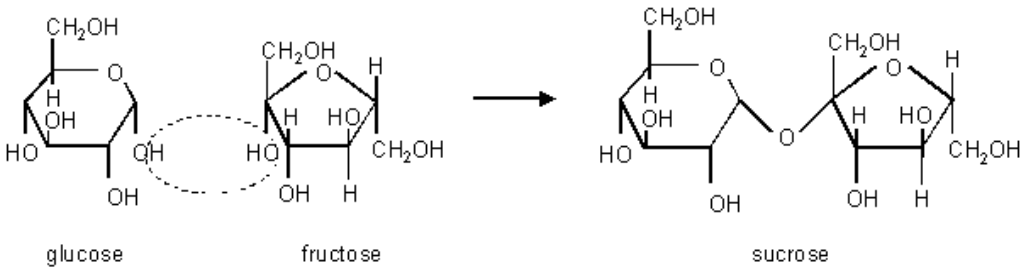


Figure 3.2 Condensation reaction of a glucose molecule and a fructose molecule
Source: http://faculty.clintoncc.suny.edu/faculty/michael.gregory/files/bio%20101/bio%20101%20lectures/biochemistry/biochemi.htm

- A disaccharide can be split to form two monosaccharides in the process known as **hydrolysis** (see Figure 3.3). Hydrolysis or a hydrolytic reaction is a reaction whereby a water molecule is added to split up a complex molecule into smaller molecules.

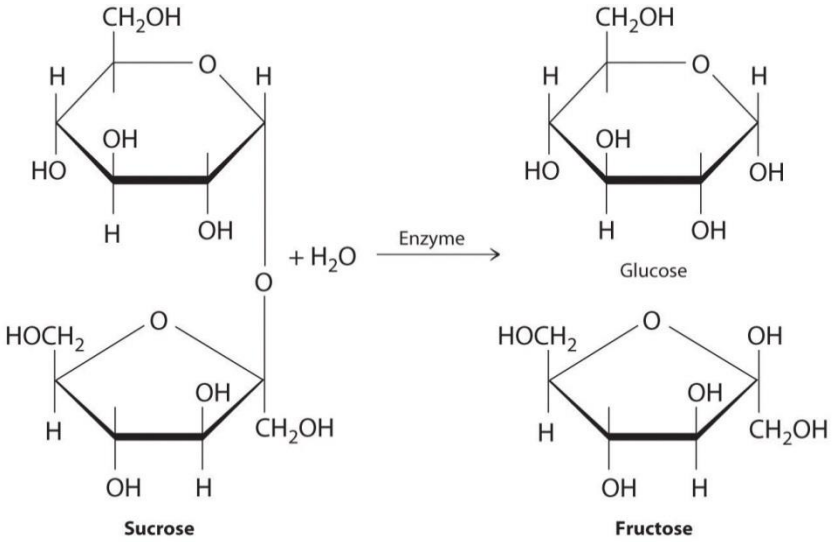


Figure 3.3 Hydrolysis of sucrose
Source: http://2012books.lardbucket.org/books/principles-of-general-chemistry-v1.0/s28-06-the-molecules-of-life.html

e) Polysaccharides

- Polysaccharides are made up of hundreds to thousands of monosaccharides (commonly glucose) joined by glycosidic linkages.

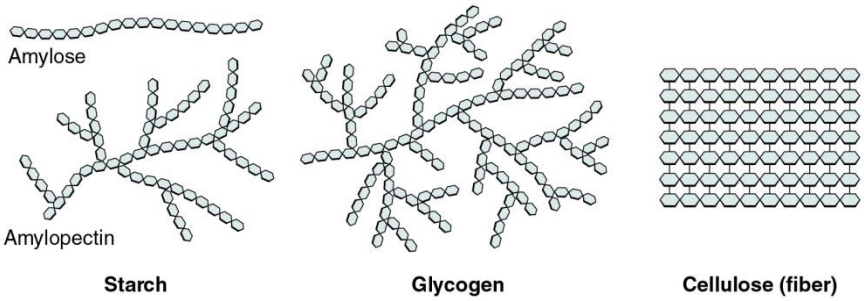


Figure 3.4 Structures of polysaccharides
Source: www.galleryhip.com

- Polysaccharides, have storage and structural roles:
  - Some polysaccharides serve for storage and are hydrolysed as sugars are needed. Plants store excess glucose as **starch** (see Figure 3.5) within chloroplasts. The simplest form of starch, amylose, is unbranched. Branched forms such as amylopectin are more complex. Animals that feed on plants, especially parts rich in starch, have digestive enzymes that can hydrolyse starch to glucose, making the glucose available as substrate for cellular respiration.
  - Humans store excess glucose as **glycogen** (see Figure 3.6) in muscles and liver. Glycogen is highly branched, like amylopectin.

- **Cellulose** is a major component of the tough walls of plant cells (see Figure 3.7). Cellulose is the most abundant organic compound on Earth.

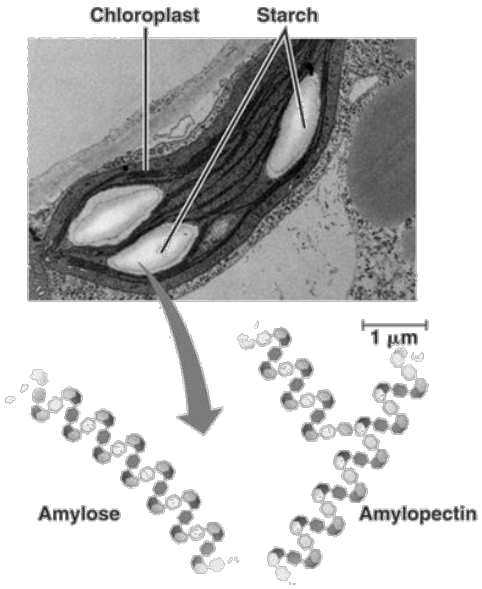


Figure 3.5 Starch is made up of long straight chains or branched chains of glucose molecules.
Source: Campbell Biology

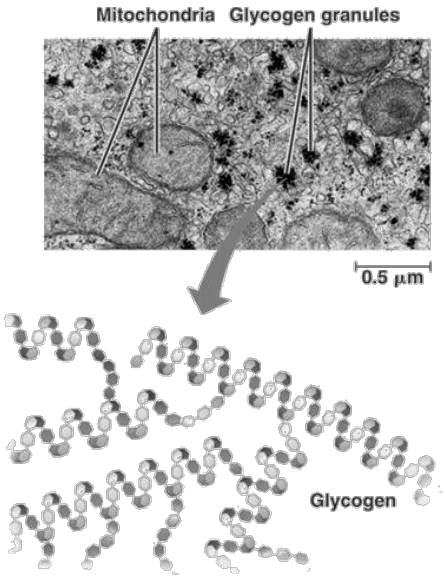


Figure 3.6 Glycogen is made up of highly branched chains of glucose.
Source: Campbell Biology

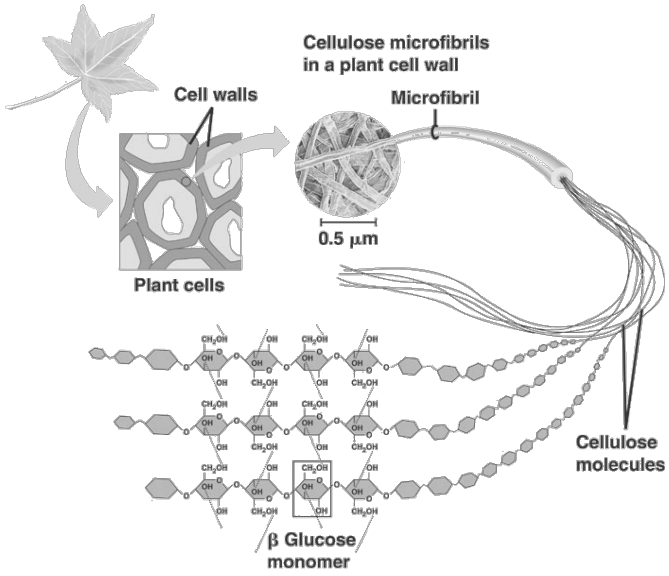


Figure 3.7 Cellulose is made up of long straight chains of glucose molecules, adjacent chains of which are held together by hydrogen bonds.
Source: Campbell Biology

Table 3.1 Comparison between starch and glycogen

starch	glycogen
polysaccharide	polysaccharide
long straight or **branched chain** of glucose molecules	**highly branched chain** of glucose molecules
storage form of glucose in **plants**	storage form of glucose in **animals**
found in various **plant parts**, e.g. root, stem	found in **liver** and **muscles**

State the functions of carbohydrates in living organisms.

- Glucose is the substrate for cellular respiration.
- Glucose is needed to synthesise lubricants (e.g. mucus) and flower nectar.
- Glucose is also needed for the formation of nucleic acids (e.g. DNA).

- Glucose is the basic unit for the formation of cellulose cell walls in plants.
- Glucose can convert to other organic molecules (e.g. fats, amino acids) in plants.
- Starch is the storage form of carbohydrates in plants.
- Glycogen is the storage form of carbohydrates in animals.

Extension

DISCUSS the formation and breakage of a glycosidic bond

In a condensation reaction, two monosaccharides can join with a glycosidic bonds to form a disaccharide. A glycosidic bond is a covalent bond formed between two monosaccharides. Similarly, hundreds to thousands of monosaccharides joined by glycosidic bonds form polysaccharides.

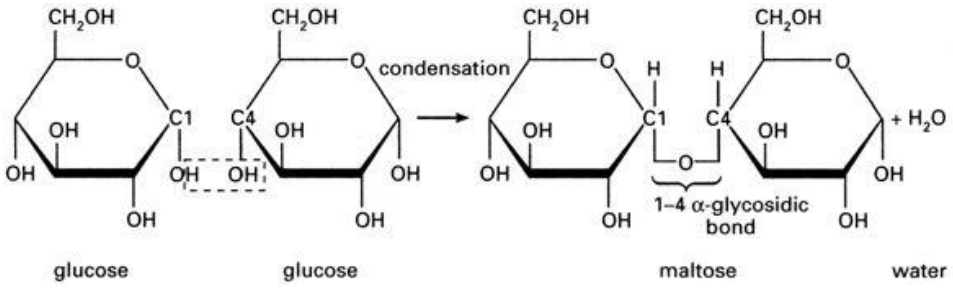


Figure 3.8 Condensation reaction in the synthesis of maltose.
The bonding of two glucose units forms maltose.

In hydrolysis, starch (both amylose and the straight chain sections of amylopectin) is hydrolysed into maltose (a disaccharide composed of 2 glucose units linked by 1 alpha 4 glycosidic bonds) by adding -H and -OH from water across the glycosidic bonds. The reaction is catalysed by enzyme amylase.

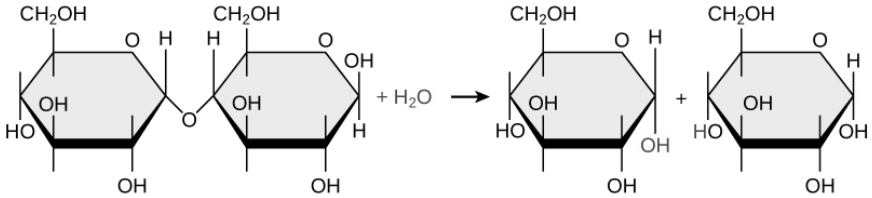


Figure 3.9 Hydrolytic reaction in the digestion of one molecule of maltose into two molecules of glucose.
The reaction is catalysed by enzyme maltase.

The enzymes that digest starch by hydrolysing its linkages cannot hydrolyse the linkages in cellulose. Cellulose in human food passes through the digestive tract and is eliminated in faeces as "insoluble fibre". As it moves through the digestive tract, cellulose abrades the intestinal walls and stimulates the secretion of mucus, which aids in the passage of food.

Some microbes can digest cellulose to glucose through the use of enzymes known as cellulase. Many eukaryotic herbivores, from cows to termites, have symbiotic relationships with cellulose-digesting prokaryotes, providing the prokaryote and the host animal access to a rich source of energy. Some fungi can also digest cellulose.

Another important structural polysaccharide is chitin. Chitin provides structural support for the cell walls of many fungi. It is also found in the exoskeletons of arthropods (including insects, spiders, and crustaceans). Chitin is similar to cellulose, except that it has a nitrogen-containing appendage on each glucose monomer. Pure chitin is leathery but can be hardened by the addition of calcium carbonate.

3.2 FATS (LIPIDS)

a) Fats (Lipids) are made up of the elements **Carbon** (C), **Hydrogen** (H) and **Oxygen** (O). Unlike carbohydrates, fats have NO general formula, and they contain **much less oxygen in proportion to hydrogen**. (ratio of H:O not 2:1)

b) Fats consist of mostly hydrocarbons which form nonpolar covalent bonds. Hence they have little or no affinity for water.

c) A fat molecule is formed from two kinds of smaller molecules: **glycerol** and **fatty acids**. In a fat molecule, **three fatty acids** are joined to **one glycerol** by an ester linkage, forming a triglyceride (see Figure 3.10).

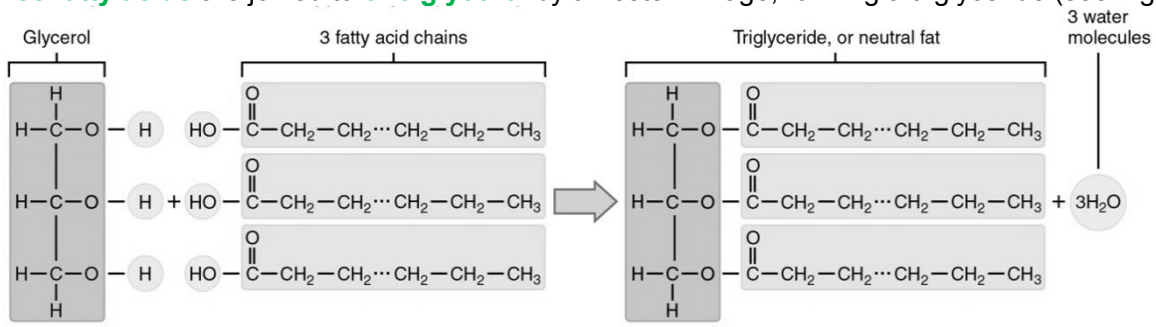


Figure 3.10 Condensation reaction of a triglyceride

d) Fatty acids vary in length (number of carbons) and in the number and locations of double bonds (see Figure 3.11). If the fatty acid has no carbon-carbon double bonds, then the molecule is a saturated fatty acid. Fats made from saturated fatty acids are "**saturated fats**". If the fatty acid has one or more carbon-carbon double bonds formed by the removal of hydrogen atoms from the carbon skeleton, then the molecule is an unsaturated fatty acid. A saturated fatty acid is a straight chain, but an unsaturated fatty acid has a kink wherever there is a *cis* double bond. Fats made from unsaturated fatty acids are "**unsaturated fats**".

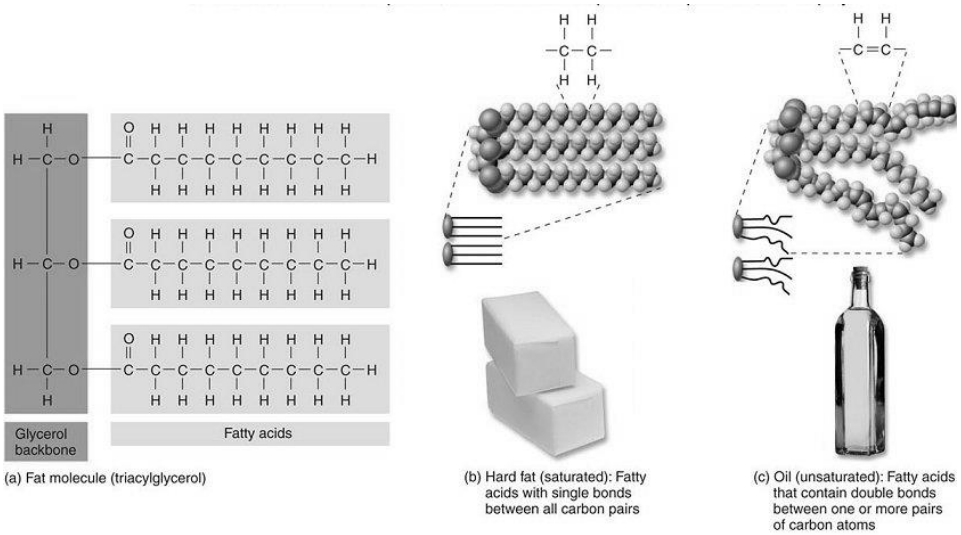


Figure 3.11 Comparison of saturated and unsaturated fats
Source: Campbell Biology

Most animal fats are saturated. Saturated fats are solid at room temperature. Plant and fish fats are liquid at room temperature and are known as oils. The kinks caused by the *cis* double bonds prevent the molecules from packing tightly enough to solidify at room temperature.

A diet rich in saturated fats may contribute to cardiovascular disease (atherosclerosis) through plaque deposits.

e) Functions of fats include:

- Storage of **energy**
  A gram of fat stores more than twice as much energy as a gram of a polysaccharide. Plants use oils when dispersal and compact storage are important, such as in seeds. Animals carry energy stores with them, so they benefit from having a more compact fuel reservoir of fat. Humans and other mammals store fats as long-term energy reserves in **adipose cells** that swell and shrink as fat is deposited and withdrawn from storage.

- Adipose tissue also functions to **cushion vital organs**, such as the kidneys

- A layer of fat can function as **insulation**. This subcutaneous layer is especially thick in whales and most other marine mammals.
- **Phospholipids** are major components of **cell membranes**.
- **Steroids** include cholesterol and certain sex hormones.

3.3 PROTEINS

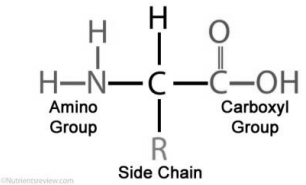
a) Proteins are made up of the elements **Carbon** (C), **Hydrogen** (H), **Oxygen** (O), **Nitrogen** (N) and in some instance, **Sulfur** (S).

b) The basic unit of protein is an **amino acid**. There are 20 naturally occurring amino acids. Short-chain proteins are known as **polypeptides**. Amino acids are joined together by **peptide bonds**.

Extension

DESCRIBE the general structure of an amino acid

- Amino acids are organic molecules with both carboxyl and amino groups. At the centre of an amino acid is a carbon atom. Four components are attached to the carbon:
  - a **hydrogen atom**
  - a **carboxyl group**
  - an **amino group**, and
  - an **R side chain**.



- Different R side chains characterise the 20 different amino acids.
  An R group may be as simple as a hydrogen atom (as in the amino acid glycine), or it may be a carbon skeleton with various functional groups attached (see Figure 3.12).

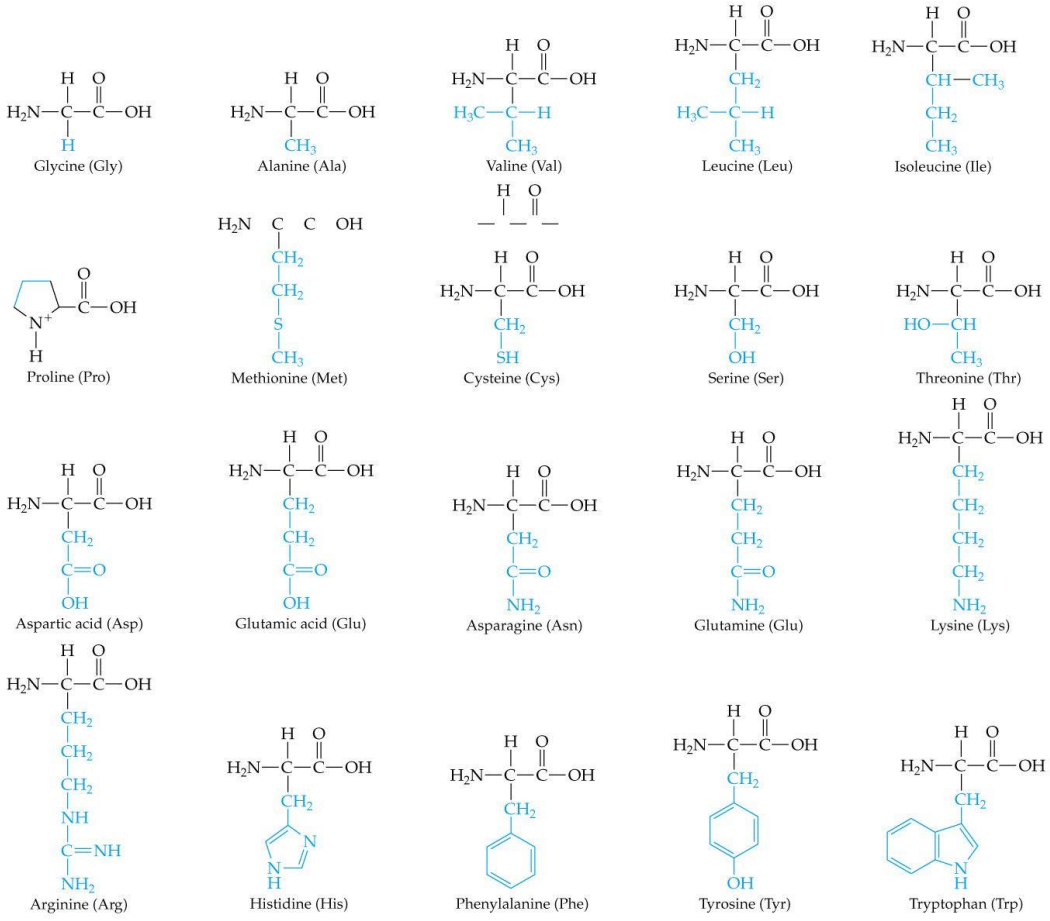


Figure 3.12 20 naturally occurring amino acids
Source: www.biology-online.org

DESCRIBE the formation and breakage of a peptide bond

Amino acids are joined together in a condensation reaction where a hydroxyl group is removed from the carboxyl end of one amino acid, and a hydrogen atom is removed from the amino group of another amino acid (see Figure 3.13). The resulting covalent bond is called a **peptide bond** (CO-NH).

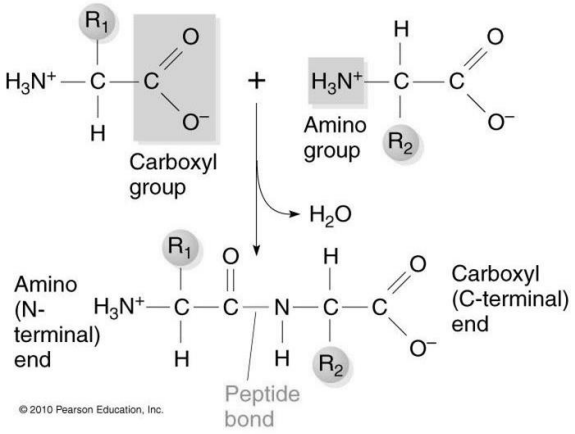


Figure 3.13 Formation of a peptide bond
Source: Pearson Education

Proteins and polypeptides are hydrolysed when the C-N bond is cleaved in a reaction catalyzed by an enzyme.

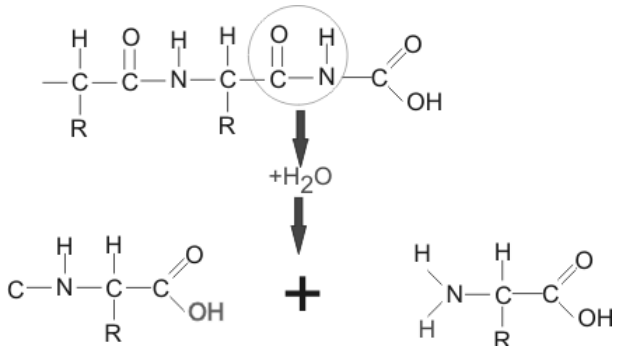


Figure 3.14 Hydrolysis of a polypeptide
Source: https://www.boundless.com/

c) Functions of proteins include
- Synthesis of new protoplasm, for growth and repair of worn out parts of the body
- Synthesis of **enzymes** and some **hormones**
- Formation of **haemoglobin** that binds oxygen
- Formation of **antibodies**, to defend against foreign substances
- Formation of support structures – e.g. silk fibres, spider webs, collagen, keratin of hair
- Formation of storage structures – e.g. ovalbumin in egg, casein in milk
- Membrane proteins that move molecules across the phospholipid bilayer

Extension

DESCRIBE briefly the primary, secondary, tertiary, quaternary structure of protein

- Proteins have four level of organization: **primary**, **secondary**, **tertiary**, and **quaternary** (see Figure 3.15).

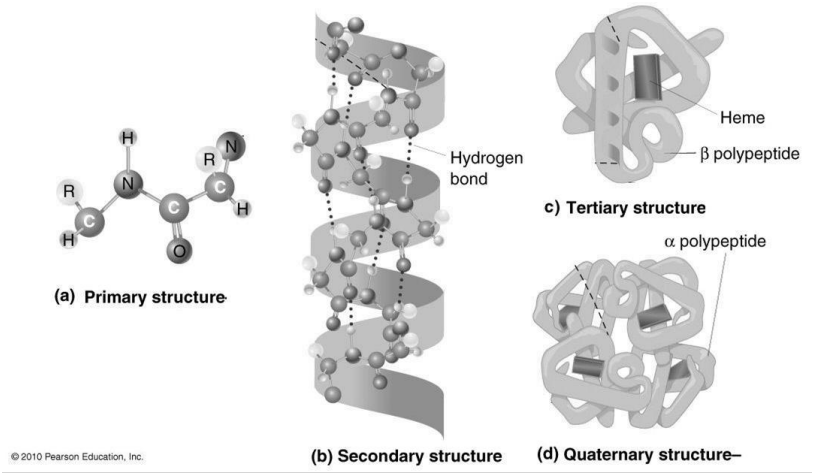


Figure 3.15 Four levels of protein structures
Source: Pearson Education

Primary Structures
- Unique sequence of amino acids in the polypeptide chain e.g. Phe-Ala-Met-Leu-Gln-Trp-Glu-Ile
- The sequence is determined by inherited genetic information, not by the random linking of amino acids. A slight change in the primary structure can affect a protein's function, e.g. substitution of one amino acid (valine) for the normal one (glutamic acid) in the primary structure of haemoglobin, can cause sickle-cell disease, an inherited blood disorder.

Secondary Structures
- Coils and folds in the polypeptide chain that give rise to 2-dimensional structures
- Due to hydrogen binding between hydrogen of amine groups and oxygen of the carbonyl groups
- Two common secondary structures are the α-helix (e.g. keratin, structural protein of hair) and the β-pleated sheet (e.g. silk protein).

DESCRIBE the types of bonding (hydrogen, ionic, disulfide and hydrophobic interactions) which hold molecule in shape

Tertiary Structures
- Overall shape of polypeptide results from the interactions between the R side chains. There are four types of bonding interactions between the R side chains (see Figure 3.16):
  - hydrogen bonds
  - ionic bonds
  - hydrophobic interactions and van der Waals interactions
  - disulfide bridges
- Include fibrous protein (e.g. cytoskeleton) and globular proteins (e.g. enzymes)

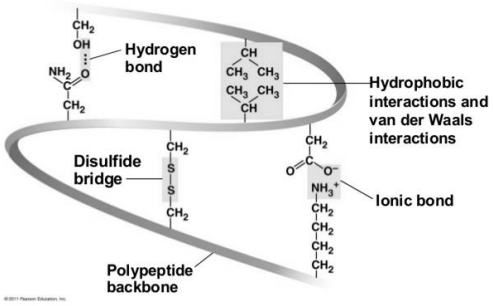


Figure 3.16 Four types of bonding interactions in tertiary protein structures
Source: Pearson Education

Quaternary structure
- Aggregation of two or more polypeptide subunits into functional proteins.
- Haemoglobin is a globular protein with quaternary structure. Haemoglobin consists of four polypeptide subunits (see Figure 3.17).

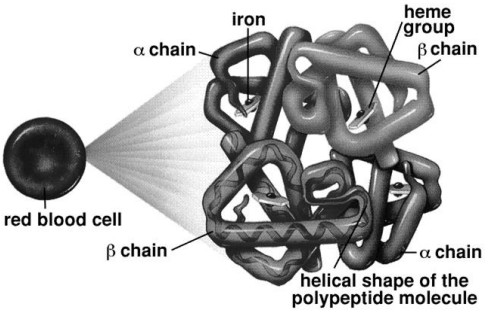


Figure 3.17 Structure of a haemoglobin molecule
Source: McGraw-Hill

COMPARE and CONTRAST the structure of enzymes (globular protein) and structural proteins like collagen as an e.g. of fibrous proteins and relate these structures to their functions.

Table 3.2 Comparison between fibrous proteins and globular proteins

Fibrous proteins	Globular proteins
long, elongated, thread-like and asymmetric in shape (parallel polypeptide chains)	folded into spherical, oval or elliptical shapes

little or no tertiary structure (cross linkages at intervals forming long fibres or sheets)	complex tertiary and sometimes quaternary structures
peptide chains are held together by strong intermolecular hydrogen bonds	peptide chains are held together by relatively weak intramolecular hydrogen bonds
insoluble in water (but soluble in concentrated acids and alkalis)	soluble in water (as hydrophobic side chains are in the centre of structure)
structural roles	roles in metabolic reactions
e.g. keratin, collagen	e.g. enzymes, insulin, haemoglobin, antibodies

DESCRIBE and carry out tests for starch (iodine in potassium iodide solution; Benedict's solution; protein (biuret test); fats (ethanol emulsion)

3.4 NUCLEIC ACIDS

a) Nucleic acids are made up of the elements **Carbon** (C), **Hydrogen** (H), **Oxygen** (O), **Nitrogen** (N) and **Phosphorus** (P).

b) Nucleic acids are the genetic materials on which the **genetic information** of all living organisms are **encoded**.

c) Nucleic acids belong to a class of biological molecules. Other classes include proteins, lipids and carbohydrates.

d) **Nucleic acids** (polymer) consist of **nucleotides** (monomer).

- **All** nucleotides consist of a
  1) **pentose sugar**
  2) **nitrogenous base**
  3) **phosphate group**

e) Two types of nucleic acids exist in **eukaryotic** & **prokaryotic** cells as well as in **viruses**:
1) Deoxyribonucleic acid (DNA)
2) Ribonucleic acid (RNA)

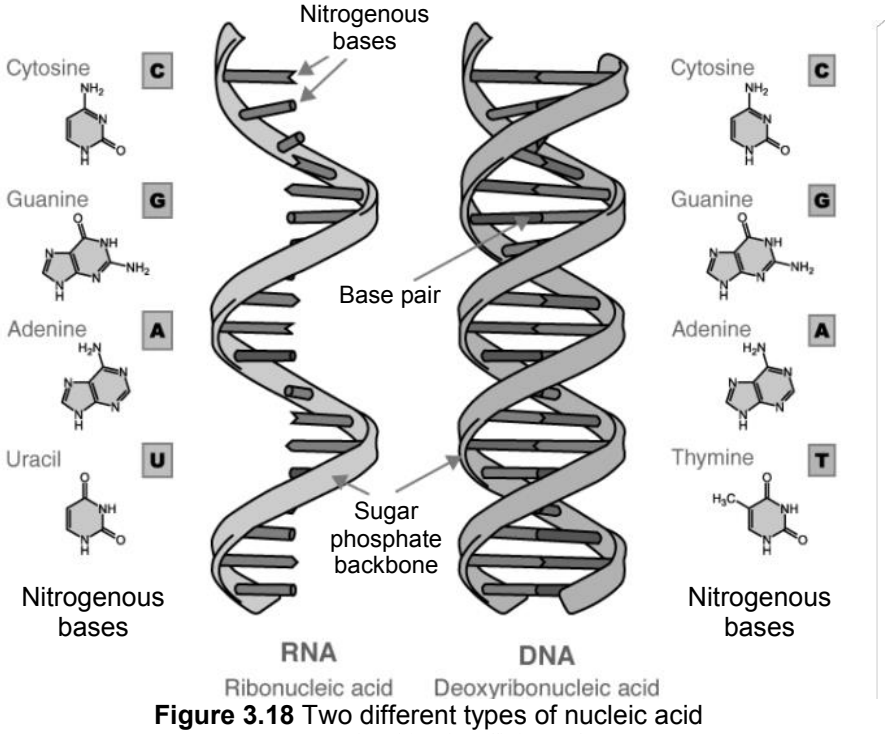


Figure 3.18 Two different types of nucleic acid
Source: Adapted from https://byjus.com/

4 FOOD TESTS

The four main types of food tests available in a secondary school laboratory, include **Iodine Test** for Starch, **Benedict's Test** for Reducing Sugars, **Biuret Test** for Protein and **Ethanol Emulsion Test** for Fats.

Preparation of Food Sample for Testing
If the food pieces are solid, cut them into small pieces and divide each chopped food sample into four portions respectively.

4.1 IODINE TEST

Test for Starch

For solid sample

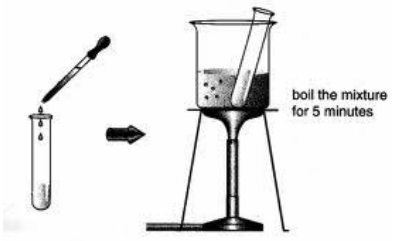
1. Place 1 cm^3 of the crushed/chopped food pieces on a white tile.
2. Place **two drops of iodine solution** (or potassium iodide solution) onto the chopped food pieces.
3. Observe and record changes in the colour of the iodine solution.
4. Observations are recorded as follows:
   (+) "solution turned from brown to **blue black** / specimen was stained **blue-black**"
   (–) "solution remained **brown** / specimen was stained **brown**"

For liquid sample

1. To 1 cm^3 of sample solution, add **two drops of iodine solution** (or potassium iodide solution).
2. Observe and record changes in the colour of the iodine solution.
3. Observations are recorded as follows:
   (+) "solution turned from brown to **blue black** / specimen was stained **blue-black**"
   (–) "solution remained **brown** / specimen was stained **brown**"

4.2 BENEDICT'S TEST

Test for Reducing Sugar



For solid sample

1. Place 1 cm^3 of the crushed/chopped food pieces into a clean test tube and label the tube appropriately.
2. Add 2 cm^3 of water to the tube to dissolve the reducing sugar in the sample. Decant (Allow the mixture to settle, pour the liquid part of the mixture into another dry test tube).
3. Add in 2 cm^3 of **Benedict's Solution** to the solution containing the nutrient. Shake thoroughly to mix.
4. Place tube in **boiling** water bath for 2–3 minutes.
5. After **2–3 minutes**, remove tubes from the water bath.
6. Observe and record **changes in the colour** of the mixture, if any.
7. Observations are recorded as follows:
   (+) "solution turned from blue to **green** / **yellow** / **orange** / **brick-red** with **precipitate** (with precipitate compulsory for orange and red)"
   (–) "solution remained blue"

For liquid sample

1. To 2 cm^3 of sample solution, add 2 cm^3 of **Benedict's Solution**. Shake thoroughly to mix.
2. Place tube in **boiling** water bath for 2–3 minutes.
3. After **2–3 minutes**, remove tubes from the water bath.
4. Observe and record **changes in the colour** of the mixture, if any.
5. Observations are recorded as follows:
   (+) "solution turned from blue to **green** / **yellow** / **orange** / **brick-red** with **precipitate** (with precipitate compulsory for orange and red)"
   (–) "solution remained blue"

Test for Non-Reducing Sugar

1. Test the sample for reducing sugars.
2. If reducing sugar is absent, use a fresh sample solution, heat 2 cm^3 of the sample solution with **dilute hydrochloric acid** for a few minutes (to hydrolyse the glycosidic bonds). Neutralise **with sodium hydrogen carbonate**.
4. Perform the Benedict's Test for Reducing Sugar.

4.3 BIURET TEST

Test for Proteins

For solid sample

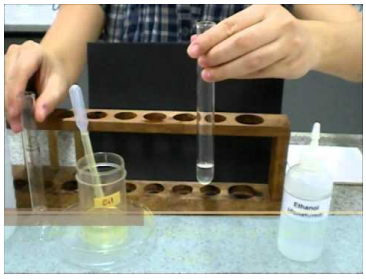
1. Place 1 cm^3 of the crushed/chopped food pieces into a clean test tube and label the tube appropriately.
2. Add 2 cm^3 of water to the tube to the chopped sample. Shake thoroughly to mix. Decant.
3. Add in equal volume **sodium hydroxide solution** to the solution containing the nutrient. Shake thoroughly to mix.
4. Add in 1% **copper sulfate solution** drop by drop. Shake the test-tube after adding each drop.
5. Observe and record any colour changes, if any.
6. Observations are recorded as follows:
   (+) "solution turned from blue to **violet**"
   (–) "solution remained blue"

For liquid sample

1. To 2 cm^3 of sample solution, add 2 cm^3 of **sodium hydroxide solution**. Shake thoroughly to mix.
2. Add in 1% **copper sulfate solution** drop by drop. Shake the test-tube after adding each drop.
3. Observe and record any colour changes, if any.
4. Observations are recorded as follows:
   (+) "solution turned from blue to **violet**"
   (–) "solution remained blue"

4.4 ETHANOL EMULSION TEST

Test for Fats



For solid sample

1. Place 1 cm^3 of chopped food pieces into a clean and dry test tube and label the tube appropriately.
2. Add 3 cm^3 of ethanol into the chopped food mixture.
3. Shake thoroughly to mix.
4. Record changes in the solution.
5. **Decant 1 cm^3 of the mixture** into another test tube.
6. Add the **equal volume of water** to the liquid portion. Observe and record formation of white emulsion, if any.

For liquid sample

1. To some drops of oil, add **1 cm^3 of ethanol**
2. Shake thoroughly to mix.
3. Add the **1 cm^3 of water** to the liquid portion. Observe and record formation of white emulsion, if any.

Results must be recorded in a suitable format

- The format in which food tests results are presented, is in the form of a **table** (should be **ruled** and **lines** must be clean).
- When samples containing unknown nutrients are tested, the results may be tabulated in the format shown below. Independent variable (i.e. food sample) is placed in the leftmost column of the table and dependent variable on the right.

Table 3.3 Tabulation of food tests results

sample	observations				deduction
	reducing sugar	protein	starch	fat	
A	Solution turned from blue to brick-red precipitate	Solution remained blue	Solution stained blue-black	White emulsion formed	Reducing sugar, starch & fats present Proteins absent
B					
C					

- Observations recorded must include **colour** of solution. DO NOT RECORD "the solution remains the same" or "no changes is seen".
- The recording language for 'Deduction' is "___ present, ___ absent". An example (Sample A) is presented in the table.

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 04 – Biological Molecules – Enzymes

Name: **Class:**

A. Content

- Mode of Enzyme Action
- Factors that Affect Enzyme Reaction

B. Learning Outcomes

Students should be able to:
(a) explain enzyme action in terms of the 'lock and key' hypothesis.
(b) investigate and explain the effects of temperature, pH on the rate of enzyme catalysed reactions.
(c) explain the mode of action of enzymes in terms of an active site, enzyme/substrate complex, lowering of activation energy and enzyme specificity.
(d) follow the time course of an enzyme-catalysed reaction by measuring rates of formation of products (e.g. using catalase) or rate of disappearance of substrate (e.g. using amylase).
(e) investigate and explain the effects of temperature, pH, enzyme concentration and substrate concentration on the rate of enzyme catalysed reactions, and explain these effects.
Use the knowledge gained in this section in new situations or to solve related problems.

C. References

1. Lam PK, Lam EYK. 2013. Biology Matters. 2nd ed. Singapore: Marshall Cavendish.
2. Campbell NA, Reece JB. 2008. Biology. 7th ed. San Francisco: Pearson Education.

D. Lecture Outline

1. Introduction
2. Mode of Actions of Enzyme
   - 2.1 Activation Energy
   - 2.2 Substrates, Formation of Enzyme-substrate Complex & Products
   - 2.3 Specificity of Enzymes & Active Sites
   - 2.4 Lock and Key Hypothesis
3. Experiments that investigate the rate of Enzyme Activity
   - 3.1 Investigating the rate of enzyme reactions using amylase
   - 3.2 Investigating the rate of enzyme reactions using catalase
4. Factors affecting the rate of Enzyme Reactions
   - 4.1 Effect of temperature on the rate of enzyme reaction
   - 4.2 Effect of pH on the rate of enzyme reaction
   - 4.3 Effect of concentration of substrate on the rate of enzyme reaction
   - 4.4 Effect of concentration of enzyme on the rate of reaction
   - 4.5 Factors limiting rate of enzyme reactions

E. Practical Work

- Effect of enzyme concentration on action of amylase on starch
- Immobilised enzymes
- Use of enzymes in fruit juice extraction

1 INTRODUCTION

Metabolism is the sum of all chemical reactions within the body of an organism.

METABOLISM = CATABOLISM (catabolic pathways) + ANABOLISM (anabolic pathways)

Catabolic pathways release energy by breaking down complex molecules to simpler compounds. An example of catabolism is cellular respiration, in which glucose is broken down in the presence of oxygen to carbon dioxide and water. The energy released by catabolic pathways can then do the work of the cell, such as active transport of substances across the membrane, and the contraction of skeletal muscle cells.

Anabolic pathways use energy to build larger complex molecules from smaller simpler ones. An example of anabolism is the synthesis of protein from amino acids.

A metabolic pathway begins with a specific molecule, which is then altered in a series of reactions to form a specific product. A specific **enzyme** catalyzes each step of the pathway.

Explain the mode of action of enzymes in terms of an active site, enzyme/substrate complex, lowering of activation energy and enzyme specificity.

2 MODE OF ACTION OF ENZYMES

- Enzymes are **biological catalysts** that alter the rate of chemical reactions without themselves being chemically changed at the end of the reaction. Most enzymes are protein in nature.
- Enzymes increase the rate of chemical reactions by **lowering the activation energy** required for the reactions. For this reason, enzymes are known as **biological catalysts**. Enzymes work both within (e.g. respiration, photosynthesis) and outside (e.g. digestion) the living cells.

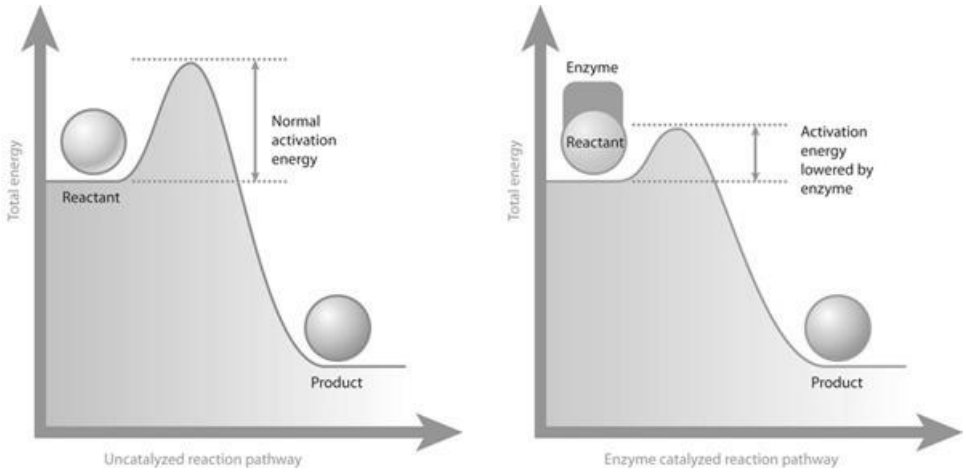


Figure 4.1 Enzyme lowers activation energy of biochemical reactions and increase rate of reaction.
Source: Nature Education (2010)

2.1 Activation Energy

Every chemical reaction between molecules involves the breaking and forming of bonds. Hence, energy needs to be invested first to strain and break existing bonds before new bonds can be formed. During breaking of existing bonds, energy is absorbed and the molecules reach an unstable condition, known as the transition state. The amount of energy that is required to bring the reactant molecules to its transition state is called the **activation energy**, E_A. After the formation of the transition state, new bonds can then be formed (as illustrated by the "downhill" part of the diagram in Figure 4.1).

For some chemical reactions, the E_A could be so low that heat energy from room temperature will be sufficient for the molecules to reach the transition state. However, in many cases, the E_A is so high that it is not possible for reactions to proceed at all unless the molecules are heated. Heating in biological systems would be inappropriate as it would denature proteins and kill cells. Thus, enzymes are required.

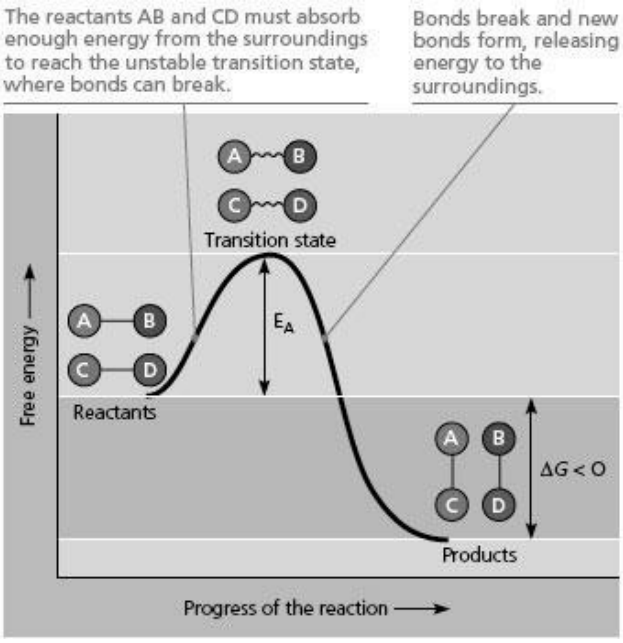


Figure 4.2 Activation energy is the amount of energy necessary to push the reactants over an energy barrier so that the "downhill" part of the reaction can begin

Source: Campbell & Reece (2004)

2.2 Lock and Key Hypothesis

The reactant that an enzyme acts on is the **substrate**. The reaction catalysed by each enzyme is very **specific**. The enzyme **binds** to a substrate(s), with a **complementary** shape that can fit into the active site of the enzyme molecule, to form an **enzyme-substrate complex**. While the enzyme and substrate are bound, the catalytic action of the enzyme converts the substrate to the **product(s)** (see Figure 4.3).

This is known as the **Lock and Key Hypothesis**. In the analogy, the enzyme is the lock and the substrate is the key.

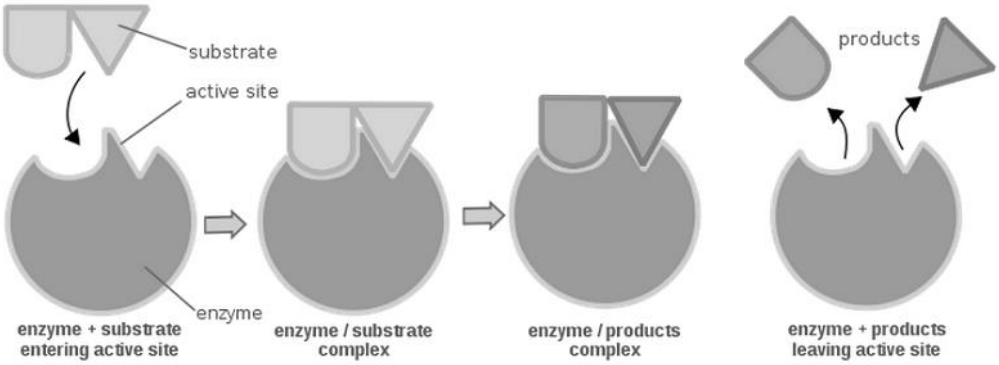


Figure 4.3 Lock and Key Hypothesis. Substrate(s) binds to the active site of the enzyme, forming an enzyme-substrate complex. At the end of the reaction, the product(s) is released from the active site.

Source: biology-igcse.weebly.com

2.3 Specificity of Enzymes & Active Sites

The specificity of an enzyme results from its **three-dimensional shape**, which is a consequence of its amino acid sequence. Only a restricted region of the enzyme – the **active site** – binds with the substrate.

The active site of an enzyme is typically a groove on the surface of the protein where catalysis occurs. The specificity of an enzyme is due to the fit between the active site and the substrate.

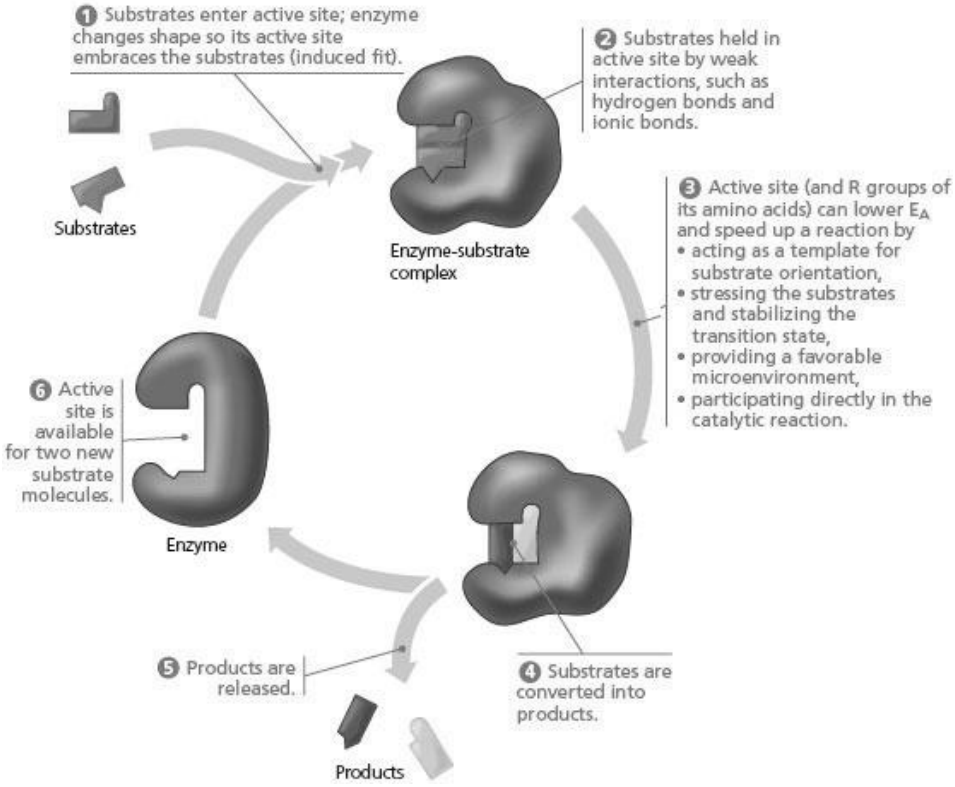
- A very small amount of enzyme molecules can effect the change of a large amount of substrate molecules.
- Enzymes are unaffected by the reaction and are reusable.

Extension

Explain enzyme action in terms of 'induced-fit' hypothesis

"How do enzymes actually work?"

Besides, the Lock and Key Hypothesis, the mode of action of enzymes can also be explained using Koshland's "Induced Fit" hypothesis (see below diagram).



In the "Induced-Fit" hypothesis, the mode of action of enzymes is described as follows:

- Enzymes have **flexible** active sites, initially almost matching the shape of their substrates.
- When the substrate(s) come into contact with the active site of the enzyme, the shape of the active site alters, inducing a **tighter** fit between them.
- This puts strain on the bonds of the substrates. At this point, the bound substrates are in the transition state.
- Following the reaction, the products are released, and the enzyme returns to its resting shape and can bind another substrate.

Follow the time course of an enzyme-catalysed reaction by measuring rates of formation of products (e.g. using catalase) or rate of disappearance of substrate (e.g. using amylase)

3 EXPERIMENTS THAT INVESTIGATE THE RATE OF ENZYME ACTIVITY

Enzyme-controlled reactions may be investigated by the following methods:

I. By measuring the rate of formation of the **products**, for example, with the use of catalase and hydrogen peroxide

II. By measuring the rate of disappearance of the **substrate**, for example, with the use of amylase and starch

3.1 Investigating the rate of enzyme reactions using amylase

- Amylase is an enzyme hydrolyses **starch** to the disaccharide **maltose**. Amylase is abundant in the saliva of human and in plant tissues like seeds. Stored starch in seeds is hydrolysed to maltose during germination.

- Iodine can be used to monitor the hydrolysis of starch into sugar. In the presence of starch, iodine turns blue-black and in the absence of starch, iodine remains brown.

- In the procedure of a typical experiment to investigate the effect of temperature on the rate of hydrolysis of starch using amylase:

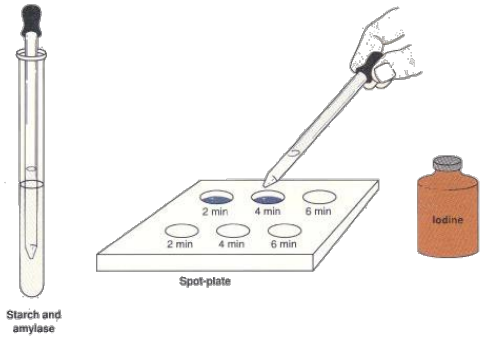
  i. Test tubes containing 5 cm^3 of starch suspension were incubated in a water bath at the appropriate temperature for 5 minutes. 1 cm^3 of amylase solution was also placed in each water bath in a separate test tube.

  ii. Three **controls** – one positive control and two negative controls – are set up as shown in Table 4.1. A **positive control** receives a treatment (or condition) with a known result. The result is usually what is expected from the treatment, so it provides us with a source of comparison. The **negative controls** do not receive the treatment (or condition) that will produce a result consistent with the positive control. If both the negative controls produce a positive result, it can be inferred that a confounding variable acted on the experiment.

Table 4.1

test-tube	1 (positive control)	2 (negative control)	3 (negative control)
contents	5 cm^3 of starch suspension + 1 cm^3 of amylase solution	5 cm^3 of distilled water + 1 cm^3 of amylase solution	5 cm^3 of starch suspension + 1 cm^3 of distilled water or boiled amylase solution
observations			

  iii. After 5 minutes, when the starch suspension and amylase solution had reached the temperature at which we were working, they were mixed together and a stopwatch started. The tube containing the reaction mixture was then kept in the water bath at the appropriate temperature.



  iv. Every 2 minutes, a few drops of the reaction mixture were added to iodine on a spotting tile to test for the presence of starch.

  v. As amylase digests starch, less and less starch will be present and the blue-black colouration will become lighter. When the iodine solution remains brown (i.e. no change of colour), starch is completely digested. The time was recorded.

  vi. The results of the experiment are presented in the form of a table and plotted on a graph.

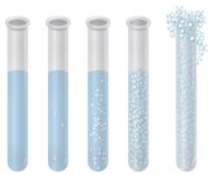
3.2 Investigating the rate of enzyme reactions using catalase

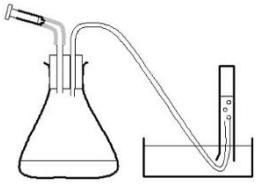
- Hydrogen peroxide (H_2O_2) is a by-product of respiration in all living cells. As H_2O_2 is harmful, cells produce the enzyme catalase to break down H_2O_2. Persons with acatalasemia (a hereditary condition) have extremely low catalase activity and, although present worldwide, it is more commonly found in Koreans.

$$2\ H_2O_2 \xrightarrow{\text{catalase}} 2\ H_2O + 2O_2$$

- The rate of oxygen production can be observed by three ways:

- measuring the height of the froth in a test tube per unit time
- counting the number of oxygen bubbles produced per unit time
- measuring the volume of oxygen gas collected in the measuring cylinder per unit time





- In the one possible procedure of an experiment to investigate the rate of decomposition of hydrogen peroxide using catalase:

i. Use the large syringe to measure 5 cubes of potato tissue (measuring 1 cm^3) into the conical flask. Place the bung securely in the flask. Half-fill the trough with water. Fill the 50 cm^3 measuring cylinder with water. Invert it over the trough of water, with the open end under the surface of the water in the bowl and with the end of the rubber tubing in the measuring cylinder.

ii. Measure 2 cm^3 of hydrogen peroxide with the syringe. Put the syringe in place in the bung of the flask but do not push the plunger straight away. Push the plunger on the syringe and immediately start the stopwatch.

iii. After 30 s, record the volume of oxygen in the measuring cylinder in a suitable table.

iv. Empty and rinse the conical flask. Add another 5 cubes of potato into the flask. Reassemble the apparatus, refill the measuring cylinder, and repeat from part ii to iii.

v. Calculate the rate of oxygen production in cm^3 per unit time. Plot a graph of rate of oxygen production against the concentration of catalase.

Investigate and explain the effects of temperature, pH, enzyme concentration and substrate concentration on the rate of enzyme catalysed reactions, and explain these effects

4 FACTORS AFFECTING THE RATE OF ENZYME REACTIONS

4.1 Effect of temperature on the rate of enzyme reaction

- At low temperatures, enzyme is **inactive** or the activity is **slow**. As the temperature rises, the rate of enzyme activity increases until an **optimum temperature** is reached.

- As temperature increases, molecules gain **kinetic energy** and move more rapidly, increasing the **frequency of collisions** between substrates and active sites. Each enzyme has an optimum temperature that has the maximum rate of reaction.

- Enzymes are usually **twice** as active for every 10 °C increase, until the optimum temperature.

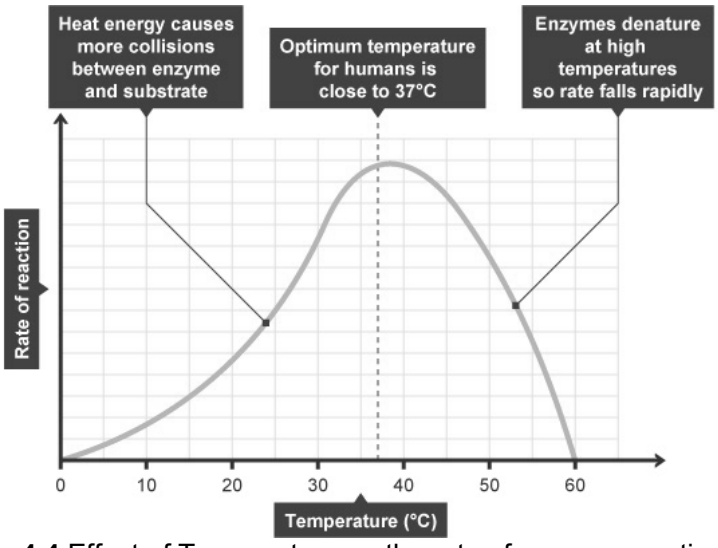


Figure 4.4 Effect of Temperature on the rate of enzyme reactions
Source: BBC (2013)

- Beyond the optimum temperature, the reaction will slow down and eventually stops. At high temperature, the weak bonds that hold protein conformation breaks and the enzyme is **denatured** (NOT killed / destroyed / died). Unlike inactivation of enzymes, denaturation is irreversible.

- Different enzymes have their own optimum temperature. Most human enzymes have optimum temperatures of about 35 – 40 °C. The thermophilic bacteria that live in hot springs contain enzymes with optimum temperatures of 70 °C or higher.

4.2 Effect of pH on the rate of enzyme reaction

- Each enzyme also has an **optimum pH**. Maintenance of the active conformation of the enzyme requires a particular pH.

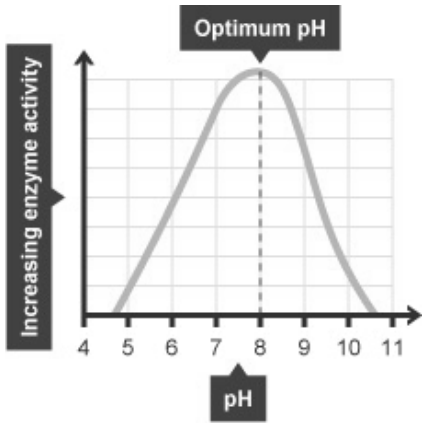


Figure 4.5 Effect of pH on the rate of enzyme reactions
Source: BBC (2013)

- The optimum pH falls between 6 and 8 (neutral conditions) for most enzymes. Solutions that are more acidic or alkaline will slow the enzyme reaction down. At extremes of pH, the enzymes will **denature**.

- However, digestive enzymes in the stomach are designed to work best at pH 2, whereas those in the intestine have an optimum pH of 8.

4.3 Effect of concentration of substrate on the rate of enzyme reaction

- The rate at which a specific number of enzymes catalyses the conversion of substrates to products depends in part on substrate concentrations (see Figure 4.6).

- At low substrate concentrations, an increase in the concentration of substrate will increase the rate of binding to available active sites. However there is a limit to how fast a reaction can occur.

- At high substrate concentrations, the active sites on all enzymes are **occupied**. The enzyme is **saturated**, and the rate of the reaction is determined by the rate at which the active site can convert substrate to product. The only way to increase the rate of reaction at this point is to add more enzyme molecules.

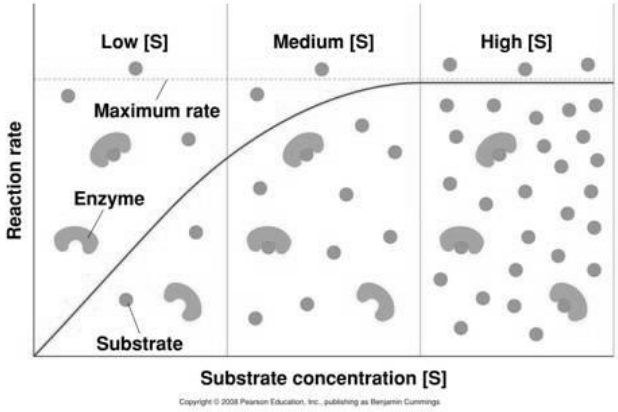


Figure 4.6 Effect of concentration of substrate on the rate of reactions
Source: Pearson Education (2008)

4.4 Effect of concentration of enzyme on the rate of reaction

- The rate of reaction is proportional to the enzyme concentration, provided that the concentration of substrate is high (substrate is in excess) and the temperature and pH are kept constant (see Figure 4.7).

- An increase in enzyme concentration will increase the number of **active sites** available. This will lead to an increase in the formation of **enzyme-substrate complex**.

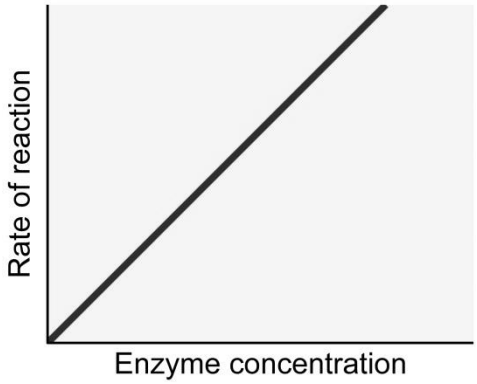


Figure 4.7 Effect of concentration of enzyme on the rate of reaction
Source: http://www.rsc.org/

4.5 Factors limiting rate of enzyme reactions (an example)

With reference to Figure 4.8, describe and explain the effect of substrate and enzyme concentrations on the rate of enzyme reactions.

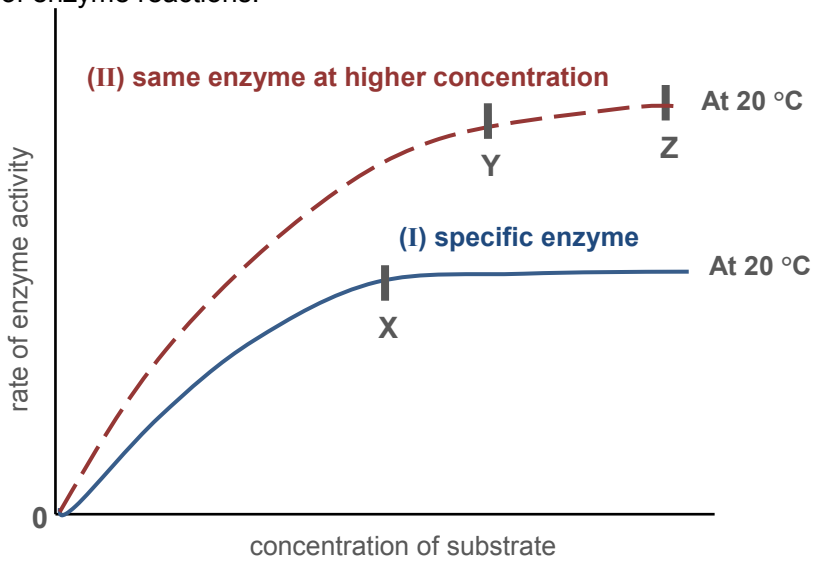


Figure 4.8 Effect of substrate and enzyme concentrations on the rate of reaction

In **graph (I)**,
- as the concentration of substrate increases, the rate of enzyme reaction increases to point X;
- after point X, increasing the concentration of substrate does not increase the rate of enzyme reaction further;
- the rate of enzyme reaction remains constant (plateaus);
- this is because all the active sites of the enzymes are used up (the enzyme molecules are saturated, NOT that reaction stopped);
- the amount of products formed per unit time remains the same;
- the rate of reaction cannot increase further because the concentration of enzyme is the **limiting factor**.

A limiting factor directly affects the rate of a chemical reaction. The rate of reaction will increase if the value of the limiting factor is increased.

In **graph (II)**,

- the concentration enzyme is increased, hence the rate of reaction increases;
- from 0 to Y, the concentration of substrate is the **limiting factor**;
- at Z, the concentration of substrate is no longer the limiting factor;
- the concentration of enzyme has become the limiting factor.

Extension

Understand that many enzymes require non-protein components known as co-factors for efficient activity

COFACTORS

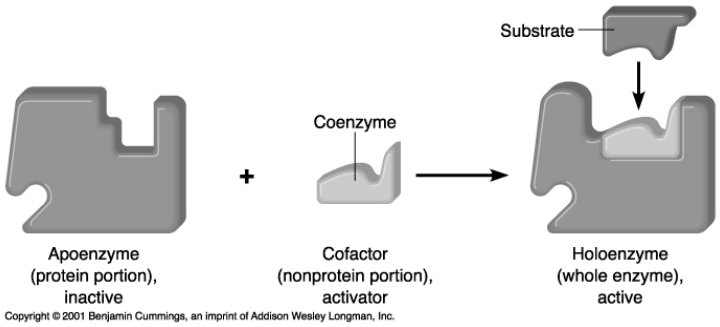


Figure 4.9 Cofactors of enzymes
Source: Benjamin Cummings (2001)

- Many enzymes require non-protein helpers, called cofactors, for activity.
- **Cofactors** bind permanently or reversibly to the enzyme.
- Some inorganic cofactors are zinc, iron, and copper in ionic form. Organic cofactors are called coenzymes. Most vitamins are coenzymes or the raw materials from which coenzymes are made.

INHIBITORS

- Binding by **inhibitors** prevents enzymes from catalysing reactions. Certain chemicals selectively inhibit the action of specific enzymes. If inhibitors attach to the enzyme by covalent bonds, inhibition may be irreversible. If inhibitors bind by weak bonds, inhibition may be reversible. Binding by the inhibitor causes the enzyme to change shape, rendering the active site less effective at catalysing the reaction.

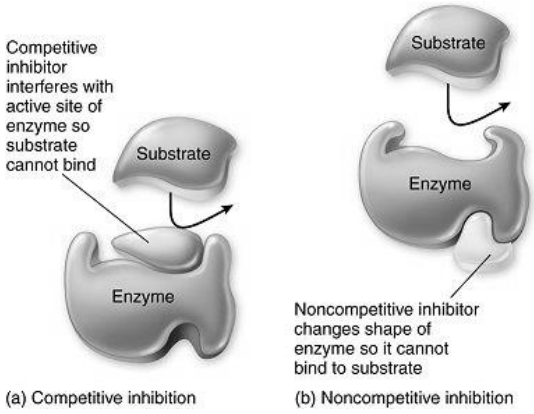


Figure 4.10 Inhibitors of enzymes
Source: Pearson Education (2008)

- Some reversible inhibitors resemble the substrate and compete for binding to the active site. These molecules are called **competitive inhibitors**. Competitive inhibition can be overcome by increasing the concentration of the substrate. **Noncompetitive inhibitors** impede enzymatic reactions by binding to another part of the molecule.

- Toxins and poisons are often irreversible enzyme inhibitors. Examples of them include:
  - Sarin, the nerve gas that was released by terrorists in the Tokyo subway in 1995, binds covalently to the R group on the amino acid serine.
  - DDT acts as a pesticide by inhibiting key enzymes in the nervous system of insects.
  - Many antibiotics are inhibitors of specific enzymes in bacteria (Penicillin blocks the active site of an enzyme that many bacteria use to make their cell walls).

Extension

Immobilized Enzymes

It is possible to attach enzymes to small bead made of **alginate**. Enzymes that have been fixed in this way are called **immobilised enzymes**. Immobilised enzymes are widely used in industry because it allows the reaction to flow continuously and the product will not be contaminated with the enzyme so will not need to be purified.

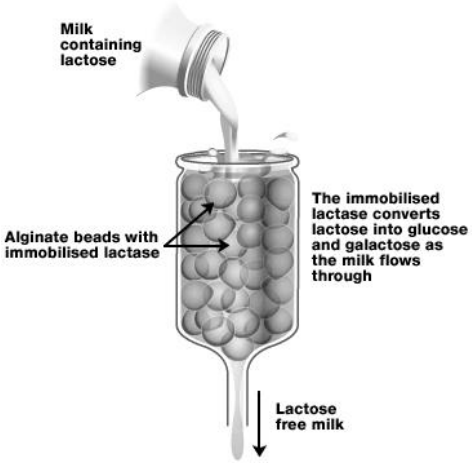


Figure 4.11 Immobilised enzymes are used in the production of lactose free milk for people who are lactose intolerant.

Other examples include:
- pectinase is used to produce and clarify fruit juices
- 'biological' washing powders to speed up the breakdown of proteins in stains like blood and egg
- immobilised sucrase can be used to convert sucrose into the much sweeter glucose and fructose to sweeten low calorie foods
- immobilised enzymes are used in glucose testing strips to measure glucose levels for diabetics

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 05 – Nutrition in Humans

Name: **Class:**

A. Content

- Structures of the Human Alimentary Canal and the Associated Organs
- Processes related to the Digestive System

B. Learning Outcomes

Students should be able to:

(a) Describe the functions of main regions of the alimentary canal and the associated organs: mouth, salivary glands, oesophagus, stomach, duodenum, pancreas, gall bladder, liver, ileum, colon, rectum, anus, in relation to ingestion, digestion, absorption, assimilation and egestion of food, as appropriate.

(b) Describe peristalsis in terms of rhythmic wave-like contractions of the muscles to mix and propel the contents of the alimentary canal.

(c) Describe digestion in the alimentary canal, the functions of a typical amylase, protease and lipase, listing the substrate and end-products.

(d) State the function of the hepatic portal vein as the route taken by most of the food absorbed from the small intestine.

(e) describe the structure of a villus and its role, including the role of capillaries and lacteals in absorption.

(f) describe the role of the liver in
- carbohydrate metabolism
- fat metabolism
- breakdown of red blood cells
- metabolism of amino acids and the formation of urea
- breakdown of alcohol, including the effects of excessive alcohol consumption

Use the knowledge gained in this section in new situations or to solve related problems.

C. References

1. Lam PK, Lam EYK. 2013. Biology Matters. 2nd ed. Singapore: Marshall Cavendish.
2. Campbell NA, Reece JB. 2008. Biology. 7th ed. San Francisco: Pearson Education.

D. Lecture Outline

1. Introduction
2. Nutrition
3. Alimentary Canal & The Accessory Glands
   - 3.1 Mouth & Salivary Glands
   - 3.2 Oesophagus
   - 3.3 Stomach
   - 3.4 Small Intestine & Accessory Organs
   - 3.5 Large Intestine
4. Peristalsis
5. Digestion in the Mouth, Stomach & Duodenum
   - 5.1 Digestion of Carbohydrates
   - 5.2 Digestion of Protein
   - 5.3 Digestion of Fats
6. Absorption in the Small Intestine
   - 6.1 Absorption of amino acids and glucose
   - 6.2 Absorption of glycerol and fatty acids
   - 6.3 Adaptation of the small intestine for absorption
7. Role of the Liver
   - 7.1 Carbohydrate metabolism
   - 7.2 Fat metabolism
   - 7.3 Breakdown of red blood cells
   - 7.4 Metabolism of amino acids and the formation of urea
   - 7.5 Breakdown of alcohol, including the effects of excessive alcohol consumption

E. Practical Work

- Visking tubing (gut model)

1 INTRODUCTION

Humans obtain a source of organic carbon and nitrogen through food. Organic molecules such as glucose are oxidised to release to energy for other cellular and physiological processes. Organic molecules such as amino acids are used to synthesise protein.

There are two main types of nutrition:

Autotrophic Nutrition

An **autotroph** is an organism that can produce its own food using light, water, carbon dioxide, or other chemicals. Most autotrophs carry out photosynthesis to make their food. In photosynthesis, autotrophs use energy from the sun to convert water and carbon dioxide into glucose. Some rare autotrophs produce food through a process called chemosynthesis. Autotrophs that perform chemosynthesis do not use energy from the sun to produce food. Instead, they make food using energy from chemical reactions, often combining hydrogen sulfide or methane with oxygen.

Heterotrophic Nutrition

A heterotroph is unable to produce organic substances from inorganic ones and they depend either directly or indirectly on autotrophs for nutrients and energy.

2 NUTRITION

Nutrition is the intake of food and the processes that convert food substances into living matter. The processes include:

a) Ingestion
Ingestion is the act of feeding and intake of food into the body. Food may be ingested in both liquid and solid forms.

b) Digestion
Digestion is the process of breaking down **large** food molecules into **smaller**, **soluble** and **diffusible** molecules that can be absorbed into the body cells. Food molecules such as starch and proteins are too large to pass through the cell membranes to enter cells. Digestion breaks bonds with the addition of water via enzymatic **hydrolysis**. A specific hydrolytic enzyme catalyses the digestion of each of the macromolecules found in food, for example
- Polysaccharides and disaccharides are digested into simple sugars;
- Fats are digested to glycerol and fatty acids; and
- Proteins are digested into amino acids.

c) Absorption
After digestion, the body cells take up the small molecules from the digestive tract in a process called **absorption**.

d) Assimilation
Some of the absorbed food molecules are converted to new protoplasm or used to provide energy in a process known as **assimilation**, for example
- glucose is oxidised to release energy; and
- amino acids are used to synthesise proteins.

e) Egestion
During **egestion**, also known as defecation, **undigested** material is removed from the body.

Describe the functions of main regions of the alimentary canal and the associated organs: mouth, salivary glands, oesophagus, stomach, duodenum, pancreas, gall bladder, liver, ileum, colon, rectum, anus, in relation to ingestion, digestion, absorption, assimilation and egestion of food, as appropriate.

3 ALIMENTARY CANAL & THE ACCESSORY ORGANS

The human digestive system consists of the alimentary canal and various accessory glands. The structures of the alimentary canal include **mouth**, **buccal cavity**, **oesophagus**, **stomach**, **small intestine** (**duodenum**, **ileum**), **colon**, **rectum** and **anus**. The accessory glands include the **salivary glands**, **pancreas**, **liver** and **gallbladder**. See Figure 5.1.

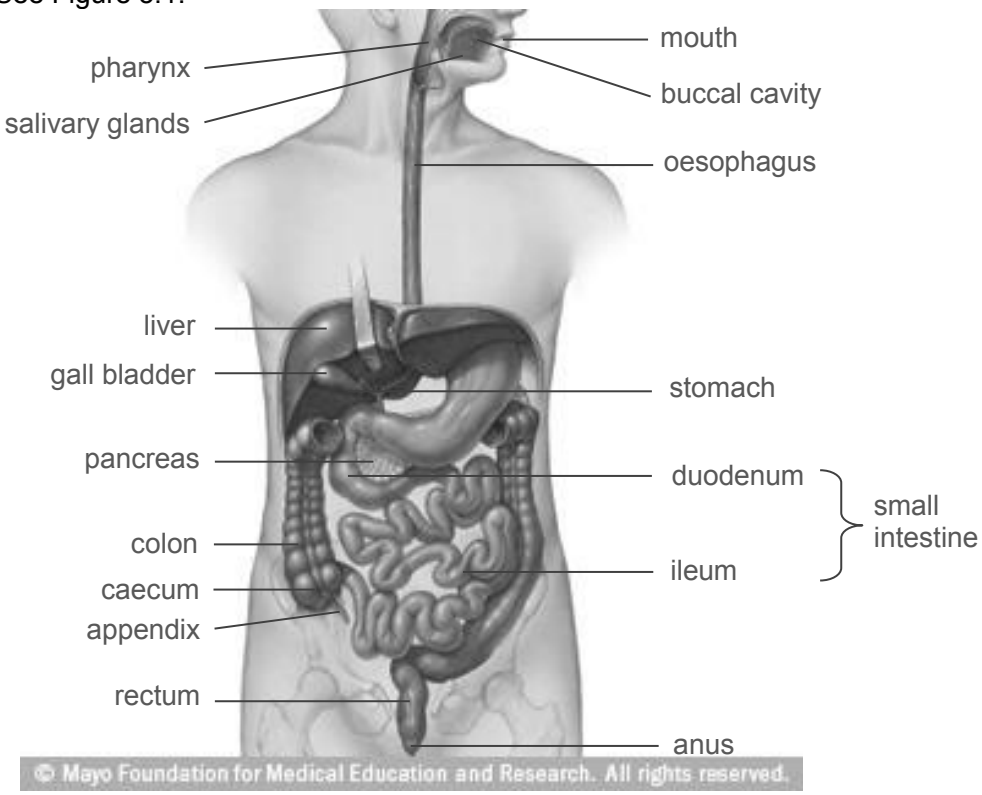


Figure 5.1 The human alimentary canal and the accessory organs

3.1 Mouth, Buccal Cavity & Salivary Glands

Both **physical** (or mechanical) and **chemical** digestion of food begins in the **buccal cavity**. During **chewing**, teeth cut, grind and break down food. Breaking food into smaller pieces increases the surface area exposed to digestive enzymes.

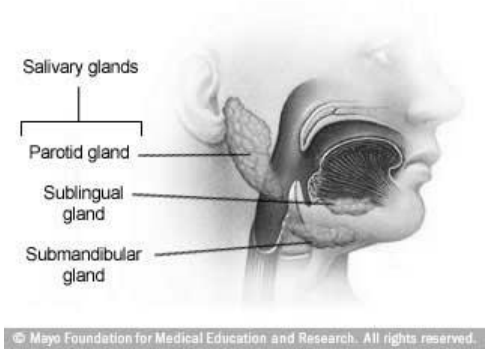


Figure 5.2 The salivary glands

The presence of food triggers a nervous reflex that causes the salivary glands (see Figure 5.2) to secrete saliva through salivary ducts to the buccal cavity. Saliva contains amylase, mucin, buffers and antibacterial agents.

- Salivary **amylase** digests starch into disaccharide maltose. The optimum pH for digestion is about pH 7.
- **Mucin** protects the soft lining of the mouth from abrasion and lubricates the food for easier swallowing.
- **Buffers** help prevent tooth decay by neutralising acid in the mouth.
- **Antibacterial agents** kill bacteria that enter the mouth with food.

The tongue rolls the food into a ball called a **bolus**. During swallowing, the tongue pushes a bolus back into the buccal cavity and pharynx. The pharynx is a junction that opens to both the oesophagus and the trachea (windpipe). When we swallow, the top of the windpipe moves up so that its opening – the glottis is blocked by a cartilaginous flap – the epiglottis (see Figure 5.3).

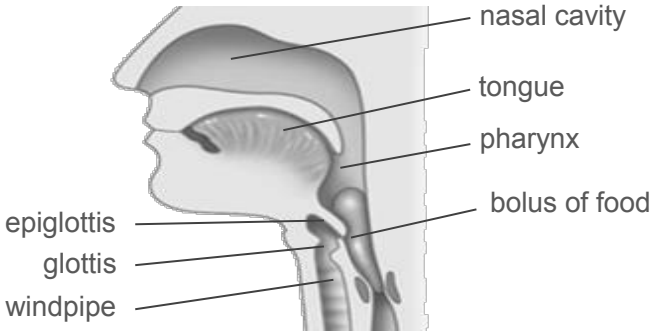


Figure 5.3 During swallowing, tongue pushes the bolus into the pharynx and the opening to the trachea is blocked by an epiglottis (Source: Campbell, 2008)

3.2 Oesophagus

The bolus will be pushed along the **oesophagus** to the stomach by means of **peristalsis** (NOT gravity), rhythmic waves of contraction by smooth muscles in the walls of the alimentary canal (see Figure 5.11). There is no breakdown of food except for the continuation of starch digestion by salivary amylase.

3.3 Stomach

The stomach is located below the diaphragm (see Figure 5.4). With accordion-like folds and a very elastic wall, the stomach can stretch to accommodate about 2 litres of food.

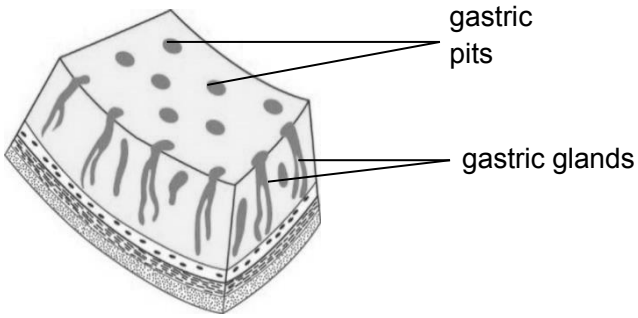


Figure 5.5 The Stomach Wall

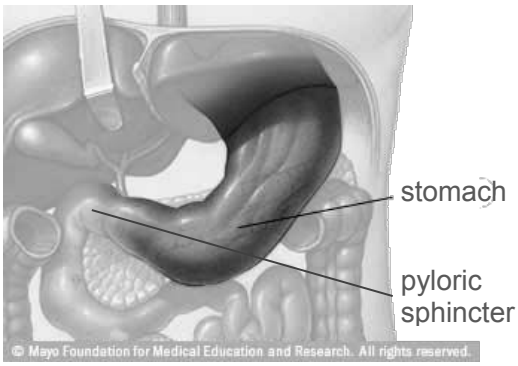


Figure 5.4 The Stomach

The gastric glands in the stomach secretes a digestive fluid called **gastric juice** and mixes this secretion with the food by the churning action of the smooth muscles in the stomach wall. The two components of gastric juice that carry out chemical digestion in the stomach are:

- **Hydrochloric acid (HC*l*)**
  The gastric juice has a pH of about 2. This low pH kills most bacteria and denatures proteins in the food. Salivary amylase denatures and starch digestion stops.

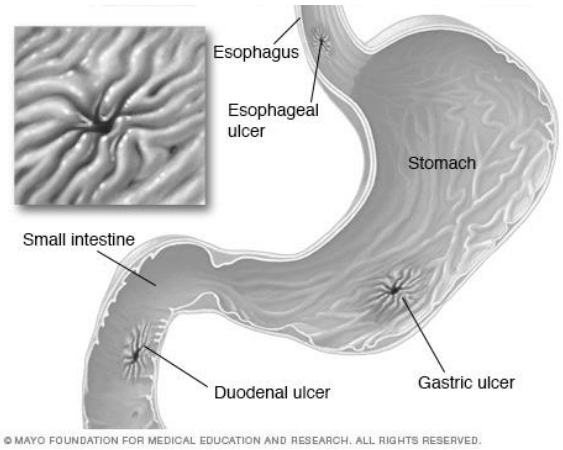
- **Pepsin**, an enzyme that digests proteins
  Pepsin, which works well in strongly acidic environments, is a protease that breaks peptide bonds in proteins, producing smaller polypeptides. Pepsin is released into the lumen in an inactive form called pepsinogen. HC*l* in the lumen of the stomach converts pepsinogen to active pepsin.

Because HC*l* and pepsin are released directly into the lumen of the stomach, not within the cells of the gastric glands, the stomach's cells are protected from self-digestion. In addition, the stomach lining is further protected by a coating of mucus, secreted by the epithelial cells. Still, the epithelium (epithelial cells) is continuously eroded, and the cells are replaced by mitosis regularly.

As a result of churning and enzyme action, the stomach contents become nutrient-rich **chyme**. The pyloric sphincter at the opening from the stomach to the small intestine regulates the passage of chyme into the duodenum. It takes about 2-6 hours after a meal for the stomach to empty.

Extension

GASTRIC ULCERS



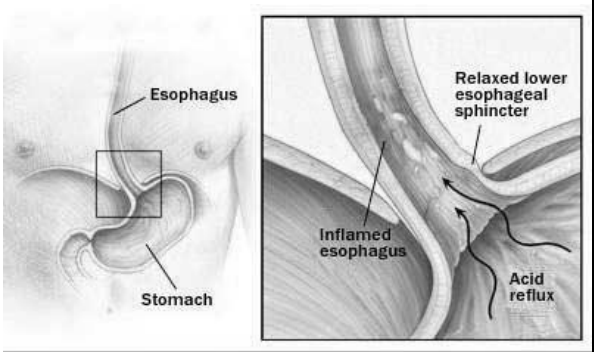
It was a myth that certain foods or stress caused peptic ulcers. The discovery that ulcers are caused by a bacterial infection, not by stress, earned Barry Marshall and J Robin Warren the Nobel Prize in 2005.

Gastric ulcers, lesions in the stomach lining, are caused by the acid-tolerant bacterium *Helicobacter pylori*. They are open sores that develop on the inner lining of the oesophagus, stomach and the upper portion of the small intestine. The most common symptom of a gastric ulcer is abdominal pain. Ulcers are often treated with antibiotics.

Extension

"HEARTBURN"

Acid reflux (more specifically known as gastroesophageal reflux) is the backward flow of stomach acid into the oesophagus. During an episode of acid reflux, regurgitated food or sour liquid may be tasted at the back of the mouth or a burning sensation in the chest ("heartburn") may be felt.



Sometimes, acid reflux progresses to gastroesophageal reflux disease (GERD), a more severe form of reflux. The most common symptom of GERD is frequent heartburn. Other signs and symptoms may include regurgitation of food or sour liquid, difficulty swallowing, coughing, wheezing, and chest pain while lying down at night.

Most people can manage the discomfort of GERD with lifestyle changes (e.g. lose excess weight, eat smaller meals) and over-the-counter medications (e.g. antacids). But some people with GERD may need stronger medications, or even surgery, to reduce symptoms.

3.4 Small Intestine & Accessory Organs

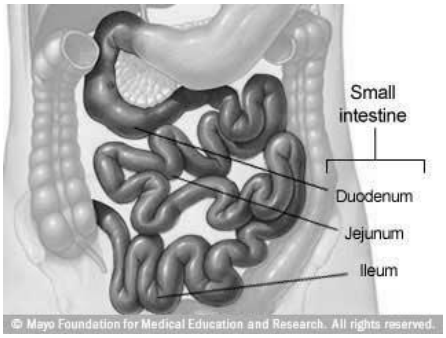


Figure 5.6 The Small Intestine

With a length of more than 6 metres, the small intestine (see Figure 5.6) is the longest section of the alimentary canal. Most of the digestion of large food molecules and the absorption of nutrients into the blood occur in the small intestine.

In the **duodenum**, the first 25 cm or so of the small intestine, chyme from the stomach mixes with digestive juices from the **pancreas**, **liver**, **gallbladder** and gland cells of the intestinal wall (see Figures 5.7 and 5.8).

Production of Pancreatic Juice

The **pancreas** produces pancreatic juice containing enzymes **trypsin**, **amylase** and **lipase**. Pancreatic juice is **alkaline** and acts as a buffer to neutralise the acidic chyme. See Figure 5.8.

Production of Intestinal Juice

The cells of the epithelial lining of the duodenum secrete intestinal juice into the lumen. Intestinal juice contains peptidase, maltase, sucrase (or invertase), lactase and lipase. Most digestion is completed in the duodenum. The remaining regions of the small intestine, the jejunum and **ileum** (coiled portion), function mainly in the absorption of digested food molecules and water.

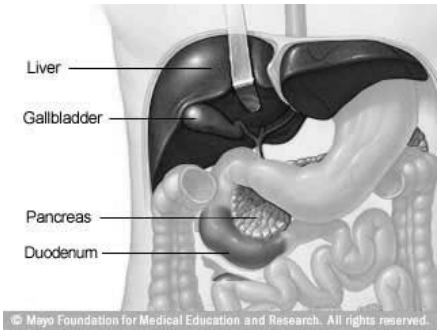


Figure 5.7 Accessory Organs of the Digestive Tract

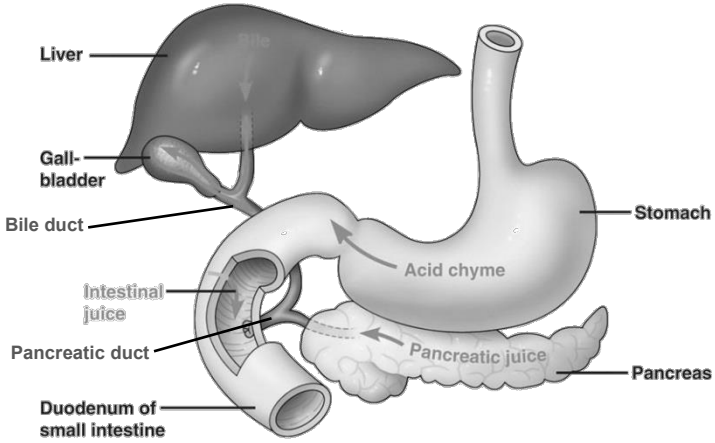


Figure 5.8 Digestion in the Small Intestine (Source: Campbell, 2008)

Emulsification of fats

The **liver** produces **bile** (no enzymes), which is stored temporarily in the **gall bladder** and released (NOT secreted) into the duodenum. Bile contains **bile salts** that aid in the digestion of fats. Bile **emulsifies** and break down big fat globule into smaller droplets (see Figure 5.9). Emulsification greatly increases the surface area to volume ratio of fats for digestion by lipase.

Bile also contains **pigments** that are by-products of red blood cell destruction in the liver. These bile pigments are eliminated from the body with the faeces. Functions of the liver will be described in detail in Section 7.

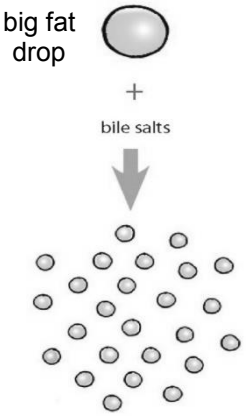


Figure 5.9 Emulsification by bile salts

3.5 Large Intestine

The large intestine, or **colon**, is connected to the small intestine at a T-shaped junction where a sphincter controls the movement of materials. One arm of the T is a pouch called the **cecum**. The relatively small cecum of humans has a fingerlike extension, the **appendix**. The main branch of the human colon is shaped like an upside-down U, about 1.5 metres long (See Figure 5.10). In man, the appendix contains white blood cells and plays a defensive role against intestinal pathogens.

A major function of the colon is to **reabsorb** water that has entered the alimentary canal as the solvent in various digestive juices. More than 90% of the water is reabsorbed by osmosis in the small intestine and the colon.

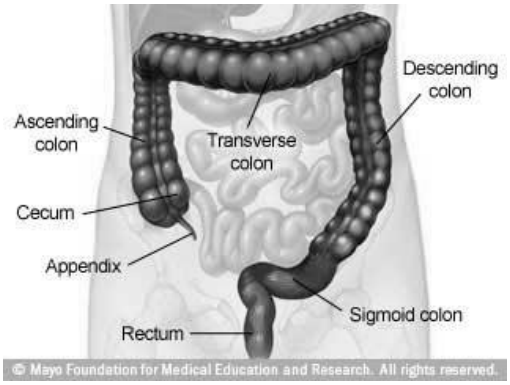


Figure 5.10 The Large Intestine

Undigested food materials (or faeces) become more solid as they are moved along the colon by **peristalsis**. Dietary **fibre** (or roughage) cannot be digested. It absorbs water and adds bulk to intestinal content. It takes 12-24 hours for the material to move along the length of the colon. In a diet lacking in fibre, too much water is reabsorbed because peristalsis moves the faeces too slowly, resulting in **constipation**. If the lining of the colon is irritated by a viral or bacterial infection, less water than usual is reabsorbed, resulting in **diarrhoea**.

The terminal portion of the colon is called the **rectum**, where faeces are stored until they can be eliminated through **egestion** (or **defecation**). Between the rectum and the **anus** are two sphincters, one involuntary and one voluntary.

Describe peristalsis in terms of rhythmic wave-like contractions of the muscles to mix and propel the contents of the alimentary canal.

4 PERISTALSIS

Peristalsis occurs throughout the alimentary canal. In the oesophagus, food is conducted from the pharynx down to the stomach by peristalsis. The act of swallowing begins voluntarily, the waves of contraction by smooth muscles of the oesophagus are involuntary.

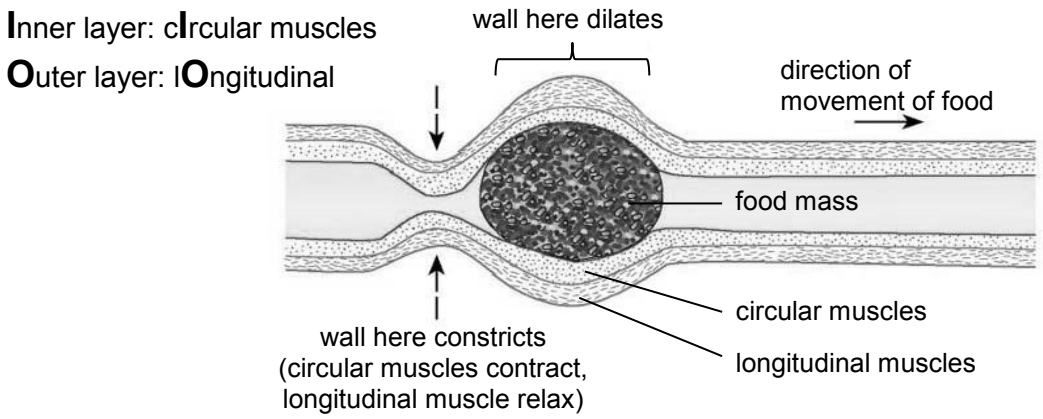


Figure 5.11 Action of the antagonistic muscles of the gut wall

The two sets of muscles along the oesophagus are longitudinal muscles and circular muscles (see Figure 5.11). The two sets of muscles work antagonistically. When one contracts, the other relaxes (see Figure 5.12). The food is squeezed and pushed forward.

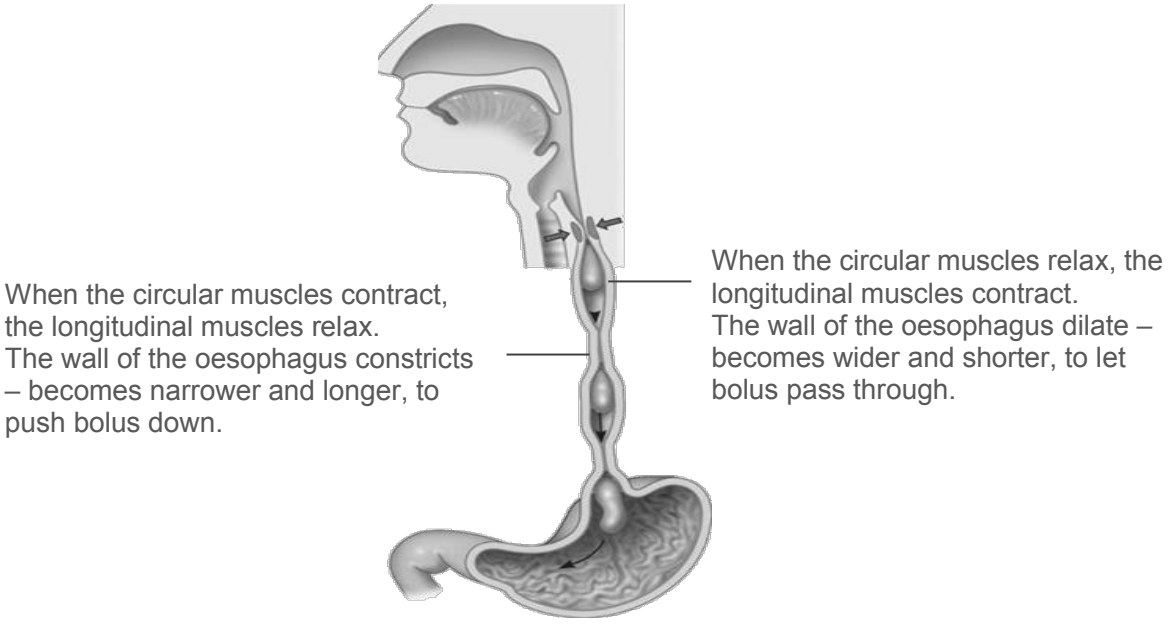


Figure 5.12 Peristalsis at the oesophagus (Source: Campbell, 2008)

Describe digestion in the alimentary canal, the functions of a typical amylase, protease and lipase, listing the substrate and end-products.

5 DIGESTION IN THE MOUTH, STOMACH & DUODENUM

Digestive enzymes are present in the
- saliva that is secreted into the buccal cavity,
- gastric juice that is secreted into the stomach,
- intestinal juice and pancreatic juice that are released into the duodenum.

5.1 Digestion of Carbohydrates

In the mouth

Enzyme salivary **amylase** digests polysaccharide **starch** to disaccharide **maltose**.

$$\text{starch} \xrightarrow{\text{amylase}} \text{maltose}$$

In the duodenum

Intestinal juice contains peptidase, maltase, sucrase (or invertase), lactase and lipase.

Pancreatic **amylase** will digest any remaining **starch** to **maltose**, and **maltase** will digest maltose to **glucose**.

$$\text{starch} \xrightarrow{\text{amylase}} \text{maltose} \xrightarrow{\text{maltase}} \text{glucose}$$

For the digestion of other carbohydrates, enzymes **lactase** and **sucrase** will digest **lactose** and **sucrose** respectively, to their monosaccharides.

$$\text{lactose} \xrightarrow{\text{lactase}} \text{glucose + galactose}$$

$$\text{sucrose} \xrightarrow{\text{sucrase}} \text{glucose + fructose}$$

5.2 Digestion of Protein

In the stomach

The epithelium lining of the stomach wall secretes **gastric juice** which contains a dilute solution of **hydrochloric acid** and two enzymes – **pepsinogen** and **prorennin** (inactive forms of enzymes).

Hydrochloric acid in gastric juice converts pepsinogen to **pepsin** and prorennin to **rennin**.

$$\text{prorennin} \xrightarrow{HCl} \text{rennin}$$

$$\text{pepsinogen} \xrightarrow{HCl} \text{pepsin}$$

Rennin curdles milk proteins by converting soluble protein **caseinogen** to insoluble **casein**. Insoluble casein remains long enough in the stomach to be digested by **pepsin**.

Enzyme pepsin digests proteins to **polypeptides**.

$$\text{protein} \xrightarrow{\text{pepsin}} \text{polypeptide}$$

In the duodenum

Enzyme **trypsin** will digest proteins to **polypeptides**, and **peptidase** will digest polypeptides to **amino acids**.

$$\text{protein} \xrightarrow{\text{trypsin}} \text{polypeptide} \xrightarrow{\text{peptidase}} \text{amino acids}$$

5.3 Digestion of Fats

In the duodenum

After the emulsification of fats (refer to Section 3.4), enzyme lipase will digest fats to fatty acids and glycerol. Each fat molecule will be hydrolysed to 1 molecule of glycerol and 3 molecules of fatty acids.

$$\text{fat} \xrightarrow{\text{lipase}} \text{glycerol + fatty acids}$$

State the function of the hepatic portal vein as the route taken by most of the food absorbed from the small intestine.

6 ABSORPTION IN THE SMALL INTESTINE

The remaining regions of the small intestine, the jejunum and **ileum**, function mainly in the absorption of digested food and water.

6.1 Absorption of amino acids and glucose

Absorption of amino acids and glucose into the **blood capillaries** of the villi is by **diffusion**, down their concentration gradients. They are also absorbed by **active transport** against concentration gradients. This active transport allows much more absorption of nutrients than would be possible with passive diffusion. The capillaries drain nutrients away and converge into **larger blood vessel** and eventually, transport the nutrients to the **hepatic portal vein**, which leads to the **liver** (See Figure 5.13).

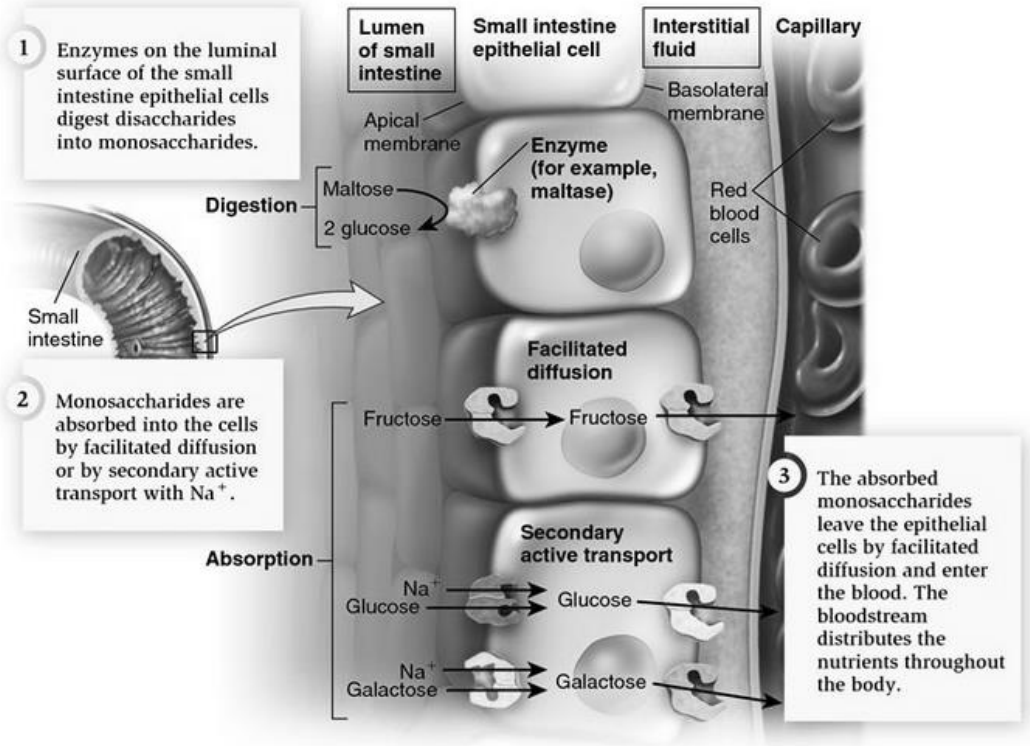


Figure 5.13 Digestion and absorption of carbohydrates in the small intestine

6.2 Absorption of glycerol and fatty acids

Glycerol and fatty acids are absorbed by **diffusion** into the epithelial cells and recombined into fat molecules within the cells. The fats are mixed with cholesterol and coated with special proteins to form

small globules called chylomicrons, which are transported into **lacteals** of each villus (See Figure 5.14). The lacteals converge into the **larger lymphatic vessels**, eventually draining into large veins that return blood to the heart.

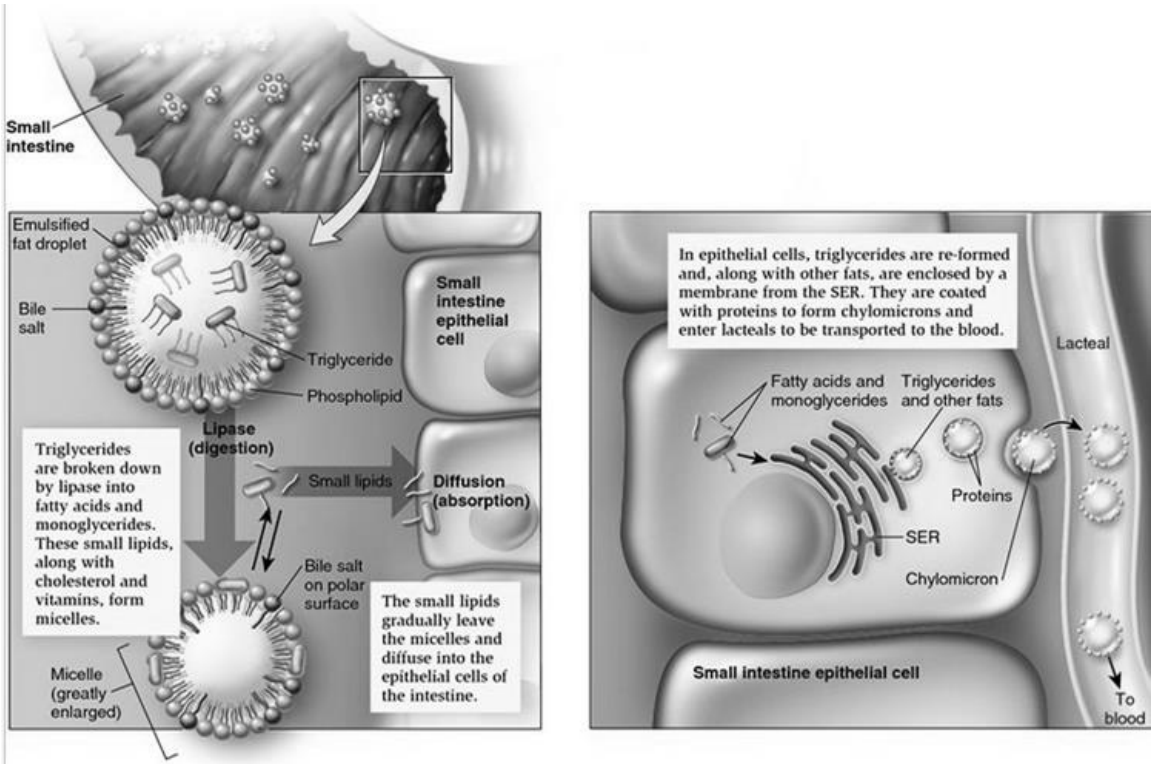


Figure 5.14 Digestion and absorption of fats

Describe the structure of a villus and its role, including the role of capillaries and lacteals in absorption.

6.3 Adaptation of the small intestine for absorption

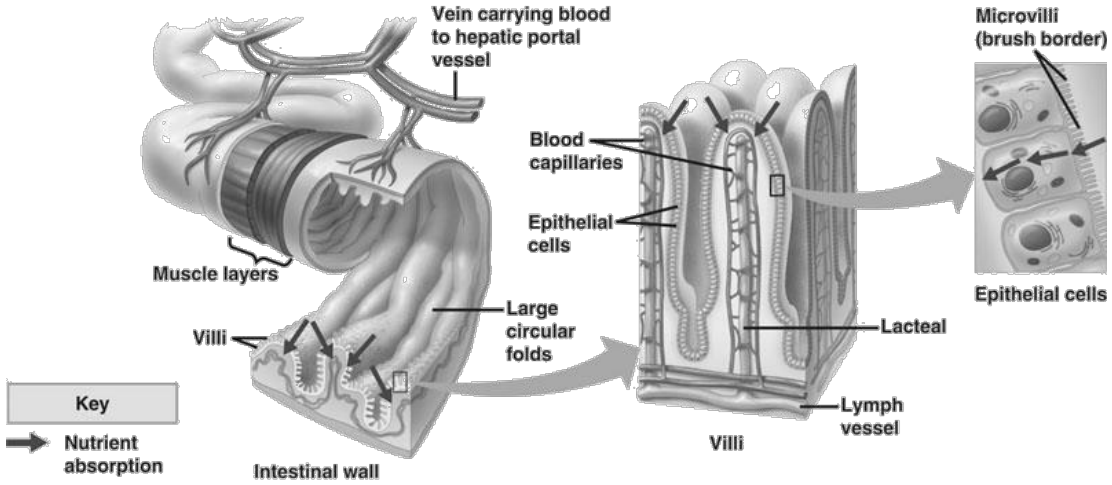


Figure 5.15 Adaptation of the small intestine for the absorption of nutrients (Source: Campbell, 2008)

a) The small intestine has a large surface area of 300 m^2 which increases the rate of absorption of nutrients (see Figure 5.15).
   - The inner surface of the small intestine is folded.
   - Large circular folds in the lining bear fingerlike projections called **villi**.
   - Each epithelial cell of a villus has many **microvilli** which further increase the surface area for absorption.

b) In each villus is a net of blood **capillaries** and a **lacteal** (or lymphatic capillary) to **transport** the absorbed nutrients.

c) The wall (epithelium) of the villi is only **one-celled thick** (thin).

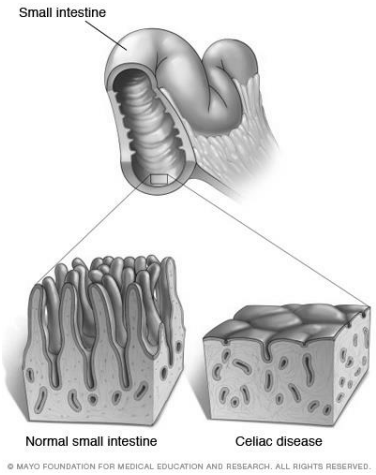
Extension

CELIAC DISEASE

Celiac disease is an immune reaction to eating gluten, a protein found in wheat, barley and rye. In persons with celiac disease, eating gluten triggers an immune response in the small intestine. Over time, this reaction produces inflammation that damages the epithelial cells on the villi and the rate of absorption of some nutrients is greatly reduced.

Malabsorption can cause weight loss, bloating and sometimes diarrhea. Eventually, the brain, nervous system, bones, liver and other organs can be deprived of nourishment. In children, malabsorption can affect growth and development.

There is no cure for celiac disease but following a strict gluten-free diet can help manage symptoms and promote intestinal healing.



Describe the role of the liver in carbohydrate metabolism, fat metabolism, breakdown of red blood cells, metabolism of amino acids and the formation of urea, breakdown of alcohol, including the effects of excessive alcohol consumption.

7 ROLE OF THE LIVER

7.1 Carbohydrate metabolism

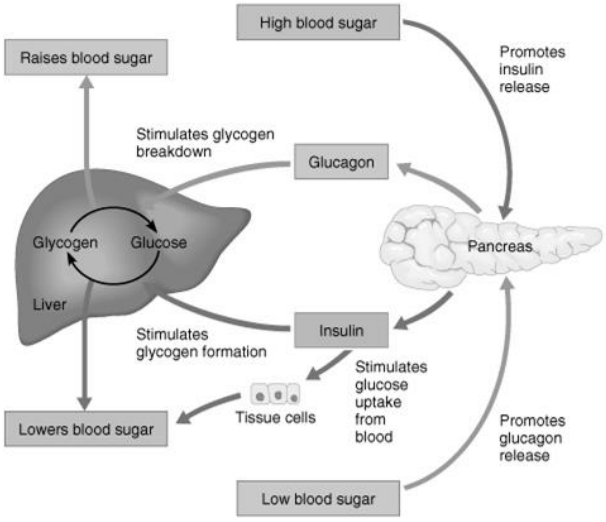


Figure 5.16 Regulation of blood glucose concentration

The liver regulates the **blood glucose concentration** to ensure that blood leaving the liver has a concentration close to 90 mg per 100 m*l*, regardless of the quantity of carbohydrate in the meal (see Figure 5.16).

If the blood glucose concentration is high, the hormone insulin is secreted into the bloodstream to stimulate the conversion of excess glucose to **glycogen**. Glycogen is stored in the liver and muscles. Blood glucose concentration will decrease to the set range.

If the blood glucose concentration is low, the hormone glucagon is secreted to stimulate the conversion of glycogen to glucose. Glucose will diffuse back into the blood to increase the blood glucose concentration to the set range.

7.2 Fat metabolism

Liver secretes bile that is temporarily stored in the gall bladder (see Figure 5.17) before releasing into the duodenum. Bile **emulsifies** large fat droplets into small fat droplets which increases the surface area to volume ratio and increases the rate of their digestion by lipase.

Fats can be stored in **adipose** tissues around important organs for protection and under the skin for insulation. It can also be used for the synthesis of cell membrane and in respiration when glucose and glycogen is used up.

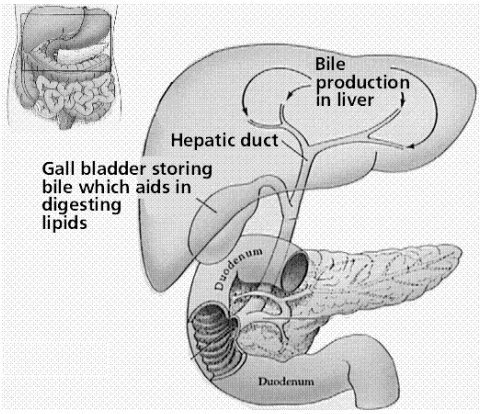
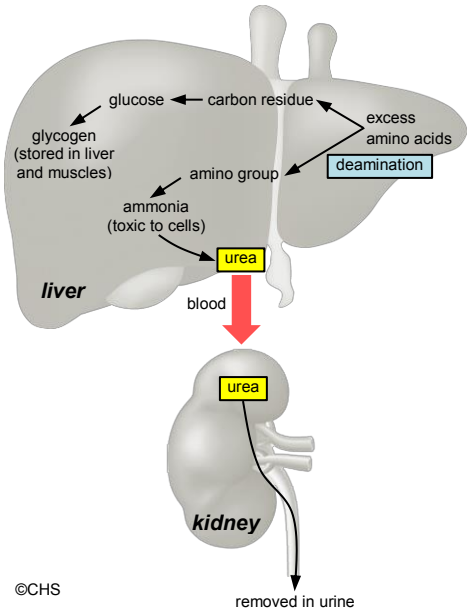


Figure 5.17 Production of bile (source: https://s10.lite.msu.edu/)

7.3 Breakdown of red blood cells

Red blood cells normally live for 110–120 days. After that, the old cells are destroyed in the **spleen**. Haemoglobin is then broken down to release iron which is stored.

7.4 Metabolism of amino acids and the formation of urea



The human body cannot store proteins or amino acids. **Excess amino acids** are produced from the digestion of a large amount of proteins.

When amino acids are absorbed by liver cells, a series of chemical reactions begins. The amino group, $-NH_2$, is removed from the main structure of the amino acid. The removal of the amino group from amino acids is called **deamination** (see Figure 5.18). The product of this reaction is ammonia, which is then converted to **urea**, which is excreted via the kidneys.

The **carbon** residues are converted to glucose, which is stored as glycogen in the body.

Figure 5.18 Deamination of excess amino acids

7.5 Breakdown of alcohol, including the effects of excessive alcohol consumption

The liver also removes toxic substances from the blood during **detoxification**. A substance that is broken down in the liver is alcohol. Alcohol is oxidised to **acetaldehyde** in a reversible reaction, catalysed primarily by **alcohol dehydrogenase** (see Figure 5.19). Acetaldehyde can be further broken down to compounds used in respiration.

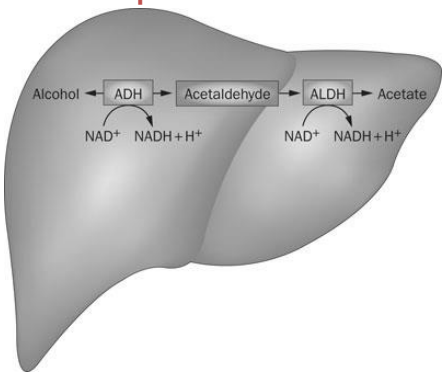


Figure 5.19 Breaking down of alcohol to acetaldehyde

Effects of excessive alcohol consumption

The short-term effects of alcohol consumption include:

- slows down some brain functions as it is a depressant
- poor muscular coordination (e.g. walking clumsily, slurred speech)
- lack of judgement (e.g. underestimating one's own ability)
- slower reaction time (increased response time, NOT reduce reaction time)
- reduced self-control and increased risk-taking that may have social implication e.g. crime
- blurred vision

The long-term effects of alcohol consumption include:

- increased risk of gastric ulcer
- **cirrhosis** of liver that may lead to liver damage and liver failure

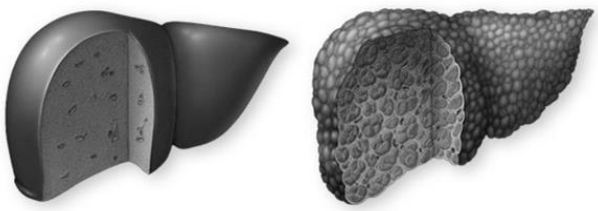
Other function of the liver:

- synthesis of proteins such as albumin (blood plasma) and fibrinogen (clotting of blood).

Extension

LIVER CIRRHOSIS

Cirrhosis is a late stage of scarring of the liver caused by many forms of liver diseases and conditions, such as hepatitis and chronic alcoholism.



As the liver repair itself each time after injury – whether from excessive alcohol consumption or other diseases, scar tissue forms. As cirrhosis progresses with the formation of more scar tissues, this makes it more difficult for the liver to function. The liver damage resulted from cirrhosis generally cannot be undone. However, with early diagnosis and treatment, further damage can be limited.

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 06 – Plant Nutrition

Name: **Class:**

A. Content
- Photosynthesis
- Leaf structure and function
- Limiting factors of photosynthesis

B. Learning Outcomes

Students should be able to:
(a) identify and label the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section under the microscope and describe the significance of these features in terms of their functions, such as the
- distribution of chloroplasts in photosynthesis
- stomata and mesophyll cells in gaseous exchange
- vascular bundles in transport

(b) state the equation, in words for photosynthesis.
(c) outline the intake of carbon dioxide and water by plants.
(d) state that chlorophyll traps light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent storage.
(e) investigate and discuss the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis (e.g. in submerged aquatic plant)
(f) discuss light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis

C. References

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D. Lecture Outline

1. Photosynthesis
2. Pigments and light absorption
3. Limiting factors of photosynthesis
4. Leaf structure and function

E. Practical Work
- Test for starch in green/variegated leaves

1. PHOTOSYNTHESIS

- Photosynthesis is a process in which **light energy** is **absorbed** by **chlorophyll** found in **chloroplasts** (Figure 6.1) and converted to **chemical energy**.
- **Carbon dioxide** and **water** are raw materials. **Glucose** and **oxygen** are products.
- Chloroplasts are bounded by a double membrane, the chloroplast envelope; outer membrane is a smooth and continuous boundary while the inner membrane gives rise to membranous structures called **lamellae** (singular: lamella) or **thylakoids**, which are flattened sacs and when stacked, form **grana** (singular: granum).
- The interior of the chloroplast is filled with a gel-like matrix called the **stroma.**
- **Starch grains** in stroma act as temporary storage of glucose.

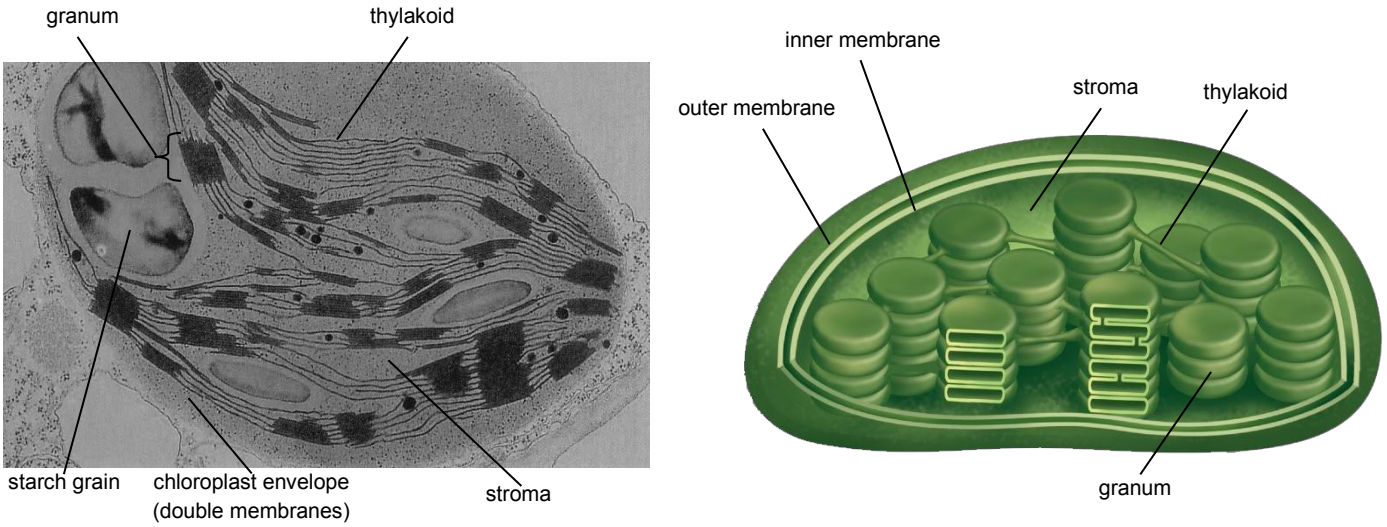


Figure 6.1 The chloroplast in electron micrograph (left) and drawing (right)

How can we study photosynthesis?

To do photosynthetic experiments, the following basic knowledge is required:
(1) **Glucose** is first product formed during photosynthesis.
(2) Presence of **starch** in the leaves suggests that photosynthesis has taken place.
- When glucose is formed more quickly than it is used up, the excess glucose is changed to starch for storage.
- Test for starch using the **iodine test**.

(3) **Destarching** ensures that starch is **absent** in the leaves prior to the experiments.
- Put the plants in the dark for **two days** so that starch is converted to **glucose**, which will be used up during respiration.

How can we find out whether sunlight is necessary for photosynthesis?

1. A potted plant is destarched by placing it in the dark for two days.
2. A leaf is removed and tested to ensure for the absence of starch.
3. A leaf, still attached to the plant, is sandwiched between two pieces of black paper and the plant is placed in strong sunlight (Figure 6.2).
4. The leaf is tested for the presence of starch after a few hours. The following is observed
5. Only the parts **exposed to sunlight** will be stained blue-black (Figure 6.3). Sunlight is necessary for photosynthesis.

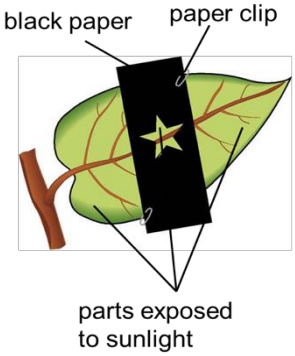


Figure 6.2 Sandwich a leaf between two pieces of black paper

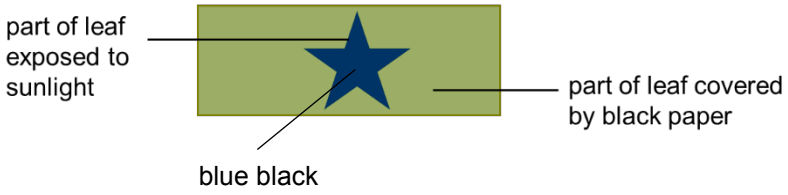


Figure 6.3 Exposed area turns blue back after undergoing iodine test

How can we find out whether carbon dioxide is necessary for photosynthesis?

1. Two potted plants are destarched by placing them in the dark for two days
2. The pots of plants are enclosed in polythene bags and placed in strong sunlight for a few hours (Figure 6.4).
3. After a few hours, a leaf is removed from each pot of plant and tested for the presence of starch (Figure 6.5).

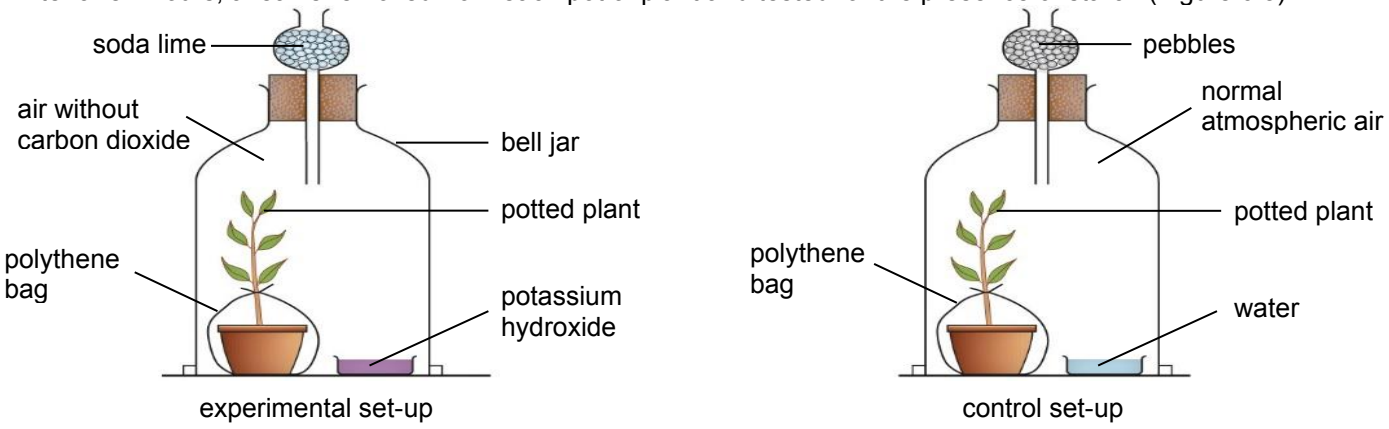


Figure 6.4 Experimental set-up to find out whether carbon dioxide is necessary for photosynthesis

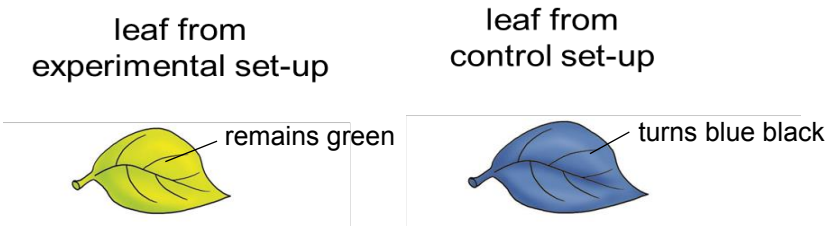


Figure 6.5 Photosynthesis can only occur in the presence of carbon dioxide

How can we find out what gas is given off during photosynthesis?

1. Freshwater plant, e.g. *Hydrilla* is set up as shown in Figure 6.6.
2. Dissolve 2–10 g of sodium hydrogencarbonate in the water in the beaker. This provides carbon dioxide to the plant. Place the apparatus in strong sunlight for a few hours.
3. After a few hours, gas bubbles will form on the leaves and slowly rise up the test tube.
4. The gas is tested with glowing splinter. Record your observation.

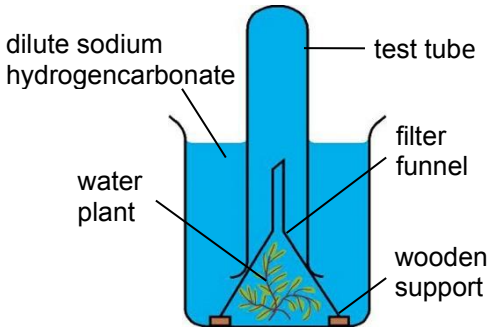


Figure 6.6 Experimental set-up to find out what gas is given off during photosynthesis

What happens during photosynthesis?

- Photosynthesis occurs in two stages: **light–dependent** and **light–independent** (dark)
- Light-dependent stage: light energy is absorbed by chlorophyll and converted to chemical energy. Light energy is also used to split water molecules into oxygen and hydrogen atoms (photolysis).
- Light-independent (dark): Hydrogen produced in photolysis is used to reduce carbon dioxide to glucose.
- The equation summarising the process is

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

- 12 molecules of water are used and 6 molecules are newly formed during photosynthesis. Thus, the overall equation can be simplified by showing only the net consumption of water:

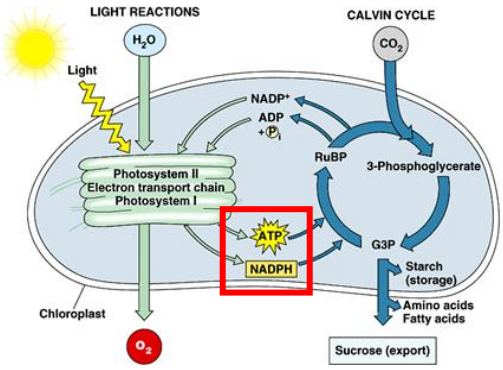
$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2$$

- Written this way, the overall equation of photosynthesis is the reverse of cellular respiration.

Extension

THE TWO STAGES OF PHOTOSYNTHESIS

Photosynthesis occurs in two stages: **light-dependent reactions** *(photo)*, converts light energy to chemical energy and light-independent reactions, also known as **Calvin cycle** uses chemical energy from light reactions to incorporate CO_2 into glucose.

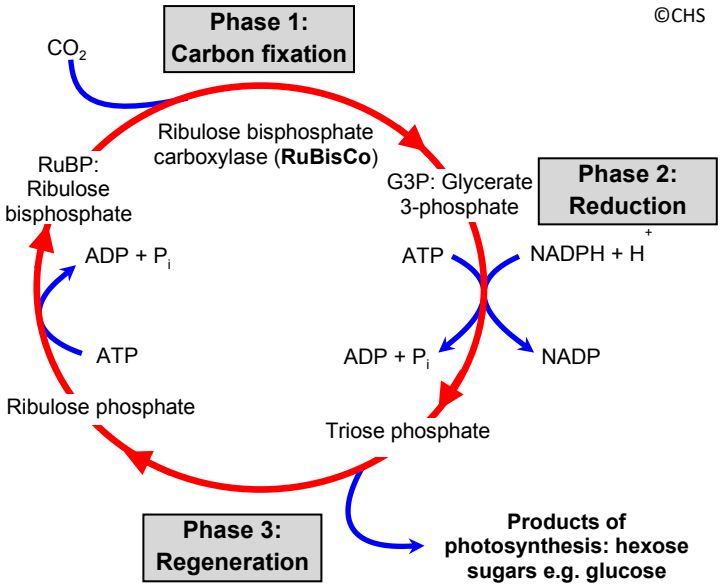


LIGHT-DEPENDENT REACTIONS

At the thylakoids, light energy is used to split water molecules, providing a source of electrons and protons (H^+ ions) and giving off O_2 as by-product. These electrons and hydrogen ions are transferred to **$NADP^+$** (nicotinamide adenine dinucleotide phosphate), forming NADPH. The light reaction also generates ATP in a process called **photophosphorylation**. Thus, light energy is initially converted to chemical energy in the form of two compounds: NADPH, a source of electrons, and ATP.

LIGHT-INDEPENDENT REACTIONS

In the stroma, sugar formation occurs in the second stage (Calvin cycle). The cycle starts with the incorporation of CO_2 into organic molecules, a process known as **carbon fixation**. The fixed carbon is reduced with electrons provided by NADPH. ATP from the light-dependent reactions also powers parts of the Calvin cycle. Therefore, it is the Calvin cycle that makes sugar, with the help of ATP and NADPH from light-dependent reactions. The metabolic steps of the cycle are referred to as the light-independent reactions because none requires light *directly*. Nevertheless, the Calvin cycle in most plants occurs during daylight as the light reactions provide NADPH and ATP the Calvin cycle requires.



THREE PHASES OF CALVIN CYCLE

In phase 1 (**Carbon Fixation**), CO_2 is incorporated into a five-carbon sugar named ribulose bisphosphate (RuBP) and the first step is catalysed by the enzyme RuBP carboxylase or Rubisco. In phase 2 (**Reduction**), ATP and NADPH from the light-dependent reactions are used to convert glycerate 3-phosphate to triose phosphate (also known as glyceraldehyde 3-phosphate), the three-carbon carbohydrate precursor to glucose and other sugars. In phase 3 (**Regeneration**), more ATP is used to convert some of the pool of triose phosphate back to RuBP.

Suggest how scientists might have determined the fate of molecules such as CO_2 and O_2 during photosynthesis.

Use of isotopes to tag molecules taken up by plants. For example, use of oxygen isotopes can identify origin of the free oxygen released in photosynthesis. $CO_2 + 2H_2{}^{18}O \rightarrow [CH_2O] + {}^{18}O_2 + H_2O$

2. PIGMENTS AND LIGHT ABSORPTION

- Substances that absorb visible light are called pigments, and different pigments absorb light of different wavelengths.
- Chlorophyll mainly absorbs blue and red light, and the leaves appear green (which is reflected).

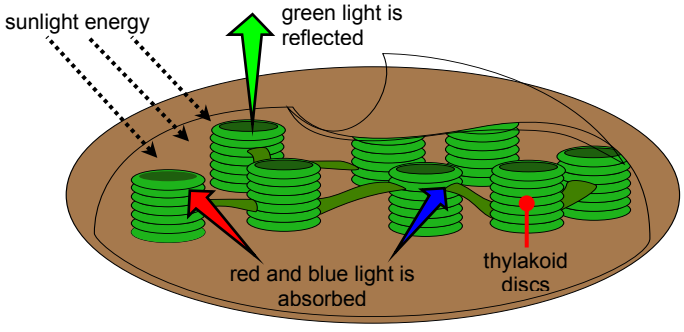
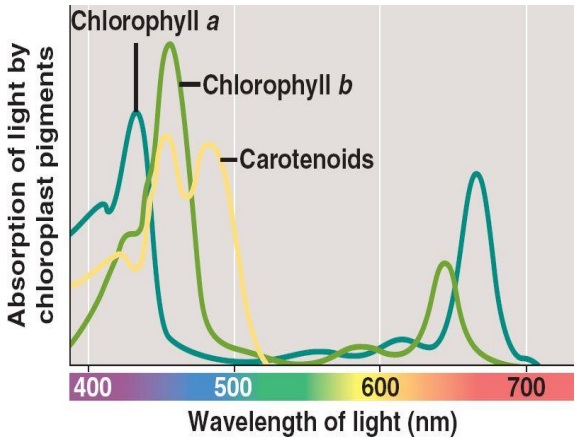


Figure 6.7 Absorption of red and blue light in a chloroplast



- The light absorption vs the wavelength of light is called the **absorption spectrum** of that pigment. Absorption spectra reveal the efficiency with which chlorophylls (e.g. chlorophyll *a* and *b*) and other pigments (e.g. carotenoids) absorb wavelengths of visible light (Figure 6.8).
- Peaks in the graphs reveal the wavelengths that each type of pigment absorbs best.

Figure 6.8 Absorption spectra of different photosynthetic pigments

- An **action spectrum** profiles the effectiveness of different wavelength light in fueling photosynthesis.
- Figure 6.9 shows that the action spectrum for photosynthetic pigments (combined) is closely correlated to the absorption spectra, suggesting that these pigments are responsible for absorbing the light used in photosynthesis.

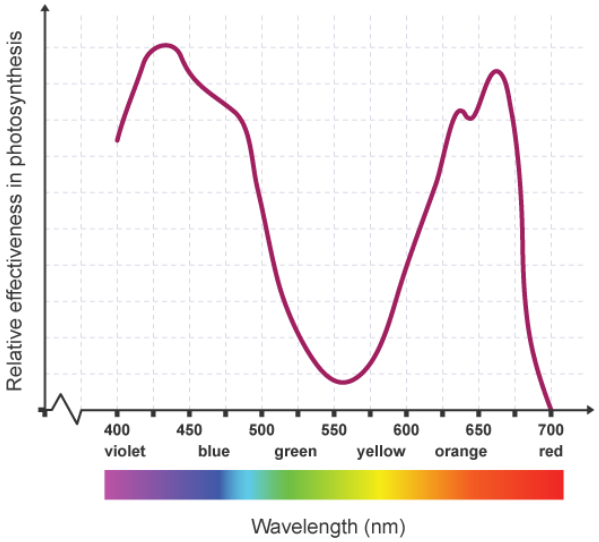


Figure 6.9 Correlation between absorption spectra of different photosynthetic pigments and action spectrum of photosynthesis Source: http://www.bbc.co.uk/education/guides/z23ggk7/revision/2

<u>Discovery of the role of red and blue light in photosynthesis</u>

- Theodor Wilhelm Engelmann's investigation of photosynthesis in *Spirogyra*, a strand like green alga was published in 1880.
- He observed the movement of aerobic bacteria towards the chloroplasts. The bacteria were moving in response to the oxygen released from photosynthesis.
- **Hypothesis**: If bacteria require oxygen, then we can expect them to gather in places where the most photosynthesis takes place.
- **Procedure**: He put a water droplet containing bacterial cells on a microscopic slide with the green alga *Spirogyra*.
- He used a crystal prism to break up a beam of sunlight and cast a spectrum of colours across the slide.
- **Results**: Bacteria gathered mostly where **violet and red** light fell on the green alga (Figure 6.10).
- Alga cells released more oxygen in the part illuminated by light of those colours – the very best light for photosynthesis.

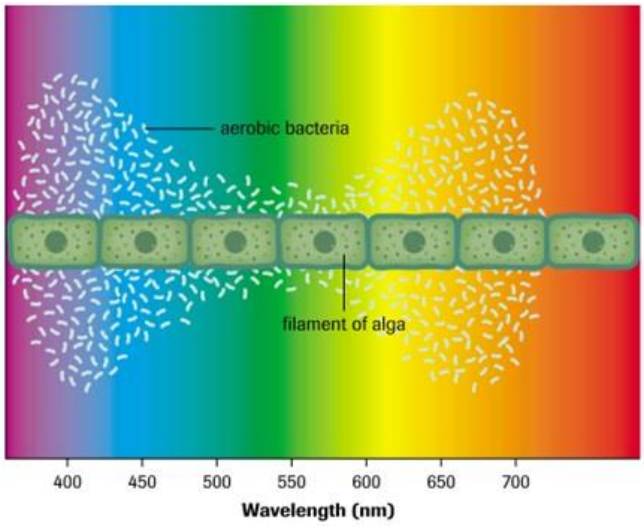


Figure 6.10 Regions where bacteria are attracted to during photosynthesis
Source: http://uoitbiology12u2014.weebly.com/metabolism-photosynthesis.html

3. LIMITING FACTORS OF PHOTOSYNTHESIS

- Any factor that directly affects or limits a process if its quantity or concentration is altered is called a **limiting factor**.
- The three main limiting factors for photosynthesis are:
  (1) **Light intensity**
  (2) **Concentration of carbon dioxide**
  (3) **Temperature**

3.1 Effect of light intensity on rate of photosynthesis:

1. The apparatus is set up with the lamp at 1 m away as shown in Figure 6.11.

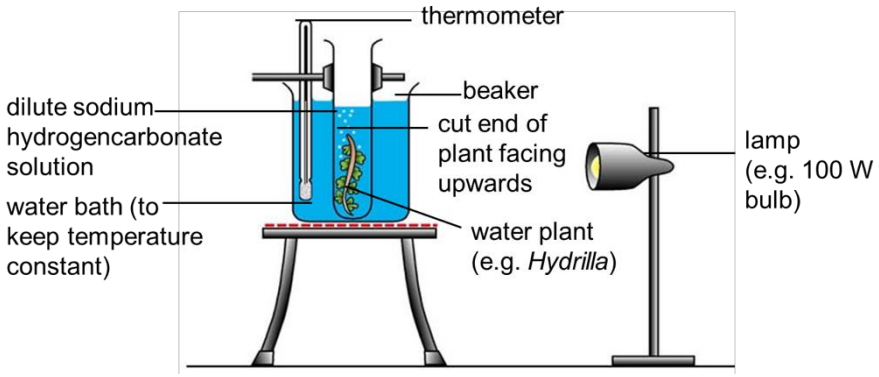


Figure 6.11 Experimental setup to investigate the effect of light intensity on rate of photosynthesis

2. Air bubbles are given off at the cut end of the plant. Some time is allowed for the rate of bubbling to stabilise.
3. The **number of bubbles produced** over a period of one minute is counted. This is repeated three times to obtain the average rate.
4. The experiment is repeated by moving light source closer to the plant at different lengths (1, 0.5, 0.25 and 0.125 m).

Table 6.1 Relationship between light intensity to rate of photosynthesis

distance between the *Hydrilla* and lamp (m)	light intensity = Power / Area = $100W/4\pi r^2$ (Wm^{-2})	number of bubbles given off in 1 min
1.0	7.96	8
0.5	31.85	28
0.25	127.39	105
0.125	510.20	105

5. It is observed that the rate of bubbling (rate of photosynthesis) increases as the distance of the lamp from the plant decreases (light intensity increases).

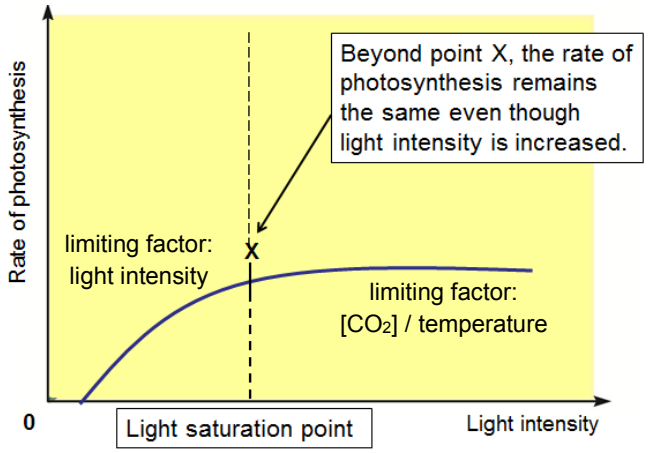


Figure 6.12 Effect of increasing light intensity on rate of photosynthesis

- Increasing the light intensity will **increase** the rate of photosynthesis up till a certain point, X.
- Point X is known as **light saturation point** (Figure 6.12).
- The light saturation point refers to the amount of light that is beyond the capability of the chloroplast to absorb; light is no longer the limiting factor of photosynthesis.
- Very high light intensities may damage the chlorophyll and decrease the rate of photosynthesis, but plants that have been naturally exposed to such conditions are usually protected by thick cuticles.

3.2 Effect of carbon dioxide concentration on rate of photosynthesis:

- When the carbon dioxide concentration is raised from 0.03% to 0.13% (Figure 6.13) while keeping the temperature constant at 20 °C, the rate of photosynthesis will **increase**.
- Carbon dioxide is needed for the **dark reactions**.
- Under normal field conditions, carbon dioxide is the major limiting factor in photosynthesis due to its scarcity (0.03%) in atmospheric air.

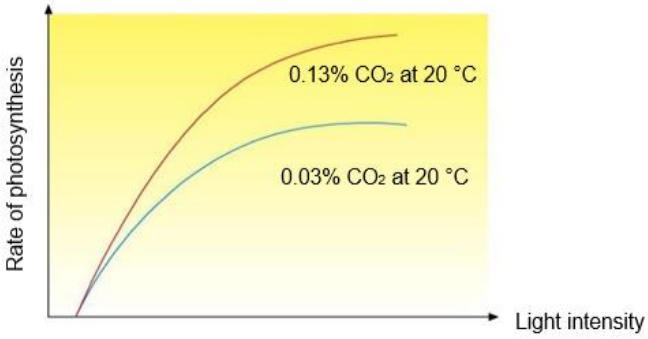


Figure 6.13 Effect of increasing carbon dioxide concentration on rate of photosynthesis

3.3 Effect of temperature on rate of photosynthesis

1. The apparatus is set up as shown in Figure 6.14.
2. Ice-cold water is added to the water bath to keep the temperature at 5 °C.
3. When the bubbles are coming out at a regular rate, the number of bubbles produced over a period of 1 minute is counted. This is repeated a few times to obtain an average rate.
4. The experiment is repeated at various temperatures (e.g. 5, 15, 25, 35, 45, 55, 65 and 75 °C).

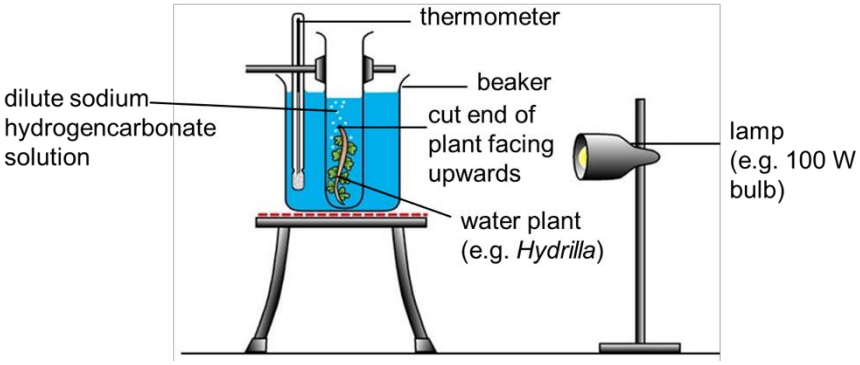


Figure 6.14 Experimental setup to investigate the effect of temperature on rate of photosynthesis

- It is observed that the rate of bubbling **increases** as the temperature is increased.
- Enzymes catalyse the reactions in photosynthesis. At temperatures higher or lower than optimum temperatures, enzymes are **denatured** or **inactive** respectively, thus affecting the rate of photosynthesis.
- Rate of photosynthesis **doubles** for every 10 °C increase in temperature up to the optimum temperature.

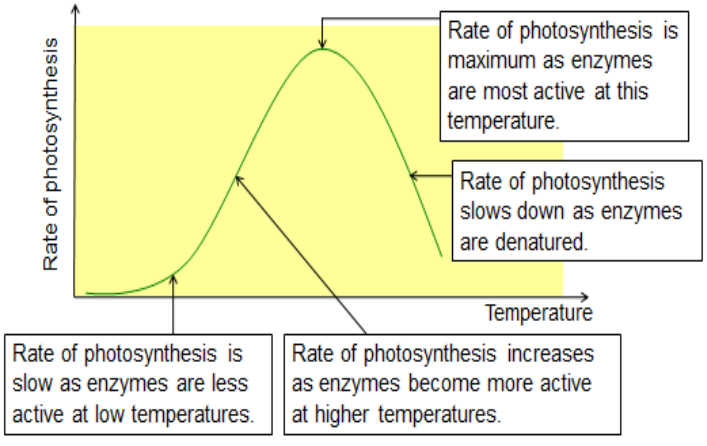


Figure 6.15 Effect of increasing temperature on rate of photosynthesis

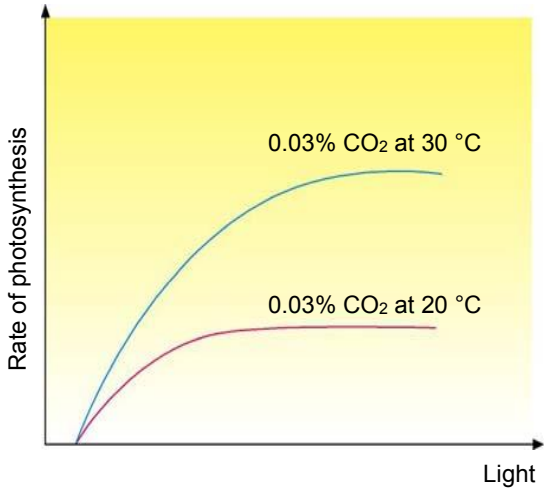


Figure 6.16 Rate of photosynthesis doubles when temperature increases by 10 °C

Fates of glucose in leaves

- Glucose is used by plant cells for **cellular respiration** or to form **cellulose cell walls**.
- Excess glucose is converted either into **sucrose** and transported to storage organs or changed into **starch** for temporary storage in the leaves.
- Glucose is also converted to other sugars (e.g. fructose in ripe fruits, sucrose in sugar cane).
- Glucose can react with nitrates to form **amino acids** which are combined to form proteins for the synthesis of **new protoplasm** in the leaf.
- Glucose can be used to form **fats** for storage, cellular respiration or synthesis of new protoplasm.

4. LEAF STRUCTURE AND FUNCTION

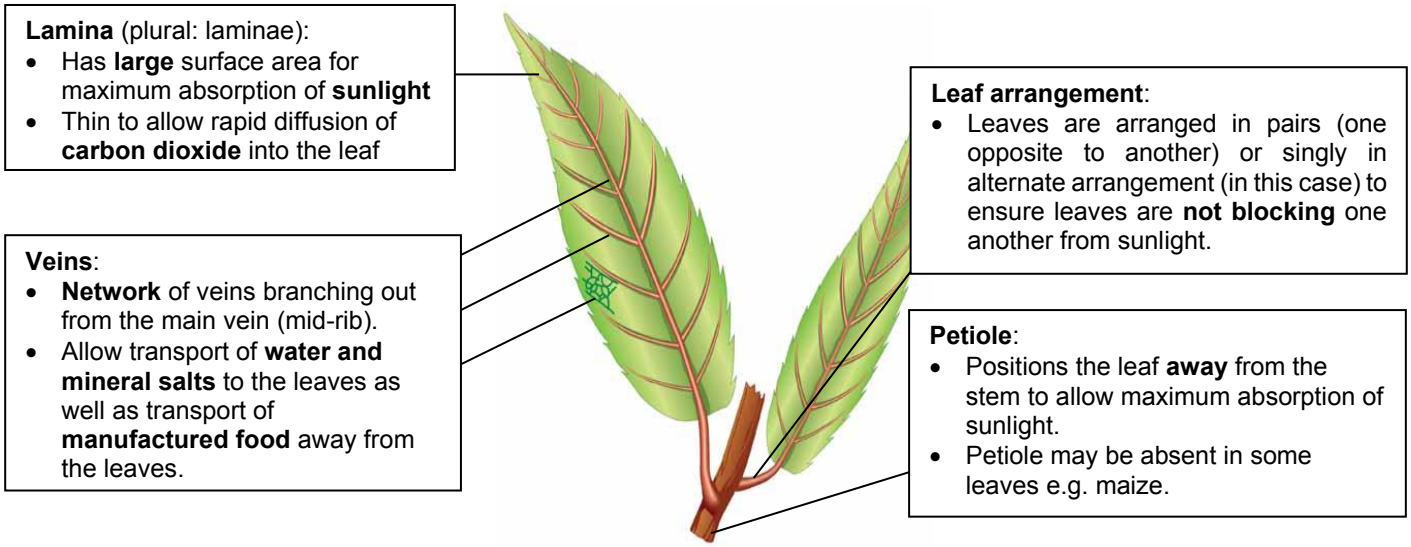


Figure 6.16 External features of a simple leaf

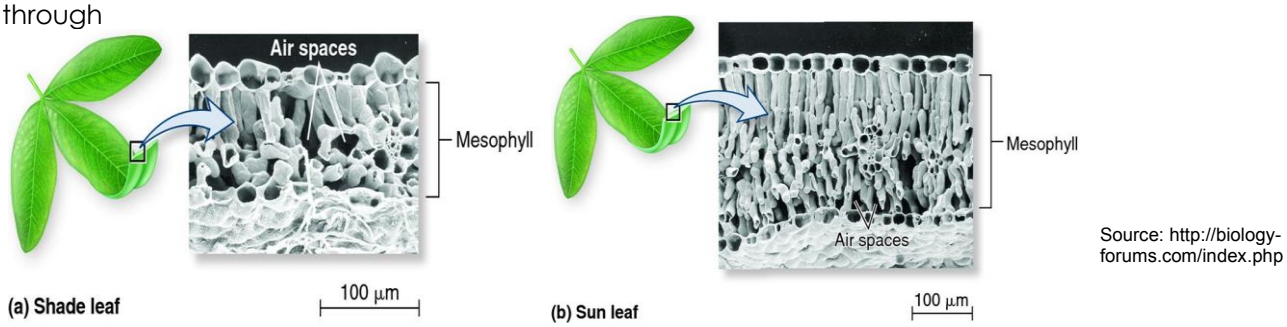
Extension

SUN AND SHADE LEAVES

Leaves that grow in the full sunlight on a daily basis (known as 'sun leaves') are structurally different from leaves that are permanently shaded (known as 'shade leaves').

Sun leaves:
1. thick leaves with a palisade mesophyll layer often two or three cells thick
2. chlorophyll are mostly restricted to the palisade mesophyll cells
3. sun leaf can absorb much of the light available to the cells when exposed to high light intensities

Shade leaves:
1. thin leaves with a single layer of palisade mesophyll cells
2. chloroplasts occur throughout mesophyll; with almost same number in both palisade and spongy layers
3. shade leaf can absorb the light available at lower light intensities; if exposed to high light, most would pass through



Source: http://biology-forums.com/index.php

Cuticle:
- **Waxy layer** to prevent excessive **water loss**.
- **Transparent** to allow sunlight to penetrate to the mesophyll layer.

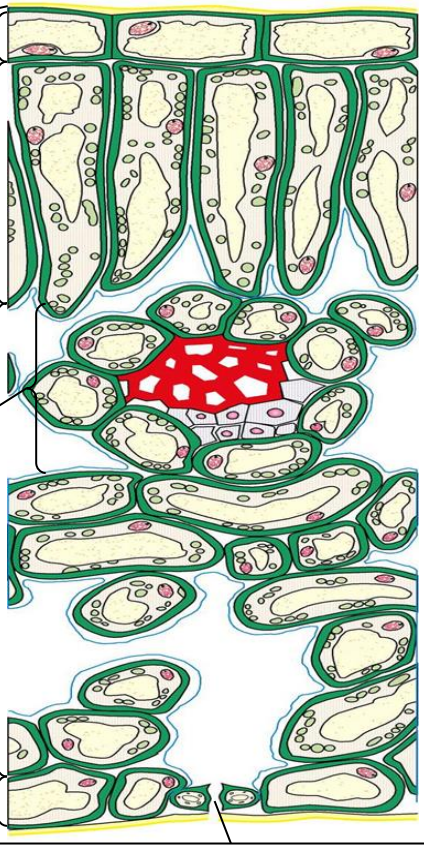
Upper epidermis:
- **Single layer** of closely packed cells.
- Covered by a waxy **cuticle** to prevent excessive **water loss**.

Palisade mesophyll:
- Layers of closely packed, **long** and **cylindrical** cells containing numerous **chloroplasts** for photosynthesis.

Vascular bundle:
- **Xylem** to transport water and mineral salts to the leaves.
- **Phloem** to transport sugars away from the leaf.

Spongy mesophyll:
- Layers of loosely packed cells with **intercellular air spaces** for gaseous exchange and few chloroplasts.

Lower epidermis:
- **Single layer** of closely packed cells.
- Covered by a waxy **cuticle** to prevent excessive **water loss**.

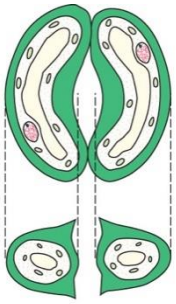


Stomata (singular: **stoma**):
- An opening controlled by **guard cells**.
- In the presence of light, allows **carbon dioxide** to enter and **oxygen** to be released.

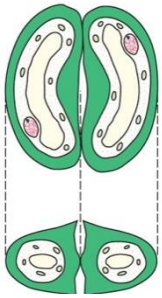
Figure 6.17 Transverse section of a leaf as seen under the microscope

Control of the stomata by guard cells

- Presence of light:
  Guard cells **photosynthesise** and release chemical energy that is used to pump ions into the cells. The ions **lower** the water potential in the guard cells. Water moves **into** the guard cells until they become **turgid**. Guard cells have unevenly thickened cell walls as the wall adjacent to the pore is very thick while the wall furthest from the pore is thin. Hence when the cells become turgid, the stoma **open**.
- Absence of light:
  The ions diffuse out of the guard cells. This **increases** the water potential. Water moves **out** of the guard cells by osmosis. The guard cells become **flaccid** which causes the stomata to **close**.



Guard cells turgid, stoma opens



Guard cells flaccid, stoma closes

Figure 6.18 The opening and closing of stoma

Entry of carbon dioxide and water into the leaf

- During the day, the plant carries out photosynthesis and **carbon dioxide** is rapidly used up.
- The carbon dioxide concentration inside the leaf is **lower** than the atmosphere, causing carbon dioxide to **diffuse** into the leaf via the **stomata** (NOT guard cells).

- The carbon dioxide dissolves in the **film of water** surrounding the mesophyll cells and diffuses into cells.
- **Water and mineral salts** move into the leaf through the xylem. Once out of the vein, these substances move from **cell to cell** right through the mesophyll of the leaf.

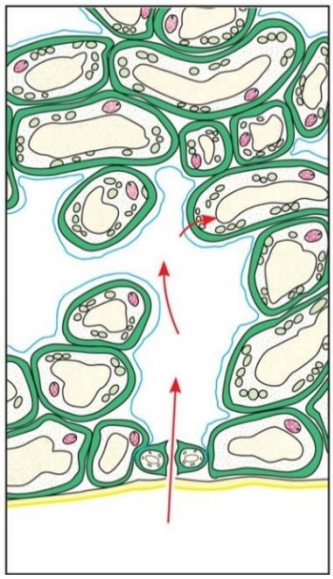


Figure 6.19 Path of CO_2 into the mesophyll cells

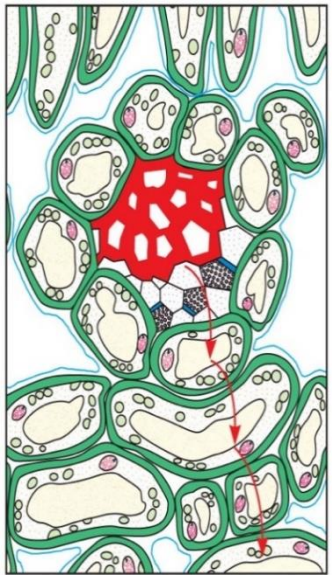
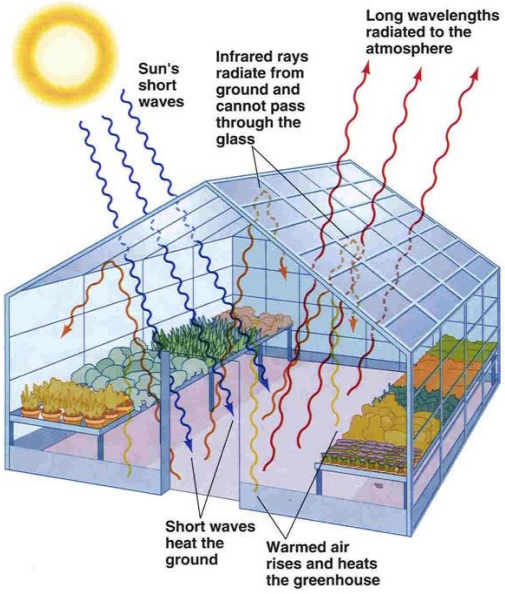


Figure 6.20 Path of water into the mesophyll cells

Extension

THE GREENHOUSE

- CO_2 is a greenhouse gas used in greenhouses in which plants are grown. It absorbs a portion of the infrared radiation and re-emit it in all directions; **trapping heat**.
- Many crops such as tomatoes give higher yield when grown in greenhouses due to the increased CO_2 concentration and temperature which increase rate of photosynthesis.
- Some companies pump waste CO_2 into greenhouses instead of the atmosphere. This not only reduces their **carbon footprint** but gives an additional profitable product.

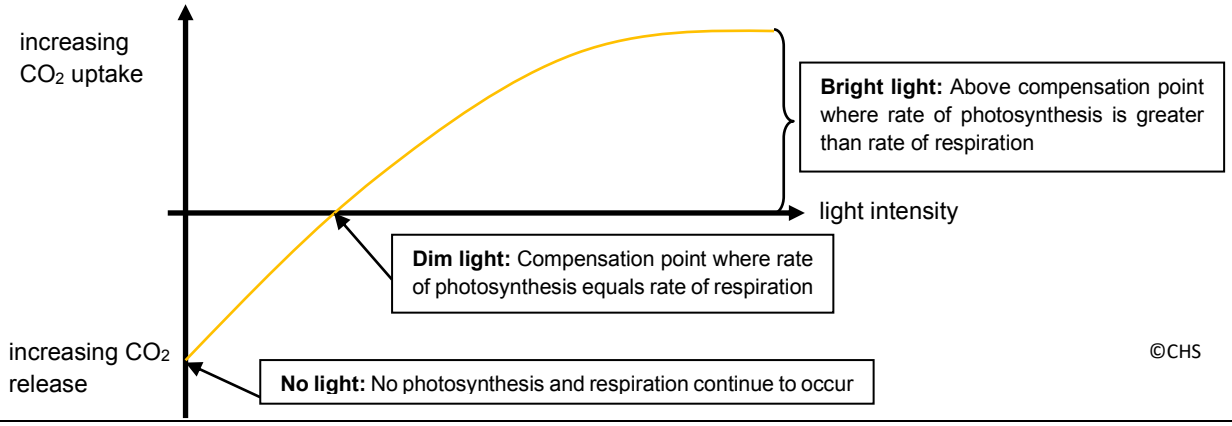


Source: http://www.indiana.edu/~geol105b/1425chap7.htm

THE COMPENSATION POINT

It is the light intensity at which the **rate of photosynthesis = rate of respiration**.

- All CO_2 produced during respiration is used for photosynthesis and all the oxygen produced during photosynthesis is used for respiration.
- **No gaseous exchange** between the plant and its environment at compensation point.



The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 07 – Transport in Plants

Name: **Class:**

A. Content

- Transport Structures in Flowering Plants
- Movement of Water and Food in Flowering Plants

B. Learning Outcomes

Students should be able to:

(a) identify the positions and explain the functions of xylem vessels, phloem (sieve tube elements and companion cells) in sections of a herbaceous dicotyledonous leaf and stem, under the light microscope.

(b) relate the structure and functions of root hairs to their surface area, and to water and ion uptake.

(c) explain the movement of water between plant cells, and between them and the environment in terms of water potential. (Calculations on water potential are not required).

(d) outline the pathway by which water is transported from the roots to the leaves through the xylem vessels

(e) define the term transpiration and explain that transpiration is a consequence of gaseous exchange in plants

(f) describe and explain

- the effects of variation of air movement, temperature, humidity and light intensity on transpiration rate
- how wilting occurs

(g) define the term translocation as the transport of food in the phloem tissue and illustrate the process through translocation studies

C. References

1. Hoh, Y. K. Longman A-Level Course in Biology (1st ed). Singapore: Longman.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Starr, C. Biology Concepts and Applications (6th ed). Brooks/Cole Publishing Company.

D. Lecture Outline

1. The transport structures of flowering plants
2. Studying the movement of substances in plants
3. Entry of water in plants
4. Moving water against gravity
5. Factors affecting rate of transpiration
6. Wilting
7. Additional reading materials

E. Practical Work

- To investigate the transport of materials in the stem of the flowering plants
- To investigate the structure of *Heliantus* (sunflower) leaf

1. THE TRANSPORT STRUCTURES OF FLOWERING PLANTS

There are two types of transport or vascular tissues: **xylem** (wood) and **phloem**.

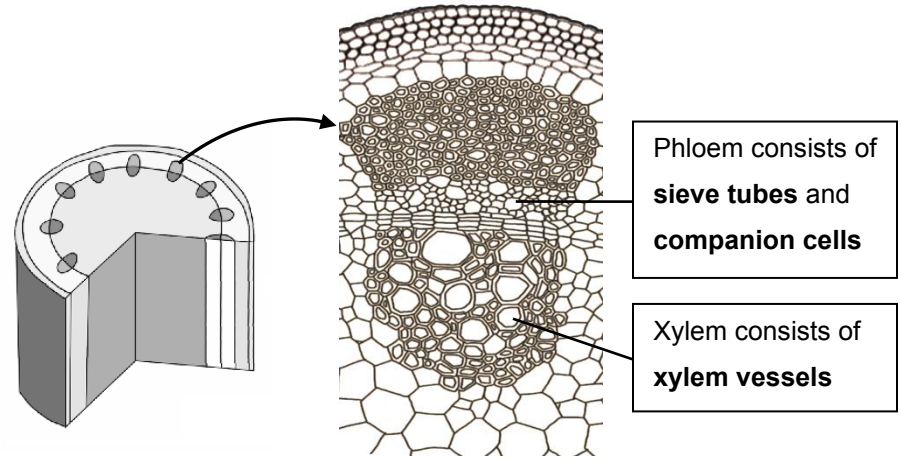


Figure 7.1 Arrangement of vascular bundles in a stem

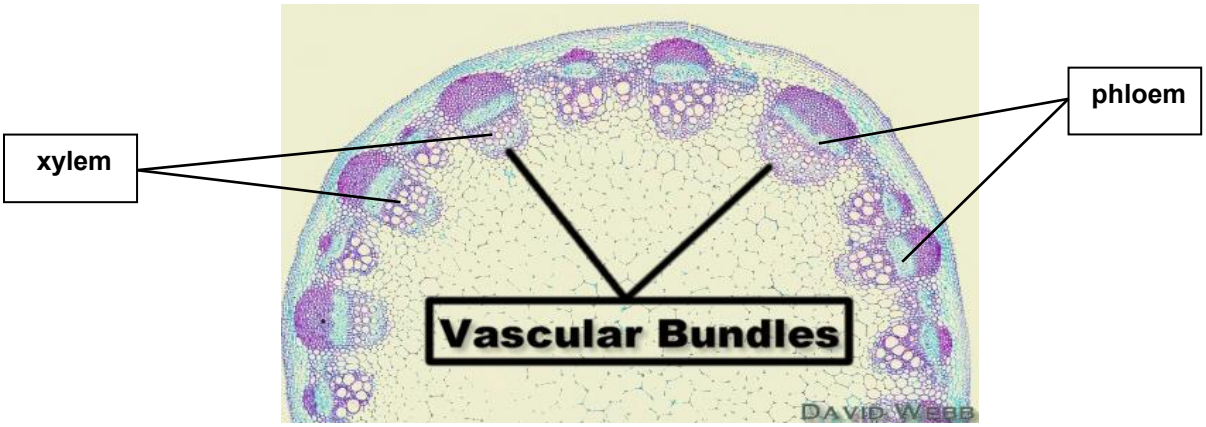


Figure 7.2 Scanning electron micrograph of a stem (transverse section)

Table 7.1 Adaptations of xylem

Functions	Adaptations
Conducts **water** and dissolved **mineral salts** from the roots to the stems and leaves (unidirectional)	Xylem vessels are **long hollow tubes** without any cross walls or protoplasm. This provides a continuous **lumen** and hence, reduces **resistance** to the flow of water.
Provides **mechanical support** for the plant when xylem vessels are bundled together (collectively).	The inner walls of xylem vessels are strengthened by deposits of **lignin** to prevent collapse of vessels.

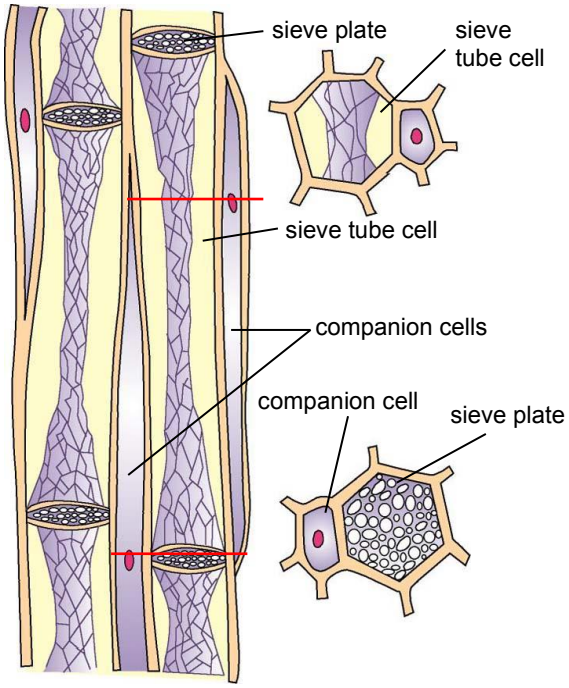


Figure 7.3 Longitudinal section of the phloem tissue

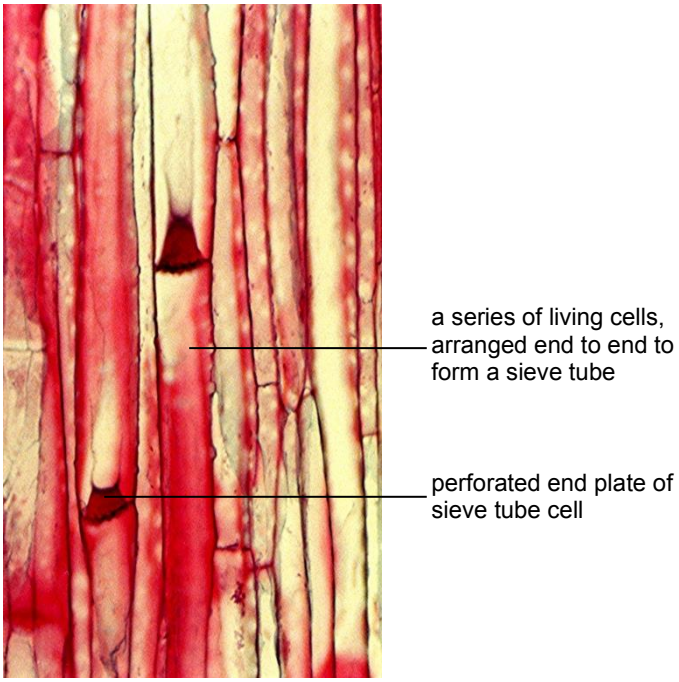


Figure 7.4 Part of a sieve tube in phloem
Source: http://metabolism.net/bidlack/

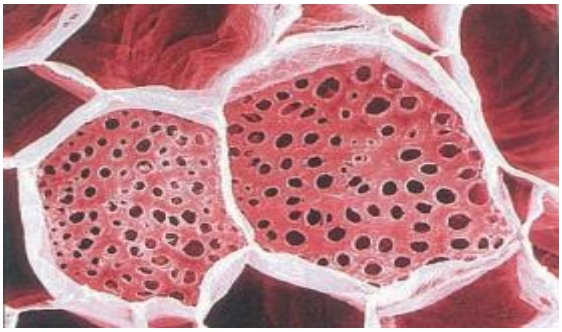
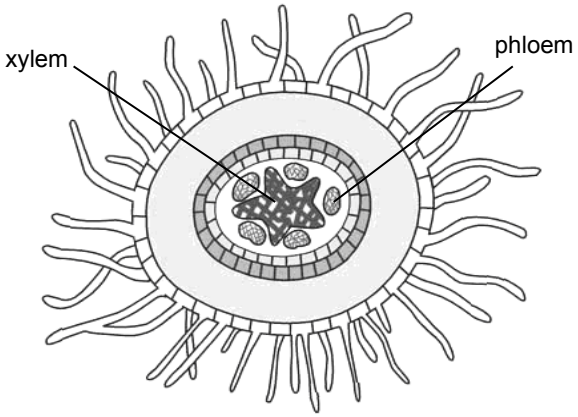
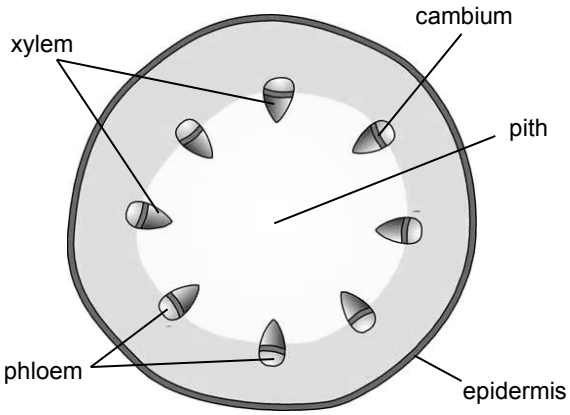


Figure 7.5 Scanning electron micrograph of the sieve plate on the end of two side-by-side sieve tubes
Source: http://www.educationphotogallery.com/

Table 7.2 Adaptations of phloem

Functions	Adaptations
Transports **sucrose** and **amino acids** from the leaves (and green parts of the plant) to the other parts of the plant when photosynthesising or from storage organs to leaves when not photosynthesising or in dark	(1) Phloem **sieve tube cell** has only a thin layer of cytoplasm and has lost its central vacuole, nucleus and most organelles (Fig 7.3). The 'end-walls' called **sieve plates** have pores (Fig 7.4). These structures allow ease of movement of manufactured food in the sieve tubes. (2) **Companion cells** have numerous **mitochondria** to release energy for the loading of sugars from mesophyll cells into phloem sieve tubes by active transport.

Table 7.3 Positions of xylem and phloem in (a) root and (b) stem

(a) Root	(b) Stem
	
(1) The xylem and phloem are not bundled together. (2) They are located at the **centre** of the root with the xylem and phloem **alternating** with each other.	(1) The xylem and phloem are grouped together to form **vascular bundles**. (2) Vascular bundles are arranged in a **ring** around the central region (pith). (3) The phloem lies outside the xylem with a tissue called **cambium** between them. Cambium cells divide and differentiate to form new xylem and phloem tissues.

2. STUDYING THE MOVEMENT OF SUBSTANCES IN PLANTS

Translocation is defined as the transport of **sucrose** and **amino acids** in **solution**, in **phloem**, from the source (e.g. leaves) to sink (e.g. storage organs).

Translocation studies using aphids

- The fluid that exudes from the cut end of the proboscis of a feeding aphid contains **sucrose and amino acids**.
- If the stem is sectioned and examined under a microscope, you will see that the feeding stylet of the aphid is inserted into the **sieve tube** (Fig. 7.6). This shows that translocation occurs in the **phloem** tissue.

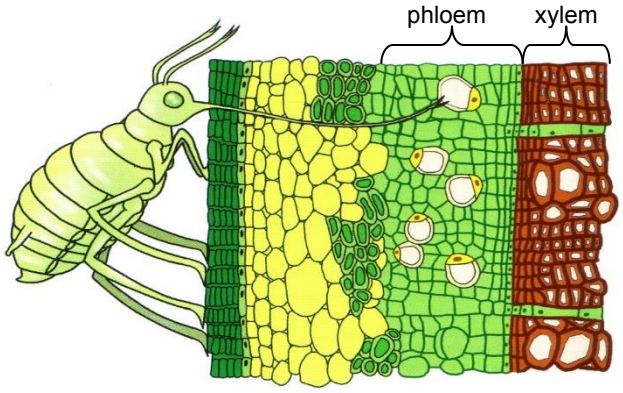


Figure 7.6 Feeding stylet inserted into the phloem

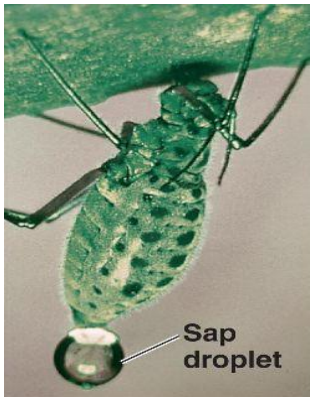


Figure 7.7 High pressure in phloem forced droplet of sugary fluid out through the terminal opening of aphid gut

Source: http://bio1152.nicerweb.com/

Translocation studies using the 'ringing experiment'

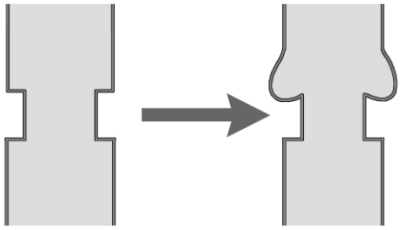
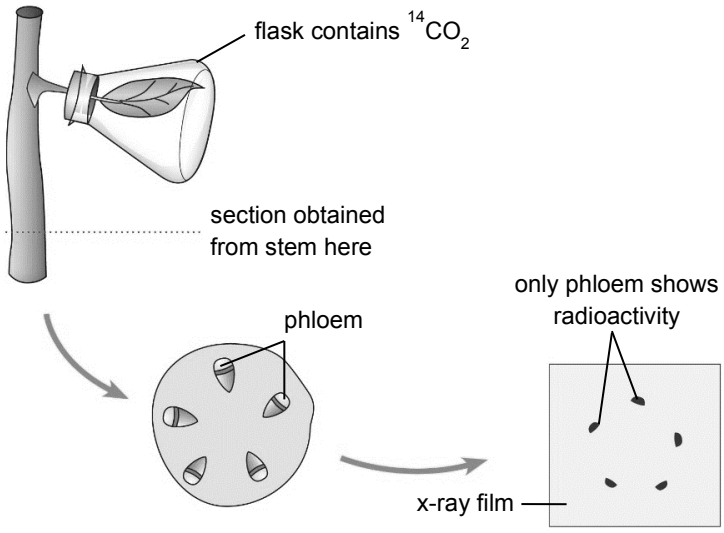


Figure 7.8 Swelling in stem caused by 'ringing experiment'

- Removing a ring of bark from a woody branch will result in the removal of the **phloem and cambium tissue** in that region. Swelling will be observed in the region above the ring.
- The swelling above the ring where the phloem is removed is caused by an **accumulation** of sugars in the region above the ring (Fig. 7.8).

Translocation studies using radioactive carbon isotopes



- CO_2 labelled with radioactive carbon (^{14}C) fed to the leaves in the light is turned into radioactive sugars.

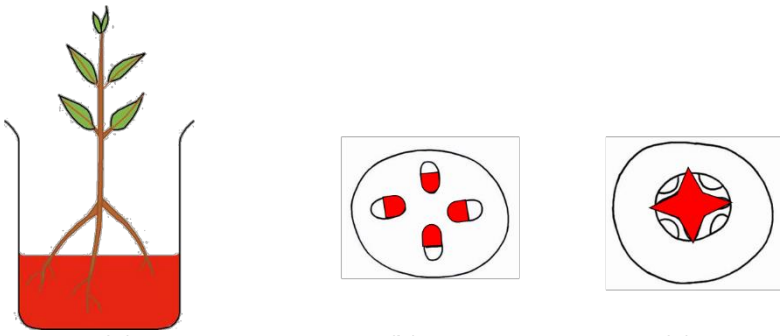
  $^{14}CO_2 + H_2O \rightarrow {}^{14}C_6H_{12}O_6 + O_2 + H_2O$

- Stem section is firmly held against photographic film in the dark for an extended period to allow the presence of radioactivity to show up.
- Radioactivity would be detected in the **phloem** showing that **sugars** containing radioactive carbon have translocated in the phloem.

Figure 7.9 Use of radioisotopes in translocation

Studying the path of water through a plant

Immersing the **roots** of a young plant in dilute red ink solution for a few hours will result in the **xylem vessels** being stained red.



(a) (b) (c)

Figure 7.10 (a) Immersing roots of a young plant in dilute red ink solution
(b) Xylem vessels stained red in stem (c) Xylem vessels stained red in root

3. ENTRY OF WATER IN PLANTS

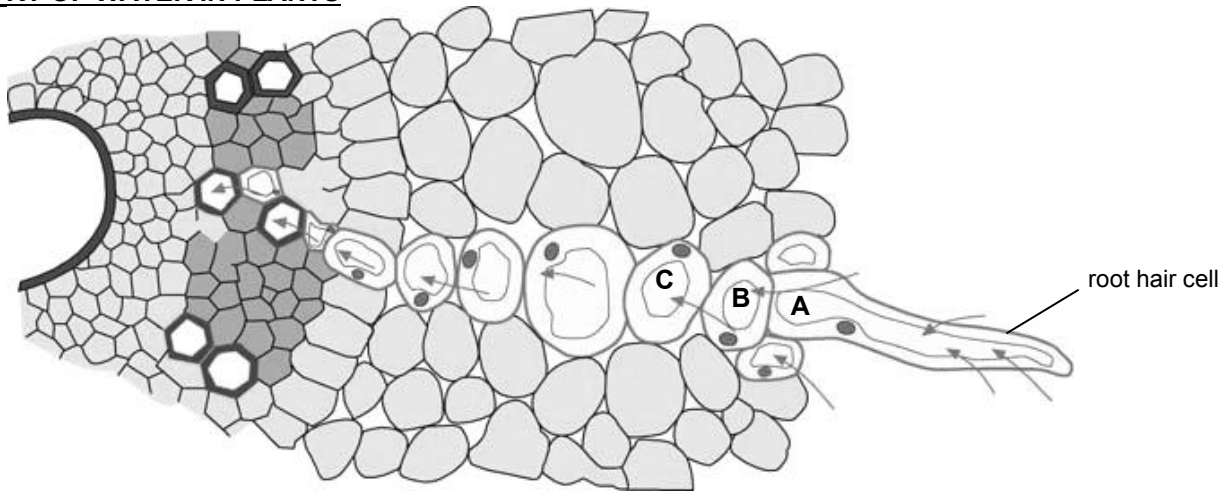


Figure 7.11 The path of water through the root

The process responsible for the intake of water into plant root hairs is **osmosis**.

3.1 Movement of water in the root (reference to Fig. 7.11)

(a) The entry of water dilutes the root hair's cell sap. The sap of the root hair cell now has a higher water potential than that of the next cell (cell B). Hence, water passes by osmosis from the root hair cell into the inner cell, down the water potential gradient.
(b) Similarly, water passes from cell B into the next cell (cell C) by osmosis.
(c) This process continues until water reaches the xylem vessels in the root (root pressure explained in Section 4.1).

3.2 Adaptations of root hair cell

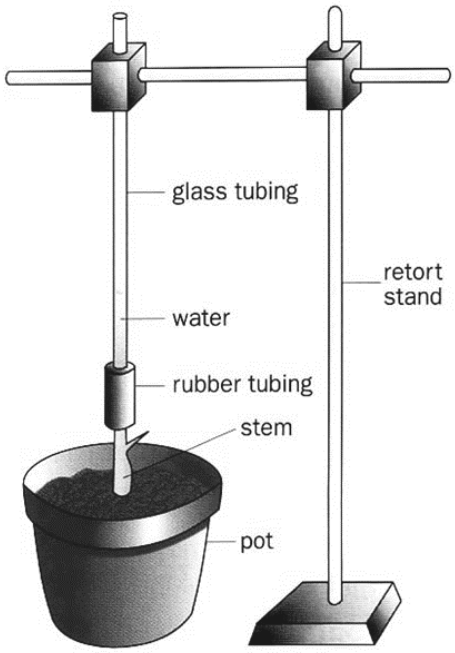
(1) They are **long and narrow** to increase the **surface area to volume ratio**.
(2) Presence of mitochondria to release energy (from cellular respiration) for **active transport** of mineral salts.
(3) Presence of selectively permeable **cell membrane** and lower water potential of cell sap allows water to enter the cell by **osmosis** down the water potential gradient.

4. MOVING WATER AGAINST GRAVITY

Three processes by which water flows from the roots to the aerial parts of a plant:

(1) **Root pressure**
(2) **Capillary action**
(3) **Transpiration pull**

4.1 Root pressure



- Root pressure is the process where the living cells around xylem vessels in the root pump ions into the xylem vessels by active transport. This lowers the water potential in the xylem vessels, causing water to move into the xylem vessels in the roots by osmosis and flows upwards.
- The effect of root pressure is more observable at night when the transpiration rate is low.
- Root pressure can be shown by cutting a plant off near the ground and attaching a glass tube to the cut end of the stem.

Figure 7.12 Water exudes from cut end of stem and rises in glass tubing due to root pressure.

4.2 Capillary action

- Capillary action is the movement of water up very **narrow tubes** like xylem vessels, due to the **cohesive** and **adhesive** interactions.
- Cohesion occurs between **like molecules**, in this case, water molecules maintained by hydrogen bonds (Fig. 7.13).
- Adhesion is the force of attraction between **unlike molecules**; water molecules and the inner surface of xylem vessels.
- This adhesion force is not a mechanism for the upward movement of water in the xylem but merely supports a column of water in it.
- Capillary action only plays a part in the upward movement of water in small plants.
- The **narrower** the xylem vessel, the **greater** the effect of capillary action (Fig. 7.14).

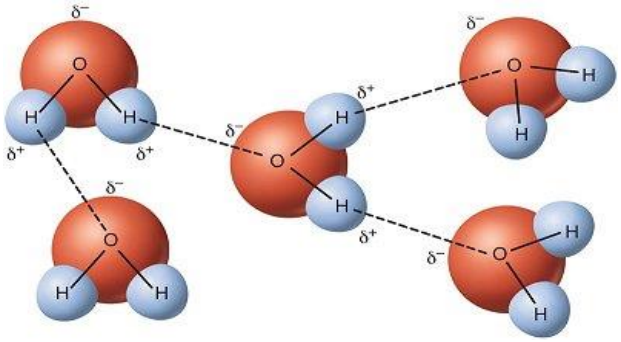


Figure 7.13 Hydrogen bonds between water molecules
Source: https://manoa.hawaii.edu

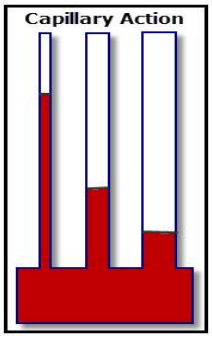


Figure 7.14 Capillary action in tubes of different diameters
Source: http://scienceprojectideasforkids.com/2010/capillary-action-transpiration/

4.3 Transpiration

- Definition: Transpiration is the loss of **water vapour** from the aerial parts of the plant, mainly through the **stomata** of the **leaves**.
- Most of the water vapour is lost from inside the leaf, only a very small amount of water may evaporate directly from the surfaces of the epidermal cells. This is **cuticular transpiration**.
- **Transpiration pull** is the main **suction force** that draws water and dissolved mineral salts up the xylem vessels, explained through the **cohesion-tension theory.**
- When the rate of transpiration is high, the water in the xylem vessel is under great tension due to the cohesive forces between the water molecules.
- Transpiration is a consequence of **gaseous exchange** in plants due to the opening of stomata to allow carbon dioxide to diffuse into the leaf for photosynthesis.

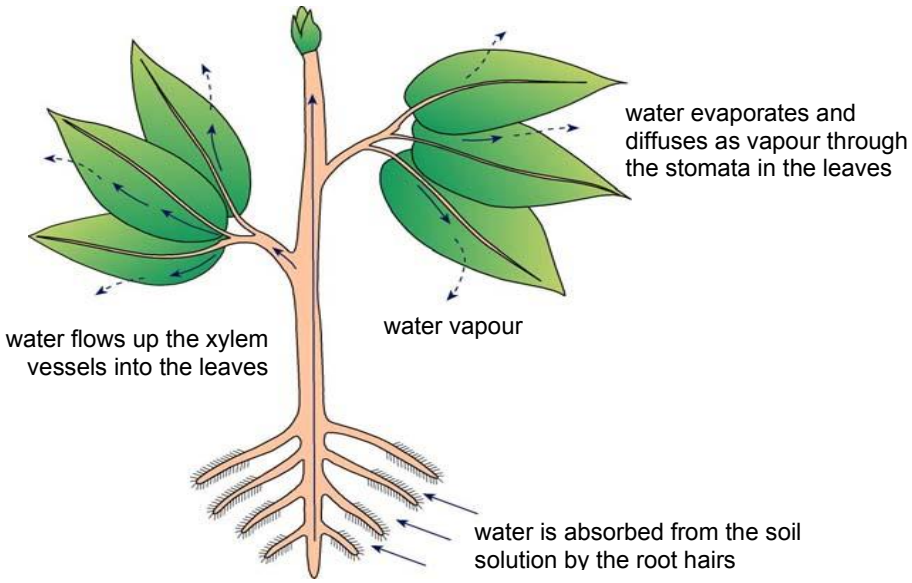


Figure 7.15 Transpiration stream in plant

How is transpiration involved in moving water against gravity?
(1) Water continuously moves out of the mesophyll cells to form a **thin film of moisture** over their surfaces.
(2) Water **evaporates** from this film of moisture into the **intercellular air spaces**. This results in a high concentration of water vapour at the sub-stomatal air spaces.
(3) Water vapour **diffuses** through the stomata out of the leaf, into the surrounding air, down the concentration gradient.
(4) As water evaporates from the mesophyll cells, the water potential of the cell sap decreases. The mesophyll cells begin to absorb water by **osmosis** from the cells deeper inside the leaf. In turn, these cells remove water from the xylem vessels.
(5) This continuous **suction force** which pulls the whole column of water up the xylem vessels is **transpiration pull**. Transpiration stream refers to the stream of water that moves up the plant.

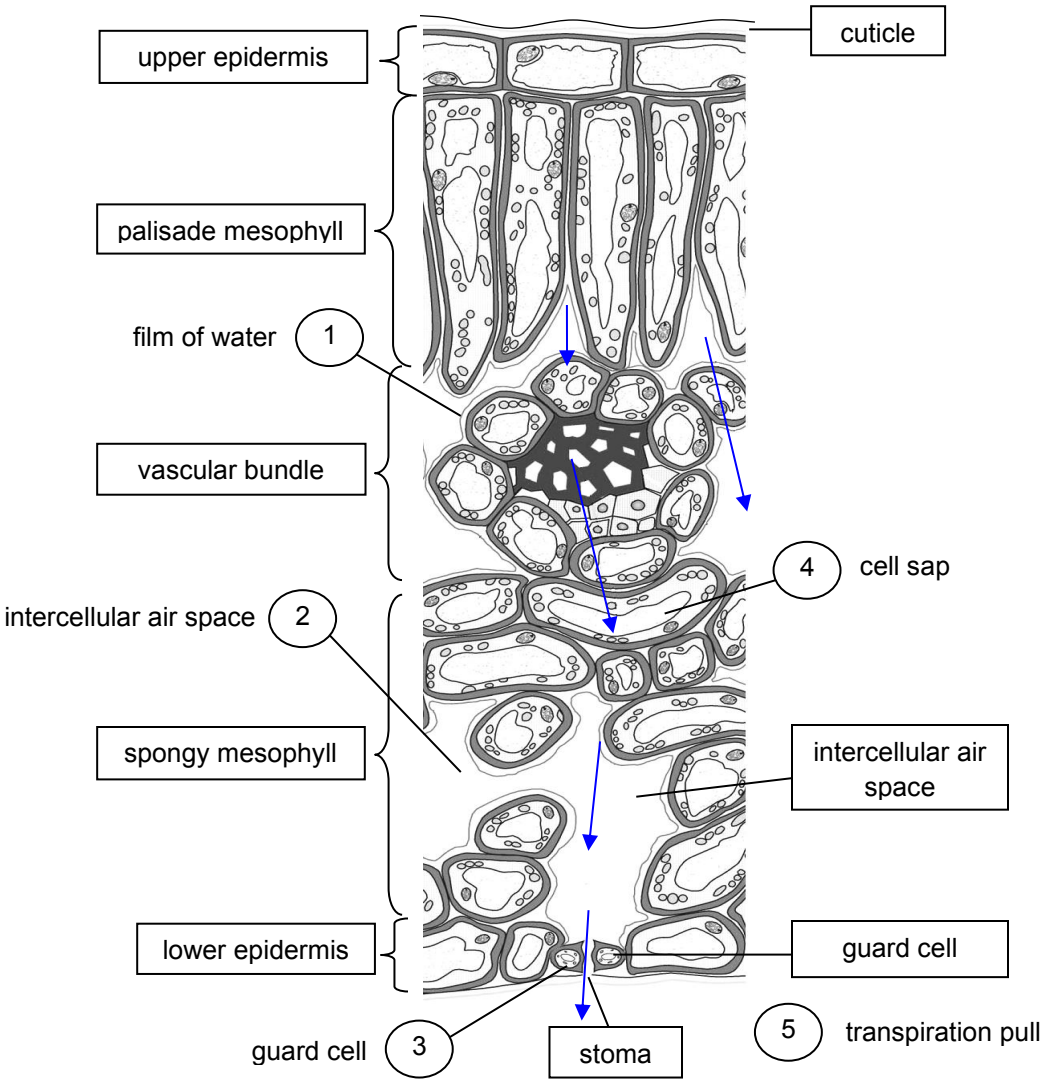


Figure 7.16 Movement of water out of the stoma of a leaf during transpiration

Importance of transpiration:
(1) Transport water and dissolved mineral salts up the plant from roots to the leaves.
(2) Cools the plant by removing latent heat of vaporisation (via evaporation of water from thin film of moisture).
(3) Supply water to cells for metabolic processes like photosynthesis and keep cells turgid.

How do we measure the rate of transpiration?
- A **potometer** is used to directly measure the rate of absorption of water in a plant (98% water loss by transpiration + 1% water consumption for cell expansion + 1% photosynthesis).
- A shoot that is to be used must be cut under water and cut end kept immersed in water for a few hours before use.
- It can be used to measure the rate of transpiration in a plant, assuming that the rate of absorption is **proportional** to the rate of transpiration.
- The rate of transpiration can be calculated using the following formula:

$$\text{rate of transpiration } (cm^3/h) = \frac{\text{volume of water lost}}{\text{time taken}}$$

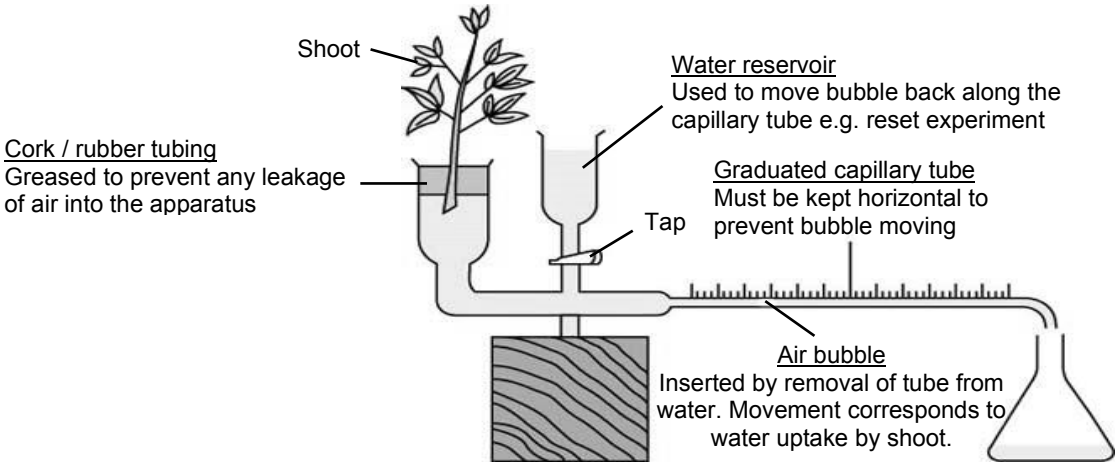


Figure 7.17 Experimental set-up to measure the rate of transpiration using a potometer

- The volume of water lost is represented by the distance moved by the air bubble in the experimental setup shown in Fig. 7.17.

5. Factors affecting rate of transpiration

- The rate of transpiration varies with time over a 24 hour period (Fig. 7.18).
- This is due to variations in the environmental factors such as air **temperature**, **humidity**, **wind (or air) movement** and **light intensity**.

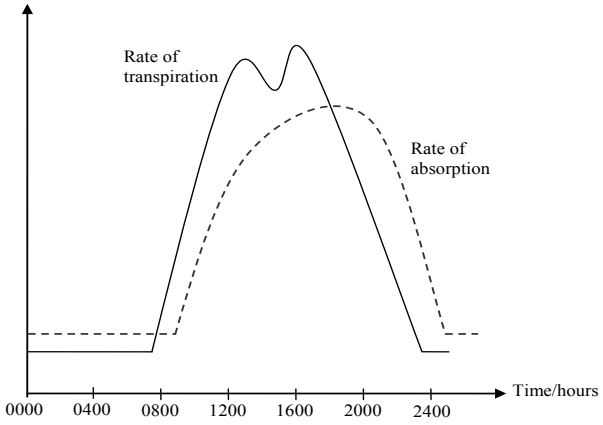


Figure 7.18 Pattern of rate of transpiration in a day

5.1 Air temperature

- An increase in temperature increases the **kinetic energy** of water molecules and the rate of **evaporation** of water from the mesophyll cells surfaces.
- This increases the rate of **diffusion** of water vapour out via the stomata. Thus, rate of transpiration **increases**.

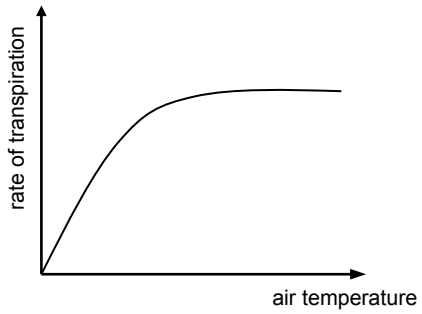


Figure 7.19 Relationship of rate of transpiration to air temperature

5.2 Air Humidity

- A rise in air humidity increases the concentration of **water vapour** in the air.
- Water vapour concentration gradient becomes **less steep** between the intercellular air spaces in leaf and the surrounding air.
- This decreases the rate of diffusion of water vapour out via the stomata. Thus, rate of transpiration **decreases**.

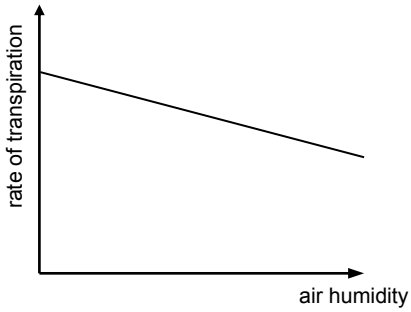


Figure 7.20 Relationship of rate of transpiration to air humidity

5.3 Wind or air movement

- Wind will **blow away water vapour** that accumulates outside the stomata.
- Water vapour concentration gradient becomes **steeper** between the intercellular airspaces in leaf and the surrounding air.
- This increases the rate of diffusion of water vapour out via the stomata. Thus, rate of transpiration **increases**.

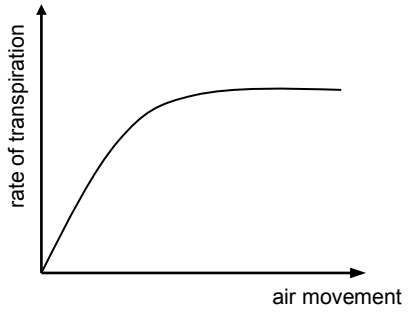


Figure 7.21 Relationship of rate of transpiration to air movement

5.4 Light intensity

- In sunlight, guard cells undergo photosynthesis. This results in guard cells becoming turgid and pulling stomata open.
- As light intensity increases, the size and number of stomatal opening increases.
- This increases the rate of diffusion of water vapour out via the stomata. Thus, rate of transpiration **increases**.

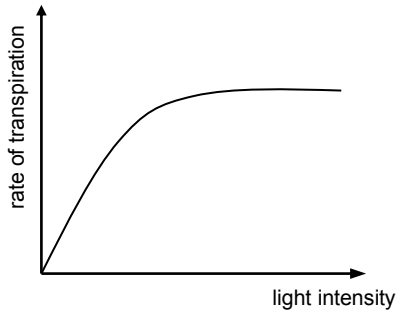


Figure 7.22 Relationship of rate of transpiration to light intensity

6. WILTING

- Wilting occurs due to **excessive transpiration**; rate of water loss exceeds rate of water absorption.
- Cells are **plasmolysed** and **loses turgor pressure** during wilting (Fig. 7.23).
- Loss of turgor pressure in the mesophyll cells results in the leaf folding up (Fig. 7.24).
- Wilting is a temporary defense mechanism of a plant to **dehydration**.
- Prolonged period of wilting will lead to the death of the plant.

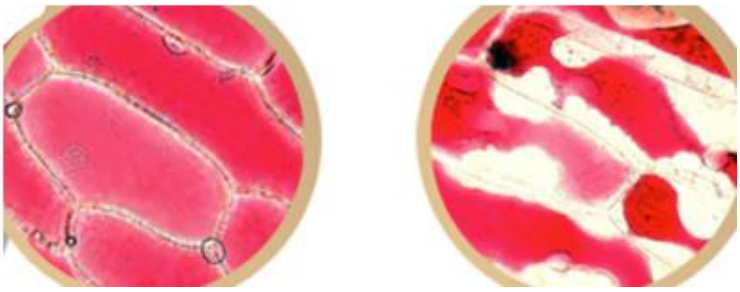


Figure 7.23 Turgid plant cell (left) and plasmolysed plant cell during wilting (right)

Figure 7.24 Normal plant (left) and wilted plant (right)

Table 7.4 Advantages and disadvantages of wilting

Advantages	Disadvantages
The surface area exposed to sunlight is reduced. This reduces water lost through transpiration.	Wilting results in the closure of the stomata. This reduces the amount of carbon dioxide entering the leaf and hence, decreases the rate of photosynthesis. The decrease in surface area of the plant exposed to sunlight also reduces the rate of photosynthesis.

7. ADDITIONAL READING MATERIALS

Mass flow hypothesis

- Sucrose is transported from the mesophyll cells into the sieve tube by **active transport**.
- Mass flow hypothesis is one of the hypotheses put forward to account for translocation within sieve tubes.

(1) Sucrose produced in the mesophyll cells is actively transported into the sieve tube elements. This decreases the water potential in the sieve tube elements by the accumulation of sucrose. As a result, water in the xylem enters the sieve tube elements by osmosis, generating a high **hydrostatic pressure**.
(2) In the roots, sucrose is either broken down into glucose to be used for respiration or converted to starch for storage. The decrease in sucrose content at this part of the sieve tube increases the water potential of the content. As a consequence, water flows out into neighbouring cells by osmosis and a low hydrostatic pressure develops.
(3) The difference in hydrostatic pressure between the source and sink causes water and solute molecules to move from the source to the sink in the same direction, also known as **mass flow**.

Criticism of mass flow hypothesis

- This hypothesis does not explain the existence of sieve plates which seem to be barriers to the movement of water and sucrose molecules.
- This hypothesis does not necessitate phloem tissue to be a living tissue.
- When ATP production is inhibited, translocation is stopped. However, the mass flow hypothesis suggests that translocation is largely a passive phenomenon. It does not explain why companion cells contain many mitochondria.

Xerophytes

- Xerophytes are plants that grow in deserts or in very dry places and have the ability to withstand a prolonged period of drought.
- These plants have certain structural features that enable them to reduce transpiration. Examples include:

(1) Some leaves have **few stomata** and these are **sunken** in grooves which allow for water vapour given off to be collected.
(2) **Protective hairs** can be found on the leaves to trap moist air in the hair layer.
(3) **Thick cuticles** are found on both the upper and lower epidermis.
(4) Leaves are rolled up or reduced to small scales or spines to **minimise surface area**.
(5) Some plant species **store much water in their leaves** which become thick and fleshy.
(6) Some plant species evolved alternative modes of carbon fixation (e.g. C4 and crassulacean acid metabolism, or CAM) to minimise water loss in the day by closing the stomata and opening them only at night, when temperatures are typically lower.

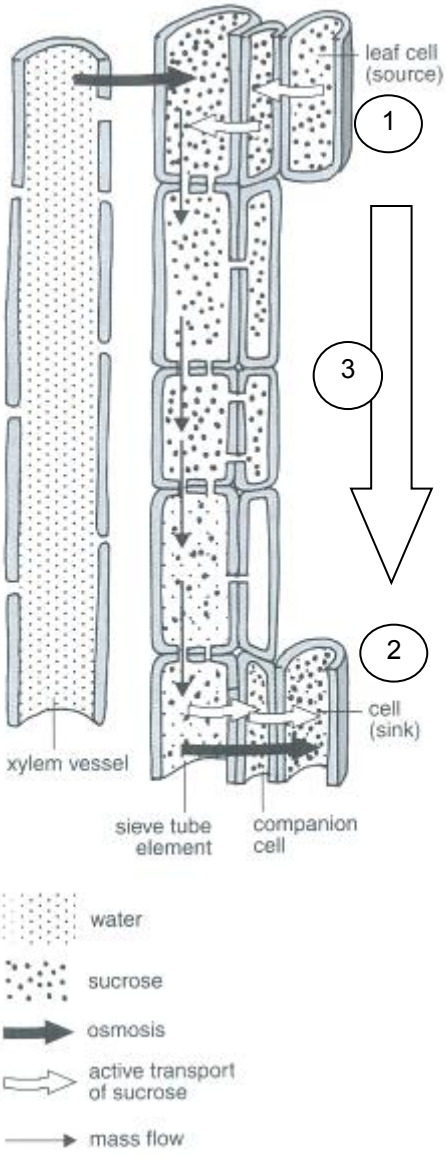


Figure 7.25 Mass flow hypothesis

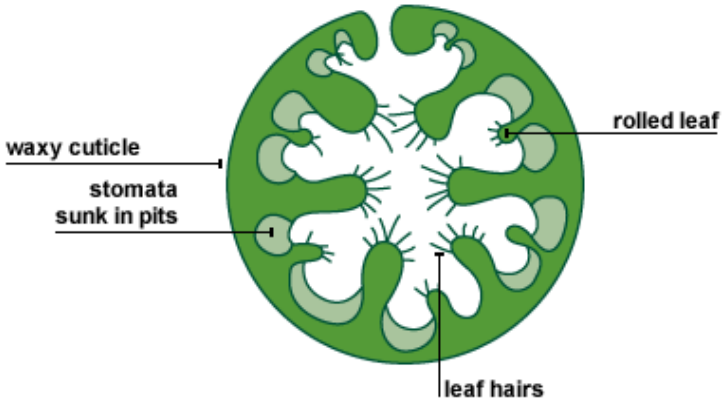


Figure 7.26 Structural adaptations in xerophytes
Source: http://www.bbc.co.uk

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 08 – Transport in Humans

Name: **Class:**

A. Content

• Circulatory system

B. Learning Outcomes

Students should be able to:

(a) identify the main blood vessels to and from the heart, lungs, liver and kidney.

(b) state the functions of blood

- red blood cells – haemoglobin and oxygen transport
- white blood cells – phagocytosis, antibody formation and tissue rejection
- platelets – fibrinogen to fibrin, causing clotting
- plasma – transport of blood cells, ions, soluble food substances, hormones, carbon dioxide, urea, vitamins, plasma proteins

(c) list the different ABO blood groups and all possible combinations for the donor and recipient in blood transfusions.

(d) relate the structure of arteries, veins and capillaries to their functions.

(e) describe the transfer of materials between capillaries and tissue fluid.

(f) describe the structure and function of the heart in terms of muscular contraction and the working of valves.

(g) outline the cardiac cycle in terms of what happens during systole and diastole. (Histology of the heart muscle, names of nerves and transmitter substances are not required).

(h) describe coronary heart disease in terms of the occlusion of coronary arteries and list the possible causes, such as diet, stress and smoking, stating the possible preventative measures.

C. References

1. Burton, I. J. GCE O Level The Cambridge Biology Revision Guide. (4th ed) Cambridge University Press.
2. Hoh, Y. K. Longman A-Level Course in Biology (1st ed). Singapore: Longman.
3. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
4. Postlethwait, J. H. and Hopson, J. L. Modern Biology (1st ed) USA: Holt, Rinehart and Winston.
5. Reece J.B., Urry L.A., Cain M.L., Wasserman S.A., Minorsky P.V. and Jackson R.B. Campbell Biology (10th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline

1. Introduction
2. Components of blood
3. Blood vessels
4. Transfer of materials
5. The human heart
6. Coronary heart disease
7. Additional reading materials

E. Practical Work

• Dissection of a mammalian heart

1. WHY DO WE NEED A TRANSPORT SYSTEM?

- Larger organisms have **smaller** surface area to volume ratio.
- Glucose, amino acids move **longer distances** to reach inner cells.
- Diffusion too **slow** and insufficient to meet needs.

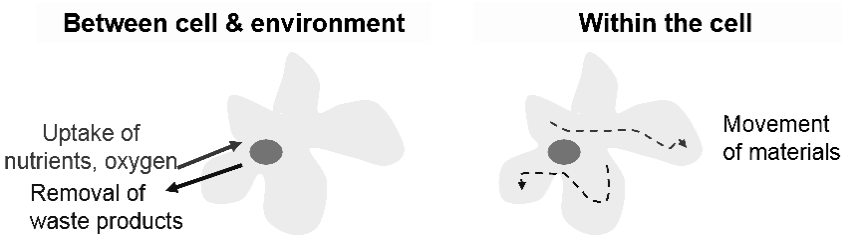


Figure 8.1 Movement of substances in a typical unicellular organism

Figure 8.2 In *Aurelia sp.*, food particles are carried throughout the body via diffusion.

Factors to consider for organisms to evolve a complex internal transport system include:

1. Shape of organism

The more compact or flattened the organism is, the shorter the distance for diffusion from exterior to inner cells. As larger organism has a lower surface area to volume ratio, diffusion becomes less efficient as more time is required for substances to diffuse from the exterior to the innermost cells.

2. Metabolism of organism

The higher the level of metabolic activity, the greater the need to deliver oxygen and glucose round the body. Mammals, which are capable of maintaining a constant body temperature (an endotherm), requires a larger amount of energy to remain active over a wide range of external temperatures as compare to cold-blooded organisms (an ectoderm).

A generic circulatory system consists of:

- **heart** (a muscular organ or pump),
- **circulatory fluid** (transport medium), and
- **blood vessels** (ensure one-way flow of circulatory fluid).

Closed circulatory systems

- Found in vertebrates like amphibians, reptiles and mammals (Figure 8.3).
- The circulatory fluid is **blood**.
- The heart pumps blood in confined and continuous circuit of blood vessels.
- In a closed circulatory system, the blood transported can be at higher pressures, thus increasing efficient delivery of oxygen and glucose to the cells of larger animals.

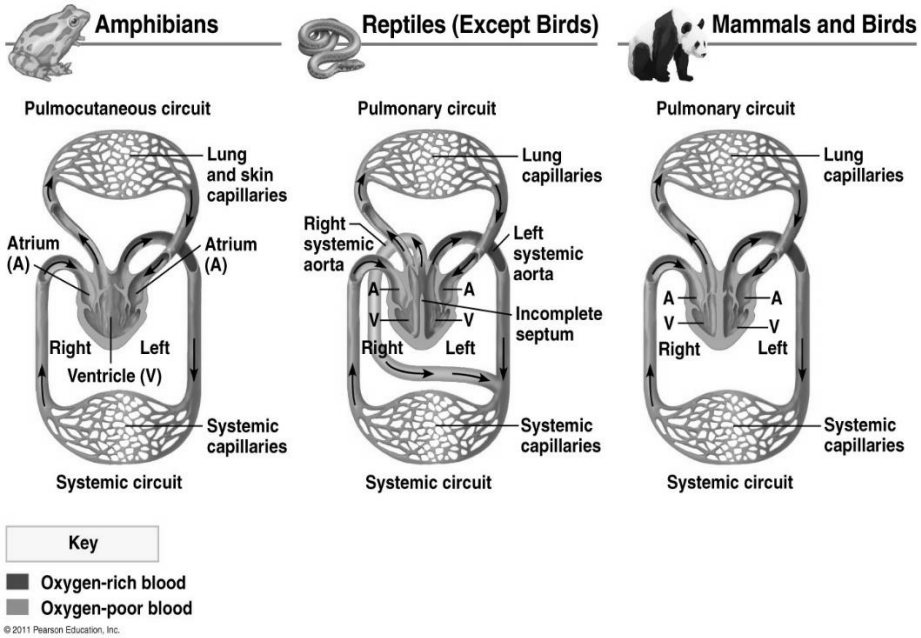


Figure 8.4 Circulatory schemes of vertebrates
Source: Campbell Biology

Extension

Open circulatory systems

- Found in many invertebrates like arthropods (e.g. grasshoppers), some molluscs and clams.
- The circulatory fluid is **hemolymph**, which occupies 20–40% of the body volume.
- Heart contraction pumps the hemolymph through the circulatory vessels into **interconnected sinuses**, where exchange of substances occurs between the hemolymph and body cells.
- Relaxation of the heart draws hemolymph back in through pores, which are equipped with valves that close when the heart contracts.
- Body movements periodically squeeze the sinuses, helping circulate the hemolymph.

Do you know?
What is the composition of hemolymph?

- Unlike blood, hemolymph contains mostly water, ions, carbohydrates, lipids, glycerol, amino acids, hormones, some cells and pigments.
- The pigments, however, are usually rather bland, and thus insect blood appears clear or tinged with yellow or green.

Source: DeSalle, R. (2001). How is bug blood different from our own? *Scientific American*, *284*(3), 44-49.

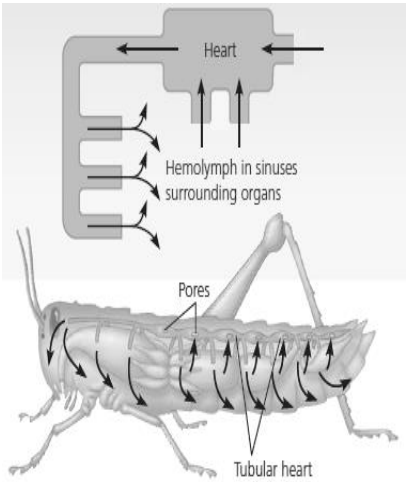


Figure 8.5 Diagrammatic illustration of an open circulatory system of a grasshopper

Human transport system

- Consists of a **blood system** and **lymphatic system**
- Blood system is a double circulation consisting of the **pulmonary circulation** and the **systemic circulation**
- Pulmonary circulation: deoxygenated blood is transported from the heart to the lungs, and returns oxygenated blood back to the heart.
- Systemic circulation: oxygenated blood is transported from heart to the body, and returns deoxygenated blood back to the heart.
- The lymphatic system is a one-way system from the interstitial fluid to cardiovascular system.

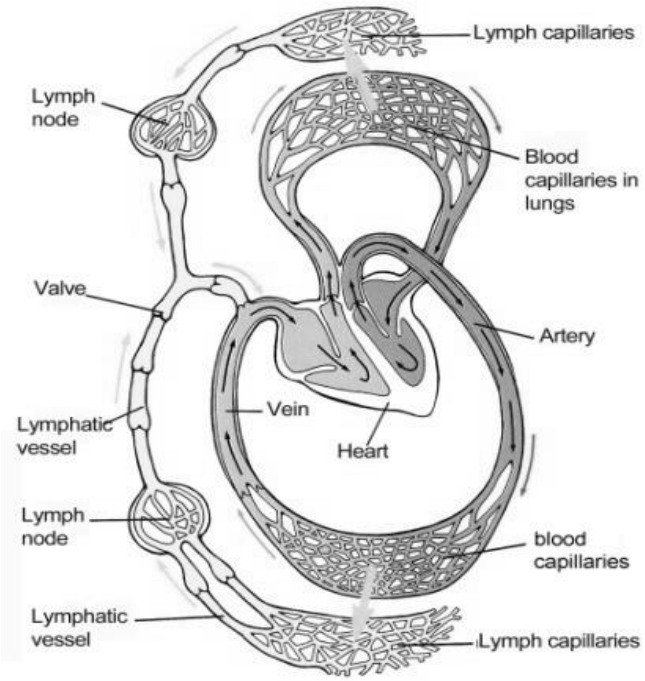


Figure 8.5 Lymphatic and blood systems

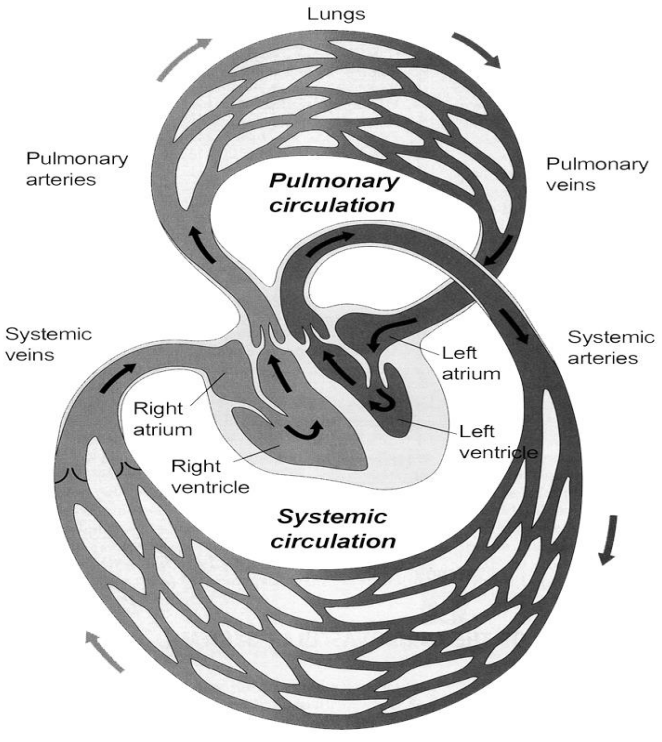


Figure 8.6 Systemic and pulmonary circulations
Source: Campbell Biology

2. COMPONENTS OF BLOOD

There are approximately 5.6 litres of blood in an average person. This takes up to about 10% of the body weight. Blood is a fluid tissue made up of **plasma**, **red blood cells**, **white blood cells** and **platelets**.

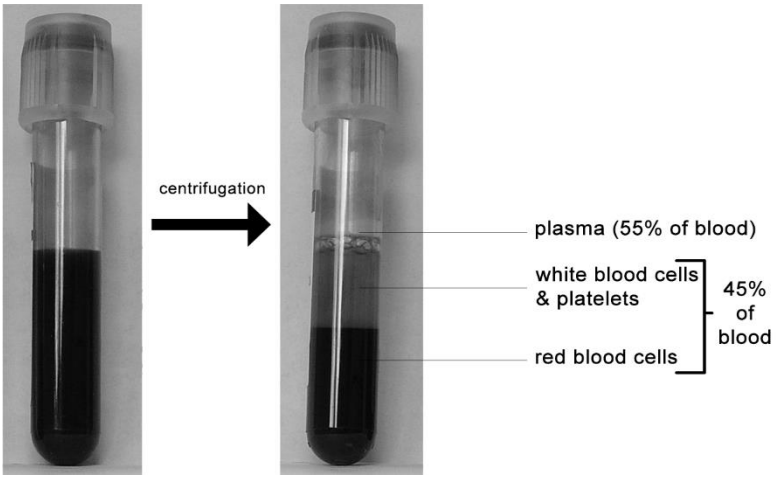


Figure 8.7 Composition of human blood after centrifugation

Blood plasma

- Pale yellowish solution composed mostly water.
- Transport substances such as digested food substances, excretory waste products, gases and hormones.
- Helps distribute heat around the body to maintain constant internal environment.

Table 8.1 List of substances transported by blood plasma

class of solute	examples
inorganic ions and salts	sodium chloride, calcium
plasma proteins	fibrinogen, albumin, antibodies
organic nutrients	glucose, amino acid
nitrogenous waste	urea
hormones	insulin, glucagon
dissolved gases	carbon dioxide, oxygen

Red blood cells (erythrocytes)

- Produced by bone marrow and contains red pigment called **haemoglobin**.
- Haemoglobin is a protein molecule composed of four sub-units. Each sub-unit consists of a globular protein attaching to a haem unit. The haem units comprised a porphyrin ring containing an atom of **iron**. Up to 4 oxygen molecules may be carried by each haemoglobin molecule (Figure 8.9).
- **Destroyed** in the **spleen** and **transported to liver** to be broken down.
- Heme from the haemoglobin is eventually broken down into **bile pigments** (e.g. bilirubin), where it is excreted in bile and urine.

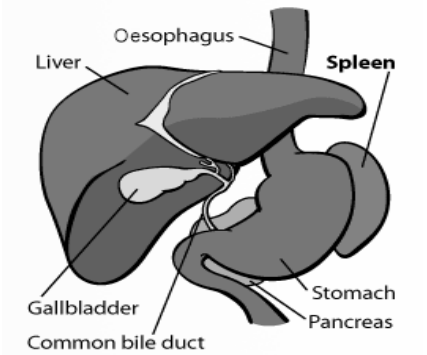


Figure 8.8 Location of the spleen and liver
Source: http://www.pedsurg.ucsf.edu/

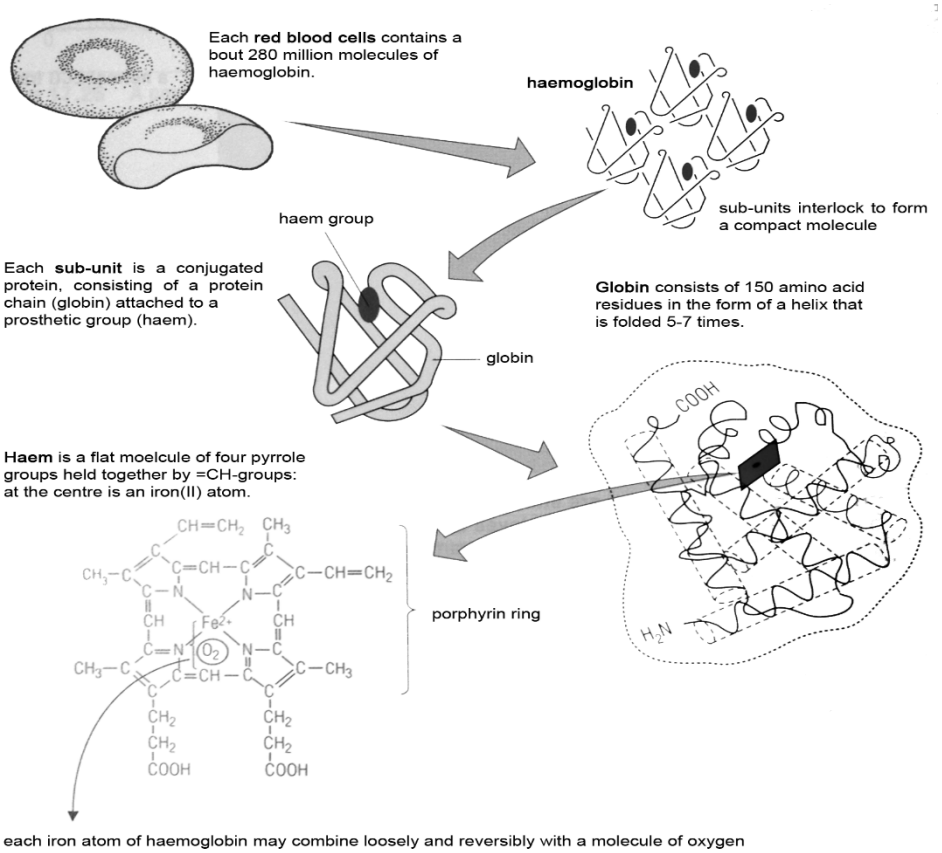


Figure 8.9 3-dimensional structure of haemoglobin molecule

Table 8.2 Adaptations of red blood cell

physical characteristics	how the adaptation relates to its function
biconcave in shape	increases surface area to volume ratio, for faster absorption of O_2
presence of **haemoglobin**	allows the red blood cell to transport oxygen
no nucleus (enucleate)	allows the red blood cell to carry more haemoglobin (NOT oxygen directly)
plasma membrane pliable or elastic	allows red blood cells to squeeze through capillaries that are smaller than its diameter
small size • 0.008 mm diameter • 0.002 mm thickness	same size as the lumen of capillary allows red blood cells to squeeze through capillaries thinness also permits efficient diffusion of respiratory gases

Table 8.3 Summary of substances transported by blood

substances transported	transported by	from	to
oxygen	red blood cells	lungs	all body cells
carbon dioxide (as hydrogen carbonate ions)	plasma	all body cells	lungs
urea (nitrogenous waste)	plasma	liver	kidney
digested food	plasma	intestine	body cells
hormones	plasma	endocrine glands	target cells
heat	plasma	liver and muscles	all body cells (excess to skin)

Transport of oxygen by red blood cells:
- As blood passes through the lungs of high oxygen concentration, oxygen **diffuses** from the alveoli (air sac) into the red blood cells.
- Haemoglobin has a great affinity for oxygen thus combines reversibly with oxygen to form **oxyhaemoglobin**.
- Blood transports oxygen to all the tissues of the body.
- As blood passes through tissue of low oxygen concentration, oxyhaemoglobin releases its oxygen (Figure 8.10).

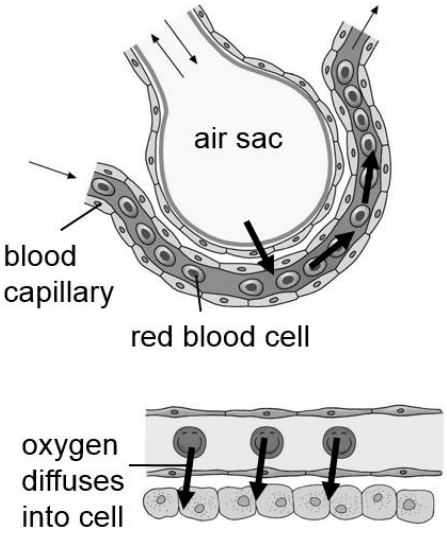


Figure 8.10 Transport of oxygen

Adaptations at high altitudes:
- People living at high altitudes have higher number of red blood cells to compensate for lower O_2 concentration.
- Increase number of red blood cells increases the amount of haemoglobin in the blood.
- Thus, more oxygen can be transported to the body cells per unit time.
- This is known as **acclimatisation**.

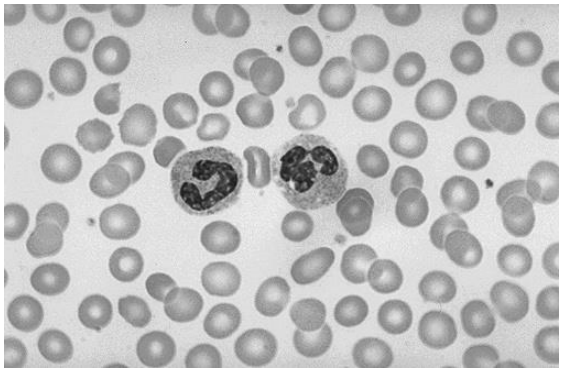


Figure 8.11 Blood smear of a normal individual under light microscope
Source: http://library.med.utah.edu/

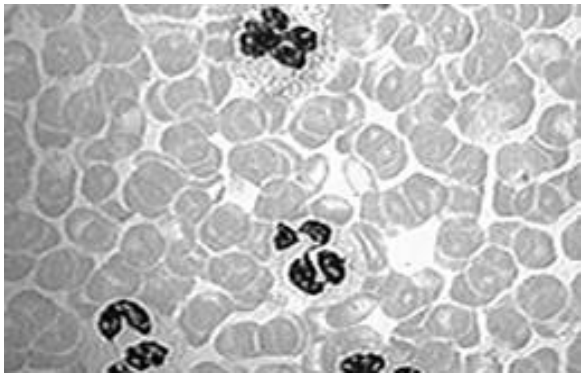


Figure 8.12 Blood smear of an individual acclimatised to higher altitudes, which contains 6 to 8 million red blood cells per cubic millimetre of blood

Effects of carbon dioxide and carbon monoxide:
- Haemoglobin can also combine with carbon dioxide (CO_2) and carbon monoxide (CO).
- Not very efficient to combine with CO_2 as most CO_2 is transported by plasma in solution as hydrogen carbonate ions (HCO_3^-).
- Carbon monoxide binds 200–250 times more readily with haemoglobin as compared to oxygen.
- If too much haemoglobin is combined with carbon monoxide (e.g. found in car exhaust fumes through incomplete combustion), less haemoglobin is available to carry oxygen. As a result, death may occur.

White blood cells (leucocytes)
- Larger than red blood cells, but are smaller in numbers (ratio of RBC:WBC is 700:1)
- Only 5 – 10 thousand cells/cm^3 of blood
- Colourless (no haemoglobin)
- Two types of white blood cells: **Lymphocytes** (e.g. B lymphocytes and T lymphocytes) and **Phagocytes** (e.g. neutrophils and macrophages)

(A) Lymphocytes

- Produced by the **bone marrow** and are then transported directly to the **lymph nodes**
- Large, rounded nucleus with small amount of non-granular cytoplasm
- Show limited movement and do not squeeze through capillary walls
- Produce **antibodies** in response to foreign proteins called **antigens** from disease-causing organisms (pathogens) such as bacteria and viruses
- Functions of antibodies:
  - cause bacteria to **agglutinate** (clump together) to facilitate ingestion by phagocytes
  - neutralises **toxins** from bacteria
  - destroy bacteria by rupturing their cell membrane
- A person who has recovered become **immune** to the infection due to the antibodies which may stay in the blood long after the disease.

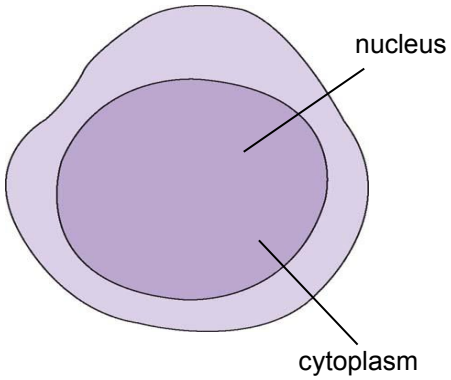


Figure 8.13 Lymphocyte

Extension

Origins of B and T Lymphocytes

- Lymphocytes originate and develop from stem cells located in the bone marrow in adults. Such stem cells may either migrate to the thymus (giving rise to **T lymphocytes**) or remain in the bone marrow (giving rise to **B lymphocytes**) to continue their path of development.
- At the end of their development, these young lymphocytes then migrate to the lymph nodes, spleen and tonsils, where they undergo final maturation.
- Mature lymphocytes are distributed around the body so that they come into contact with foreign pathogens and with each other.

B lymphocytes and the Antibody-mediated Immune Response (Humoral Immunity)

- B lymphocytes ("bone-derived lymphocytes cells") have a lifespan of a few days.
- B lymphocytes migrate directly from bone marrow to lymph nodes to undergo their final maturation, during which it makes just one type of antibody molecule.
- If a pathogen enters the body, B lymphocytes that recognise the pathogen (B lymphocytes with cell surface receptors that fit the antigens) will respond by:
  1. multiplying repeatedly to make huge number of identical B lymphocytes.
  2. Some of these activated B lymphocytes become **plasma cells** to produce vast quantities of antibody-specific-to-the-antigen very quickly.
  3. Other B lymphocytes are subsequently retained in the lymph nodes as "**memory cells"** so that if the second infection of identical antigen (secondary infection) returns to the body there is an almost immediate immune response. This is called **acquired immunity**.

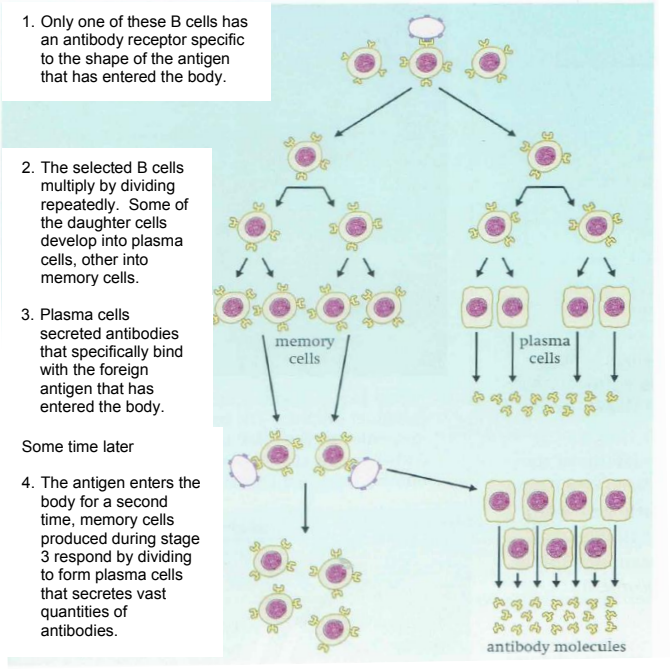


Figure 8.14 Function of B lymphocytes during infection

T lymphocytes and the Cell-mediated Response (Cellular Immunity)

- First-formed T lymphocytes migrate from the bone marrow of a foetus and reach the lymph nodes via the thymus gland (located directly behind the sternum and between the lungs).
- T lymphocytes are also known as "**thymus-derived lymphocytes**".
- The thymus gland helps to weed out and destroy lymphocytes that would otherwise react to the body's own cells. Thus, a normal immune system cannot produce antibodies against the body's own tissues.
- Mature T lymphocytes have specific cell surface receptors called T lymphocytes receptors (structure are similar to the antibodies and they are each specific to one antigen).
- T lymphocytes are activated when encounter this antigen in contact with another host cell.

- T lymphocytes do not respond to foreign antigens like B lymphocytes. Instead, they response to foreign pathogens by:
- Differentiating into various classes of cells to help combat the pathogen: **helper T cells**, **suppressor T cells** and **killer T cells**.
- **Helper T cells** ① activate B cells and stimulate plasma cells to initiate antibody production and ② activate the phagocytic cells (macrophages) of the bloodstream to ingest pathogens (refer to Figure 8.17 for the formation and action of T lymphocytes).
- **Suppressor T cells** (or regulatory T cell) inhibit the activities of the immune system so that the system does not kill its own cells and tissues.
- **Killer T cells** (or cytotoxic T cells) ③ destroy infected body cells directly after they are identified by the receptors on the surface of its plasma membranes.

For example, cells attacked by a virus antigen on their plasma membrane may be destroyed by killer T cells before replication of the virus is completed. Incidentally, the killer T cells of our immune system identify the cells of skin grafts and of transplanted organs as foreign and set about slowly rejecting them.

Do you know?
When a person is infected by the human immunodeficiency virus (HIV), the virus attacked the helper cells. This result in the inability of the helper T cells to stimulate plasma cells to initiate antibody production and activate phagocytes to ingest foreign pathogens. This is why AIDS patients are ultimately vulnerable to a wide range of infections.

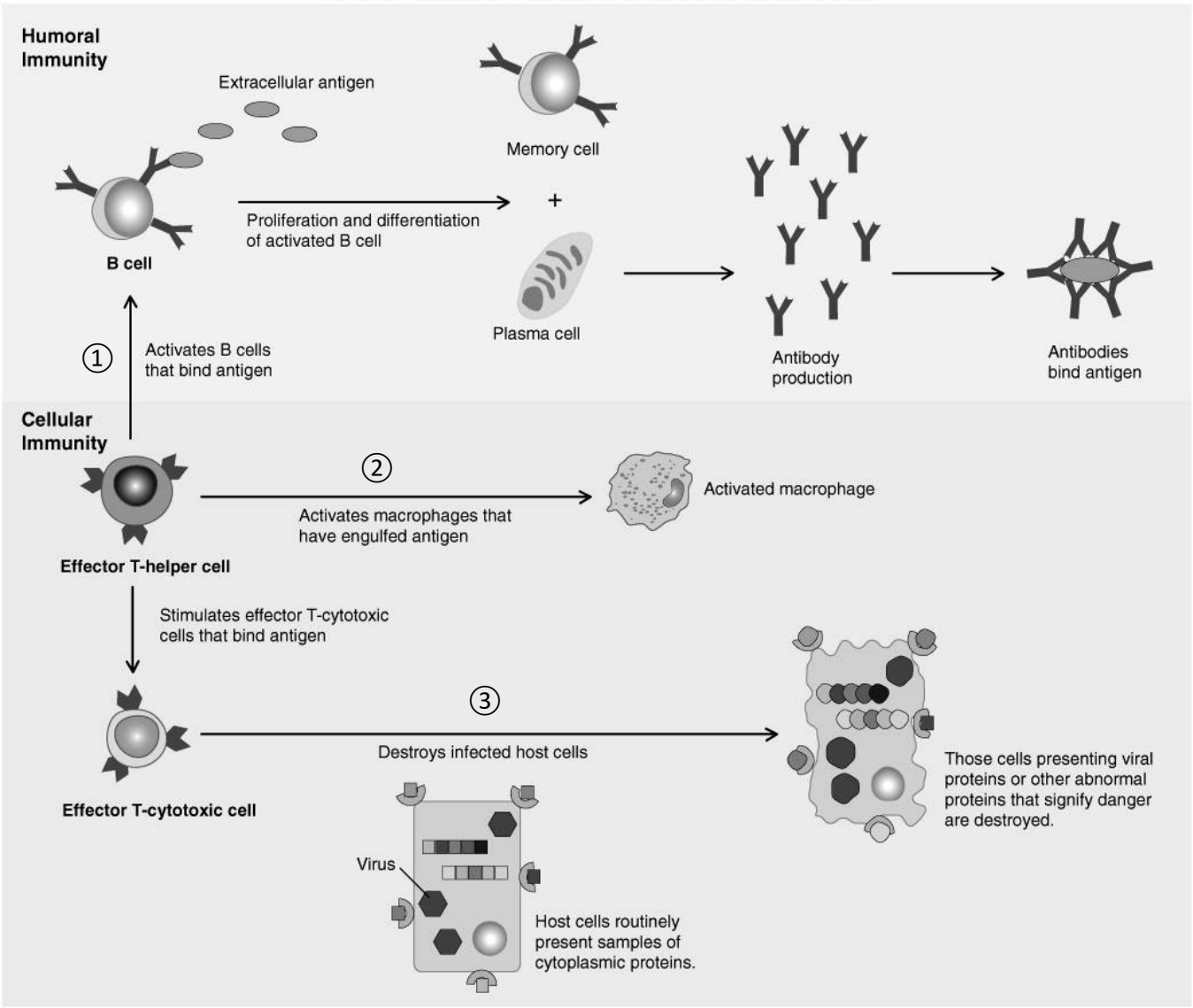


Figure 8.15 Formation and actions of lymphocytes

(B) Phagocytes

- Produced by the bone marrow
- Bean-shaped or multi-lobed nucleus
- Capable of amoeboid movement and can squeeze through capillary walls, to infected areas in the body
- Relatively shorter life span than lymphocytes
- Able to ingest foreign particles through a process called **phagocytosis**
  - Phagocytosis is a specific form of endocytosis, where the phagocyte **engulfs** the foreign particles (e.g. bacteria) to form a vesicle.
  - Vesicle is fused with lysosome containing hydrolytic enzymes which digest the bacteria.

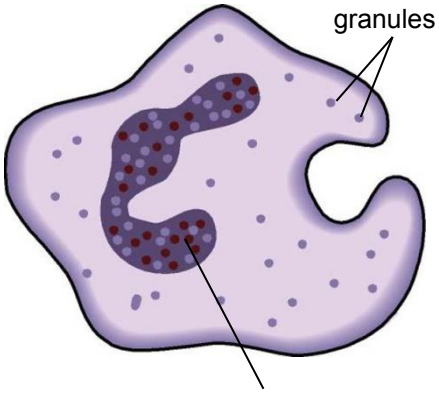


Figure 8.16 Phagocyte

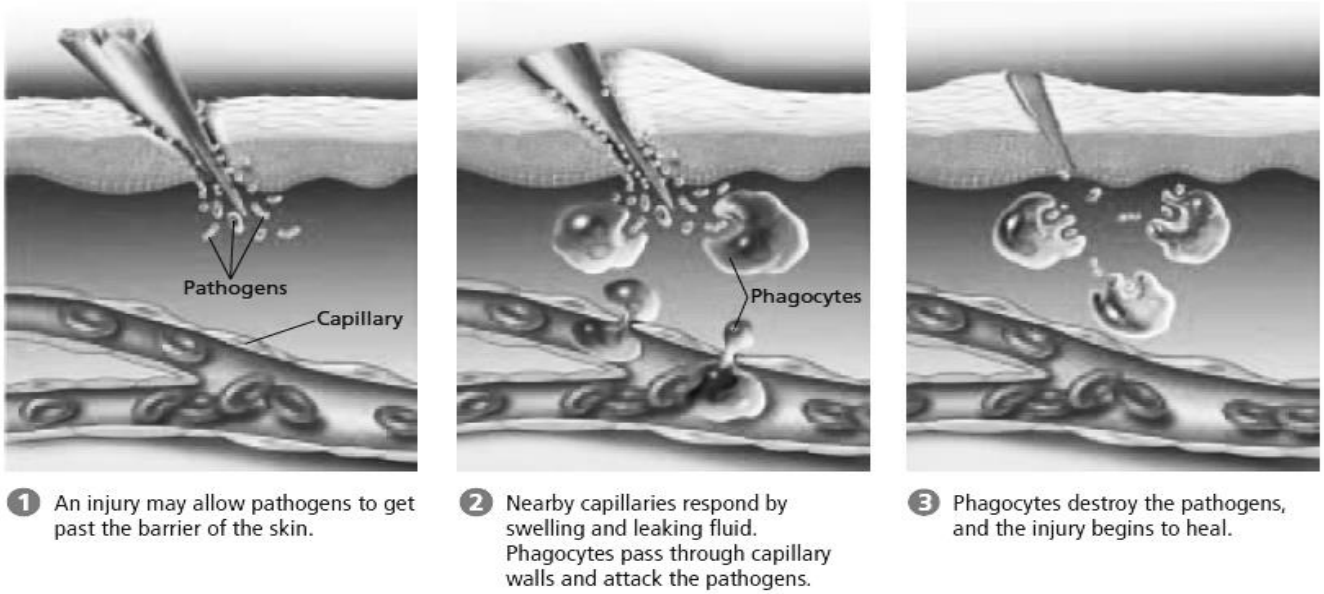


Figure 8.17 Process whereby phagocytes ingest foreign pathogens

Blood platelets (thrombocytes)

- Not true cells but membrane-bound fragments of cytoplasm
- Initiate **blood clotting**
- Purpose of blood clotting
  1. prevents excessive loss of blood
  2. prevents entry of bacteria and foreign particles

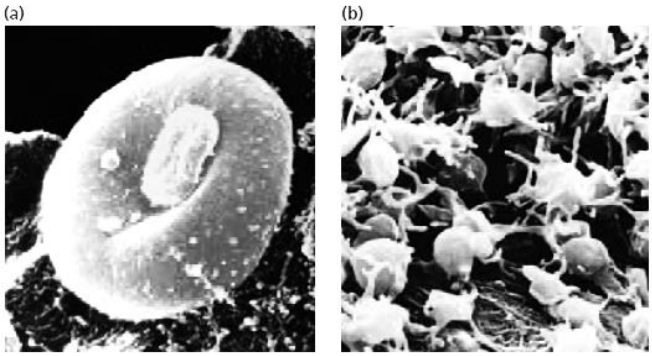


Figure 8.18 Photomicrographs of platelets in human blood. (a) A single inactivated platelet positioned on top of a red blood cell. (b) Platelets change shape during clotting process. When activated, the platelets settle and spread on the substrate.

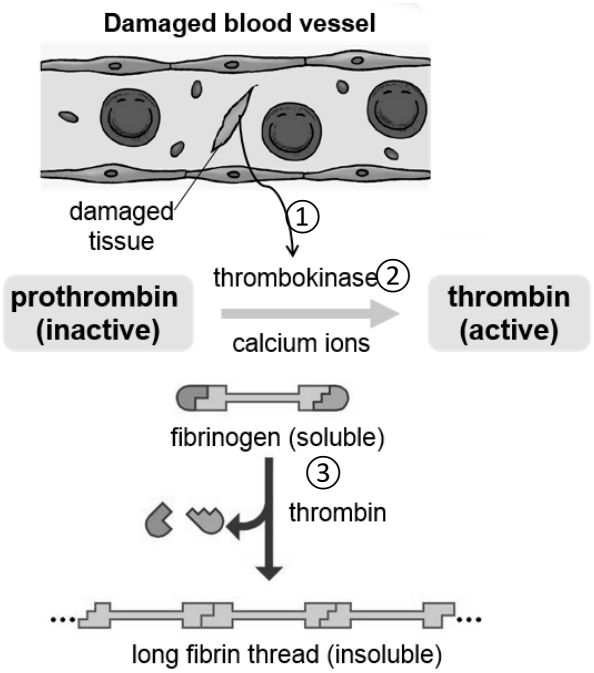


Figure 8.19 Diagrammatic process of blood clotting

Blood clotting process:
① Damaged tissues and blood platelets release an enzyme known as **thrombokinase**.
② Thrombokinase, coupled with calcium ions, converts the protein **prothrombin** (inactive), present in blood plasma, into **thrombin** (active).
③ Thrombin is also an enzyme. It catalyses the conversion of **soluble fibrinogen** protein to **insoluble fibrin threads**.

1. Fibrin threads entangle blood cells and the whole mass forms a **scab**.
2. After blood has clotted, a yellowish liquid called **serum** is left behind. Serum is blood plasma with the clotting factors removed.

Recovery and repair process:
1. The inflammation site synthesises collagen fibres to help form new tissues together with dividing epidermal cells.
2. Capillaries grow into new tissue, bringing nutrients and oxygen.
3. The tissue differentiates into skin beneath the scab, which eventually falls off.

Preventing formation of clots:
1. Presence of anticoagulants like **herapin**, in plasma
2. Secretion of chemicals like nitric oxide which suppresses activation of blood platelets

ABO blood groups
- We are classified into a blood group (e.g. A, B, AB, O) based on the types of antigens on surfaces of our RBCs.
- Our blood plasma contains antibodies which do not react with the antigens on our RBCs.

Table 8.4 Antigens and antibodies in various blood groups

blood group	antigen on RBC	antibody in plasma
A	antigen A	antibody b
B	antigen B	antibody a
AB	antigen A and B	no antibodies

What causes clumping of red blood cells?
- **Agglutination** is the clumping of red blood cells, which may lead to death, as the clumps block up small blood vessels.
- Antigen A will react with antibody a to cause agglutination. Similarly, antigen B will react with antibody b.

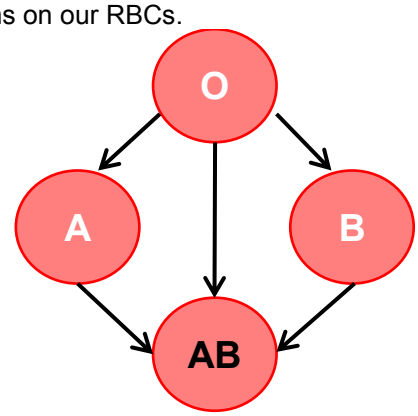


Figure 8.20 Representation of blood compatibility

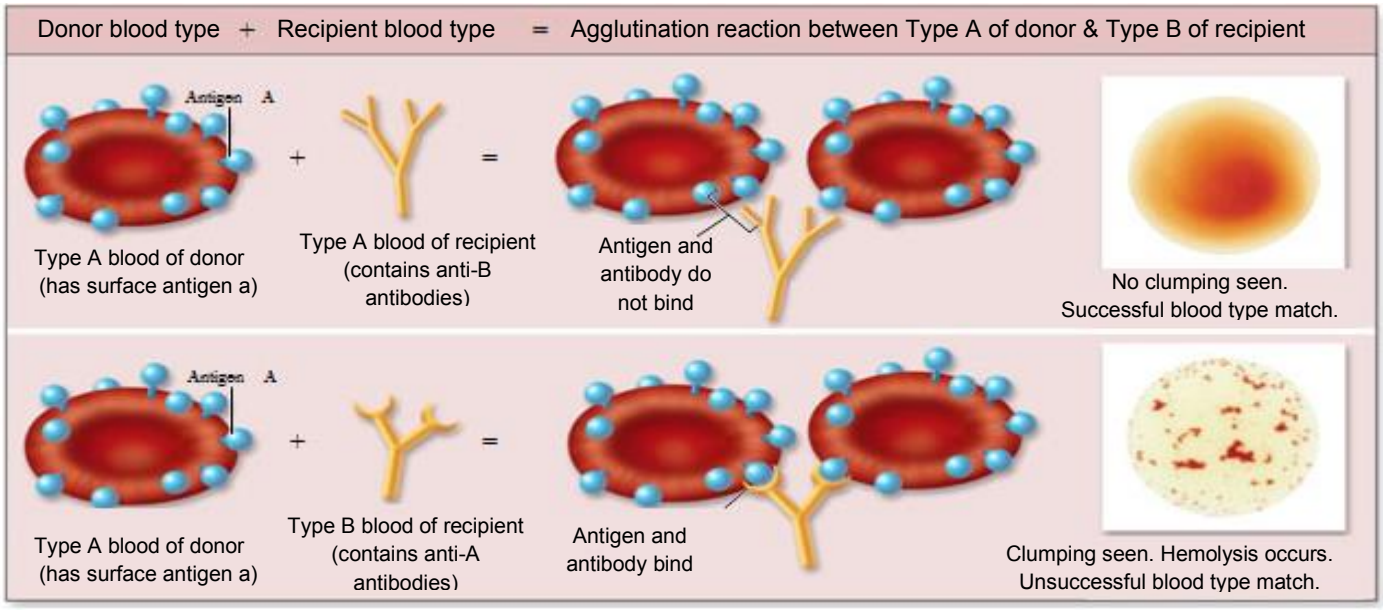


Figure 8.21 Agglutination reactions between various antigens and antibodies

Table 8.5 Blood compatibility between various donors and recipients

Recipient's blood group	**Antibody in recipient's serum / plasma**	**Donor's blood group**			
		A (antigen A)	B (antigen B)	AB (antigen A & B)	O (no antigens; **universal donor**)
A	b	–	+	+	–
B	a	+	–	+	–
AB (**universal acceptor**)	no antibodies	–	–	–	–
O	a and b	+	+	+	–

+ : agglutination i.e. blood groups are incompatible – : no agglutination i.e. blood groups are compatible

- When blood transfusion is carried out, we consider only effect the recipient's plasma has on donor's RBCs.
- Same blood group can be donated to each other.
- In addition, blood group O can be donated to A, B, and AB.
- Blood group A and B can be donated to AB.
- AB blood group cannot be donated to recipient with blood group A and blood group B.

Organ Transplant and Tissue Rejection

- Tissue or organ transplant is a medical procedure, which involves the transfer of tissues or organs from one body to another.
- If a transplanted organ is not compatible to the patient's original tissues, it will lead to **tissue rejection**.
- Any organ from another person may be treated as a foreign body by the recipient's immune system, and will be attacked by the antibodies produced by lymphocytes.
- Risk of tissue rejection can be reduced by
  1. ensuring tissues of both donor and recipient are as genetically close as possible
  2. use of immunosuppressive drugs which inhibits responses of recipient's immune system. Unfortunately, the patient's resistance to other infections is also reduced.

3. BLOOD VESSELS

- General flow of blood after leaving from the heart: Artery → arteriole → capillary → venule → vein
- **Arteries** transport oxygenated blood (except pulmonary artery) away from the heart.
- Arteries branches out into tiny vessels called **arterioles**.
- Arterioles further branches into microscopic blood vessels called **capillaries**.
- Capillaries are the site for exchange of substances to target organs.
- Capillaries are linked together in branches called **venules**, which eventually join back to form **veins**.
- Veins carry deoxygenated blood (except pulmonary vein) towards the heart.

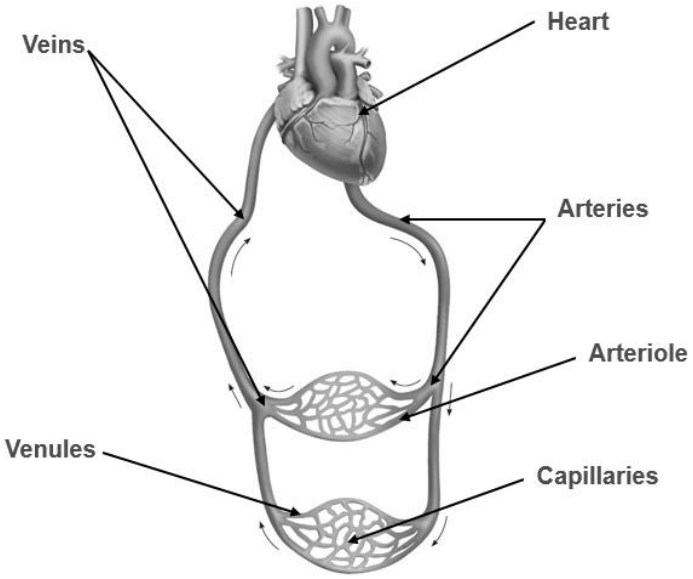


Figure 8.22 Types of blood vessels in the circulatory system

Arteries

- Arteries receives oxygenated blood directly from the heart, and branches into arterioles & eventually capillaries.
- Blood moves under high pressure and in **pulses**

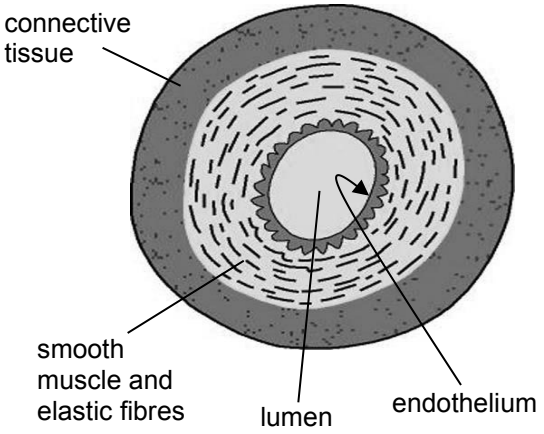


Figure 8.23 Cross-section of an artery

Table 8.6 Adaptations of arteries

structure	function
Thicker muscular walls	- Thicker muscular wall brings about **constriction** and **dilation** of artery to maintain the pressure - Muscles contract → artery constricts → lumen narrower → less blood flows through it per unit time - Muscles relax → artery dilates → lumen wider → more blood flows through it per unit time
Elastic tissues	- Help withstand high blood pressure caused by ventricular contractions of the heart - Allow stretching and recoiling of artery wall, which helps to push blood along the artery and also give rise to the pulse

Veins

- Venules join to form bigger veins, which carry deoxygenated blood back towards the heart.
- Blood moves under low pressure

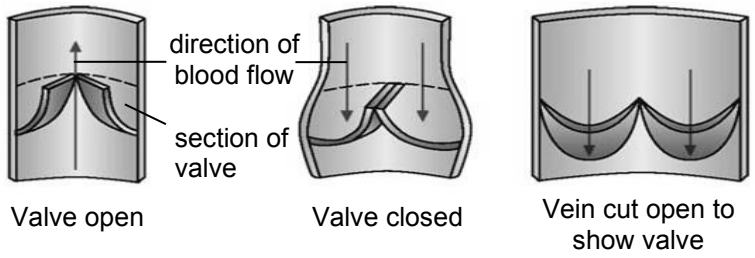


Figure 8.24 How semi-lunar valve in a vein works

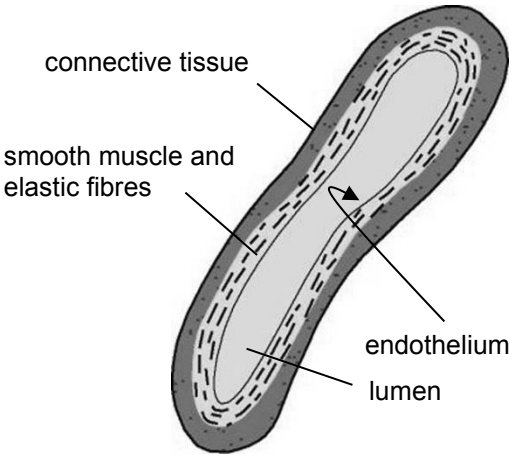


Figure 8.25 Cross-section of a vein

Table 8.7 Adaptations of veins

structure	function
Lesser muscular and elastic walls than artery and bigger lumen size than artery	- Blood flows more slowly and smoothly.
Presence of **semi-lunar valves**	- Veins have semi-lunar valves to prevent **backflow** of blood when **closed**.
Surrounded by skeletal muscles	- Muscle **contractions** exert a pressure on wall of veins and push the blood forward, back towards the heart.

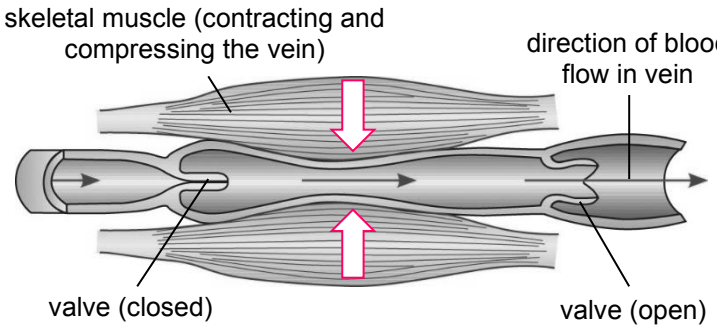


Figure 8.26 Muscle contraction around a vein

Figure 8.27 Transverse section of semi-lunar valves closed (left) and opened (right)

Capillaries

- Microscopic blood vessels found between cells of almost all tissues.
- Wall is made up of only single layer of cells called **endothelium** (e.g. no elastic or muscular tissues so it cannot constrict or dilate).

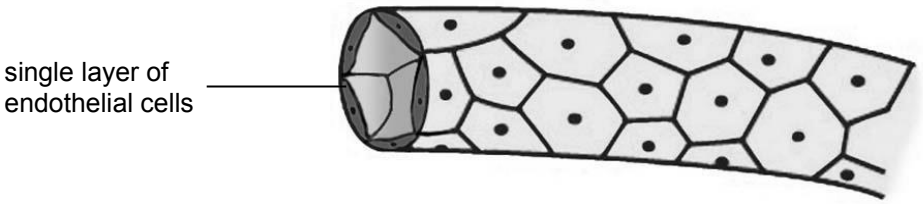


Figure 8.28 A highly magnified capillary

Table 8.8 Adaptations of capillaries

structure	function
Partially permeable endothelium (wall)	- Enables smaller substances (e.g. glucose, O_2) to diffuse quickly across
One-cell thick (thin) endothelium (wall)	- Enables faster movement of substances across
Capillaries network are highly and repeatedly branched.	- Provide large surface area for the exchange of substances between blood and tissue cells - When an arteriole branches into capillaries, the total cross-sectional area increases. This lowers the blood pressure. The flow of blood is slow down, giving more time for the exchange of substances.

Table 8.9 Differences between artery, capillary and vein

	artery	capillary	vein
location	deep within body	forms network within tissues	near surface of body, surrounded by skeletal muscles
structure: nature of walls	thick, elastic and muscular	single layer of endothelial cells to facilitate more efficient exchange of materials	relatively thin, less muscular and elastic
size of lumen	small lumen	lumen size of red blood cell	large lumen
valves	absent except pulmonary arteries and aorta	absent	presence of semi-lunar valves to prevent backflow of blood
function	ensure furthest parts of body receive sufficient supplies of oxygenated blood	large surface area allows better exchange of materials between blood and tissue cells	returns deoxygenated blood to the heart and excess tissue fluid to blood
direction of blood flow	away from heart	from arteries to veins	towards heart
nature of blood	oxygenated (except pulmonary artery)	oxygenated at arteriole end and deoxygenated at venule end (except in lungs)	deoxygenated (except for pulmonary vein)
pressure of blood flow	under high pressure, fast and in spurts as the ventricle of the heart contracts	pressure greatly reduced due to repeated branching of capillaries. Reduced pressure leads to slow and smooth flow of blood so that exchange of materials can take place more efficiently	pressure is low, thus blood flow is slow and smooth, aided by contraction of adjacent skeletal muscles
permeability	impermeable	permeable	impermeable
cross section	relatively circular	relatively oval	relatively circular
colour	red	bluish-red	bluish-red

4. TRANSFER OF MATERIALS

Tissue fluid

- The capillaries are the sites of exchange between the blood and the cells of the body. The tiny spaces between cells contain a colourless liquid called **tissue fluid** (**interstitial** or **intercellular fluid**).
- Due to higher blood pressure, fluid (basically plasma) is forced out at arterial end of capillary to form tissue fluid.
- Function: act as a medium for transfer of substances between capillaries and cell.
- Dissolved food (glucose, amino acids) and oxygen diffuses from blood capillaries into tissue fluid and then into cells.
- Waste products and carbon dioxide diffuses from cells into tissue fluid and then into blood capillaries.
- Tissue fluid are returned to the circulatory system via:
  1. Venous end of the capillary network (90%);
  2. Lymphatic capillaries (10%).

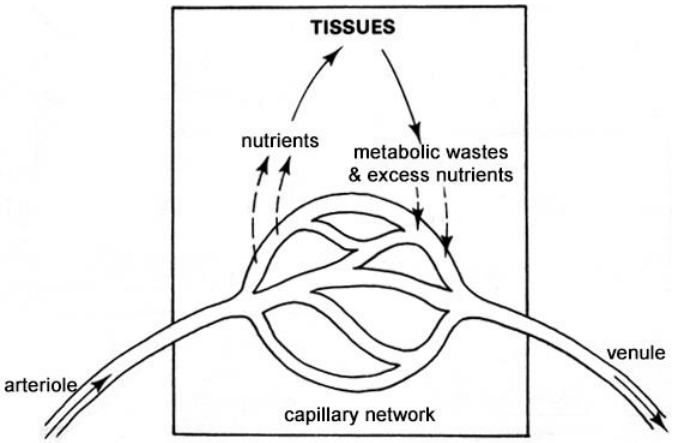


Figure 8.29 Exchange of substances at the capillaries

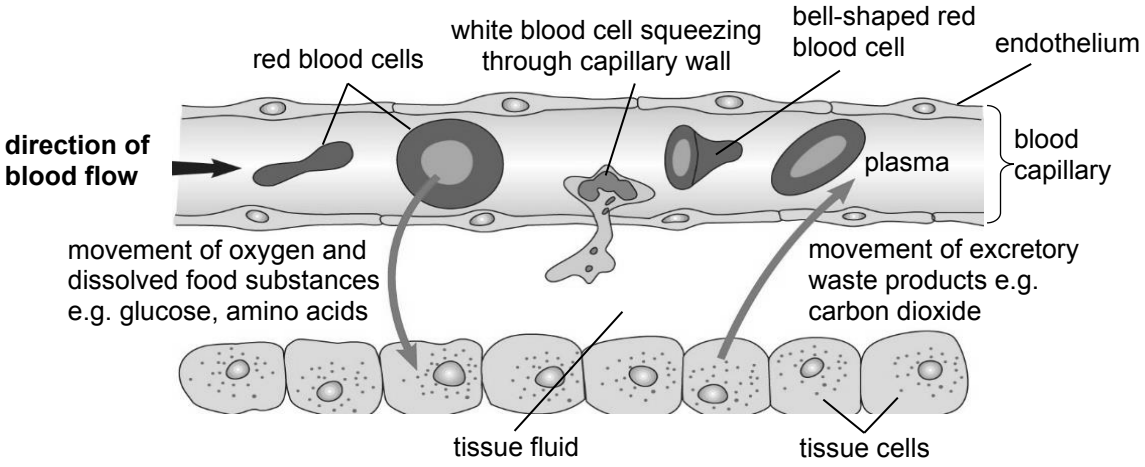


Figure 8.30 Relationship between a blood capillary, tissue fluid and tissue cells

- Blood cannot lose too much fluid (plasma), which can result in a decrease of hydrostatic pressure. When tissue fluid is not returned to the blood, it causes accumulation and swelling in organs and tissues of the body. This condition is called **oedema**.

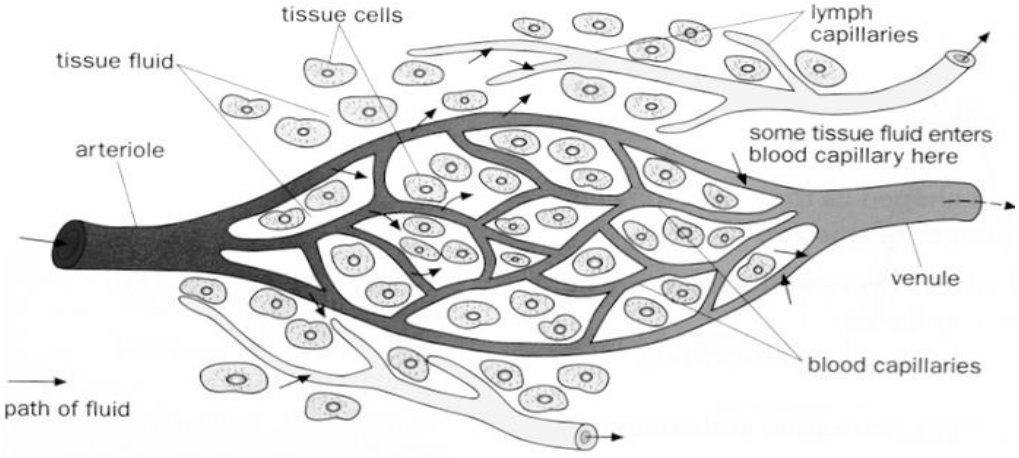


Figure 8.31 Movement of fluids from blood capillaries to lymph vessels
Source: Clegg and Maclean

Lymphatic System
- A separate network of primarily lymphatic vessels connected to lymph nodes, that help rid the body of toxins and unwanted materials (Figure 8.32).
- Tissue fluid moves into lymphatic vessels by osmosis forming lymph.
- Lymphatic vessels are similar to veins in two ways:
  - **have valves** to ensure one directional flow.
  - **muscles** which help to squeeze the lymph along as they contract.
- Lymph is returned to the blood stream via the subclavian veins.

Functions of the Lymphatic System
- Remove excess tissue fluid that might impair normal function.
- Digested fats are transported from the intestinal to the bloodstream via the lacteals.
- Lymph nodes contain lymphocytes which fight pathogens.

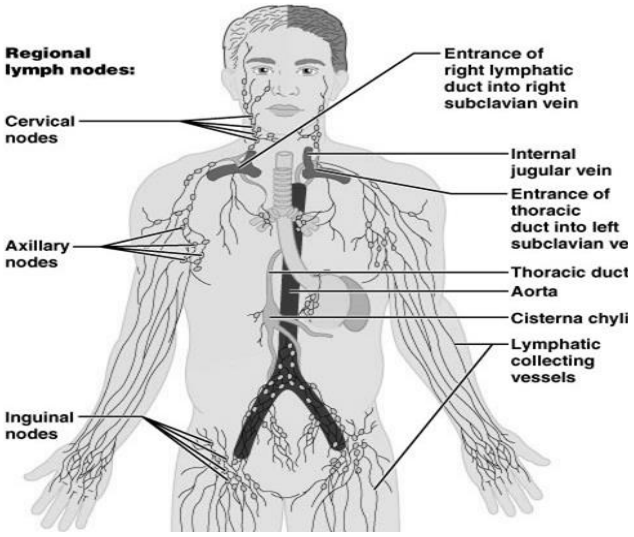


Figure 8.32 Lymphatic system in man
Source: http://apbrwww5.apsu.edu

5. THE HUMAN HEART

Double circulation in humans
- The double circulation in humans consists of the **pulmonary circulation** (between heart and lungs) and **systemic circulation** (between heart and rest of the body).
- Blood passes through the heart **twice** in one complete circuit.
- Advantages of a double circulation:
  1. Blood enters lungs at lower pressure, thus allowing sufficient time for blood to be well oxygenated.
  2. Heart pumps oxygenated blood at high pressure to the rest of the body to be distributed to the tissues more quickly.

Position of the heart
- Roughly conical shape, with apex slanted to the left side.
- Surrounded by a two-layered bag called **pericardium**. The pericardial fluid between the two membranes helps to reduce friction when the heart is beating.

Structure of the heart
- Consists of 4 chambers:
  - two upper chambers are called **auricles** or **atria** (singular: atrium).
  - two larger lower chambers are called **ventricles**
- Right side of heart completely separated from left side by a muscular wall called **median septum**, to prevent mixing of oxygenated and deoxygenated blood.
- Atria have relatively thinner walls than ventricles.
  - Distance between respective atria and ventricles is relatively short. Thus, lesser cardiac muscles are needed to pump blood at lower pressure from the atria to ventricles during atria systole.
- Left ventricle has relatively thicker walls than right ventricle.
  - Left ventricle pumps blood at higher pressure to the rest of the body (systemic circulation), that is, longer distance as compared to the right ventricle pumping blood to the lungs (pulmonary circulation) that is, shorter distance to the heart.

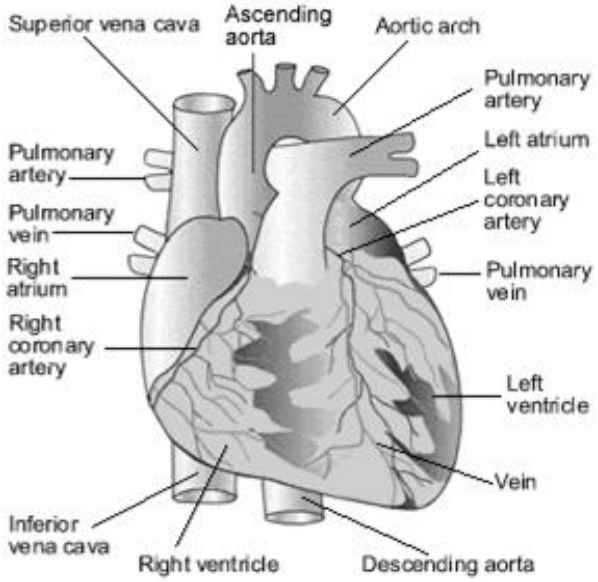


Figure 8.32 Structure of the human heart
Source: http://healthfavo.com/

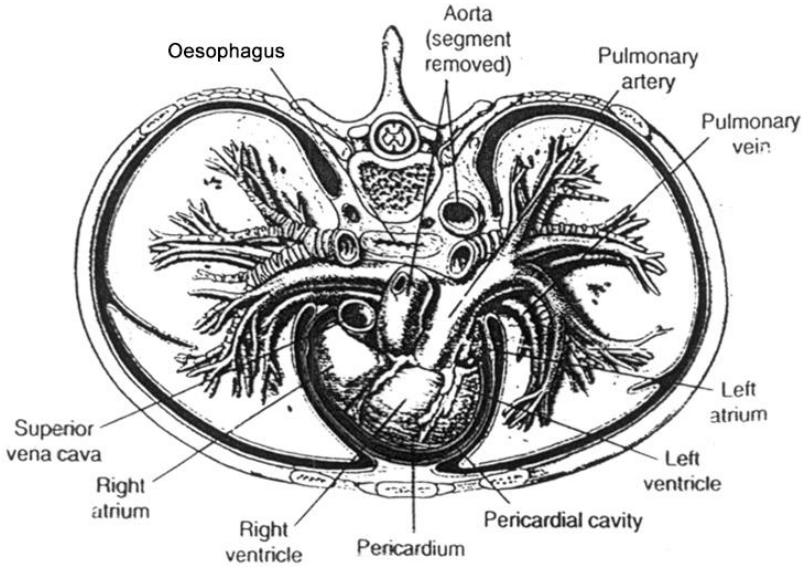


Figure 8.33 Position of the human heart in the chest cavity

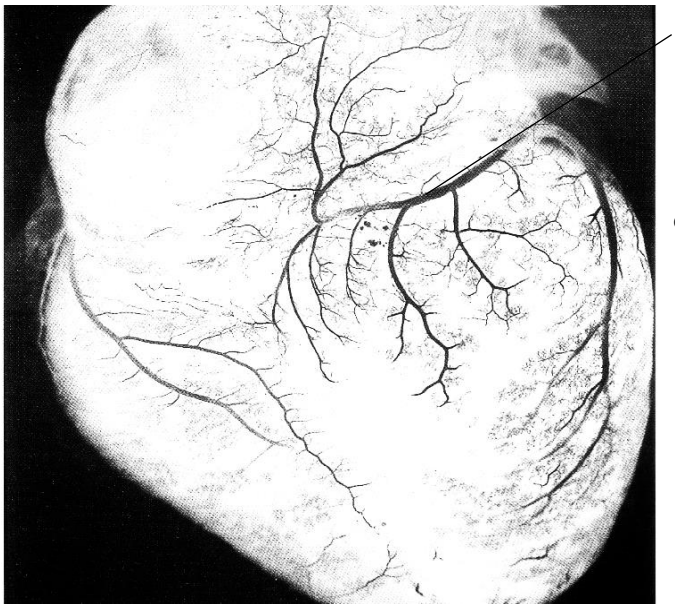


Figure 8.34a External appearance of the human heart

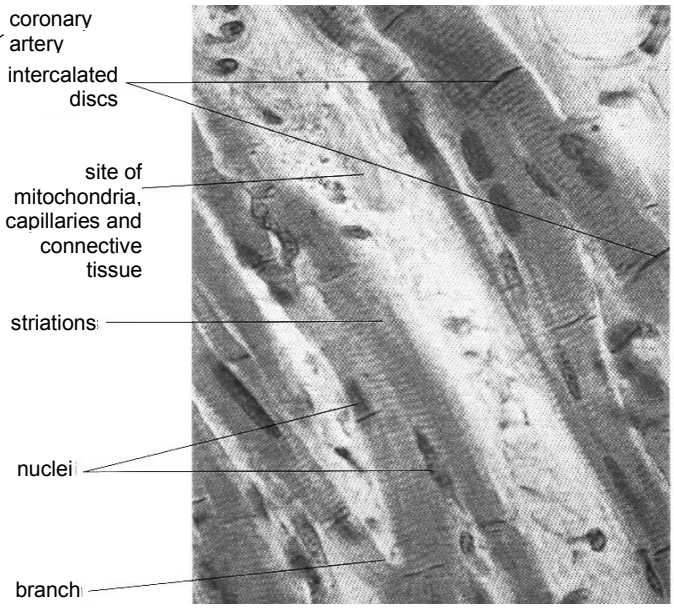


Figure 8.34b Photomicrograph of cardiac muscle

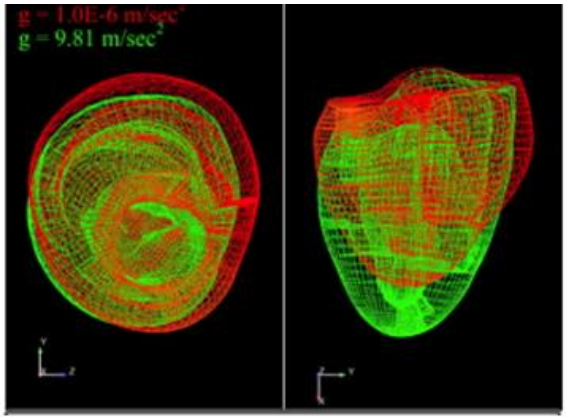


Figure 8.35 Predicted changes in the transverse (left) and longitudinal (right) sections of heart on Earth (green) and in space (red)
Source: https://www.space.com/

SPACE & FLIGHT SCIENCE PROGRAMME

- When astronauts spend long periods of time at zero gravity in space, it is reported that their hearts become more spherical (Figure. 8.35) and lose muscle mass.
- This is so as the heart lessens its effort to pump blood against gravity, from the lower limbs up to the head.
- These physiological changes can have serious cardiac problems after the return to Earth.
- However, it has also been reported that these changes are temporary, with the astronauts' hearts returning to the normal, slightly elongated shape upon the return to Earth.

What paths does blood take through the heart?

- Deoxygenated blood from various parts of the body is returned to the right atrium by the **venae cavae** (singular: vena cava).
- Right atrium contracts to push blood into the right ventricle. The **tricuspid valve** opens when the pressure in the right ventricle becomes lower than the pressure in the right atrium.
- The flaps of the tricuspid valve are attached to the ventricle wall by **chordae tendineae**.
- Right ventricle contracts and the blood pressure forces the tricuspid valve to close, preventing backflow of blood into the atrium. Chordae tendineae prevent the valves from being reverted into the atrium when the right ventricle contracts.

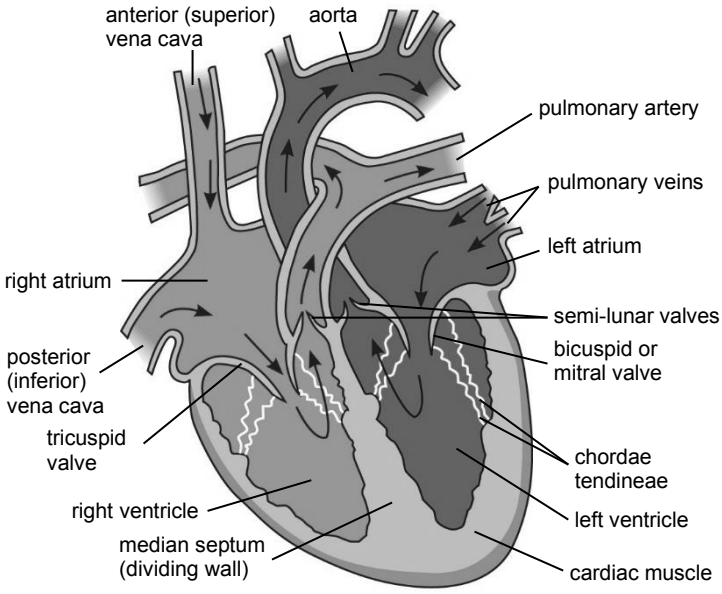


Figure 8.36 Longitudinal section of the human heart

- Blood leaves the ventricle through the **pulmonary arteries** to the lungs. Semi-lunar valves in the pulmonary arteries close to prevent backflow of blood into the right ventricle.
- Oxygenated blood from the lungs is returned to the left atrium by the **pulmonary veins**.
- Left atrium contracts to push blood into the left ventricle. The **bicuspid valve** opens when the pressure in the left ventricle becomes lower than the pressure in the left atrium.
- Left ventricle contracts and the blood pressure forces the bicuspid valve to close, preventing backflow of blood into the atrium.
- Blood leaves the ventricle through the **aorta** to the rest of the body. Semi-lunar valves in the aorta close to prevent backflow of blood into the left ventricle.

Heart valves

- Heart valves (Figure 8.37) prevent backflow and ensure a one-way flow of blood through the heart.
- Bicuspid valve (or mitral valve) is located between left atrium & ventricle and is made up of two flaps. Tricuspid valve is located between the right atrium & ventricle and is made up of three flaps.
- Both bicuspid and tricuspid valves can be referred as **atrio-ventricular valves**.

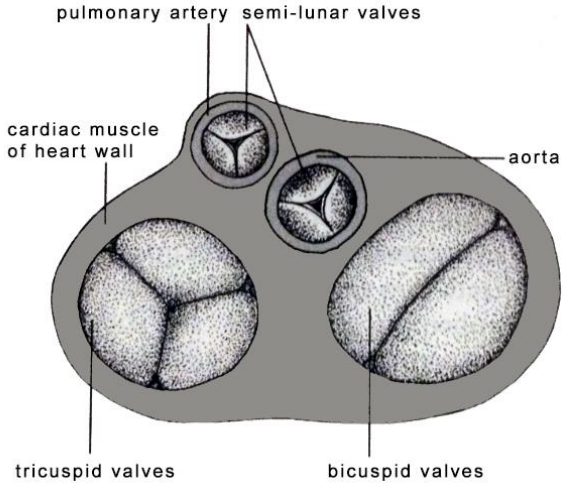


Figure 8.37 Transverse section of the human heart

Cardiac cycle

- Defined as the sequence of events that takes place in one heartbeat (Figure 8.38).
- Contraction and relaxation of the ventricles is called **ventricular systole** and **ventricular diastole** respectively.
- 1 ventricular systole + 1 ventricular diastole = 1 heartbeat
- Average normal heartbeat of an adult ≈ 72 beats/min
- There are generally 3 stages in a cardiac cycle:

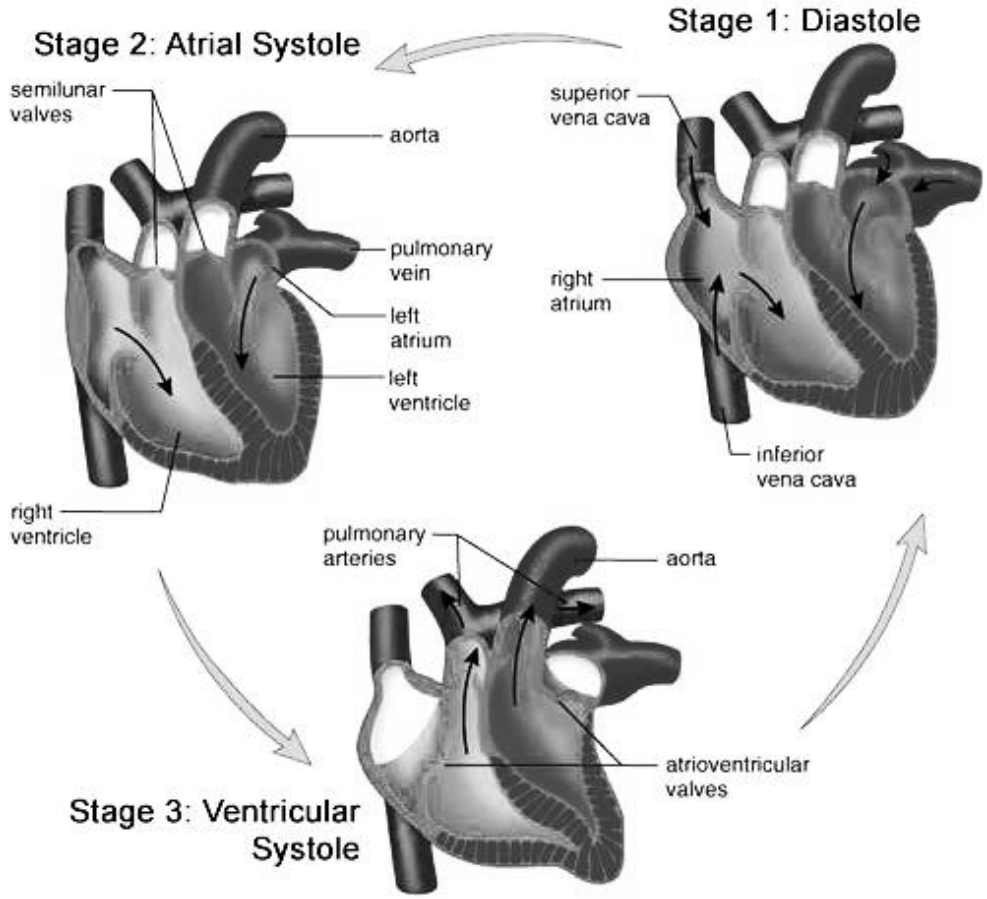
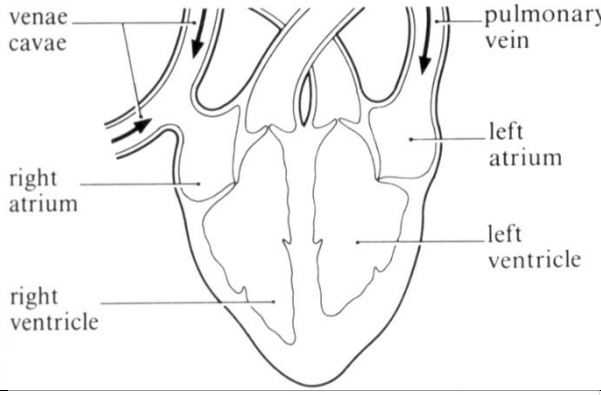
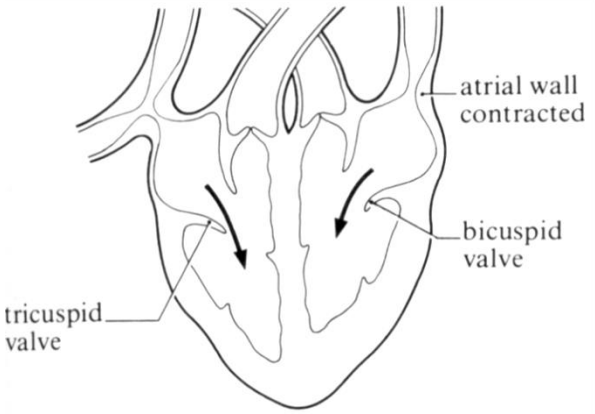
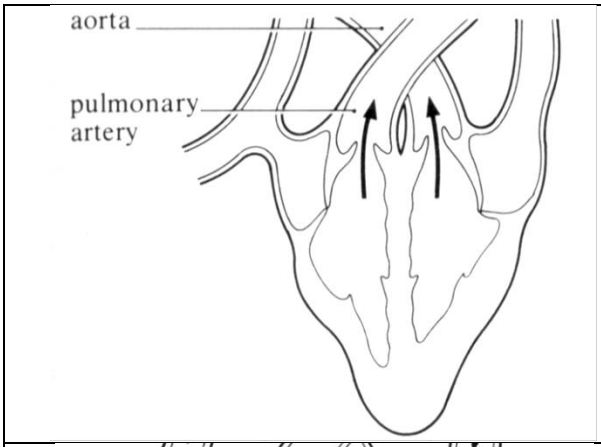


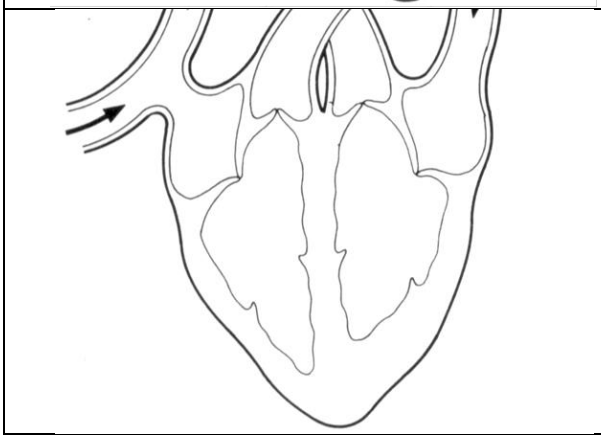
Figure 8.38 Stages in a cardiac cycle
Source: http://facweb.bhc.edu/academics/science/robertsk/biol101/heart.htm

Table 8.10 Stages of the cardiac cycle

	**Stage 1: Diastole (together with ventricular diastole is 0.4 s)** - This is the **resting period** of the heart chambers. - All muscles are relaxed and **blood flows into the heart**. - **Bicuspid & tricuspid valves** will open when pressure in the atria is more than pressure in the ventricles to allow passive flow (NOT pumping) of blood into the ventricles**.** - Oxygenated blood enters the left atrium, and deoxygenated blood enters the right atrium.
	**Stage 2: Atrial Systole (0.15 s)** - Muscles of **atria contract**, but the muscles of the ventricles remain relaxed. - **Bicuspid & tricuspid valves** are **opened (fully).** Blood is pumped into the ventricles from the atria. - **Aortic and pulmonary valves** remain **closed**.



Stage 3: Ventricular Systole (0.3 s)
- Muscles of the ventricles contract, while the muscles of the **atria** begin to **relax.**
- The steep increase of pressure in the ventricles forcefully closes the bicuspid & tricuspid valves.
- This produces the first **loud** heart sound "Lub".
- Soon the ventricular pressure exceeds the blood pressure in the aorta & pulmonary arteries, forcing the aortic & pulmonary valves open.
- Thus, blood is forced from the heart into these vessels.



Stage 1: Ventricular Diastole
- As the ventricles start to relax, pressure within them falls.
- The **high pressure in the aorta & pulmonary arteries** tend to result in some blood flowing back towards the ventricles.
- This **closes the aortic & pulmonary valves**, preventing backflow of blood.
- The impact of this backflow against the valves causes the second **softer** heart sound "Dub".

Pressure changes in the heart

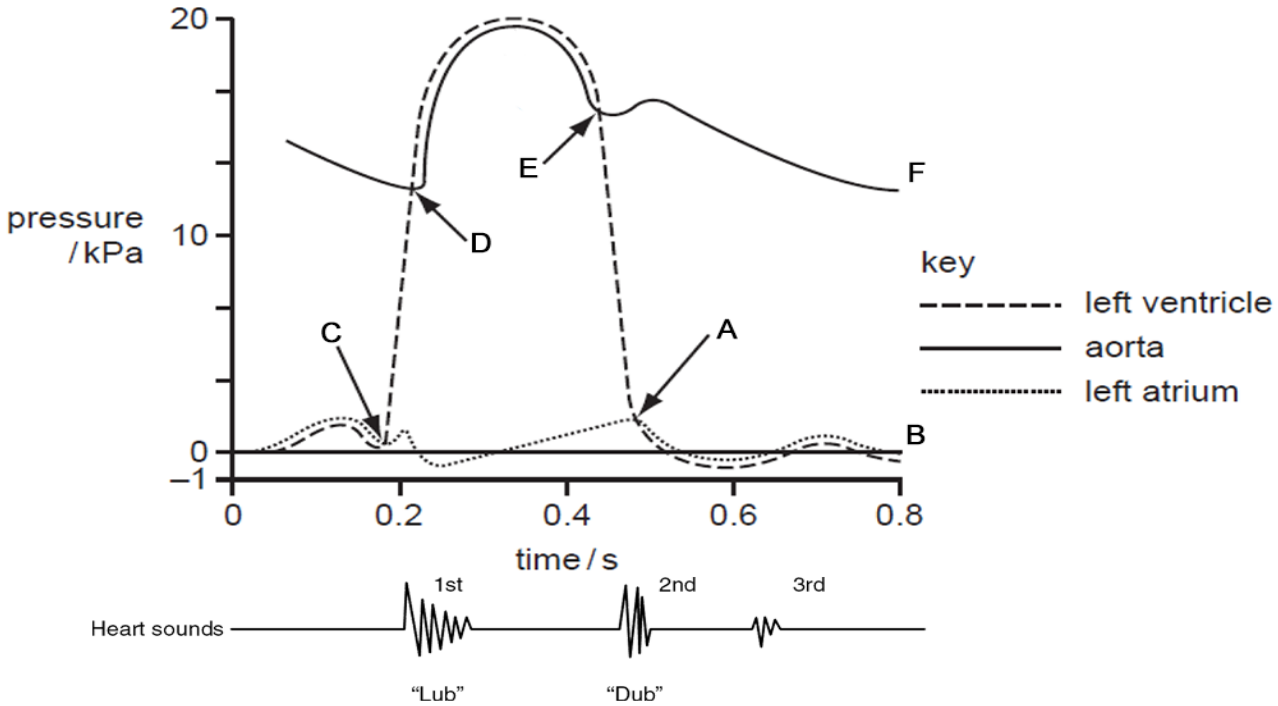


Figure 8.39 Graph of pressure changes involving aortic, ventricular and atrial pressure

A to **B**: Diastole → Left atrial pressure is slightly higher than that of left ventricle because blood continually flows into left atrium from the pulmonary vein. Blood continues to flow from left atrium to left ventricle, thus **bicuspid valve opens**. Ventricular volume **rises**.

B to **C**: Atrial systole. Contraction of left atrium **elevates** atrial pressure to be higher than ventricular pressure. Extra amount of blood is forced into left ventricle.

C to **E**: Ventricular systole. Ventricular pressure **rises** sharply. Ventricle is emptied and ventricular volume **falls**. Blood is pumped from the left ventricle into the aorta from **D** to **E.**

C: **Bicuspid valve closes**. 'Lub' – first loud heart sound.

D: When ventricular pressure exceeds that in the aorta, **semi-lunar valve in aorta (aortic valve) opens**. Blood leaves left ventricle via the aorta. Left atrium pressure drops.

E: Ventricular diastole begins – ventricle relaxes. Ventricular pressure **falls** sharply.
Backflow of blood in the aorta **closes semi-lunar valve (aortic valve)**. 'Dub' – second softer heart sound.

E to **F**: Aortic pressure remains **high** because a large amount of blood has been stored in the very distensible blood vessels during systole.
Aortic pressure **falls** as blood runs off slowly through the systemic circulation.

Suggest how will the graph of pressure changes in the right side of human heart be like.
Similar trend to the left side of human heart as they undergo the same cardiac cycle. However, the maximum pressure reached will be lower as the right ventricle pumps blood at a lower pressure.

Blood pressure graph

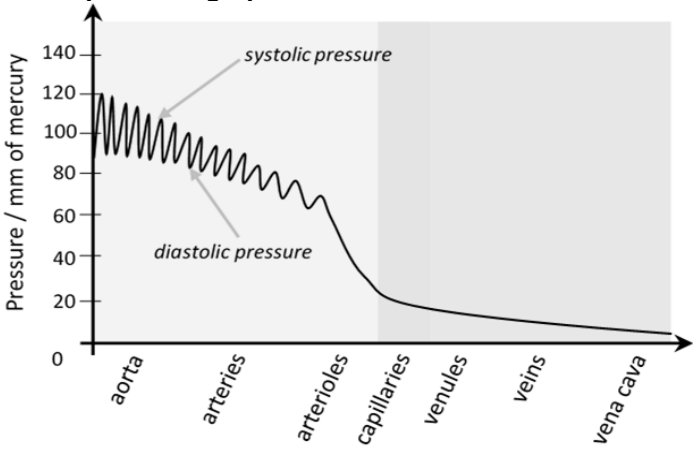


Figure 8.40 Blood pressure in the various blood vessels

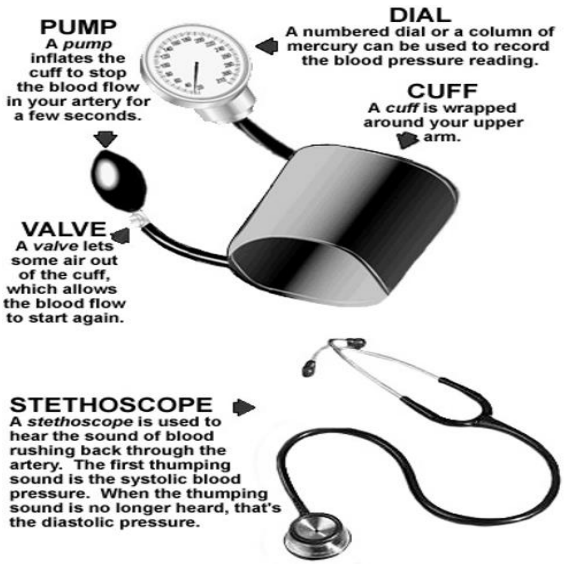


Figure 8.41 Using a sphygmomanometer to measure blood pressure

- Blood pressure is the force of blood on walls of blood vessels.
- Measured using a sphygmomanometer
- Systolic (120–140 mm Hg) / Diastolic (75–90 mm Hg) pressure.
- Blood pressure is highest near aortic arch and becomes weaker the further the arteries are away from the heart
- Blood pressure of 140/90 mm Hg → high blood pressure

The pulse

- When ventricles contract, blood is pumped into the arteries. This sudden increase in pressure causes the arteries to dilate.
- After each dilation, the walls of the arteries recoil and force the blood along the arteries in waves.
- This is known as **pulse wave** or the **pulse**.
- The expansion of the arteries can be felt as a pulse, particularly where the artery is near the skin surface, and passes over a bone.
- **Pulse beats per min = heartbeats per min**

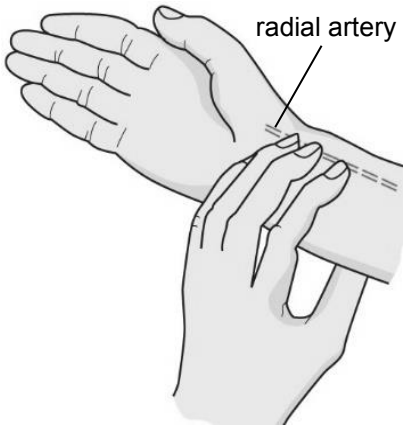


Figure 8.42 Taking the radial pulse

Main blood vessels of the body

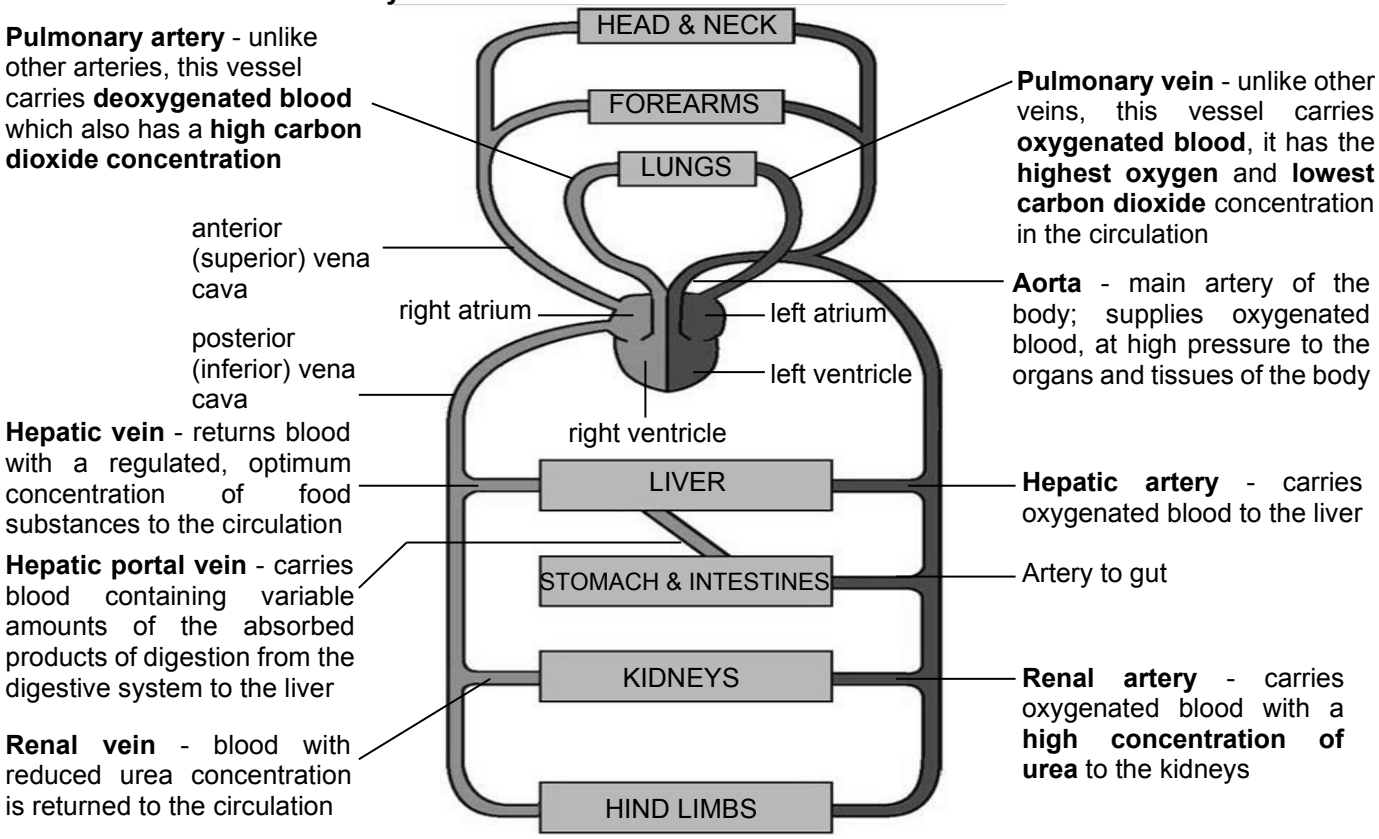


Figure 8.43 Main arteries and veins of the human circulatory system

6. CORONARY HEART DISEASE

- Two small **coronary arteries** emerge from the **aorta** and runs on the outside of the heart.
- Function of coronary arteries is to supply oxygen and nutrients to the **cardiac muscles** (NOT into the heart chambers).

Causes of coronary heart disease

- **Atherosclerosis** is the deposition of fatty substances on the inner surface of an artery.
- Process (Figure 8.46):
  - Accumulation of **cholesterol** and polysaturated **fats** as "plaques" on the inner wall (NOT lumen) of coronary arteries.
  - Lumen of arteries narrows (Figure 8.46) and blood pressure increases (as heart needs to pump harder).
  - Affected arteries develops a rough inner surface and becomes stiffer.
  - Risk of a **thrombosis** (blood clot) being trapped increases.
  - Supply of blood and O_2 for heart muscles reduced or cut off.
  - When heart muscle cells do not receive sufficient O_2 for respiration, these cells die, leading to **heart attack** (myocardial infarction).

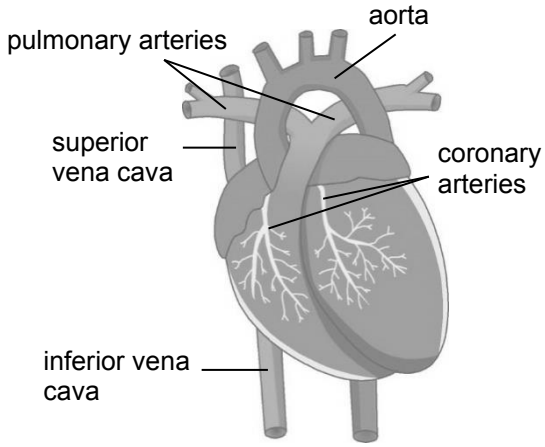


Figure 8.44 Coronary arteries

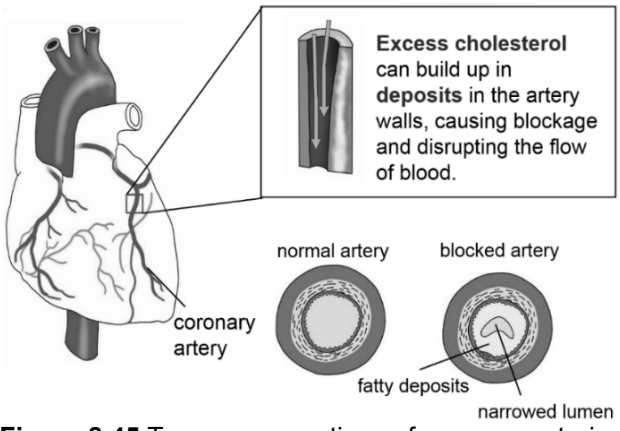


Figure 8.45 Transverse sections of coronary arteries

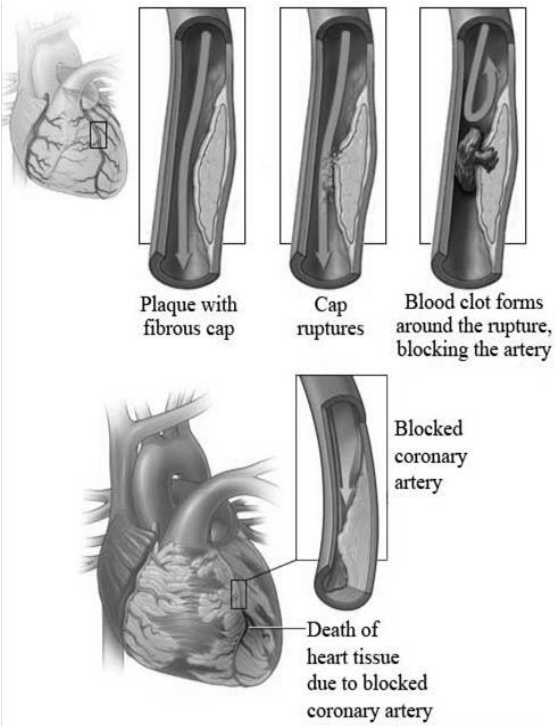


Figure 8.46 A blocked coronary artery as seen on the surface of the heart
Source: http://www.womens-health-advice.com

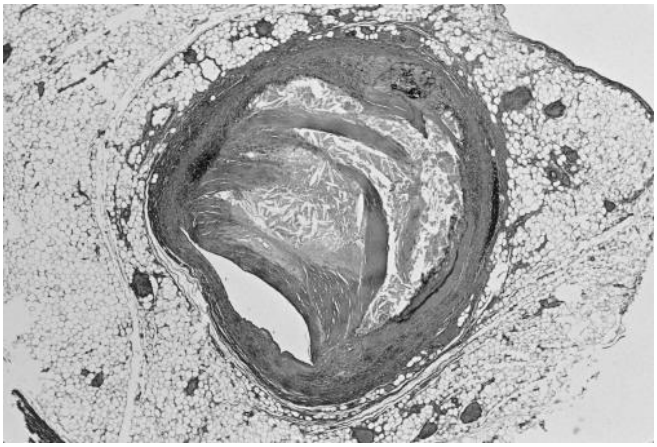


Figure 8.47 A blocked coronary artery
Source: http://www.gettyimages.com

Risk factors and preventive measures

- Risk factors: diet rich in cholesterol and saturated animal fats, emotional stress, smoking, sedentary lifestyle.
- Preventive measures:
  - Proper diet low in cholesterol
  - Avoid smoking
  - Regular physical exercise
  - Proper stress management

Extension

Cure

1. Balloon angioplasty

Angioplasty is a procedure that widens a narrow or obstructed blood vessel using a balloon catheter. A thin tube is threaded through a blood vessel in the arm or groin up to the involved site in the artery. The tube has a tiny balloon on the end. When the tube is in place, the doctor inflates the balloon to push the plaque outward against the wall of the artery. This widens the artery and restores blood flow.

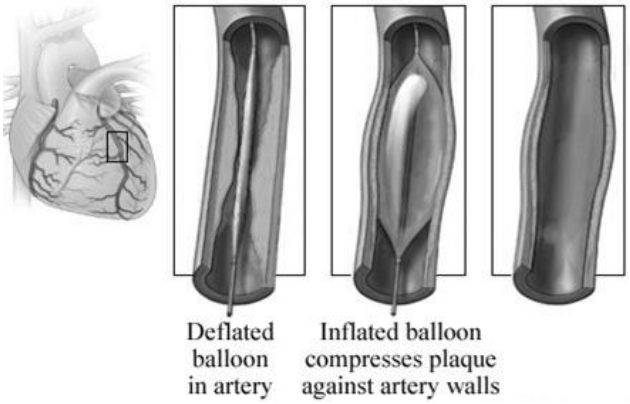


Figure 8.48 Balloon angioplasty
Source: http://www.qualitycardiaccare.com

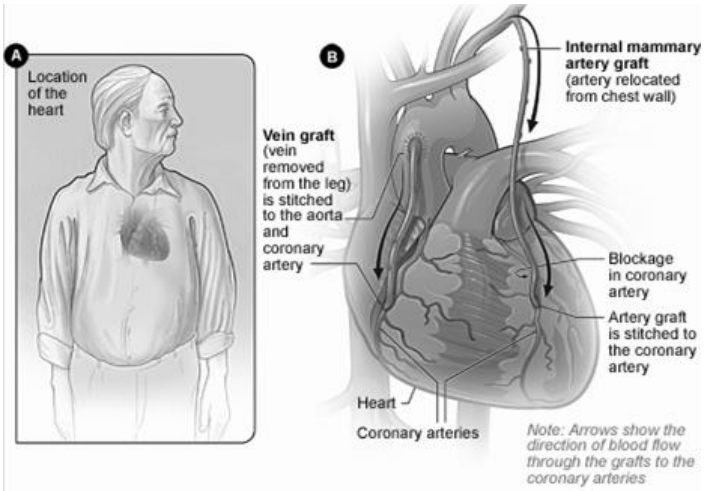


Figure 8.49 Coronary artery bypass graft
Source: http://www.nhlbi.nih.gov

2. Coronary artery bypass graft (CABG)
A healthy piece of artery or vein from the body (e.g. vein is transplanted from leg, or artery transplanted from chest or wrist) is connected, or grafted, to the blocked coronary artery. The grafted artery or vein bypasses the blocked portion of the coronary artery. This creates a new path for oxygenated blood to flow to the cardiac muscle cells.

7. ADDITIONAL READING MATERIALS

William Harvey's Circulation Experiment

- William Harvey (1578-1657) was an English physician. He was the first known to describe completely and in detail the systemic circulation and properties of blood being transported to the brain and body by the heart.
- He also recorded one of his experiments in his *On the Motions of the Heart and Blood* (1628).
- Although venal valves had already been discovered earlier, Harvey went one-step further by demonstrating that venal blood flows only toward the heart.
- He ligatured an arm to make obvious the veins and their valves, then pressed blood away from the heart and showed that the vein would remain empty because blocked by the valve.
- Harvey's experiment illustrating the venous valves (nodes or portals) and the unidirectional nature of emptying and filling.
- He also mentioned that "*now if you reckon the business, how much by one compression moves upwards by suppression of the portal, and multiplying that by thousands, you shall find so much blood passed by this means through a little part of a vein, that you will find yourself perfectly persuaded concerning the circulation of the blood, and of its swift motion*".

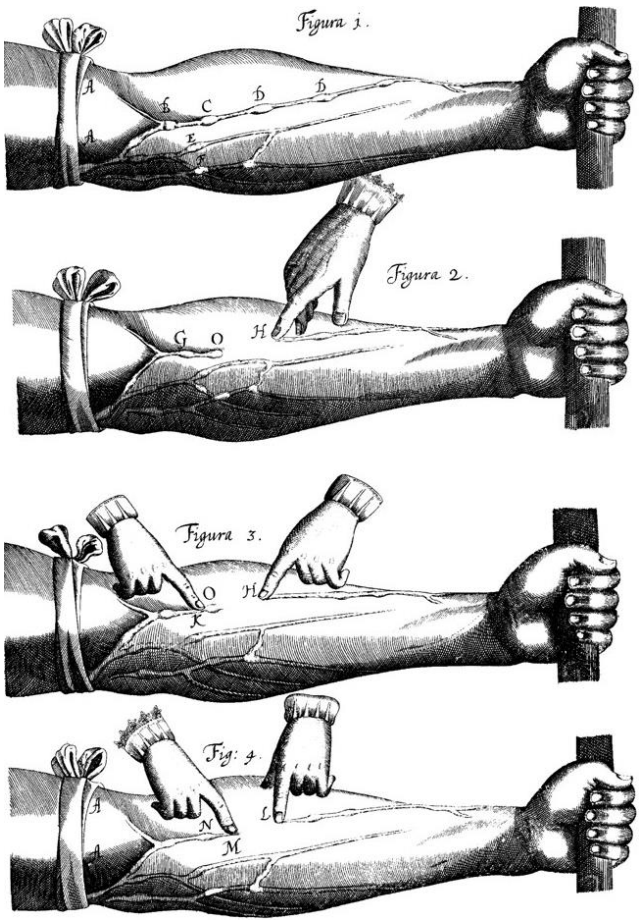


Figure 8.50 William Harvey's demonstration of presence of valves in veins
Source: http://physiologyonline.physiology.org/content/17/5/175

Regulation of Heartbeat

- Cardiac muscle continues to contract rhythmically even after the heart has been surgically removed from the body, provided that it is maintained in a favourable medium.
- Origin of heartbeat is due to the inherent property of the cardiac muscle, which is myogenic.
- The pacemaker, or sinoatrial node (SAN) triggers excitation. This structure is found in the wall of the right atrium.
- Muscle tissye conducts the excitation to both atria. The base of the right atrium contains a second node, called atrio-ventricular node (AVN), which then passes on the excitation via bundles of exceptionally long muscle fibres, the Purkinje fibres (collectively known as bundle of His), and to all parts of both ventricles. This triggers the ventricles to contract.
- As ventricles contract, the atria relax. Subsequently the ventriocles relax and the cycle is complete.

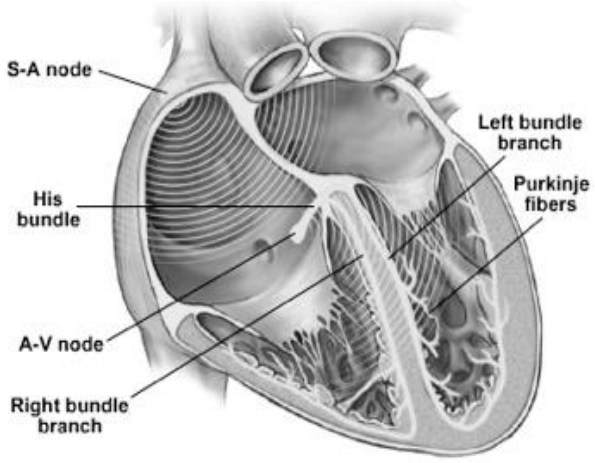


Figure 8.51 The His-Purkinje system
Source: http://neurohdu.files.wordpress.com

- After being stimulated, it reaches a brief period, called refractory period, when muscle is insensitive to further stimulation.
- Cardiac muscle has a relatively long refractory period. This allows the cardiac muscle to beat forecefully without fatigue and without developing a permanently contracted state known as tetanus.

Atrial Septal Defects (ASDs)

- Also known as having hole(s) in the heart.
- No signs or symptoms upon birth. As individuals grow, symptoms start to occur.
- One such symptom is heart murmur, an extra or unusual sound heart during a heartbeat.
- Consequence if not treated: extra blood flow to the right side of the heart can damage the heart and lungs and cause heart failure.

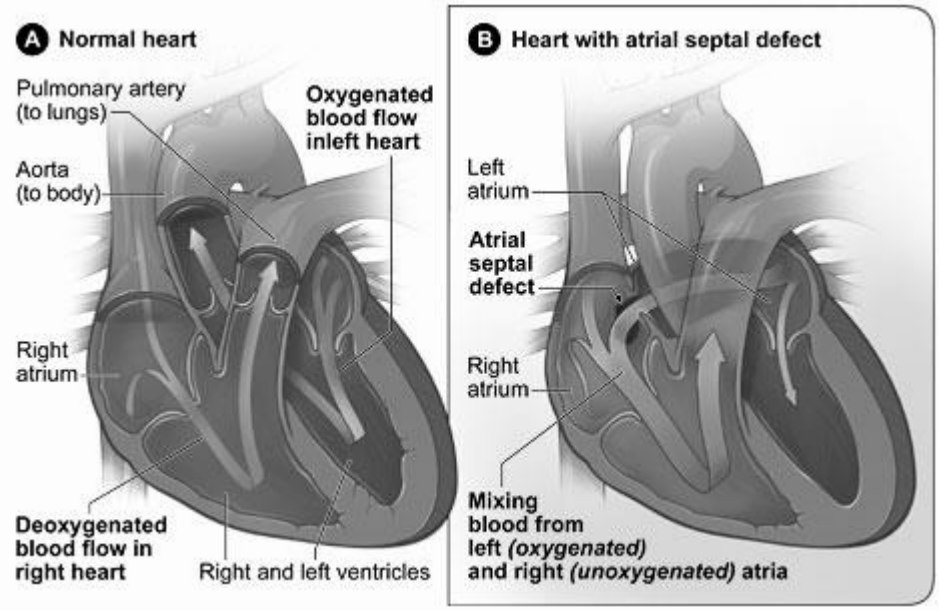


Figure 8.52 Diagram of patient suffering from ASDs
Source: http://www.nhlbi.nih.gov/health/

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 9 – Respiration

Name: **Class:**

A. Content
- Human gaseous exchange
- Aerobic respiration
- Anaerobic respiration

B. Learning Outcomes

Students should be able to:
(a) identify on diagrams and name the larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries
(b) state the characteristic of, and describe the role of, the exchange surface of the alveoli in gas exchange
(c) describe the removal of carbon dioxide from the lungs, including the role of the carbonic anhydrase enzyme
(d) describe the role of cilia, diaphragm, ribs and intercostal muscles in breathing
(e) describe the effect of tobacco smoke and its major toxic components – nicotine, tar and carbon monoxide on health
(f) define and state the equation, in words and symbols for aerobic respiration in humans
(g) define and state the equation, in words only for anaerobic respiration in human
(h) describe the effect of lactic acid in muscles during exercise

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
4. Reece J.B., Urry L.A., Cain M.L., Wasserman S.A., Minorsky P.V. and Jackson R.B. Campbell Biology (9th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline

1. Importance of respiration
2. Aerobic and anaerobic respiration
3. Gaseous exchange
4. Gaseous exchange system in humans
5. Effects of tobacco smoke on human health

E. Practical Work
- Using hydrogencarbonate indicator to indicate release of carbon dioxide

1. INTRODUCTION

All living things respire. Respiration is a multi-step process that occurs in the mitochondria of all living cells. As each step in respiration is controlled by enzymes, the process is affected by temperature.

Definition of respiration: The breakdown of food substances (e.g. glucose) through oxidation in living cells, with the release of energy in living cells.

Complex organisms respire aerobically to survive. Examples of energy-consuming processes include

- muscular contraction such as heartbeats
- cellular transport processes such as active transport
- synthesis of polymers from monomers, e.g. proteins from amino acids
- cell division and growth
- transmission of nerve impulses

During respiration, some energy is also released as heat, which is circulated around the body to keep one warm.

Photosynthesis and respiration in plants

- Green plants photosynthesise and respire.
- In the dark, only respiration occurs and thus the rate of respiration exceeds the rate of photosynthesis. Rate of sugar breakdown (during respiration) is more than rate of sugar formed (during photosynthesis). There will be net removal of oxygen and net gain in amount of carbon dioxide produced.
- As light intensity increases, there comes a point where the rate of respiration equals the rate of photosynthesis. Thus, rate of sugar breakdown equals rate of sugar formation. There is no net uptake or loss of carbon dioxide or oxygen. This is known as the **compensation point** (refer to Figure 9.2).

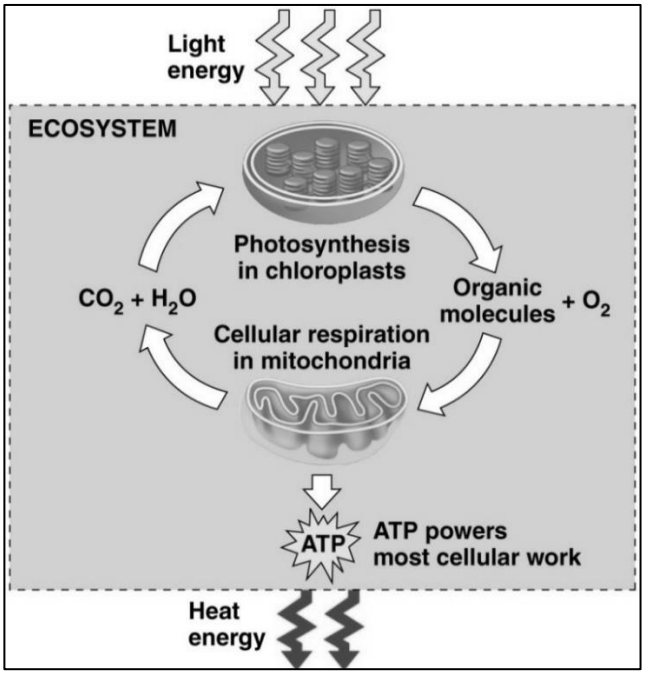


Figure 9.1 Comparison between respiration and photosynthesis
Source: Campbell Biology

- Beyond the compensation point, rate of photosynthesis exceeds rate of respiration. Thus, rate of sugar formation is greater than rate of sugar breakdown. There will be net removal of carbon dioxide and net gain in amount of oxygen produced.

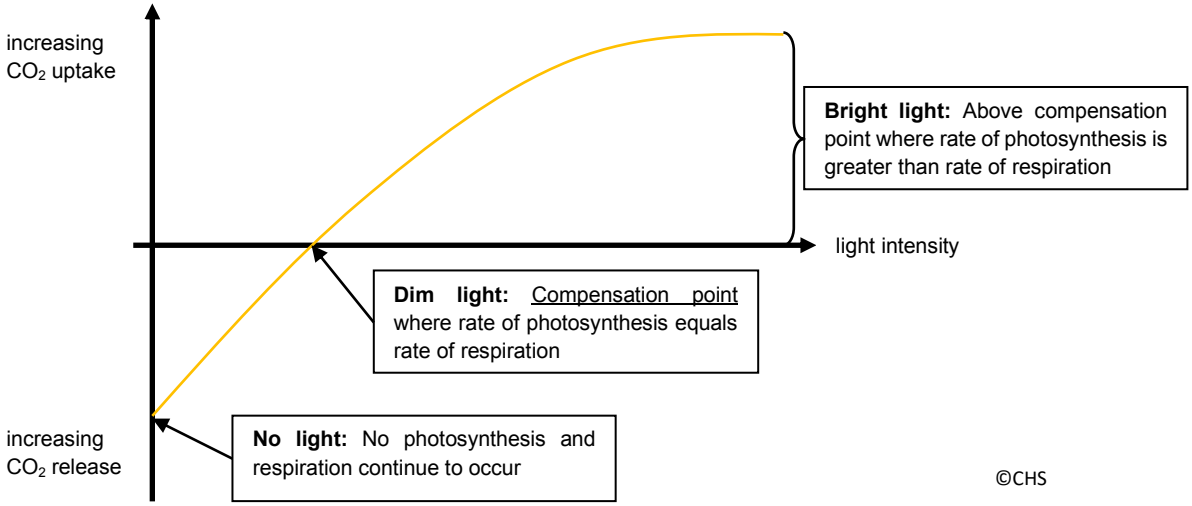


Figure 9.2 Photosynthesis and compensation point

Table 9.1 Comparison between respiration and photosynthesis

Respiration	Photosynthesis
energy is released (NOT produced)	energy is stored in carbohydrate molecules
oxygen is used, carbon dioxide and water are given off	carbon dioxide and water are used, oxygen is given off
catabolic process, involving the breakdown of carbohydrate molecules	anabolic process, involving the building up of carbohydrate molecules
occurs at all times in all cells	occurs only in cells containing chlorophyll
independent of sunlight	occurs only in the presence of sunlight
results in loss of dry mass	results in gain of dry mass

2. AEROBIC AND ANAEROBIC RESPIRATION

There are 2 forms of respiration: aerobic respiration and anaerobic respiration.

2.1 Aerobic Respiration

Definition: breakdown of glucose in the presence of oxygen with release of a large amount of energy. Carbon dioxide and water are released as waste products.

glucose + oxygen → carbon dioxide + water + large amount of energy

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

2.2 Anaerobic Respiration

Definition: breakdown of glucose in the absence of oxygen with release of a small amount of energy

Anaerobic respiration in yeast

- Yeast can respire both aerobically and anaerobically.
- Anaerobic respiration in yeast is also known as **alcoholic fermentation**, as ethanol and carbon dioxide are released as waste products.
- Most of the energy is still stored in ethanol. This explains why only a small amount of energy is released.

glucose → carbon dioxide + ethanol + small amount of energy

$$C_6H_{12}O_6 \rightarrow 2\ CO_2 + 2\ C_2H_5OH + \text{small amount of energy}$$

Anaerobic respiration in muscles

- Skeletal muscles can respire both aerobically and anaerobically (see Figure 9.3).
- During vigorous muscular contractions, muscle cells first respire aerobically. The rate of breathing and heartbeat increase to take in and transport more oxygen around the body. However, due to the limit in the rate of breathing and heartbeat, and the need to release energy to meet the demand, the muscle cells start to carry out anaerobic respiration. When exercising, some skeletal muscles carry out anaerobic respiration while the other skeletal muscle cells and body cells carry out aerobic respiration.

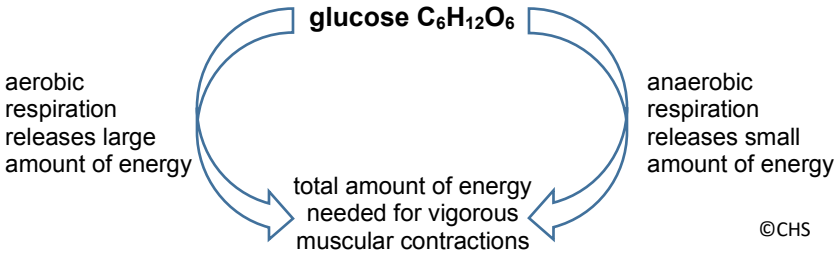


Figure 9.3 Changes in muscles during vigorous contractions

- During anaerobic respiration, the small amount of energy that is released is sufficient to keep the muscle cells contracting. **Lactic acid** is also formed in the process. Anaerobic respiration in human skeletal muscles is known as lactate fermentation.

glucose → lactic acid + small amount of energy

$$C_6H_{12}O_6 \rightarrow 2\ C_3H_6O_3 + \text{small amount of energy}$$

- Since there is insufficient oxygen to meet the demands of muscular contractions, the muscles are said to incur an **oxygen debt** (see Figure 9.4). Oxygen debt is the amount of oxygen needed to break down all the lactic acid accumulated in the muscles during anaerobic respiration.
- Lactic acid concentrations build up slowly in the muscles and may eventually become high enough to cause **fatigue**. The body will then need to rest and recover.
- During the period of rest, the rate of breathing continues to be high to provide enough oxygen to repay the oxygen debt. Lactic acid is also removed from the muscles and transported to the liver. Some of the lactic acid is oxidised to release energy, which is used to convert the remaining lactic acid into glucose, which will be transported back to the muscle cells and stored as glycogen. When all the lactic acid has been utilised, the oxygen debt is repaid.

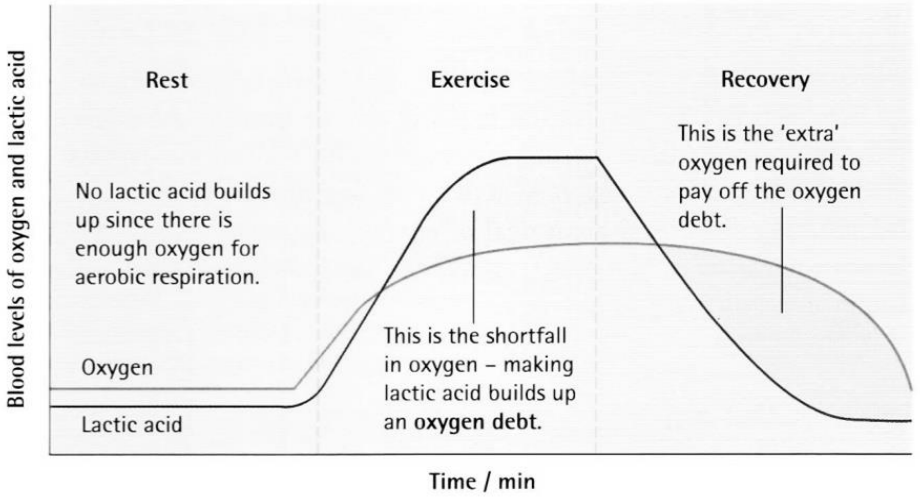


Figure 9.4 The blood levels of oxygen and lactic acid during rest, exercise and recovery periods

2.3 Studying Respiration

To show that carbon dioxide is released during aerobic respiration

1. Set up the apparatus as shown in Figure 9.5. The purpose of potassium hydroxide solution, an alkali, in flask A is to react with any carbon dioxide, which is acidic, in the environment. This is to ensure that carbon dioxide is not introduced into the experimental set-up. The limewater, which tests for the presence of carbon dioxide, in flask B ensures that no carbon dioxide enters the set-up.
2. A suction pump is used to suck out the air through delivery tube E. This causes air to be drawn into flask A. The air flows through the apparatus as shown by the arrows.
3. After some time, the limewater in flask D becomes cloudy, indicating that carbon dioxide has been released by the snails respiring in flask C.

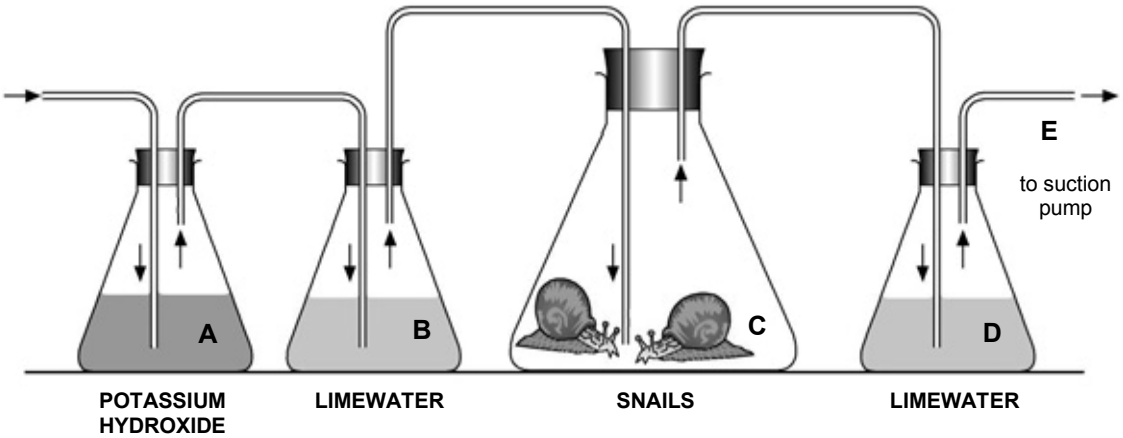


Figure 9.5 Experimental set-up to find out whether carbon dioxide is given off during aerobic respiration

4. Instead of limewater, a hydrogencarbonate indicator, which turns yellow in the presence of acid (carbon dioxide dissolves in water to form a carbonic acid) can be used (refer to Figure 9.6 for the colour chart of hydrogencarbonate indicator).

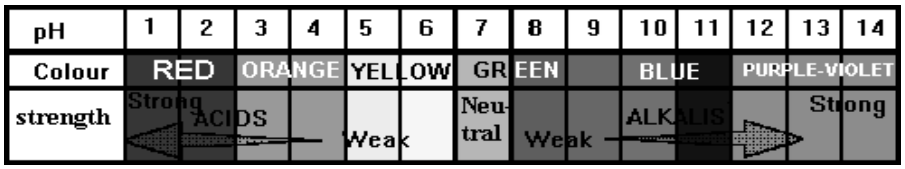


Figure 9.6 Colour chart for hydrogencarbonate indicator

5. If potted green plants are used instead of snails, the flask has to be covered with aluminium foil or the set-up has to be placed in the dark. This is so that the plants will not be carrying out photosynthesis (and using up the carbon dioxide produced) at the same time.

To show that carbon dioxide is released during anaerobic respiration

1. Set up the apparatus as shown in Figure 9.7.
2. Add a few grains of dry yeast to some distilled water in a boiling tube. Stir well.
3. After 20 minutes, add an equal volume of boiled and cooled dilute glucose solution to the yeast suspension and mix well. Add a little oil to ensure that no oxygen enters the mixture.
4. The limewater in the test tube becomes cloudy, indicating that carbon dioxide has been released by yeast.

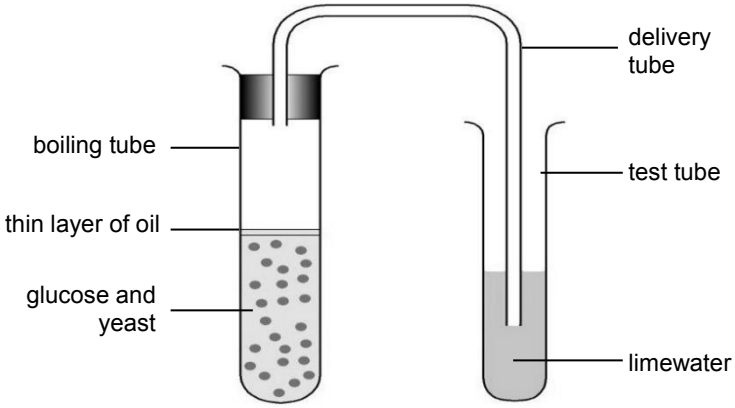


Figure 9.7 Experimental set-up to find out whether carbon dioxide is given off during anaerobic respiration

To show that heat is released during respiration

1. Soak some barley seeds in water. Add a little dilute antiseptic solution to the seeds. The antiseptic solution prevents the growth of decomposers (e.g. bacteria).
2. When germination begins, place some of the seeds in vacuum flask A, as shown in Figure 9.8. Insert the thermometer so that its bulb is completely surrounded by wet germinating seeds and its stem is supported by cotton wool. Cotton wool helps to insulate the apparatus and support the seeds.
3. Set up a control – vacuum flask B using the same number of seeds. The seeds are killed by boiling, cooled and then soaked in dilute antiseptic solution. The solution prevents the decay of the dead seeds, which may produce a rise in temperature.
4. After 1–2 days, compare the temperature readings in both flasks. Vacuum flask A will show a higher temperature than that of vacuum flask B.

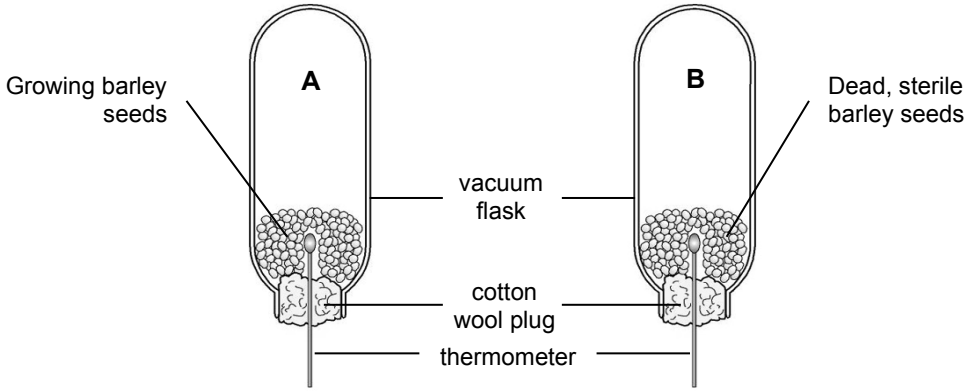


Figure 9.8 Experimental set-up to find out whether heat is given off during respiration

3. GASEOUS EXCHANGE

Definition: Exchange of gases between an organism and the environment

3.1 Gaseous Exchange in Animals

- Unicellular organisms: have a large surface area: volume ratio. Therefore, they do not need any special gas exchange system. Oxygen and carbon dioxide can be efficiently exchanged between the organism and the environment by diffusion through the cell surface membrane.
- Large animals: have a small surface area: volume ratio. Therefore, these animals use special organs, such as lungs in mammals or gills in fishes, as their gas exchange systems. These organs have enlarged surface areas and thin coverings.

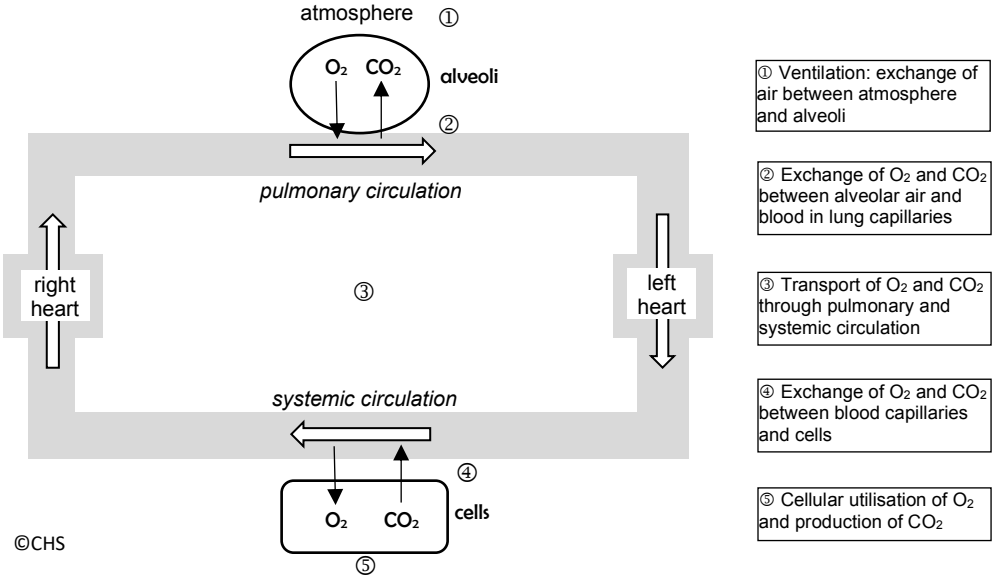


Figure 9.9 Steps involved in gaseous exchange in humans

3.2 Gaseous Exchange in Plants

- The leaves of plants have large surface area: volume ratio, therefore simple diffusion of gases is sufficient to meet their needs.
- Gaseous exchange occurs mainly through the stomata of leaves and young stems. Oxygen diffuses from cell to cell to reach those cells that are not directly exposed to air.
- The roots of plants take in oxygen and release carbon dioxide by diffusion through the root hair cells.
- Unlike photosynthesis, respiration in plants occurs all the time in all cells, independent of chlorophyll and sunlight. At compensation point, the rate of photosynthesis is equal to the rate of respiration, i.e. the amount of carbon dioxide taken in / oxygen given out during photosynthesis is equal to the amount of carbon dioxide given out / oxygen taken in during respiration.

4. GASEOUS EXCHANGE SYSTEM IN HUMANS

- The organs involved in gas exchange in humans include the 2 lungs in the thorax and the air passages (which consist of the nasal passages, pharynx, larynx, trachea, bronchi and bronchioles) leading to them. The thoracic cavity, ribs, diaphragm and related muscles are also important parts of the gas exchange system.
- **Passage of air flows through**: mouth & nostrils → pharynx → larynx (voice box) → trachea (wind pipe) → bronchi (singular: bronchus) → bronchioles → alveoli (singular: alveolus)

4.1 Nose

- Air enters the body through 2 nostrils (which have a fringe of hairs), which lead into nasal passages (which are lined with a moist mucous membrane). The air is moistened and warmed before it enters the lungs.
- Defensive function:
  (i) Hairs and mucous membrane trap dust and bacteria in the air,
  (ii) Small sensory cells in the mucous membrane detect harmful chemicals.

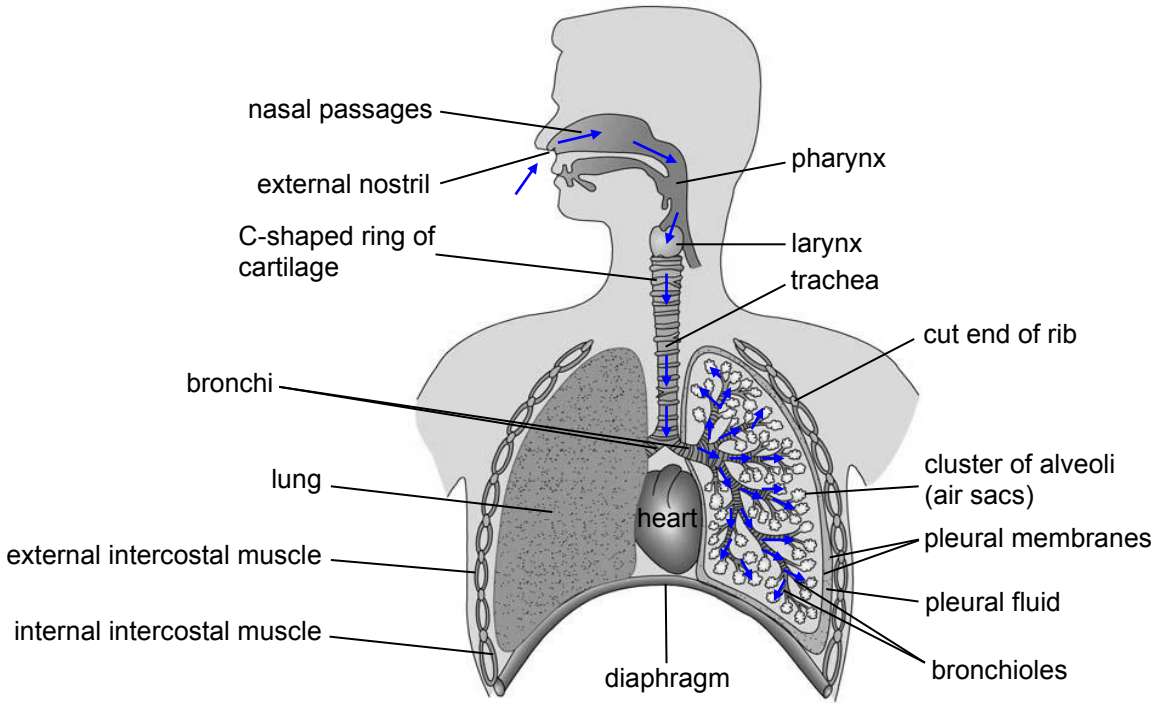


Figure 9.10 The human gas exchange system (arrows depicting passage of air flow)

4.2 Trachea and Bronchi (Singular: Bronchus)

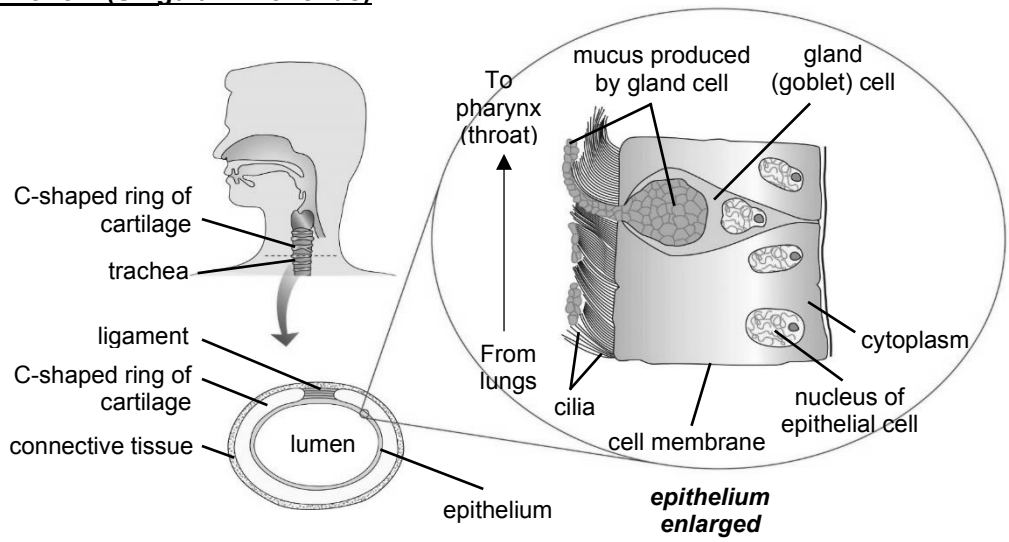


Figure 9.11 Structure of trachea

- Air enters the trachea through an opening known as the glottis.
- Structure: (i) Lies in front of the oesophagus, (ii) Extends from the larynx into the chest cavity, (iii) Supported by C-shaped rings of cartilage, which ensure the trachea is always kept open.
- Defensive function:
  (i) **Gland (goblet) cells** which secrete **mucus** to **trap dust and bacteria**,
  (ii) Ciliated cells that bear **cilia** to **sweep** the trapped dust and bacteria **upwards** into the pharynx. From the pharynx, they are swallowed into the oesophagus.
- **Bronchi** from the lower end of the trachea lead to the lungs.

4.3 Lungs

- Structure: (i) Each lung lies within the pleural cavity, which is lined by 2 transparent elastic membranes called the pleura (singular: pleuron) or pleura membranes. A thin layer of lubricating fluid (known as pleural fluid) between the pleura allows the membranes to glide over each other easily when the lungs expand and contract during breathing.
  (ii) Inside each lung, each bronchus divides repeatedly and ends in very fine **bronchioles**, which in turn end in a cluster of **alveoli** (singular: alveolus) or air sacs.

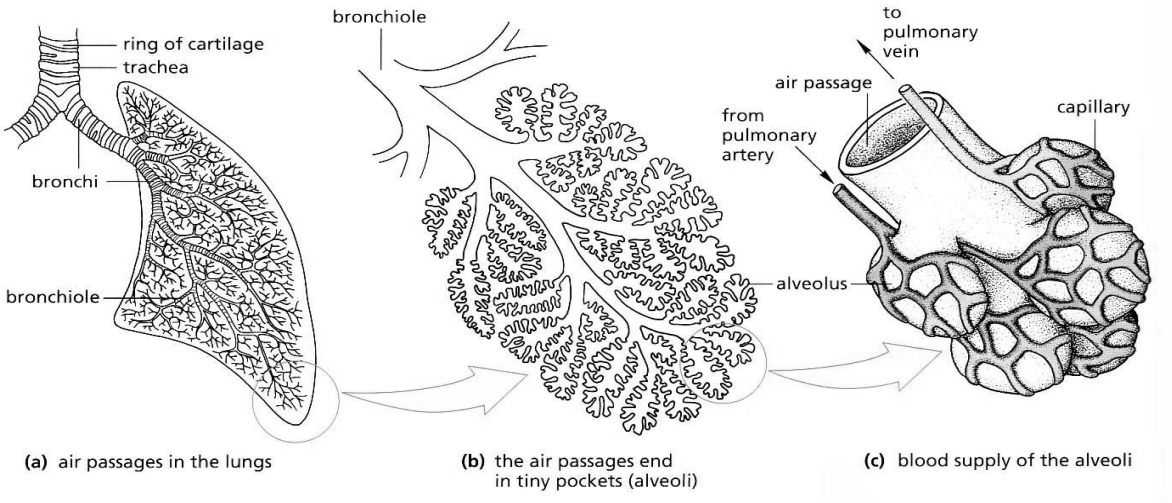


Figure 9.12 How the trachea leads to the bronchi, which branches into bronchioles and alveoli
Source: Clegg and Mackean

- **Lung Capacity**: A spirometer (Figure 9.14) is an instrument which measures the volume of air breathed in and out of the lungs. Total volume of air in lungs is 5000 cm^3. However, only part of this volume is exchanged in each breathing cycle. At rest, the volume breathed in and breathed out is about 500 cm^3. This volume of air is known as tidal volume. During exercise or when deep breaths are taken, an additional 1500 cm^3 known as inspiratory reserve volume is breathed in and an additional 1500 cm^3 known as expiratory reserve volume is breathed out. There is always some residual volume of 1500 cm^3 left inside the lungs.

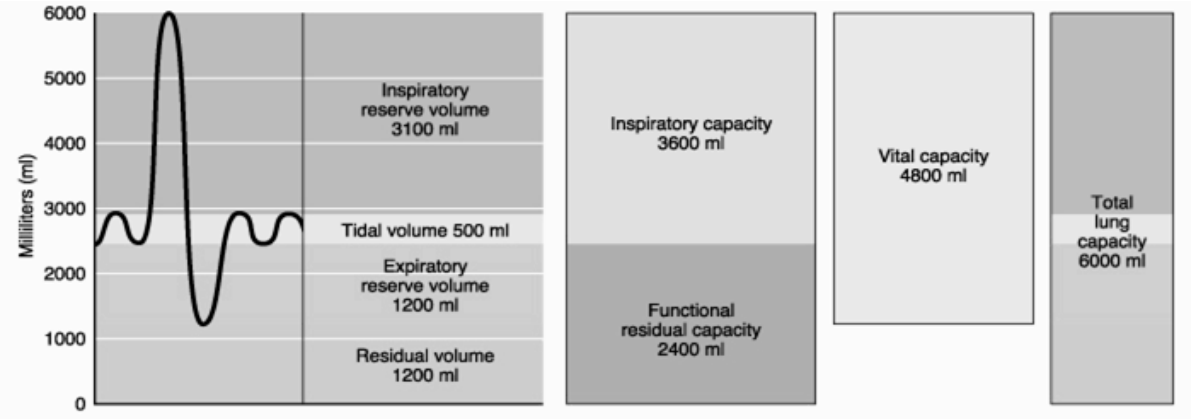


Figure 9.13 Volume of air in lungs

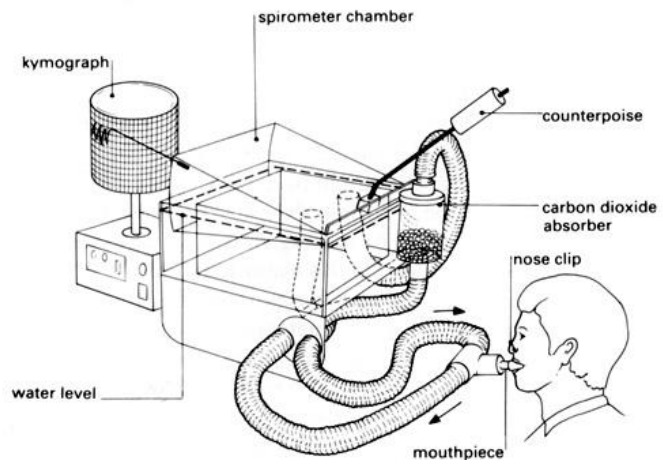
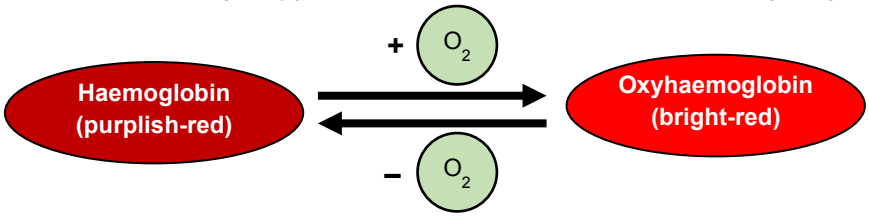


Figure 9.14 Capacity of lungs measured by spirometer
Source: http://www.nuffieldfoundation.org/

- **Transport of oxygen from lungs to tissues**: Oxygen **dissolves** in the moisture lining the alveolar walls and then **diffuses** through the alveolar wall into the blood capillaries (through the one cell thick capillary wall). Oxygen will then enter the blood plasma before combining with **haemoglobin** in the red blood cells to form **oxyhaemoglobin**. Oxygenated blood is transported away from the lungs, and when it passes through the tissues, oxygen is released from oxyhaemoglobin in the RBC and diffuses out to the blood capillaries into the cells of the tissues.

> ***Pathway of oxygen molecule:***
> ***Air in alveolus ⇔ thin film of water ⇔ one-cell thick alveolar wall ⇔ one-cell thick endothelium of capillary ⇔ blood plasma ⇔ red blood cell***

(in tissues of high oxygen but low carbon dioxide concentrations e.g. lungs)



(in tissues of low oxygen but high carbon dioxide concentrations e.g. rest of body cells)

Figure 9.15 Reversible reactions of haemoglobin to oxyhaemoglobin

- **Transport of carbon dioxide from tissues to lungs for removal**: Carbon dioxide that is produced from aerobic respiration by the tissues diffuses into the blood and enters the red blood cells. In the red blood cells, carbon dioxide reacts with water to form **carbonic acid**, which is catalysed by the enzyme **carbonic anhydrase**. The carbonic acid is then converted to **hydrogencarbonate ions**, which diffuse out of the red blood cells and are carried in the blood **plasma**.

  In the lungs, the hydrogencarbonate ions diffuse back into the red blood cells where they are converted back into carbonic acid, and then carbon dioxide and water. The carbon dioxide then diffuses out of the blood capillaries into the alveoli.

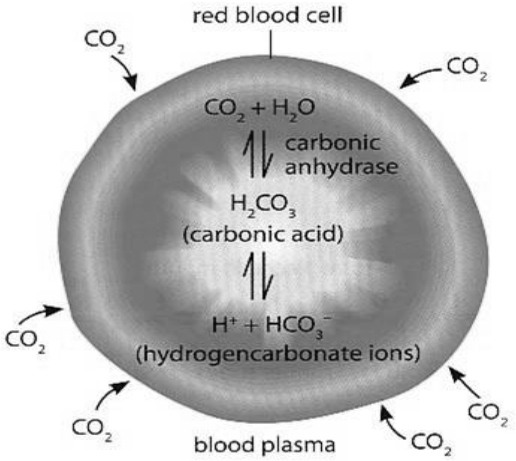


Figure 9.16 How carbon dioxide diffuses into the RBC and converts to hydrogencarbonate ions

4.4 Alveoli (Singular: Alveolus)

- Structure: (i) A typical pair of human lungs contains about 700 million alveoli, producing about 70 m^2 of surface area, (ii) Each alveolus is wrapped in a fine mesh of capillaries, (iii) Each alveolus contains collagen and elastic fibres, which allow it to stretch as it is filled with air during inhalation.
- **Gas exchange in the alveoli**: Oxygen **diffuses** from alveolar air into the blood capillaries and carbon dioxide diffuses from the blood capillaries into alveolar air. A **concentration gradient** for both gases is maintained by
  (i) a continuous flow of blood through the blood capillaries and
  (ii) constant breathing of air. Blood flow at the capillaries is slow to allow for sufficient time for gas exchange.

Table 9.2 Summary of structural features of the trachea, bronchus, bronchiole and alveolus

	cilia	mucus	gas exchange	elastic fibres	cartilage
trachea	✓	✓	×	×	✓
bronchus	✓	✓	×	×	✓
bronchiole	✓	✓	×	✓	×
alveolus	×	×	✓	✓	×

Do you know that our alveoli will tear apart if our body (not within a spacesuit) is subjected to the vacuum in outer space?! Under extremely low air pressure, air trapped in the lungs expands and this can easily break apart the one cell thick wall of our alveoli. To make matters worse, water and dissolved gases in the blood will also form bubbles by vapourising and this blocks our blood flow. The lack of oxygen transported to our brain will lead to unconsciousness, before the eventual death.

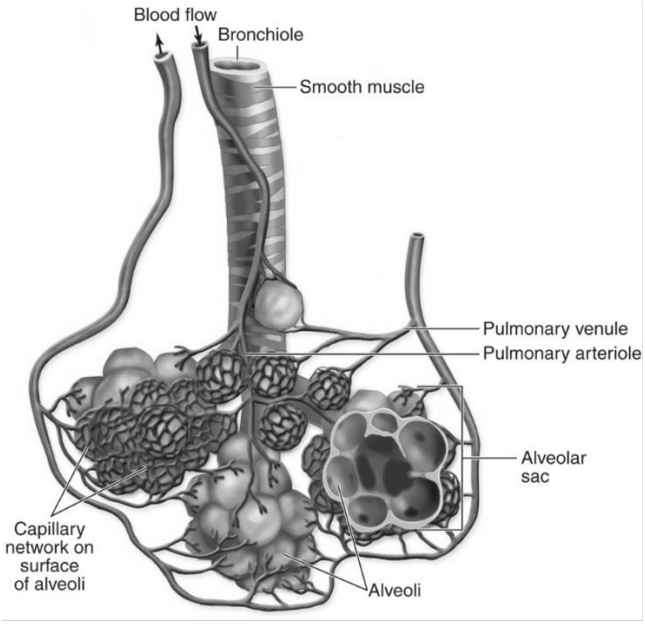


Figure 9.17 Relationship between blood capillaries and alveoli in the lungs Source: McGraw-Hill

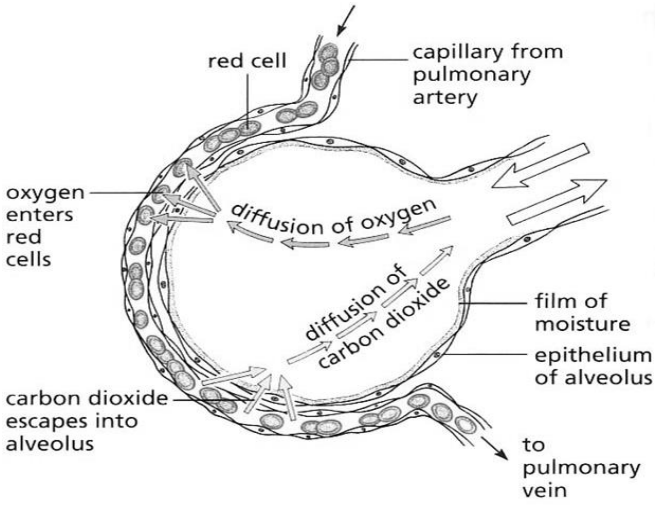


Figure 9.18 Transverse section of the alveolus showing gas exchange Source: Clegg and Mackean

- **Adaptations of alveoli for gas exchange**:
  (i) Numerous alveoli provide a **large surface area**,
  (ii) Wall of alveolus is only **one cell thick**, which provides a short diffusion distance for gases,
  (iii) A thin film of **moisture** covers the surface of the alveolus, which allows oxygen to **dissolve**, and
  (iv) Alveoli are richly supplied with blood capillaries to transport the gases away.

How many layers of cell membrane must a molecule of oxygen pass to move from the alveolar air spaces into a red blood cell?

5. To pass through the alveolar epithelium, RBC passes two layers of cell membrane. The capillary epithelium is a further two layers to pass through before diffusing through the cell membrane of RBC.

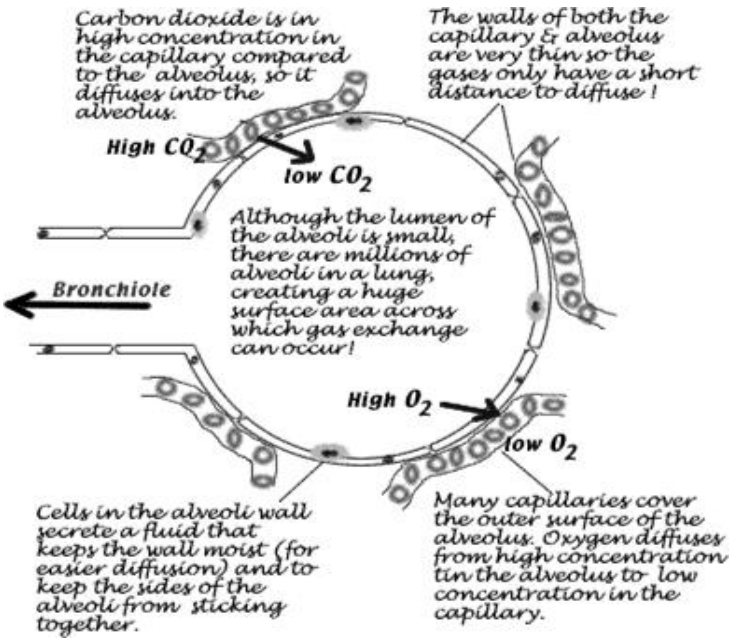


Figure 9.19 Adaptations of the alveoli
Source: http://science.halleyhosting.com/sci/ibbio/Anatomy/respiratory/notes/3.htm

4.5 Thoracic (Chest) Cavity

- **Structure**: The ribs are attached ventrally (front) to the chest bone/sternum and dorsally (back) to the backbone/ vertebral column. 2 sets of antagonistic muscles – **external and internal intercostal muscles** can be found between the ribs. The thorax is separated from the abdomen by the **diaphragm** (a sheet of muscle).
- **Breathing Mechanism**:
  - Breathing (i) is part of the gaseous exchange process, (ii) refers to the muscular contractions and movements of the ribs which result in air moving in and out of the lungs.
  - Breathing movements consist of 2 phases – (i) **Inspiration / Inhalation** and (ii) **Expiration / Exhalation**.

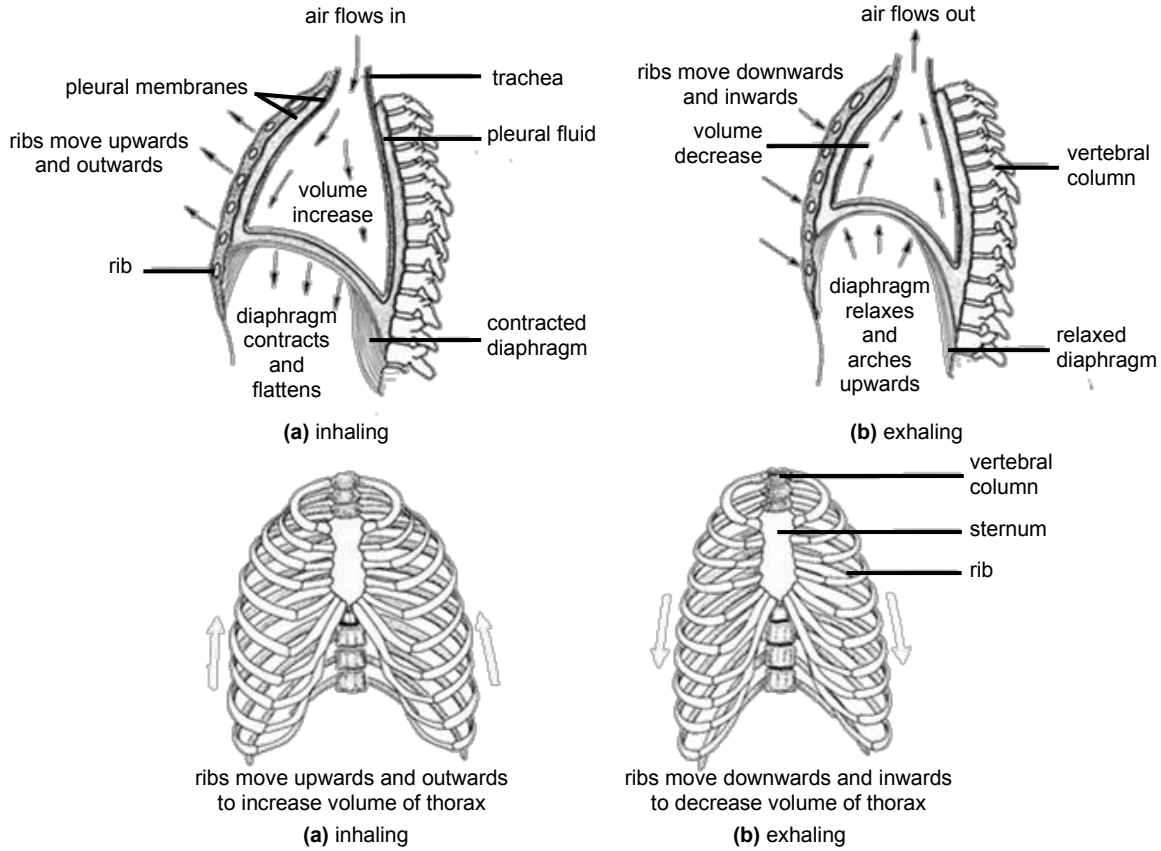
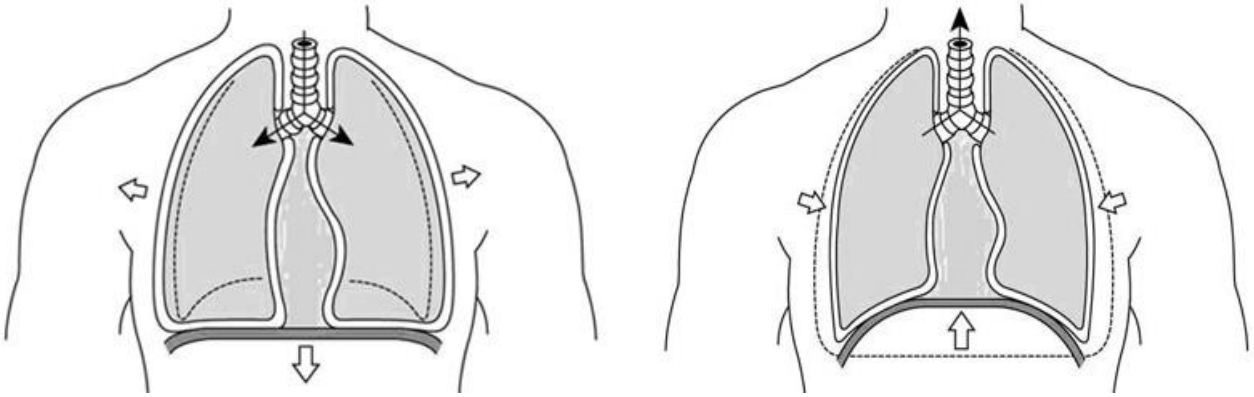


Figure 9.20 Movement of thorax, ribs and diaphragm during inhalation and exhalation
Source: Clegg and Mackean

Table 9.3 Summary of events during inspiration and expiration

part of breathing mechanism	inspiration	expiration
intercostal muscles	• External intercostal muscles contract, internal intercostal muscles relax.	• External intercostal muscles relax, internal intercostal muscles contract.
ribs and sternum	• Ribs and sternum move upwards and outwards.	• Ribs and sternum move downwards and inwards.
diaphragm	• Diaphragm contracts and flattens.	• Diaphragm relaxes and arches upwards.
volume of thorax / lungs	• Volume of thorax / lungs increases.	• Volume of thorax / lungs decreases.
pressure in lungs	• Air pressure in lungs decreases.	• Air pressure in lungs increases.
movement of air into lungs	• Atmospheric pressure higher than pressure in lungs, therefore, air flows into lungs passively. (air is NOT drawn in forcefully)	• Atmospheric pressure lower than pressure in lungs, therefore, air flows out of lungs passively. (air is NOT expelled out forcefully)



(a) (b)

Figure 9.21 Changes in thoracic volume during (a) inhalation and (b) exhalation
Source: http://uninursety.com/

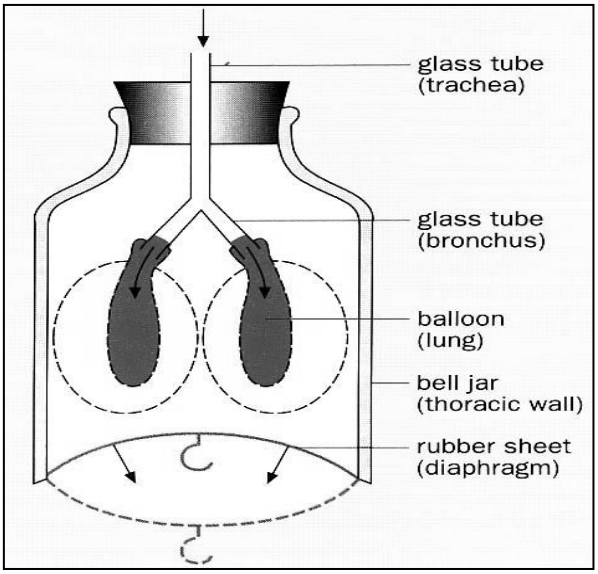


Figure 9.22 Model showing breathing mechanism: when the rubber sheet (diaphragm) is pulled down, the increase in volume causes a drop in air pressure in the bell jar. Atmospheric pressure outside is now higher than inside the jar and will rush into the jar to fill up the balloons (lungs).

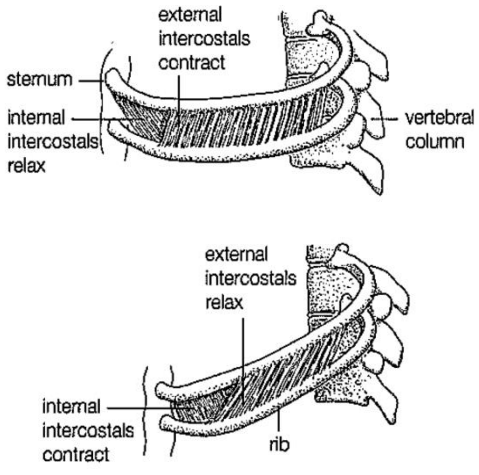


Figure 9.23 How intercostal muscles move the ribs

What is the stimulus for breathing?

- The stimulus for breathing is a lowered pH as a result of high concentration of **carbon dioxide** released into the blood, **not** a lack of oxygen.
- As shown in Figure 9.24, breathing rate decreases when subject is breathing in 100% oxygen, and increases when subject breathes in a mixture of 92% oxygen and 8% carbon dioxide. Therefore, the higher the concentration of carbon dioxide, the higher the breathing rate.

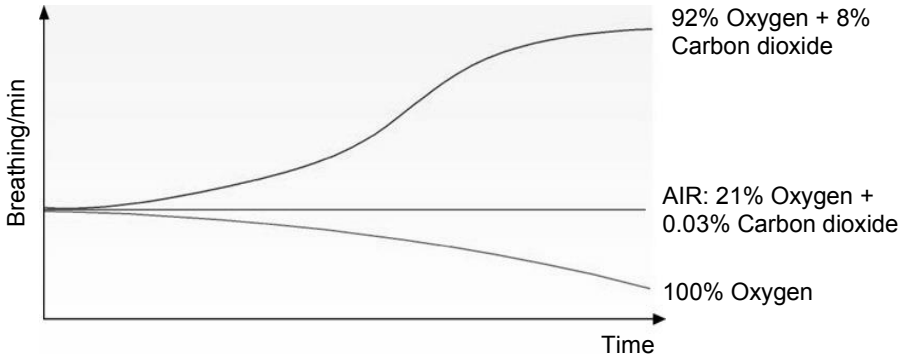
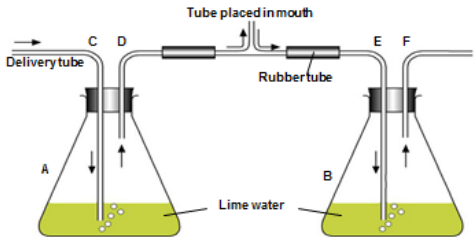


Figure 9.24 Effect of concentration of carbon dioxide on breathing rate

Table 9.4 Summary of difference in composition of inspired and expired air

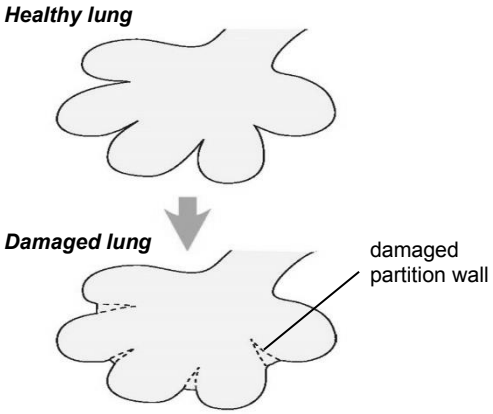
component (experimental set-up to test for differences)	inspired air	expired air
oxygen	21.0%	16.4%
carbon dioxide 	0.03%	4.0%
nitrogen	78.0%	78.0%
water vapour (use dry cobalt chloride paper – one waved in air and the other at mouth)	variable (rarely saturated)	saturated (because some water evaporates from the surfaces of the alveoli)
temperature	variable	body temperature 37 ˚C (because some heat escapes from the blood into alveolar air)
dust particles	variable but usually present	little, if any

5. EFFECTS OF TOBACCO SMOKE ON HUMAN HEALTH

Irritant particles in the air or chemicals found in tobacco smoke can enter the lungs and respiratory tubes and affect human health. While most of the particles are filtered off by hairs in the nose or trapped in the mucus of the trachea, long term exposure can cause harm to the human body.

Table 9.5 Chemicals in tobacco smoke and their harmful effects to human health

chemical	properties of the chemical	effects on the body
nicotine	• Addictive drug • Causes the release of the hormone adrenaline • Makes blood clot easily	• Increases heartbeat and blood pressure • Increases risk of blood clots in blood vessels
carbon monoxide	• Combines with haemoglobin to form carboxyhaemoglobin, which reduces the efficiency of RBC to transport oxygen	• Death if concentrations in air is increased by 1%

chemical	properties of the chemical	effects on the body
	• Increases the rate of fatty deposits on the arterial wall • Damages the lining of blood vessels	• Increases risk of atherosclerosis • Increases risk of blood clots in blood vessels
tar	• Contains cancer causing chemicals which induce uncontrolled cell division of epithelial cells lining the airways • Paralyses cilia lining the air passages, mucus and dust cannot be removed.	• Blocks air sacs and reduces efficient gas exchange • Prevents removal of dust particles trapped in the mucous lining of the airways
irritants (e.g. hydrogen cyanide, acrolein, formaldehyde)	• Paralyses cilia lining the air passages, mucus and dust cannot be removed.	• Increases risk of **chronic bronchitis** Signs of chronic bronchitis are: (a) Epithelium lining becomes inflamed, (b) Excessive mucus secreted by the epithelium, (c) Airways become blocked, making breathing difficult, (d) Person has to cough persistently to clear airways in order to breathe. This increases the risk of getting lung infections. • Increases risk of **emphysema** Signs of emphysema: (a) Violent coughing breaks partition walls between the air sacs,  (b) Surface area for gaseous exchange decreases. (c) Lungs become inflated with air, (d) Lungs lost their elasticity, (e) Breathing becomes difficult and person wheezes and suffers breathlessness. • When a person has chronic bronchitis and emphysema, he is said to suffer from <u>chronic obstructive lung disease</u>.

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 10 – Excretion

Name: **Class:**

A. Content
- Structure and function of kidneys
- Dialysis machine

B. Learning Outcomes

Students should be able to:
(a) define excretion and explain the importance of removing nitrogenous and other compounds from the body.
(b) outline the function of kidney tubules with reference to ultra-filtration and selective reabsorption in the production of urine.
(c) outline the role of anti-diuretic hormone (ADH) in the regulation of osmotic concentration.
(d) outline the mechanism of dialysis in the case of kidney failure.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
4. Reece J.B., Urry L.A., Cain M.L., Wasserman S.A., Minorsky P.V. and Jackson R.B. Campbell Biology (10th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline
1. Importance of excretion
2. Human urinary system
3. Osmoregulation
4. Kidney dialysis

E. Practical Work
- Composition of different body fluids I

1. IMPORTANCE OF EXCRETION

Excretion is a process by which **metabolic** waste products and **toxic** materials are removed from the body of an organism.

Metabolism

- The sum of all the chemical reactions within a living organism.
- **Metabolism = Anabolism + Catabolism**
- Anabolism: Chemical reactions in which complex substances are synthesised from simpler substances.
  Examples: photosynthesis, growth and mineralization of bones
- Catabolism: Chemical reactions in which complex substances are broken down into simpler substances.
  Examples: respiration, breakdown of fats into glycerol and fatty acids

- Metabolic wastes are termed **excretory products.**
- Examples of metabolic waste products are:
  - urea (from deamination)
  - carbon dioxide (from tissue respiration)
  - oxygen (from photosynthesis)
  - bile pigments (from haemoglobin breakdown and found in bile)
  - water (specifically from tissue respiration only)

Accumulation of metabolic wastes could be harmful as it could:
- alter the pH and water potential of body fluids.
- poison the enzyme systems.

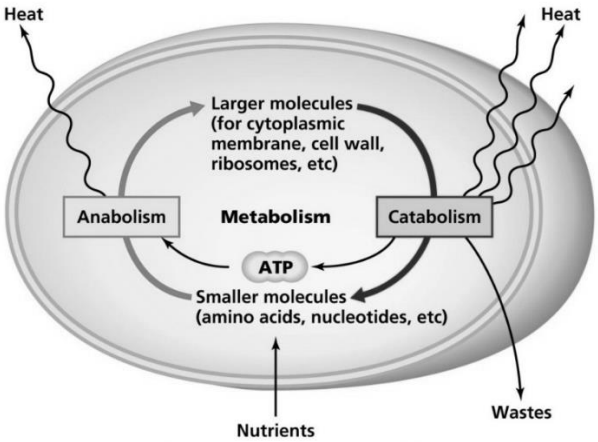


Figure 10.1 Metabolism is the sum of all the chemical reactions.

Table 10.1 Excretory products and organs in humans

Excretory product	Organ	Excreted as
• Carbon dioxide (from cellular respiration)	Lungs	• Gas in exhaled air
• Mineral salts • Nitrogenous waste products - urea (from deamination of proteins) - uric acid (from nucleic acids breakdown) - creatinine (from muscle tissue breakdown)	Kidneys Skin	• Constituent of urine • Constituent of sweat, but only in small quantities
• Excess water	Kidneys Skin Lungs	• Main constituent of urine • Main constituent of sweat • Water vapour in exhaled air
• Bile pigments (from haemoglobin breakdown)		• Constituent of faeces, via the intestines

Distinguish between excretion and egestion.
Excretion is the removal of metabolic wastes whereas egestion refers to the removal of undigested wastes.
Is oxygen produced during photosynthesis an excretory product of plants?
Yes. Photosynthesis is a metabolic process (e.g. anabolic reaction) and oxygen is released as a by-product.
Which two organs are considered the main excretory organs in our body?
Lungs and kidneys. Skin is not considered as the release of sweat (contains urea) is to serve thermoregulatory purposes instead of excretion.

2. HUMAN URINARY SYSTEM

The urinary system in humans consists of:
- a pair of **kidneys**,
- **renal artery** and **renal vein**,
- a pair of **ureters**,
- a **bladder**, and
- a **urethra**.

Kidney

- Located in the abdominal cavity and attached to the dorsal wall on either side of the vertebral column, behind the liver.
- Right kidney is positioned slightly lower than the left kidney, due to the asymmetry within the abdominal cavity caused by the liver.

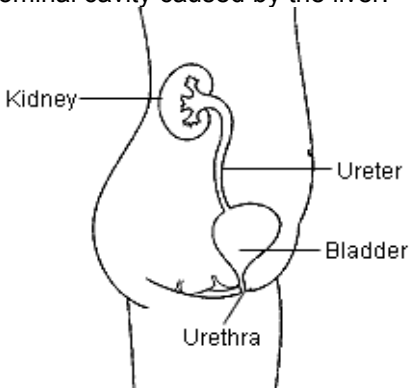


Figure 10.2 Side view of human urinary system
Source: https://www.niddk.nih.gov/

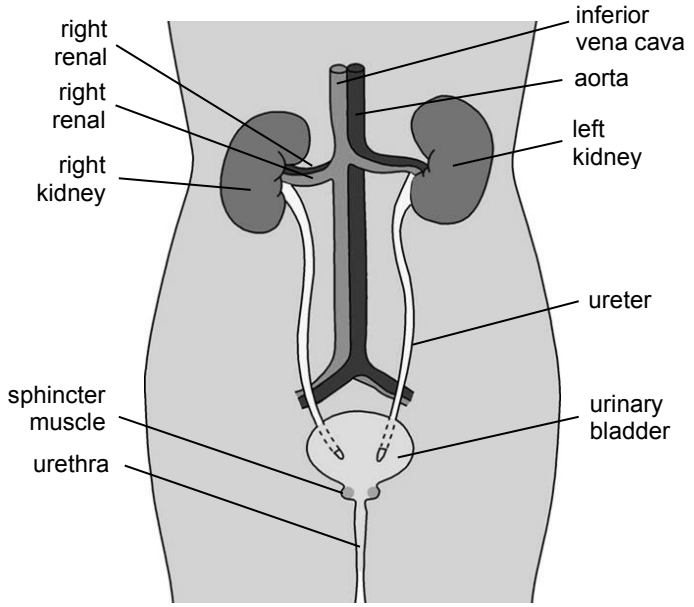


Figure 10.3 Schematic drawing of the human urinary system
Source: Clegg and Mackean

- Each kidney is a red-brown and bean shaped structure, about 10 cm long, 6 cm wide and 3 cm deep.
- Concave edge has a depression called **hilus**, where the ureter arises.
  - The hilus is also the point at which the renal artery enters the kidney and renal vein leaves the kidney.
- Each kidney is covered and protected by a tough, transparent membrane, the capsule.
- A section through the kidney shows
  - A dark, outer region called the **cortex**.
  - An inner lighter region called the **renal medulla**.
  - Each renal medulla contains 12 to 16 **renal pyramids**.
- Where the ureter joins the kidney, there is a space called the **pelvis**. The pyramids channel urine into the pelvis.
- Made up of numerous blood capillaries and tiny units called **nephrons**.

Functions:

- Excretion: remove nitrogenous wastes e.g. urea
- Osmoregulation: maintain a constant water potential in blood

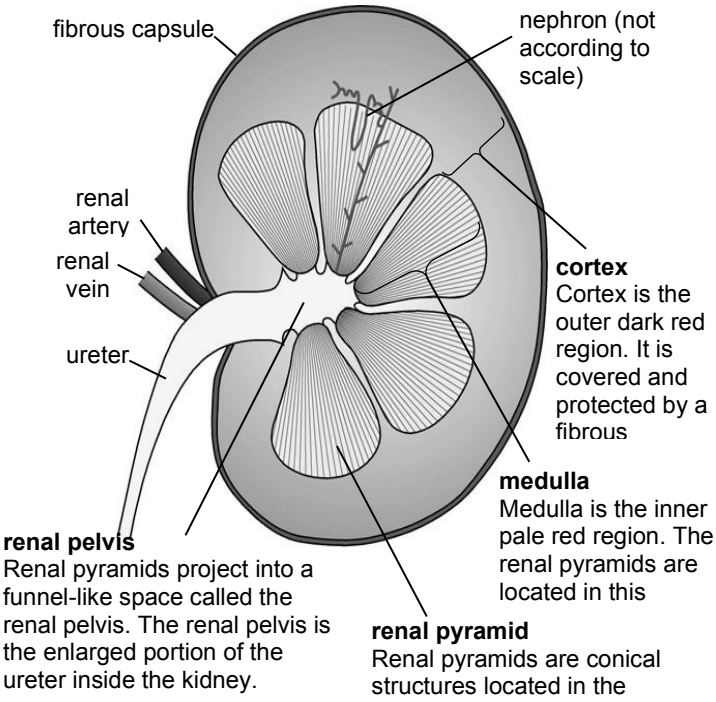


Figure 10.4 Section through kidney showing the regions

Renal artery

- Carries oxygenated blood from heart to kidneys.
- Contains lesser carbon dioxide but more urea.

Renal vein

- Carries deoxygenated blood from kidneys back to the heart.
- Contains more carbon dioxide but less urea.

Ureter

- A 25 cm long tube that transports urine from each kidney to the urinary bladder.

Bladder
- An organ that temporarily stores about 400–500 cm^3 of urine excreted by the kidneys.
- It is a distensible sac with a wall of smooth muscle.
- Sphincter muscle at base of bladder prevents urine from escaping when contracted (voluntary control).

Urethra
- A muscular tube that emerges from base of bladder and allows urine to be passed out of body.
- The male urethra (≈ 22.3 cm) is longer than the female urethra (≈ 4 cm).
- The male urethra also serves as a conduit for semen to be ejaculated during sexual intercourse.

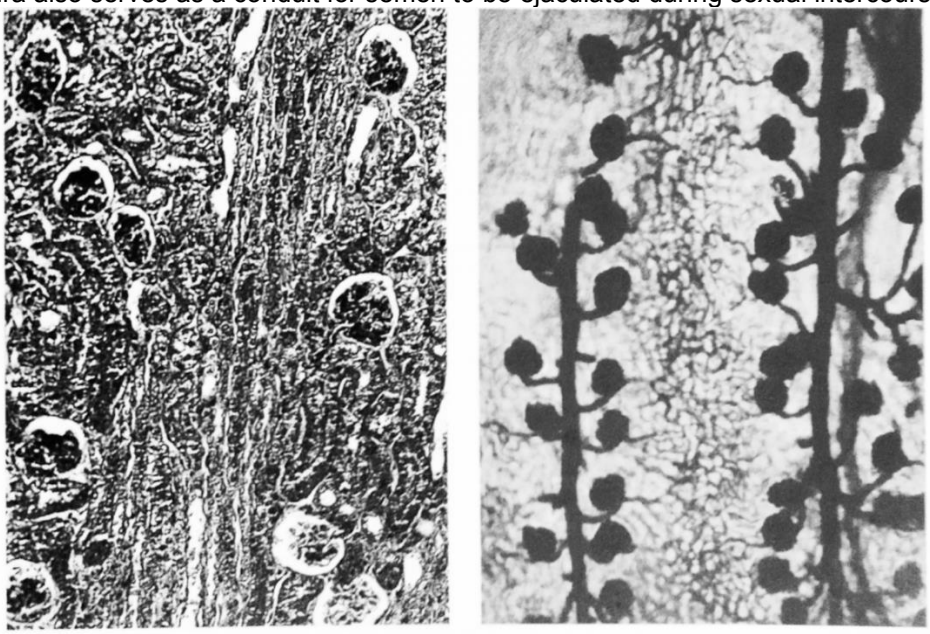


Figure 10.5 Photomicrographs of cortex of kidney showing Bowman's capsules (left), and injected with dyes to show blood supply (right) (X50)

Nephron
- Four main parts of a nephron are the:
  - **Bowman's capsule** (or renal capsule),
  - **Proximal** (first) **convoluted tubule**
  - **loop of Henle**
  - **Distal** (second) **convoluted tubule**
- Several nephrons open into a tube called the **collecting duct**.
- Blood enters kidney via renal artery and eventually branches out into a mass of capillaries in the Bowman's capsule known as **glomerulus**.
- Blood leaving the glomerulus branches into the second capillary bed, which surrounds the rest of the nephron. After which, the blood is then returned to the renal vein.

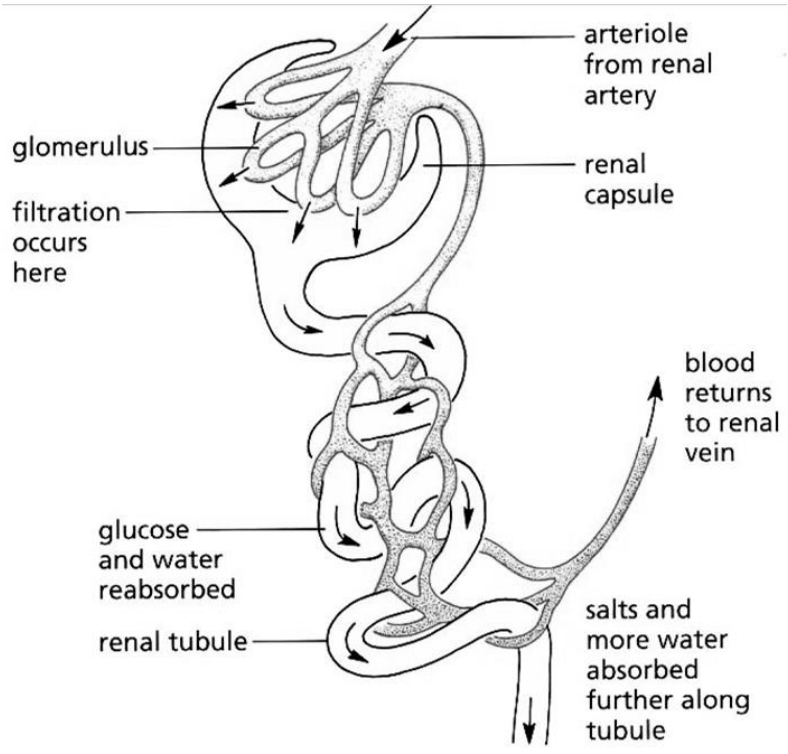


Figure 10.6 Portion of a nephron showing glomerulus, renal capsule and renal tubule
Source: Clegg and Mackean

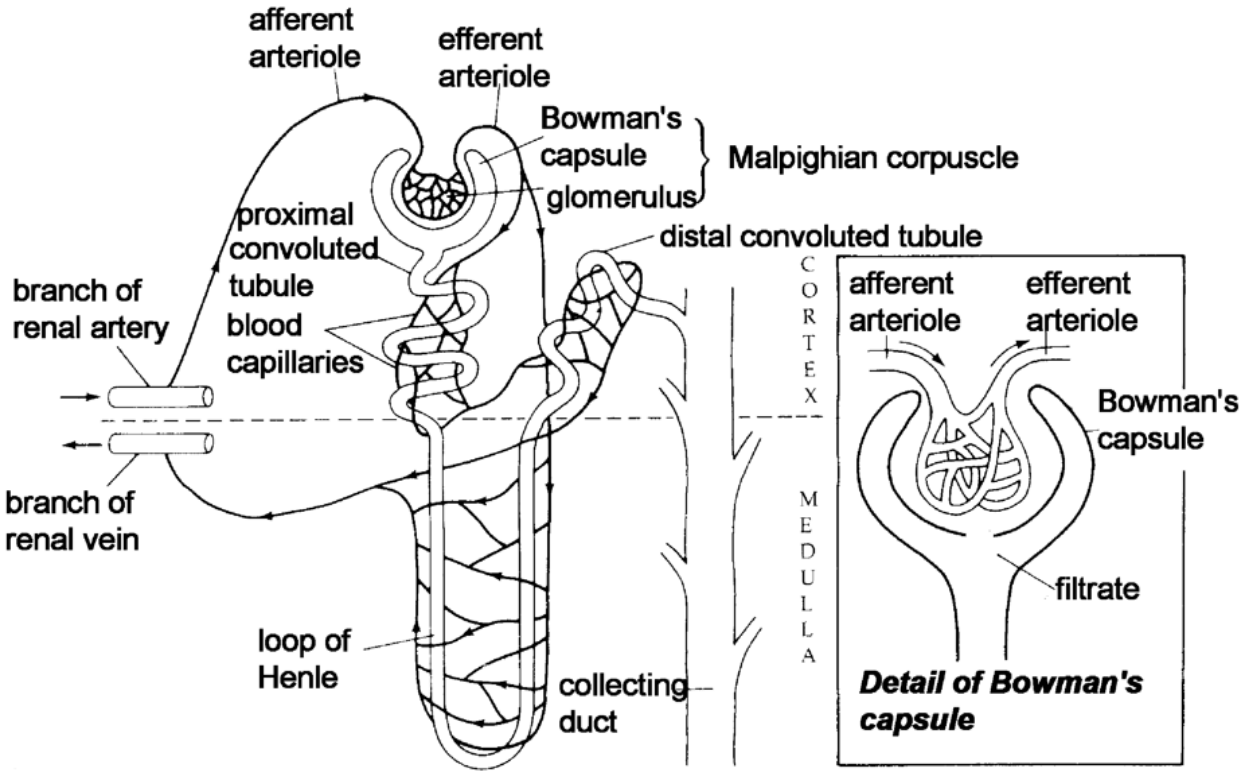


Figure 10.7 Diagram of a kidney tubule with its blood supply

Urine formation

Urine formation involves two main processes:

- **Ultra-filtration**
- **Selective reabsorption**

Ultra-filtration

- Afferent arteriole is wider than the one leaving it (efferent arteriole).
  - The **heart**, coupled with the difference in the diameters of both afferent and efferent arterioles, create a **high pressure** in glomerulus, which forces part of the blood plasma through the capillary walls into the Bowman's capsule.
  - Water and smaller molecules (e.g. glucose, amino acids, mineral salts, urea) are forced into the Bowman's capsule.
  - Larger molecules (e.g. red blood cells, white blood cells, platelets, fats and proteins) are too large to pass out and are retained.

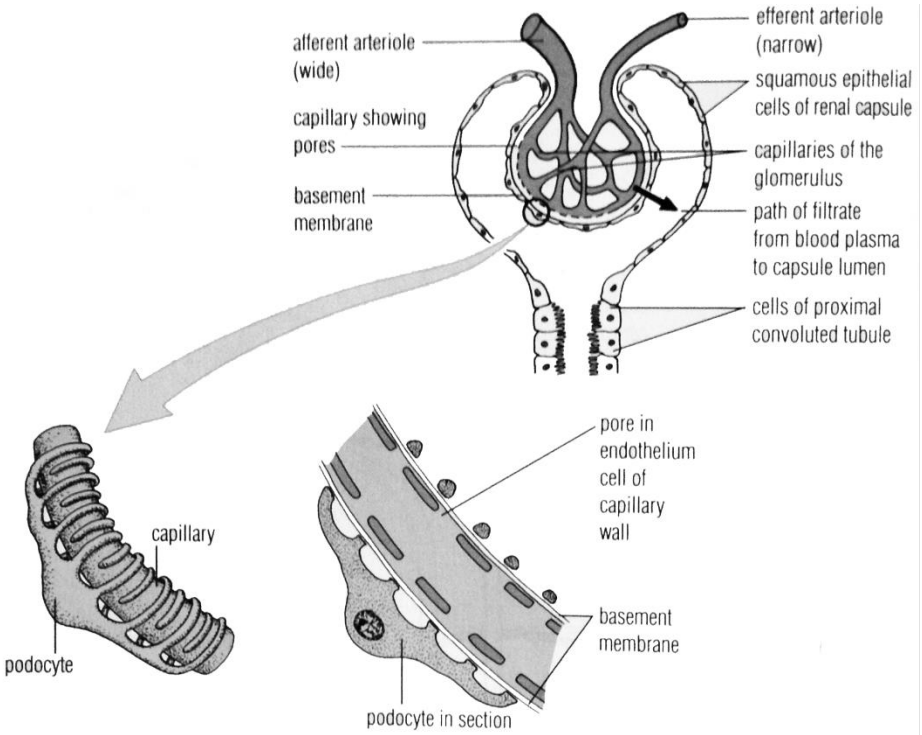


Figure 10.8 Schematic drawing of the Bowman's capsule and glomerulus
Source: Clegg and Mackean

- Ultrafiltration can only occur in presence of a:
  1. **high hydrostatic pressure**
     The afferent arteriole with the wider diameter than the efferent arteriole creates the high blood pressure required for ultrafiltration.

2. **partially permeable membrane**
   The glomerular blood capillaries have numerous pores in its wall and is wrapped around a continuous layer called the **basement membrane**. The basement membrane, separating the glomerulus from the Bowman's capsule, only allow water and very small molecules to pass through.

Selective reabsorption

- Filtrate from glomerulus moves from Bowman's capsule to the proximal convoluted tubule, loop of Henle and distal convoluted tubule.
- Capillaries surrounding the tubules absorb useful materials from the filtrate back into the blood.
  - All **glucose**, **amino acids** and most of the **mineral salts** are reabsorbed back by **active transport**.
  - Water is reabsorbed by **osmosis**.
- 99% of filtrate formed from ultrafiltration is reabsorbed back into the bloodstream.
- Fluid in collecting duct, containing **excess water**, **excess salts** and waste products such as **urea**, **uric acid** and **creatinine**, passes into renal pelvis, forming urine.
- Composition of urine varies depending on diet and certain diseases e.g. diabetes.

Table 10.2 Composition of fluids in the kidney (concentrations are given in g per 100 cm^3 of fluid)

component	blood plasma entering glomerulus	filtrate in renal capsule	urine in collecting duct
water	90–93	97–99	96
blood proteins	7-9	Some of the smallest blood protein molecules only	0.0
glucose	0.10	0.10	0.0
urea	0.03	0.03	2.0
other nitrogen-containing compounds	0.003	0.003	0.24
ions: sodium chloride others (Ca^{2+}, Mg^{2+}, K^{+}. PO_4^{3-}, SO_4^{2-})	 0.32 0.37 0.038	 0.32 0.37 0.038	 0.30–0.35 0.60 0.475
pH	7.35–7.45		4.7–6.0 (average 5.0)

Clegg and Mackean

3. OSMOREGULATION

- Osmoregulation is the control of water and solute concentrations in the blood to maintain a constant water potential in the body.
- If the blood plasma is too diluted, the blood cells will swell and burst.
- Regulation is achieved by the action of a hormone, **anti-diuretic hormone (ADH)**, also known as vasopressin.
- ADH is produced by the **hypothalamus** in the brain and is released by the **pituitary gland** when the water potential in the blood plasma decreases.
- ADH functions to increase the permeability of the distal convoluted tubules and the collecting duct, such that water reabsorption is enhanced.

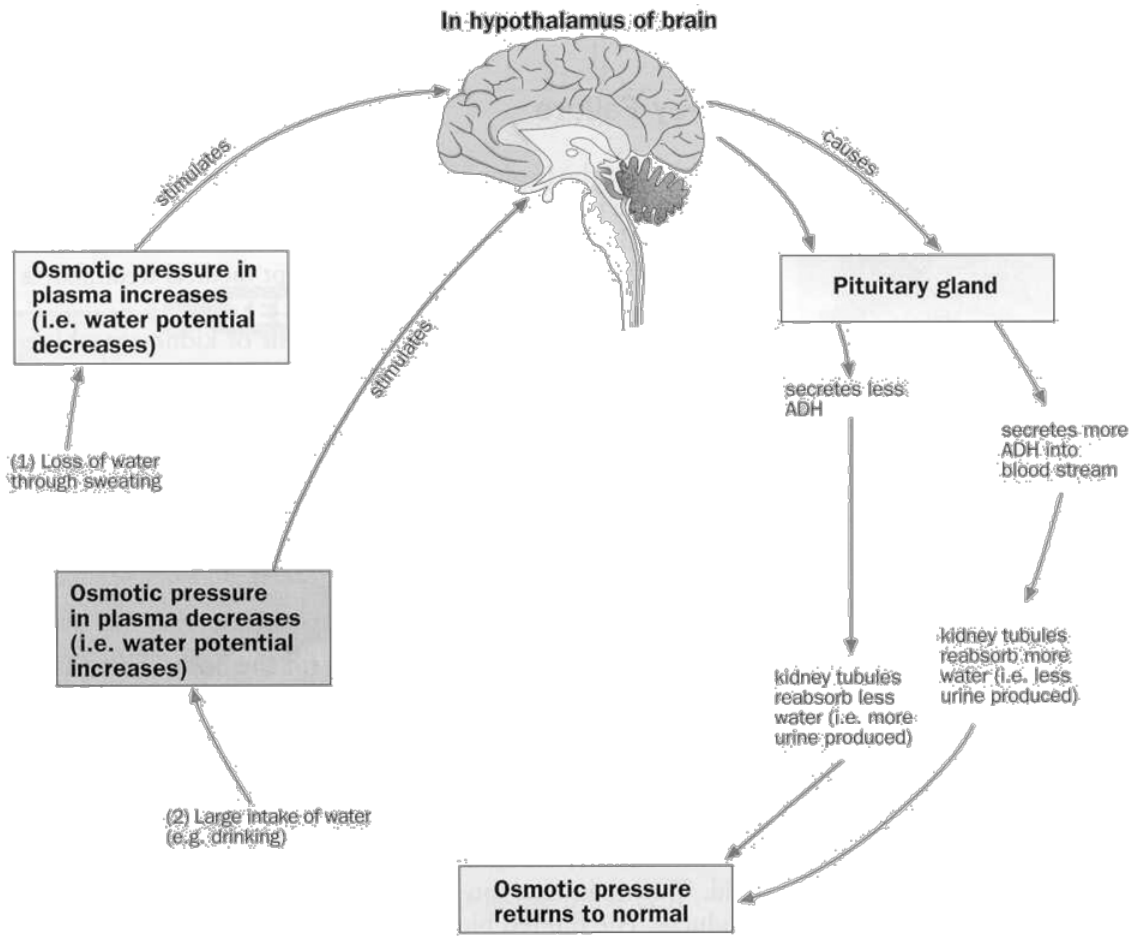


Figure 10.9 Overview of osmoregulation

Extension

Relationship between osmotic pressure, osmotic concentration and water potential

- Osmotic pressure (Ψ_s), (or solute potential / osmotic potential) is the measure of the tendency of a solution to take in water by osmosis.
  - It is the minimum pressure which needs to be applied to a solution to prevent the inward flow of water across a partially permeable membrane.
  - By definition, Ψs of pure water is 0. When solutes are added, they bind water molecules. This results in fewer free water molecules, reducing the capacity of water to move or do work. Thus, increase in solute concentration has a negative effect on water potential, which is why the Ψs of a solution is always expressed as a negative value.
  - For example, if a typical animal cell loses water, water potential drops. Lesser water molecules in the cell means lesser free water molecules, thus osmotic pressure increases.
- In many cases the water potential (Ψ) of a tissue equals to the sum of solute potential (Ψ_s) and pressure potential (Ψ_p).
  - $\Psi = \Psi_s + \Psi_p$
- Osmotic concentration, (or osmolarity), is a measure of solute concentration.
  - Osmolarity of a solution is usually expressed as Osm/L.
  - Two solutions with the same osmolarity are said to be isosmotic. If a selectively permeable membrane separates the solutions, water molecules will continually cross the membrane at equal rates in both directions. Thus, there is no net movement of water by osmosis.
  - When two solutions differ in osmolarity, the solution with the higher concentration of solutes is said to be hyperosmotic, and the more dilute solution is said to be hypoosmotic.
  - Water flows by osmosis from a hypoosmotic solution to a hyperosmotic one.

How is water potential of blood related to blood pressure?

- Kidneys control water and solute levels in blood by controlling amount of water reabsorbed.
- ↑ water reabsorption, ↑ blood volume, ↑ blood pressure. Large increase in blood pressure may cause blood vessels in brain to burst.
- Drugs known as diuretics will reduce production of ADH.

4. KIDNEY DIALYSIS

- A person can lead a normal life with only one functioning kidney. If both kidneys fail to work, urea and other wastes will accumulate in the blood to dangerous levels, which may lead to death.
- Treatment:
  - **Dialysis**
  - **Kidney transplant**

Possible causes

- Kidney failure may be an outcome of a variety of conditions such as bacterial infection, external mechanical injury and high blood pressure.
- During renal failure, the tubules are no longer able to remove excess water, excess salts or urea.
- If glomeruli are damaged, large molecules such as plasma proteins may escape into the filtrate, and end up in the urine.

Dietary restrictions

- Regulation of salt intake
- Regulation of protein intake to reduce accumulation of nitrogenous waste products in the blood.

Dialysis (or haemodialysis) machine

- What the kidney performs by filtration & selective reabsorption, a **dialysis machine** performs in one step, that is, **diffusion**.
- Blood is drawn from a vein in the patient's arm and is allowed to flow through the tubing in the dialysis machine (the dialyser).
- Presence of a (peristaltic) pump is used to facilitate movement of blood from patient's arm into the machine. The pump also prevents backflow of blood without the need of valves.
- The tubing is surrounded by a **dialysis fluid** (**dialysate**).

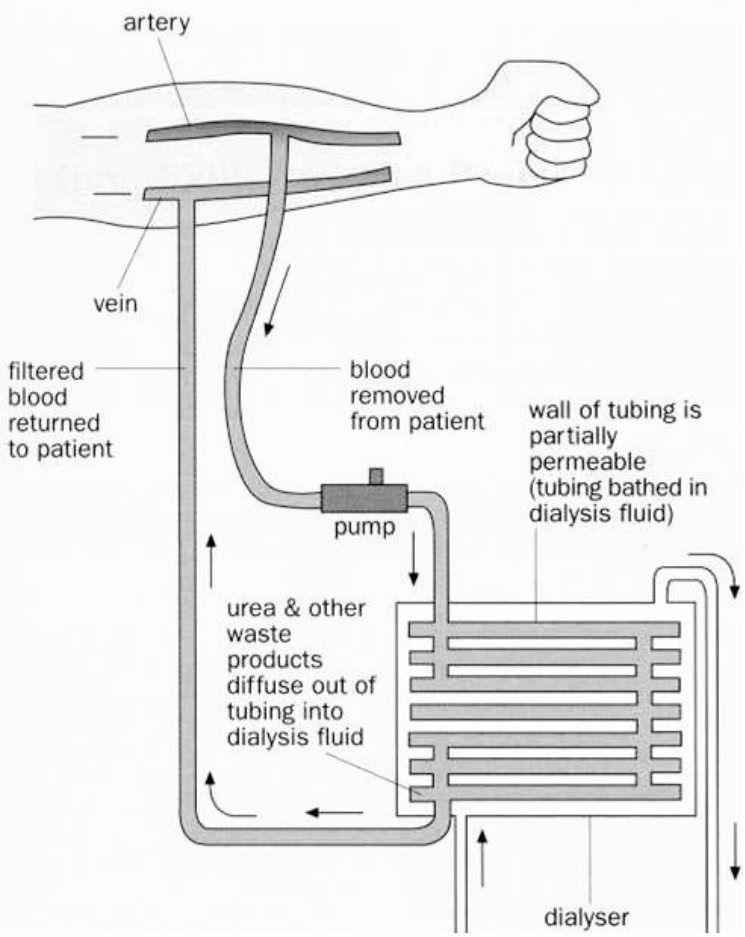


Figure 10.10 Simplified mechanism of a dialysis machine

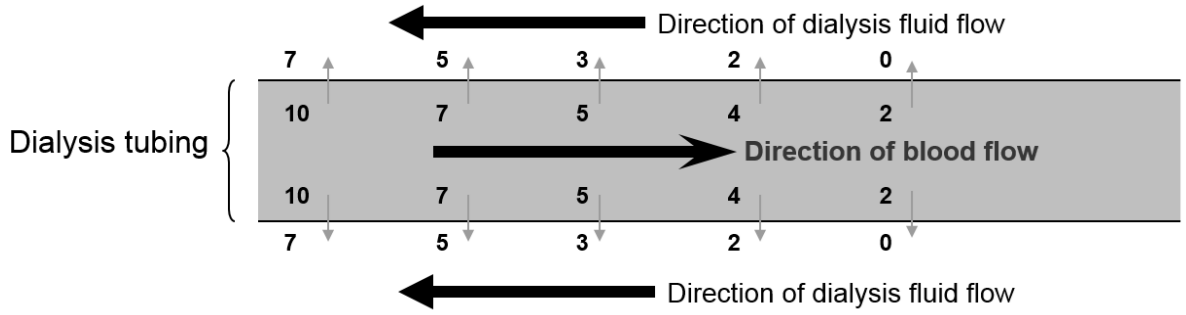
- A dialysis treatment can last for 3–4 hours and patients are required to go three times a week. (https://nkfs.org/treatment-options/what-is-haemodialysis/)

Features of dialysis machine

- Walls of tubing is **partially permeable** to allow small molecules to pass through.
- Tubing is **narrow**, **long** and **coiled** to increase the surface area to volume ratio which helps speed up the rate of exchange of substances between the blood and the dialysis fluid.
- Dialysis fluid contains the same concentration of essential substances as healthy blood plasma.
- Urea (and other wastes and ions) in the blood diffuses through the wall of tubing into the dialysis fluid.
- Big molecules like proteins and red blood cells, remain in the blood as they are too big to pass through the wall of tubing.
- Direction of blood flow is **opposite** to the flow of the dialysis fluid. This maintains the diffusion gradient for the removal of waste products.

Counter current system

- Counter current systems expend metabolic energy to create concentration gradients (Figure 10.11).
- Such counter current system is seen in the loop of Henle, where it maintains a high salt concentration in the interior of the kidney, enabling the kidney to form concentrated urine.
- Similarly, diffusion is maximised as urea is able to diffuse from blood to dialysis fluid throughout the dialysis tubing.



KEY

10: arbitrary units of urea

Figure 10.11 Illustration of removal of urea from blood to dialysis fluid

Extension

Peritoneal Dialysis (PD)

- An alternative treatment to haemodialysis (see Figure 10.11).
- A soft tube called a catheter inserted permanently at the abdomen to allow filling and draining of dialysate into and out of the peritoneum or abdominal cavity, which is surrounded by the peritoneal membrane.
- The walls of the patient's abdominal cavity are lined with a membrane called the peritoneum.
- The peritoneum acts as a partially permeable membrane which filters out wastes and extra fluids from the patient's body when the dialysate is drained. The used solution, containing wastes and extra fluid, is then thrown away.
- Dialysate contains a sugar called dextrose that will pull wastes and extra fluid into the abdominal cavity.
- The process of draining and filling is called an exchange and takes about 30 minutes.
- A typical schedule calls for four exchanges a day, each lasting about 4 to 6 hours.
- Unlike haemodialysis, which requires a need of a dialysis machine, peritoneal dialysis can be carried out at home, at work, or on trips.
- Peritoneal dialysis does not need vascular access and needling. In haemodialysis, two needles are inserted every session to allow blood to drain and return to the body after filtering.
- Peritoneal dialysis patients tend to have better quality of life than haemodialysis patients. They can enjoy the independence of being in charge of their own treatment.

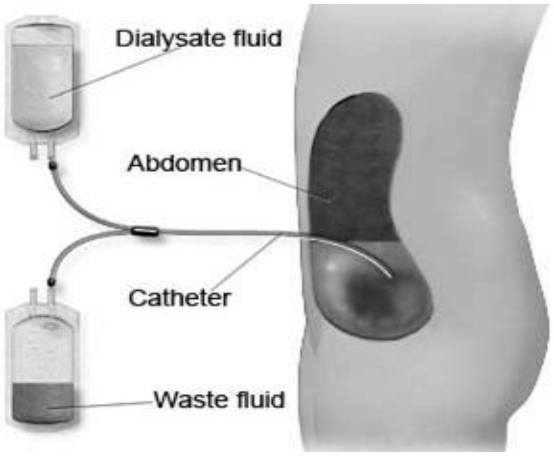


Figure 10.12 Diagram of peritoneal dialysis
Source: http://www.homedialysis.org/

Kidney Transplant

- In a transplant, the donor kidney is usually placed in the groin region of the abdomen while the patient's kidneys are left in their usual positions in the body.
- The surgery is not difficult because there are only 3 tubes to join up (Figure 10.13):
  - **(i)** renal artery to the iliac artery;
  - **(ii)** renal vein to iliac vein;
  - **(iii)** ureter to patient's bladder.

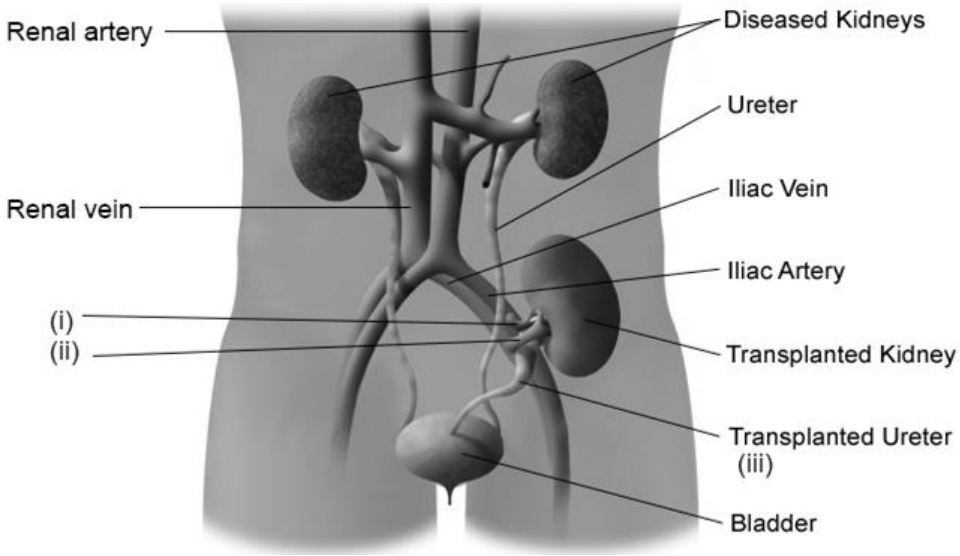


Figure 10.13 Diagram of a patient after undergoing a kidney transplant

- A transplanted kidney must be similar to the to the patient's original tissues (tissue matching) to avoid **tissue rejection**.
- If the kidney transplanted comes from someone with different tissue proteins, the antibody production of the patient must be reduced by immunosuppressive drugs to allow the patient to accept the transplant. Unfortunately, the patient's resistance to disease organisms is also reduced.

Table 10.3 Comparison of kidney dialysis and kidney transplant

	kidney dialysis	kidney transplant
treatment	3 times a week. Each session lasts between 6 to 10 hours.	one-time operation. Waiting list for a compatible donor can take years.
lifespan	lifespan is affected due to restricted lifestyle.	may have a longer renewed lifespan.
dietary habits	must maintain a strict diet and fluid restriction.	diet can resume normally.
surgery	fistula or AV graft has to be surgically inserted prior to regular treatments.	new transplanted kidney usually functions immediately. There are chances of rejection.
lifestyle	disrupted work schedules due to regular treatments.	lifestyle resumes as a normal healthy person.

The End

Catholic High School
Integrated Programme
Year 3 Biology
Lecture Notes 11 – Homeostasis

Name: **Class:**

A. Content
- Principles of homeostasis
- Skin

B. Learning Outcomes

Students should be able to:
(a) define homeostasis as the maintenance of a constant internal environment.
(b) explain the basic principles of homeostasis in terms of stimulus resulting from a change in the internal environment, a corrective mechanism and a negative feedback.
(c) identify on a diagram of the skin: hairs, sweat glands, temperature receptors, blood vessels and fatty tissue.
(d) describe the maintenance of a constant body temperature in humans in terms of insulation and the role of: temperature receptors in the skin, sweating, shivering, blood vessels near the skin surface and the co-ordinating role of the brain.
(e) explain the need for control in organised systems and explain the principles of homeostasis in terms of receptors, effectors, and negative feedback.

C. References

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D. Lecture Outline

1. Introduction
2. Mechanisms of homeostasis
3. Examples of homeostasis
4. Structure of human skin
5. Regulation of body temperature (thermoregulation)
6. Additional reading materials

E. Practical Work
- Composition of different body fluids II
- Effect of crowding together (data logger)

1. INTRODUCTION

Homeostasis (‘*homoios’* = similar, ‘*stasis’* = standing still) is the maintenance of a constant internal environment despite external fluctuations in the surroundings. The internal environment refers to the fluid medium that surrounds all cells e.g. blood, tissue fluid.

Through the various organ systems within the organism, blood composition such as pH, blood sugar level, water potential and blood pressure are regulated precisely within narrow limits. Homeostasis enables the body to be independent from external environmental changes and to operate at the optimal level.

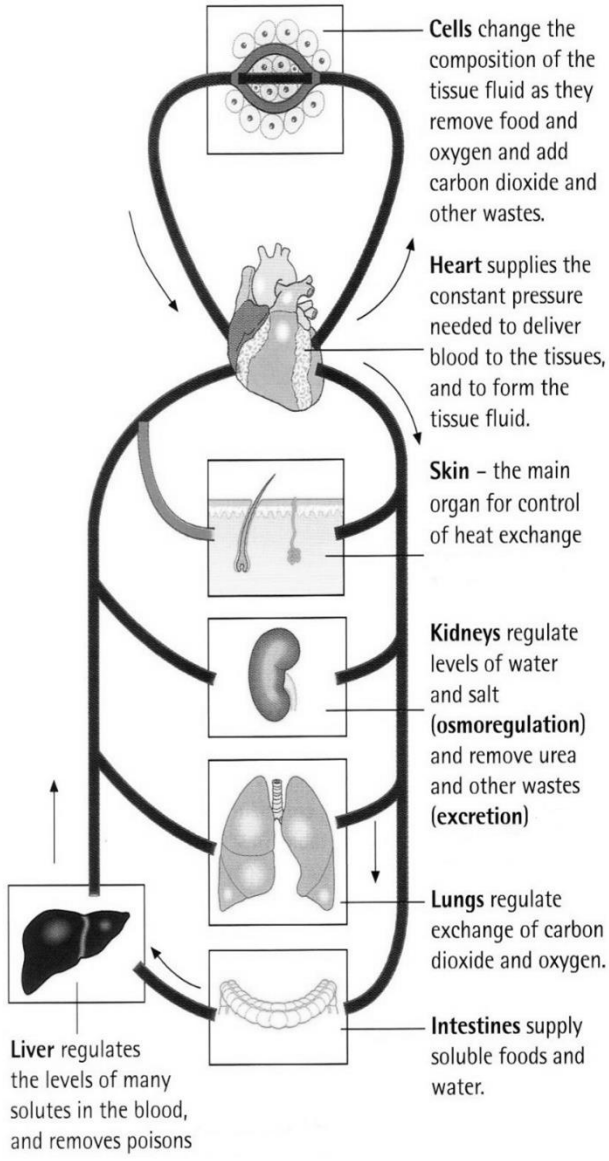

Figure 11.1 The homeostatic mechanisms of the body

2. MECHANISMS OF HOMEOSTASIS

Homeostatic control mechanisms have three main components: a **receptor**, a **control centre** and an **effector**. The receptor detects any change or deviation in the normal set value (or reference point) of the condition. It then sends this information to the control centre, which in turn instructs the effector to direct an appropriate corrective response to return the system to the normal set value.

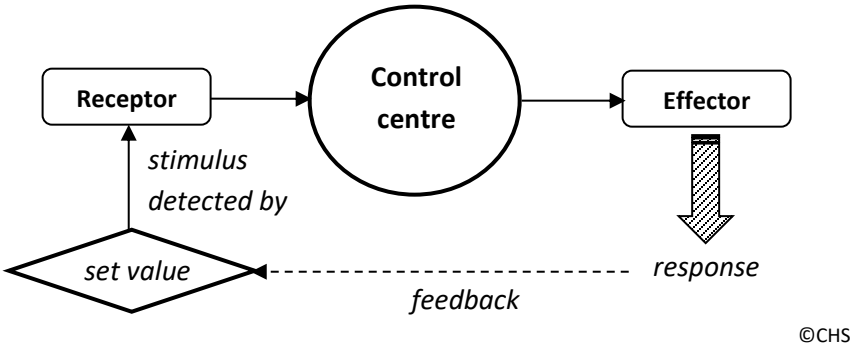

Figure 11.2 Homeostatic control mechanism

Negative feedback is part of many homeostatic controls in living things. In negative feedback, the body brings about an **opposite** counterchange to the changes detected in that direction to restore the system to its steady state. Negative feedback usually involves some fluctuation about the 'normal condition'. It does not keep that condition absolutely constant as time is needed for information to be passed from receptor to the effector.

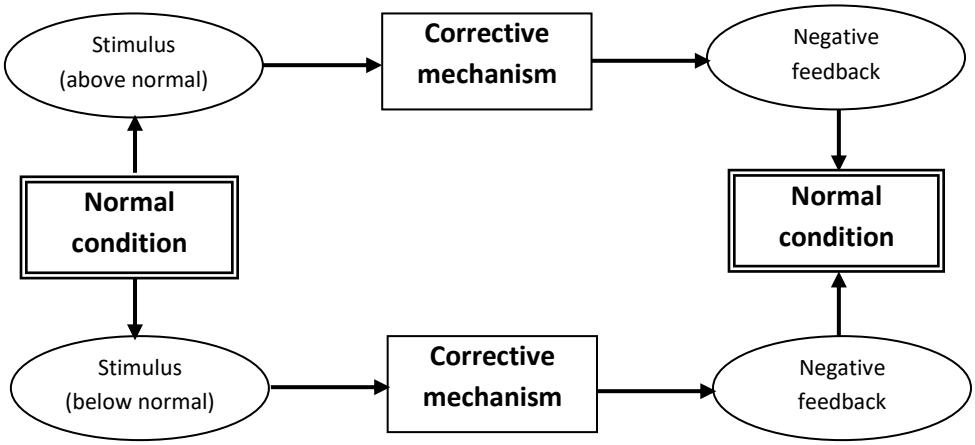

Figure 11.3 Principles of homeostasis

Examples of negative feedback mechanisms include control of water balance, body temperature and glucose. Other examples involve the control of heart rate, blood pressure, pH and the regulation of oxygen and carbon dioxide levels in the blood.

3. EXAMPLES OF HOMEOSTASIS

Regulation of Blood Glucose Level

Liver is a homeostatic organ that regulates the level of glucose (blood sugar) in the blood. The normal blood glucose level in human is about 90 mg of glucose per 100 cm^3 of blood. Any deviations from this level for prolonged periods of time may be fatal to the body as glucose is the ideal food substrate for cellular energy for most tissues.

After a meal, the temporary increase in blood glucose concentration (hyperglycaemia) stimulates the islets of Langerhans β-cells in the **pancreas** to release the hormone **insulin** into the blood. Insulin diffuses from the pancreas into the surrounding blood capillaries and is transported to the liver and muscles. Insulin

(1) promotes conversion of excess glucose to glycogen for storage (in muscles and liver cells);
(2) causes increased cellular respiration (which uses glucose as a respiratory substrate to release energy);
(3) increases permeability of cell membranes to glucose (so that glucose can be taken up quickly by muscles and liver cells).

All these effects allow the blood glucose level to return to its original level. Insulin remaining in the bloodstream is then sent to the **liver** to be destroyed (deamination) and then removed via the **kidneys** (as urea).

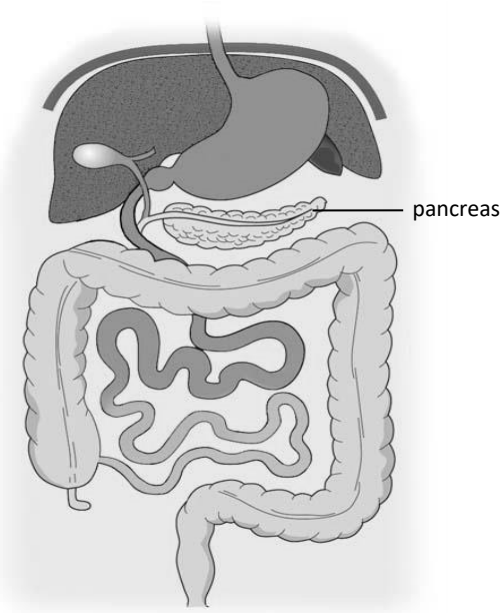

Figure 11.4 Location of pancreas

During fasting or prolonged periods without food, the blood glucose levels falls below the threshold level (hypoglycaemia). This triggers the release of the hormone **glucagon** from the islets of Langerhans α-cells in the pancreas which promotes the conversion of glycogen to glucose. Glucose enters the bloodstream and returns the glucose concentration to the threshold value.

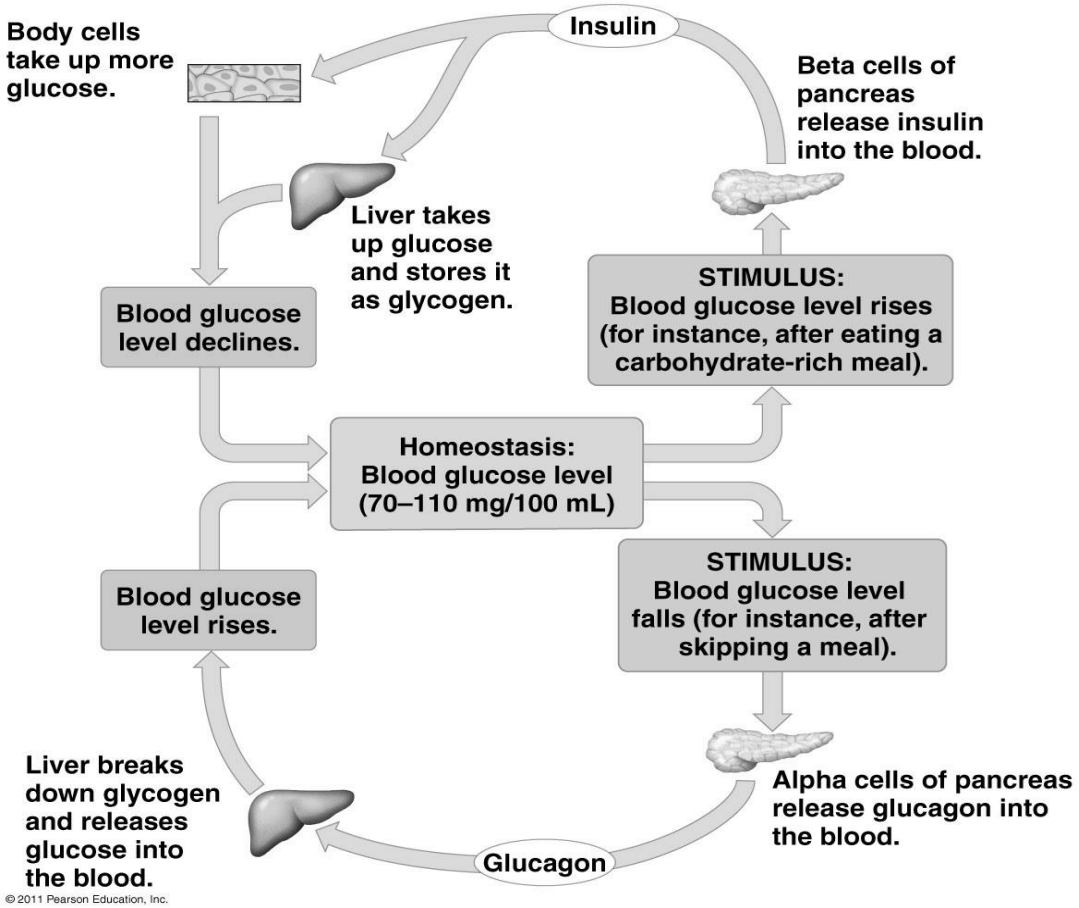

Figure 11.5 Regulation of blood sugar
Source: Pearson Education

Regulation of Blood Water Potential in Human

Kidneys play an important role in **osmoregulation** by helping to regulate the water potential in the blood. Osmoregulation is controlled by **antidiuretic hormone** (**ADH**) produced by the hypothalamus in the brain. ADH is then released by the **pituitary gland** into the bloodstream and it increases water reabsorption at the kidney nephrons. The water potential of our blood has to be kept constant as a diluted blood may lead to water entering our red blood cells and its subsequent lysis. On the other hand, if our blood is too concentrated, water may leave our red blood cells, leading to its shrinkage and crenation.

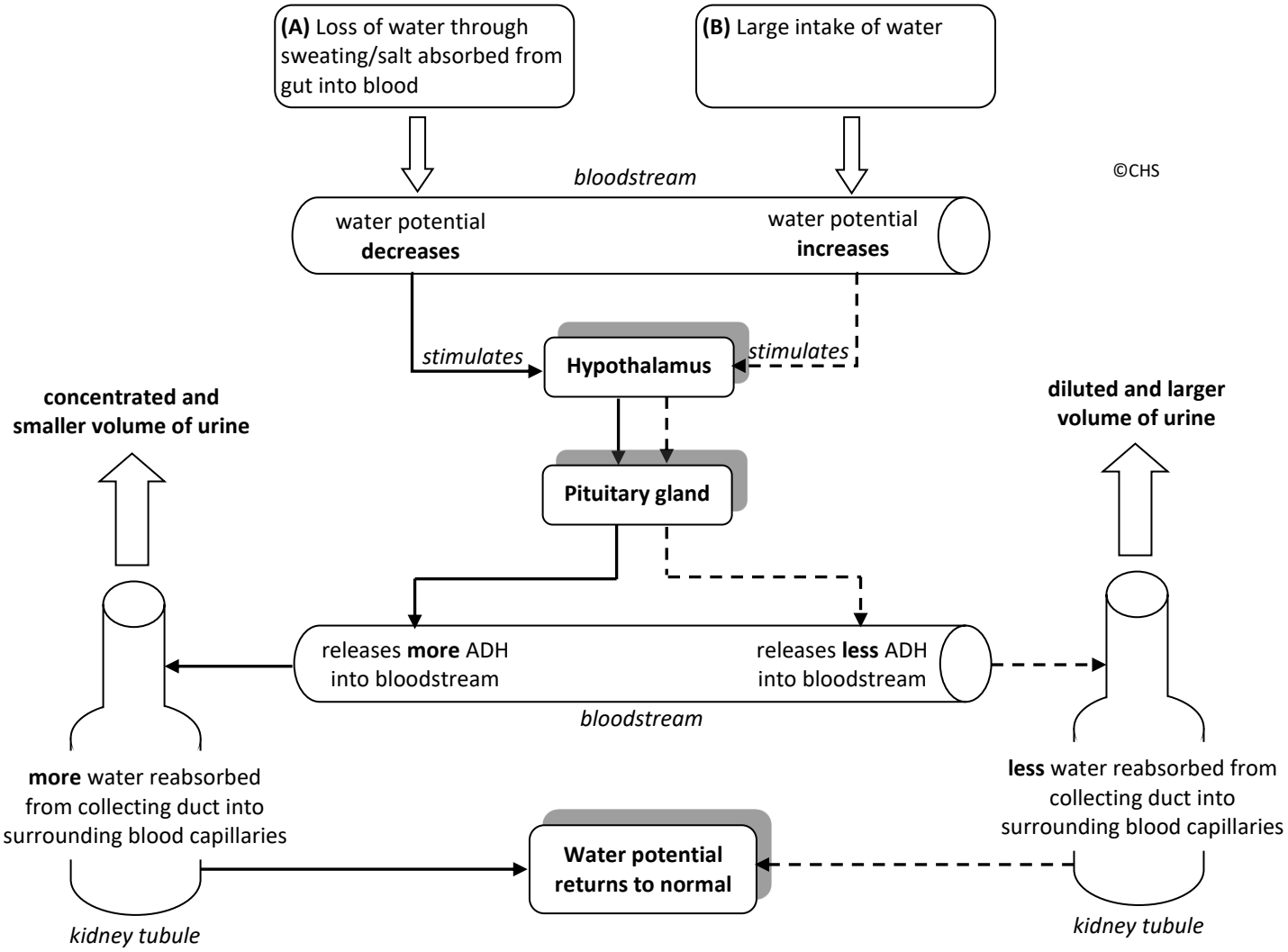

Figure 11.6 Osmoregulation

Regulation of Blood Water Potential in Desert Animals

In an arid environment, the physiological and structural adaptations of desert mammals enable them to minimise their water losses and reduce the amount of water they need to drink. These animals often produce very concentrated urine through a long loop of Henle, thus reducing water loss through urination. The lengths of the loops of Henle increase progressively in desert animals which are more adapted to drier habitats.

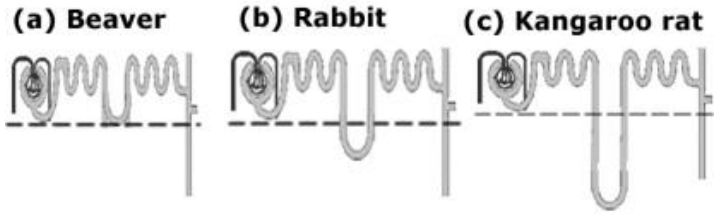

Figure 11.7 Comparison of length of loop of Henle in mammals living in habitats with decreasing water availability

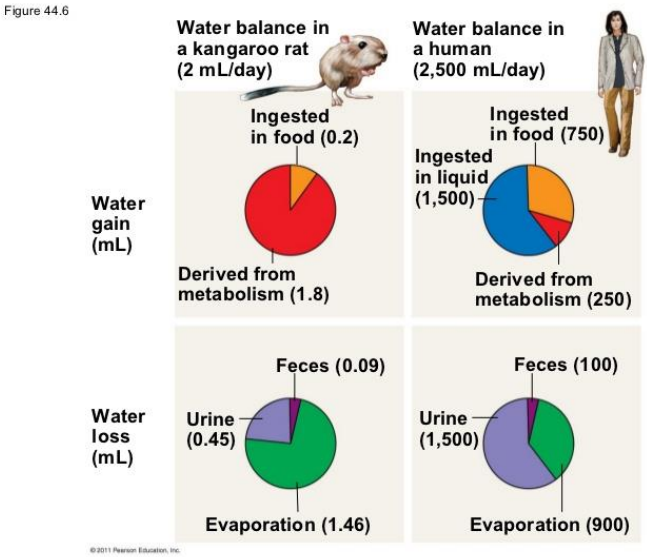

Figure 11.8 Water balance in human and desert-dwelling animal
Source: Pearson Education

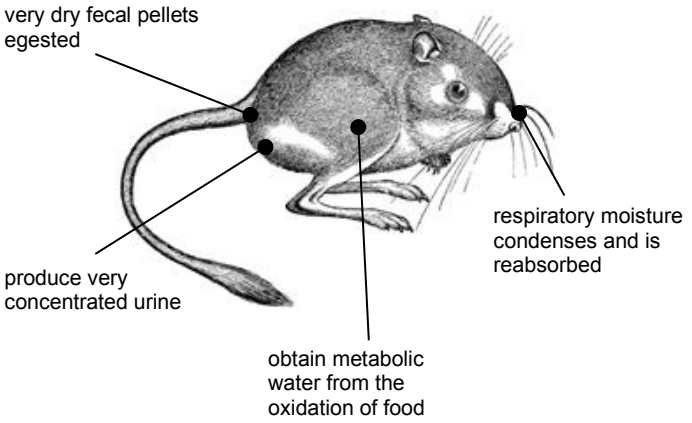

Figure 11.9 Adaptations of kangaroo rat
Source: http://www.discoverseaz.com/Wildlife/Kangaroo_rat.html

4. STRUCTURE OF HUMAN SKIN

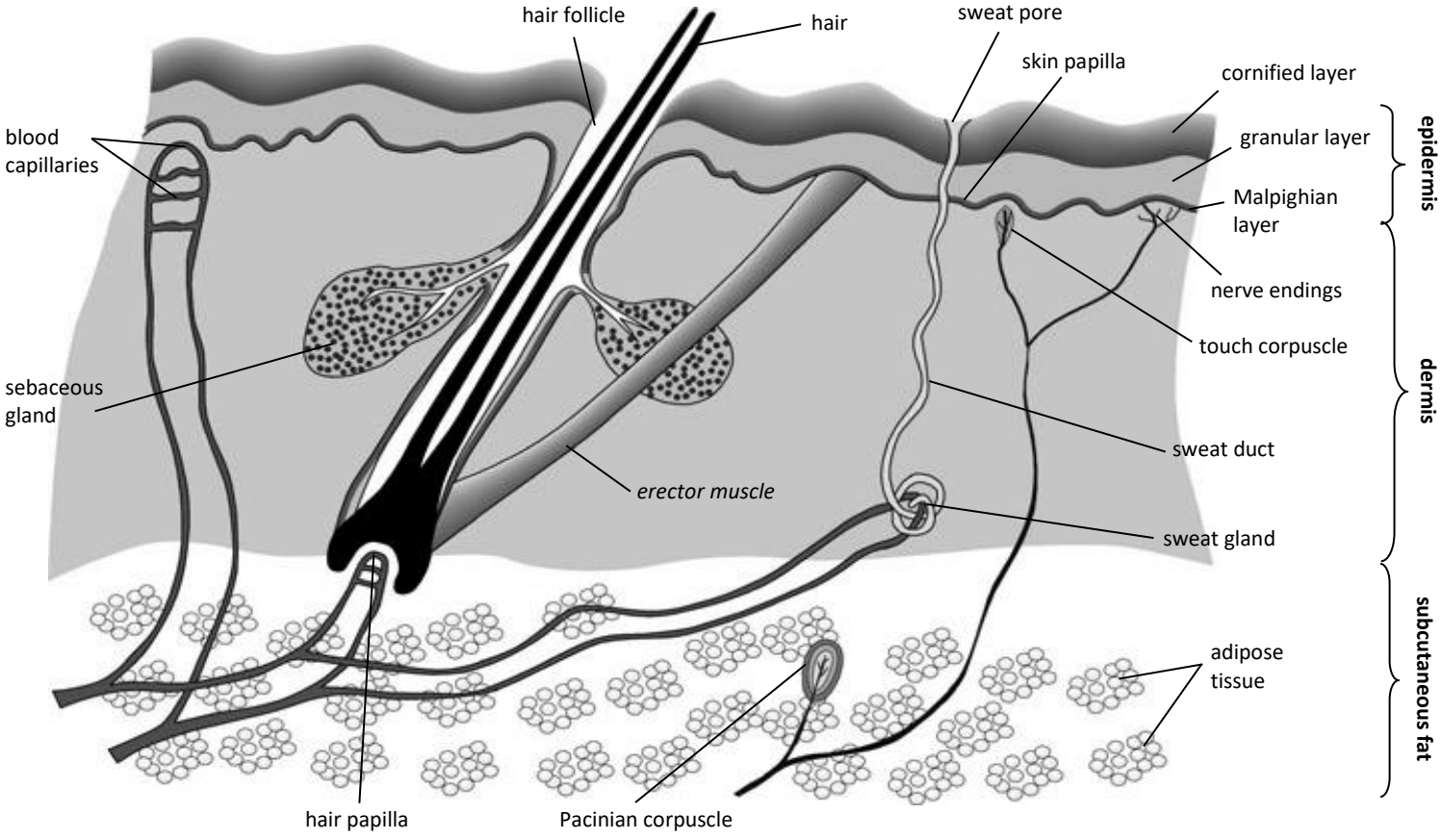

Figure 11.10 Structure of the human skin

The human skin is the largest and heaviest organ of the body. Some functions of the skin are:
- thermoregulation;
- thermal insulation;
- protection from physical damage, dehydration, UV rays;
- energy reserves due to adipose tissues;
- reception of external stimuli;
- vitamin production;
- minor role of nitrogenous excretion.

The skin composed of two layers: **(A) Epidermis** and **(B) Dermis**.

(A) Epidermis
The outer epidermis (*epi* = on the outside, *derma* = skin) does not possess blood vessels and relies on the diffusion of nutrients from the blood supply in the dermis. Epidermis is made up of three layers:

1. Cornified layer
   - layer of dead cells deposited with a protein called keratin
   - waterproof and resistant layer which is constantly replaced
   - prevents entry of pathogens and protects against mechanical injury
   - thickest on the palms of hands and soles of feet

2. Granular layer
   - layer of living cells which move up to form the cornified layer
   - produced by Malpighian layer

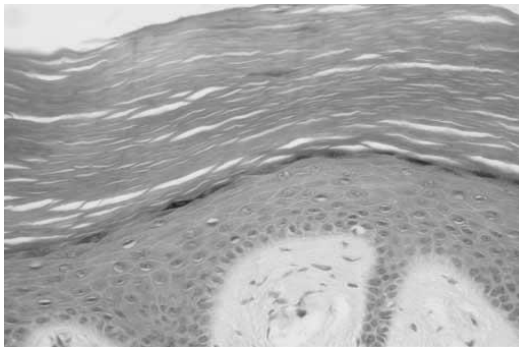

Figure 11.11 Skin epidermis from the heel of the foot
Source: http://eugraph.com/histology/skin/epid.html

3. Malpighian layer
   - layer of living cells which is pigmented with dark brown melanin (*melan* = black) which gives skin its characteristic colour
   - melanin absorbs ultra-violet (UV) rays and protects body from its damaging effects
   - undergoes cell division (e.g. mitosis) to produce new cells

(B) Dermis
The thicker dermis (*derma* = skin), located below the epidermis is largely made up of connective tissues and is vascularised with blood vessels that nourishes the skin. As the dermis contains collagen and elastic fibers, they offer great resistance to overstretching and tearing of the skin. It possesses:

1. Hair
- produced by **hair follicle** and made up mainly of the protein, keratin
- **hair papilla** is a mass of blood capillaries, nerve and connective tissues found at the base of each hair follicle
- attached near the base of each hair is a **hair erector muscle**
- contraction of the hair erector muscle causes the hair to "stand on end", leading to the sensation of 'goose pimples" in humans
- relaxation of the erector muscle causes the hair to lie flat

2. Blood vessels
- **arteries** and **arterioles** carry blood to the **surface capillaries** near the skin surface
- arteries and arterioles (NOT capillaries) undergo **vasodilation** (*vaso* = blood vessels) and **vasoconstriction** during regulation of temperature

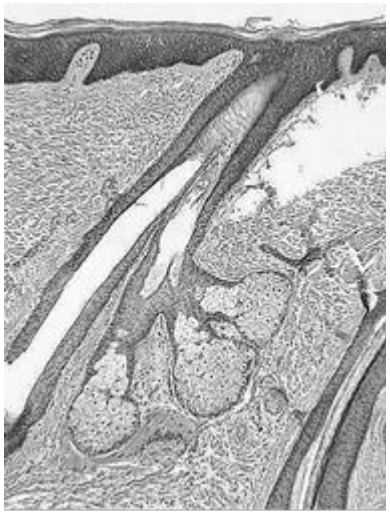

Figure 11.12 Photomicrograph of sebaceous gland
Source: http://faculty.ivytech.edu/

3. Sebaceous (oil) glands
- found in all areas of the skin except palms of hands and soles of feet
- secretes an oily substance known as **sebum** which lubricates and waterproof the skin and hair
- sebum has antiseptic and bactericidal properties

4. Sweat (sudoriferous) glands
- exocrine glands that secrete **sweat** which is made up of water, salts (mainly sodium chloride) and small amounts of urea
- secretes sweat which flows through a sweat duct that open onto skin surface via the sweat pore
- **evaporation** of **water** in sweat removes latent heat of vapourisation, cooling the skin

5. Sensory receptors
- structures that detect external changes or stimuli e.g. pain, pressure, temperature, touch
- receptors that detect temperature changes are known as **thermoreceptors**

Situated below the dermis is a layer of **subcutaneous fat** (hypodermis) which contains fat-containing cells known as **adipose tissue**. It serves as energy storage and also helps insulate the body against either heat loss or heat gain.

5. REGULATION OF BODY TEMPERATURE (THERMOREGULATION)

The regulation of body temperature (thermoregulation) is achieved by maintaining a balance between heat gain and heat loss.

change in body heat = heat produced + heat gained – heat lost

Thermoregulation is controlled by the **hypothalamus** in the brain which monitors temperature of the blood which flows through it. The hypothalamus receives signals from thermoreceptors in the body and sends nerve impulses to various effectors when the temperature deviates from a set point (average body temperature ≈ 36.9 ˚C).

Heat can be transferred in either direction between the environment and the organism depending on the heat gradient e.g. from hot to cold. Humans gain heat mainly through metabolism like cellular respiration in tissues (endogenous source) and absorption of solar energy (exogenous source).

Heat is gained mainly from the environment by **radiation**, **convection** and **conduction**. Excess heat (up to 30%) is also produced during exercise when there is increased cellular respiration to release energy for muscular contractions.

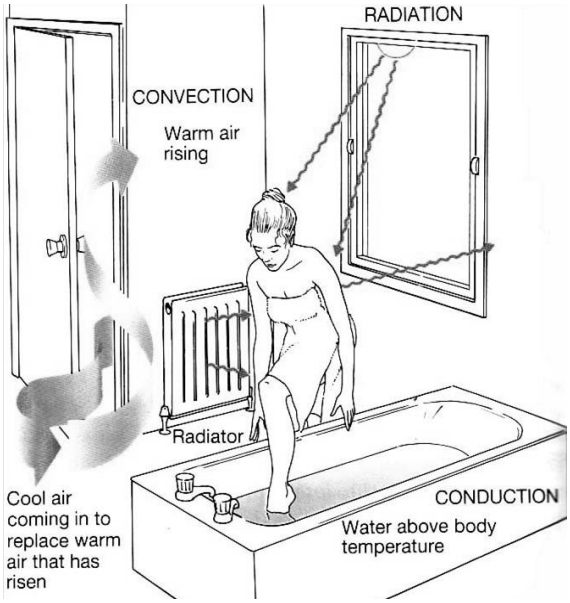

Figure 11.13 Methods of heat transfer
Source: Clegg and Mackean

Heat can be lost from the humans by radiation, convection and conduction, and by **evaporation** of water in the sweat. Radiation can account for up to more than 50% of the total heat lost.

Table 11.1 Heat production in the human body at rest

organ	organ mass/ % of body mass		heat production at rest/% of total	
kidneys	0.45	7.7	7.7	72.4
heart	0.45		10.7	
lungs	0.9		4.4	
brain	2.1		16.0	
abdominal organs, not including kidneys	3.8		33.6	
skin	7.8	92.3	1.9	27.6
muscle	41.5		15.7	
other	43.0		10.0	
total	100.0		100.0	

Clegg and Mackean

Responding to raising of body temperature

When the body gains excess heat (e.g. through physical exercise, consumption of hot food), the sweat glands are activated and **sweat** is released onto the skin surface. **Evaporation** of the water in the sweat removes latent heat of vapourisation, thus reducing the body temperature.

Arterioles undergo **vasodilation** which increases blood flow to the surface capillaries. The arterio-venous shunt vessel constricts so that blood is directed to the surface capillaries. Excess heat is lost mainly via **radiation**. In addition, metabolic rate slows down.

In mammals, hair erector muscles relax so that hairs lie flat.

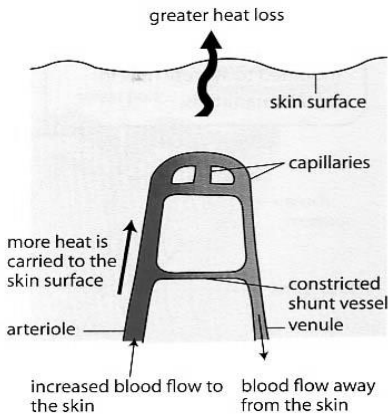

Figure 11.14 Vasodilation of arteriole

Responding to lowering of body temperature

When heat is lost from the body to the environment, heat needs to be generated in order to maintain steady state. Heat gain can be achieved through involuntary muscular contractions e.g. **shivering**. **Metabolic rate** also increases to produce more heat. This heat is then transferred around the body.

In addition, heat loss is further minimized through **vasoconstriction** (NOT contraction) of **arterioles** which carry less blood to the surface capillaries. The arterio-venous shunt vessel dilates so that less blood is directed to the surface capillaries. As a result, blood now flows further away from the skin surface, reducing heat loss by radiation. Sweat glands become less active. The adipose tissue also acts as an excellent layer of insulator.

In mammals, their hairs can be raised through contraction of the erector muscles to trap a layer of air which is a poor conductor of heat to reduce heat loss by radiation. However, this has no effect on humans.

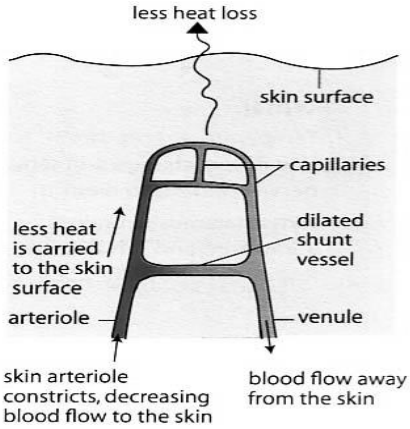

Figure 11.15 Vasoconstriction of arteriole

Hypothermia is a condition caused when the body's core temperature drops below 35 °C. Prolonged exposure to extremely low temperatures e.g. below 0 °C may lead to frostbite, whereby localised regions of the skin is damaged. This occurs due to the constriction of the blood vessels underneath the skin to prevent heat loss under extreme cold conditions. When blood flow is reduced to low levels, death of the skin tissue may occur due to a lack of oxygen and formation of ice crystals around the cells. Severe hypothermia results in mental confusion, organ failure and death.

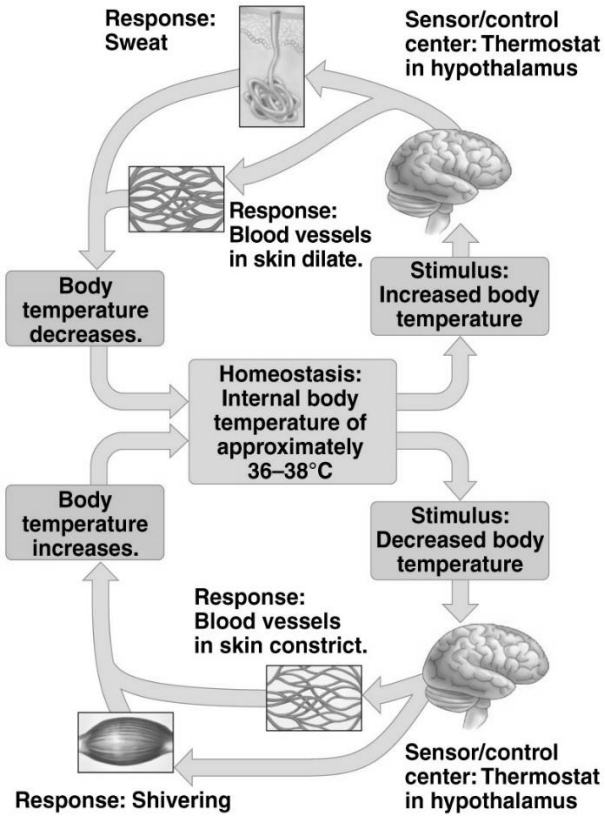

Figure 11.16 Thermoregulation in human
Source: Pearson Education

6. ADDITIONAL READING MATERIALS

Structural adaptations in temperature regulation

Animals living in hot regions typically have external ears richly supplied with blood capillaries. Through vasodilation of arterioles underneath the skin, excess heat are removed mainly via radiation. These ears also have little fur to avoid trapping a layer of air to facilitate heat loss. The large ears provide a large surface area for the excess heat to be removed faster.

Animals living in cold icy habitats e.g. polar bears avoid frostbite by means of a countercurrent heat exchange mechanism (Figure 11.17). In their legs, the main artery and vein run parallel and are very close together. All along the length of the leg heat is exchanged between the artery and vein due to the presence of a heat gradient. The blood leaving the legs is at almost the same temperature as the arterial blood. This allows the foot tissues to be supplied with nutrients and the tissue is held at a temperature that prevents freezing and minimises the loss of heat by conduction. This arrangement is also found in the flippers and flukes of seals and whales.

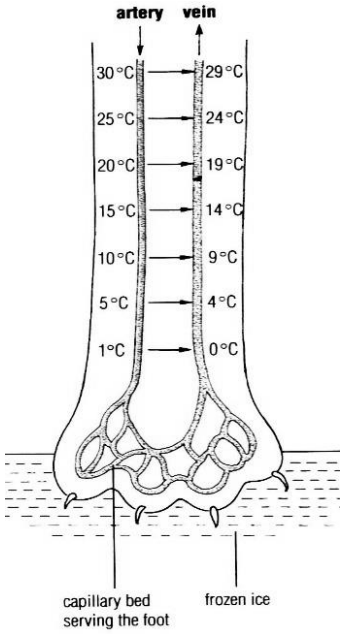

Figure 11.17 Countercurrent heat exchange mechanism

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 12 – Nervous System

Name: **Class:**

A. Content
- Central nervous system
- Peripheral nervous system
- Reflex action

B. Learning Outcomes

Students should be able to:
(a) state the relationship between receptors, the central nervous system and the effectors.
(b) state that the nervous system – brain, spinal cord and nerves, serves to co-ordinate and regulate bodily functions.
(c) outline the functions of sensory neurones, relay neurones and motor neurones.
(d) discuss the function of the brain and spinal cord in producing a co-ordinated response as a result of a specific stimulus in a reflex action.
(e) explain the need for communication systems within organisms.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
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6. Vander, A. J., Sherman, J. H. and Luciano, D. S. Human Physiology (6th ed). McGraw-Hill, United States of America

D. Lecture Outline

1. Introduction
2. Nervous tissues and neurones
3. Types of actions
4. Additional reading materials

E. Practical Work

Practical – Calculating Reaction Time

1. INTRODUCTION

Sensitivity is the ability to detect change and to respond appropriately to it. Changes that are detected are called **stimuli** (singular: **stimulus**). Many stimuli arise externally to an organism, but others arise from an organism's internal environment. Stimuli lead to **responses**.

Examples of responses to stimuli include:
- Withdrawal of hand when in contact with a hot object
- Movement of plants towards light or away from light (phototropism)
- Movement of a bacterium towards food

The detection and response to external environmental changes and the regulation of the internal environment are brought about by two multicellular systems: the **nervous system** and the **endocrine system**. The actions of these two systems are coordinated.

Actions can be **voluntary** (controlled by will), or **involuntary** / automatic (cannot be controlled by will), or sometimes be a mixture of both.
- Examples of voluntary action include throwing a ball and waking up in the morning.
- Examples of involuntary action include breathing and heart beating.

2. NERVOUS SYSTEM & NEURONES

The human nervous system is made up of:
- the **central nervous system** (**CNS**), consisting the **brain** and **spinal cord**; and
- the **peripheral nervous system** (**PNS**), consisting of the **nerves**, ganglia and sense organs, forming the connecting link between the organs and the CNS.

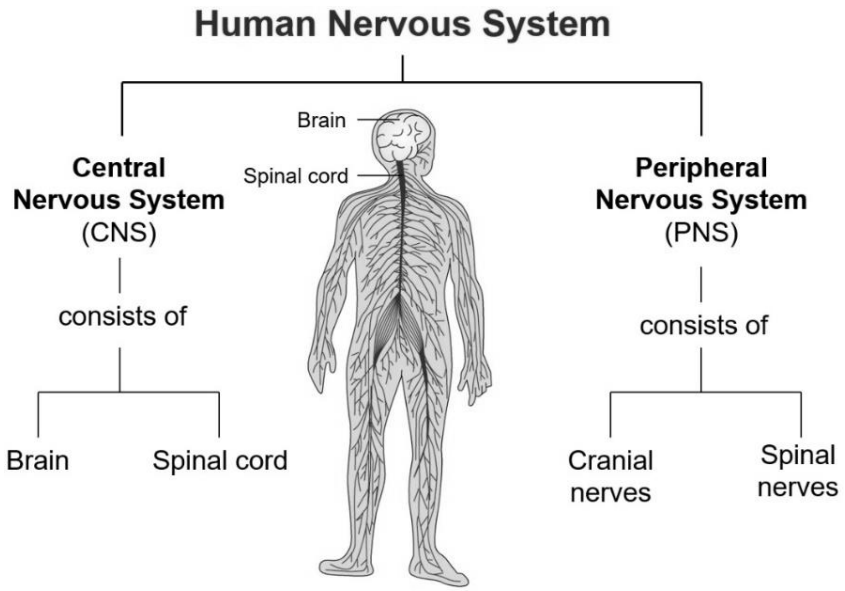

Figure 12.1 Components of human nervous system

Neurone
- Neurones are specialised **cells**, which serves as the pathways of communication between the brain and the body.
- **Nerve impulses** are transmitted along the neurones from organs that receive stimuli at the **receptors** (such as nerve endings at the skin), to organs that effect change at the **effectors** (e.g. muscles, glands).
- A neurone has a **cell body**, an **axon** and a **dendron**.
- The cell body contains the nucleus and cytoplasm.
- Axons carry nerve impulses away from the cell body; dendrons carry nerve impulses to the cell body.
- There are three types of neurones:
  1) **Sensory neurone** (**receptor neurone**) – transmit nerve impulses from sense organs (e.g. eye) to CNS (e.g. brain).
  2) **Relay neurone** (**intermediate neurone**) – found within CNS, receive impulses from sensory neurones or from other intermediate neurones. These impulses are relayed to either motor or other intermediate neurones.
  3) **Motor neurone** (**effector neurone**) – transmit nerve impulses from CNS, to effectors (e.g. muscle, glands).

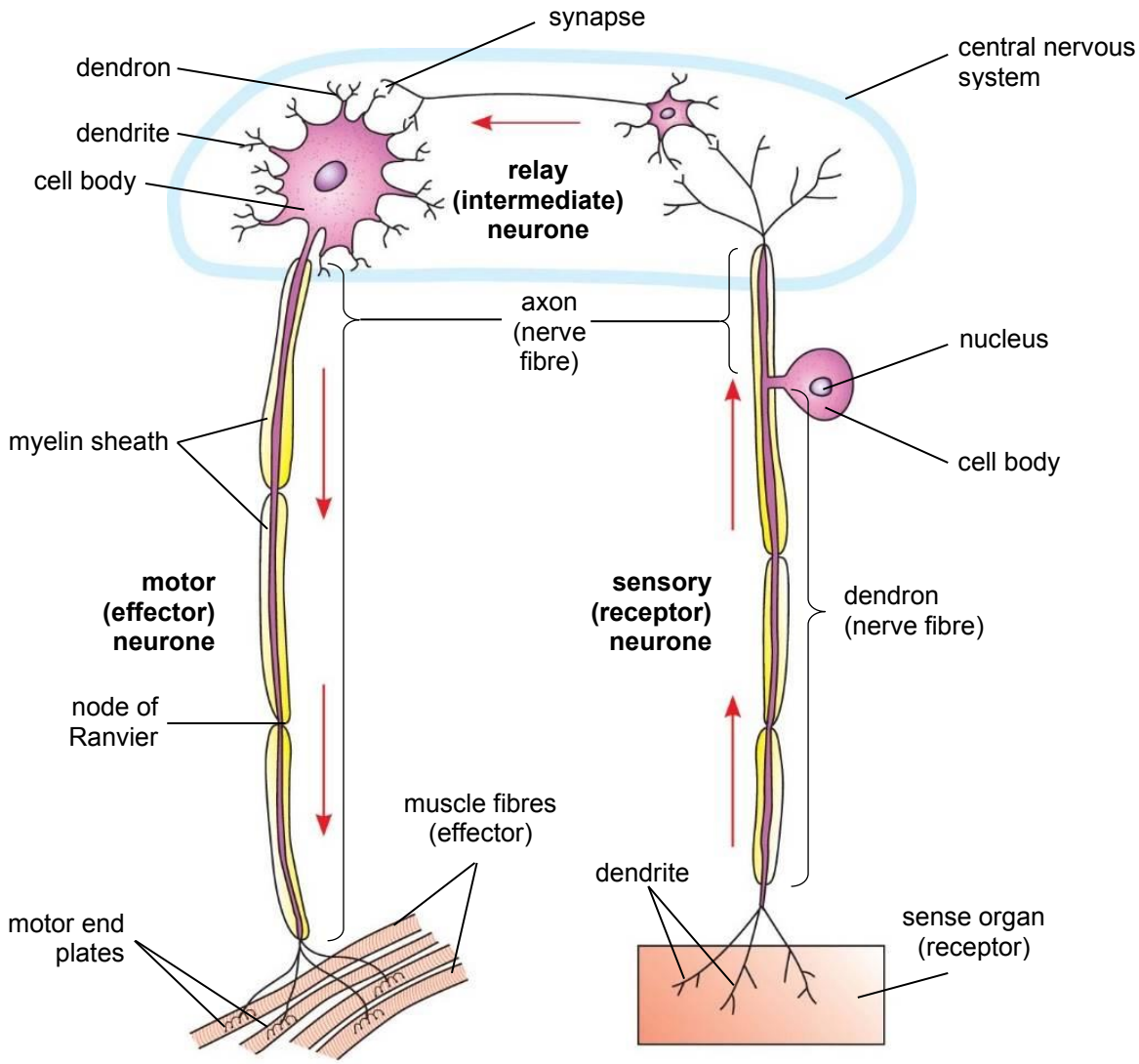

Figure 12.2 Relationship between a sensory neurone, a relay neurone and a motor neurone

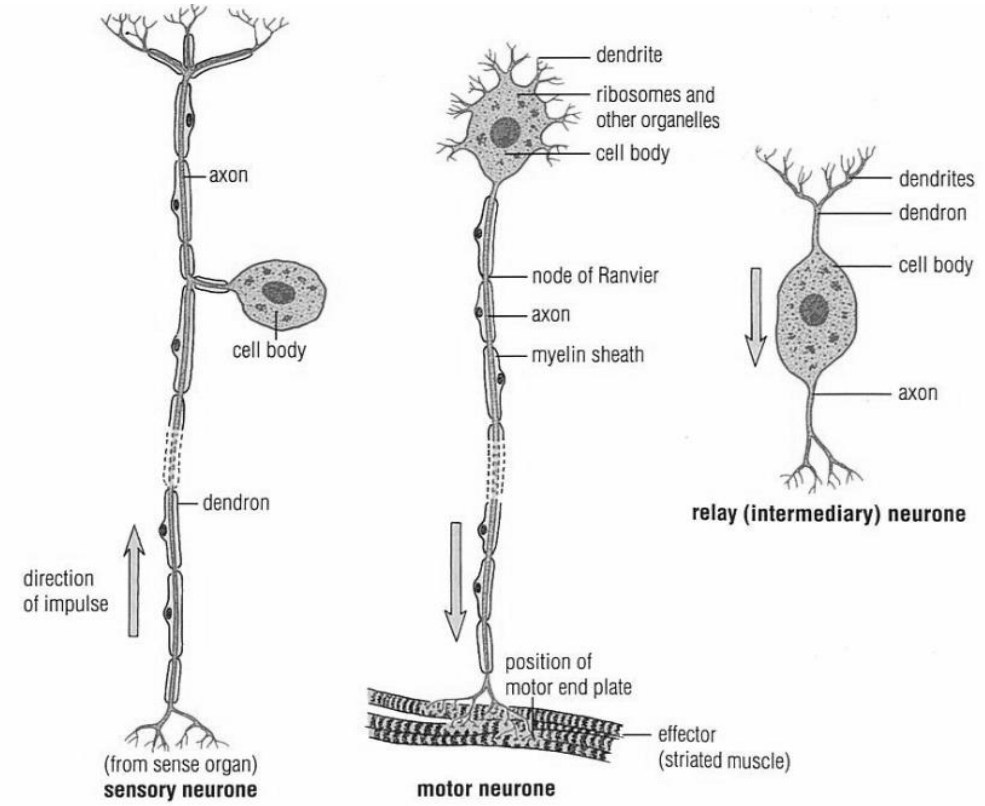

Figure 12.3 Sensory, motor and relay neurones

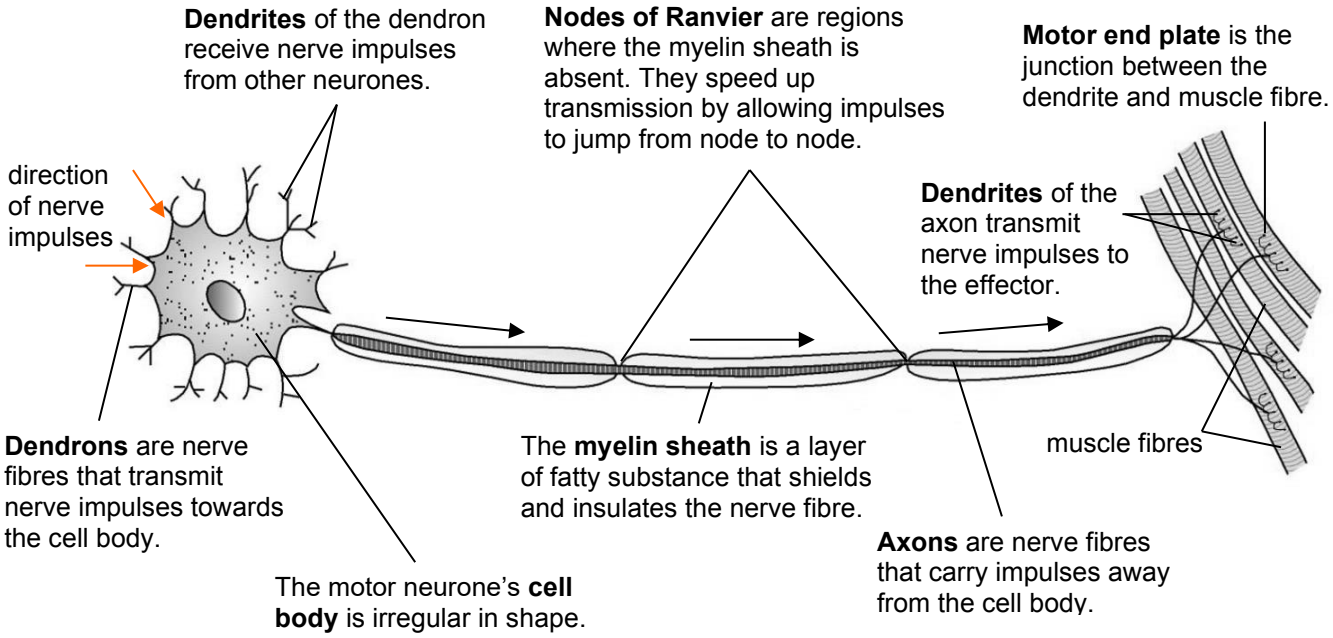

Figure 12.4 Structures and functions of a motor neurone

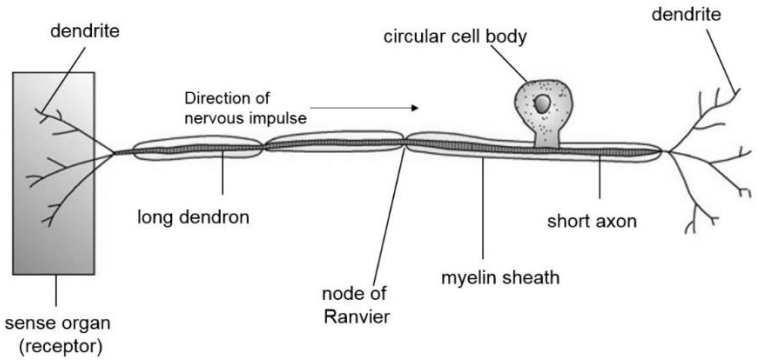

Figure 12.5 Structures of a sensory neurone

Nerve fibre

- A **nerve fibre** is a strand of cytoplasm extending from the cell body and is specialised for transmitting **nerve impulses**.
- Nerve impulses are transmitted at speeds of 100 m/s. This means that nervous coordination is extremely fast and responses are virtually immediate. Impulses can be transmitted over considerable long distances within the body.
- Dendrites can be as long as 1 m, stretching from foot to spinal cord. Some neurones do not have dendrites while others can have more than 10,000.

Nerve

- A **nerve** is a bundle of nerve fibres enclosed in a sheath of connective tissue.
- Sensory nerve fibres conduct nerve impulses from sense organs.
- Motor nerve fibres conduct nerve impulses to the effectors.
- Spinal nerves contain mixed fibres, which are made up of sensory and motor nerve fibres.

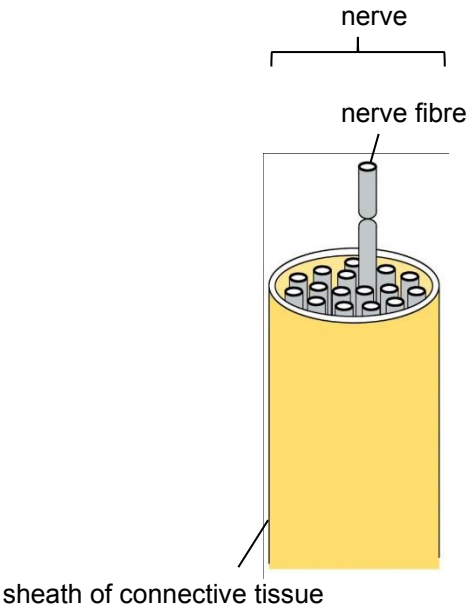

Figure 12.6 Relationship between a nerve fibre and nerve

Table 12.1 Differences between a motor neurone and a sensory neurone

motor neurone	sensory neurone
transmits impulses away from the CNS	transmits impulses towards the CNS
has numerous short dendrons	has a long dendron
has one long axon	has a short axon
has a satellite and terminal cell body	has a circular and non-terminal cell body

Explain, why the axons of relay neurones are short, whereas those of motor neurones may be very long.
Axons of relay neurones transmit nerve impulses to the motor neurones within the CNS whereas those of motor neurones need to transmit nerve impulses to the effectors outside the CNS which is further away.

Synapse

- A synapse is a junction between two neurones or between a neurone and an effector (a muscle or gland).
- Neurones rarely have direct electrical contact with each other; the impulse cannot transmit directly from one neurone to another.
- Nerve impulses are transmitted **electrically** through neurones but **chemically** across synapses.
- The main purpose is to ensure flow of impulses is in one direction only.
- Impulses are carried across synapses via neurotransmitters (by chemical means).
- Impulses are also transmitted across the motor end plate (from the axon dendrite to the muscles) via **neurotransmitters**.

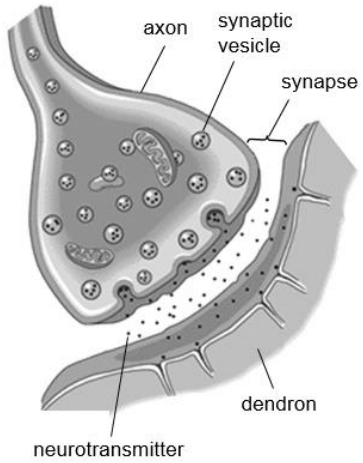

Figure 12.7 Simplified diagrammatic representation of a synapse

Spinal cord

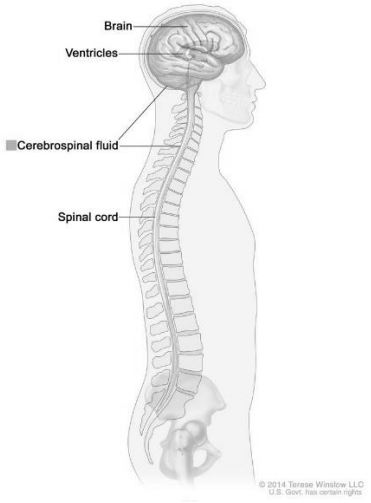

Figure 12.8 Cerebrospinal fluid flowing in the brain and spinal cord
Source: www.cancer.org

- The spinal cord passes through the vertebral column (backbone) which protects it.

Extension

- The canal contains **cerebrospinal fluid** (CSF), which is a clear and colourless fluid that flows in and around the hollow spaces of the brain and spinal cord, and between two of the meninges (the thin layers of tissue that cover and protect the brain and spinal cord).
- CSF serves as a buffer for the brain's cortex, providing basic mechanical and immunological protection to the brain inside the skull. It also serves a vital function in cerebral autoregulation of cerebral blood flow.
- The spinal cord extends from medulla oblongata to end of vertebral column. It is enclosed and protected in the vertebral column.
- The medulla oblongata helps regulate breathing, heart function, digestion, sneezing, and swallowing. This part of the brain is a centre for respiration and circulation.
- Spinal nerves emerge at intervals along the length of the spinal cord. There are 31 pairs of spinal nerves in humans.

- The functions of the spinal cord are to relay impulses in and out at any particular point along the cord, and to relay impulses up and down the body, including to and from the brain.
- The central part of the spinal cord contains cell bodies, synapses and non-myelinated relay neurones. This region is called the **grey matter**. Relay neurones lie within the grey matter of the spinal cord, and transmit nerve impulses from:
    - sensory neurones → brain
    - brain → motor neurones
    - sensory neurones → motor neurones
- The outer part of the cord contains myelinated fibres running longitudinally, and is known as the **white matter**.
- All sensory fibres enter through the dorsal root and motor fibres all leaves through the **ventral root**.
- Cell bodies of all sensory fibres are situated in the **dorsal root** and they make a bulge called a **ganglion**.

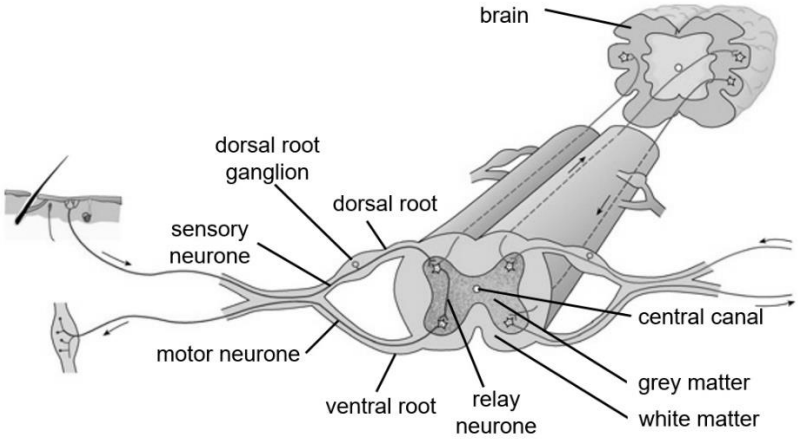

Figure 12.9 Thoracic segment of a spinal cord, showing the neurones and the pathways to and from the brain

3. TYPES OF ACTIONS

Actions can be **voluntary** and **involuntary** (automatic). Voluntary and involuntary actions involve different pathways.

Voluntary actions

- Actions that are deliberate, controlled by will and does not happen automatically.
- brain (cerebrum) → relay neurone (along in spinal cord) → motor neurone → effector

Involuntary actions (e.g. reflex actions)

- A reflex action is an **immediate response** to a specific stimulus without conscious control.
- Reflex actions allow us to respond immediately to dangers in our environment.
- These actions are **involuntary** (**automatic**) and are not under the control of a person's will.
- The shortest pathway of nerve impulses from the receptor to the effector is known as the **reflex arc**.
- A reflex arc consists of a receptor (sense organ), a sensory neurone, a relay neurone in a reflex centre (spinal cord or brain), a motor neurone and an effector (e.g. muscle)
- There are two types of reflex actions:
- **Spinal reflexes**: reflexes that are controlled by the spinal cord. (e.g. knee-jerk reflex, withdrawal of hand from sharp/ hot object)
- **Cranial reflexes**: reflexes that are controlled by the brain (excluding cerebrum) but occur without a person's consciousness. (e.g. dodging one's head by a sudden loud bang, pupil reflex, salivation)

In what ways is a reflex action different from a voluntary action?

reflex action	voluntary (deliberate) action
relatively fast	relatively slow
involves spinal cord (spinal reflex) or brain (cranial reflex)	involves the cerebrum / brain
involuntary / without conscious control	voluntary / with conscious control
involves a sensory neurone	no sensory neurone involved
involves a stimulus	no stimulus involved

Spinal reflex:

- A knee-jerk reflex is an example of spinal reflex.

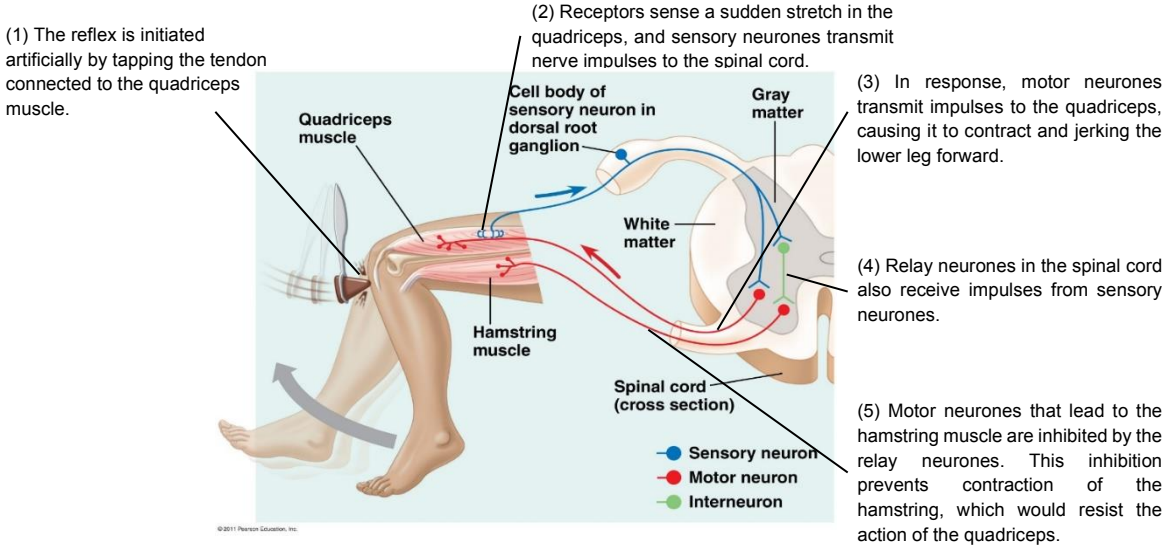

Figure 12.10 The human knee-jerk reflex action

- Withdrawal reflex such as touching of hot or sharp objects is an example of spinal reflex.
- Unlike the knee-jerk reflex, it involves **three neurones and two synapses**. This can be referred as a polysynaptic reflex.
- In an example of touching a hot object:
  1) Heat stimulates the receptors in your skin.
  2) Nerve impulses are produced and they are transmitted along the sensory neurone to spinal cord.
  3) In the spinal cord, nerve impulses are transmitted across the synapse to the relay neurone, and then across another synapse to the motor neurone. At the same time, nerve impulses are transmitted to the brain.

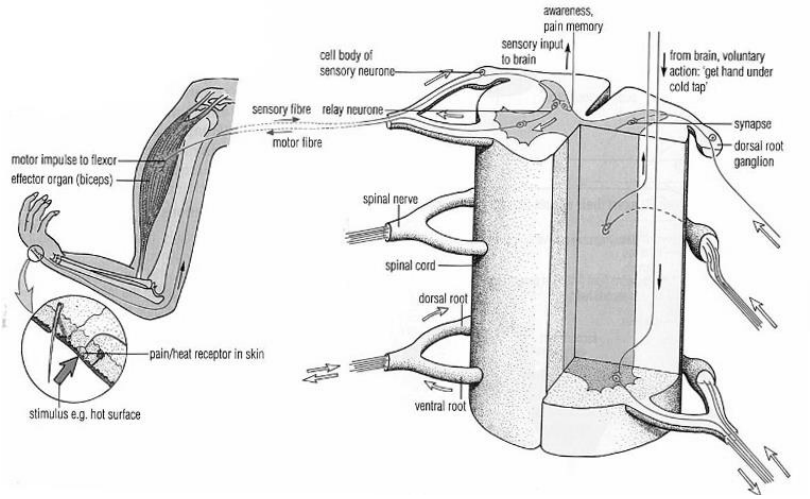

Figure 12.11 A withdrawal reflex action

  4) Upon receiving the nerve impulses from the relay neurone, the motor neurone transmits nerve impulses to the effector.
  5) The effector muscle contracts, resulting in the withdrawal of the hand from the hot object.

Cranial reflex
- A pupil reflex is an example of cranial reflex.
- In **bright light** the eye pupils constrict to reduce the amount of light entering the eye. This is to prevent overstimulation of the receptors at the retina.
- In **dim light** the eye pupils dilate to increase the amount of light entering the eye to facilitate vision.

Extension

Conditioned reflex actions
- Reflex action acquired from past experience or learning with a stimulus which is originally ineffective in producing the response.
- An example includes Pavlov's experiment.
- In Pavlov's experiment, Pavlov used a bell as his neutral stimulus. Whenever he gave food to his dogs, he also rang a bell.
- After a number of repeats of this procedure, he tried the bell on its own instead of giving food to his dogs. The bell on its own now caused the dogs to increase in salivation.
- The dogs had learned an association between the bell and the food. Thus, a new behaviour had been learnt. Because this response was learned (or conditioned), it is called a conditioned response.
- Through this experiment, Pavlov found that for associations to be made, the two stimuli had to be presented close together in time. He called this the law of temporal contiguity. If the time between the conditioned stimulus (bell) and unconditioned stimulus (food) is too great, then learning will not occur.

Is a reflex part of the central nervous system, the peripheral system or both? Explain.
Both since it involves components from both CNS (e.g. spinal cord) and PNS (e.g. effector).

6. ADDITIONAL READING MATERIALS

Action Potential
Action potential, the brief (about one-thousandth of a second) reversal of electric polarization of the membrane of a nerve cell (neuron) or muscle cell. In the neuron an action potential produces the nerve impulse, and in the muscle cell it produces the contraction required for all movement.

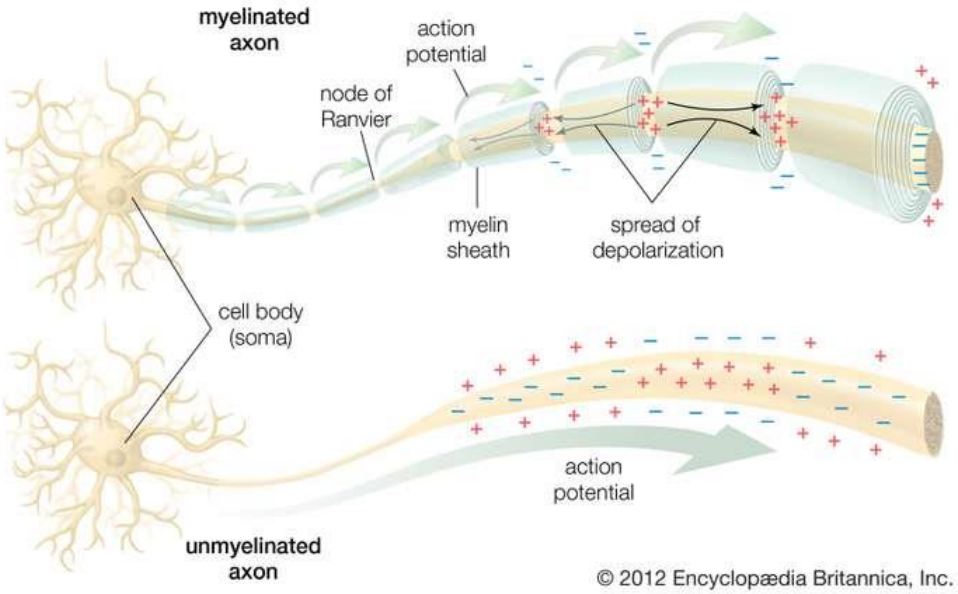

Figure 12.12 Conduction of the action potential by a neurone

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 14 – Eye

Name: **Class:**

A. Content

- Structure and functions of a human eye
- Pupil reflex

B. Learning Outcomes

Students should be able to:
(a) describe the gross structure of the eye as seen in front view and in horizontal section.
(b) state the principal functions of component parts of the eye in producing a focused image of near and distant objects on the retina.
(c) describe the pupil reflex in response to bright and dim light.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
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D. Lecture Outline

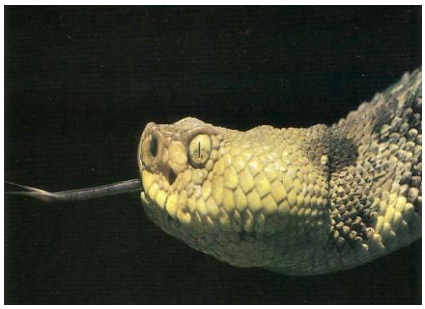
1. Introduction
2. Components of a human eye
3. Pupil reflex
4. Additional reading materials

E. Practical Work

- Dissection of Mammalian Eye

1. INTRODUCTION

Sense organs are receptors that detects stimuli, including heat, light, pressure and chemicals and converts them to nerve impulses. Receptors vary from single nerve cell endings to complex organs like eyes and ears.



(a) Thermoreceptors found between the eye and nostril of rattlesnake

(b) Lorenzini organs in shark that detect bioelectric fields

(c) Chemoreceptors in insects

Figure 14.1 In the animal kingdom, there is a wide diversity of receptor organs

2. COMPONENTS OF A HUMAN EYE

A human eye is a spherical structure that measures about 2.5 cm in diameter. It lies in the orbit (socket) of skull, attached by **rectus muscles**. Rectus muscles control eye movement.

Wall of the eye is composed of three layers: **sclera**, **choroid** and **retina**. Filling the eye are the **aqueous humour** (in front of lens) and **vitreous humour** (behind the lens).

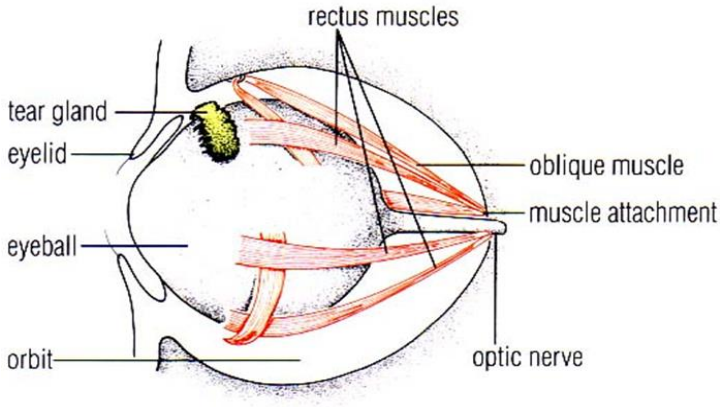


Figure 14.2 Rectus muscles work to move the eye up, down, side to side, and rotate the eye.

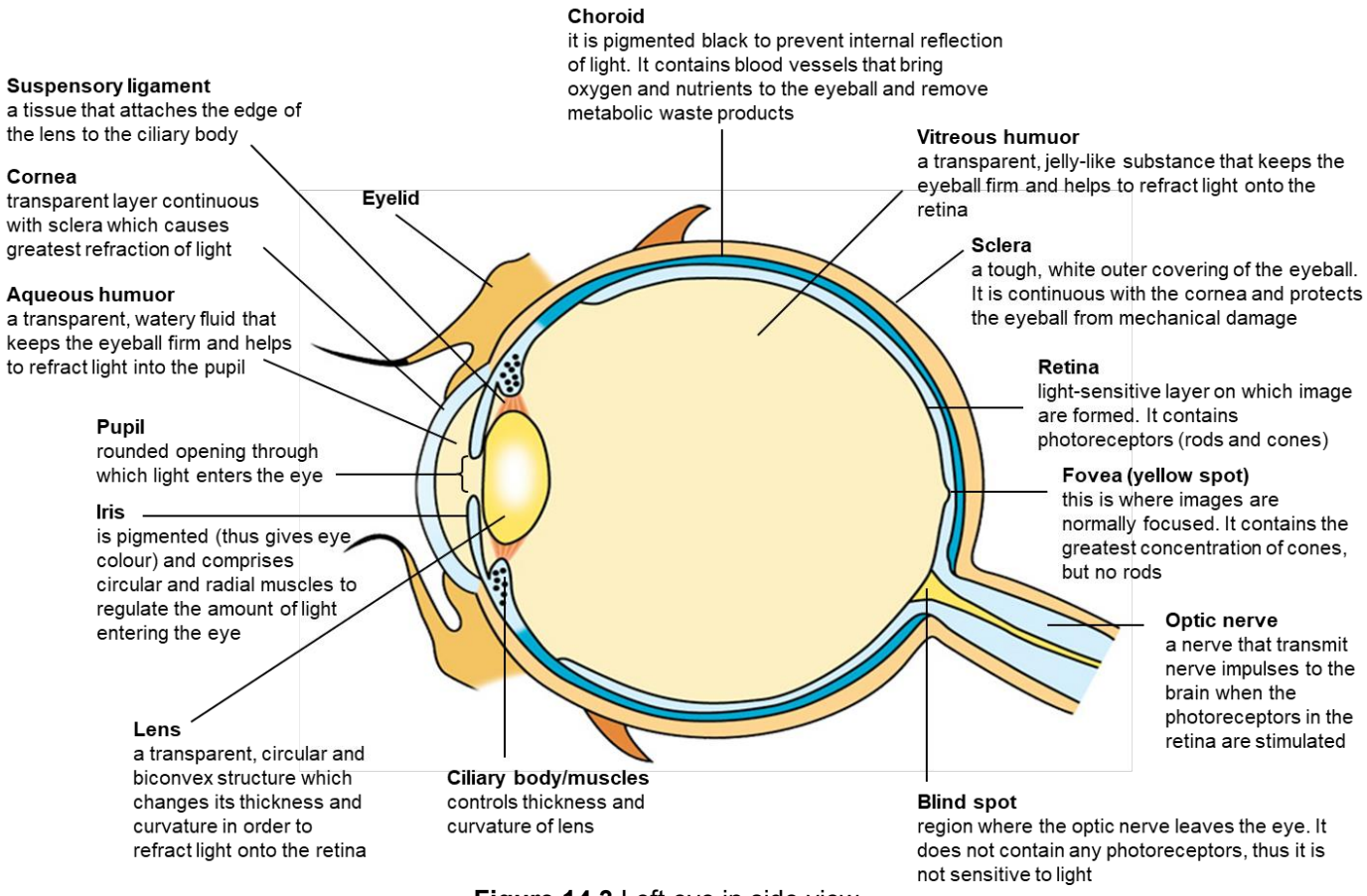


Figure 14.3 Left eye in side view

Table 14.1 Functions of different parts of a human eye

Parts of a human eye	Function(s)
Cornea	A dome-shaped transparent layer that is able to refract light rays into the eye. Cornea causes the most refraction of light.
Conjunctiva	A mucus membrane that covers the anterior surface of the eyeball (**sclera**). Mucus is secreted to keep the front of the eyeball moist.
Aqueous humour	(1) Transparent liquid that maintains the **pressure** needed to inflate the eye. (2) Provides **nutrients** for the cornea and lens as they do not have their own blood supply.
Pupil	A rounded opening / hole in the centre of the iris, allowing light to enter the eye.
Iris	Control amount of light entering the eye by changing pupil size / diameter. Circular sheet of muscles, consisting of two sets of involuntary muscles – **circular** and **radial muscles**, which are antagonistic. It also contains a pigment which gives the eye its colour.
Lens	Elastic part of eye's optical system, which helps focus object's image on retina.
Suspensory ligament	A series of fibres that connect the ciliary body of the eye with the lens, holding it in place.
Ciliary body	The region that controls the shape of the lens, and the ciliary epithelium, which produces the **aqueous humour**.
Choroid	The middle layer of the eye. (1) The choroid coat contains blood capillaries that **transports oxygen and nutrients** to the eye and **remove metabolic waste products** from the eye. (2) It is pigmented black to **prevent reflection of light** in the interior of the eyeball.
Vitreous humour	Transparent jelly-like material that keeps eyeball firm and refracts light onto the retina.
Retina	The innermost layer of the eye which consists of neurones and two main types of **photoreceptors** (**rods** and **cones**). Photoreceptors are receptors sensitive to light. The photoreceptors contain molecules called photopigments, which absorb light. **Image** is thus formed here since it contains photoreceptors. Photoreceptors connected to nerve fibre in **optic nerve** which carries nerve impulses to the brain.
Blind spot	The region where the nerve fibres meet and become the optic nerve.
Fovea	Area near centre of retina where cones are most concentrated; gives rise to most acute vision.
Sclera (Sclerotic coat)	The outermost layer of the eye. It is basically a tough protective coat that contains and protects the eye. Eye muscles attached to this layer facilitates the movement of the eyeball.
Eyelid	(1) Protects the cornea from mechanical damage. (2) Squinting prevents excessive entry of light. (3) Blinking spreads tears over the eyes so that dust can be wiped off.
Eyelashes	Short hairs projecting from the border of the eyelid, which: (1) shields the eye from dust particles; (2) protects the eye from extreme light.
Tear (lachrymal) gland	**Secretes tears**, a watery solution of salts, some mucus and bactericidal enzyme lysozyme, which can: (1) **wash away** dust particles; (2) keep the cornea **moist** for atmospheric oxygen to dissolve; (3) **lubricate** the conjunctiva, reducing friction when the eyelids move.

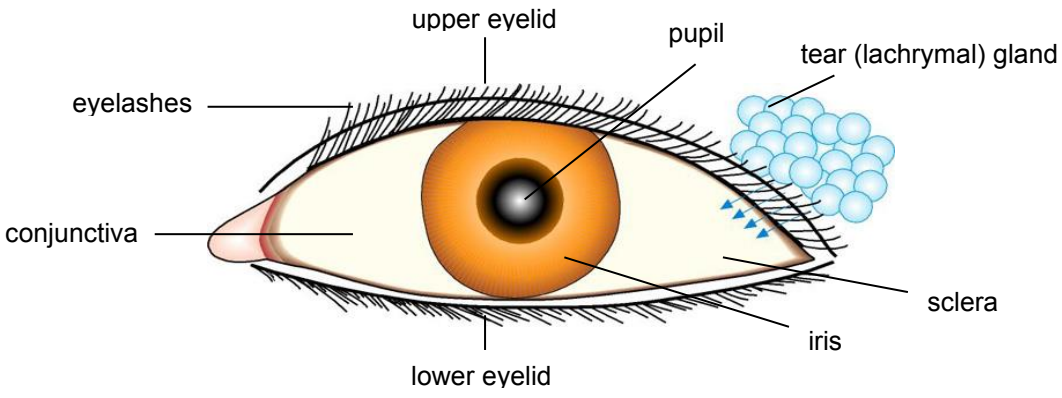


Figure 14.4 Parts of a human eye in anterior view

Photoreceptors: rod cells

- Rods are involved in vision at **low light intensity** (or dim light).
- The photosensitive pigment is **visual purple** (rhodopsin).
- When exposed to light, visual purple breaks down. Visual purple reforms in absence of light.
- At high light intensity, visual purple is broken down faster than it is being reformed. This explains why the eyes have to adapt to the dark when moving from bright light.
- Formation of visual purple requires vitamin A, lack of vitamin in diet causes night-blindness.

Photoreceptors: cone cells

- Cones are sensitive to **high light intensity**, and to **differences in wavelength**.
- Mammals with cones in their retinas are able to distinguish colours.
- There are 3 types of cones: red, green and blue.
- **Yellow spot** (**fovea**) is the region with highest concentration of cones and no rods.
- The optical axis is a theoretical line through the centre of the lens. The fovea, the place of most acute vision is on the optical axis.

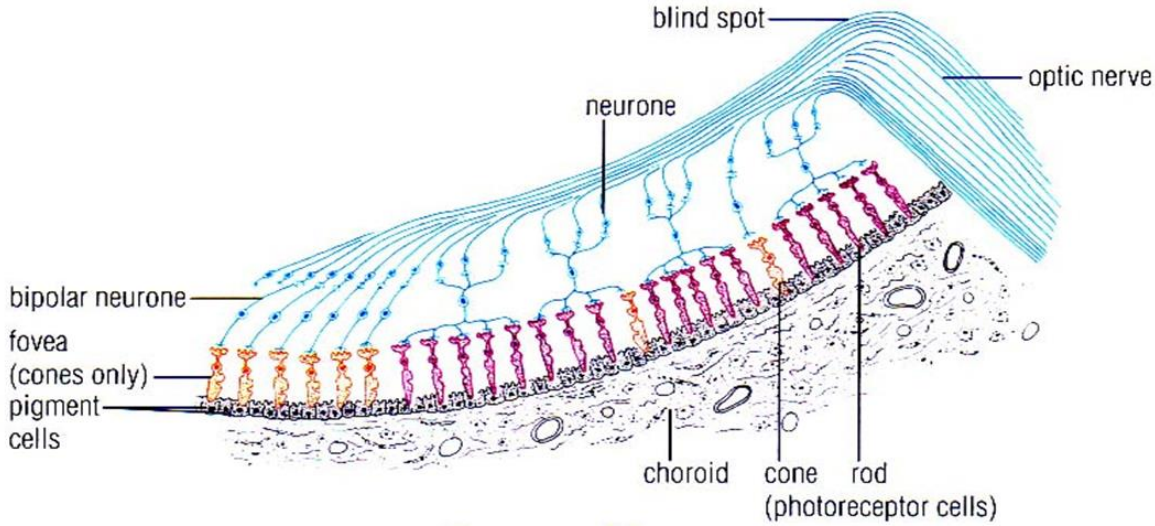


Figure 14.5 Parts of retina enlarged

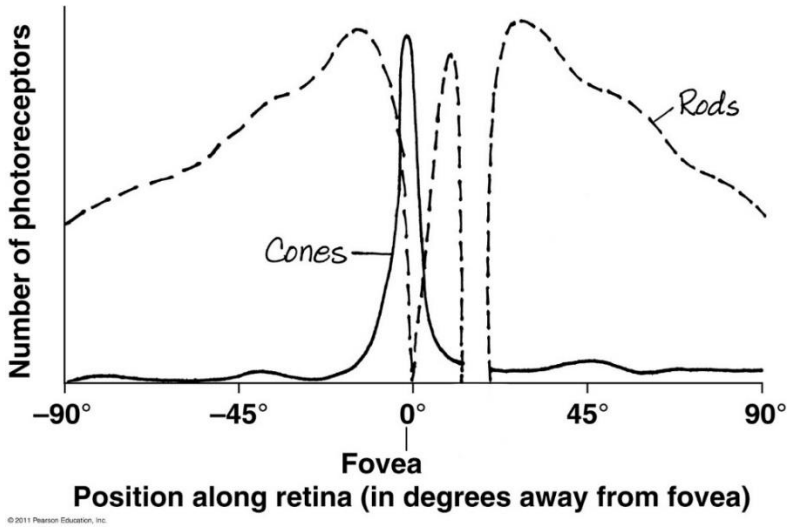


Figure 14.6 Graph of photoreceptor number in relation to position along retina in degrees away from fovea

3. PUPIL REFLEX

Pupil reflex is the involuntary change of **pupil size** or diameter by the **iris** to control the amount of light entering the eye.

The iris is controlled by 2 sets of involuntary muscles; the **radial** and **circular** muscles, which are antagonistic. A reflex action occurs as a result of changes in light intensity. This protects the eye from excessive light exposure, which could damage the retina.

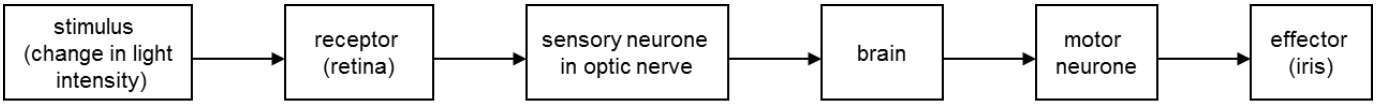
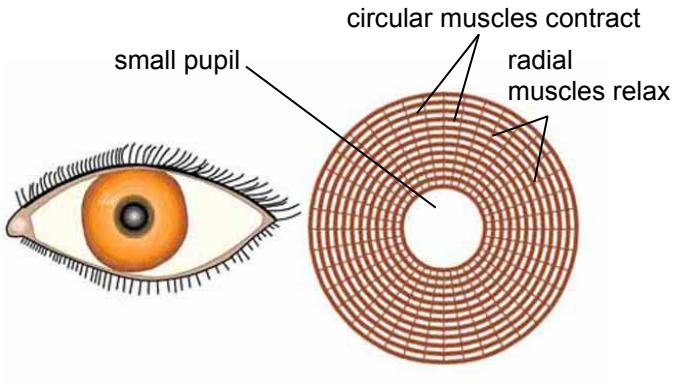
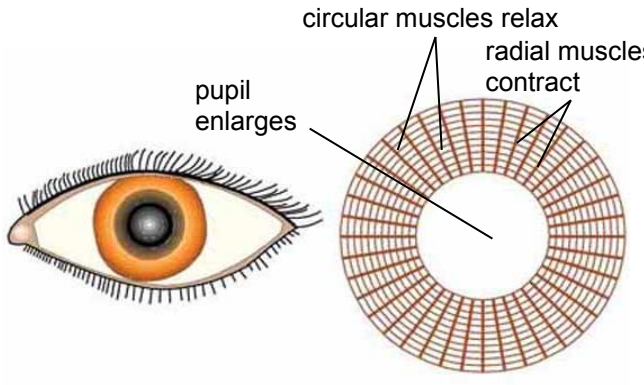


Figure 14.7 Flowchart of the reflex arc of pupil reflex

Sometimes, light intensity is too strong that decreasing the pupil size is not enough and the eyelid will shut to screen off part of the light.



Eye in bright light
- circular muscles of iris contract
- radial muscles of iris relax
- pupil diameter decreases
- less light enters eye



Eye in dim light
- circular muscles of iris relax
- radial muscles of iris contract
- pupil diameter increases
- more light enters eye

Figure 14.8 Mechanism of pupil reflex under different light conditions

Formation of image
- Light rays (reflected from an object) are **refracted** when they passes through the **cornea** and **aqueous humour** onto the lens.
- Light rays are further refracted onto the **retina** when it passes through the **lens**.
- Image on the retina either stimulates the rods or cones, depending on the intensity of light.
- Image formed is vertically **inverted**, laterally **reversed** and **diminished**.
- Impulses are generated when light falls on the retina and these impulses are transmitted via the optic nerve to the brain so that we are able to see the right way up, front to back and the right size.

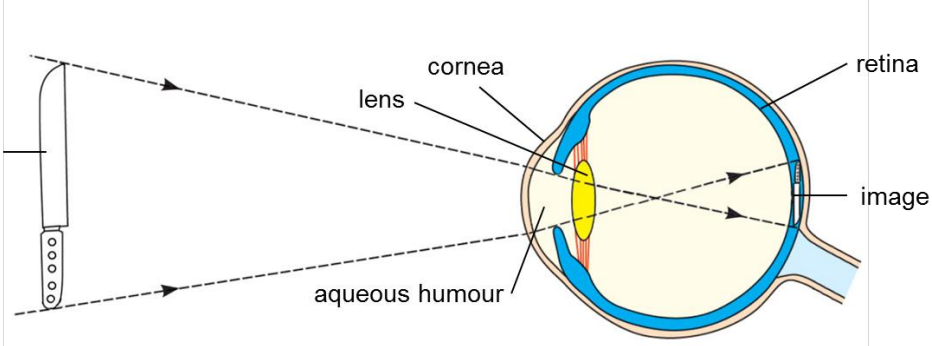


Figure 14.9 Diagrammatic representation on formation of an image on the retina

Role of brain in vision
- **Inverted image** is formed on the retina.
- Photoreceptors are stimulated.
- Nerve impulses generated are transmitted to the **optic centre** of the brain through the **optic nerve**.
- The brain interprets the information and forms an upright image.
- If the blind has his sight restored, objects appear upside down to him at first.
- The brain can integrate information from the overlapping visual fields of both eyes. It interprets them as one image.

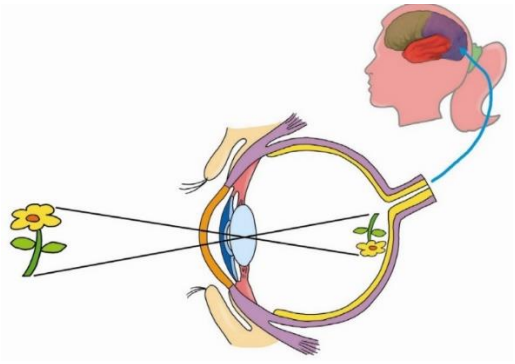


Figure 14.10 Pathway for the formation of an upright image at the brain

Accommodation or focussing

- Accommodation or focusing is the reflex mechanism by which light rays from an object are brought to focus on the retina.
- During focussing, the **thickness** or **curvature of the lens** is adjusted to allow light rays to be focused onto the retina.
- The objective of focusing is to **form a clear and sharp image** on the retina.

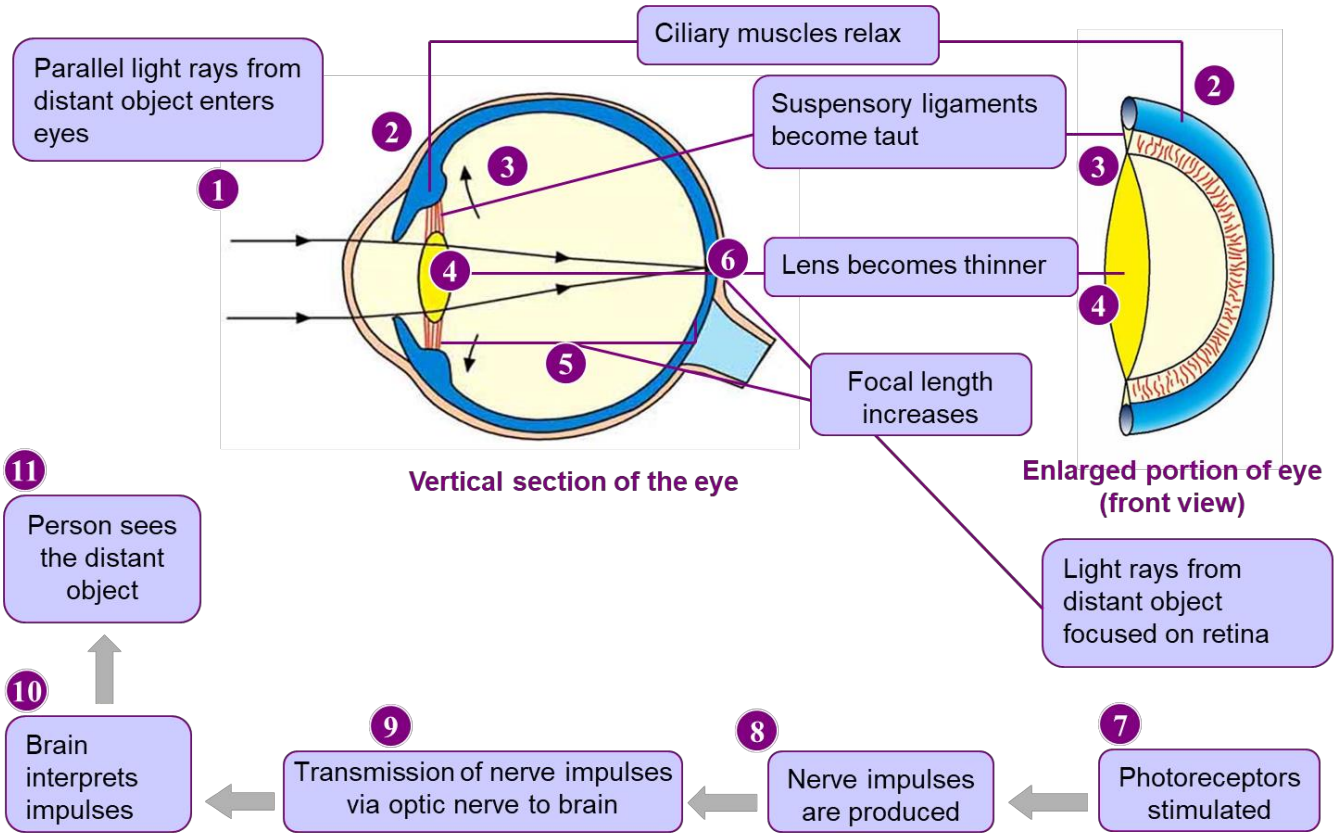


Figure 14.11 Flowchart of accommodation when looking at a distant object

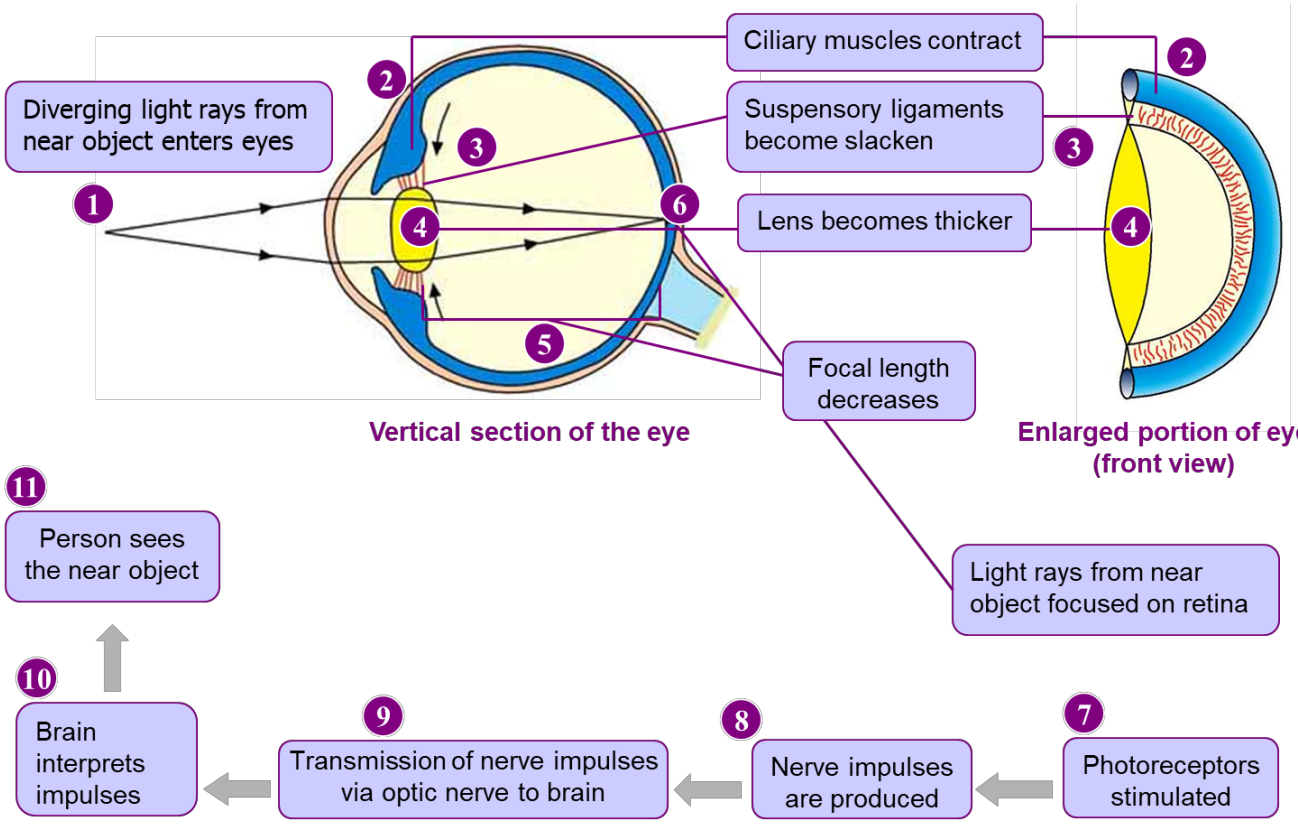


Figure 14.12 Flowchart of accommodation when looking at a near object

4. ADDITIONAL READING MATERIALS

Colour blindness

Colour blindness is believed to be due to failure of one or more of the three classes of primary colour cones. Deficiencies in the cones most receptive to red and green light give rise to red-green colour blindness. Colour blindness is a sex-linked characteristic. It is inherited condition that affects males very much more often than females because the gene for colour blindness is a recessive gene carried on the X chromosome.

Cataracts

A cataract is a condition where the clear lens of the eye becomes cloudy, preventing sufficient light rays from entering the eye. The protein in the lens is arranged in a precise way that keeps the lens clear and allows light pass through it. As humans age, some of the protein may clump together and start to cloud a small area of the lens. Over time, it may grow larger, making it harder to see. Besides advancing age, cataract risk factors include:

- Ultraviolet radiation from sunlight and other sources
- Diabetes, hypertension, obesity
- Smoking
- Previous eye injury or inflammation, previous eye surgery
- Hormone replacement therapy
- Significant alcohol consumption
- High myopia
- Family history

Cataract can be treated with surgery, if it cannot be corrected with glasses and interferes with daily activities.

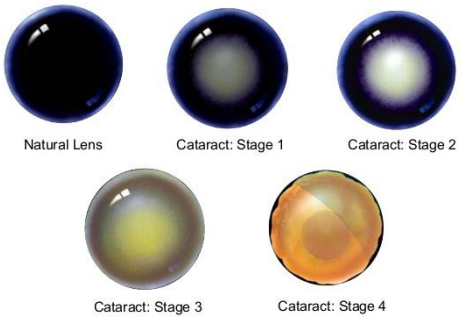


Figure 14.14 Various stages of cataract
Source: http://image.slidesharecdn.com

Pinkeye (Conjunctivitis)

A pinkeye is the inflammation of the conjunctiva due to either an irritation to the eye or an infection. Viral and bacterial pinkeye are contagious and spread easily. Since most pinkeye is caused by viruses, often the adenovirus, which is a common respiratory virus that can also cause a sore throat or upper respiratory infection. Medicines are not usually used to treat viral pinkeye, so it is important to prevent the spread of the infection. Bacterial infection can be caused by staphylococcal infection, *Haemophilus influenzae* and gonorrhoea. Treatments include the use of proper antibiotics.

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 14 – Hormones

Name: **Class:**

A. Content

- Endocrine glands
- Hormones (insulin, glucagon and adrenaline)

B. Learning Outcomes

Students should be able to:

(a) define a hormone as a chemical substance, produced by a gland, carried by the blood, which alters the activity of one or more specific target organs and is then broken down by the liver.

(b) explain what is meant by an endocrine gland, with reference to the islets of Langerhans in the pancreas.

(c) state the role of the hormone adrenaline in boosting blood glucose levels and give examples of situations in which this may occur.

(d) explain how the blood glucose concentration is regulated by insulin and glucagon as a homeostatic mechanism.

(e) describe the signs, such as an increased blood glucose level and glucose in urine, and the treatment of diabetes mellitus using insulin.

(f) explain what is meant by an endocrine gland, with reference to the islets of Langerhans in the pancreas.*

(g) explain how the blood glucose concentration is regulated by insulin and glucagon.*

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
4. Miller, K. R. and Levine, J. Biology. Pearson Prentice Hall.
5. Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V. and Jackson, R. B. Campbell Biology (9th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline

1. Introduction
2. Endocrine glands and their hormonal secretions
3. Comparing hormonal and nervous controls
4. Additional reading materials

E. Practical Work

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1. INTRODUCTION

Coordination and response in human involves two systems:

- **nervous system**, and
- **endocrine system**.

The endocrine system controls body activity by releasing chemical messengers known as hormones into the blood.

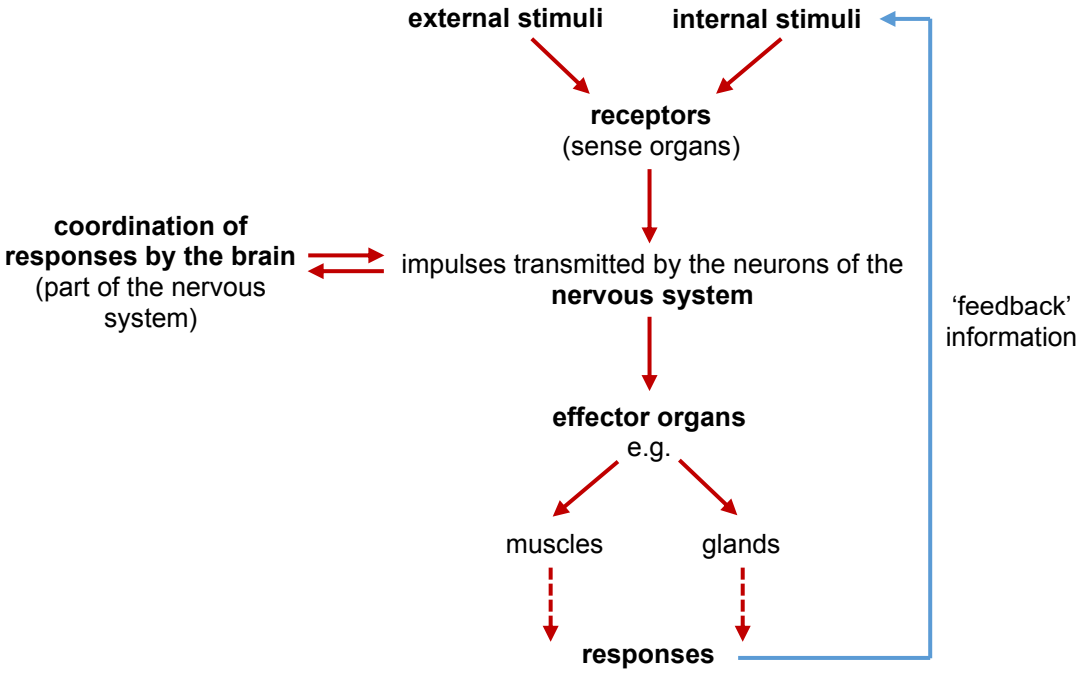


Figure 13.1 Coordination by the human nervous system

Definition

A hormone is a **chemical** substance, produced by an **endocrine gland**, carried by the **blood**, which alters the activity of one or more specific **target organs** and is then destroyed by the liver (and excreted by the kidneys).

Extension

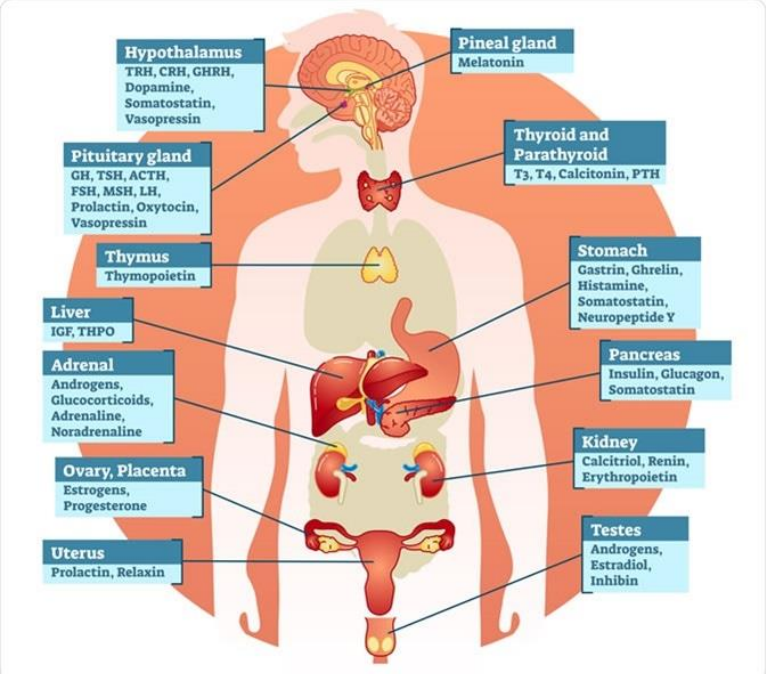


Figure 13.2 Some of the endocrine glands and hormones in the human body

There are 8 major endocrine glands producing more than 50 hormones in the human body. Hormones serve to control and coordinate activities throughout the body.

Some hormones have similar functions, similar mechanisms of influence, and many important interrelationships.

Source: National Cancer Institute, National Institutes of Health

Endocrine glands

- Endocrine glands are ductless glands because hormones produced diffuse directly into surrounding blood.
- Endocrine glands contains an extensive network of blood vessels to transport hormones to their specific target organs, in other words, they are well-vascularised.

- Generally, most hormones are secreted by exocytosis directly into the bloodstream, and are transported indiscriminately all over the body (exception includes steroid hormones, which are lipid-soluble, and thus can diffuse through cell membrane).
- The endocrine system is (highly) integrated with nervous system. Examples include adrenal glands and pituitary glands.

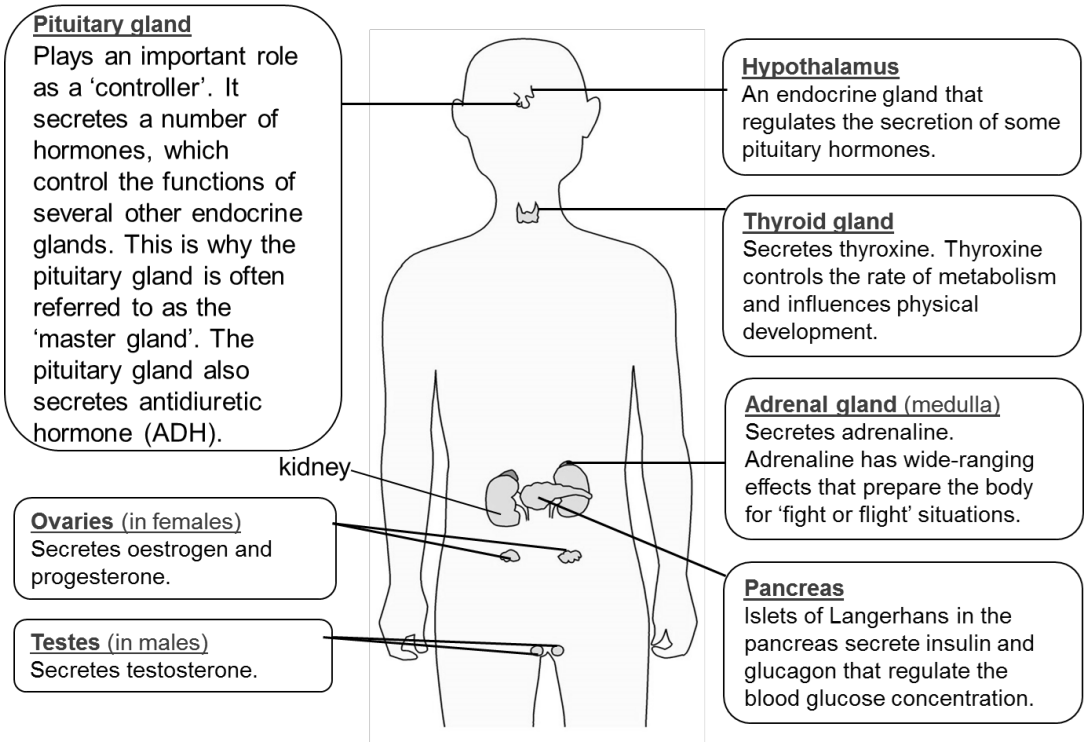


Figure 13.3 Summary of the human endocrine glands and hormones (as learnt in our Biology syllabus)

The structure of the endocrine glands can be contrasted with ducted glands, also known as **exocrine glands**.

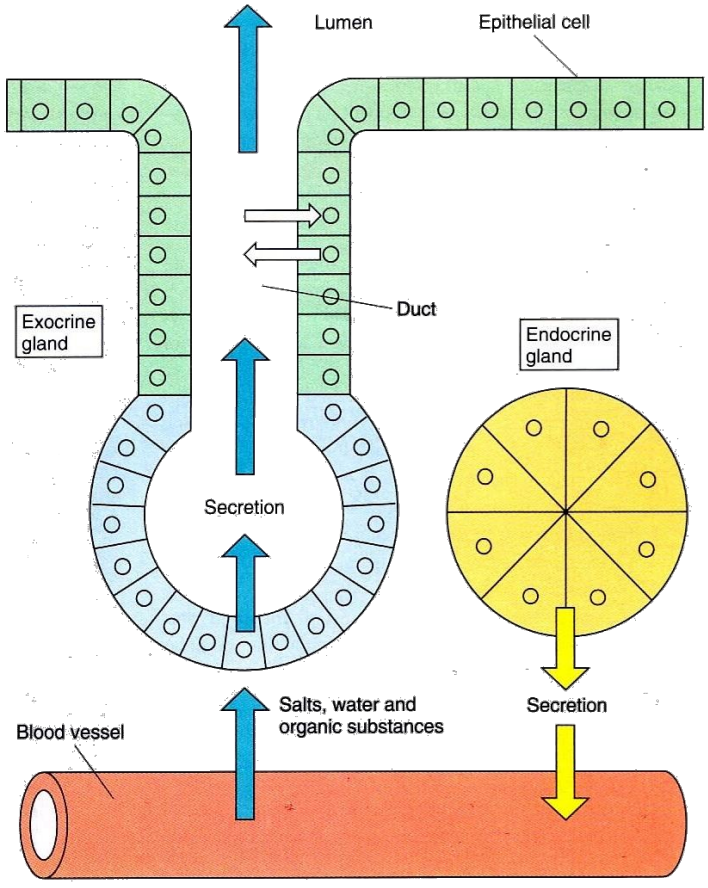


Figure 13.4 Diagrammatic representation of both endocrine and exocrine glands

2. ENDOCRINE GLANDS & THEIR HORMONAL SECRETIONS

Insulin

- The **pancreas** contains cells, known as **Islets of Langerhans**. The two distinct types of Islets of Langerhans are referred as α-cells and β-cells.
- The β-cells in Islets of Langerhans produce the hormone **insulin**.
- Insulin is released in response to a rise in blood glucose levels. Target organs for insulin are the **liver** and **muscles**.
- This effect will decrease blood glucose by:
  - increasing permeability of cell membranes (e.g. liver) to glucose so that glucose uptake is increased.
  - stimulating the conversion of excess glucose to **glycogen** for storage.
  - increasing rate of cellular respiration so that more glucose is used up.
- Over-secretion of insulin can result in hypoglycaemia (low blood glucose concentration).

Diabetes Mellitus

- The disease diabetes mellitus is caused by a deficiency of insulin or a decreased response to insulin in target tissues. There are several types of diabetes.
- In **Type 1 Diabetes**, also known as insulin-dependent diabetes mellitus, the affected individual does not produce enough insulin. This is because the immune system destroys the β-cells of the pancreas.
- This results in a high glucose concentration of blood plasma in the affected person.
- Blood glucose concentration will reach a level that exceeds kidney's ability to completely reabsorb all the glucose. Glucose will be present in **urine**.
- Treatment:
  - Mild cases – **reducing** person's carbohydrate intake.
  - Severe cases – regular **insulin injections** (intravenously) and **regulation** of carbohydrate intake.

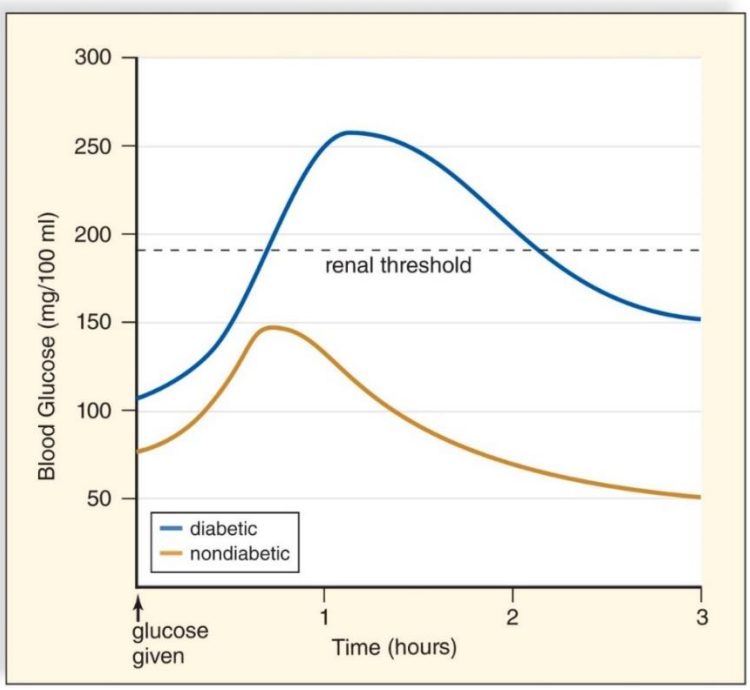


Figure 13.5 Graph of blood glucose concentration of diabetic and nondiabetic individuals

- The renal threshold (Figure 13.5) is the concentration of a substance (e.g. glucose) dissolved in the blood above which the kidneys begin to remove it into the urine. When the renal threshold of blood glucose is exceeded, reabsorption of glucose by the proximal convoluted tubule is incomplete. This results in glucose remaining in the urine.

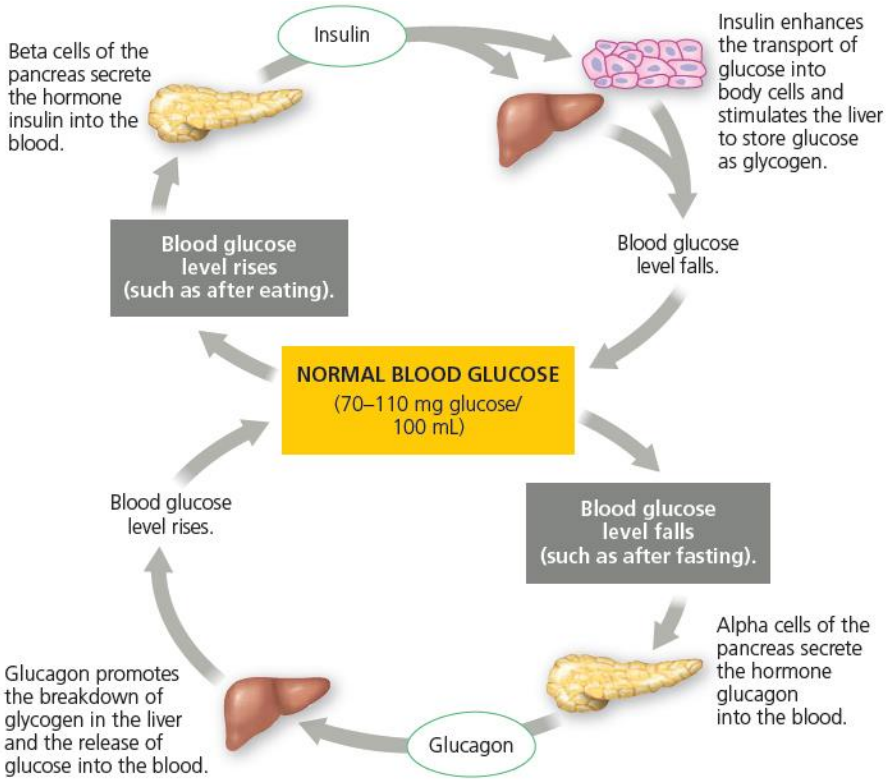


Figure 13.6 Homeostatic regulation of blood glucose

- In **Type 2 Diabetes**, also known as noninsulin-dependent diabetes mellitus, is characterised by a failure of target cells to respond normally to insulin. In this instance, insulin is produced, but target cells fail to take up glucose from the blood, and blood glucose levels remain elevated.
- Although heredity can play a role in Type 2 Diabetes, excess body weight and lack of exercise significantly increase the risk. This form of diabetes generally appears after age 40, but even children can develop the disease, particularly if they are overweight and sedentary. More than 90% of people with diabetes have Type 2.
- The condition is managed by monitoring blood glucose concentration with regular exercise and a healthy diet. Some may require medications.

Glucagon

- The α-cells in Islets of Langerhans produce the hormone **glucagon**.
- The main target organs are the **liver** and **muscles**.
- Glucagon is secreted when blood glucose concentration decreases below normal levels. Glucagon increases blood glucose concentration by stimulating
  - the conversion of glycogen (in muscles or liver) to glucose.
  - the conversion of fats and amino acids into glucose

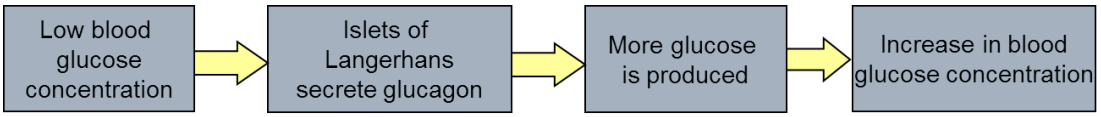


Figure 13.7 Flowchart on effect of glucagon

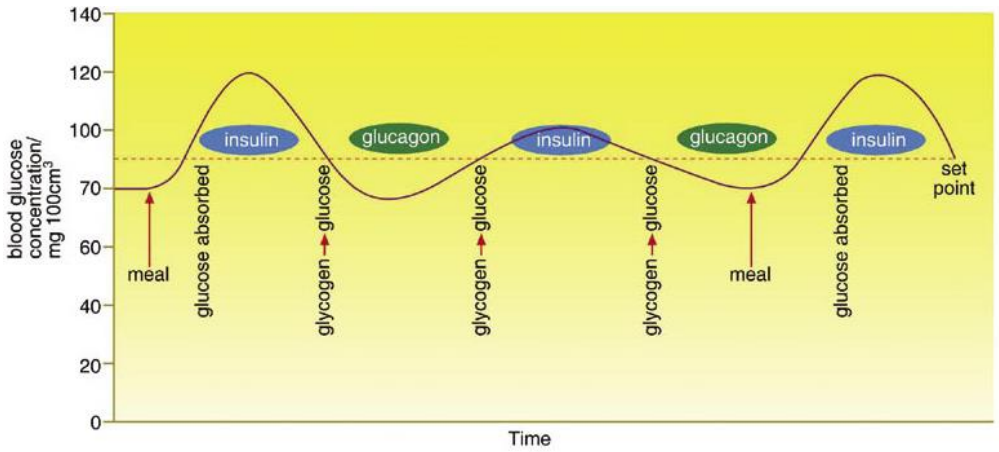


Figure 13.8 Secretion of insulin and glucagon are controlled by negative feedback mechanisms

Explain what it means to say that secretion of a hormone is regulated by negative feedback.
The release of a hormone will bring about an opposite effect to the changes detected.

Adrenaline

- Adrenaline (this 'fight or flight' hormone is also known by the name epinephrine), is secreted by **adrenal gland** which are located atop the kidneys.
- For humans, each adrenal gland is actually made up of two glands: adrenal cortex (outer portion) and adrenal medulla (central portion).
- Stimulus for secretion is fear, anger, anxiety and stress.
- The target organs of adrenaline include the respiratory and circulatory systems, liver, skeletal and other muscles.

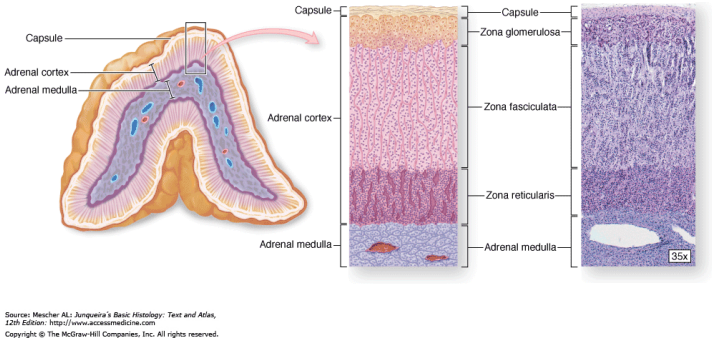


Figure 13.9 Transverse section of an adrenal gland

- Effect is to prepare body for "fight or flight" by:
  - stimulating the conversion of glycogen (in liver and muscles) to glucose to increase blood glucose level.
  - increasing heart rate, which results increase in blood pressure, and this will allow faster transport of oxygen and glucose to muscles and brain.
  - increasing rate of breathing by relaxing bronchioles resulting in more air flow into lungs.
  - diverting blood away from the digestive tract and towards skeletal muscles.
- Effects of adrenaline include:
  - increased heart rate and rise in blood pressure;
  - increased rate and depth of breathing;
  - increased rate of respiration to release more energy;
  - increased blood glucose concentration by the breakdown of glycogen stored in the liver and muscles;
  - dilation of pupils to enhance vision;
  - increased rate of blood coagulation;
  - constriction of arterioles to channel more blood to skeletal muscles; and
  - contraction of hair erector muscles, causing the hair to stand giving the appearance of 'goose pimples'.

Table 13.1 Effects of adrenaline on various target organs

Target organ	Effects of adrenaline	Biological advantage	Effect or sensation
Heart	Beats faster	Faster circulation of blood containing glucose and oxygen to the muscles	Thumping heart
Breathing centre of the brain	Faster and deeper breathing	Increased oxygenation of the blood; rapid removal of carbon dioxide	Panting
Arterioles at skin	Constrict	Less blood going to the skin means more is available to the muscles	Person goes paler
Arterioles of the digestive system	Constrict	Less blood for the digestive system, allows more to reach the muscles	Dry mouth
Muscles of alimentary canal	Relax	Peristalsis and digestion slow down; more energy available for action	'hollow' feeling in stomach
Muscles of body	Tense	Ready for immediate action	Tense feeling; shivering
Liver	Conversion of glycogen to glucose	Glucose available in blood for energy release during cellular respiration	No sensation
Fat deposits	Conversion of fats to fatty acids	Fatty acids available in blood, for muscle contraction	No sensation

3. COMPARING HORMONAL AND NERVOUS CONTROLS

Similarities between hormonal and nervous controls

Both have the following components:

- A **receptor** that detects a stimulus
- An **impulse** or **chemical** that is transmitted
- An **effector** (target organ that carries out the response)

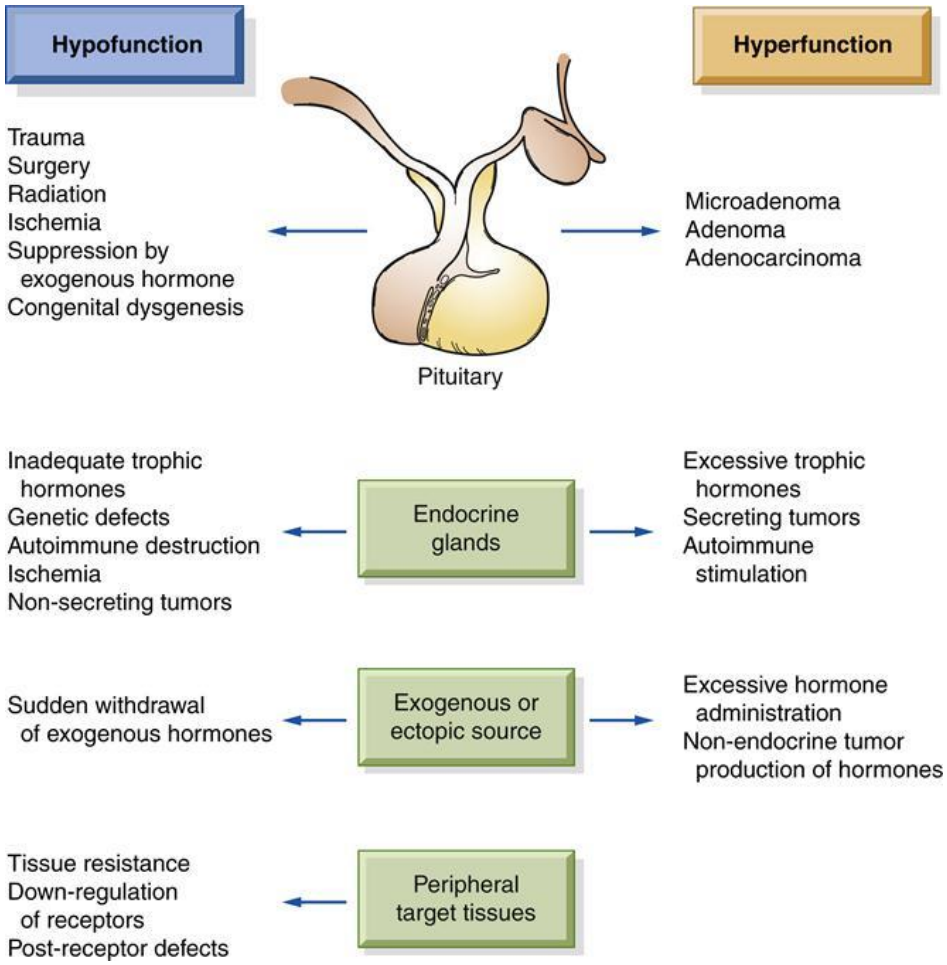
Table 13.2 Differences between hormonal and nervous controls

Hormonal control	Nervous control
Involves hormones (chemical)	Involves nervous impulses (electrical signals)
Hormones transported by blood	Impulses transmitted by neurones
Slow response	Quick response
Response can be either short-lived or long-lived	Response short-lived
Always involuntary	May be voluntary or involuntary
May affect more than one target organ	Usually localised

4. ADDITIONAL READING MATERIALS

When hormone levels are too high or too low, the person suffers an endocrine disease or disorder. Endocrine diseases and disorders also occur if your body does not respond to hormones the way it is supposed to. Apart from diabetes, do you know of other common endocrine disorders?

Reference: The National Institute of Diabetes and Digestive and Kidney Diseases Health Information Center



The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 15 – Reproduction in Plants

Name: **Class:**

A. Content
- Asexual reproduction
- Sexual reproduction in plants

B. Learning Outcomes

Students should be able to:
(a) define and differentiate between asexual and sexual reproduction
(b) identify and describe the sepals, petals, stamens and carpels an insect-pollinated, dicotyledonous flower
(c) state the functions of the sepals, petals, anthers and carpels
(d) identify and describe the stamens and stigmas of a wind-pollinated flower
(e) outline the process of pollination and distinguish between self-pollination and cross pollination
(f) compare an insect-pollinated and a wind-pollinated flower
(g) describe the growth of the pollen tube and its entry into the ovule followed by fertilisation (production of endosperm and details of development are not required)

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
3. Mackean, D. G. GCSE Biology (3rd ed). John Murray (Publishers) Ltd.
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D. Lecture Outline

1. Introduction
2. Parts of a flower
3. Pollination
4. Fertilisation
5. Additional reading materials

E. Practical Work
- Observing and drawing of insect-pollinated and wind-pollinated flowers

1. INTRODUCTION

Reproduction is an essential part of the life cycle of the plant. There are two types of reproduction in flowering plants (angiosperms):
1) **asexual reproduction**
2) **sexual reproduction**

Definition

Asexual reproduction is the process resulting in the production of **genetically identical** offspring from one parent, without fusion of gametes.

Asexual reproduction involves **mitosis**. Genetically identical offspring produced asexually are known as **clones**. Asexual reproduction is also known as vegetative reproduction.

Sexual reproduction is a process involving the **fusion** of the **nuclei** of two **gametes** to form a **zygote**. It produces genetically dissimilar offspring.

In flowering plants, sexual reproduction involves highly adapted structures known as flowers.

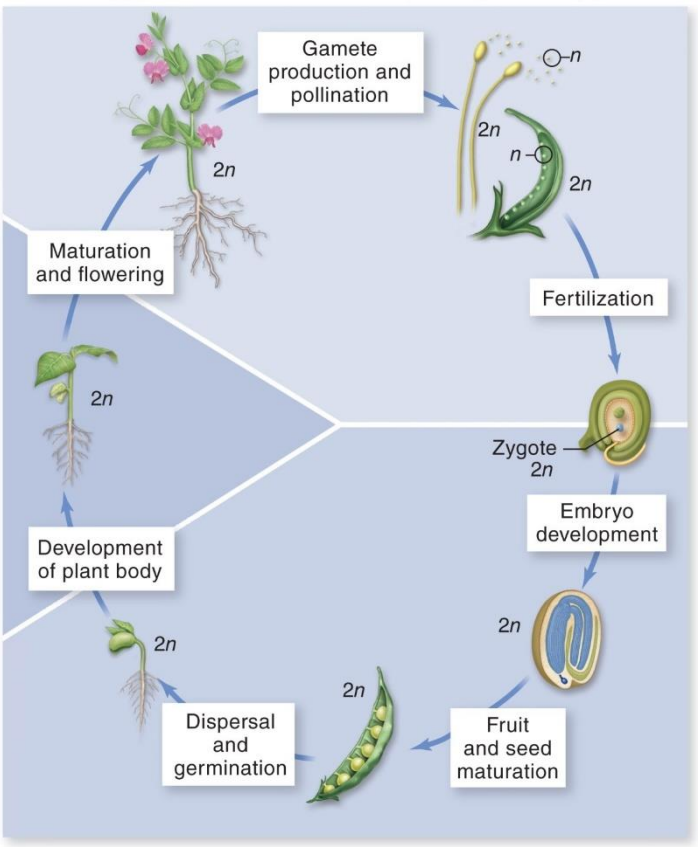

Figure 15.1 Life cycle of a flowering plant

Table 15.1 Differences between asexual and sexual reproduction

	Sexual reproduction	Asexual reproduction
Parents	Normally involves two unisexual (male or female) parents or parents are hermaphrodite.	Only involve single parent.
Gametes	Special reproductive cells, called gametes and the nuclei fuse to form a zygote (fertilisation).	No special reproductive cells and fertilisation is involved.
Offspring	Offspring are genetically dissimilar to the parents. Variation arises in gamete formation and also because fusion of gametes from different parents generates more variety in the genes of the offspring	Offspring are genetically identical to the parent (apart from mutations that may arise in somatic cells).
Advantage(s)	(1) Increases genetic variation in the offspring. (2) Offspring inherit beneficial characteristics from both parents.	(1) May produce offspring faster. (2) No need for two parents/gametes (only one parent needed) (3) Relatively certain method of reproduction/less wastage/less energy. (4) Since parent can survive in that particular habitat, genetically identical offspring should be suited as well. (5) Well-developed before separation from parent which allows rapid colonisation.
Disadvantage(s)	(1) Two parents may be required. (2) Slower process of producing offspring.	(1) Lack of genetic variation in offspring. (2) Adverse conditions and disease will be likely to affect all members. (3) Overcrowding and competition for resources.

2. PARTS OF A FLOWER

A flower which is the reproductive organ of the flowering plant, is formed from a bud. In the flower, the male and female reproductive structures, the **androecium** and the **gynoecium** differentiate and develop. Flowers may occur singly (or solitary) on plants (e.g. *Tulipa*) or more commonly in cluster called **inflorescence** (e.g. *Ranunculus*).

A complete flower consists of the following parts: **pedicel**, **receptacle**, **sepals**, **petals**, **stamens** and **carpels** (**pistil**).

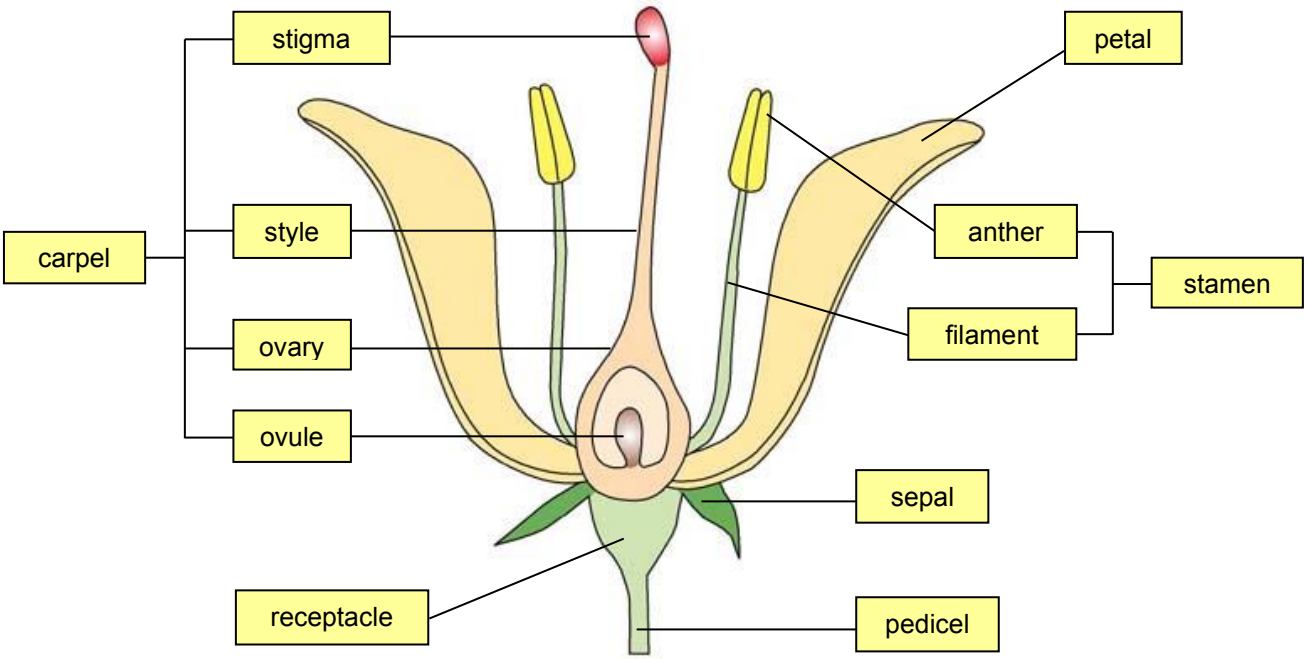

Figure 15.2 Structure of a typical flower

Table 15.2 Functions of different parts of a flower

Parts of flower		Function(s)
petal		In insect-pollinated flowers, petals: (1) are brightly-coloured to attract insects for pollination; (2) act as landing platforms for insects; (3) may have nectar guides to guide insects to nectar; (4) may be scented to attract insects. All the petals of a flower make up the **corolla**.
sepal		(1) Protect other parts of flower during the bud stage; (2) Carry out photosynthesis. All the sepals of a flower make up the **calyx**.
stamen	filament	Holds anther in best position to release pollen grains.
	anther	Produce and contain pollen grains.
carpel	stigma	(1) Receives the pollen grains; (2) Secretes sugary fluid to stimulate germination of pollen grains.
	style	Holds stigma in best position to trap pollen grains.
	ovary	Produces and protects one or more ovules.
	ovule	Produces the female gamete.
receptacle		Point of attachment for the other parts of the flower.
pedicel		Holds each flower.

In which structure(s) of a flower does meiosis occurs?
Ovary and anther

Stamen

The stamen is made up of an **anther** supported by a **filament**. Each anther is bilobed and each lobe contains two **pollen sacs**. When the anther matures, it splits open along the line of dehiscence, releasing the pollen grains.

The anther also contains a vascular bundle that serves to carry water, sucrose and amino acids from the main plant body to the developing pollen grains in the pollen sacs.

What are the sucrose and amino acids used for in the developing pollen grains?
Sucrose: respiratory substrate to release energy for growth
Amino acid: formation of proteins which is used to form new cells

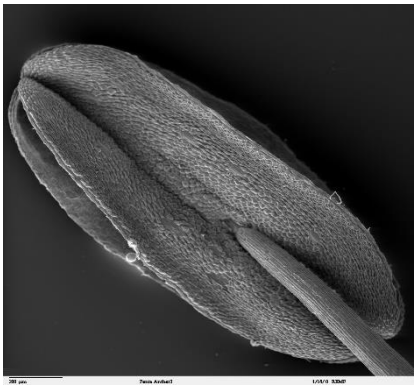

Figure 15.3 SEM micrograph of *Penta lanceolate* anther
Source: http://remf.dartmouth.edu/imagesindex.html

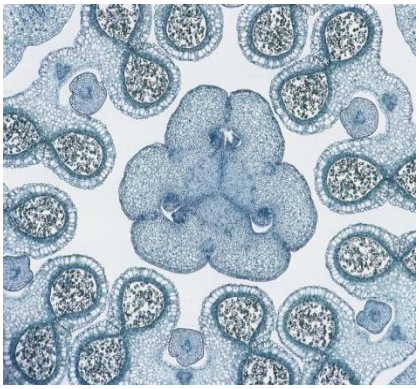

Figure 15.4 SEM micrograph of immature bud of lily flower in T.S.
Source: https://www.pinterest.com

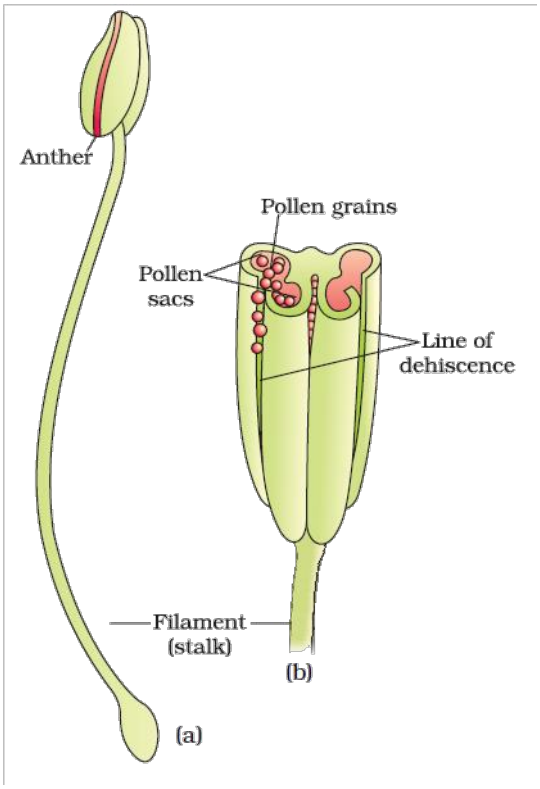

Figure 15.5 (a) A typical stamen
(b) Cut section of an anther

Pollen grains are generally spherical measuring about 20 to 50 μm in diameter. Each pollen grain is produced by **meiosis** and subsequently divides to form a generative nucleus and a pollen tube (vegetative) nucleus (Fig. 15.6). The pollen grain is surrounded by a thin cellulose cell wall, the **intine**, and an outer wall, the **exine**, with a sculptured pattern characteristic of the species.

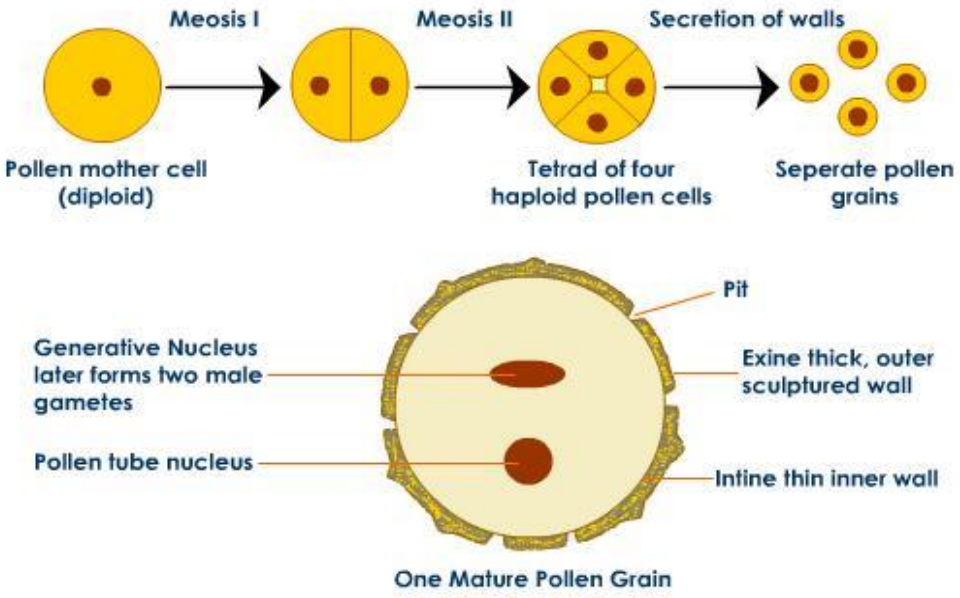

Figure 15.6 Structure of a pollen grain

Carpel (pistil)

The carpel of the flower consists of:
1) an **ovary**;
2) a **style**;
3) one or more **stigmas**.

A flower may contain a single carpel or many carpels, and carpels may be free or fused together. The ovary and ovule will develop into a fruit and a seed respectively after fertilisation.

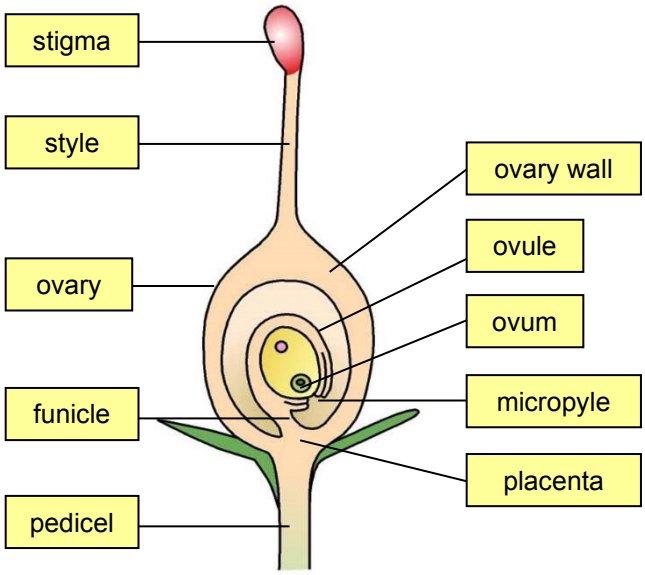

Figure 15.7 L.S. of a carpel showing one ovule

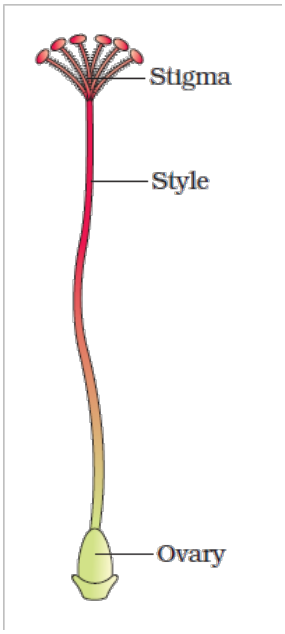

Figure 15.8 A dissected flower of *Hibiscus* showing carpel (other floral parts have been removed)

Types of flowers

A complete flower has sepals, petals, androecium (male part) and gynoecium (female part). A **bisexual** (**hermaphrodite**) flower has both stamens and pistil in the same flower whereas a **unisexual** flower possesses either stamens or pistils. A flower possessing only stamens is considered a male flower (staminate flower) while a flower possessing only the pistil is a female flower (pistillate flower).

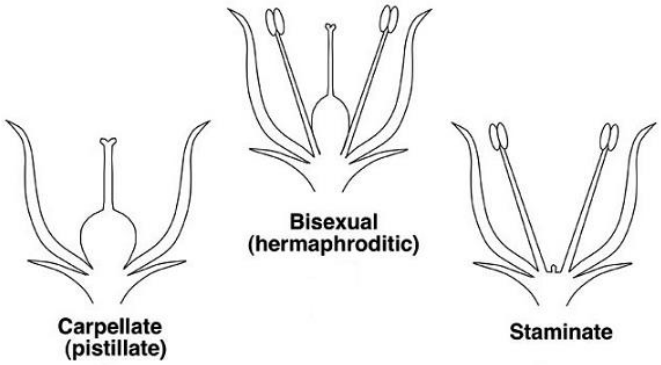

Figure 15.9 Flower sexual conditions
Source: http://nickrentlab.siu.edu/PLB304/Lecture09FloralMor/FloralMorph1.html

A **monoecious** ('*mono*' = one, '*oikos*' = house) plant has both male and female unisexual flowers on the same plant. If the male and female unisexual flowers are on separate plants, the plant is known as **dioecious**.

Flowers can also be classified based on the position of its ovary. When the gynoecium rests on the receptacle above the attachment of other floral parts, the ovaries are described as **superior**. When the receptacle grows upwards and encloses the ovary completely, with other floral parts arising above the ovary, the ovaries are described as **inferior**.

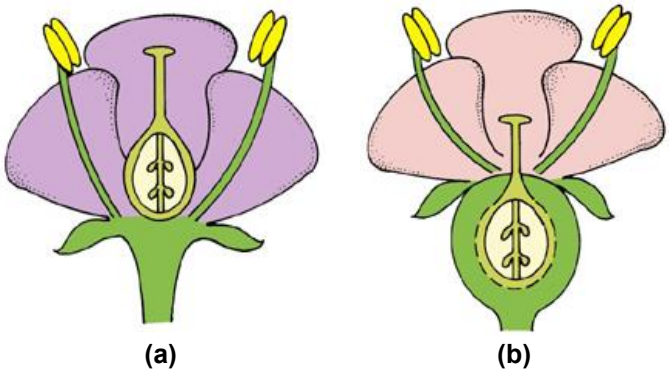

Figure 15.10 Positions of ovary in relation to other floral parts. (a) Superior ovary (b) Inferior ovary
Source: http://www.bio.miami.edu/dana/226/226F09_22print.html

3. POLLINATION

Pollination is defined as the transfer of pollen grains from anther to stigma.
The pollen grains may be by pollinating agents e.g. wind or insects.

There are two types of pollination: **self-pollination** and **cross-pollination**.
Self-pollination: Transfer of pollen grains from the anther to the stigma of the same flower or of a different flower on the same plant.
Cross-pollination: Transfer of pollen grains from one plant to the stigma of a flower in another plant of the same species.

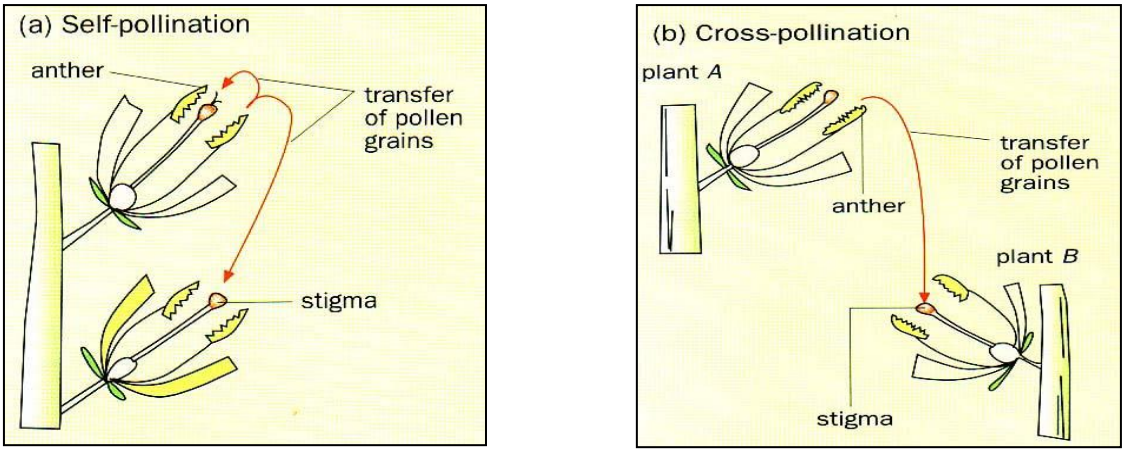

Figure 15.11 (a) Self-pollination and (b) cross-pollination

Some plants possess features that favour cross-pollination. These features may include:
1) dioecious plants bearing either male or female flowers (e.g. papaya, mulberry)
2) anthers and stigmas maturing at different times (e.g. custard apple)
3) positions of stigmas and anthers situated from each other (e.g. linseed)

Table 15.3 Advantages and disadvantages of cross-pollination

Advantages	Disadvantages
Offspring produced may have valuable qualities from both parents.	Two parent plants are required.
Offspring have greater genetic variability which will increase chances of survival during changes in environment e.g. more resistant to diseases.	External factors/agents e.g. wind, insects for pollination needed.
	Less likely to happen as compared to self-pollination.
	More energy and pollen is wasted as compared to self-pollination.

Insect-pollinated (entomophilous) flowers

- Flowers that are wind-pollinated have different characteristics from flowers that are insect-pollinated. Petals of insect-pollinated flowers are often large and brightly-coloured. They may also be scented or marked by nectar guides.
- Pollinators visit flowers for **nectar** or **pollen**, both of which contains rich source of nutrients.
- Examples of insect-pollinated flowers include *Lathyrus odoratus* (sweet pea) and *Clitoria*.

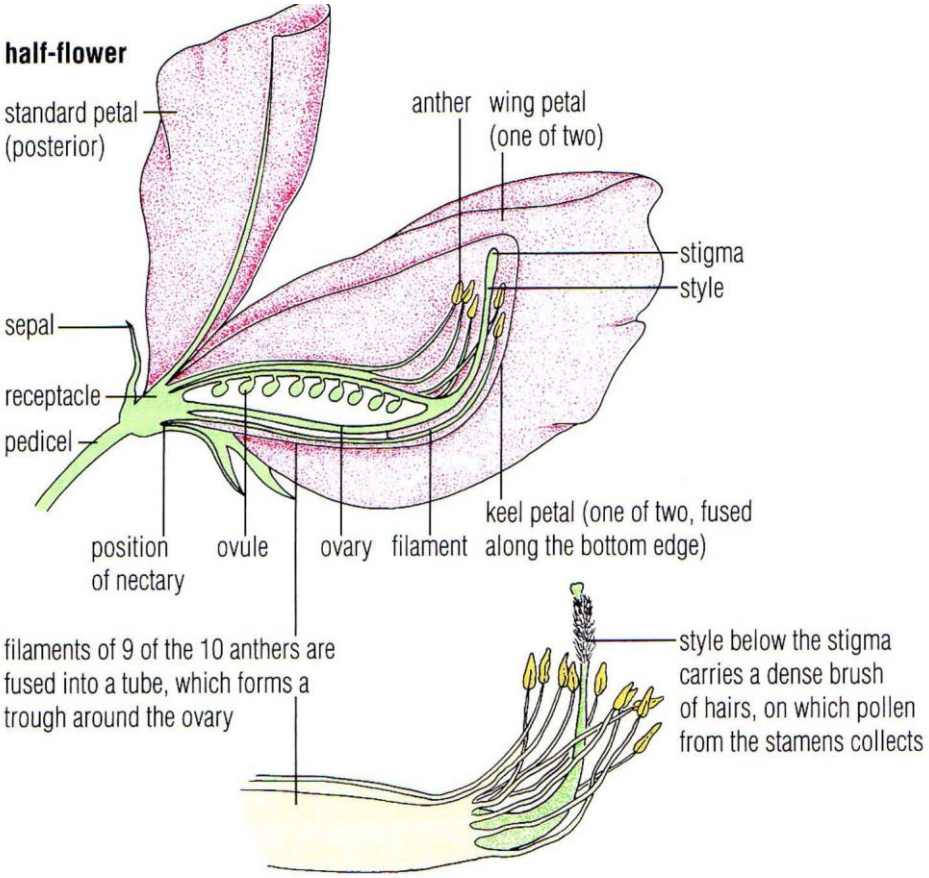

Figure 15.12 Flower of *Lathyrus odoratus* (sweet pea)

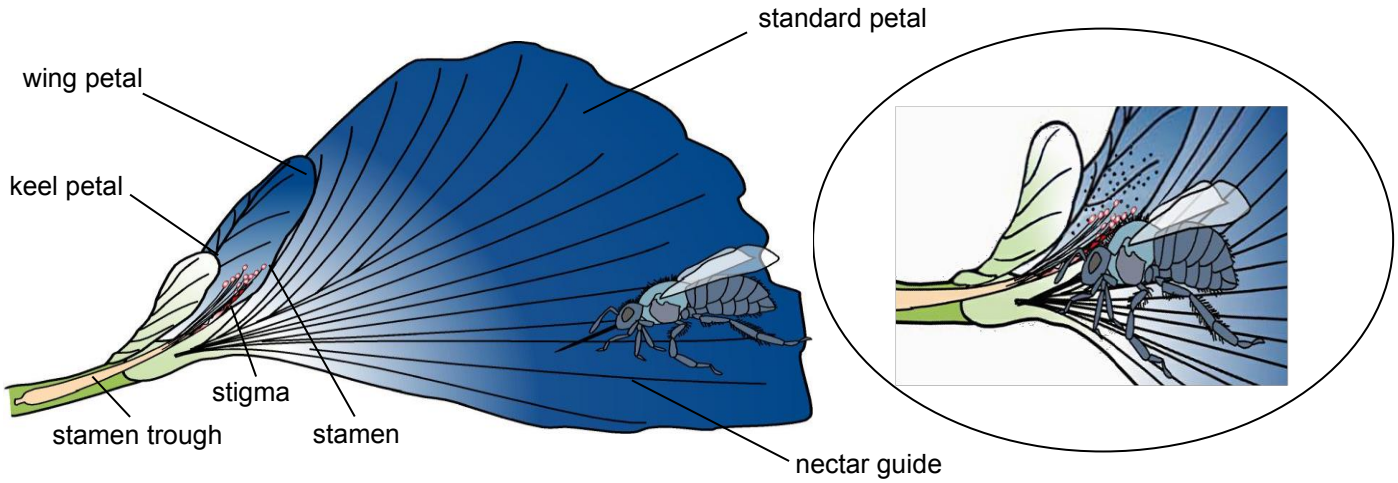

Figure 15.13 Insect pollination of *Clitoria*

1. An insect is attracted to a flower and lands on its petal.
2. The insect follows the nectar guide into the flower towards the nectaries to collect the nectar.
3. The pollen grains are deposited onto the hairy back of the insect as the stigma and anthers brushes against its back.
4. Pollen grains from another flower on the insect's back are also transferred to the sticky stigma.
5. In this instance, both self- and cross-pollination are possible.

Wind-pollinated (anemophilous) flowers

- Wind-pollinated flowers often have small and inconspicuous petals. The anthers and stigmas hang outside the flower. Mature stamens have long filaments that hang downwards and **pendulous** (e.g. can swing freely). Stigma may be large and feathery to provide large surface area to increase chances of catching pollen grains floating in the air. Scent and nectar guides are also absent from the flowers.
- Only around 10% of flowering plants are wind-pollinated.
- Examples of wind-pollinated flowers include grasses (*Ischaemum muticum*) and oaks.

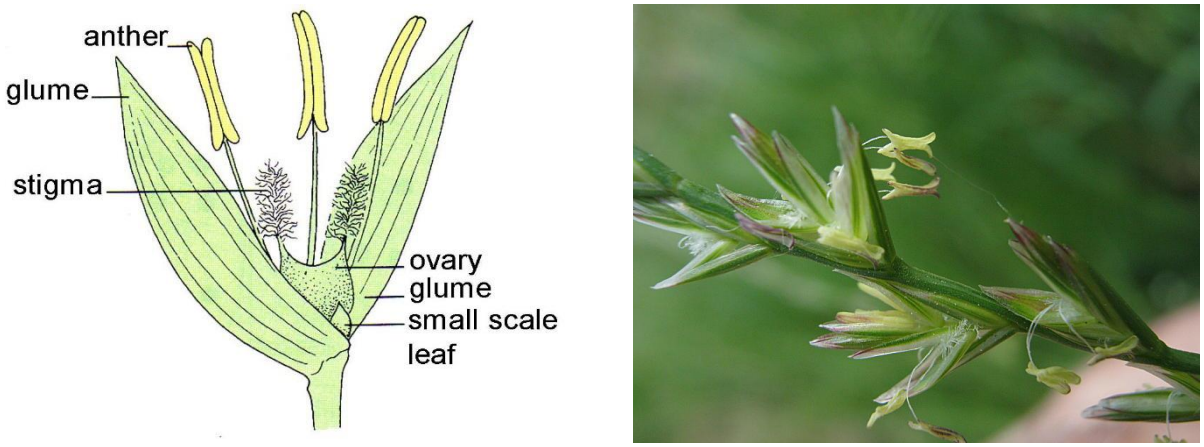

Figure 15.14 Flower of *Lolium perenne*
Source: http://www.actaplantarum.org/

Table 15.4 Differences between typical insect-pollinated and wind-pollinated flowers

characteristic	wind-pollinated (anemophilous) flower	insect-pollinated (entomophilous) flower
petal	1) Small petals 2) Not brightly coloured (usually green), or petals absent; flowers therefore inconspicuous.	1) Large petals 2) Colourful petals so flowers are conspicuous to attract insects. *If flowers relatively inconspicuous they may be gathered together in inflorescences.*
scent	Not scented	Scented (to attract insects)
nectary/nectar *	Absent	Present
nectar guide *	Absent	May be seen on the petals to guide the insect towards the nectar
stigma (shape)	Largely branched and feathery to increase surface area to catch more pollen	Small and sticky stigma to hold pollen
stigma (position)	Outside flower	Enclosed/protected within flower
style	Long	Short
stamen	Pendulous stamens hanging outside flower to release pollen (wind more likely to dislodge pollen from exposed anthers)	Stamens enclosed/protected within flower
anther	Anthers versatile, i.e. attached only at midpoints to tip of filament so that they swing freely in air currents	Anthers fixed at their bases or fused along their backs to the filaments so that they are immovable
pollen grain	1) Large quantities of pollen to increase chances of pollination (owing to high wastage) 2) Pollen grains are relatively light and small. 3) Pollen grains have dry and smooth walls.	1) Less pollen produced 2) Pollen grains are relatively heavy and large. 3) Pollen grains have spiny/rough walls and stickiness help attachment to insect body.

- Wind-pollinated flowers produce large quantities of light and smooth pollen grains to increase the chances of the pollen grains settling on the stigmas.
- On the other hand, pollen grains from insect-pollinated flowers are produced in much smaller quantities. They are also heavier and sticky or have rough surfaces to facilitate attachment to insects' bodies.

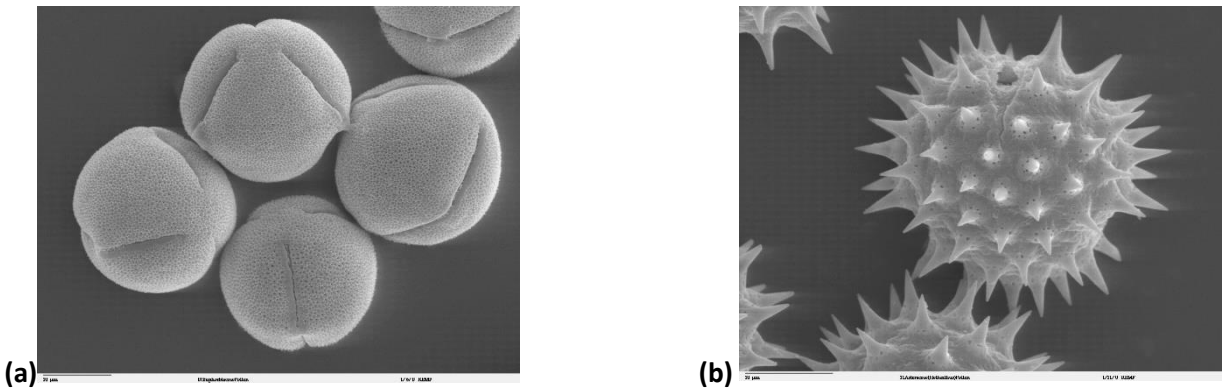

Figure 15.15 SEM micrograph of pollen grains of
(a) a wind-pollinated flower and (b) an insect-pollinated flower
Source: http://remf.dartmouth.edu/imagesindex.html

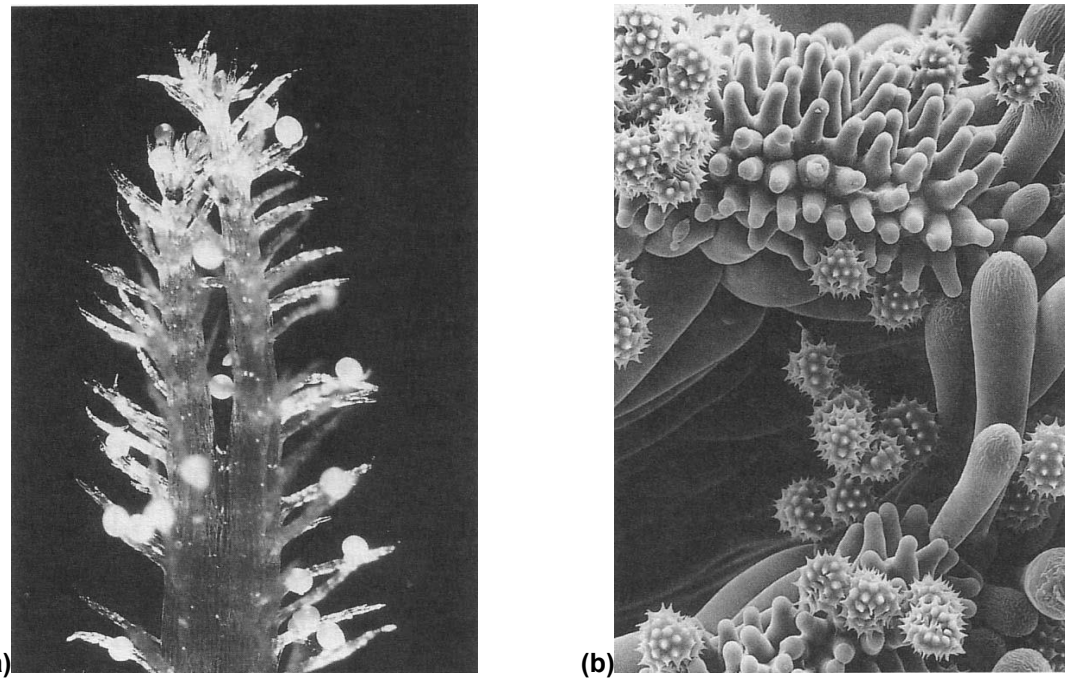

Figure 15.16 SEM micrograph of pollen grains on the stigma of (a) a wind-pollinated flower and (b) an insect-pollinated flower

4. FERTILISATION

Fertilisation refers to the **fusion** of the **nuclei** of the **male** and **female gametes** to form a **zygote**. In plants, pollination has to take place followed by fertilisation in order for sexual reproduction to be completed.

Distinguish between pollination and fertilisation.
Pollination refers to the transfer of pollen from anther to stigma whereas fertilisation refers to the fusion of the nuclei of the male and female gametes.

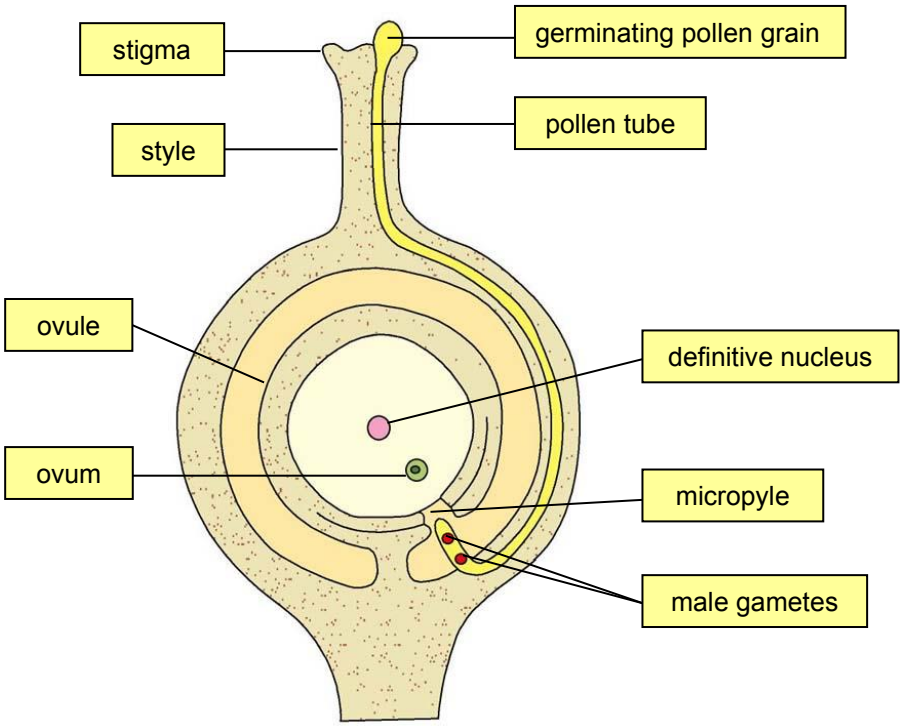

Figure 15.17 Fertilisation of an ovule in the ovary of a plant

1. Pollen grain lands upon compatible stigma of flower of same species.
2. Sucrose solution secreted by epidermal cell of stigma stimulates **germination** of pollen grain.

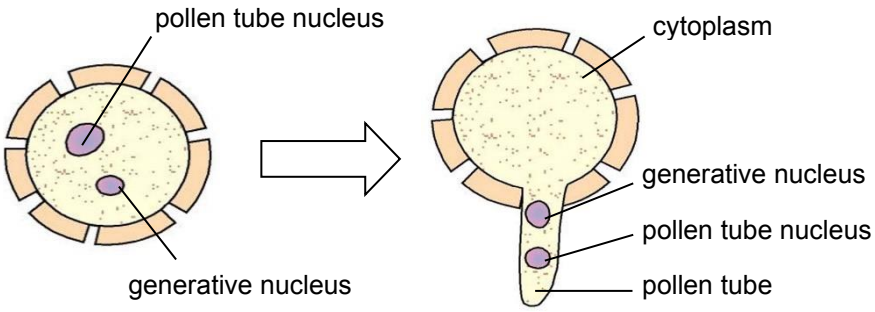

Figure 15.18 Germination of pollen grain

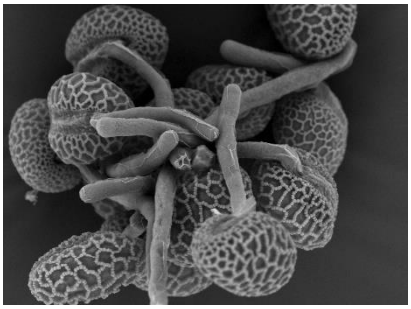

Figure 15.19 SEM micrograph of germinated pollen grains
Source: https://en.wikipedia.org/wiki/Pollen_tube

3. **Pollen tube** emerges and grows rapidly down style to ovary (where ovum is). Growth of tube controlled by pollen tube (vegetative) nucleus and involves enzymes secreted.
4. Two nuclei e.g. pollen and generative nuclei pass into pollen tube.
5. Upon reaching the **micropyle**, pollen tube nucleus degenerates and generative nucleus divides by mitosis to give rise to two **male gametes**.
6. The two male gametes enter the ovule to complete the **double fertilisation** process.

   1 male gamete (n) + ovum (n) → **zygote** (2n)
   1 male gamete (n) + definitive nucleus (2n) → **endosperm** (3n)

7. The zygote will divide and develop into the **embryo** in the seed. The endosperm nucleus will give rise to the food storage tissue called the endosperm. Endosperm contains food reserves for the embryo in the seed.

After fertilisation, the ovary develops into the fruit and the ovule develops into the seed.

5. ADDITIONAL READING MATERIALS

Asexual reproduction

Flowering plants reproduce vegetatively when a part (or parts) of the parent plant becomes separated and grows independently. As vegetative reproduction is asexual, new plants are normally genetically similar to the parent plant.

BULBS

The bulb is a perennating underground bud with swollen, fleshy leaf-bases attached to a short conical upright stem. Vegetative reproduction occurs when additional axillary buds (always found at the nodes where leaves attached) form additional bulbs besides the existing bulb in subsequent years. The onion, garlic and daffodil are familiar examples.

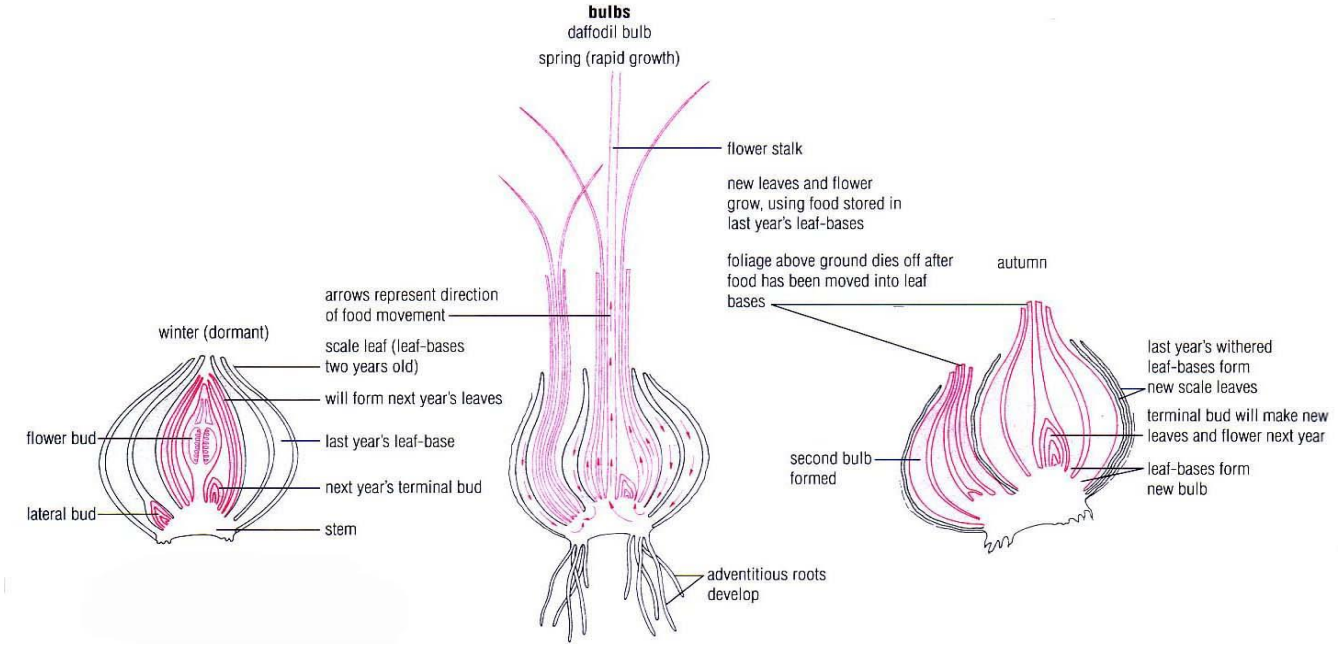

Figure 15.20 Vegetative reproduction in onion

TUBERS

The tuber is also a perennating swollen underground organ (e.g. stems, roots) that stores large amount of food reserves from the previous growing season. New shoots may sprout from its axillary buds in the subsequent growing season to form new plants. Examples of stem and root tubers include potato and sweet potato respectively.

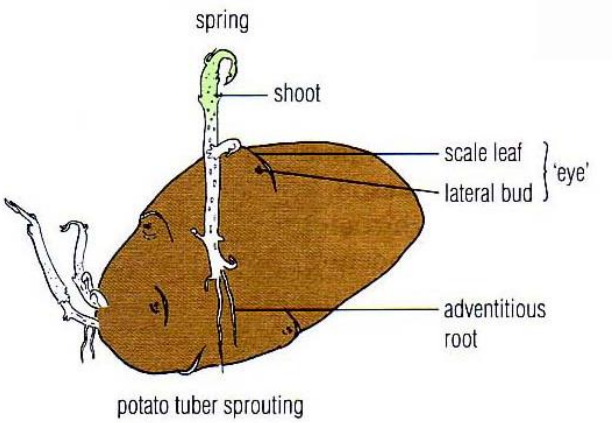

Figure 15.21 Vegetative reproduction in potato tuber

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 16 – Sexual Reproduction in Humans

Name: **Class:**

A. Content

- Male and Female Reproductive Systems
- Menstrual Cycle
- Sexual Reproduction in Humans
- Sexually Transmitted Infections

B. Learning Outcomes

Pre-requisites:
(a) identify on diagrams, the male reproductive system and give the functions of: testes, scrotum, sperm ducts, prostate gland, urethra and penis.
(b) identify on diagrams, the female reproductive system and give the functions of: ovaries, oviducts, uterus, cervix and vagina.
(c) briefly describe the menstrual cycle with reference to the alternation of menstruation and ovulation, the natural variation in its length, and the fertile and infertile phases of the cycle with reference to the effects of progesterone and estrogen only.
(d) describe fertilisation and early development of the zygote simply in terms of the formation of a ball of cells which becomes implanted in the wall of the uterus.

Students should be able to:
(a) state the functions of the amniotic sac and the amniotic fluid.
(b) describe the function of the placenta and umbilical cord in relation to exchange of dissolved nutrients, gases and excretory products. (Structural details are not required).
(c) discuss the spread of human immunodeficiency virus (HIV) and methods by which it may be controlled.

C. References

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6. Starr, C. Biology Concepts and Applications (6th ed). Brooks/Cole Publishing Company.
7. Toole, G. and Toole, S. Understanding Biology for Advanced Level (4th ed). Nelson Thornes (Publishers) Ltd.

D. Lecture Outline

1. The Male Reproductive System
2. The Female Reproductive System
3. Gametes
4. Puberty
5. The Menstrual Cycle
6. Sexual Reproduction in Humans
7. Sexually Transmitted Infection
8. Additional Reading Materials

E. Practical Work

- Fieldtrip (NUS Anatomy Museum) + reflection

1. THE MALE REPRODUCTIVE SYSTEM

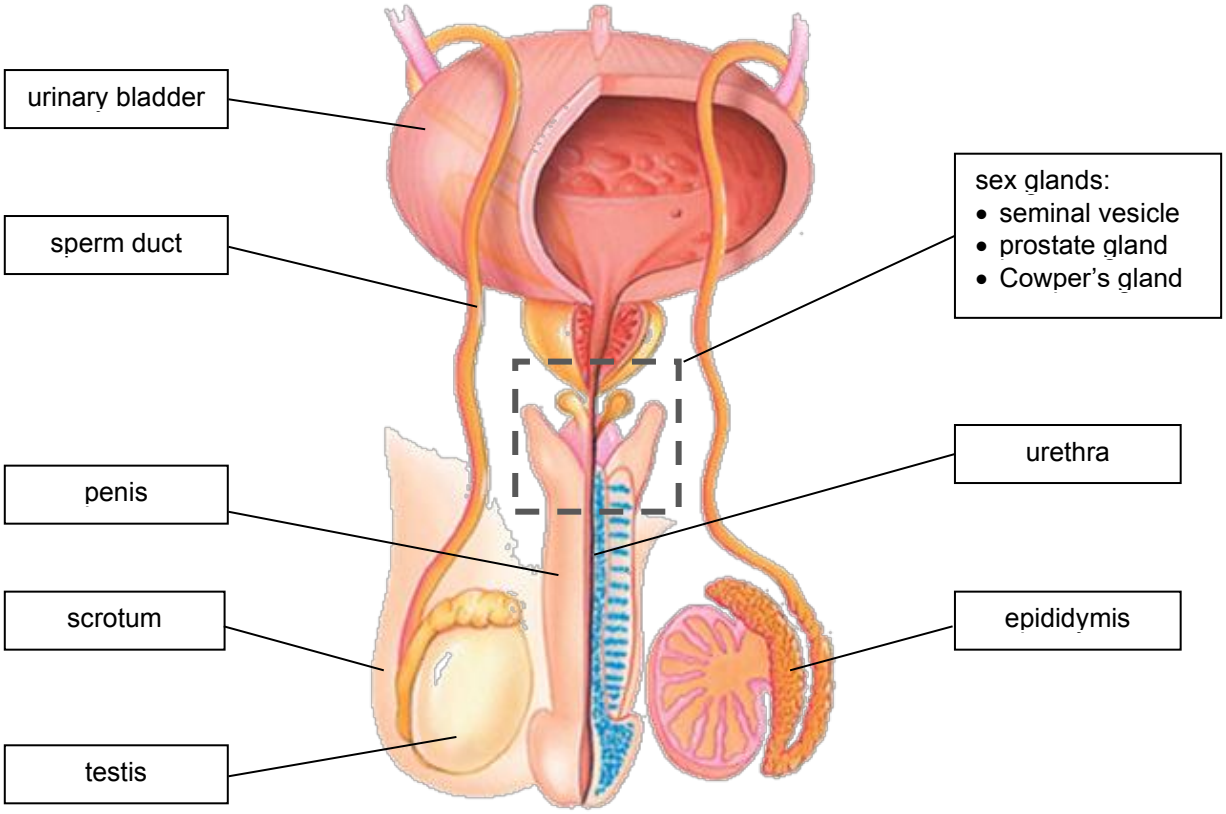

Figure 16.1 Front view of the male reproductive system

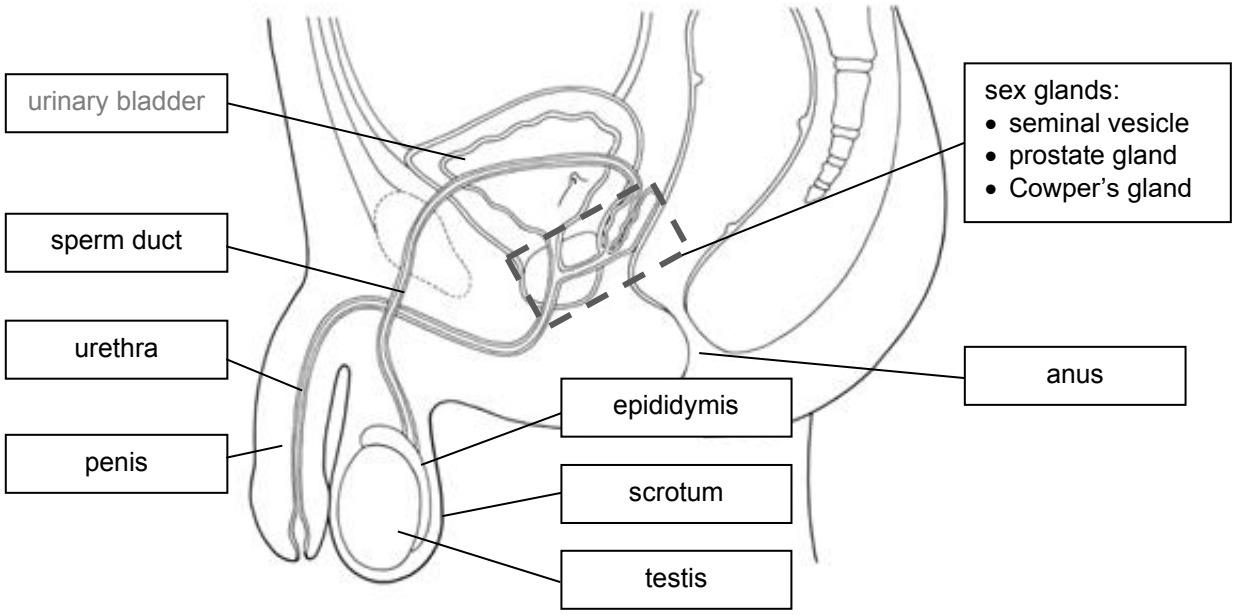

Figure 16.2 Side view of the male reproductive system

Table 16.1 Organ to function of male reproductive system

organ(s)	description/function
testis (plural: **testes**)	produces **sperms** (during spermatogenesis) and male sex hormone **testosterone**
epididymis	stores inactive sperms produced by the testis
scrotum	holds testis outside the body cavity at a temperature about 2 °C below that of the abdomen.
sperm duct (also known as 'vas deferens')	pathway travelled by sperms after they are released from the testis and opens into urethra
prostate gland, **Cowper's gland** & **seminal vesicle**	accessory sex glands that add secretions to semen. The fluids contain nutrients that nourish the sperm and enzymes that activate the sperms.
Cowper's gland (also known as 'bulbo-urethral gland')	secretes clear mucus that neutralises any acidic urine remaining in the urethra
prostate gland	secretes fluid that contains enzymes and nutrients
seminal vesicle	contains mucus, fructose (an energy source for sperm), a coagulating enzyme
urethra	extends from the urinary bladder, through the penis, to the outside of the body where **urine** and **semen** are passed out
penis	contains the **urethra** as well as spongy erectile tissue which fills with blood from during sexual arousal

2. THE FEMALE REPRODUCTIVE SYSTEM

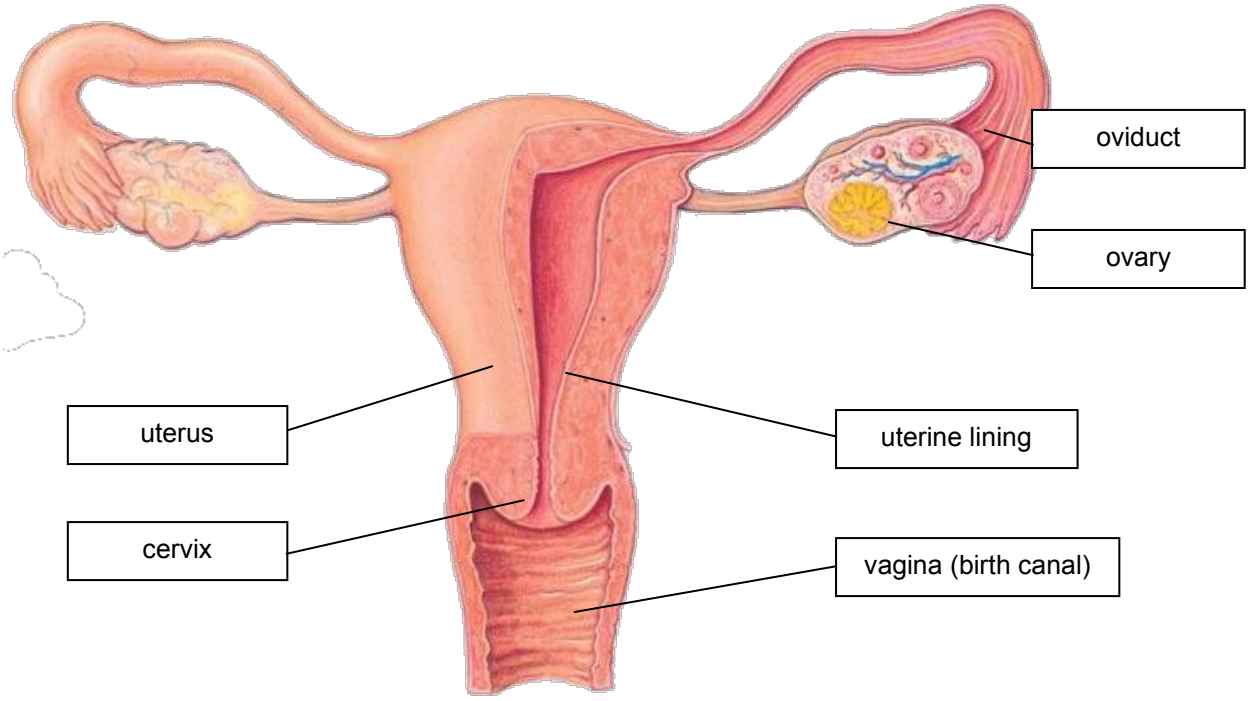

Figure 16.3 Front view of the female reproductive system

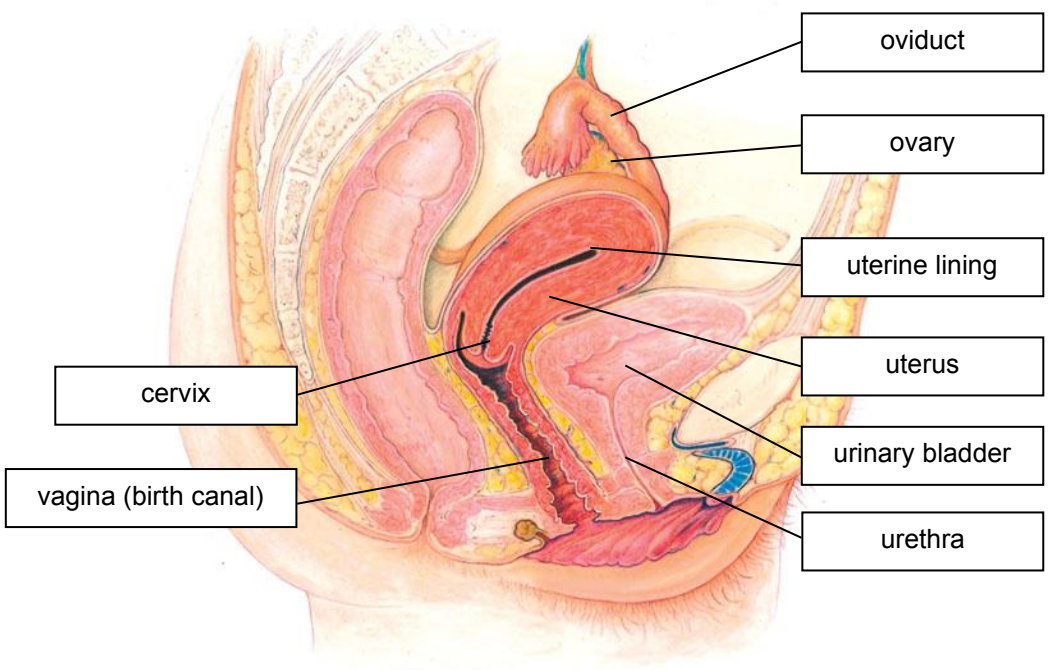

Figure 16.4 Side view of the female reproductive system

Table 16.2 Organ to function of female reproductive system

organ(s)	description/function
ovaries	produce **eggs** / **ova** (singular: **ovum**) and female sex hormones such as **oestrogen** and **progesterone**
oviduct (also known as 'fallopian tube')	where mature eggs are released into during ovulation. Fertilisation also occurs. **Cilia** and peristalsis of the oviduct wall convey the egg/embryo through the oviduct to the uterus.
uterus (also known as 'womb')	organ in which the **fetus** develops during pregnancy / gestation. The uterus wall is largely made of smooth muscle. The highly vascularized inner lining of the uterus is called the endometrium.
uterine lining (also known as '**endometrium'**)	inner lining of the uterus, which thickens and develops a rich blood supply in preparation for the possible **implantation** of an **embryo**. After implantation, for the first 2-4 weeks of development, the embryo obtains nutrients directly from the endometrium.
cervix	circular ring of muscles at the lower end of the uterus, which opens into the vagina. The first stage of labour (birth process) involves the dilation of the cervix.
vagina (also known as birth canal)	semen is deposited in the vagina during sexual intercourse

3. GAMETES

- Gametes are reproductive cells – in humans, they are the **sperms** and **eggs (ova)**.
- Gametes have **haploid** (*n*) number of chromosomes in their nucleus.
- Unlike gametes, other body (somatic) cells contain **diploid** (2*n*) number of chromosomes.
- This ensures that upon fertilisation (fusion of nuclei of male and female gametes), the number of chromosomes in the zygote (fertilised egg) can be maintained, as compared to the body cells.

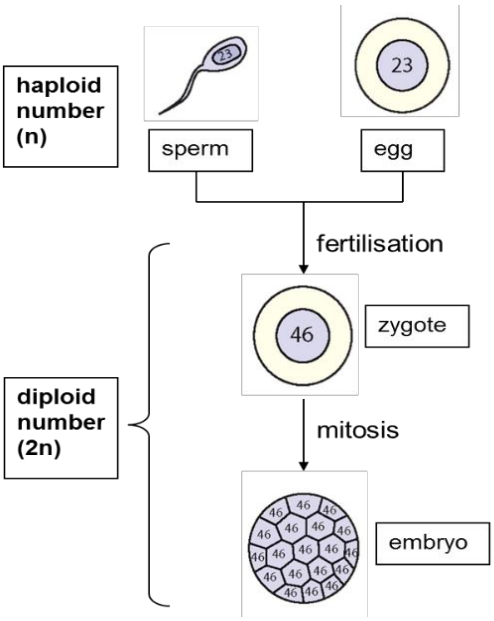

Figure 16.5 Fertilisation and mitosis

3.1 Sperm

- The sperm or spermatoazoon (plural: spermatozoa) is made up of a **head**, a **middle piece** and a **tail** (flagellum).
- Head contains the haploid cell nucleus, a small amount of cytoplasm, and an enzyme-containing **acrosome**, to break down egg membrane.
- Middle piece contains numerous **mitochondria** to release energy for sperm to swim.
- Tail enables the sperm to **swim** towards the egg in the fluid medium of semen.

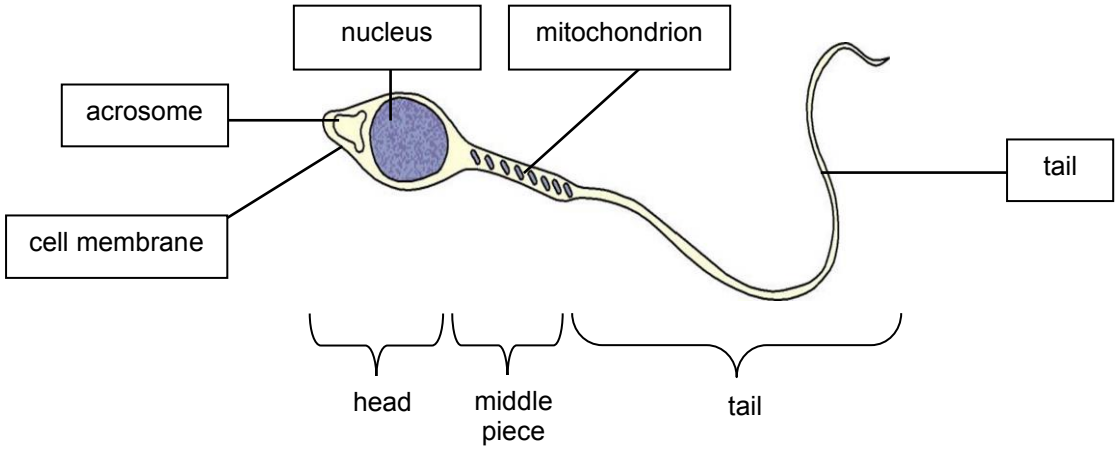

Figure 16.6 A sperm (spermatozoon)

3.2 Egg

- The egg or ovum (plural: ova) has a spherical shape (10 times bigger than a sperm) and made up of a **nucleus, cytoplasm** and **cell surface membrane**.
- The nucleus contains the chromosomes, the cytoplasm contains a small amount of yolk which provides nourishment for zygote/embryo development.
- Cell surface membrane is surrounded by an **outer membrane**.

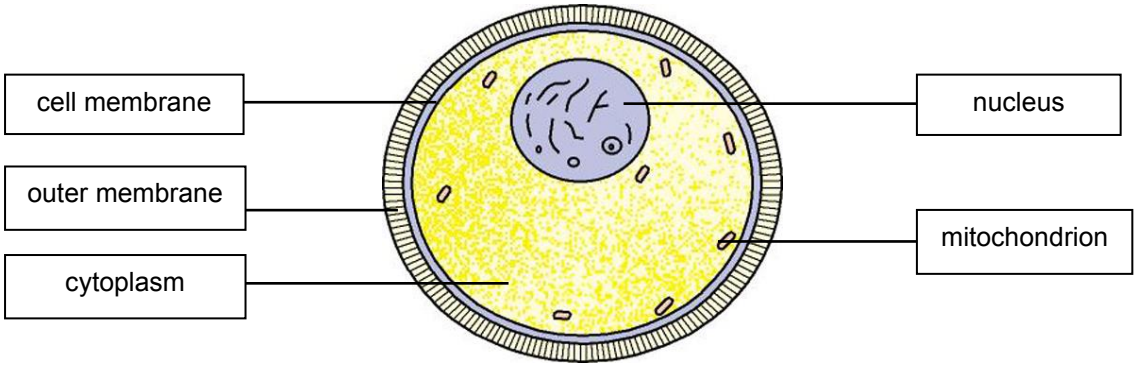

Figure 16.7 An egg (ovum)

Why does the sperm only contain a small amount of cytoplasm as compared to the ovum?
The ovum carries more cytoplasm which contains nutrients for the developing zygote after fertilisation. The sperm only has a small amount of cytoplasm as most of its nutrients are derived from the surrounding seminal fluid.

Table 16.3 Comparison between a sperm and an ovum

	Sperm	**Ovum**
Similarities	Gametes (reproductive cells) Haploid nucleus (23 chromosomes) Formed by meiosis Short-lived	
Amount of cytoplasm	Very little cytoplasm	An abundance of cytoplasm which provides nourishment for zygote development
Motility	Very active; uses its tail to swim towards the ovum	Immobile; moved by sweeping action of cilia in oviduct
Number	Large number of sperms is released by ejaculation	Only one egg is released per month
Sex chromosome	Either X or Y chromosomes (in addition to 22 autosomes)	Only X chromosomes (in addition to 22 autosomes)
Size	Each sperm is about 60 μm long with a diameter of 2.5 μm for the head	Diameter of 120 μm to 150 μm (about 10 times larger than sperm)
Structure	Has a head, a middle piece and a tail	Spherical in shape

4. PUBERTY

- Puberty is the stage of human growth and development in which a person becomes physically mature.
- During this period, the **sex organs** (**gonads**) mature and **sex hormones** are released into the bloodstream.
- The release of sex hormones results in the development of **secondary sexual characteristics**.

Table 16.4 Comparison between the physical changes in males and females during puberty

males	**females**
penis and testicles increase in size	breasts and uterus enlarge
production of sperms starts	menstruation and ovulation start
pubic, facial and underarm hair start to grow	pubic and underarm hair start to grow
voice deepens due to enlargement of larynx	hips widen

5. THE MENSTRUAL CYCLE

- For a female, the first sign of puberty is usually the monthly discharge of blood or menses from the uterus via the vagina.
- This is called **menstruation**.
- The average menstrual cycle for an adult woman spans around **28 days**.
- It starts from puberty until **menopause** (cessation of the menstrual cycle) which takes place between 45 and 55 years of age.

5.1 Changes in a follicle during the menstrual cycle:

- The ovaries contain developing follicles.
- Each **primary follicle** (young follicles) consists of a potential egg cell that is surrounded by a layer of follicle cells.

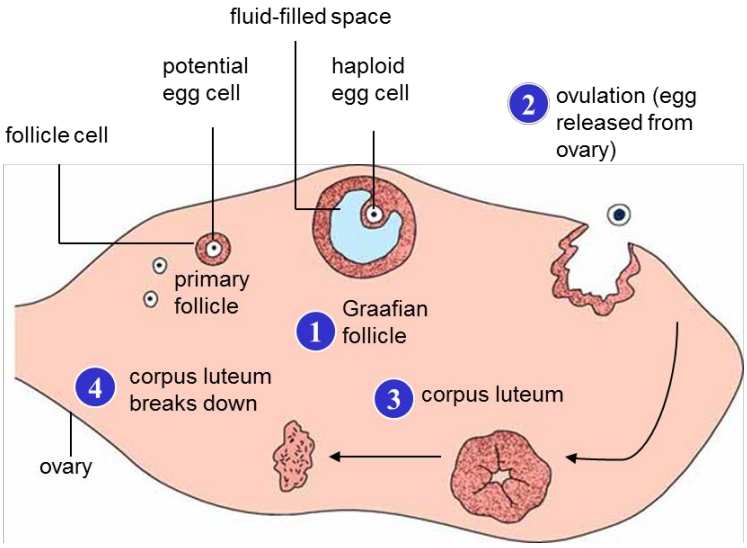

Figure 16.8 Changes in one follicle during a menstrual cycle

1 Graafian follicle
- A primary follicle develops into a **Graafian** follicle which contains a **mature egg** that is ready for release into the oviduct.
- Usually, only **one** egg is released every month.

2 Ovulation
- At about the 14th day from the beginning of menstruation, Graafian follicle ruptures to release the mature egg into the oviduct. This is **ovulation**.

3 Corpus luteum
- After ovulation, the Graafian follicle develops into a **corpus luteum**, which produces hormones (oestrogen and progesterone) that are needed to maintain the thickness of uterine lining during a pregnancy.

4 Corpus luteum breaks down
- If **fertilisation** does not occur, it will eventually break down. Menstrual cycle repeats again.

5.2 Stages in the menstrual cycle

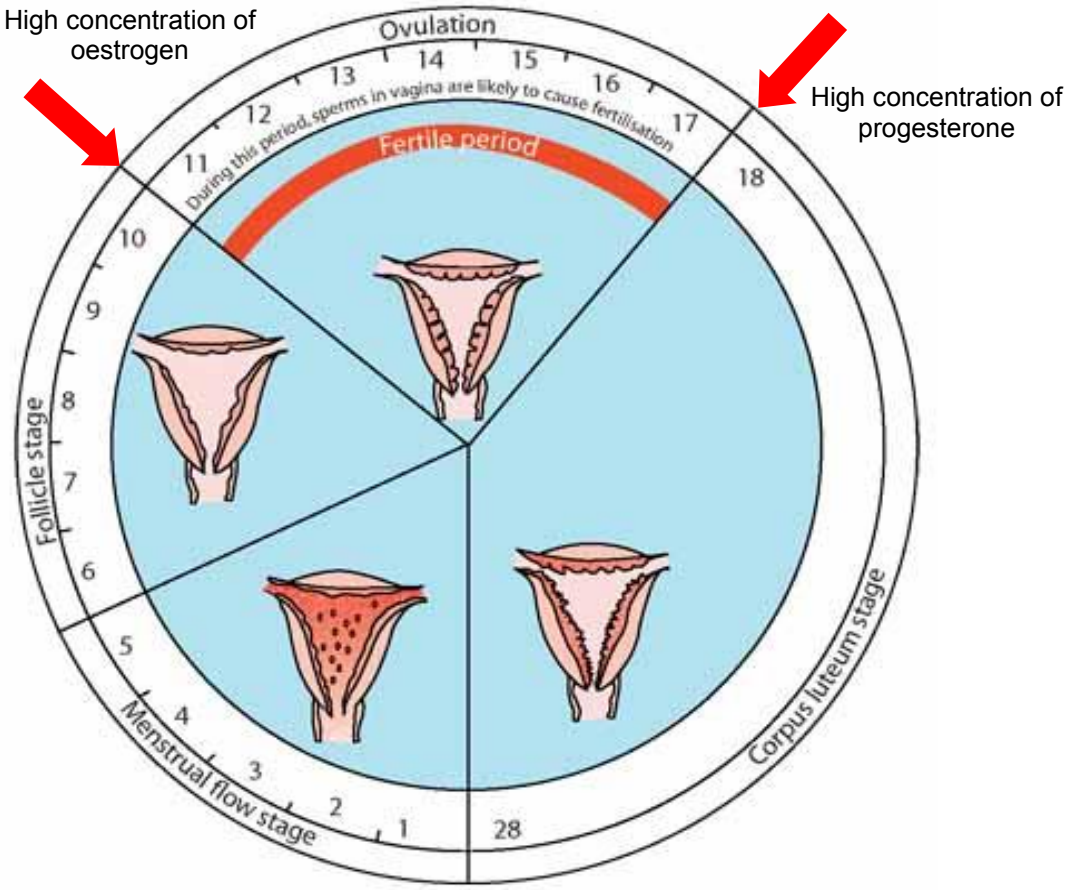

Figure 16.9 Summary of changes during a menstrual cycle of 28 days with ovulation on day 14

Menstrual flow stage (Day 1- 5)
- The first day of menstruation is the first day of the menstrual cycle.
- The **uterine lining** breaks down and flows out of the body through the vagina.
- The pituitary gland secretes **follicle-stimulating hormone (FSH)** into the bloodstream.

Follicle stage (Day 6–13)
- FSH stimulates:
  (1) follicle development in the ovaries
  (2) **oestrogen** secretions by the developing follicle
- Oestrogen causes the **repair and growth** of the uterine lining.
- A high concentration of oestrogen in the blood:
  (1) inhibits FSH production, which prevents the maturation and growth of more follicles
  (2) stimulates the pituitary gland to secrete **luteinising hormone (LH)**

Ovulation (Day 14)
- LH causes **ovulation** and the formation of the **corpus luteum**.
- The corpus luteum secretes **progesterone** (and some oestrogen).

Corpus luteum stage (Day 15–28)
- **Progesterone** prepares the uterine lining for the fertilised egg by:
  (1) **thickening** and **maintaining** it
  (2) supplying it with **blood capillaries**
- Progesterone inhibits:
  (1) Ovulation
  (2) FSH production

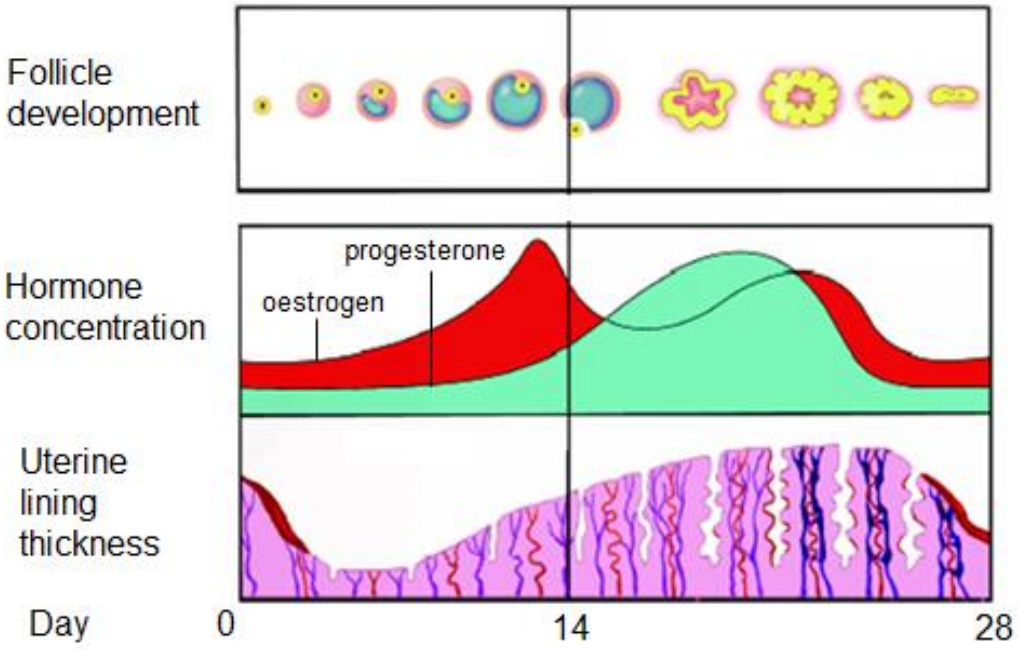

Figure 16.10 Patterns of hormones concentration to follicle development and uterine lining thickness

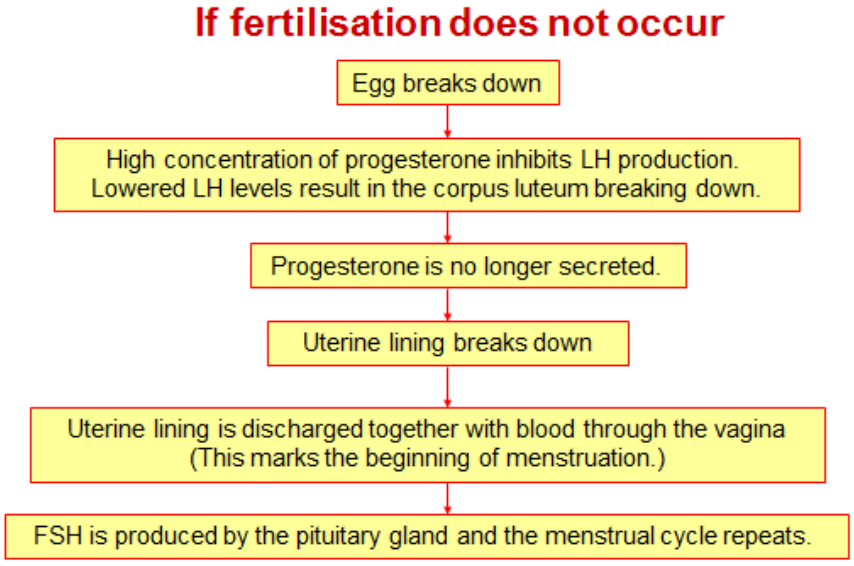

Figure 16.11 A repeat of menstrual cycle

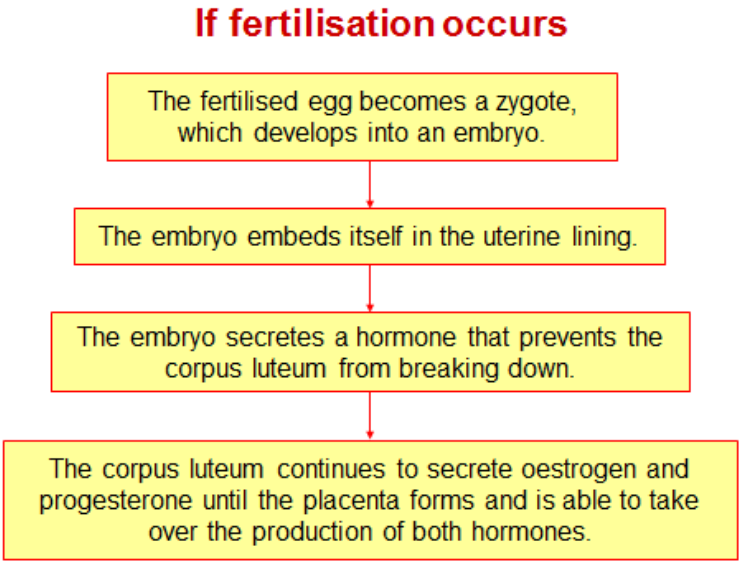

Figure 16.12 Menstrual cycle stops

5.3 Fertile and infertile periods
- Days 11 to 17 of the menstrual cycle are known as the **fertile** period (refer to Fig 16.9). The probability of fertilisation occurring during this time is higher. During this period, sperms in vagina are likely to meet the ovum in the oviduct to cause fertilisation.
- The rest of the days in the menstrual cycle are known as the **infertile** period.

6. SEXUAL REPRODUCTION IN HUMANS

6.1 Copulation
- This is also known as sexual intercourse.
- The penis is erected and stiff to allow for insertion into the vagina.
- Erection of penis is brought about by the filling of blood in the spaces in the spongy tissues of the penis; veins draining penis are constricted and arterioles are dilated.
- Erection of penis is an involuntary action and sexual arousal involves other reflexes e.g. increased blood pressure and heart beat.

6.2 Ejaculation
- This is brought about by rhythmic, wave-like contractions of muscles of ejaculatory ducts and urethra (spinal reflex).
- Sphincter muscle at the base of bladder is closed as another reflex action which prevent urination (during ejaculation).
- About 3–5 cm^3 of semen is released (1 cm^3 semen contain ≈ 40–150 x 10^6 sperms)
- Semen is alkaline (pH 7.2–7.6) and neutralises the acidic vaginal canal (pH 3.8–4.5) producing an environment of pH 6.0–6.5.

6.3 Fertilisation
- Fertilisation takes place in the upper part of **oviduct** (**fallopian tube**) when a sperm (*n*) fuses with an ovum (*n*) to form a **zygote** (2*n*).
- Only a few hundreds sperm reach this part, often assisted by waves of muscular contraction in the uterus and oviduct walls.
- The sperm releases enzymes from its **acrosome** to break down part of the **egg membrane** and to disperse the follicle cells.
- Only one sperm is allowed to enter the egg. Once a single sperm has entered, the egg membrane changes such that no other sperm can penetrate it.
- Identical twins are produced by one fertilised egg (zygote). After fertilisation, this zygote divides by mitosis into two identical zygotes. Non-identical twins are resulted from fertilisation of two eggs by two different sperms.

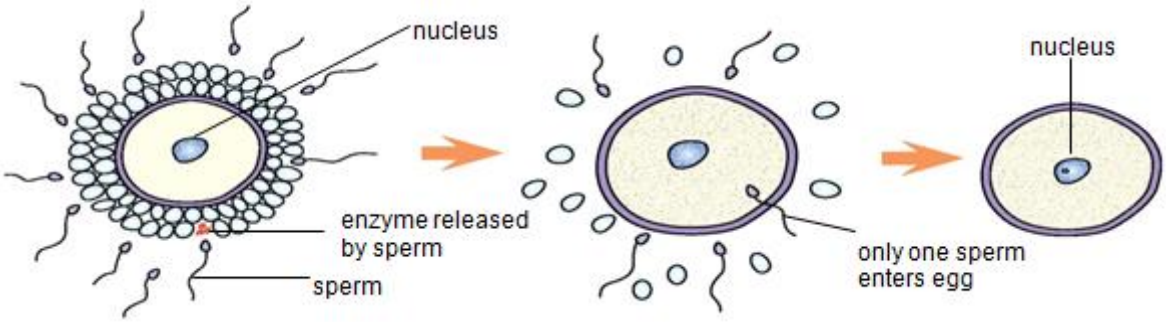

Figure 16.13 Fertilisation

6.4 Development of embryo and implantation

- Zygote travels down the oviduct by ciliary action, divides by **mitosis** and develops into an **embryo** (within first 8 weeks).
- Stages of embryo development: Sperm + egg → **zygote** → morula → blastocyst → fetus
- A morula is distinct from a blastocyst in that blastocyst has a cavity inside the mass of cells.
- **Implantation** takes place when the blastocyst reaches the uterus and gets embedded in the **uterine lining**.

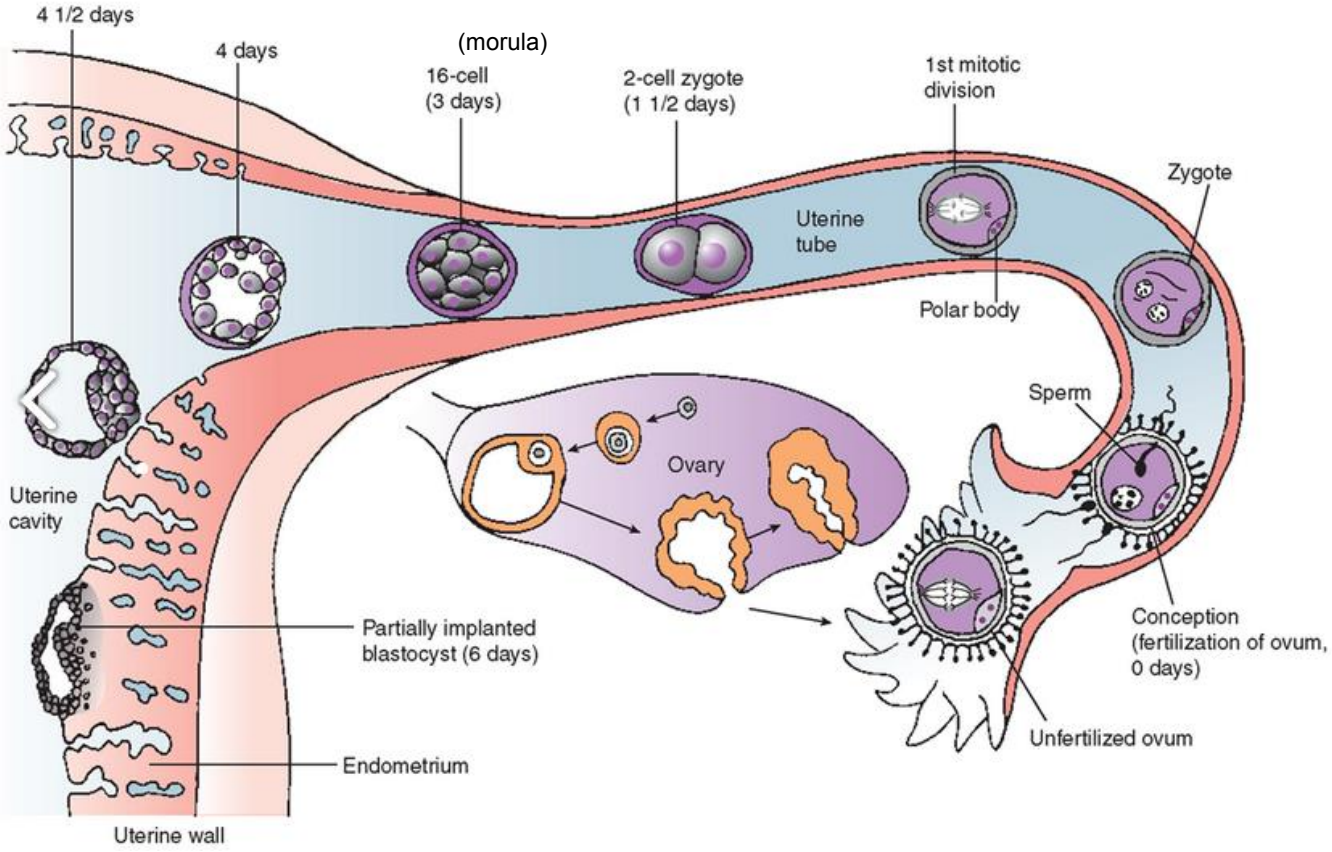

Figure 16.14 Early stages of embryonic development in the oviduct

6.5 Development of placenta and amniotic sac

- After implantation, **embryonic villi** grow from the embryo into the uterine lining to come into close contact with the maternal blood spaces.
- The villi and the uterine lining make up the **placenta** (refer to Fig. 16.15).
- This is the **site of exchange** between maternal and fetal blood circulations of nutrients and waste products.
- Substances exchanged are:
  (1) water (via osmosis)
  (2) CO_2 and O_2 (via diffusion)
  (3) antibodies from mother
  (4) nutrients (e.g. glucose, amino acids) and waste products
- Placenta also produces **progesterone** to maintain the thickness of uterine lining.
- Blood from both circulations do not mix because:
  (1) mother's **blood pressure** is too high for the fetus
  (2) mother and fetus may have different blood types, and **agglutination** may occur

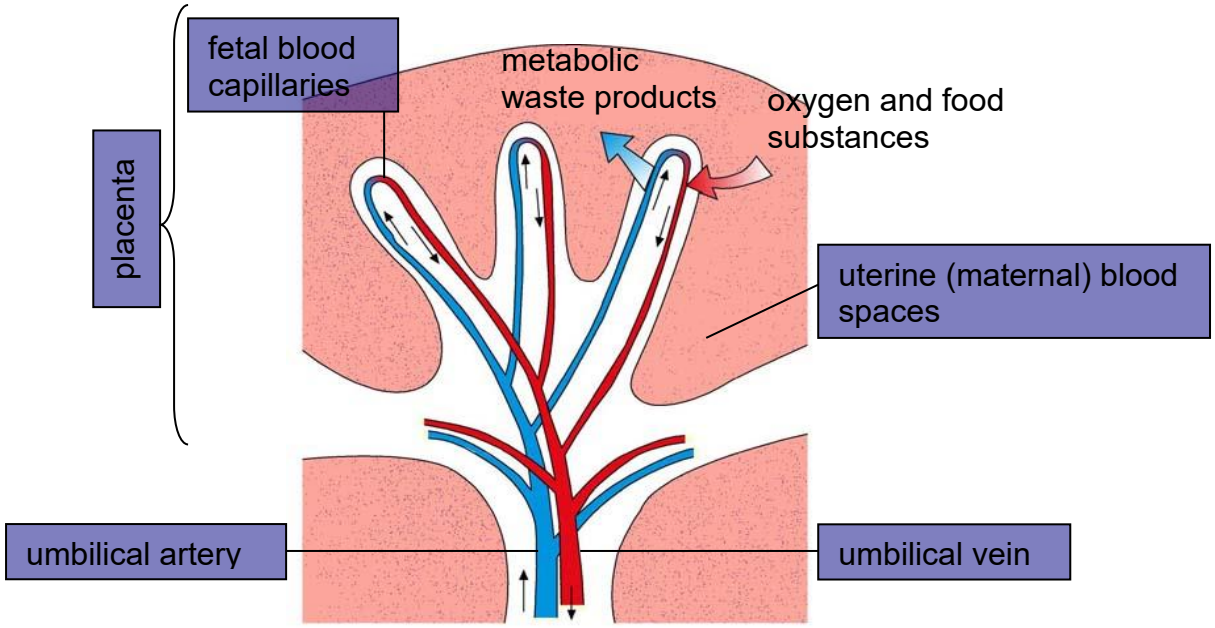

Figure 16.15 The placenta

- An **umbilical cord** attaches the embryo to the placenta.
- Functions of umbilical cord:
  (1) The **umbilical arteries** transport **deoxygenated blood** and **metabolic waste products** e.g. carbon dioxide and urea from the fetus to placenta.
  (2) The **umbilical vein** transport **oxygenated blood** and food substances e.g. **glucose**, **amino acids** from the placenta to fetus.
- An **embryonic membrane** (**amnion**) encloses the fetus in a fluid-filled space known as **amniotic cavity**.
- Functions of amniotic fluid:
  (1) shock absorber
  (2) protects against mechanical injury
  (3) lubricates birth canal during birth
  (4) buoys and allows fetus to move freely
  (5) protect fetus from temperature fluctuations

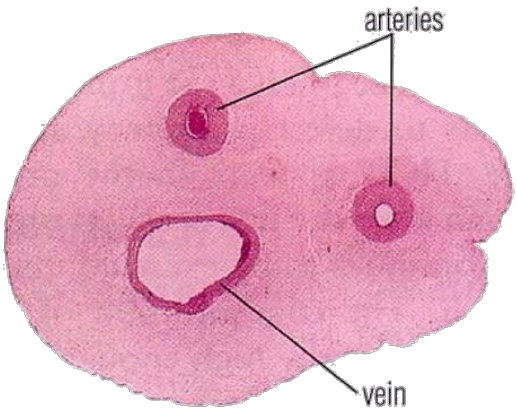

Figure 16.16 Cross-sectional area of umbilical cord (x2)

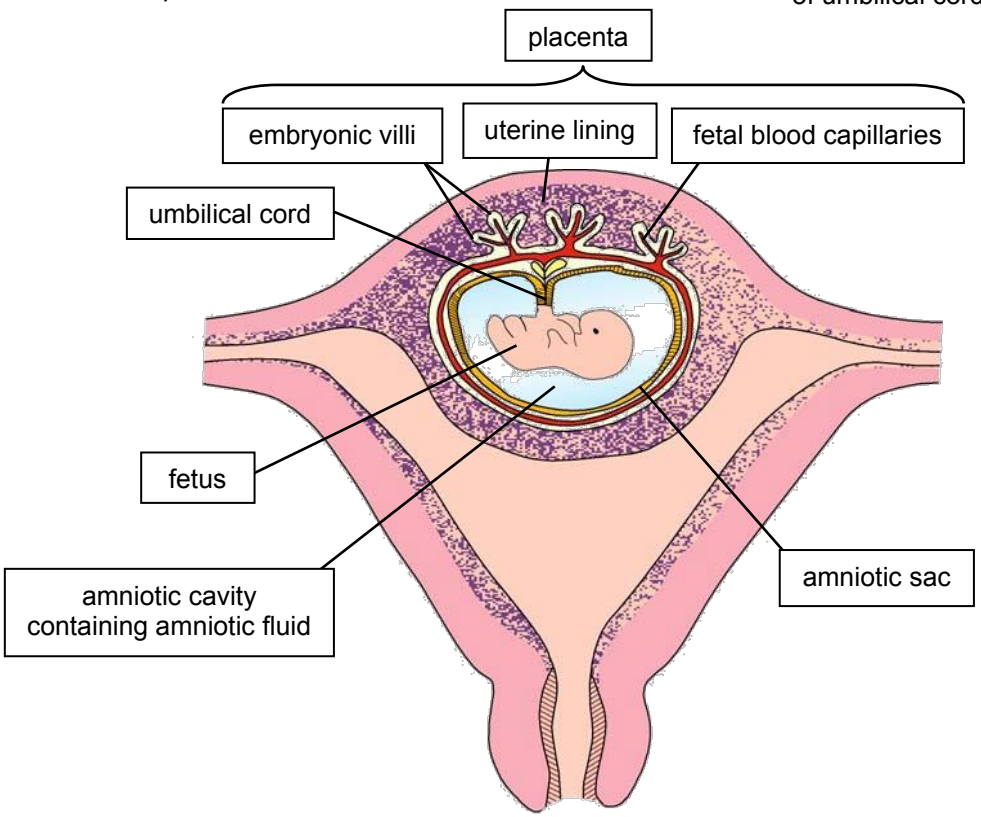

Figure 16.17 Fetus in the uterus

A fetus is surrounded with fluid and its lungs are filled with fluid. Why does it not suffocate?
Exchange of gases such as oxygen and carbon dioxide occurs at the placenta and these gases are transported via the umbilical cord.

7. SEXUALLY TRANSMITTED INFECTIONS

A sexually transmitted infection (STI) can be transmitted from an infected person to an uninfected person via:
(1) semen or vaginal fluid
(2) blood

7.1 Acquired Immunodeficiency Syndrome (AIDS)

- AIDS is caused by the **Human Immunodeficiency Virus** (**HIV**).
- HIV destroys the immune system and patients die from common diseases like pneumonia.
- Antibiotics do not work since it is a viral disease. No known treatment and can only be prevented.

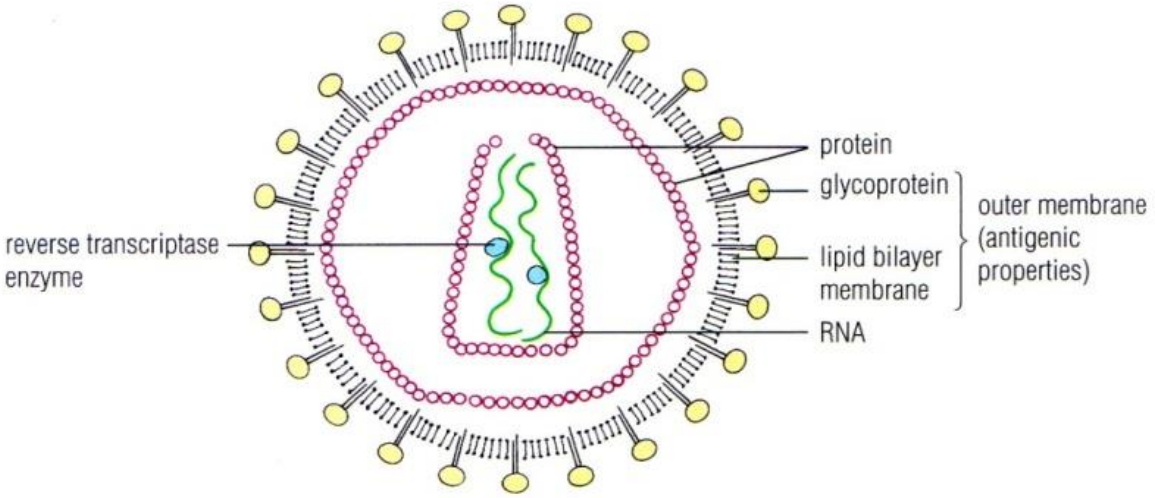

Figure 16.18 Structure of HIV

- Common symptoms of AIDS include:
  (1) severe diarrhoea that lasts for months
  (2) pneumonia
  (3) Kaposi's sarcoma
  (4) widespread tuberculosis
- Mode of transmission:
  (1) unprotected **sexual intercourse** with an infected person
  (2) sharing of **hypodermic needle** with an infected person
  (3) having a **blood transfusion** with an infected person
  (4) substance exchange at the **placenta** (from infected mother to fetus)
- HIV infection can be prevented by:
  (1) keeping to a single sex partner, or abstaining from sex
  (2) using a condom during sexual intercourse
  (3) not abusing drugs as drug abusers are in the habit of sharing needles
  (4) not sharing instruments that can break skin and get contaminated with blood
  (5) making sure needles used for hypodermic purposes are sterilised

8. ADDITIONAL READING MATERIALS

8.1 Chorionic villus sampling (CVS)

- Samples of cells from the placenta are withdrawn from the uterus via the vagina for analysis during the 8 to 10 weeks of gestation.
- This is not routinely offered to all pregnant women but to those who face a high risk that the baby could have a genetic condition.
- It can be used to detect for chromosomal mutations such as Down syndrome and sickle cell anemia.

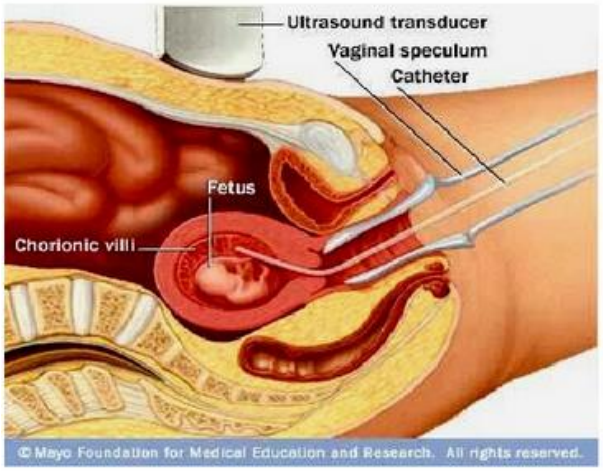

Figure 16.19 Chorionic villus sampling

8.2 Amniocentesis

- It is a process where some **amniotic fluid** is withdrawn during the 16 – 20 weeks of gestation to detect for **chromosomal abnormalities**.
- Amniotic fluid contains embryonic cells which can be cultured, fixed and stained to be observed under the microscope for chromosomal mutation.
- There is a small risk of miscarriage with both CVS and amniocentesis.

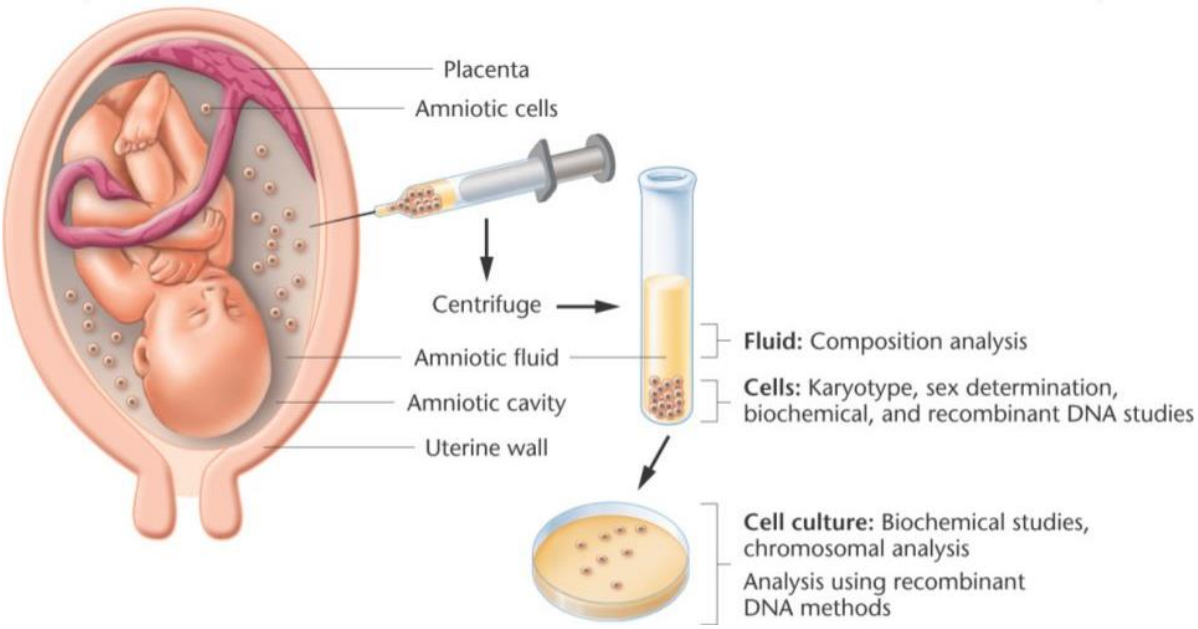

Figure 16.20 Amniocentesis

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 17 – Cell Division

Name: **Class:**

A. Content
- Mitosis
- Meiosis

B. Learning Outcomes

Students should be able to:
(a) STATE and explain the importance of mitosis in growth, repair and asexual reproduction.
(b) EXPLAIN the need for the production of genetically identical cells and fine control of replication.
(c) IDENTIFY, with the aid of diagrams, the main stages of mitosis.
(d) DESCRIBE with the aid of diagrams, the behaviour of chromosomes during the mitotic cell cycle and the associated behaviour of the nuclear envelope, cell membrane and centrioles.
(e) STATE and explain what is meant by homologous pairs of chromosomes.
(f) IDENTIFY, with the aid of diagrams, the main stages of meiosis.
(g) DESCRIBE, with the aid of diagrams, the behaviour of chromosomes during meiosis, and the associated behaviour of the nuclear envelope, cell membrane and centrioles. (Names of the main stages are expected, but not the sub-divisions of prophase)
(h) DEFINE the terms haploid and diploid, and explain the need for a reduction division process prior to random fertilisation in sexual reproduction.
(i) STATE and explain how meiosis and fertilisation can lead to variation.

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Lam, P. K. and Lam, E. Y. K. GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
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D. Lecture Outline

1. Introduction
2. Cell cycle
3. Mitosis
4. Meiosis
5. Additional reading materials

E. Practical Work
- Cell Division (Meiosis)

1. INTRODUCTION

There are some types of cells that are continuously dividing throughout the lifetime of the organism (e.g. bone marrow) whilst others stop dividing upon reaching maturity (e.g. neurone of nervous system, guard cells of stomata).

Cell division occurs in 2 main steps: **nuclear division** (**karyokinesis**) and **cytoplasmic division** (**cytokinesis**).

There are 2 types of nuclear division: **Mitosis** and **Meiosis**.

Haploid and Diploid
Ploidy refers to the **number of single sets of chromosomes** in a cell of an organism.

Diploid: two complete sets of chromosomes, one derived from each parent (maternal and paternal). The condition is designated as **2*n*** (where *n* = 1 set of chromosomes).

Haploid: one complete set of unpaired chromosomes. The condition is designated as ***n***.

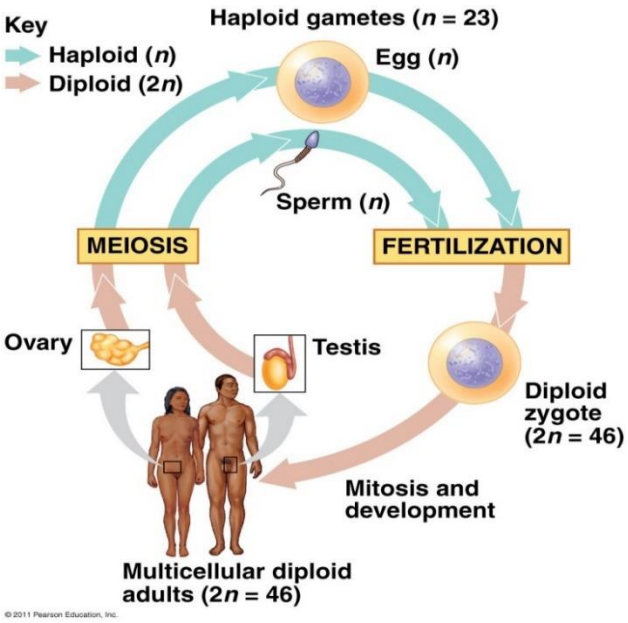
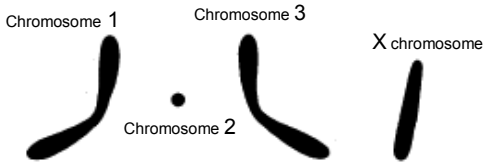


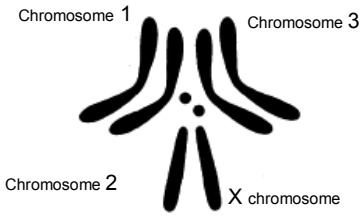
Figure 17.1 Life cycle of a human being

Do you know?
What is meant by "a set of chromosome"?

- A number is given to every different type of chromosomes in a cell of a specific organism (exception is the sex chromosome, either X or Y).
- For example, in fruit fly, there are 4 different types chromosome. The chromosomes are named, chromosome 1, chromosome 2, chromosome 3 and chromosome X / Y.
- Chromosome X & Y are known as sex chromosomes. Chromosome 1, 2 and 3 are known as autosomes.
- Autosomes are chromosomes that code for phenotypic characteristics (refer to Heredity chapter) except gender and sexual characteristics.
- Sex chromosomes carry the genes that determine the gender of the organism.
- Each set of chromosome contains only one of each type of chromosome.



One set of chromosomes
n=4



Two sets of chromosomes
2*n*=8
(one set from mother, one set from father)

Qns to ask yourself:
If there are 22 chromosomes in each of the root cells of a plant, what is the diploid and haploid number of chromosomes for this species?
Diploid number or 2*n* = 22 and
Haploid number or *n* = 11

2. CELL CYCLE

Definition:
Cell cycle is defined as the sequence of events, which occurs between the formation of a cell and its division into daughter cells.
The length of the cell cycle is variable, depending on the type of cells and external factors such as food and temperature.
The cell cycle consists of the following 3 main stages:

Table 17.1 The 3 stages of cell cycle

Stages in cell cycle	Main events
Interphase ('resting stage')	Period of synthesis and growth. Cell produces many materials required for carrying out all its functions. **Cell replicates its DNA** to prepare for nuclear division.
Nuclear division	Nuclear division involving separation of chromatids into daughter cells. Either mitosis or meiosis.
Cytokinesis	Division of cytoplasmic contents into 2 daughter cells.

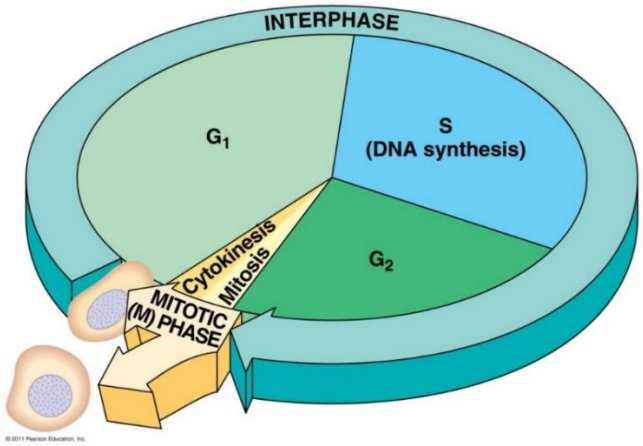


Figure 17.2 The cell cycle

Interphase

Most of the cell cycle is spent in the interphase whereby the cell carries its usual functions and prepares to divide. It grows larger and the amount of organelles (e.g. centrioles) and DNA doubles. Interphase is divided into the following three stages:

Table 17.2 Phases of interphase

G_1 stage:	Cell cycle checkpoint. If DNA is damaged, apoptosis will occur. Otherwise, the cell is committed to divide if growth signals are present and nutrients are available.
S stage:	Growth and DNA replication. The chromosome replicate to form two identical sister chromatids that have identical DNA sequences.
G_2 stage:	Cell cycle checkpoint. If DNA is damaged, apoptosis will occur. Otherwise, the cell is committed to divide if growth signals are present and nutrients are available.

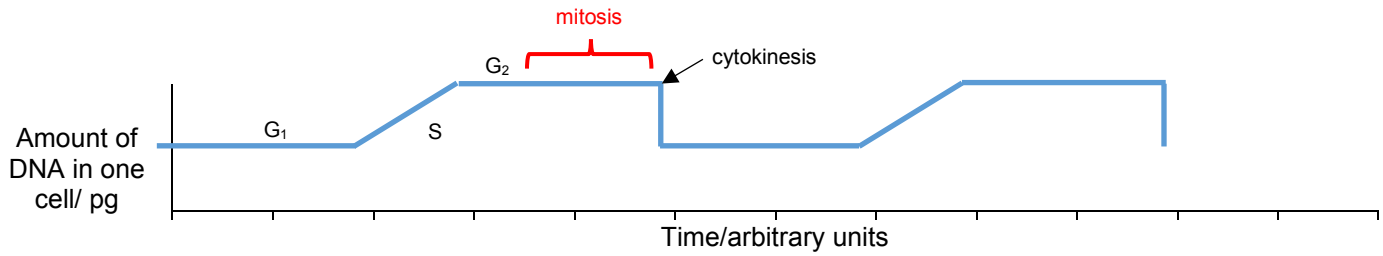


Figure 17.3 Changes in amount of DNA in a rapidly dividing cell

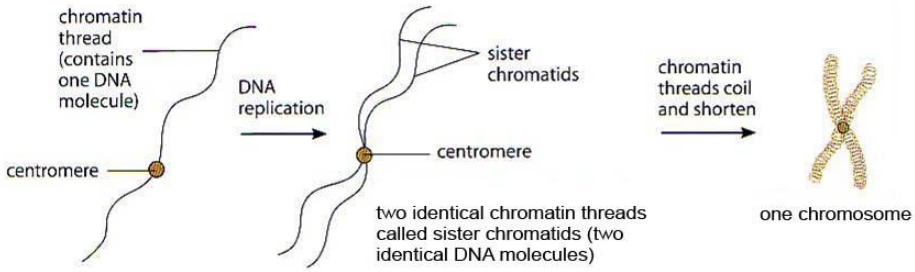
Chromosomes are important structures involved in the transmission of hereditary information from generation to generation. In non-dividing cells, chromosomes exist as long and thin threads known as **chromatin** that may stain with certain dyes to become visible.

During DNA replication, the chromatin **replicates** to form two identical **sister chromatids**. Chromatins coil and shorten to become **chromosomes**. The sister chromatids are joined at a point called the **centromere**.

The functions of the centromere are:
(1) to hold sister chromatids together;
(2) to attach to spindle fibre.

Do you remember?
Which would you expect to see when you look at cells through a light microscope? **Chromatins or chromosomes?**

- **Chromatins are <u>invisible</u> under the light microscope.**
- **<u>Chromosomes</u>** are **<u>visible</u>** only when the **genetic material (DNA)** is **condensed**



One chromatin:
- found in non-dividing cells
- made of 1 DNA molecule
- invisible under light microscope

One chromatin:
- found in dividing cells just before mitosis/meiosis
- made of 2 DNA molecules join together by centromere
- invisible under light microscope

One duplicated chromosome:
- found in dividing cells during mitosis or meiosis
- made of 2 DNA molecules
- each DNA molecule makes up one chromatid
- visible under light microscope

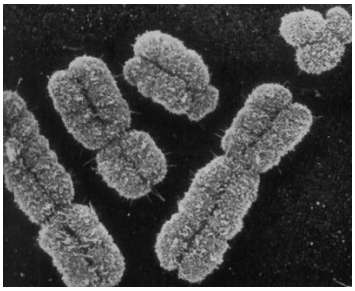


Figure 17.4 Electron micrograph of chromosomes
https://www.geocaching.com

Figure 17.3 How a chromosome is formed

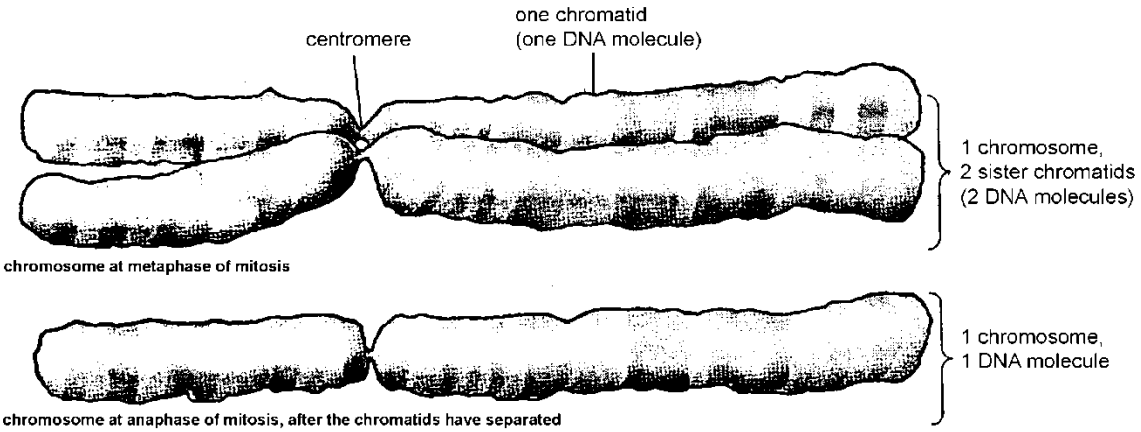
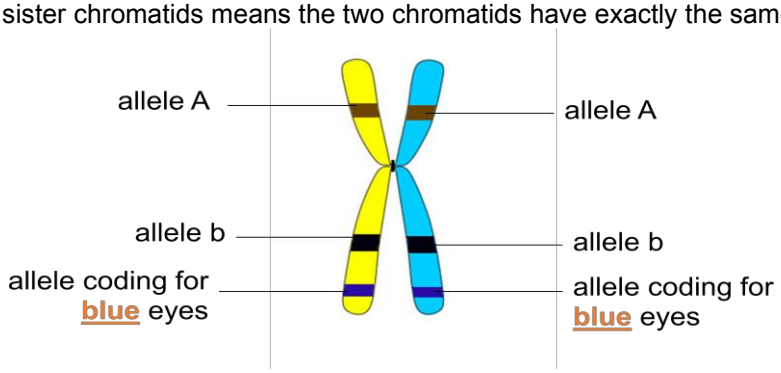


Figure 17.5 Difference between chromatin, chromosome and sister chromatids

Conceptual Understanding
one chromatid = **one DNA molecule** (Figure 17.5).
one duplicated chromosome = **two chromatids** joined at centromere = **two DNA molecules** joined at centromere

Do you know?
What is the meaning of "genetically identical"?
- **Genetically identical** means having the same alleles (or nucleotide sequences – see chapter on Molecular Genetics)
- Genetically identical sister chromatids means the two chromatids have exactly the same alleles.



Why is it necessary for the sister chromatids to be genetically identical?
- During mitosis, the sister chromatids separate to become the chromosomes of two daughter nuclei. This ensures daughter nuclei would be genetically identical to each other and to the original nuclei. This maintains genetic stability after every mitotic division.

Amount of DNA

- A typical way of measuring the amount of genetic material in the nucleus is to count the number of chromosomes.
  - For example, in human cell there are 46 chromosomes.
- Another method to measure DNA is by the mass of DNA.
- The unit for measuring mass of DNA is picogram, pg.
  - For example, the amount of DNA in a cell at G1 is 10 pg.

3. MITOSIS

Definition of mitosis:
Mitosis is a nuclear division (nucleus divides) such that the daughter nuclei produced contain the same number of chromosomes as the parent nucleus. The daughter cells are **genetically identical** to the parent cell.

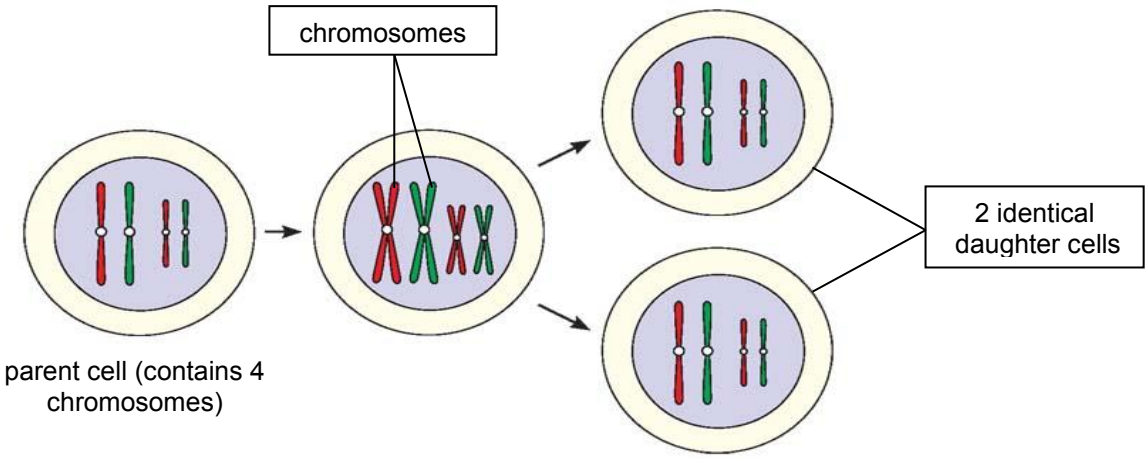
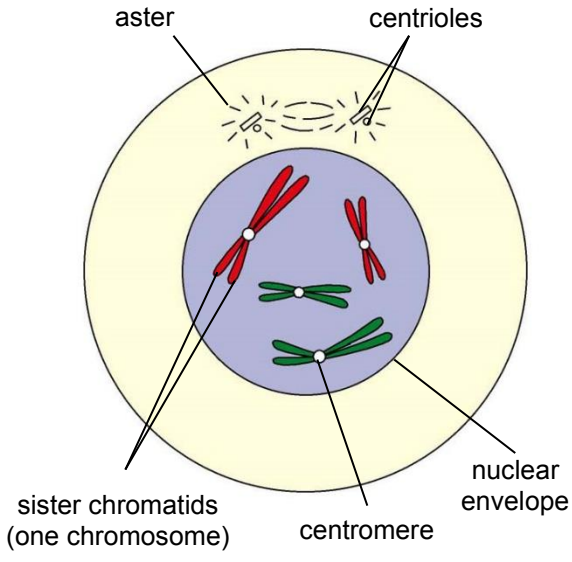
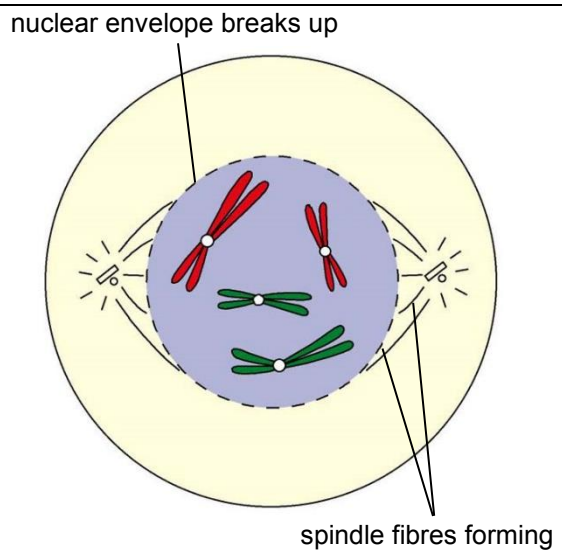


Figure 17.6 Overview of mitosis

Mitosis is a continuous process that is consists of four stages: prophase, metaphase, anaphase, telophase.

Stages in mitosis	**Main events**	
Prophase		Early Prophase Chromatin threads condense, coil and shorten to become chromosomes (which is visible under microscope). Chromosomes now seen to be composed of two **sister chromatids** joined together at the **centromere**.

<table>
<tr><th>Stages in mitosis</th><th colspan="2">Main events</th></tr>
<tr><td></td><td> 
</td><td><u>Late Prophase</u>

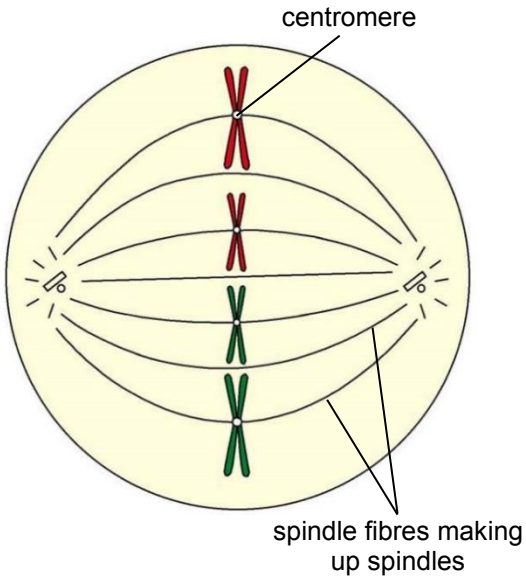
The two pairs of centrioles move apart to opposite poles of the cell. In animal cells, short microtubules known as asters are formed radiating from the centrioles.

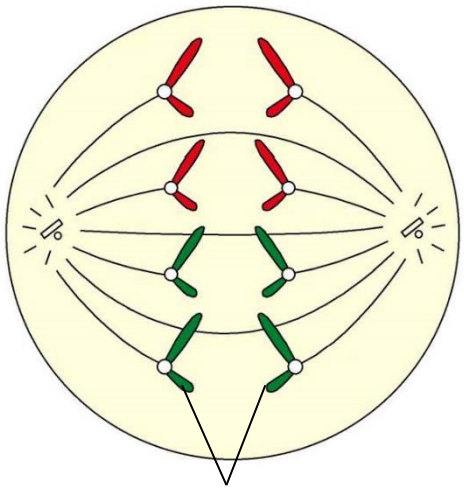
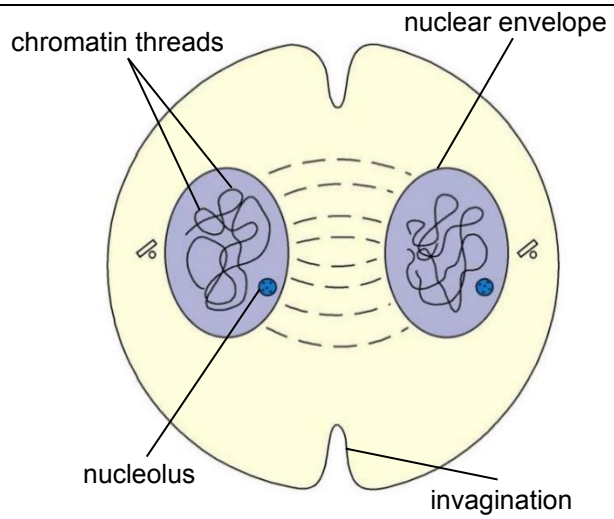
The nucleolus decreases in size and disappears as their nucleic acid is passed to some chromatids.

What is the function of the nucleolus?
The nucleolus is responsible for the formation of ribosomes.

Nuclear envelope disintegrates and disappears.

A spindle is formed with spindle fibres extending from the poles to the equator of the cell. The spindle fibres ‘guide’ the movement of chromosomes.

What is the chromosome number and amount of DNA in the cell at this point?
Chromosome number is diploid e.g. 2n (where n = 1 set of chromosome). In the figure on the left, 2n is 4.
Amount of DNA is 2x (where x = amount of DNA in a non-dividing cell).</td></tr>
<tr><td>Metaphase</td><td> 
</td><td>Chromosomes line up around equatorial plate of spindle with centromere of each chromosome attached to a spindle fibre.
• This facilitates the equal division of chromosomes and the production of genetically identical daughter cells.</td></tr>
</table>

Anaphase		Each **centromere divides** and spindle fibre shortens and pulls chromatids to opposite poles of the cell. When the chromatids are separated, they are known as **daughter chromosomes**.
Telophase		Spindle fibres break down and a nuclear envelope starts to reform around the chromosomes. The nucleolus reforms and the chromosomes **uncoiled** to return to the original chromatin threads.

Colchicine is a chemical that stops chromatids from separating during mitosis. Which phase will the cell reach and then stop dividing? Metaphase

After telophase, **cytokinesis** which is the division of cytoplasm, occurs. In an animal cell, cell membrane begins to invaginate towards the region previously occupied by the spindle equator (Fig. 17.7).
In a plant cell, a series of **Golgi vesicles line up** in the **middle** of the parent cell (Fig. 17.8). The Golgi vesicles **fuse to form the cell plate**, which eventually forms the **cell wall**.

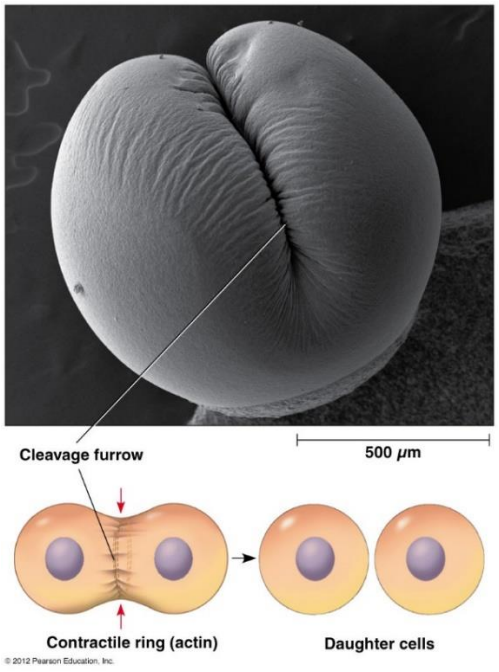


Figure 17.7 Cytokinesis in animal cell
http://www.mun.ca/biology/desmid/brian/BIOL2060/BIOL2060-19/CB19.html

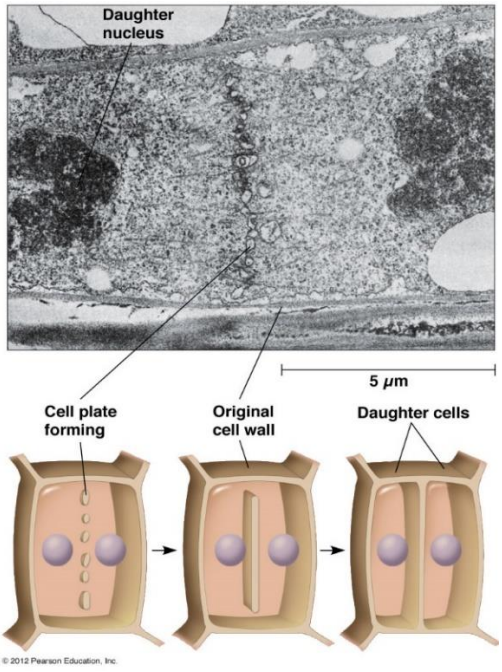


Figure 17.8 Cytokinesis in plant cell
http://www.mun.ca/biology/desmid/brian/BIOL2060/BIOL2060-19/CB19.html

Importance of mitosis

Mitosis produces daughter cells which are genetically identical. Mitosis is important as it

(1) allows production of new cells for growth;
(2) repairs worn-out parts of tissue or organisms;
(3) allows asexual reproduction in plants.

4. MEIOSIS

Definition of meiosis:

Meiosis (‘*meio’* = to reduce) is a form of nuclear division such that the daughter nuclei produced contain half the number of chromosomes as the parent nucleus. Meiosis is also known as **reduction division** as it involves a reduction from the diploid number (2*n*) to the haploid number (*n*).

There are **two** divisions in meiosis e.g. meiosis I and meiosis II. Thus, a single diploid cell gives rise to four haploid cells (Fig. 17.9). Each division consists of prophase, metaphase, anaphase and telophase. Meiosis occurs during the formation of gametes.

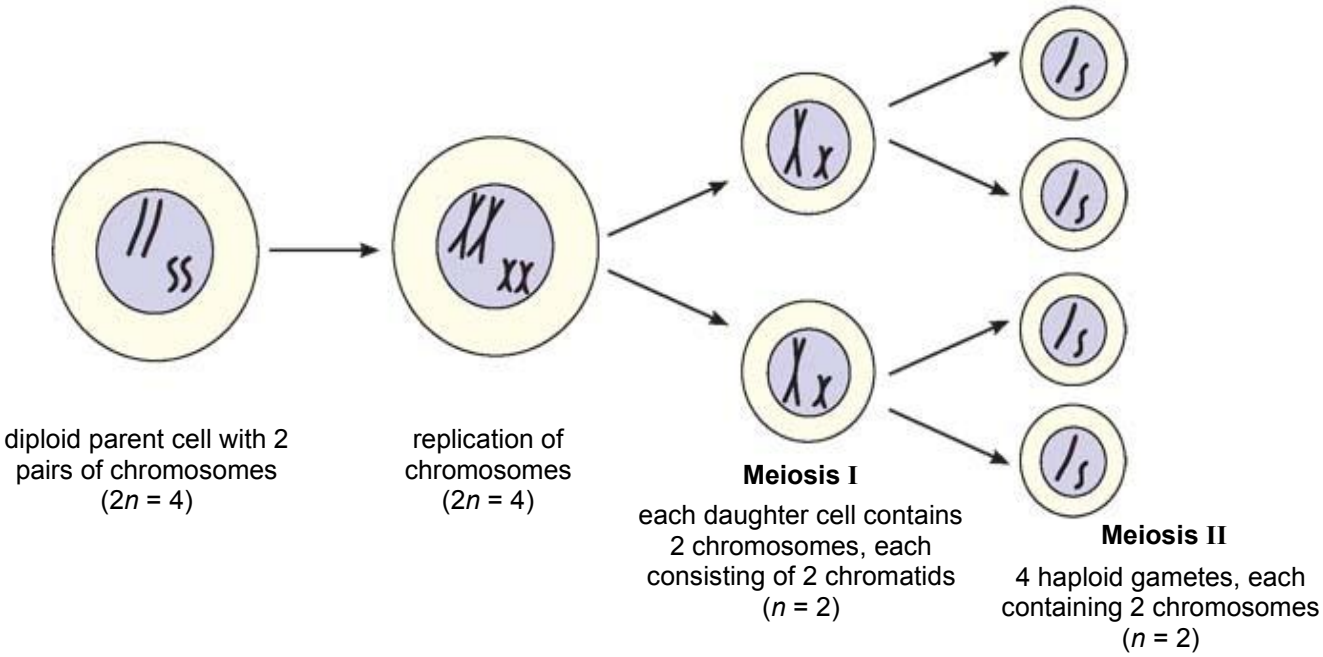
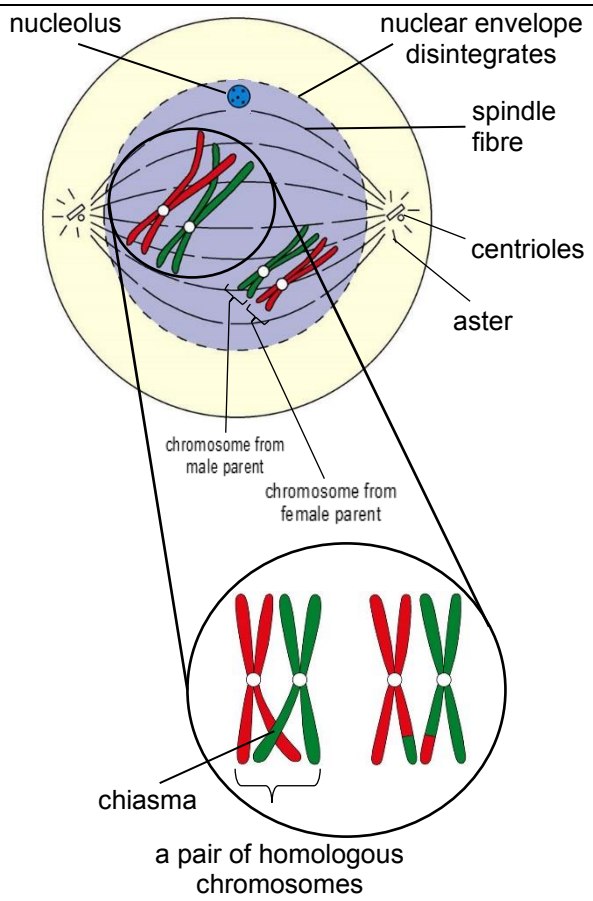


Figure 17.9 Overview of meiosis

<table>
<tr><th>Stages in Meiosis</th><th colspan="2">Main events</th></tr>
<tr><td>Prophase I</td><td> 

a pair of homologous chromosomes</td><td>Asters start to appear around the centrioles which have move apart to opposite poles of the cell.

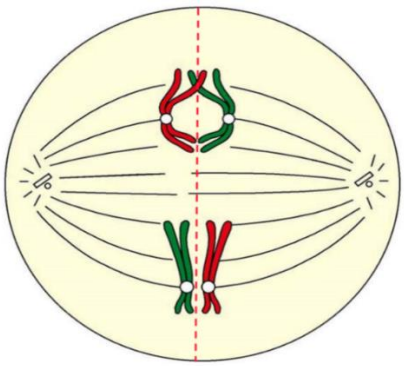
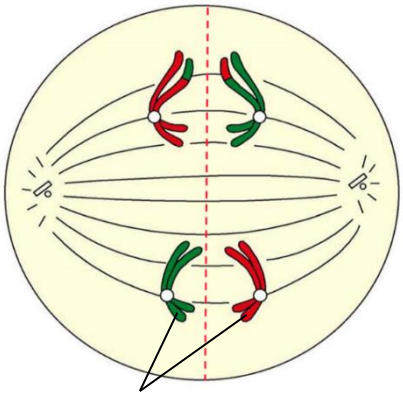
Nuclear envelope and nucleolus disappear and spindle fibres start to form.

Chromatin threads condense, coil and shorten to become chromosomes (which is visible under microscope).

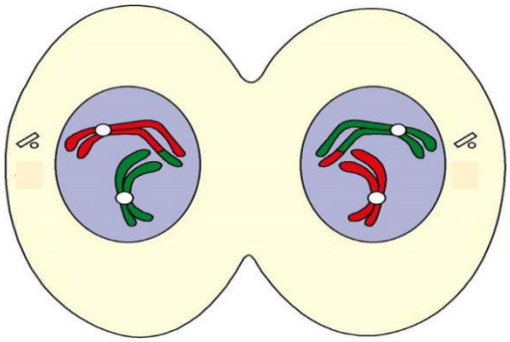
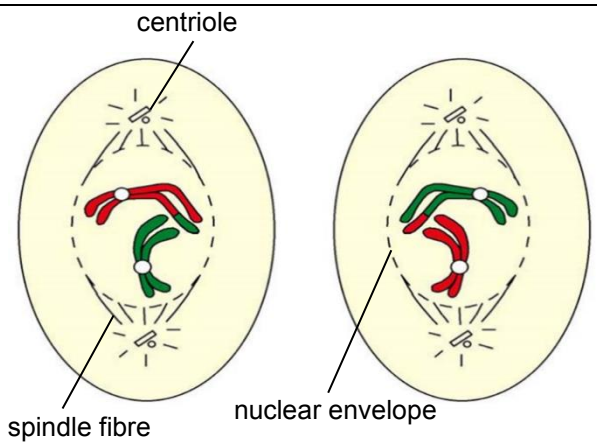
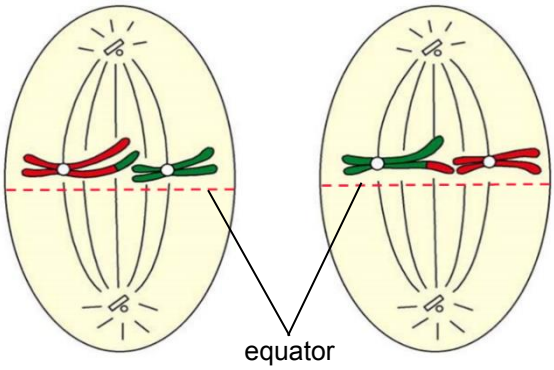
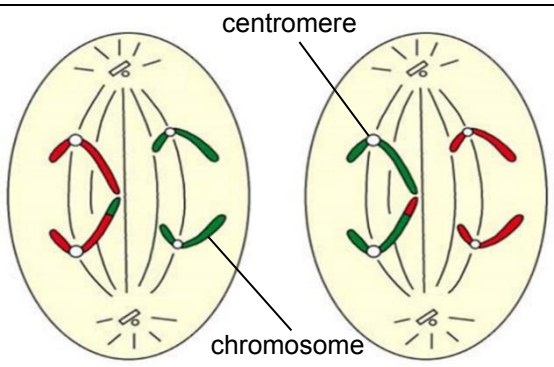
Homologous chromosomes pair up along their whole length to form a bivalent. This process of pairing up by homologous chromosomes, aligned gene by gene is known as synapsis.

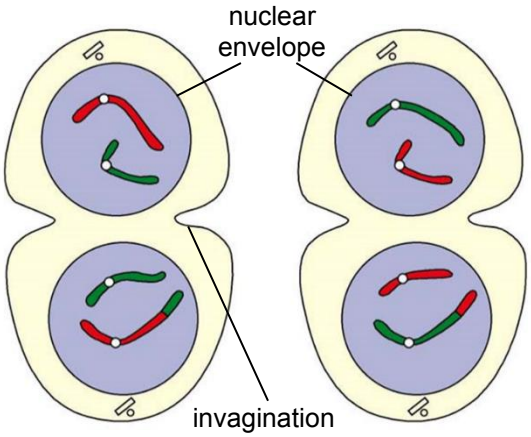
Non-sister chromatids of homologous chromosomes may cross and twist around each other at chiasma (plural: chiasmata). There may be 2 or 3 chiasmata formation per homologous chromosomes pair.

As a result, crossing over may take place between non-sister chromatids where nonsister chromatids exchange DNA segments and new combinations of genes may be formed. The resultant chromosomes after crossing over are called recombinant chromosomes.

What's the difference between chiasma formation and crossing over?
Chiasma refers to the point at which paired chromosomes remain in contact whereas crossing over is the exchange of genetic material between homologous chromosomes.</td></tr>
<tr><td>Metaphase I</td><td>  </td><td>Spindle is completely formed. Pairs of homologous chromosomes arrange themselves along the equator of the cell. The two chromosomes of each pair faces opposite poles of the cell.</td></tr>
<tr><td>Anaphase I</td><td> 
homologous chromosomes moving apart</td><td>Homologous chromosomes separate and move to opposite poles of the cell.

Note that each chromosome here is still made up of two chromatids.</td></tr>
</table>

Telophase I		A nuclear membrane forms around the chromosomes at each pole, leading to the formation of nucleus. This is followed by division of cytoplasm (**cytokinesis**). The cell membrane invaginates and the cytoplasm cleaves into two, producing two daughter cells, each with a **haploid** number of chromosomes. The centrioles divide. *What is the chromosome number and amount of DNA in each daughter cell at this point?* Chromosome number is haploid e.g. *n* (where *n* = 1 set of chromosome). In the figure on the left, *n* is 2. Amount of DNA is *x* (where *x* = amount of DNA in a non-dividing cell).
Prophase II		Centrioles duplicate and move to opposite poles. Nuclear envelope breaks down and disappears. Spindle fibres appear.
Metaphase II		Spindle is completely formed. Centromeres are attached to spindle fibres. Chromosomes aligned themselves along the equator of the spindle. Note that each chromosome here is still made up of two chromatids.
Anaphase II		Centromeres divide. Chromatids separate and are pulled towards opposite poles of the cell. Each chromatid is now a chromosome.

Telophase II		Chromosomes arrive at opposite poles and begin uncoiling. Spindle fibres disappear. Nuclear envelopes forms around the daughter chromosomes at each pole. The cell membrane invaginates and cleavage of cytoplasm (cytokinesis) results in four daughter cells being produced, each with half the number of chromosomes as the parent cell.

Importance of meiosis

The significance of meiosis includes:

(1) Production of haploid gametes (reproductive cells) e.g. sperm, egg involves meiosis. If meiosis does not occur, the fusion of nuclei of gametes during fertilisation will result in a doubling of the chromosome number with each generation.

(2) Genetic variation is increased due to crossing over and independent assortment of chromosomes, which leads to gametes having different combinations of chromosomes. Genetic variation increases the fitness of an organism and thus increases its survival rate.

What phases are represented by W, X and Y in Fig. 17.10?
W = interphase, X = telophase I, Y = telophase II

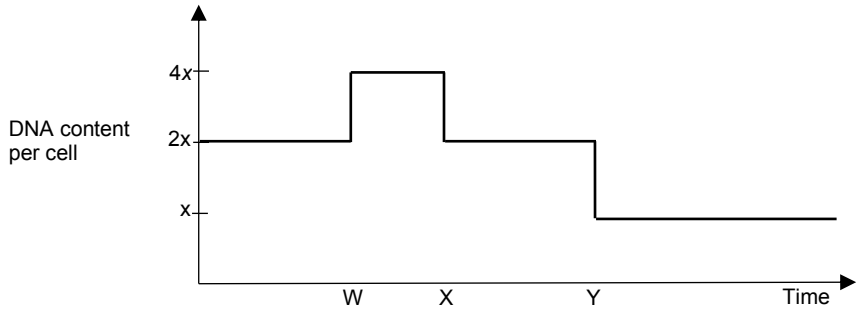


Figure 17.10 Amount of DNA in a cell over time

Table 17.3 Comparisons between meiosis and mitosis

Characteristics	**Meiosis**	**Mitosis**
Similarities	Both are forms of cell division. Both occur in diploid cells. Both involve basic stages prophase, metaphase, anaphase and telophase.	
Differences		
Number of chromosomes	Results in formation of haploid (*n*) e.g. sperm, egg cells	Results in formation of diploid (2*n*) cells
Number of nuclear division	Involves two nuclear divisions	Involves only one nuclear division
Crossing over	Crossing over may occur during prophase I	No crossing over
Pairing of homologous chromosomes	Homologous chromosomes pair at prophase I (synapsis)	Pairing of homologous chromosomes does not occur
Centromere	Centromeres do not split during anaphase I	Centromeres split during anaphase
Purpose	Production of reproductive cells	Growth and repair
Number of daughter cells produced	4 genetically dissimilar daughter cells	2 genetically identical daughter cells
Variation	Recombination of chromosomes gives rise to variation	No genetic variation
Location	In sexual reproductive cells during gamete formation	All other plant and animal cells during growth or repair of body parts

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 18 – Inheritance

Name: **Class:**

A. Content

- Genetics & Inheritance
- Monohybrid Inheritance
- Chromosomal & Gene Mutations
- Continuous & Discontinuous Variations

B. Learning Outcomes

At the end of the chapter, students should be able to:

(a) DEFINE a gene as a unit of inheritance and distinguish clearly between the terms gene and allele.
(b) EXPLAIN the terms locus, allele, dominant, recessive, codominant, homozygous, heterozygous, phenotype and genotype.
(b) EXPLAIN how genotype is linked to phenotype and how genes are inherited from one generation to the next via the germ cells or gametes.
(c) PREDICT the results of simple crosses with expected ratios of 3:1 and 1:1, using the terms homozygous, heterozygous, F1 generation and F2 generation.
(d) EXPLAIN why observed ratios often differ from expected ratios, especially when there are small numbers of progeny.
(e) USE genetic diagrams to solve problems involving monohybrid inheritance (Genetic diagrams involving autosomal linkage or epistasis are not required).
(f) EXPLAIN co-dominance and multiple alleles with reference to the inheritance of the ABO blood group phenotypes – A, B, AB, O, gene alleles I^A, I^B and I^O.
(g) DESCRIBE the determination of sex in humans – XX and XY chromosomes.
(h) DESCRIBE mutation as a change in the structure of a gene such as in sickle cell anaemia, or in the chromosome number, such as the 47 chromosomes in the condition known as Down syndrome.
(i) NAME radiation and chemicals as factors which may increase the rate of mutation.
(j) DESCRIBE the difference between continuous and discontinuous variation and give examples of each.
(k) EXPLAIN the genetic basis of continuous variation (many, additive, genes control a characteristic) and discontinuous variation (one or few genes control a characteristic).
(l) USE genetic diagrams to solve problems involving test crosses.

Use the knowledge gained in this section in new situations or to solve related problems.

C. References

1. Lam, P. K. and Lam, E. Y. K. (2012). GCE 'O' Level: Biology Matters (2nd ed). Marshall Cavendish Education.
2. Miko, I. (2008) Gregor Mendel and the principles of inheritance. Nature Education 1(1):134
3. Pierce, B. (2010). Genetics: A Conceptual Approach (3rd ed). W.H. Freeman & Company.
4. Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V. and Jackson, R. B. Campbell Biology (9th ed). The Benjamin/Cummings Publishing Company, Inc.

D. Lecture Outline

1. Introduction
2. Gene
3. Monohybrid Inheritance
4. Codominance
5. Sex Determination in Humans
6. Mutation
7. Continuous & Discontinuous Variations

E. Practical Work

- Genetic Variation in Plants

1. INTRODUCTION

Heritable traits (such as brown, green, or blue eyes) among individuals in a population are transmitted from parents to offspring. One possible explanation for heredity is a "blending" hypothesis. This hypothesis proposes that genetic material contributed by each parent mixes in a manner analogous to the way blue and yellow paints blend to make green. With blending inheritance, a freely mating population would eventually give rise to a uniform population of individuals.

Everyday observations and the results of breeding experiments tell us that heritable traits do not blend to become uniform. An alternative hypothesis, "particulate" inheritance, proposes that parents pass on discrete heritable units, genes, that retain their separate identities in offspring. Genes can be sorted and passed on, generation after generation, in undiluted form.

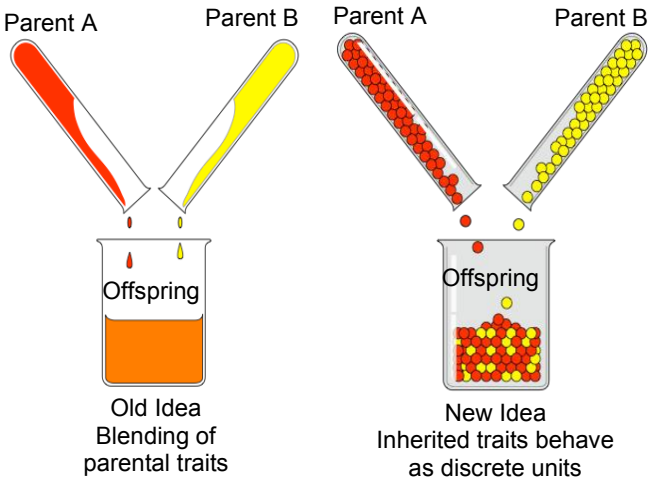


Figure 18.1 Mendel's view of inheritance

Mendel's Experimental, Quantitative Approach

Modern genetics began in an abbey garden, where a monk named Gregor Mendel documented a particulate mechanism of inheritance.

Mendel grew up on a small farm in what is today the Czech Republic. In 1843, Mendel entered an Augustinian monastery and from 1851 to 1853, and studied at the University of Vienna. He was influenced by a physicist who encouraged experimentation and the application of mathematics to science and by a botanist who stimulated Mendel's interest in the causes of variation in plants. These influences came together in Mendel's experiments.

After university, Mendel taught school and lived in the local monastery, where the monks had a long tradition of interest in the breeding of plants, including peas. Around 1857, Mendel began breeding garden peas to study inheritance.

Figure 18.2 Gregor Mendel

Pea plants have several advantages for genetic study. They have distinct heritable features, or characters, with different variant traits. They have a short generation time; each mating produces many offspring. Mendel was able to strictly control the matings of his pea plants. Each pea plant has male (stamens) and female (carpel) sexual organs. In nature, pea plants typically self-fertilise. Mendel could also use pollen from another plant for cross-pollination.

2. GENE

DEFINE a gene as a unit of inheritance and distinguish clearly between the terms gene and allele.

EXPLAIN the terms locus, allele, dominant, recessive, codominant, homozygous, heterozygous, phenotype and genotype.

Gene is a unit of inheritance. An **allele** is an alternative form of a gene. Genes are located at the same position, or genetic **locus** (plural: loci), on a chromosome. For example, the gene for flower color in pea plants exists in two versions, one for purple flowers and one for white flowers (Figure 18.3).

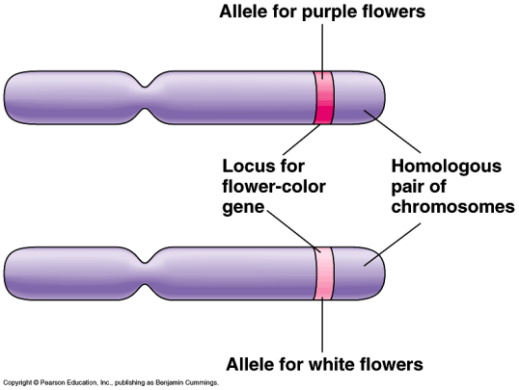


Figure 18.3 Alleles are alternative versions of a gene
Source: Pearson Education

Each gene resides at a specific locus on a specific chromosome. The DNA at that locus can vary in its sequence of nucleotides. The purple-flower and white-flower alleles are two DNA variations at the flower-color locus.

Genetic Vocabulary

Each pair of alleles represents the **genotype** of a specific gene. Genotypes are described as **homozygous** if there are two identical alleles at a particular locus and as **heterozygous** if the two alleles differ. Genotype describes the genetic make-up of an organism, the combination of alleles. **Phenotype** describes the observable, physical characteristics that an organism has.

Some alleles are **dominant** or **recessive**. The characteristic controlled by a dominant allele develops if the allele is present on one or both chromosomes in a pair. The characteristic controlled by a recessive allele develops only if the allele is present on both chromosomes in a pair. An organism that is heterozygous at a specific locus will express the dominant phenotype. For example, the allele for brown eyes is dominant, while the allele for blue eyes is recessive (Figure 18.4). An individual who inherits one or two alleles for brown eyes will have brown eyes (Individuals A and B). An individual will only have blue eyes if they inherit two copies of the allele for blue eyes (Individual C).

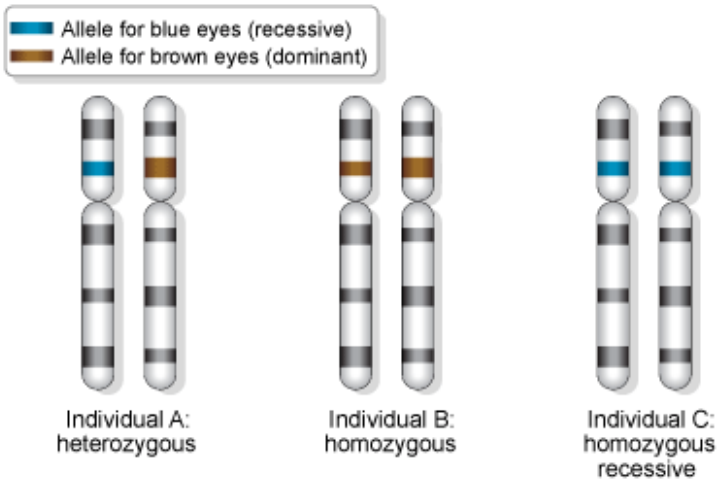


Figure 18.4 Inheritance of eye colour in humans.

3. MONOHYBRID INHERITANCE

Mendel started his experiments with varieties that were **true-breeding**. When true-breeding plants self-pollinate, all their offspring have the same traits as their parents. In a typical breeding experiment, Mendel would cross-pollinate (hybridise) two contrasting, true-breeding pea varieties (Figure 18.5).

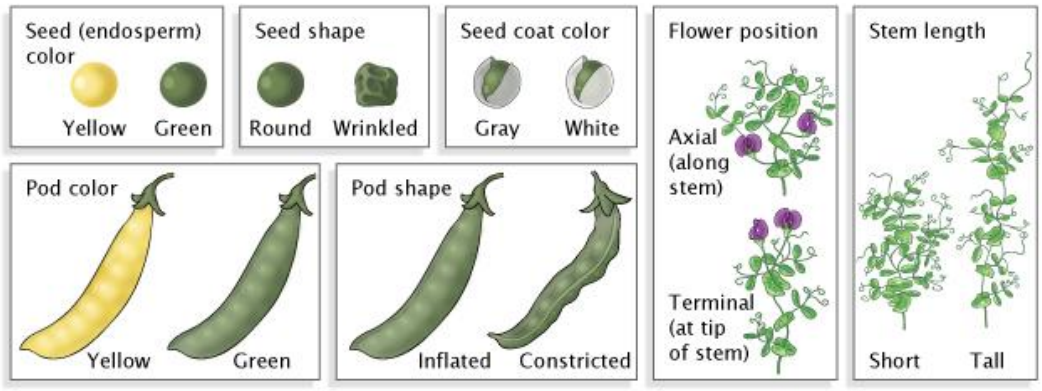


Figure 18.5 Mendel studied seven characteristics in peas
The seven traits observed by Mendel in pea plants were as follows: seed color (yellow or green); seed shape (round or wrinkled); seed coat color (gray or white); flower position (axial or terminal); stem length (short or tall); pod color (yellow or green); and pod shape (inflated or constricted).
Source: © 2013 Nature Education

The true-breeding parents are the **P (parental) generation**, and their hybrid offspring are the **F1 (first filial) generation** (Figure 18.6). Mendel would then allow the F1 hybrids to self-pollinate to produce an **F2 (second filial) generation**. It was mainly Mendel's quantitative analysis of F2 plants that revealed two fundamental principles of heredity: the **law of segregation** and the **law of independent assortment**. He discovered these basic principles several decades before chromosomes were observed under the microscope.

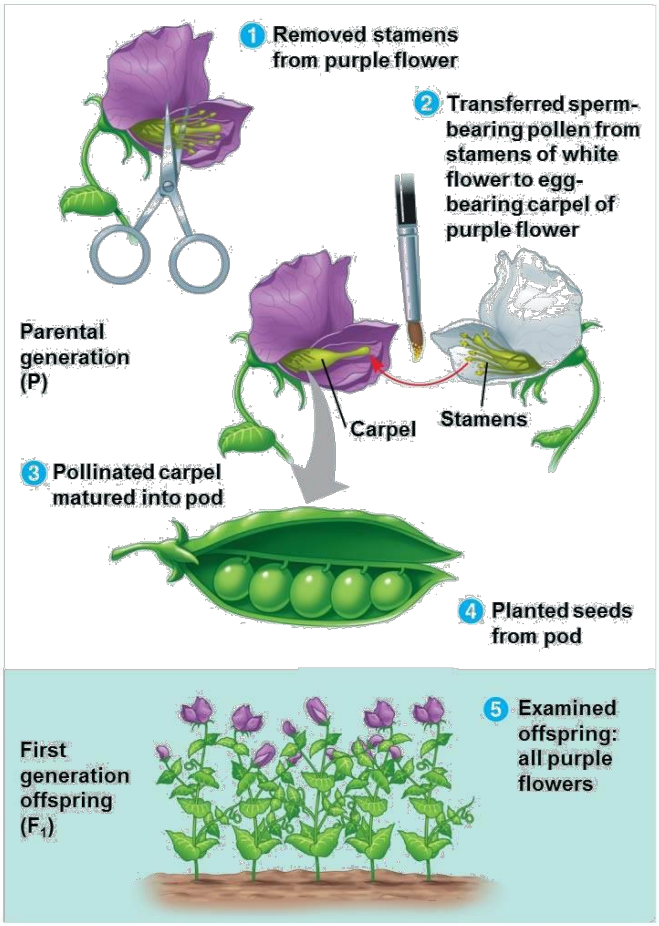


Figure 18.6 Mendel used the scientific approach to identify two laws of inheritance.

The Law of Segregation

If the blending hypothesis were correct, the F1 hybrids from a cross between purple-flowered and white-flowered pea plants would have pale purple flowers. Instead, the F1 hybrids all have purple flowers, just as purple as their purple-flowered parents. When Mendel allowed the F1 plants to self-fertilise, the F2 generation included both purple-flowered and white-flowered plants. The white trait, absent in the F1 generation, reappeared in the F2.

Mendel recorded 705 purple-flowered F2 plants and 224 white-flowered F2 plants. This cross produced a ratio of three purple flowers to one white flower in the F2 offspring. Mendel reasoned that the heritable factor for white flowers was present in the F1 plants but did not affect flower color. Purple flower color is a dominant trait, and white flower color is a recessive trait.

The reappearance of white-flowered plants in the F2 generation indicated that the heritable factor for the white trait was not diluted or lost by coexisting with the purple-flower factor in F1 hybrids.

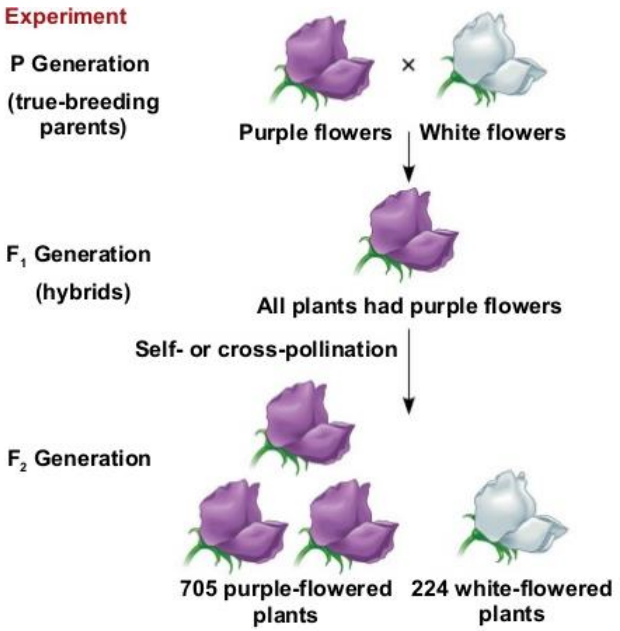


Figure 18.7 Mendel's monohybrid crosses of purple-flowered and white-flowered pea plants
Source: © 2014 Pearson Education

Mendel found similar 3:1 ratios of two traits in F2 offspring when he conducted crosses for six other characters, each represented by two different traits. See Table 18.1.

Table 18.1 Mendel's monohybrid experiments

trait	parental plants		F2 generation	ratio of dominants to recessives in F2 generation
seed shape	 round	 wrinkled	5474 round 1850 wrinkled	2.96 : 1
seed colour	 yellow	 green	6022 yellow 2001 green	3.01 : 1
pod colour	 green	 yellow	428 green 152 yellow	2.82 : 1
flower position	 axial	 terminal	651 axial 207 terminal	3.14 : 1
pod shape	 inflated	 constricted	882 inflated 299 constricted	2.95 : 1
stem length	 tall	 dwarf	787 tall 277 dwarf	2.84 : 1

EXPLAIN why observed ratios often differ from expected ratios, especially when there are small numbers of progeny.

From Table 18.1, it is observed that the ratio in the F2 generation becomes closer to the expected ratio of 3 : 1 when a larger number of plants are used in the experiment. Statistically, ratios are inaccurate when sample numbers are small and ratio figures are based on chance and probabilities.

The Law of Independent Assortment

Mendel's first experiments followed only a single character, such as flower colour. All the F1 progeny produced in these crosses were monohybrids, heterozygous for one character. A cross between two heterozygotes is a monohybrid cross.

The laws of probability govern Mendelian inheritance. Mendel's laws of segregation and independent assortment reflect the same laws of probability. Values of probability range from 0 (an event with no chance of occurring) to 1 (an event that is certain to occur).

In a coin toss, the outcome of one coin toss has no impact on the outcome of the next toss. Each is an independent event, just like the distribution of alleles into gametes. Like a coin toss, each ovum from a heterozygous parent has a ½ chance of carrying the dominant allele and a ½ chance of carrying the recessive allele. The same probabilities apply to the sperm.

Using the multiplication rule, the probability that two or more independent events will occur together in some specific combination can be determined. The probability that a heterozygous pea plant (Pp) will self-fertilise to produce a white-flowered offspring (pp) is the probability that a sperm with a white allele will fertilise an ovum with a white allele. The probability is ½ x ½ = ¼.

The addition rule can be used to determine the probability that an F2 plant from a monohybrid cross will be heterozygous rather than homozygous. The probability of an event that can occur in two or more different ways is the sum of the individual probabilities of those ways. The probability of obtaining an F2 heterozygote by combining the dominant allele from the egg and the recessive allele from the sperm is ¼. The probability of combining the recessive allele from the egg and the dominant allele from the sperm also ¼. Using the rule of addition, the probability of an F2 heterozygote as ¼ + ¼ = ½ can be calculated.

Extension

Mendel's character of round versus wrinkled pea seed shape

The dominant allele (round) codes for an enzyme that helps convert an unbranched form of starch to a branched form in the seed. The recessive allele (wrinkled) codes for a defective form of this enzyme that leads to an accumulation of unbranched starch. Excess water is then drawn into the seed due to osmosis. The seeds wrinkle when the excess water dries. Both homozygous dominant and heterozygous pea plants produce enough enzymes to synthesise adequate amounts of branched starch. As a result, they do not fill with excess water and they form smooth seeds as they dry.

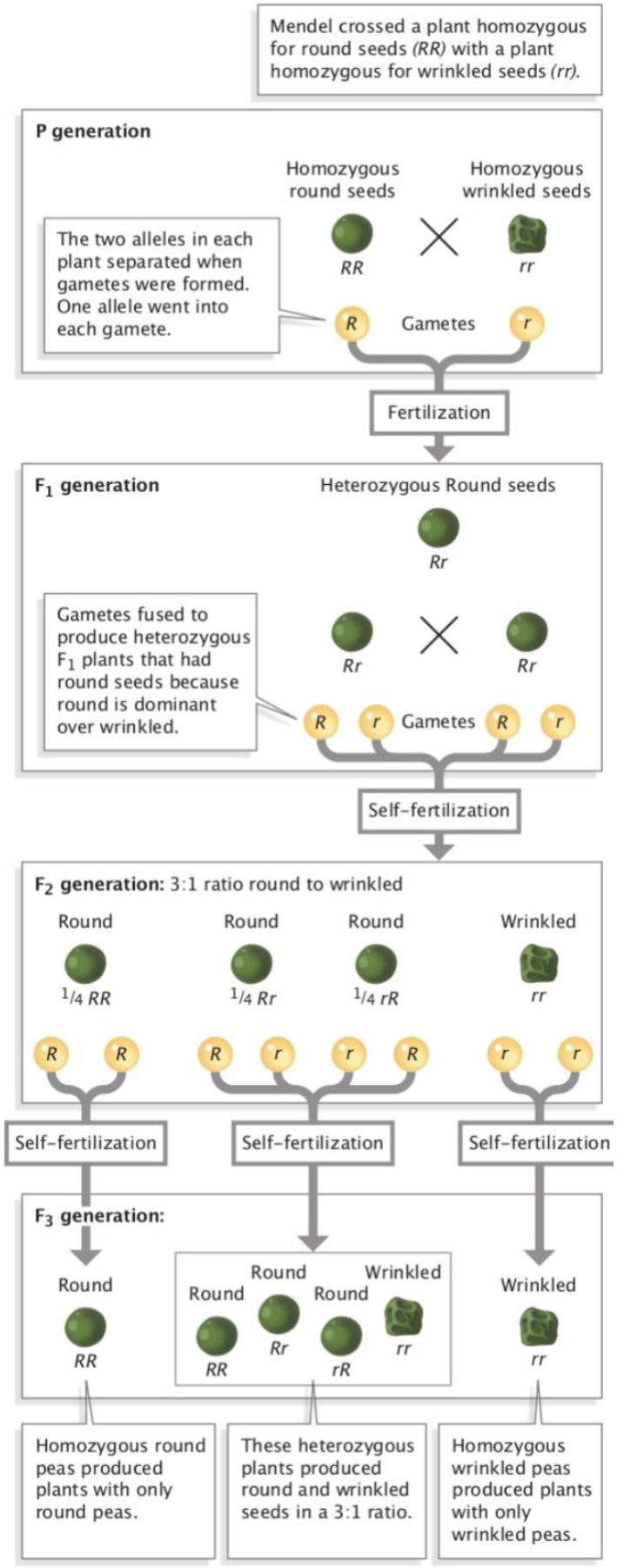


Figure 18.8 Mendel's monohybrid crosses of round and wrinkled seeds of pea plants
Source: © 2013 Nature Education

Genetic Diagram

EXPLAIN how genotype is linked to phenotype and how genes are inherited from one generation to the next via the germ cells or gametes.

A genetic diagram will show how inheritance works.

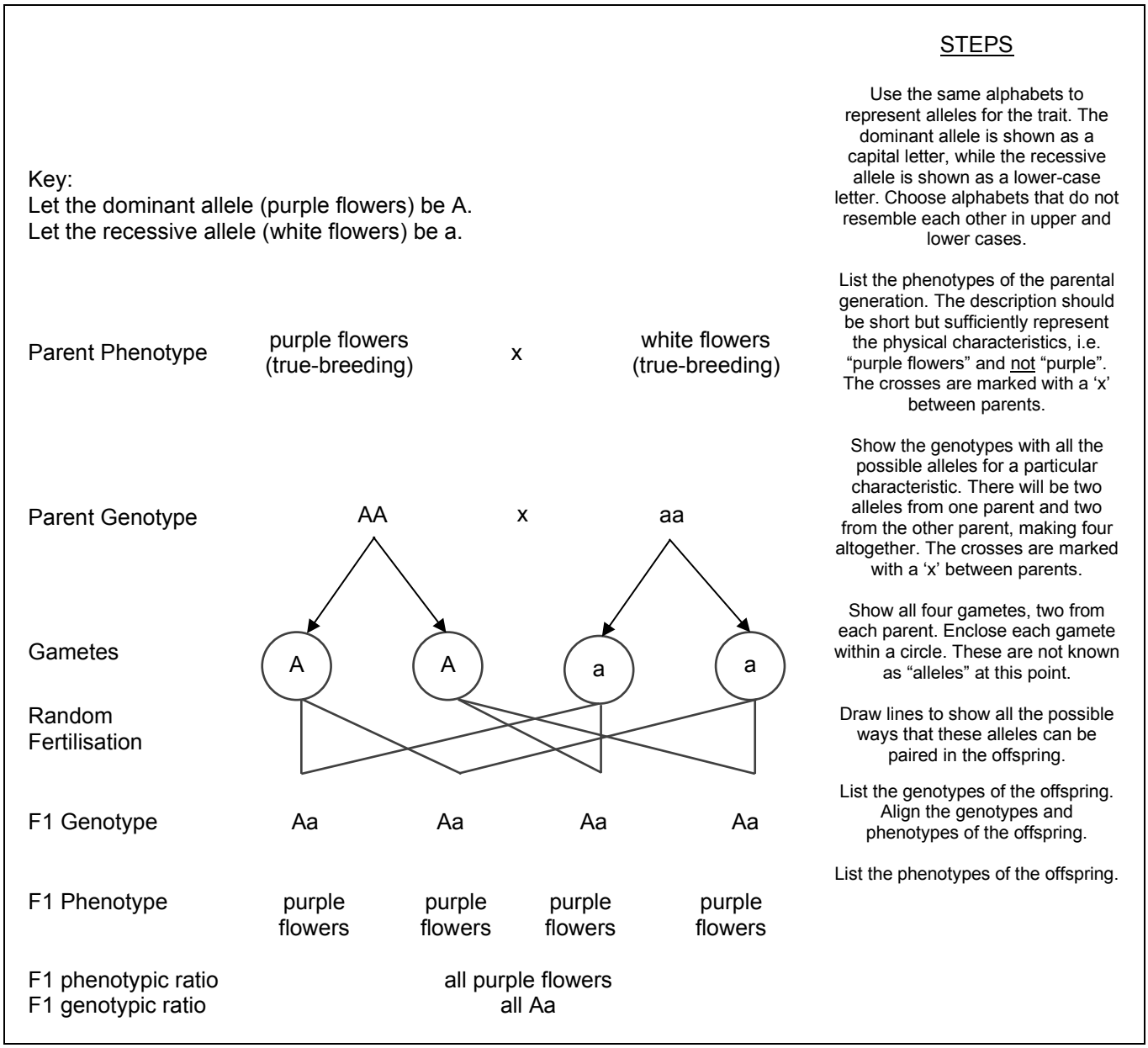


Figure 18.9 A complete genetic diagram that shows the outcome of Mendel's first cross

If the two alleles at a locus differ, then the dominant allele, determines the organism's appearance. The other, the recessive allele, has no noticeable effect on the organism's appearance. In the flower-color example, the F1 plants inherited a purple-flower allele from one parent and a white-flower allele from the other. The plants had purple flowers because the allele for that trait is dominant.

Key:
Let the dominant allele (purple flowers) be A.
Let the recessive allele (white flowers) be a.

F1 Phenotype	purple flowers (heterozygous)	x	purple flowers (heterozygous)
F1 Genotype	Aa	x	Aa
Gametes	A, a		A, a
Random Fertilisation			
F2 Genotype	AA	Aa	Aa	aa
F2 Phenotype	purple flowers	purple flowers	purple flowers	white flowers
F2 phenotypic ratio	3 purple flowers : 1 white flower		
F2 genotypic ratio	1 AA : 2 Aa : 1 aa		

Figure 18.10 A complete genetic diagram that shows the outcome of Mendel's second cross

USE genetic diagrams to solve problems involving test crosses.

The Testcross

How can we determine the genotype of an individual that has the dominant phenotype? The organism must have one dominant allele but could be homozygous dominant or heterozygous. The answer is to carry out a **testcross** (Figure 18.11).

Early use of the test cross was as an experimental mating test used to determine what alleles are present in the genotype.

The organism in question is crossed with an organism that is homozygous for the recessive trait. If the testcross results in any recessive offspring, then the parent organism is heterozygous for the allele in question. If the testcross results in only phenotypically dominant offspring, then the parent organism is homozygous dominant for the allele in question.

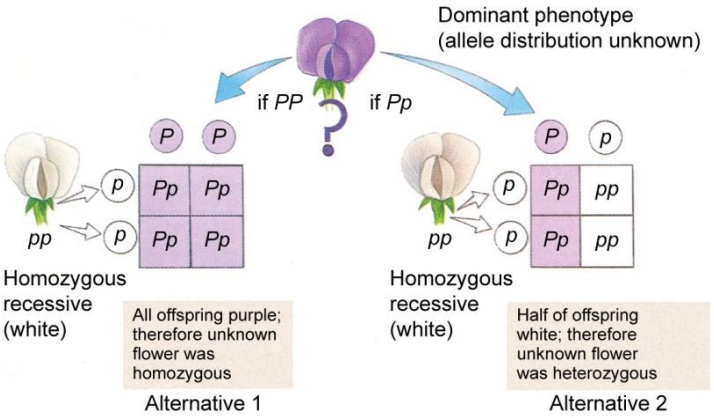


Figure 18.11 Test Cross showing an experimental cross of an individual organism of dominant phenotype but unknown genotype, with an organism with a homozygous recessive genotype (and phenotype)
Source: The McGraw-Hill Companies, Inc.

Punnett Square

A Punnett square may be used to predict the results of a genetic cross between individuals of known genotype (Figure 18.12).

STEPS for setting up a Punnett square

1. Set up a two by two (2 x 2) Punnett Square.
2. Write the alleles for Parent 1 on the left side of the Punnett square. Each gamete will have one of the two alleles of the parent.
3. Write the alleles from Parent 2 above the Punnett square. Again, each gamete will have one of the two alleles of the parent.
4. Like a multiplication table, fill each square with each of the four possible genotypes in the four boxes.

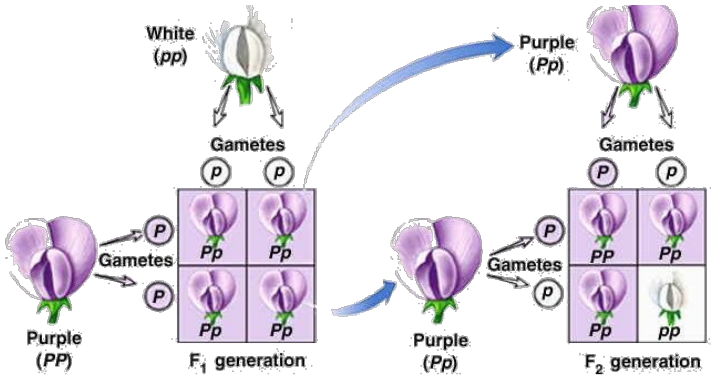


Figure 18.12 A Punnett square showing the outcomes of monohybrid genetic crosses
Source: The McGraw-Hill Companies, Inc.

Incomplete Dominance

Alleles show different degrees of dominance and recessiveness in relation to each other. One extreme is the complete dominance characteristic of Mendel's crosses. Some alleles show **incomplete dominance**, in which heterozygotes show a **distinct intermediate phenotype** not seen in homozygotes (Figure 18.13). This is not blending inheritance because the traits are separable.

Offspring of a cross between heterozygotes show three phenotypes: each parental phenotype and the heterozygous phenotype. The phenotypic and genotypic ratios are identical: 1:2:1. A clear example of incomplete dominance is the flower color of snapdragons. A cross between a white-flowered plant and a red-flowered plant produces all pink F1 offspring. Self-pollination of the F1 offspring produces 25% white, 25% red, and 50% pink F2 offspring.

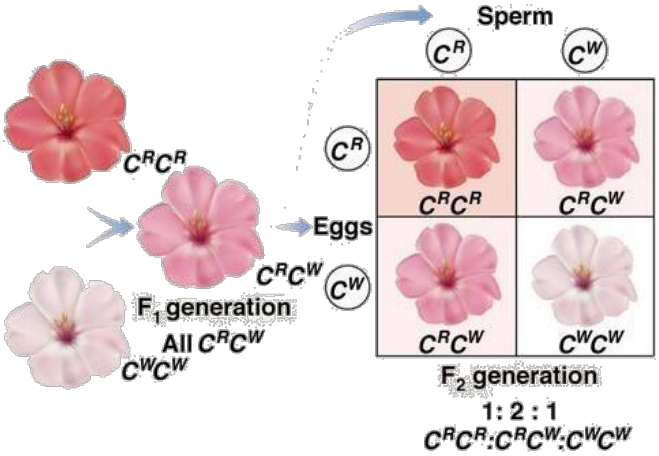


Figure 18.13 Genetic diagram showing incomplete dominance
Source: The McGraw-Hill Companies, Inc.

4. CODOMINANCE

EXPLAIN co-dominance and multiple alleles with reference to the inheritance of the ABO blood group phenotypes – A, B, AB, O, gene alleles I^A, I^B and I^O.

Codominance occurs when two alleles are simultaneously expressed in the phenotype.

An example of codominance occurs in the human **ABO blood group** system. The ABO blood groups in humans are determined by three alleles: $\mathbf{I^A}$, $\mathbf{I^B}$, and $\mathbf{I^O}$. Both the I^A and I^B alleles are dominant to the I^O allele. The I^A and I^B alleles are codominant to each other. Because each individual carries two alleles, there are **six** possible genotypes and **four** possible phenotypes (blood groups) as shown in Figure 18.14.

I^A and I^B alleles code for proteins (i.e. antigens) that exist on the surface of red blood cells; in contrast, the third allele, I^O, codes for no protein. Thus, if one parent is homozygous for blood group A and the other is homozygous for blood group B, the offspring will have a new phenotype, blood group AB. In people with blood group AB, both A and B proteins are expressed on the surface of red blood cells equally. Therefore, this I^AI^B phenotype is not an intermediate of the two parental phenotypes, but rather is an entirely new phenotype that results from codominance of the I^A and I^B alleles. In this system, I^AI^B is not the only heterozygote; people may also be I^AI^O or I^BI^O.

(a) Phenotype (blood group)	(b) Genotypes (see p.258)	(c) Antibodies present in blood serum	(d) Results from adding red blood cells from groups below to serum from groups at left			
			A	B	AB	O
A	I^AI^A or I^Ai	Anti-B				
B	I^BI^B or I^Bi	Anti-A				
AB	I^AI^B	—				
O	ii	Anti-A Anti-B				

Figure 18.14 Table showing three blood type alleles, six possible ABO genotypes and four phenotypes
Source: Pearson Education

DESCRIBE the determination of sex in humans – XX and XY chromosomes.

5. SEX DETERMINATION IN HUMANS

In a human somatic cell (any cell other than a gamete), there are 23 pairs of chromosomes – 22 pairs of **autosomal chromosomes** (non-sex chromosomes that are also known as autosomes) and 1 pair of **sex chromosomes** (Figure 18.15). Autosomes come in pairs of homologous chromosomes. Homologous chromosomes have the same genes arranged at the same loci. For all of the genes on the autosomes, both males and females have two copies.

In humans and other mammals, the sex chromosomes are X and Y. An individual who inherits two X chromosomes develops as a female. An individual who inherits one X chromosome and one Y chromosome develops as a male.

In a female, the two X chromosomes have the same genes arranged at the same loci. Hence females have two copies of every gene, including the genes on sex chromosomes. In a male, the X and Y chromosomes have different genes. For the genes on the sex chromosomes, males have just one copy. The Y chromosome has few genes, but the X chromosome has more than 1000.

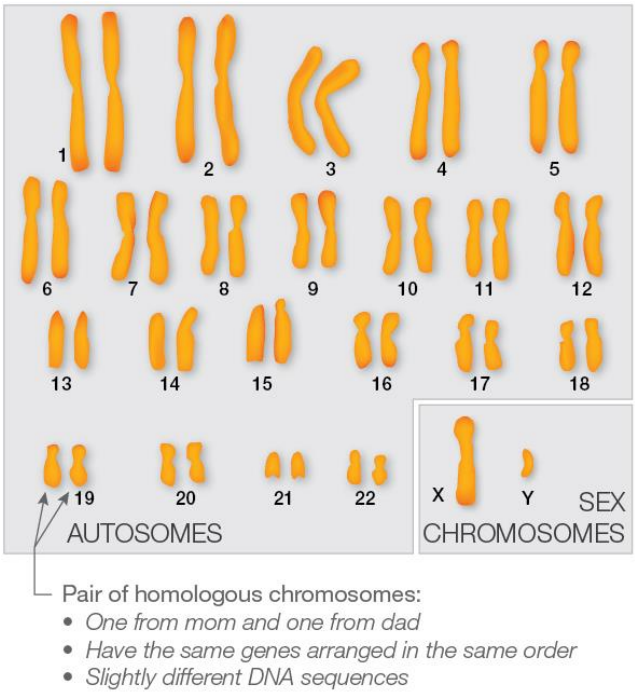


Figure 18.15 Karyotype of a human that shows autosomal and sex chromosomes
Source: © 2013 Nature Education

In both testes (**XY**) and ovaries (**XX**), the two sex chromosomes segregate during meiosis, and each gamete receives one chromosome. Each ovum receives an X chromosome. Half the sperms receive an X chromosome, and half receive a Y chromosome. Therefore, each conception has about a 50-50% chance of producing a particular sex (Figure 18.16).

If a sperm bearing an X chromosome fertilises an ovum, the resulting zygote is female (**XX**). If a sperm bearing a Y chromosome fertilizes an ovum, the resulting zygote is male (**XY**).

Other animals have different methods of sex determination. The X-0 system is found in some insects. Females are XX and males are X. In birds, some fishes, and some insects, females are ZW and males are ZZ. In bees and ants, females are diploid and males are haploid.

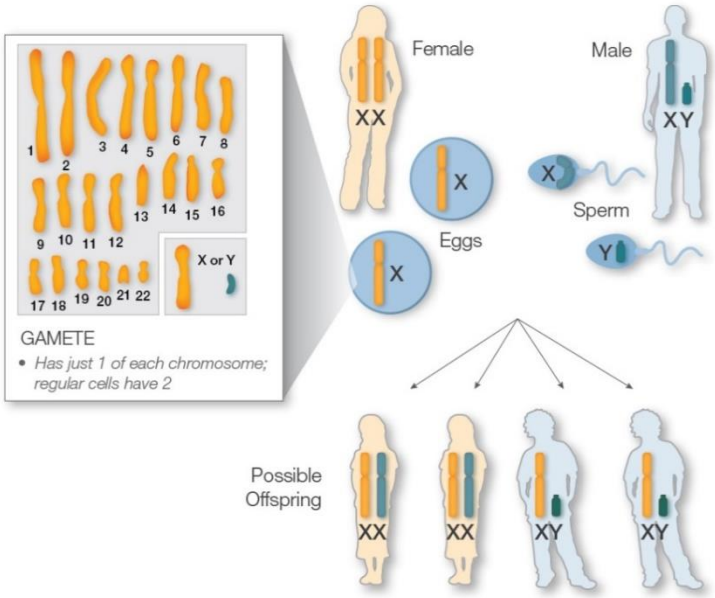
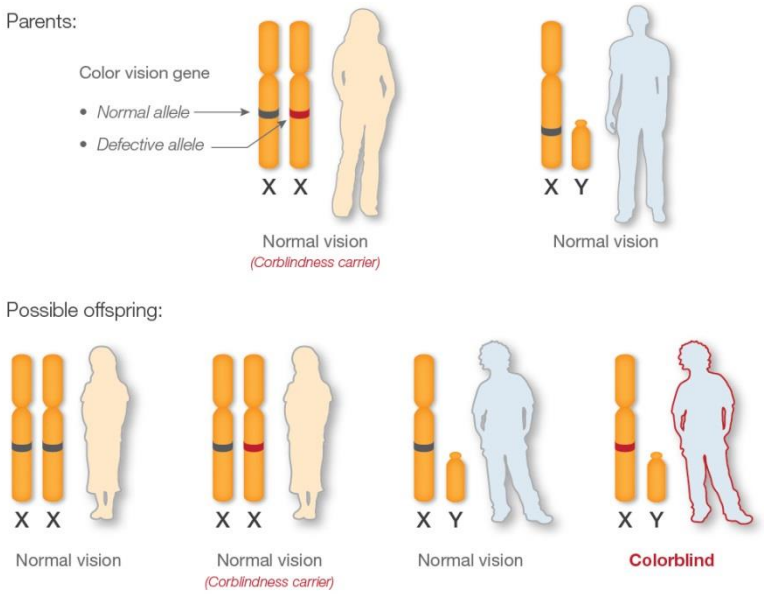


Figure 18.16 Sex determination in humans. Male offspring get an X from their mother and a Y from their father. Y chromosomes are always pass from father to son.
Source: © 2013 Nature Education

Extension

Inheritance of Sex-Linked Recessive Disorders



In humans, a number of genetic disorders are sex-linked, including Duchenne muscular dystrophy and hemophilia. Why are these and other sex-inked disorders much more common in males than in females? Genes code for proteins, and proteins make traits. Two alleles working together that affect the phenotype. For genes on autosomes, there are two copies – one from each parent. The two alleles may be the same, or they may be different.

When one allele is defective, a functional second allele can often work well enough on its own. Males have just one X-chromosome, which they receive from their mother. However, with sex-linked recessive disorders, if males inherit one defective allele, they will be affected with the disorder. Females have two X-chromosomes. If they inherit one defective allele, they will not be affected but they will be carriers of disorder.

Red/green colourblindness is caused by a defective gene on the X-chromosome. Males have just one X-chromosome, which they receive from their mother, inheriting one defective copy of the gene will render them colourblind. Females have two X-chromosomes; to be colourblind they must inherit two defective copies, one from each parent. Consequently, red-green colourblindness is much more frequent in boys (1 in 12) than in girls (1 in 250).

DESCRIBE mutation as a change in the structure of a gene such as in sickle cell anaemia, or in the chromosome number, such as the 47 chromosomes in the condition known as Down syndrome.

6. MUTATIONS

Gene mutation and **chromosome mutation** occur naturally and generally have a low frequency.

Gene mutation

These are **changes** in the **DNA sequence** (Figure 18.17). Most commonly, a single base is **substituted** for another. Sometimes a base is **deleted** or an extra base is **added**. The cell is able to repair most of these changes. When a DNA change remains unrepaired in a cell that will become an egg or a sperm, it is passed down to offspring.

The terms "mutant" and "mutation" are often used to describe something undesirable. But mutation is not always bad. Mutation also generates new variations that can give an individual a survival advantage.

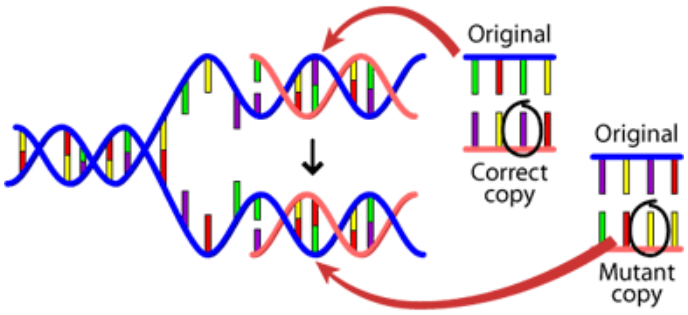


Figure 18.17 Gene mutation is a change from the original DNA sequence
Source: http://evolution.berkeley.edu/

Example

Sickle cell anaemia is the result of a mutation to the **beta globin gene** (located at chromosome 11) and is inherited in an autosomal recessive pattern (a child will not inherit the disease unless both parents pass down a defective allele).

Red blood cells that contain normal hemoglobin are circular and biconcave in shape. The shape allows the cells to be flexible so that they can move through tiny blood capillaries to transport oxygen.

Sickle-cell hemoglobin aggregates into long rods that deform red blood cells into a sickle (or crescent) shape. Sickle-shaped cells are **not flexible** and can stick to vessel walls, clumping and blocking capillaries. Oxygen cannot be transported to nearby body tissues and the lack of oxygen can cause sudden and severe pain. Sickle cells cannot change shape easily, so they tend to burst or hemolyse. Normal red blood cells live about 90-120 days, but sickle cells last only 10-20 days. See Figure 18.18.

The **lower number of red blood cells** will reduce the rate of respiration and less energy is released. Hence a person affected with sickle cell anaemia will suffer breathlessness and fatigue. Over a lifetime, the disease can harm major organs.

Doctors can use regular blood transfusions to prevent brain damage and administer new drugs to prevent or treat other problems.

Individuals that are heterozygous for the sickle cell allele (carriers) are usually healthy. They have increased resistance to the malaria parasite, which spends part of its life cycle in red blood cells. In tropical Africa, where malaria is common, the sickle-cell allele is both a boon and a bane. Homozygous normal individuals die of malaria and homozygous recessive individuals die of sickle-cell anaemia, while carriers are relatively free of both.

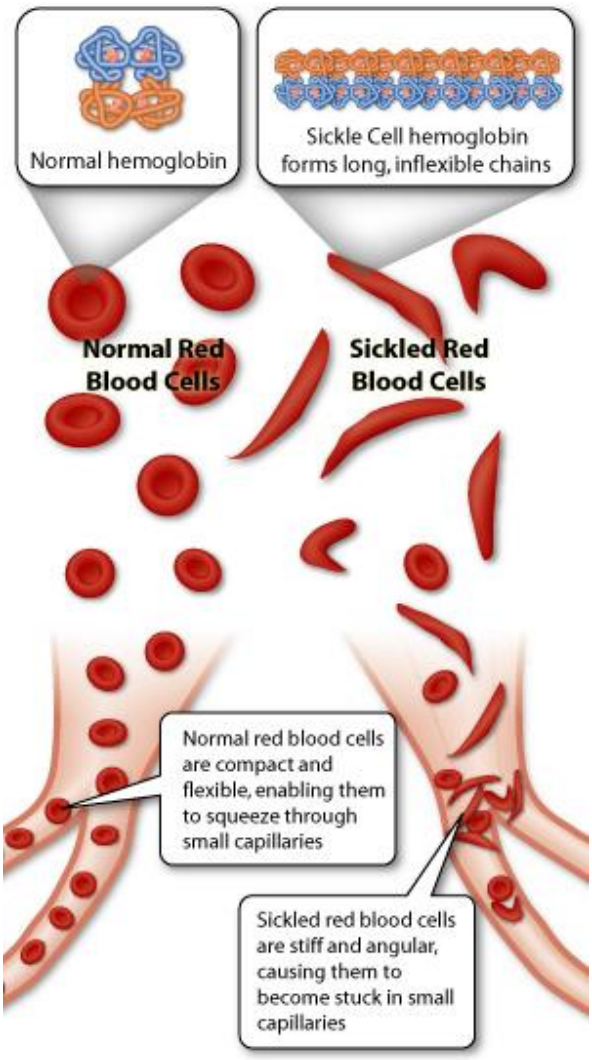


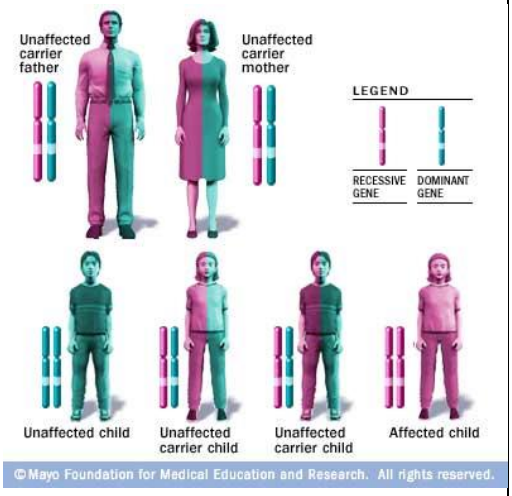
Figure 18.18 (On the left) Normal red blood cells move freely in a blood vessel. (On the right) Abnormal sickle shaped red blood cells blocking blood flow in a blood vessel
Source: © Genetic Science Learning Center

Extension

Genetic Disorders

Recessively Inherited Disorders

Thousands of genetic disorders, including disabling or deadly hereditary diseases, are inherited as simple recessive traits. These conditions range from relatively mild (albinism) to life-threatening (cystic fibrosis). Individuals who do not have the disorder are either homozygous dominant or heterozygotes. Although heterozygotes may lack obvious phenotypic effects, they are carriers who may transmit a recessive allele to their offspring. Most people with recessive disorders are born to carriers with normal phenotypes. In a mating between two carriers of albinism, each child has a ¼ chance of inheriting the disorder, a ½ chance of being a carrier, and a ¼ chance of being homozygous dominant. Normally, it is relatively unlikely that two carriers of the same rare, harmful allele will meet and mate. Individuals who share a recent common ancestor are more likely to carry the same recessive alleles.

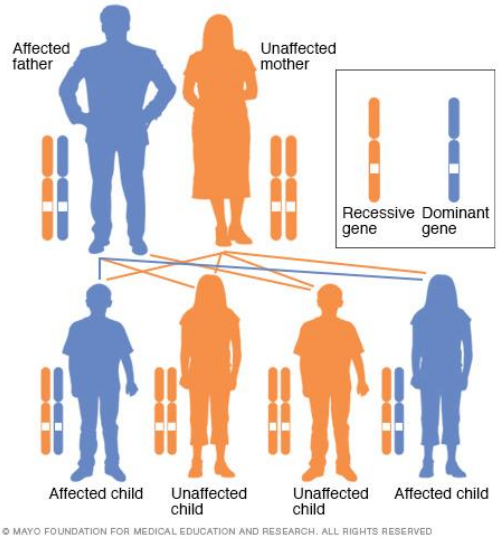


Albinism

An allele that causes a recessive condition such as albinism codes for a malfunctioning protein or for no protein at all. An individual affected with albinism lacks the pigment melanin in their skin, eyes and hair. Heterozygotes have a normal phenotype because one normal allele produces enough of the required protein.

Cystic Fibrosis

The normal allele at this gene codes for a membrane protein that transports chloride between cells and extracellular fluid. If these channels are defective or absent, abnormally high extracellular levels of chloride accumulate. Then the mucous coats of certain cells become thicker and stickier than normal. This mucous build-up in the pancreas, lungs and digestive tract causes poor absorption of nutrients, chronic bronchitis, and bacterial infections. Without treatment, affected children die before age 5, but with treatment, they can live past their late 20s.



Dominantly Inherited Disorders

Although most harmful alleles are recessive, a number of human disorders are due to dominant alleles. Any child born to a parent who has the allele for a dominantly inherited disorder has a 50% chance of inheriting the disease. Lethal dominant alleles are much less common than lethal recessive alleles. If a lethal dominant allele kills an offspring before he or she can mature and reproduce, the allele will not be passed on to future generations. In contrast, a lethal recessive allele can be passed on by heterozygous carriers who have normal phenotypes.

Achondroplasia

Achondroplasia, a form of dwarfism, has a prevalence of one case in 25,000 people. Heterozygous individuals have the dwarf phenotype. Achondroplasia is an example of a trait for which the recessive allele is far more prevalent than the dominant allele.

Huntington's Disease

A lethal dominant allele can escape elimination if it causes death at a relatively advanced age, after the individual has already passed on the lethal allele to his or her children. Huntington's disease is a degenerative disease of the nervous system. The dominant lethal allele has no obvious phenotypic effect until the individual is about 35 to 45 years old. Then the deterioration of the nervous system is irreversible and inevitably fatal. Any child born to a parent who has the allele for Huntington's disease has a 50% chance of inheriting the disease and the disorder. Recently, molecular geneticists have used pedigree analysis of affected families to track the Huntington's allele to a locus near the tip of chromosome 4.

A dominant allele is not necessarily more common in a population than the recessive allele. For example, one baby in 400 is born with polydactyly, a condition in which individuals are born with extra fingers or toes. Polydactyly is due to a dominant allele. However, the recessive allele is far more prevalent than the dominant allele.

Chromosome mutation

Aneuploidy is the term used to describe any abnormal number of chromosomes either an increase or decrease in total number. Several serious human disorders are due to alterations of chromosome number and structure. Although the frequency of aneuploid zygotes may be quite high in humans, most of these alterations are so detrimental to development that the embryos are spontaneously aborted long before birth. Surviving individuals have a set of symptoms (syndrome) characteristic of the type of aneuploidy.

One aneuploid condition, **Down syndrome**, is due to three copies of **chromosome 21**, or **trisomy 21** (Figure 18.19). Although chromosome 21 is the smallest human chromosome, trisomy 21 severely alters an individual's phenotype in specific ways.

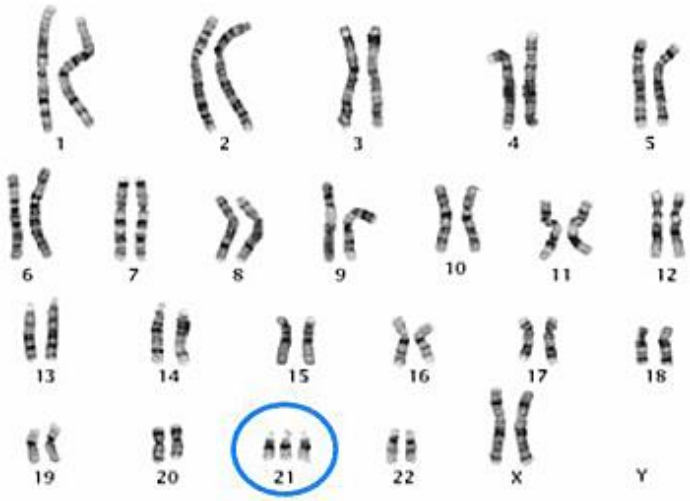


Figure 18.19 Embryology Trisomy 21
Source: Hill, M.A. (2016) Embryology Trisomy 21. Retrieved from https://embryology.med.unsw.edu.au/

Down Syndrome is the historic name used for this condition identified by J L H Down, who described the "phenotypic features that includes mental retardation and characteristic facies" in 1866.

Individuals with Down syndrome have characteristic facial features, short stature, heart defects, susceptibility to respiratory infection, mental retardation, and increased risk of developing leukemia and Alzheimer's disease. Most are sexually underdeveloped and sterile.

Down syndrome results from **nondisjunction** during gamete production in one parent (Figure 18.20). The frequency of Down syndrome increases with the age of the mother.

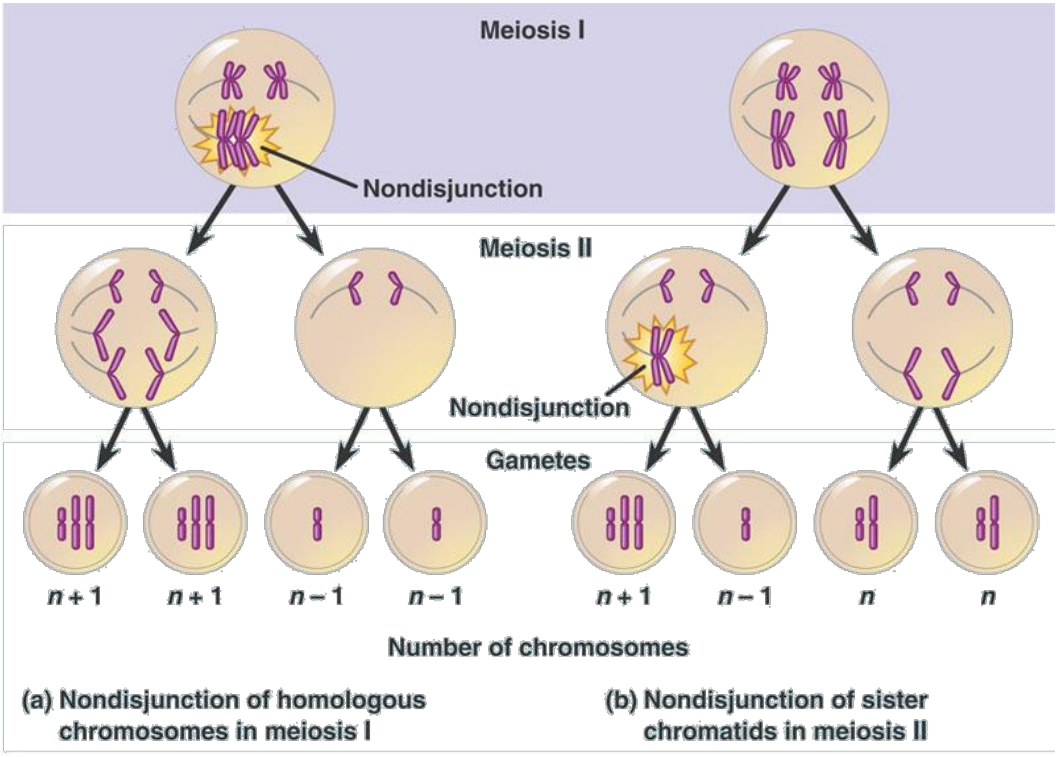


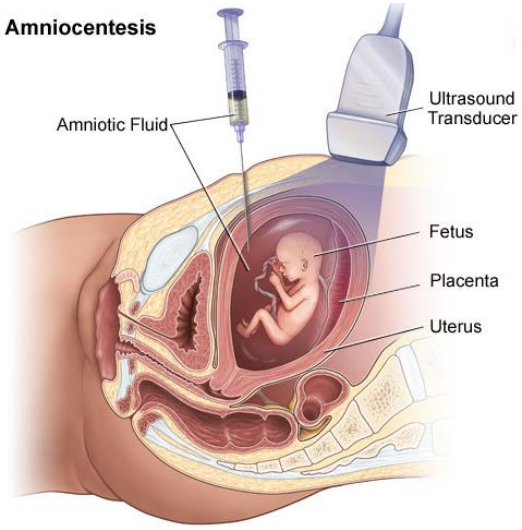
Figure 18.20 Down syndrome or trisomy 21 is caused by nondisjunction of chromosome 21 in a parent who is chromosomally normal
Source: © 2014 Pearson Education

Extension

Amniocentesis & Other In-utero Techniques

Tests are available to determine in utero whether a child has a particular disorder. One technique, amniocentesis, can be used from the 14th to 16th week of pregnancy to assess whether the fetus has a specific disease. Fetal cells extracted from amniotic fluid are cultured and karyotyped to identify some disorders. Other disorders can be identified from chemicals in the amniotic fluids. Other techniques such as ultrasound allow fetal health to be assessed visually in utero.

Amniocentesis can cause complications such as maternal bleeding or fetal death in about 1% of cases. Therefore, the technique is usually reserved for cases in which the risk of a genetic disorder or other type of birth defect is relatively great. If fetal tests reveal a serious disorder, the parents face the difficult choice of terminating the pregnancy or preparing to care for a child with a genetic disorder.



Extension

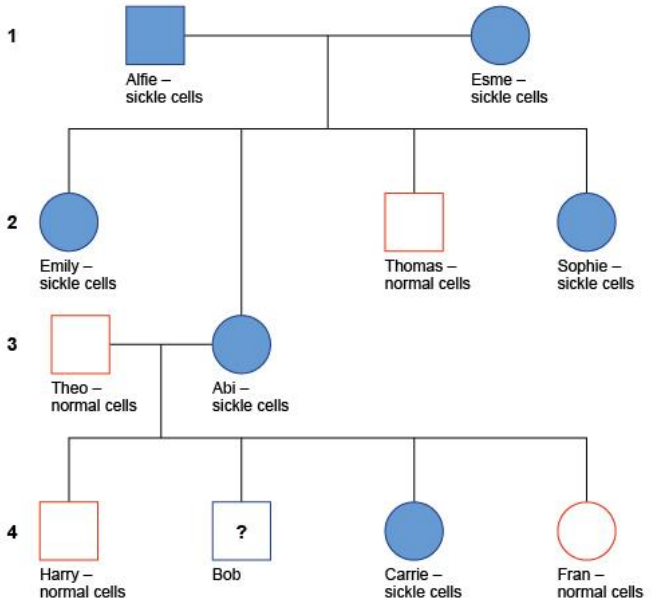
Genetic Testing & Counseling

A preventive approach to simple Mendelian disorders is sometimes possible. The risk that a particular genetic disorder will occur can sometimes be assessed before a child is conceived or early in pregnancy. Many hospitals have genetic counselors to provide information to prospective parents who are concerned about a family history of a specific disease.

Pedigree Analysis

In pedigree analysis, rather than manipulate mating patterns of people, geneticists analyse the results of matings that have already occurred. Information about the presence or absence of a particular phenotypic trait is collected from as many individuals in a family as possible, across generations. The distribution of these characters is then mapped on the family tree.

Example:
Alfie and Esme both have sickle cell anaemia. Of their four children, three have sickle cell, one does not (Thomas). One child, Abi who has sickle cell disease, has children with Theo, who has normal cells. They have four children. Two have normal cells and one has sickle cells. Doctors can work out the chance of Bob having sickle cells. Note that you will not be asked to work out actual probabilities from pedigree diagrams, but will need to know how to do this with Punnett squares.



For standard pedigree nomenclature, you may refer to https://www.meb.uni-bonn.de/cancer.gov/.

NAME radiation and chemicals as factors which may increase the rate of mutation.

Radiation and **chemicals** increase the rate of frequency of mutation. Radiation such as UV rays, X-rays and gamma rays and chemicals such as mustard gas, caffeine and colchicine damage thousands of nucleotides in every cells every day.

Most of the time, mutation is reversed. DNA repair constantly occurs in cells, fixing mismatched nucleotides and splicing broken DNA strands back together. Yet some DNA changes remain. If a cell accumulates too many changes, it either stops dividing or self-destructs. If any of these processes go wrong, the cell could become cancerous.

7. CONTINUOUS & DISCONTINUOUS VARIATIONS

DESCRIBE the difference between continuous and discontinuous variation and give examples of each.

Variations are differences in traits between individuals of the same species. Some traits in a certain species of organisms show **discontinuous variation**, and some traits show **continuous variation**.

In **discontinuous variation**, the phenotypes are **distinct**, with **no intermediates** (no other possibilities or values in between). The trait is controlled by a **single pair of genes** or a **small number of genes**. The characteristic **cannot be altered by the environment**.

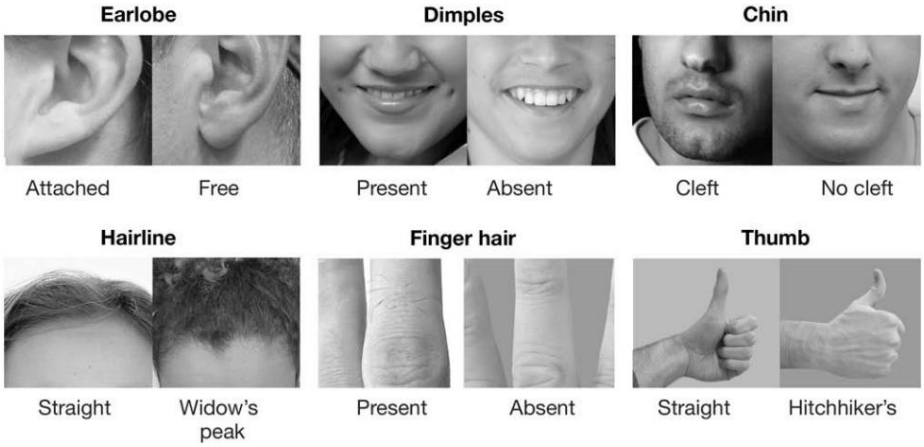
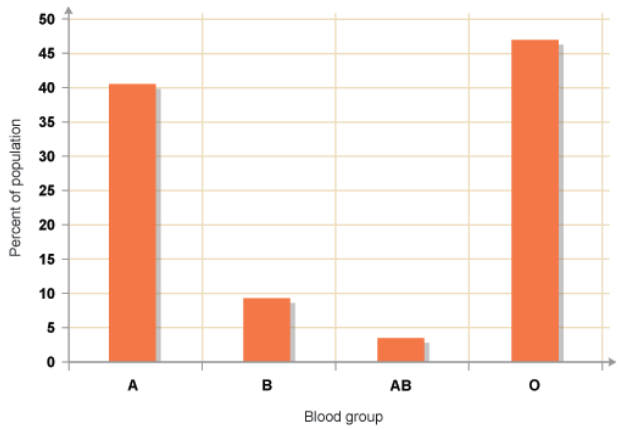
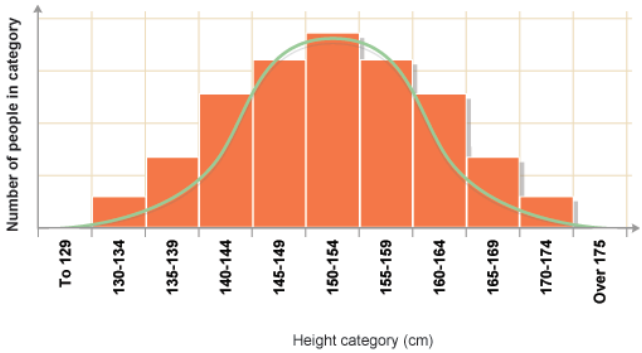


Figure 18.21 Examples of human traits that show discontinuous variation

In **continuous variation**, there are **no distinct phenotypes** but a **whole range of possible intermediates** yielding a normal distribution. The trait is controlled by **two or more independent pairs of genes** which affect the same trait in the same way in an additive fashion. The phenotype arises from the **interaction between the genotype and the environment**. Examples of continuous variation include height and weight in humans.

Table 18.2 Comparison between discontinuous & continuous variation

discontinuous variation	**continuous variation**
phenotypes are distinct, with no intermediates	no distinct phenotypes but a whole range of possible intermediates
controlled by a single pair or a small number of genes	controlled by many genes (polygenic effect)
cannot usually be altered by the environment	always the result of interaction between the genotype and environment
drawn as a **bar chart** with gaps between bars and no increasing x-axis Example:  	drawn as frequency **histogram** or polygon (the data shows a normal distribution) Example:  [the more people you measure, and the smaller the categories you use, the closer the results will be to the curved line]
examples: gender (male or female), human ABO blood group, eye colour	examples: height, weight, intelligence

EXPLAIN the genetic basis of continuous variation (many, additive, genes control a characteristic) and discontinuous variation (one or few genes control a characteristic).

Phenotype depends on both environment and genes. In plants, a single tree may have leaves that vary in size, shape, and greenness, depending on exposure to wind and sun.For humans, nutrition influences height, exercise alters build, sun-tanning darkens skin, and experience improves performance on intelligence tests. Even genetically identical twins accumulate phenotypic differences as a result of their unique experiences.

The product of a genotype is generally not a rigidly defined phenotype, but a range of phenotypic possibilities, the norm of reaction, determined by the environment. In some cases, the norm of reaction has no breadth, and a given genotype specifies a particular phenotype (e.g. blood type). In contrast, a person's red and white blood cell count varies with factors such as altitude, customary amount of exercise and presence of infection.

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 19 – Molecular Genetics

Name: **Class:**

A. Content
- Nucleic Acids – DNA & RNA
- Transcription & Translation
- DNA Recombinant Technology

B. Learning Outcomes

At the end of the chapter, students should be able to:
(a) OUTLINE the relationship between DNA, genes and chromosomes.
(b) DESCRIBE the structure and roles of DNA and RNA (tRNA, rRNA and mRNA) (Mitochondrial DNA is not required).
(c) STATE that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides.
(d) STATE that each gene is a sequence of nucleotides, as part of a DNA molecule.
(e) EXPLAIN how a change in the sequence of the DNA nucleotide (gene mutation) may affect the amino acid sequence in a protein, and hence the phenotype of the organism e.g. sickle cell anaemia (Knowledge of substitution, addition, deletion and frameshift mutation are not required).
(f) EXPLAIN that genes may be transferred between cells. Reference should be made to the transfer of genes between organisms of the same or different species – transgenic plants or animals.
(g) Briefly EXPLAIN how a gene that controls the production of human insulin can be inserted into bacterial DNA to produce human insulin in medical biotechnology.
(h) DISCUSS the social and ethical implications of genetic engineering

Use the knowledge gained in this section in new situations or to solve related problems.

C. References

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D. Lecture Outline
1. Introduction
2. DNA, Genes & Chromosomes
3. Nuclei Acids
4. Transcription & Translation
5. Gene Mutation
6. Recombinant DNA Technology
7. Social & Ethical Implications of Genetic Engineering

E. Practical Work
- Bacterial Transformation

1. INTRODUCTION

The second half of the 19th century was a time of remarkable advances in genetic research. In the 1860s, Gregor Mendel and Charles Darwin began to explore possible mechanisms of **heredity**. Over the next few decades, Walther Flemming, Theodor Boveri, and Walter Sutton made significant discoveries involving **chromosomes**. In the early 20th century, Thomas Hunt Morgan and other researchers provided concrete evidence that linked the inheritance of genetic traits to the behavior of chromosomes.

The chemical nature and structure of **deoxyribonucleic acid** (**DNA**) (Figure 19.1) were elucidated in the middle of the 20th century. Prior to that point, scientists spent years speculating which types of molecules within cells contained the hereditary information. Eventually, researchers confirmed DNA as the substance responsible for the transfer of traits from one generation to the next.

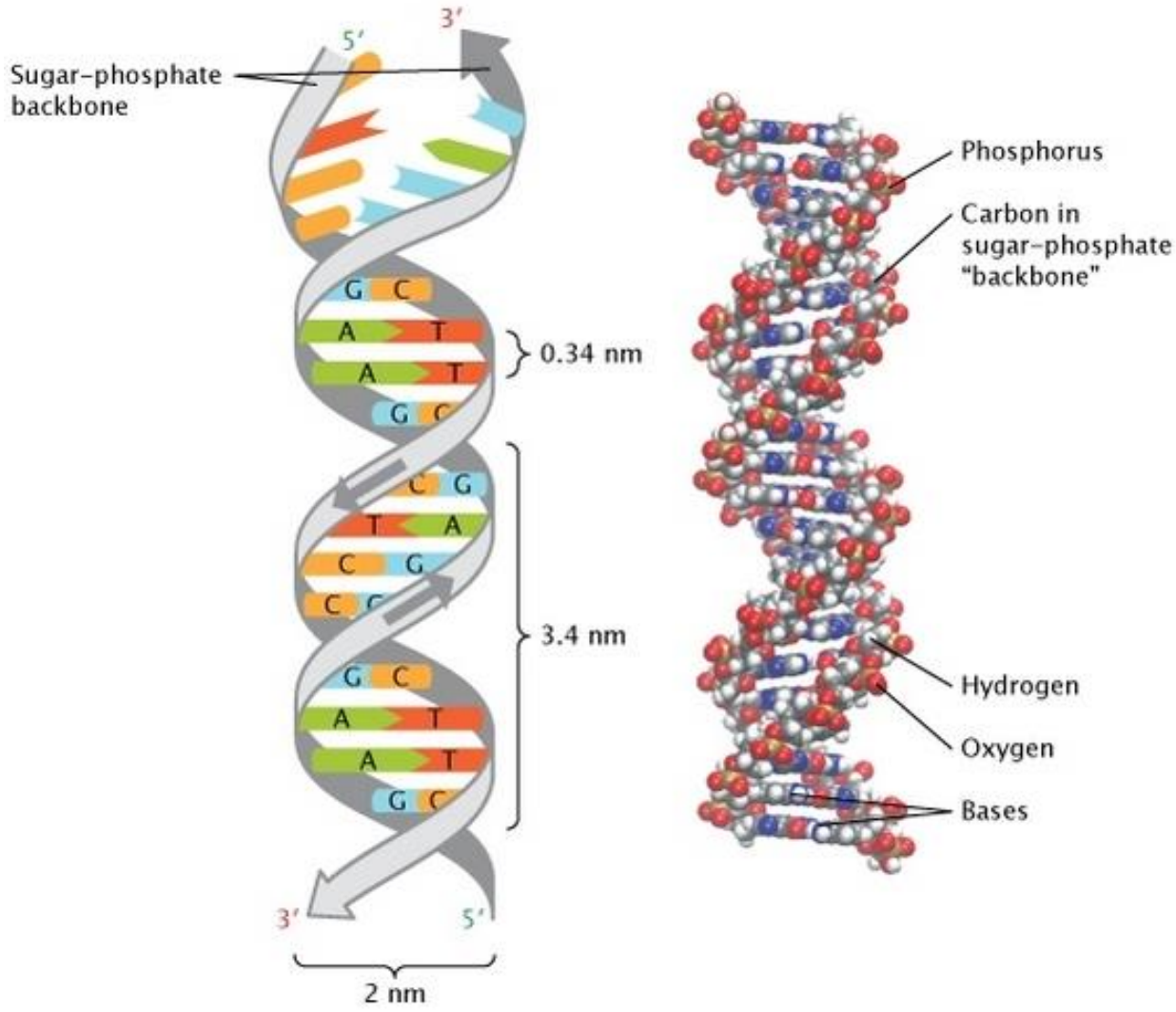


Figure 19.1 The double-helical structure of DNA
The 3-dimensional double helix structure of DNA, correctly elucidated by James Watson and Francis Crick. Complementary bases are held together as a pair by hydrogen bonds.

Many people believe that American biologist James Watson and English physicist Francis Crick discovered DNA in the 1950s. In reality, DNA was first identified in the late 1860s by Swiss chemist Friedrich Miescher. In the decades following Miescher's discovery, other scientists – notably Phoebus Levene and Erwin Chargaff – carried out a series of research efforts that revealed additional details about the DNA molecule, including its primary chemical components and the ways in which they joined with one another. Chargaff's realization that A = T and C = G, combined with some important X-ray crystallography work by English researchers Rosalind Franklin (Figure 19.2) and Maurice Wilkins, contributed to Watson and Crick's derivation of the three-dimensional, double-helical model for the structure of DNA. Without the scientific foundation provided by numerous scientists, Watson and Crick may never have reached their ground breaking conclusion of 1953: that the DNA molecule exists in the form of a three-dimensional **double helix**.

Double helix refers to the double-stranded DNA that is composed of two linear strands that run opposite to each other, known as anti-parallel strands and these strands are twist together (Figure 19.1).

The structure of DNA can also be described as a ladder. The chemical backbones of the ladder are made up of sugar and phosphate molecules that are connected by chemical bonds. The rungs of the ladder are pairs of units between A and T or between C and G. These pairs are called base pairs and they connect the two sugar-phosphate backbones through hydrogen bonds.

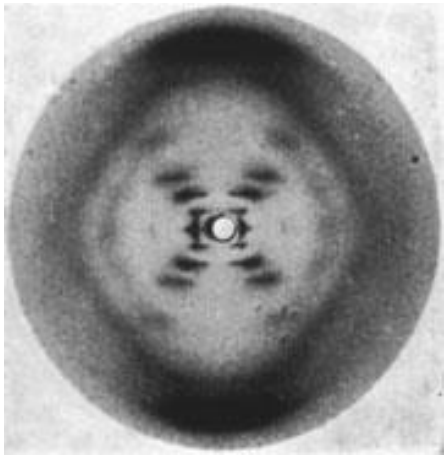


Figure 19.2 Rosalind Franklin's X-ray diffraction image of DNA. Images like this one enabled the precise calculation of molecular distances within the double helix.

2. CHROMOSOMES, DNA & GENES

OUTLINE the relationship between DNA, genes and chromosomes.

The haploid human genome contains approximately 3 billion base pairs of DNA packaged into 23 chromosomes. Most cells in the body (except for female ova and male sperm) are diploid, with 23 pairs of chromosomes. That makes a total of 6 billion base pairs of DNA per cell. Because each base pair is around 0.34 nanometers long (a nanometer is one-billionth of a meter), each diploid cell therefore contains about 2 meters of DNA [$(0.34 \times 10^{-9}) \times (6 \times 10^{9})$]. Moreover, it is estimated that the human body contains about 50 trillion cells, which works out to 100 trillion meters of DNA per human!

2.1 Chromosomes

The process of fitting DNA into dense compact forms is known as **DNA packaging**. During DNA packaging, long pieces of double-stranded DNA are tightly looped, coiled and folded so that they fit easily within the cell. DNA wraps around special **proteins** called **histones**, thereby compacting it enough to fit inside the nucleus. The resulting DNA-protein complex is called **chromatin** (Figure 19.3).

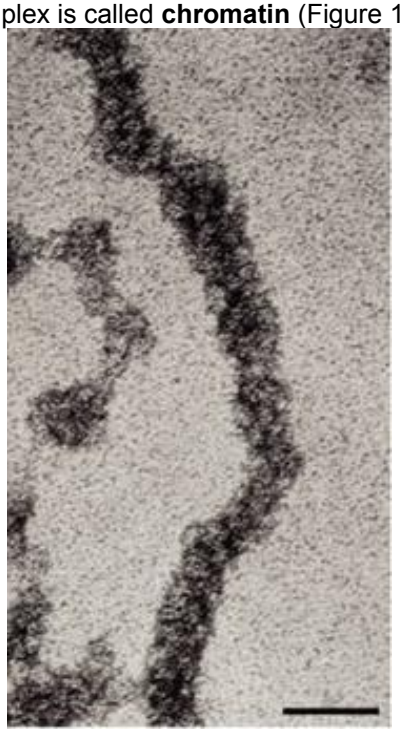


Figure 19.3(a) Electron micrograph of chromatin A 30nm fiber of chromatin. Scale bar = 50nm.

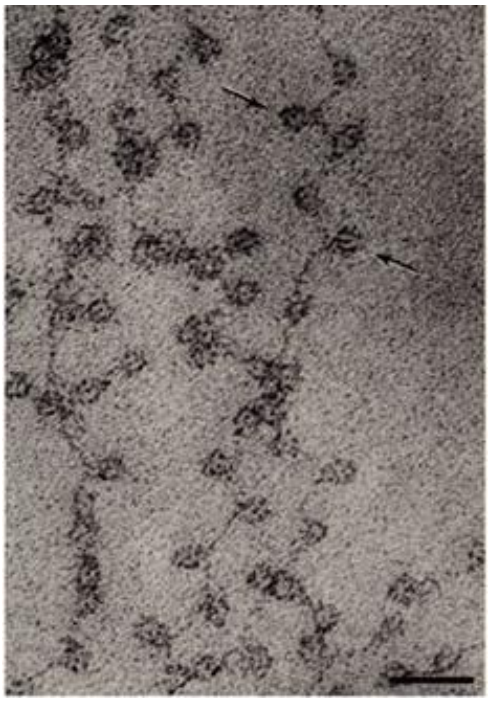


Figure 19.3(b) Electron micrograph of chromatin. In this micrograph, nucleosomes are indicated by arrows.

DNA can be further compressed through a twisting process called supercoiling. In both eukaryotes and prokaryotes, the highly compacted DNA is then arranged into structures called **chromosomes** (Figure 19.4). Chromosomes take different shapes in different types of organisms. Most eukaryotes have one or more linear chromosomes, which often appear as X-shaped structures. At different times during the cell cycle, the DNA can be tightly compacted into a structure that is visible under a microscope, or it can be more loosely distributed and resemble a pile of string. Refer to Figure 19.4 for the levels of organisation in DNA.

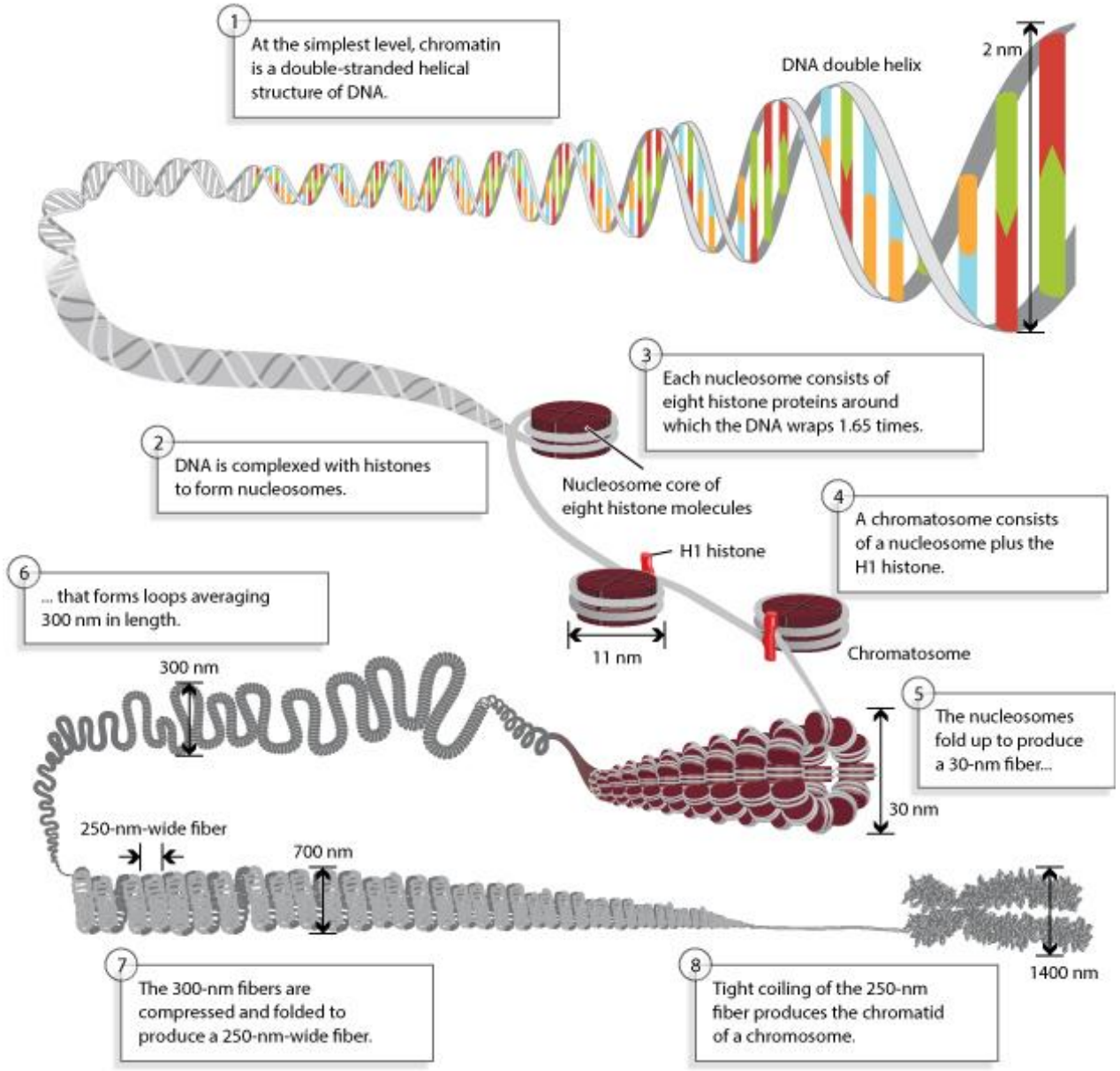


Figure 19.4 Chromosomes are composed of DNA tightly-wound around histones. Each nucleosome is composed of DNA wound around eight histone proteins. Nucleosomes fold up to form a 30-nanometer chromatin fiber, which forms loops averaging 300 nanometers in length. The 300 nm fibers are compressed and folded to produce a 250 nm-wide fiber, which is tightly coiled into the chromatid of a chromosome.

2.2 Deoxyribonucleic acid (DNA)

DNA is a linear molecule made up of basic units known as **deoxyribonucleotides**. Each nucleotide consists of three parts: a **nitrogenous base**, a **deoxyribose (pentose) sugar**, and a **phosphate group** (Figure 19.5).

The nitrogenous bases are rings of carbon and nitrogen that come in two types: purines and pyrimidines. Purines have a six-membered ring joined to a five-membered ring. In a DNA molecule, there are two different pyrimidines – **cytosine** (C) and **thymine** (T), and two different purines – **adenine** (A) and **guanine** (G).

The deoxyribose (pentose) sugar is joined to the nitrogenous base. The combination of a pentose and a nitrogenous base is a nucleoside.

The addition of a phosphate group creates a **nucleotide**. **Polynucleotides** are synthesised when adjacent nucleotides are joined by covalent bonds. The process creates a repeating **sugar-phosphate backbone** (Figure 19.6).

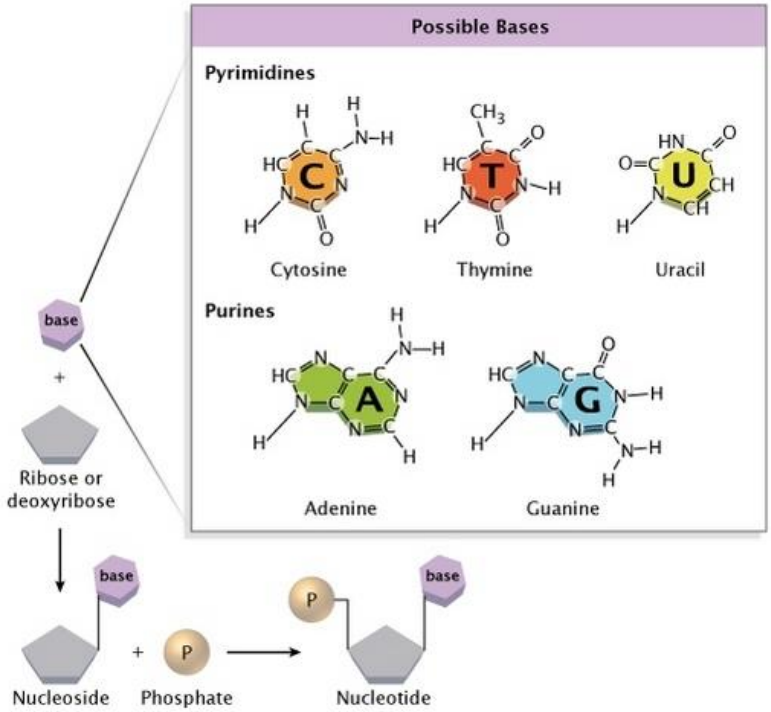


Figure 19.5 The chemical structure of a nucleotide.
The five-carbon sugar is either a ribose (in RNA) or a deoxyribose (in DNA) molecule.

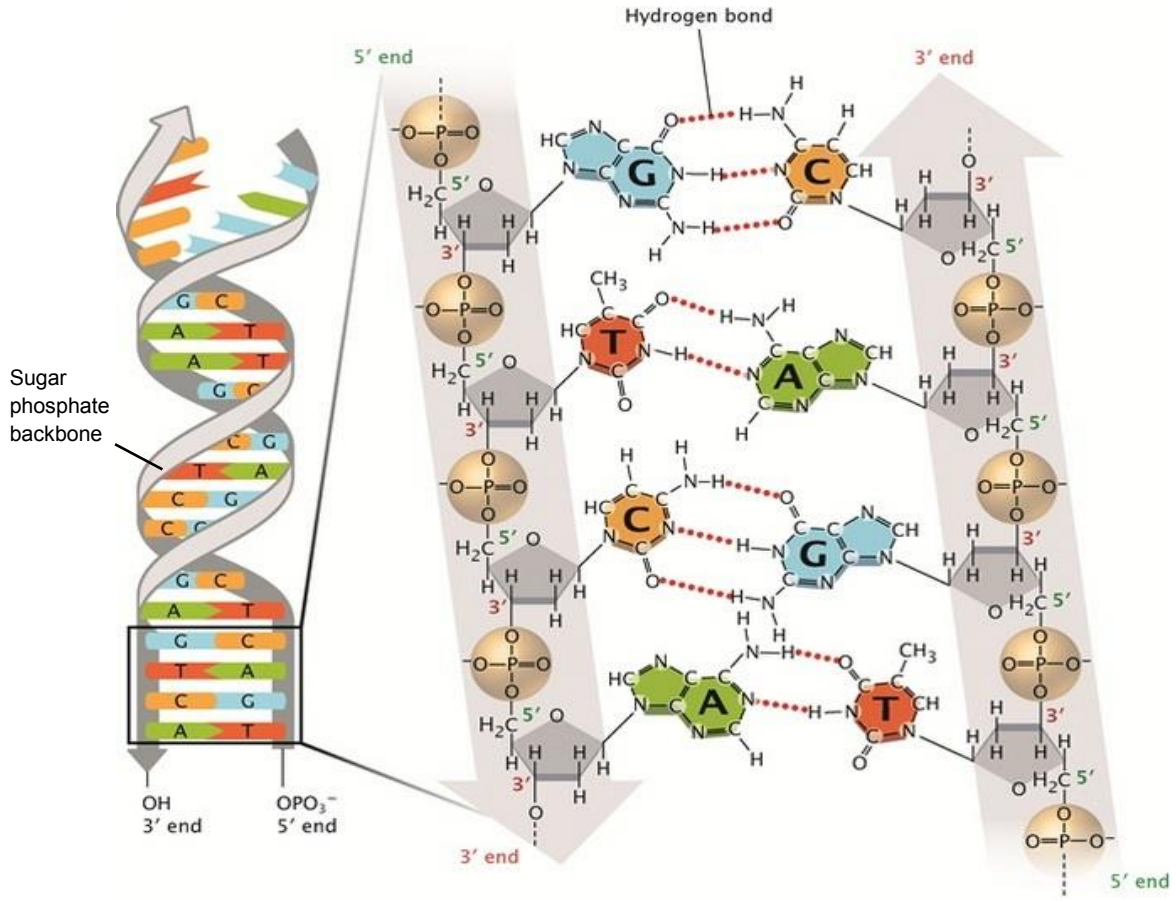
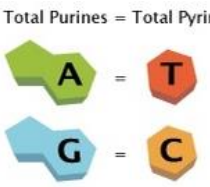


Figure 19.6 Base pairing in DNA.
Two hydrogen bonds connect T to A; three hydrogen bonds connect G to C.

The two polynucleotides or strands are held together by **hydrogen bonds**. Because of their shapes, only some bases are compatible with each other. Adenine (A) always pairs with thymine (T) and guanine (G) with cytosine (C). With these **base-pairing rules**, if we know the sequence of bases on one strand, we know the sequence on the opposite strand. The two strands are **complementary** (Figure 19.6).

Prior to cell division, each of the strands serves as a template to order nucleotides in a new complementary strand. This results in two identical copies of the original double-stranded DNA molecule, which are then distributed to the daughter cells during mitosis.

The two free ends of the polynucleotide are distinct. One end has a phosphate attached to a 5' carbon; this is the 5' end. The other end has a hydroxyl group on a 3' carbon; this is the 3' end. The sugar-phosphate backbones run in opposite 5' → 3' directions from each other, an arrangement referred to as **antiparallel** (Figure 19.6).



Extension

Chargaff's rule
All DNA follows Chargaff's Rule, which states that the total number of purines in a DNA molecule is equal to the total number of pyrimidines.

2.3 Genes

STATE that each gene is a sequence of nucleotides, as part of a DNA molecule.

A **gene** is a *sequence of deoxyribonucleotides (bases)*. Each gene encoded for the synthesis of a single **polypeptide**, which can be used to make **proteins**.

Each gene stores a message (known as the genetic code) that determines how a protein should be made.

3. NUCLEIC ACIDS

DESCRIBE the structure and roles of DNA and RNA (tRNA, rRNA and mRNA).

There are two types of **nucleic acids**: **DNA** and **ribonucleic acid** (**RNA**) (Figures 19.7(a) & 19.7(b)). RNA is chemically similar to DNA, except that it contains **ribose** as its sugar and substitutes the nitrogenous base **uracil** for thymine (Figure 19.8).

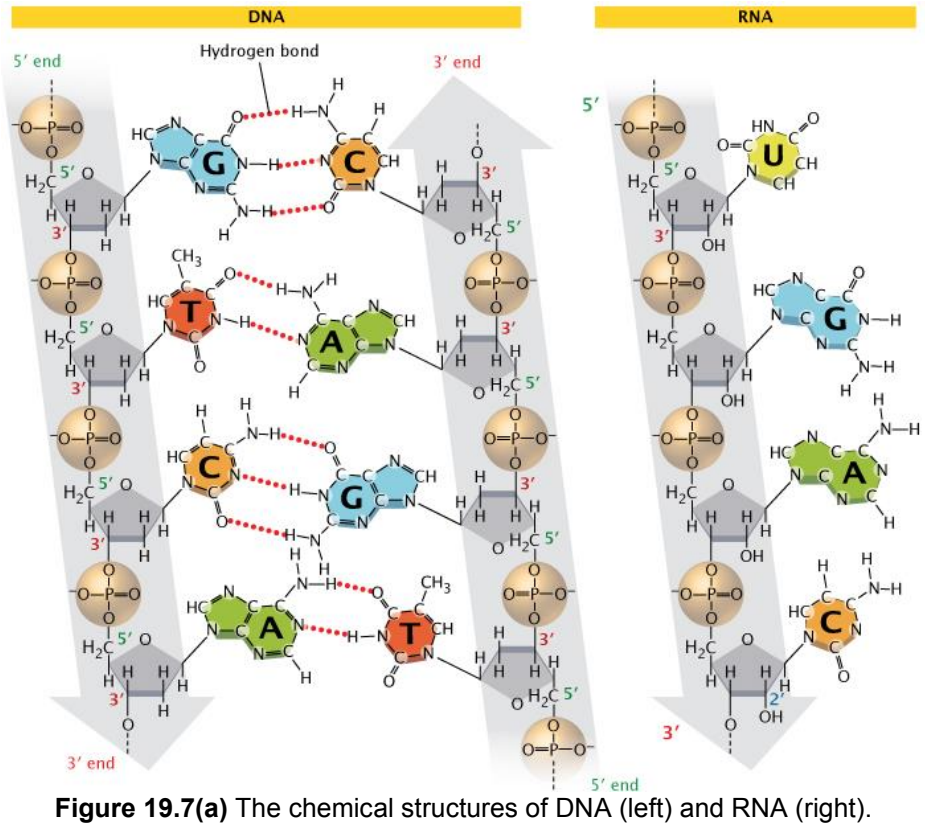


Figure 19.7(a) The chemical structures of DNA (left) and RNA (right).

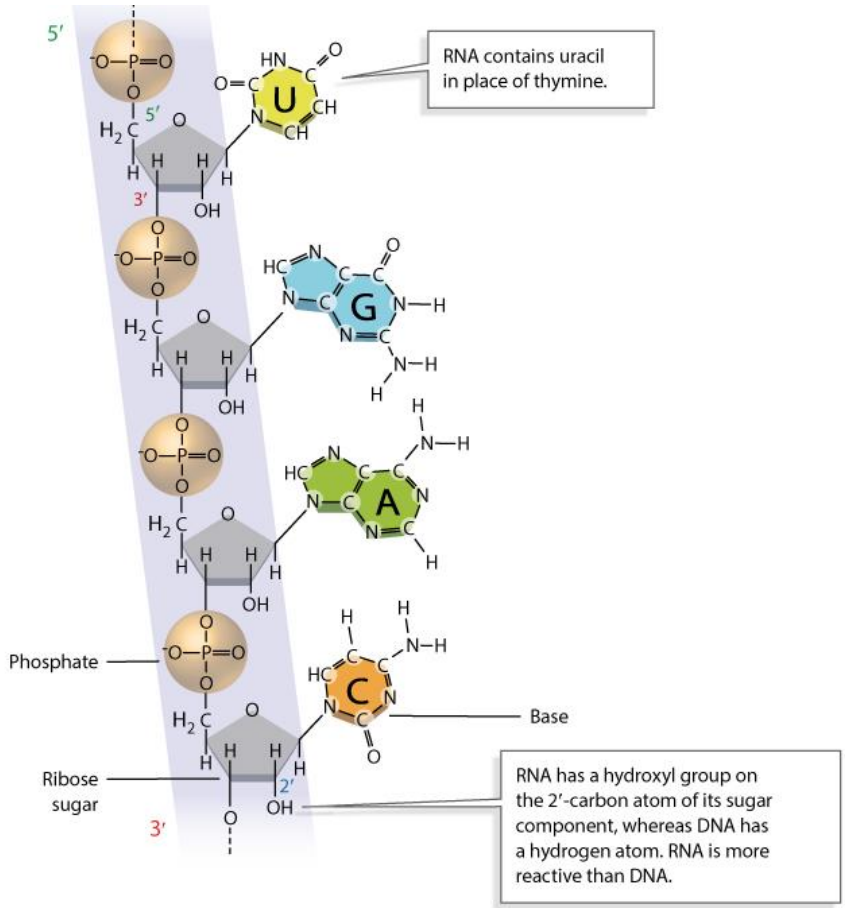


Figure 19.7(b) A region of single-stranded RNA.

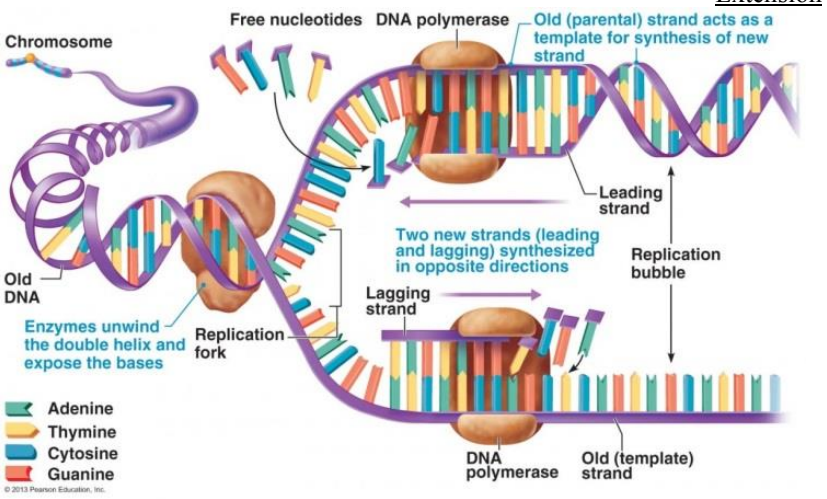
RNA is **single-stranded**. The nucleotide thymine (T) is not present in RNA; rather than binding with thymine, the nitrogenous base adenine (A) base-pairs with the nitrogenous base uracil (U) in RNA.

RNA and DNA are the molecules that enable living organisms to reproduce their complex components from generation to generation. Organisms inherit DNA from their parents. Each DNA molecule is very long, consisting of hundreds to more than a thousand genes. DNA provides directions for its own replication. Before a cell divides, its DNA is copied. The copies are then passed to the next generation of cells.

Extension

DNA Replication

Scientists have devoted decades of effort to understanding how DNA replicates itself. In simple terms, replication involves use of an existing strand of DNA as a template for the synthesis of a new, identical strand. American enzymologist and Nobel Prize winner Arthur Kornberg compared this process to a tape recording of instructions for performing a task: "[E]xact copies can be made from it, as from a tape recording, so that this information can be used again and elsewhere in time and space" (Kornberg, 1960). In reality, the process of replication is far more complex than suggested by Kornberg's analogy.



Researchers typically utilise simple bacterial cells in their experiments, but they still do not have all the answers, particularly when it comes to eukaryotic replication. Nonetheless, scientists are familiar with the basic steps in the replication process, and they continue to rely on this information as the basis for continued research and experimentation.

Although DNA encodes the information that programs all the cell's activities, it is not directly involved in cellular activities. DNA directs **RNA synthesis** and through RNA, controls **protein synthesis**. Proteins implements the instructions contained in DNA.

4. TRANSCRIPTION & TRANSLATION

STATE that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides.

Transcription and **translation** are the two main processes linking gene to protein (Figure 19.8). Genes provide the instructions for making specific proteins. The intermediary between DNA and protein synthesis is the **RNA**.

Each gene along a DNA molecule directs the synthesis of a specific type of RNA called **messenger RNA** (**mRNA**). The mRNA molecule directs the ordering of amino acids in a polypeptide.

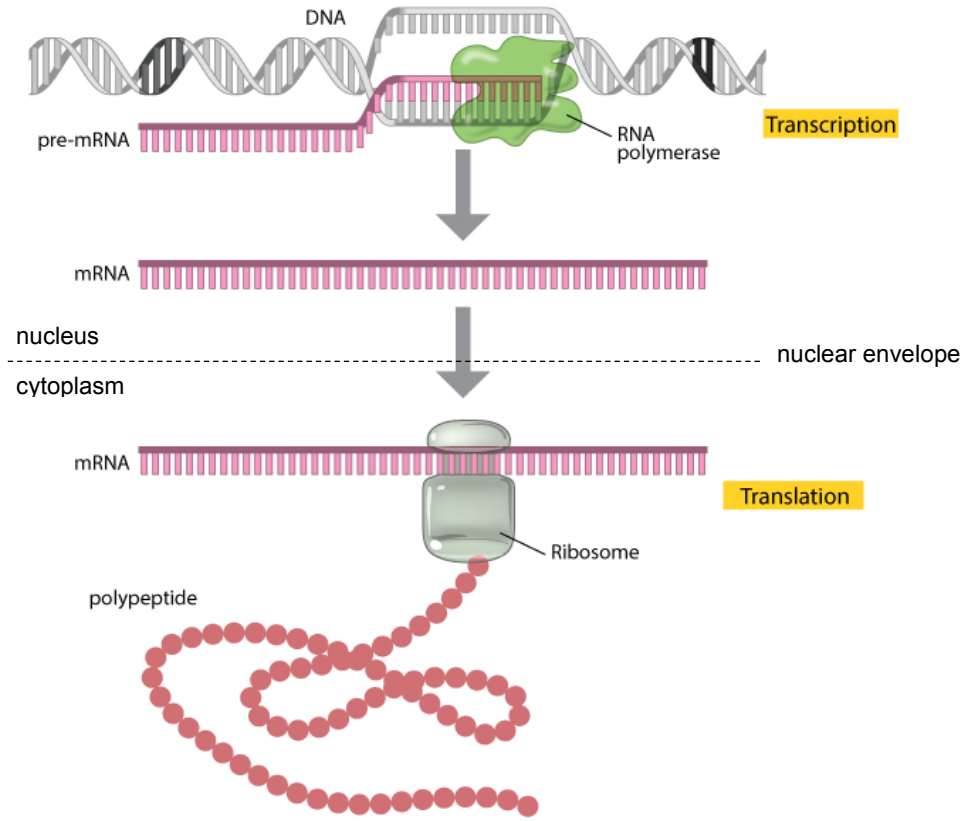


Figure 19.8 The flow of genetic information is DNA → RNA → protein.
This is the Central Dogma, a term coined by Francis Crick in 1958.

Translation occurs on cellular structures called **ribosomes**. In eukaryotes, DNA is located in the nucleus, but most ribosomes are in the cytoplasm. mRNA moves information and directions from the nucleus to the cytoplasm (Figure 19.8). Prokaryotes lack nuclei but still use RNA to carry a message from DNA to the ribosomes.

4.1 Transcription

The process of transcription takes place in the **nucleus**. It begins when an enzyme called RNA polymerase attaches to the template DNA strand and begins to catalyse production of complementary RNA.

The process of transcription is summarised as follows (Figure 19.9):

(a) The DNA strands untwist and then, unzips. The H-bonds between the strands break.
(b) The DNA strand provides a template for the synthesis of a complementary RNA strand. The complementary RNA molecule is synthesised according to **base-pairing rules**, except that **uracil** is the complementary base to adenine.
(c) A **mRNA** molecule is produced. The mRNA base triplets are called **codons**.
(d) The mRNA leaves the nucleus via nuclear pores and enters into the cytoplasm.

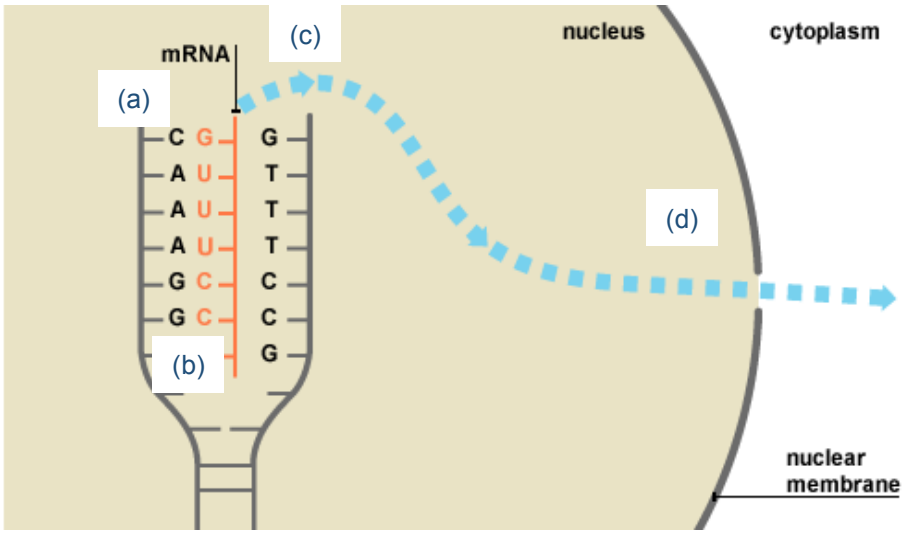


Figure 19.9 The process of transcription.

4.2 Translation

In the process of translation (Figure 19.10), a cell interprets a series of codons along an mRNA molecule and builds a **polypeptide**. Translation takes place on the **ribosomes** in the **cytoplasm**, or on the ribosomes found bound to the rough endoplasmic reticulum (RER). The interpreter is **transfer RNA** (**tRNA**), which transfers amino acids in the cytoplasm to a ribosome.

A cell has all 20 amino acids available in its cytoplasm, either by synthesising them from scratch or by taking them up from the surrounding solution.

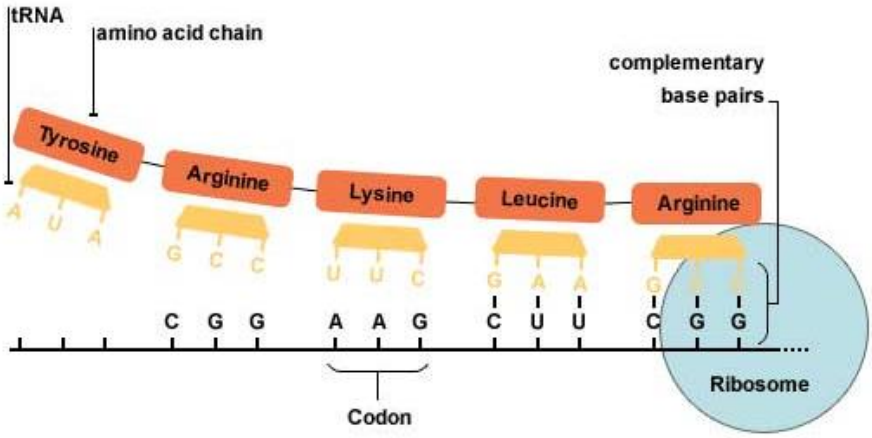


Figure 19.10 The process of translation.

The process of translation is summarised as follows:

a) The **mRNA** strand attaches to a ribosome.
b) Each mRNA codon codes for a **specific amino acid**. The **tRNA** molecules transport **specific amino acids** to the ribosome. The **anti-codons** and **codons** match up and form **complementary base pairs**. If the codon on mRNA is UUU, a tRNA with an AAA anticodon and carrying phenylalanine will bind to it.
c) Codon by codon, the ribosome adds each amino acid carried by tRNA to the growing end of the polypeptide chain in the prescribed order.
d) **Peptide bonds** form between the adjacent amino acids to form the polypeptide (protein).

After translation, the protein is passed from the rough ER to the Golgi apparatus inside vesicles. The Golgi apparatus will modify and package the proteins in a secretory vesicle, which will move toward the cell membrane, fuse with phospholipid bilayer and release the protein out of the cell.

4.3 Amino Acid Sequence

In the genetic code, nucleotide base triplets specify amino acids. If the genetic code consisted of a single nucleotide or even pairs of nucleotides per amino acid, there would not be enough combinations (4 and 16, respectively) to code for all 20 amino acids. Triplets of nucleotide bases are the smallest units of uniform length that can code for all the amino acids. With a triplet code, three consecutive bases specify an amino acid.

During translation, each codon specifies which one of the 20 amino acids will be incorporated at the corresponding position along a polypeptide. Because codons are composed of triplet bases, the number of nucleotides making up a complete gene sequence must be three times the number of amino acids making up the protein product, i.e. it takes at least 300 nucleotides to code for a polypeptide that is 100 amino acids long.

Sixty-one of 64 triplets code for amino acids (Figure 19.11). The codon AUG not only codes for the amino acid methionine but also indicates the "start" or initiation of translation (**start codon**). Three codons do not indicate amino acids but are "stop" signals marking the termination of translation (**stop codon**).

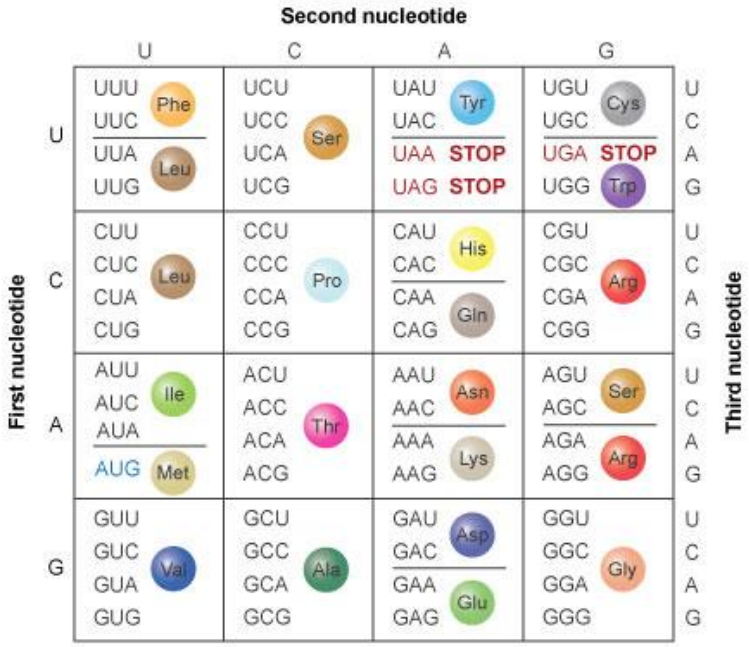


Figure 19.11 The Genetic code which showed that amino acids are specified by each mRNA codon. Multiple codons can code for the same amino acid.

5. GENE MUTATION

EXPLAIN how a change in the sequence of the DNA nucleotide (gene mutation) may affect the amino acid sequence in a protein, and hence the phenotype of the organism e.g. sickle cell anaemia.

Mutations are changes in the **genes** of a cell. Mutations may be the source of new genes. Mutations include large-scale mutations (in which long segments of DNA are affected), as well as point mutations (chemical changes in just one base pair of a gene). If a point mutation occurs in a gamete or in a cell that produces gametes, it may be inherited. If the mutation has an adverse effect on the phenotype of an organism, the mutant condition is referred to as a genetic disorder or hereditary disease.

For example, **sickle-cell anaemia** is caused by a mutation of a **single** base pair in the gene that codes for one of the polypeptides of haemoglobin (Figure 19.12). A change in a single nucleotide in the DNA's template strand leads to an abnormal protein.

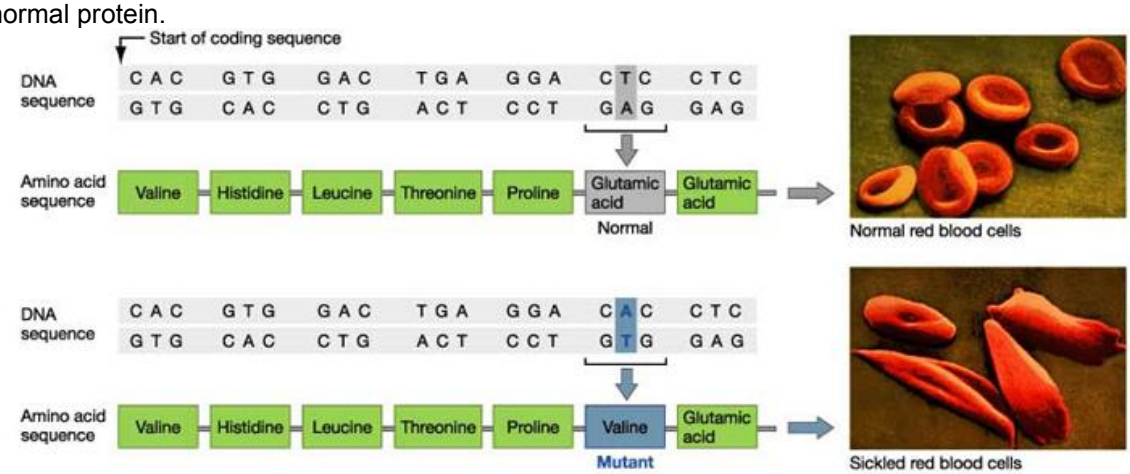


Figure 19.12 Sickle-cell disease is caused by a single point mutation in the beta-haemoglobin gene that converts a GAG codon into a GTG which codes for the amino acid valine rather than glutamic acid.

Mutagens are **chemical** or **radiation** (e.g. x-rays and ultraviolet light) that cause mutations.
Changes in amino acids at crucial sites, especially active sites of enzymes, are likely to affect function. Mutations can have little or no impact on protein function, detrimental or occasionally lead to an improved protein.

6. RECOMBINANT DNA TECHNOLOGY

EXPLAIN that genes may be transferred between cells.

By 2007, researchers had completely sequenced hundreds of prokaryotic genomes and dozens of eukaryotic ones, including all 3 billion base pairs of the human genome. Advances in DNA technology (methods of working with and manipulating DNA) had their roots in the 1970s. A key accomplishment was the invention of techniques for making recombinant DNA, DNA molecules that are formed when segments of DNA from **two different species** are combined *in vitro* (Figure 19.13).

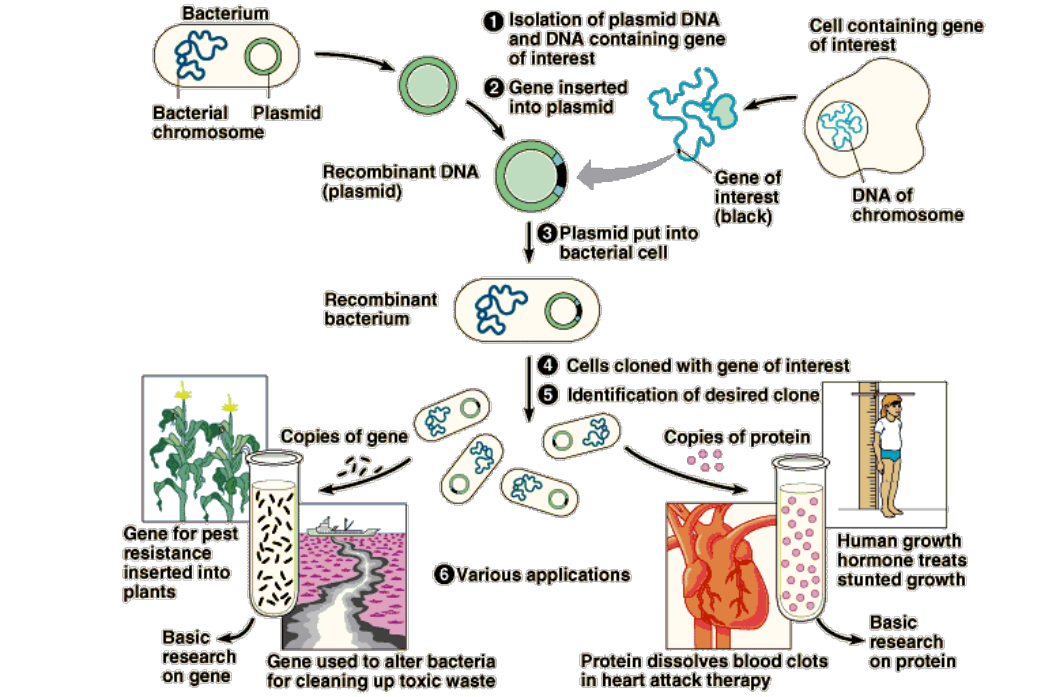


Figure 19.13 DNA Recombinant Technology uses enzymes to cut and paste together DNA sequences of interest.

Scientists have developed methods to isolate the small, well-defined portion of a chromosome that contains the **gene of interest**. One common technique to cloning pieces of DNA uses bacteria whose chromosome is a large circular DNA molecule. In addition, bacteria have **plasmids**, small circular DNA molecules with a small number of genes that replicate independently from the chromosome. The gene cloning begins with the insertion of the gene of interest into a bacterial plasmid to produce a **recombinant DNA molecule**. The plasmid is returned to a bacterial cell, producing a **recombinant bacterium**. Every time the bacterium reproduces, the recombinant plasmid is replicated as well.

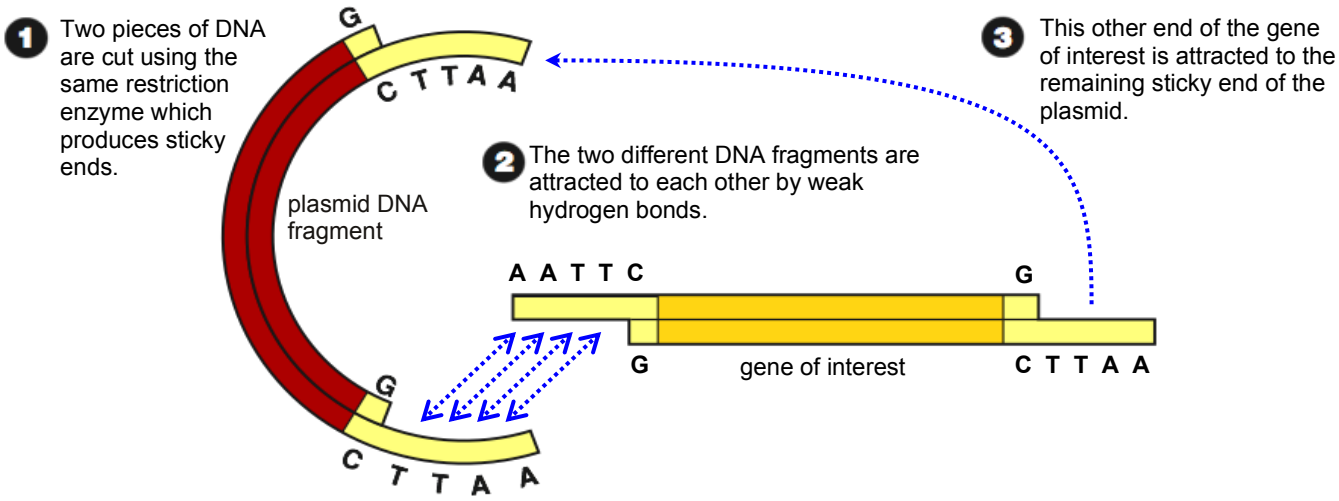


Figure 19.15 Constructing a recombinant plasmid.

Restriction enzymes cut DNA molecules at **specific** locations known as **restriction sites** (short DNA nucleotide sequences). In nature, bacteria use restriction enzymes to cut foreign DNA, to protect themselves against phages or other bacteria. Each restriction enzyme cleaves a specific sequence of bases.

Restriction enzymes cut the covalent sugar-phosphate backbones of both strands, often in a staggered way that creates single-stranded **sticky ends**. These extensions can form hydrogen-bonded base pairs with complementary single-stranded stretches (sticky ends) on other DNA molecules cut with the same restriction enzyme. These DNA fusions can be made permanent by **DNA ligase**, which seals the strand by catalysing the formation of covalent bonds to close up the sugar-phosphate backbone.

Recombinant plasmids are produced when restriction fragments from foreign DNA are spliced into plasmids. The original plasmid used to produce recombinant DNA is called a cloning **vector**, defined as a DNA molecule that can carry foreign DNA into a cell and replicate there. Bacterial plasmids are widely used as cloning vectors because they can easily be isolated from bacteria, manipulated to form recombinant plasmids by *in vitro* insertion of foreign DNA, and then reintroduced into bacterial cells.

BRIEFLY EXPLAIN how a gene that controls the production of human insulin can be inserted into bacterial DNA to produce human insulin in medical biotechnology.

Production of Insulin using Recombinant DNA

Throughout most of the 20th century, people with diabetes depended on insulin extracted from pigs or cows. Unfortunately, only so much insulin can be extracted from these animals, and some diabetics developed allergic reactions to cow and pig insulin. Insulin was the first protein to have its amino acid sequence and structure determined. Insulin is made up of two polypeptide chains.

With recombinant DNA, scientists can insert the human insulin gene into a bacterial plasmid. Steps for the production of insulin encoded by the gene by the **transgenic** bacterium are as follows:

1. The bacterial **plasmid** is removed from the bacterium.
2. The **restriction site** is cut with **restriction enzymes**, revealing '**sticky ends**'.
3. The **gene of interest** – the human insulin gene – is inserted into the restriction site of the plasmid.
4. The complementary **sticky ends** are sealed with **DNA ligase**.
5. The plasmid is returned to the bacterial cell.
6. The transformed bacteria are plated on a **solid nutrient medium**. Each bacterium forms a clone by repeating cell divisions.
7. The recombinant bacteria are cultured in large **fermentation tanks** to produce insulin in large quantities.
8. The substance is harvested and insulin is purified for use.

DISCUSS the social and ethical implications of genetic engineering.

7. SOCIAL & ETHICAL IMPLICATIONS OF GENETIC ENGINEERING

Biotechnology includes such early practices as selective breeding of farm animals and the use of microorganisms to make wine and cheese. Today, biotechnology also encompasses genetic engineering, the direct manipulation of genes for practical purposes. DNA technology is now applied in areas ranging from agriculture to criminal law to medical diagnosis, but many of its most important achievements are in basic research.

Despite the fact that the genes being transferred occur naturally in other species, there are unknown consequences to altering the natural state of an organism through foreign gene expression.

7.1 Effects on the Environment

- The release of a new genetically engineered species would also have the possibility of causing an imbalance in the ecosystem.
- Examples:
  - Salmon have been engineered to grow larger and mature faster, and will feed on fish that previously they are unable to.
  - Enhanced mating advantages of the genetically modified fish led to a reduction in the viability of their offspring.

7.2 Effects on Humans

- There are potential health risks.
- Examples:
  - Exposure to new allergens in genetically modified foods

- Eating foods with antibiotic-resistance genes may reduce the effectiveness of antibiotics to fight disease.
- Genetically modified strain of bacterium or virus may turn virulent and cause a serious health epidemic.
- Biological weapons may reproduce faster, in larger quantities in shorter periods of time.

7.3 Economic Issues

- Examples:
  - Private companies will claim ownership of the organisms they create and not share them at a reasonable cost with the public.
  - Large-scale farm production centres that can afford the costly seeds will dominate over small farmers who cannot afford the technology.

7.4 Ethical and Social Issues

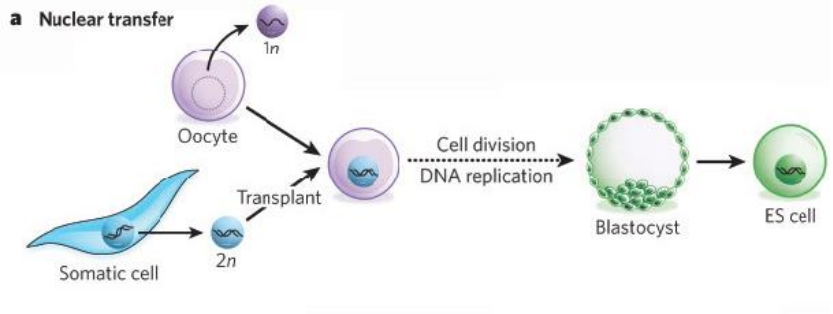
- Public reaction to the use of genetic engineering has been mixed. The production of medicines has generally been welcomed. However, "Playing God" has become a strong argument against genetic engineering.
- One major concern is that once an altered gene is placed in an organism, the process cannot be reversed.

Genetic engineering will benefit mankind when used for purposes such as increasing the availability and quality of food and medical care, and contributing to a cleaner environment. With due diligence and thorough attention, they can result in an improved economy without doing more harm than good, and they could also make the most of their potential to alleviate hunger and disease worldwide.

Extension

Successful cloning by Somatic Cell Nuclear Transfer (SCNT) in mammals

In 1997, Ian Wilmut and colleagues created the first ever cloned mammal, Dolly, who is undoubtedly the most famous sheep that ever lived (Wilmut *et al.* 1997). They created Dolly by using the SCNT strategy to fuse an adult sheep mammary cell with a sheep egg cell whose nucleus had been removed and then implanting the resulting cell into an adult recipient female sheep. This milestone achievement showed that the genome of fully differentiated mammalian cells remains genetically totipotent. Stem cells are able to generate all the cell types that make up an organism and the extra-embryonic tissues; in mammals, only zygotes and cells from early-blastocyst-stage embryos are considered totipotent.



b

Source: © Nature Publishing Group

a In the major steps of SCNT, researchers transplant the nucleus of a somatic cell (which is diploid) into an enucleated oocyte. In the environment of the oocyte, the somatic cell nucleus is reprogrammed so that the cells derived from it are pluripotent. From this oocyte, a blastocyst forms, from which embryonic stem (ES) cell lines are derived in tissue culture. If development proceeds to completion, an entire cloned organism forms.
Reference: Yamanaka S. & Blau H.M. (2010) Nuclear reprogramming to a pluripotent state by three approaches. Nature 465, 704–712.

b Wilmut and colleagues created lamb number 6LL3, better known as Dolly, in 1997 at the Roslin Institute. They derived Dolly from the mammary gland of a Finn Dorset ewe using a Scottish Blackface ewe as the recipient.
Reference: Wilmut, I., Schnieke, A. E., McWhir, J., Kind, A. J. & Campbell, K. H. (1997) Viable offspring derived from fetal and adult mammalian cells. Nature 385, 810–813.

Another milestone in stem cell research happened in 1998 when James Thomson and colleagues at the University of Wisconsin reported that they could isolate and culture human embryonic stem (ES) cells from a region of an early-stage embryo called the inner cell mass (Thomson *et al.* 1998). Cultured human ES cells are pluripotent stem cells because they can be grown under specific conditions that coax them to form each of the different cell types of the human body. How can scientists use ES cells in research? The ability to culture and maintain human ES cells in a pluripotent state provided an incredibly powerful research tool that has enhanced our understanding of human developmental biology, propelled drug discovery, and advanced the field of regenerative medicine, which focuses on rebuilding and repairing damaged or diseased tissue.

Soon after Dolly, scientists cloned mice using similar SCNT strategies that often involved the fusion of nuclei from highly differentiated cells, including neurons and lymphocytes (Eggan *et al.* 2004; Hochedlinger & Jaenisch 2002). Scientists have now cloned an ever-expanding assortment of mammals, showing that terminally differentiated cells remain genetically totipotent and capable of supporting the development of an entire organism.

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 20 – Evolution

Name: **Class:**

A. Content

- Natural Selection
- Evolution
- Artificial Selection

B. Learning Outcomes

Students should be able to:
(a) state that competition which arises from variation leads to differential survival of, and reproduction by, those organisms best fitted to the environment.
(b) explain, with examples, how environmental factors act as forces of natural selection.
(c) explain why variation is important in selection.
(d) assess the importance of natural selection as a possible mechanism for evolution.
(e) explain how natural selection may bring about evolution.
(f) give examples of artificial selection such as in the production of economically important plants and animals

C. References

1. Clegg, C. J. and Mackean, D. G. Advanced Biology: Principles and Applications (2nd ed). John Murray (Publishers) Ltd.
2. Hoh, Y. K. Longman A-Level Course in Biology (1st ed). Singapore: Longman.
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5. Reece, J, B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., Jackson, R. B. Campbell Biology (10th ed). Pearson.
6. Starr, C. Biology Concepts and Applications (6th ed). Brooks/Cole Publishing Company.
7. Toole, G. and Toole, S. Understanding Biology for Advanced Level (4th ed). Nelson Thornes (Publishers) Ltd.

D. Lecture Outline

1. Evolution by Natural Selection
2. Environmental Factors on Natural Selection
3. Artificial Selection
4. Additional Reading Materials

E. Practical Work

- NIL

1. SELECTION

1.1 Variation

- **Variations** in organisms may arise due to:
  (1) crossing over and independent assortment of chromosomes during meiosis
    - crossing over during prophase I of meiosis
    - independent assortment and segregation of **homologous chromosomes** during metaphase I and anaphase I of meiosis respectively.
    - independent assortment and segregation of **chromatids** during metaphase II and anaphase II of meiosis (if crossing over occurred previously) respectively.
    - random fertilisation of gametes
  (2) **mutation** in genetic material
    - chromosomal and genetic mutation (refer to the topic on heredity)
  (3) environmental factors, e.g. diet, exposure to sunlight

- Mutation provides new alleles to the **gene pool** for natural selection to act on.
- Genetic variation is important to help organism **adapt** and **survive** in changing environments.

Figure 20.1 A population of Asian ladybird beetles which vary in colour and spot pattern

1.2 Natural Selection and descent with modification

- 'The Theory of Evolution by Natural Selection' was put forward by the English naturalist, Charles Darwin (Fig. 20.2).
- Darwin proposed that the **environment would *select for* individuals that are most adapted for it to survive and reproduce**.
- **Environment *selects against* individuals** that are **not adapted**.
- Those selected against cannot **survive and reproduce**.
- How successful or fit an individual is measured by the **ability to survive and reproduce**.
- Successful individuals would **reproduce and pass on their advantageous traits to their offspring** (i.e. "**fitness**": **ability to survive and reproduce**).
- If the **environment change**, the **appearance and characteristics of individuals in a population will change**.
- Organisms may be classified as **new species** if significant changes have accumulated.
- Darwin called the process "**natural selection**" or "**descent with modification**".
- Note: Darwin did not know about genetics or the mechanisms of inheritance. He theorised characteristics were passed down from parent to offspring via "factors".

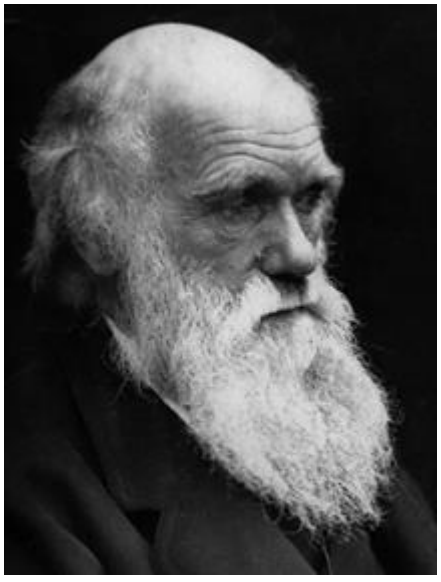

Figure 20.2 Charles Darwin (1809-1882)

1.3 The Darwin Theory of Evolution and Neo-Darwinism by Natural Selection

- The theory is concluded by key observations and inferences made by Darwin around 1859 and modifications was made subsequently to include the genetic, paleontology, ecological explanations forming Neo-Darwinism theory.

Key observations

(i) Organisms **produce more offspring** that are needed to replace the parents.

(ii) Natural populations tend to remain **stable** in size over long periods.

Inference 1: There is competition for survival (a 'struggle for existence')

- From the two previous observations, Darwin concluded that members of a species are constantly **competing with each other for resources** like food, shelter, mates, territory, etc.
- Therefore only a **few individuals** would **survive long enough to reproduce**.
- Many **die** in the struggle for survival.

(iii) There is **variation among individuals within a population** of a given species.

- Individuals in a population are **genetically different** from one another, hence there is **variation within a species**.

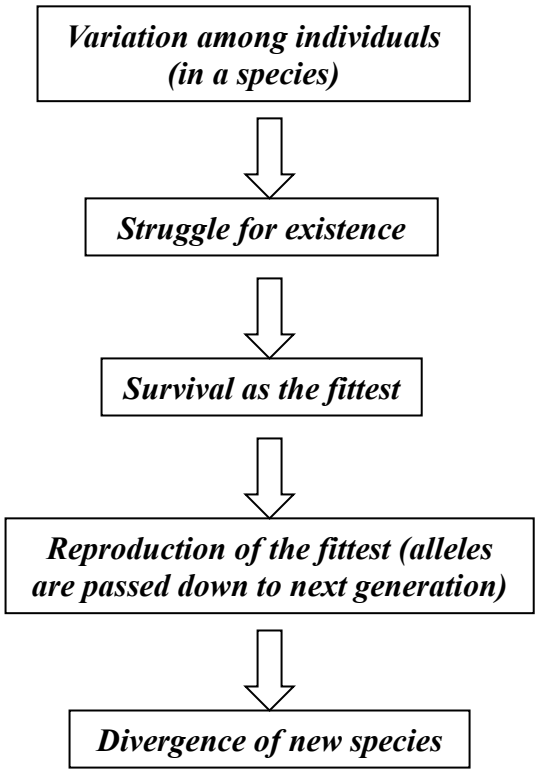

Figure 20.3 Mechanism of evolution

Inference 2: The best variants have a selective advantage; survival of the fittest occurs.

- The best adapted variants will be selected for by the natural conditions operating at the time.

Genetic Explanation:

- The environment exerts **selection pressure** (weather, predation, food supply, etc) on individual of a population.
- The individuals with the **alleles** coding for **traits** best suited for the **prevailing environment** are more likely to survive.
- They will be **better adapted** to **survive** and **reproduce** fertile and viable offspring.
- These individuals are at a **selective advantage**.
- Conversely, those with **alleles** coding for traits unable to withstand the environmental pressures, **die** before reaching reproductive age. These individuals are at a **selective disadvantage**.

(iv) **Fit individual produces similar offspring.**

- Successful individuals produce offspring with characteristics or traits **similar** to themselves.
- This is due to the inheritance of **favourable alleles** from their parents.
- These offspring are more likely to be **successful if the environment remains constant**.

(v) **Origin of new species**

- Organisms may be classified as **new species** if significant changes have accumulated in the populations over many generations.
- **Geographical isolation** usually occurs which cause a population to become distinct from another closely related population to the point that they can no longer interbreed. This is because the separated population will adapt to their own particular environments and may diverge, eventually forming a new species.
  Fig 20.3 summarises the mechanism of evolution.

Individuals in a population are often said to be 'struggling for survival'. What is the key fact that causes this struggle?

Competition for resources

The theory of evolution by natural selection explains, in scientific terms, how living things evolve over time. What is being selected in this process?

Traits that help an organism survive in a particular environment

2. ENVIRONMENTAL FACTORS ON NATURAL SELECTION

2.1 White and melanic peppered moth

- There are two forms of peppered moth (*Biston betularia*) in Britain; the typical form is white while the carbonaria (*melanic*) form is black.
- Selection pressure exerted by the environment: **Predation** during both the pre-industrial revolution and during the industrial revolution period.

Pre-industrial revolution period:

- During pre-industrial revolution, tree barks were covered in lichens.
- The white peppered moth was well camouflaged in this environment (see Fig 20.14a).
- Thus the white peppered moth was at a selective advantage as they were not easily seen and preyed on by birds.
- The melanic peppered moth was a result of a spontaneous mutation and their numbers were relatively low as compared to the white form.
- The melanic peppered moth was at a selective disadvantage as they were easily seen and preyed on by birds.

Figure 20.4 (a) Melanic moth selected against at the pollution-free tree bark at rural areas

- **The white peppered moths survived long enough to reproduce** to **pass on the advantageous trait to the offspring** compared to the dark-coloured moths.
- Hence the white peppered moth was the predominant form.

Industrial revolution period in 1900s:

- During industrial revolution, soot from the factories covered the tree barks.
- The melanic peppered moth was well camouflaged in this environment (see Fig 20.14b).
- Thus the melanic peppered moth was at a selective advantage as they were not easily seen and preyed on by birds.
- On the other hand, the white peppered moth was at a selective disadvantage as they were easily seen and preyed on by birds.
- Thus, the **number of white peppered moth dropped to low levels while the number of melanic peppered moth increased to high levels.**

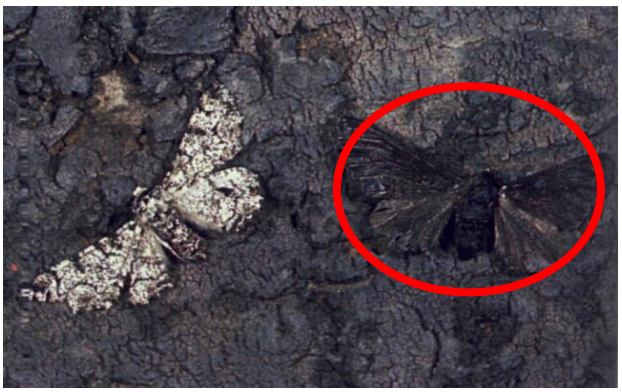

Figure 20.4 (b) White moth selected against at the blackened tree bark

- This is because more melanic peppered moth survived long enough to pass on the advantageous trait to the offspring as compared to the white peppered moth.

2.2 Sickle cell anaemia in humans

- Sickle cell anaemia is a genetic disorder characterised by red blood cells assuming sickle shape.
- The normal haemoglobin (haemoglobin A) in red blood cells is replaced by abnormal haemoglobin (haemoglobin S).
- Unlike the normal haemoglobin, haemoglobin S crystallise when the oxygen level is low, changing the shape of red blood cell from biconcave disc-shaped to a crescent (sickle) shape.
- Haemoglobin S is due to a **gene mutation** (substitution of one nucleotide), which resulted in the incorporation of hydrophobic valine (instead of hydrophilic glutamic acid) at the sixth amino acid residue of the ß-globin chain of the haemoglobin molecule (refer to Fig 20.5).

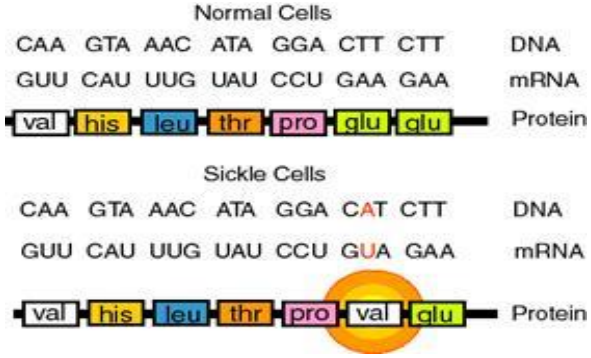

Figure 20.5 Gene mutation in sickle cell anaemia

- Hb^A represents the allele for haemoglobin A while Hb^S represents the allele for haemoglobin S.
- Individuals who are homozygous for the Hb^S allele suffer from sickle cell anaemia whereas heterozygous individuals (Hb^A Hb^S) suffer from sickle cell trait.
- As heterozygous individuals produce both normal and abnormal haemoglobin, Hb^A and Hb^S alleles are **co-dominant**.
- Sufferers of sickle cell anaemia are affected in the following ways:
  (1) The sickle red blood cells tend to stick together and obstruct blood flow in the small blood vessels, reducing the oxygen-carrying capacity in the body.
  (2) Sickle red blood cells are more fragile than normal red blood cells. They rupture easily, resulting in anaemia, fatigue and even death.
- Sufferers of sickle cell trait are usually healthy but their red blood cells can sickle under very low oxygen concentrations such as at high altitude.

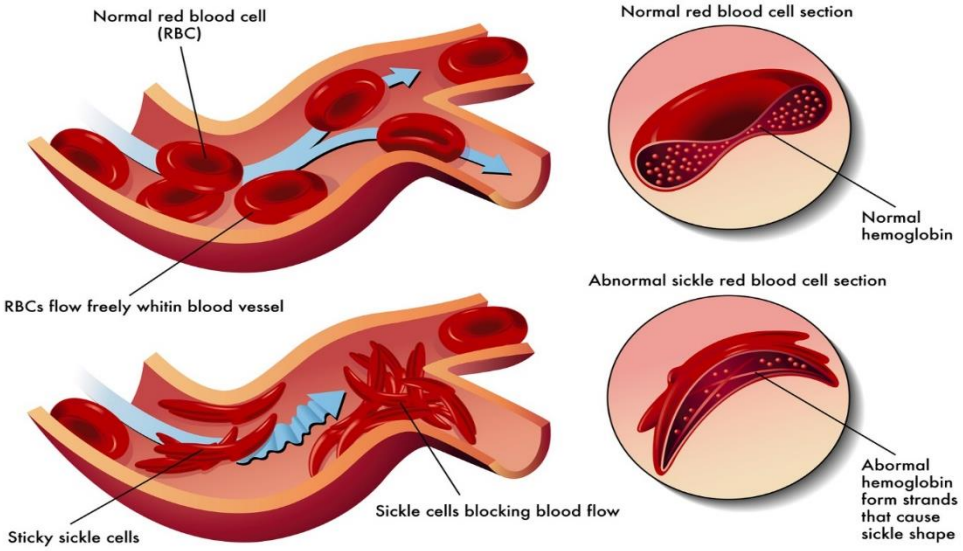

Figure 20.6 Sickle cell anaemia

- In West Africa, the frequency of the Hb^S allele is higher than expected.
- Places with a high frequency of the Hb^S allele also have a high incidence of malaria, which is caused by the protozoan parasite, *Plasmodium that* is transmitted to humans by the *Anopheles* mosquito.
- This is so as heterozygous (Hb^AHb^S) individuals have less chance of contracting malaria as compared to Hb^AHb^A individuals. This condition is known as **heterozygous advantage**.
- *Plasmodium* spends part of its life cycle in the human red blood cell.
- When the parasites invade the bloodstream, the red blood cells that contain haemoglobin S die, trapping the parasites within them and stopping the infection.
- With a higher resistance to malaria, heterozygous individuals gain fitness and are able to better survive and produce offspring, contributing Hb^S allele to the population and next generation.

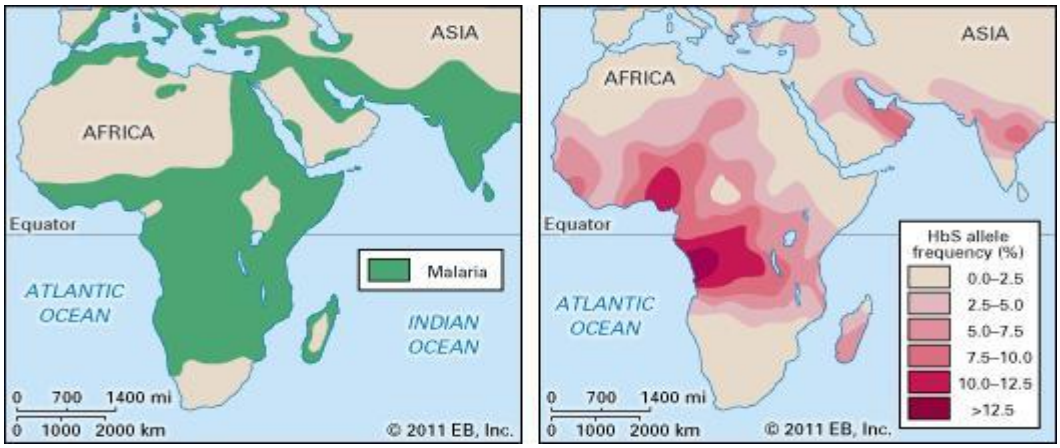

Figure 20.7 Positive correlation between sickle cell allele (Hb^S) and malaria cases

2.3 Antibiotic resistance in bacteria

- Antibiotics such as penicillin are widely used in the 1940s in medicine to kill pathogenic bacteria.
- This provided a strong selection pressure for strains of bacteria that are resistant to the effects of antibiotics.
- Such strains of bacteria possess the **antibiotic resistance gene**, responsible for producing an enzyme to break down the antibiotics.

- The greater the quantity and frequency of antibiotic use, the greater the selection pressure for antibiotic resistance.
- Mutation rate is relatively high in bacteria (approximately one in every 10^8 replications) as it has a much shorter life span.
- Thus, antibiotic resistance may arise spontaneously as a result of **chance mutation**.
- *Staphylococcus* is an example of a bacterium that has acquired resistance to penicillin and related antibiotics.
- Such strains are termed as "**superbugs**".
- Completing the full course of antibiotics is important to ensure that all bacteria in the body are destroyed, preventing any from mutating and gaining antibiotic resistance.

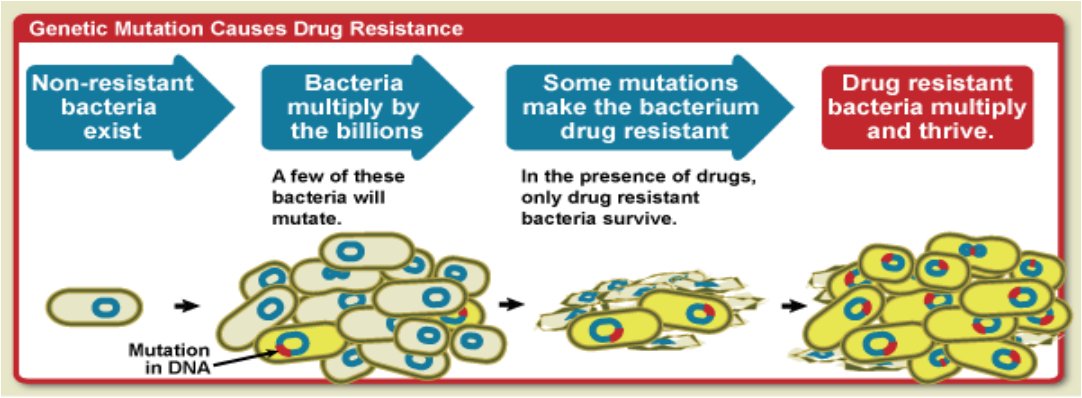

Figure 20.8 Antibiotic resistance from genetic mutation

2.4 Finches on Galapagos Islands

- Environmental factors, such as the type and availability of food can act as a force of natural selection.
- There are 13 species of finches on the Galapagos Islands, with six major types of beaks, each suited to a particular diet.
- It is thought that these different species of finches evolved from one common ancestor to fill different food niches.
- This process of evolution is called **adaptive radiation**.

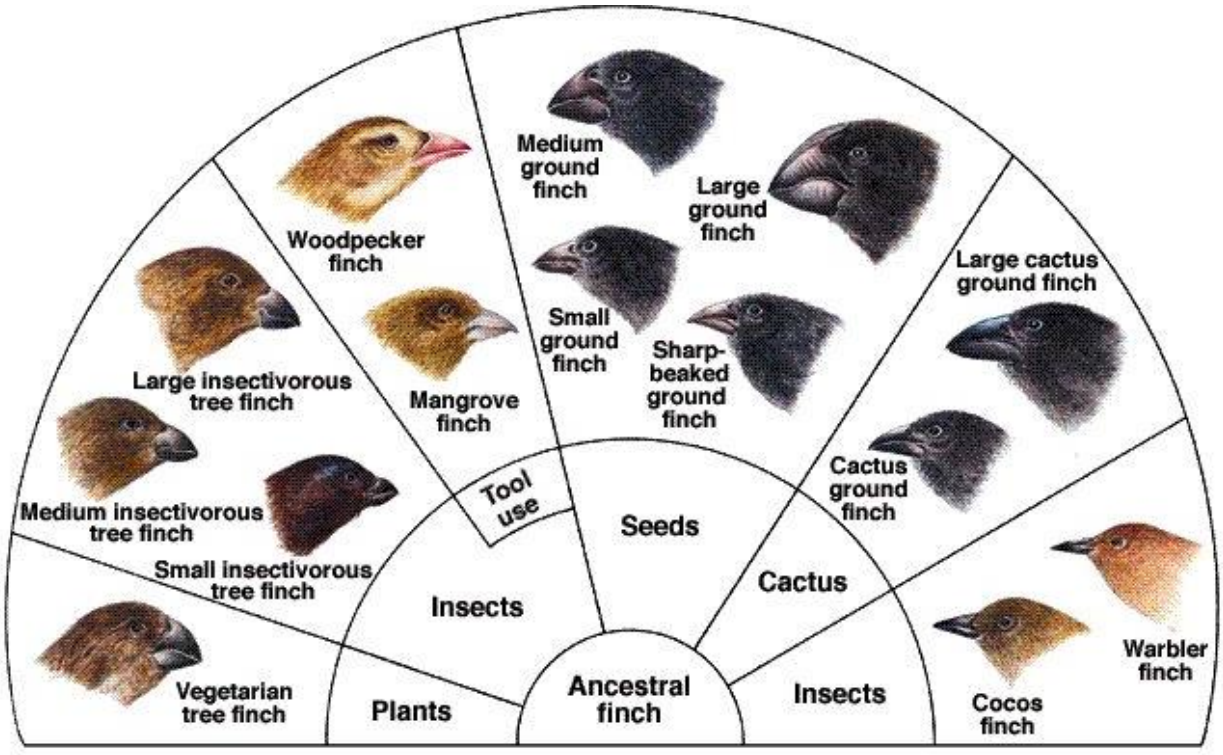

Figure 20.9 Adaptive radiation in Galapagos finches based on the different food sources

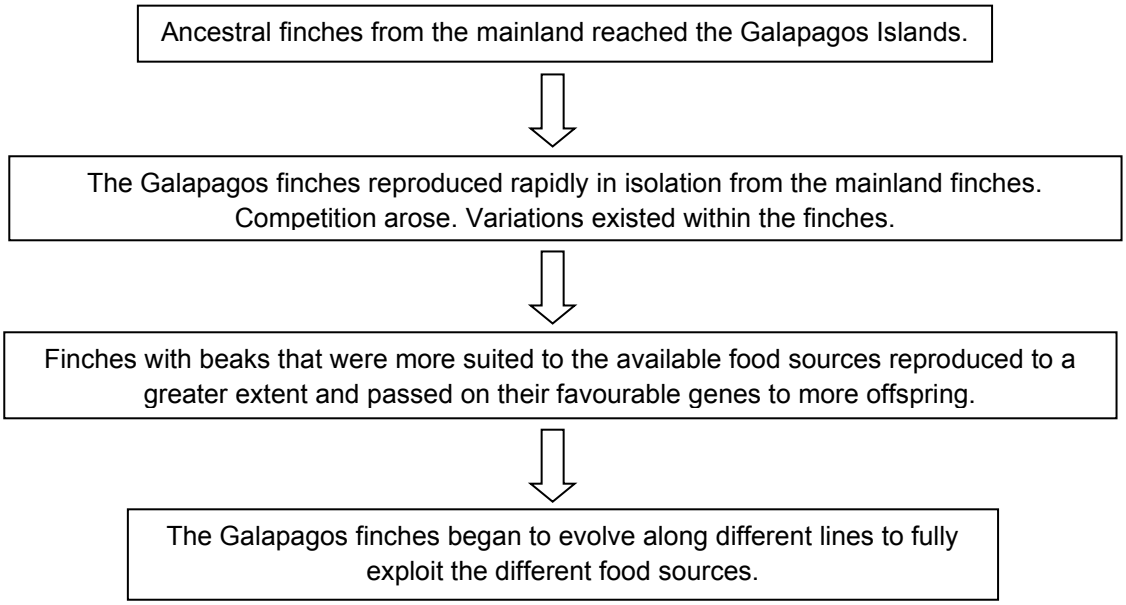

Figure 20.10 Mechanism of evolution of Galapagos finches

3. ARTIFICIAL SELECTION

- **Artificial selection** occurs when humans breed plants and animals with **favourable inheritable traits** to produce improved varieties or breeds.
- This is also known as **selective breeding**.
- Animals and plants may be bred for the following qualities:
  (1) higher yields of better quality
  (2) increased resistance to pest and disease
  (3) increased tolerance to extreme weather and temperatures, e.g. drought and frost

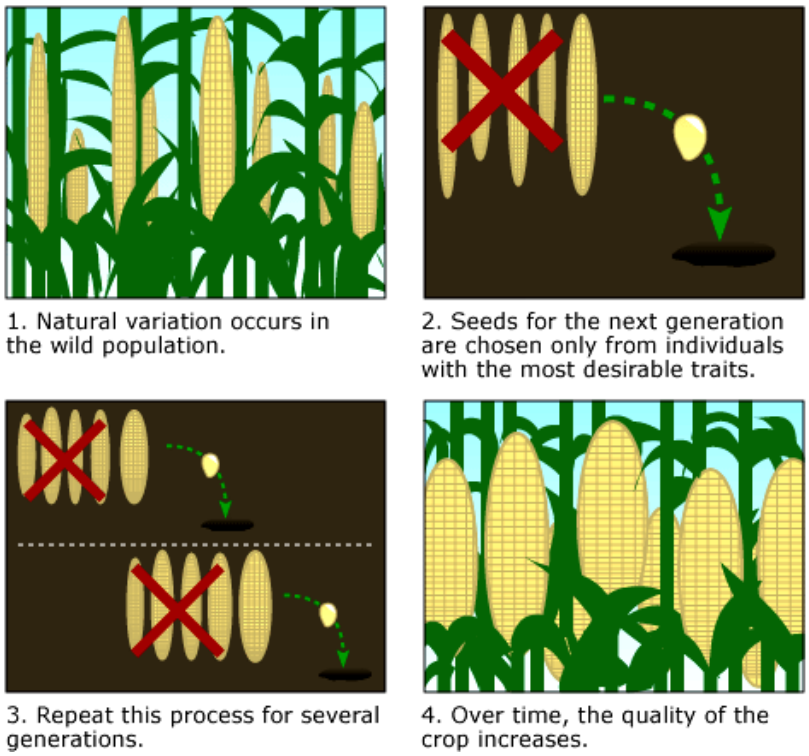

Figure 20.11 Artificial selection of corn to produce higher yields of better quality

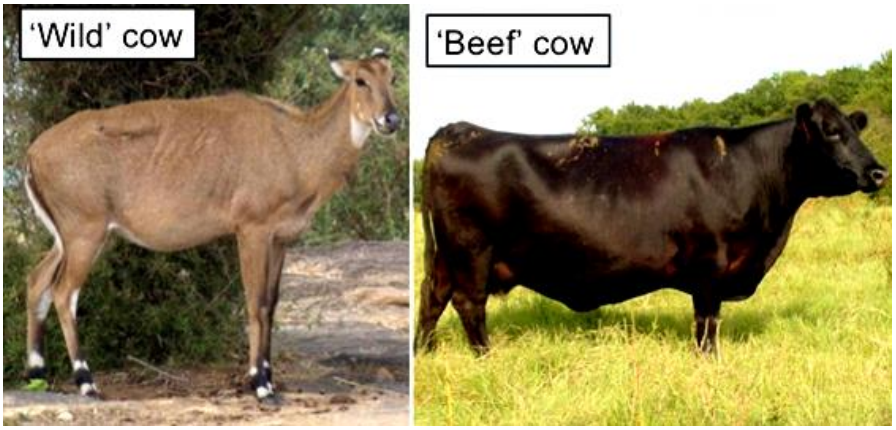

Figure 20.12 Inbreeding of cows with more body mass over generations to produce 'beef' cow

- Breeding may also be carried out between different varieties (with different characteristics) to produce offspring with the combined, desired traits of both parents.
- This process is called **hybridisation** and the offspring are known as **hybrids**.
- Example – Shorthorn cattle produce good quality beef, while Brahman cattle can tolerate warm weather and are parasite-resistant, but produce poor quality beef. When crossed, the hybrid, called Santa Gertrudis cattle, is heat-tolerant, parasite-resistant and produces good quality beef.
- **Deleterious** (harmful) recessive alleles may accumulate in the population with prolonged inbreeding.
- This increases the risk of the inbred offspring inheriting deleterious recessive alleles in the homozygous condition.

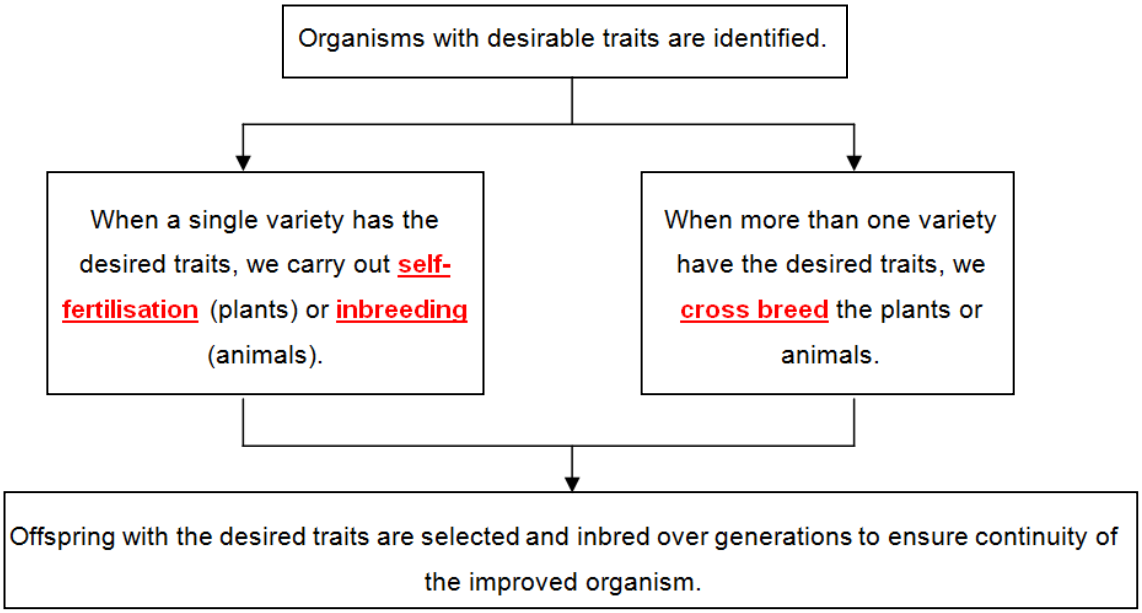

Figure 20.13 Steps involved in selective breeding

Table 20.1 Comparison between natural and artificial selection

natural selection	artificial selection
results from mutations in gene	results from manipulation by humans
brought about by changes in environmental conditions	humans select organisms with desired traits to reproduce
very slow process	relatively faster process
may be advantageous or harmful to Man	advantageous to Man

4. ADDITIONAL READING MATERIALS

4.1 Lamarck's Theory of Evolution

- Jean Lamarck's theory, also known as the inheritance of *acquired* characteristics was put forward in 1809 before Darwin's work.
- The essential features of Lamarck's theory are as follows:
  (1) When an organism developed a need for a particular structure, this need induced the development of the structure.
  (2) Structures that are not used tend to degenerate.
  (3) Acquired characteristics could be inherited by the offspring.
- According to his theory, life, created long ago in a simple state will slowly improve as a result.
- The force for change was a drive toward perfection.
- He suggested that the constant stretching of giraffes' neck to browse upon leaves made it lengthen permanently and this can be inherited by the offspring.
- Lamarck's hypothesis is largely abandoned as it has not been supported by experimental tests.
- Offspring of a muscle-bound parent can inherit his genes, but not the increased muscle mass, as opposed to Lamarck's theory.

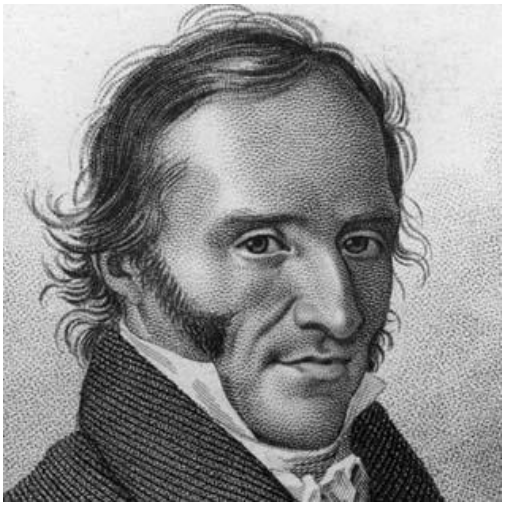

Figure 20.14 Jean Baptiste de Monet de Lamarck (1744-1829)

4.2 Types of Natural Selection

- There are three types of natural selection: directional, stabilising and disruptive selection.
- **Directional selection** is selection that operates against one extreme of a range of variations in a particular characteristic and thus tends to shift the entire population to the opposite extreme.
- **Stabilising selection** maintains the constancy of a species over many generations. Both extremes within a population are selected against, thereby decreasing the variation within a population. It normally occurs when the environment remains constant over time.
- **Disruptive selection** is selection that operates against the middle range of variation in a particular characteristic, tending to split a population into two showing the two extremes of the range. It occurs when environment conditions are varied in a way that favours both extremes over the intermediate form.

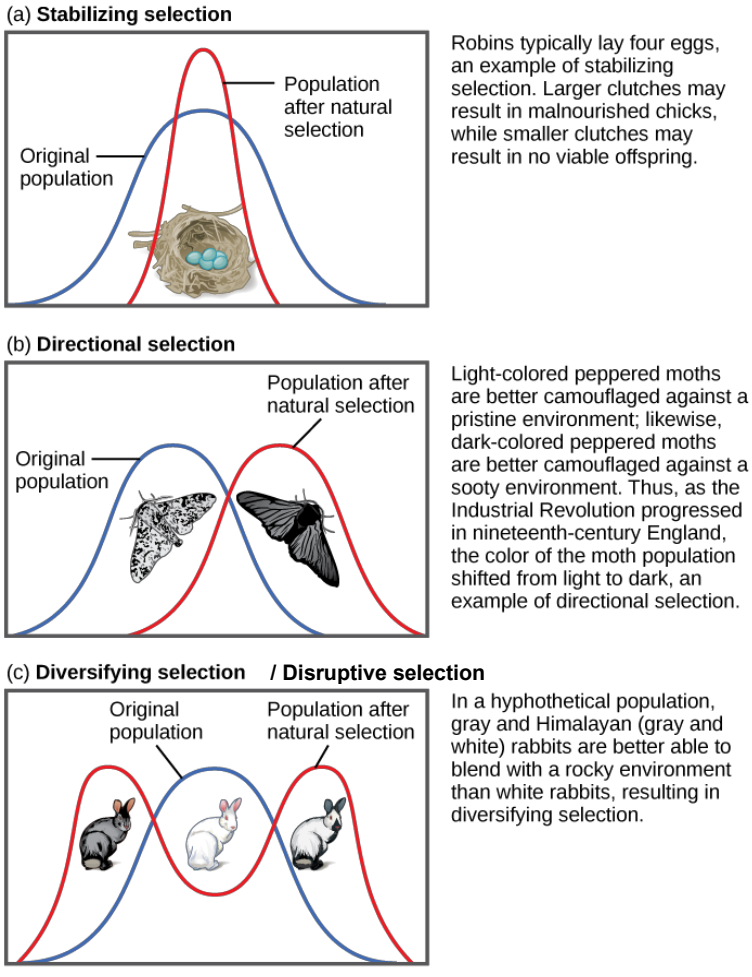

Figure 20.15 Different types of natural selection

The End

Catholic High School
Integrated Programme
Year 4 Biology
Lecture Notes 21 – Ecology & Ecosystem

Name: **Class:**

A. Content

- Ecology
- Energy and Nutrient Flow
- Ecological Pyramids
- Humans' Impact on the Ecosystem
- Conservation

B. Learning Outcomes

Pre-requisites:
(a) briefly describe the non-cyclical nature of energy flow.
(b) explain the terms producer, consumer and trophic level in the context of food chains and food webs.
(c) explain how energy losses occur along food chains, and discuss the efficiency of energy transfer between trophic levels.
(d) describe and interpret pyramids of numbers.
(e) describe how carbon is cycled within an ecosystem.

Students should be able to:
(a) describe and interpret pyramids of biomass and energy.
(b) evaluate the effects of
• water pollution by sewage and by inorganic waste
• pollution due to insecticides including bioaccumulation up food chains and impact on top carnivores
(c) outline the roles of microbes in sewage disposal as an example of environmental biotechnology.
(d) discuss reasons for conservation of species with reference to the maintenance of biodiversity, management of fisheries and management of timber production.

C. References

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6. Starr, C. Biology Concepts and Applications (6th ed). Brooks/Cole Publishing Company.
7. Toole, G. and Toole, S. Understanding Biology for Advanced Level (4th ed). Nelson Thornes (Publishers) Ltd.

D. Lecture Outline

1. Ecology
2. Non-cyclical Flow of Energy
3. The Carbon Cycle
4. Pyramid of Number, Biomass and Energy
5. Water Pollution and Sewage Treatment
6. Conservation
7. Additional Reading Materials

E. Practical Work

-

1. ECOLOGY

- **Ecology** is the study of how organisms interact with each other and with their environment.
- The environment in which organisms live can be divided into **abiotic** and **biotic** environments.
- The **abiotic** environment consists of physical, non-living factors such as light intensity, water availability, oxygen content, salinity and pH, of the soil and water.
- The **biotic** environment consists of all the living things that an organism interacts with.

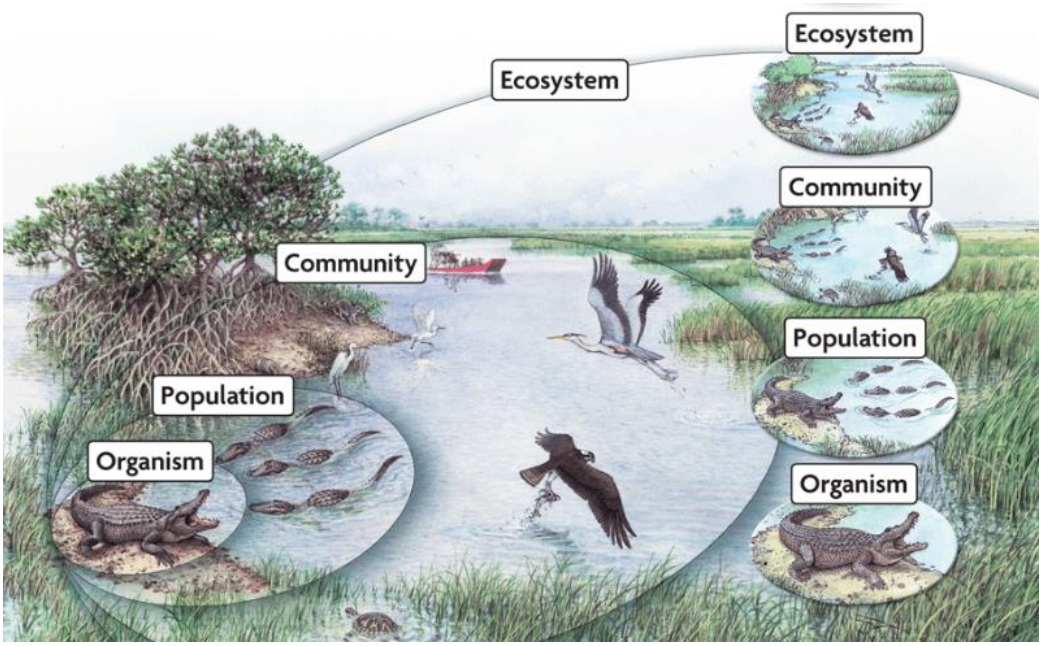


Figure 21.1 Organisation levels in ecology

- A group of organisms of the same species living in a particular **habitat** (e.g. mangrove) makes up a **population**.
- All the populations of organisms living and interacting with one another make up a **community**.
- A community and its abiotic environment together make up an **ecosystem**.
- An ecosystem consists of four basic elements, namely the abiotic component, biotic component, energy and nutrients.
- Organisms are **interdependent** within a community and is affected by the surrounding organisms.
- A **niche** is the position a species occupies within its habitat. It includes the physical space, its interactions with other organisms and its effects on the environment.
- **Symbiosis** describes the close and often long-term interaction between two different species.
- There are five types of symbiotic relationships, namely commensalism, competition, mutualism, parasitism and predation.
  (1) **Commensalism** – one organism benefits from the other without affecting it, e.g. vultures feeding off the carcass left by lion.
  (2) **Competition** – only one organism benefits from the limited natural resources, while lowering the survivability of the other organism e.g. two male deer competing over a female mate
  (3) **Mutualism** – both organisms benefit e.g. hummingbird gathers nectar from flowers while pollinating it
  (4) **Parasitism** – one organism benefits at the expense of the other, the host, e.g. mosquito feeding on the blood of a human
  (5) **Predation** – one organism (predator) obtain energy and nutrients from another organism (prey)

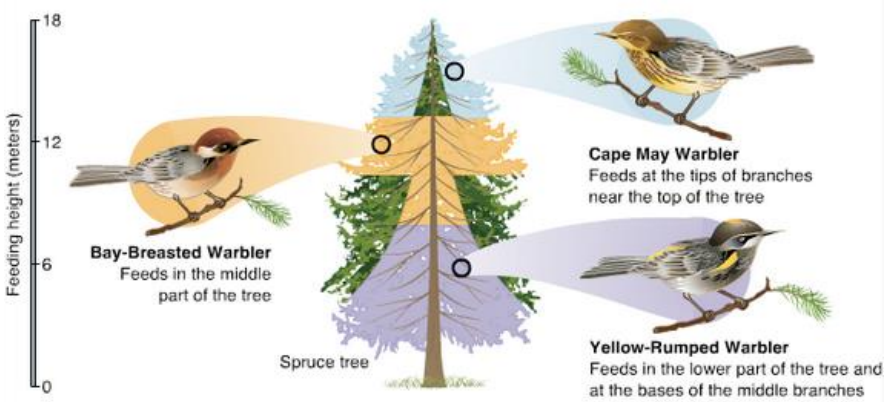


Figure 21.2 Different species of warbler occupy different niches by feeding in different areas of the tree

2. NON-CYCLICAL FLOW OF ENERGY

2.1 Producers and consumers

- Living organisms in an ecosystem can be categorised into three nutritional groups – producers, consumers and decomposers.
- **Producers** are also known as **autotrophs**.
- They are able to synthesise complex organic substances from simple inorganic raw materials, e.g. carbon dioxide and water, using light energy (via photosynthesis) or energy from chemical reactions (via chemosynthesis).
  Examples include green plants, algae, phytoplankton and certain bacteria.
- All other organisms in the system are **consumers,** also known as **heterotrophs,** who feed on the tissues, products, and remains of other organisms.
- Consumers are described by their diets; **herbivores** eat plants, **carnivores** eat flesh, **parasites** live in or on a host and feed on its tissues.
- **Detritivores**, such as crabs, eat detritus – particles of decomposing organic matter.
- Wastes and remains of all organisms are degraded to inorganic compounds which can be returned to the physical environment by 2 main groups of **decomposers**; bacteria and fungi.
- **Omnivores** feed on plants and animals while **scavengers** ingest dead plants, animals, or both, all or some of the time.

2.2 Food chains and food webs

- The **feeding** relationships between organisms in a community can be represented by a **food chain**.
- Every food chain starts with the producer.
- Each arrow (→) means "eaten by" or "energy transfer".
- Each stage of a food chain is called **trophic level**.
- Producers form the first trophic level, followed by **primary consumers**, **secondary consumers**, and then **tertiary consumers**.
- A **food web** consists of interlinked food chains, showing the feeding relationships between organisms and some animals have more than one food source.

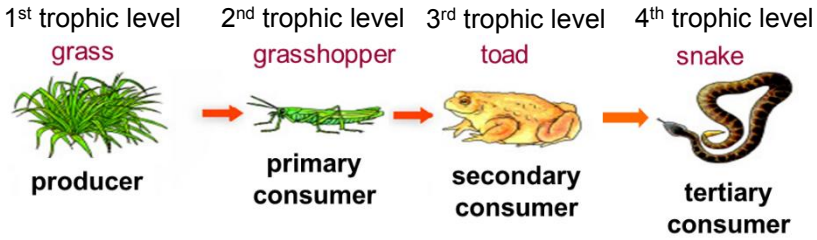


Figure 21.3 A food chain

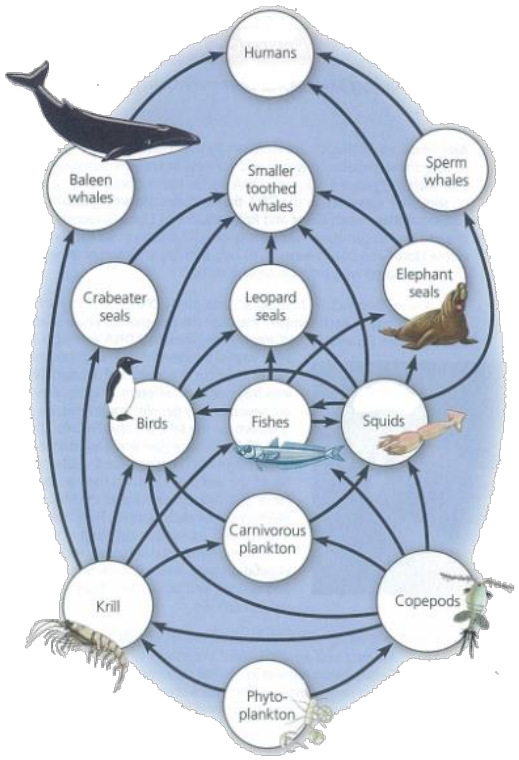


Figure 21.4 A food web

2.3 Energy transfer between trophic levels

- In an ecosystem, energy flow is **non-cyclic** (linear).
- As energy flows from the Sun through producers to the consumers, most (around 90%) of it is lost as **heat** via respiration.
- Energy is also lost in **faeces** (undigested foods), **excretory products** and **uneaten parts** (dead bodies).
- Energy that is lost **cannot be recycled** (cannot be used again by the producers or consumers).
- Energy transfer between trophic levels is **inefficient**; only about **10%** of energy is transferred from one trophic level to the next.
- The transfer of energy from producers to primary consumers is the least efficient, typically 1% to 10 % of the biomass of the producers. The low level of energy transfer is due to the following:
  (1) High amount of lignin and cellulose which is indigestible by animals due to the lack of enzymes.
  (2) Poisonous plant compounds (such as phenolics) are not consumed by animals.
  (3) Certain parts of plants such as the roots are inaccessible to herbivores.
- The inherent inefficiency in energy transfers between trophic levels limits the length of food chains (usually not more than 4 or 5 trophic levels).

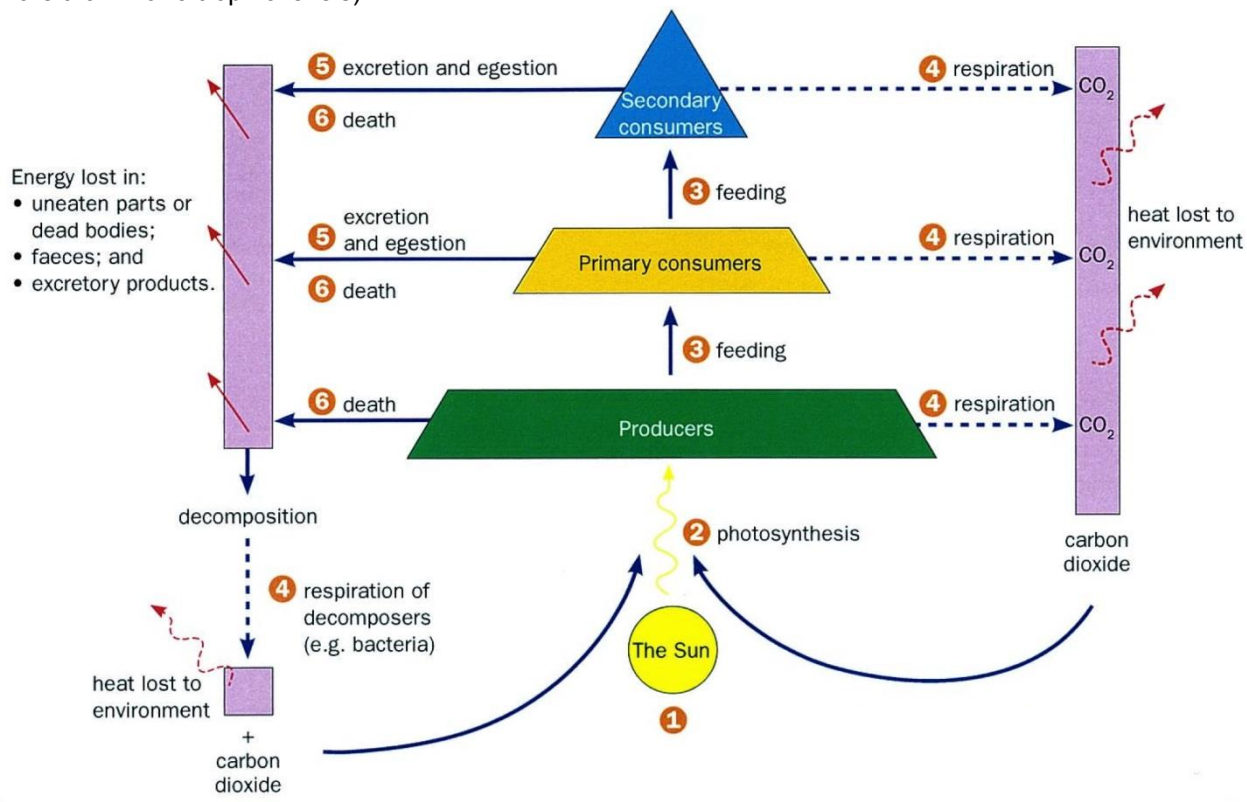


Figure 21.5 Energy flow and its relation to nutrition and respiration in the ecosystem

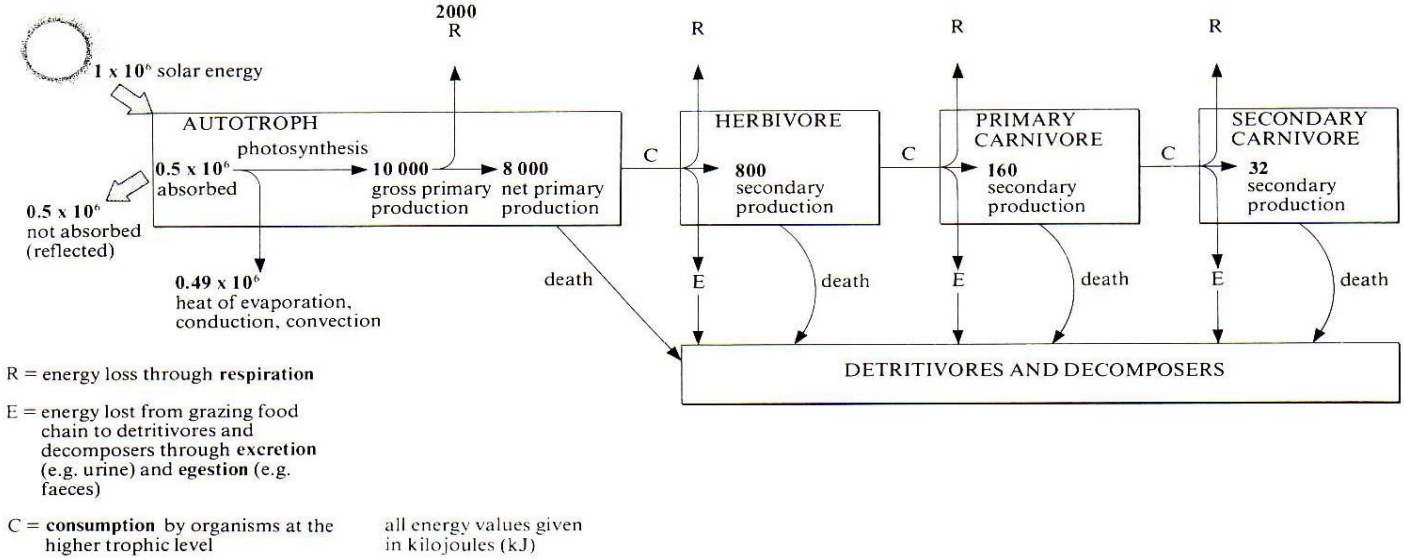


Figure 21.6 One-way energy flow through a grazing food chain. Figures represent kJ m^{-2} yr^{-1}.

3. THE CARBON CYCLE

- In a balanced ecosystem, nutrients are not lost but are continually **recycled**.
- Carbon is one of the nutrients that is cycled in the environment. It is constantly removed from and released into the atmosphere in the form of **carbon dioxide**.
- The **carbon cycle** shows the passage of carbon within an ecosystem.
- The importance of the carbon cycle is to:
  (1) ensure a continuous supply of carbon dioxide for **photosynthesis** to take place
  (2) allow **energy** to flow through the ecosystem via photosynthesis and feeding.

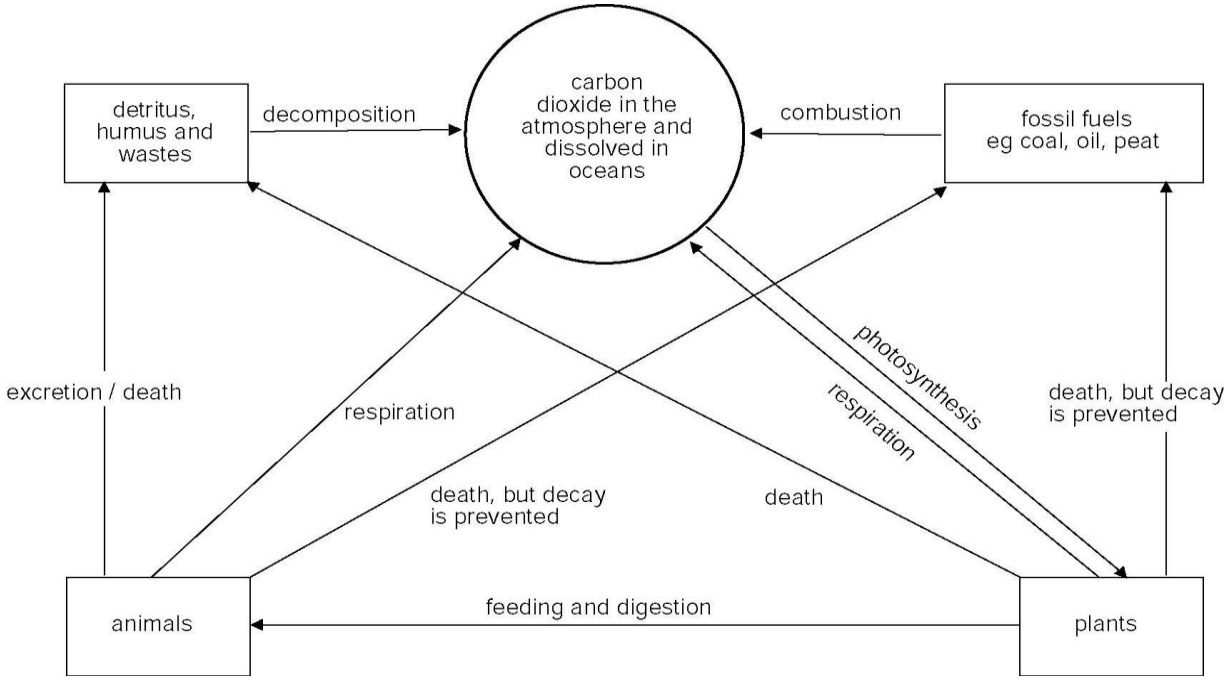
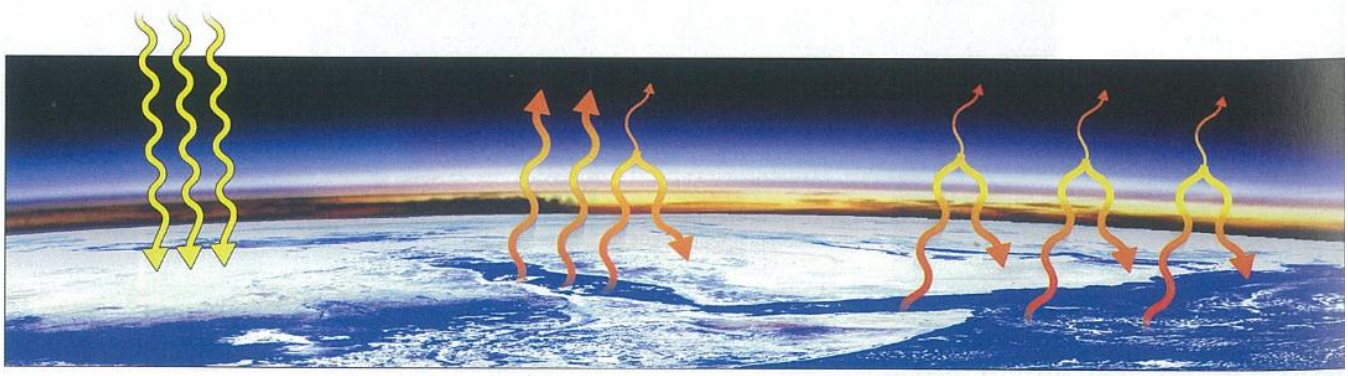


Figure 21.7 The carbon cycle

- Carbon dioxide in the atmosphere is removed via **photosynthesis** where plants use carbon dioxide to synthesise glucose.
- Carbon dioxide is released into the atmosphere by the following processes:
  (1) **Respiration** – glucose is broken down in living organisms to release energy, together with carbon dioxide
  (2) **Decomposition** – dead organisms are broken down by decomposers, and carbon dioxide is released due to respirations by the decomposers
- In anaerobic or highly acidic conditions, decomposers are unable to break down remains of dead organisms. These accumulate to form **fossil fuels**, e.g. coal, oil.
- Human activities such as **combustion** of fossil fuels and **deforestation** alter the carbon cycle by increasing the concentration of atmospheric carbon dioxide.
- Carbon dioxide is a greenhouse gas which is capable of absorbing infrared radiation, thereby trapping heat in the atmosphere.
- This results in **global warming** or **greenhouse effect** which brings about an increase in global temperature.



(a) Wavelengths in rays from the sun penetrate the lower atmosphere, and they warm the Earth's surface.

(b) The surface radiates heat (infrared wavelengths) to the atmosphere. Some heat escapes into space. But greenhouse gases and water vapor absorb some infrared energy and radiate a portion of it back toward Earth.

(c) Increased concentrations of greenhouse gases trap more heat near Earth's surface. Sea surface temperatures rise, so more water evaporates into the atmosphere. Earth's surface temperature rises.

Figure 21.8 The greenhouse effect

3.1 Carbon sinks

- A carbon sink is an area that stores more **carbon compounds** than it releases for an **indefinite** period of time.
- **Oceans** are the largest carbon sinks on Earth.
- Carbon compounds found in oceans is buried in the seabed in the form of **natural gas** and **oil**.
- In forests, a large amount of carbon compounds is stored in **trees**.
- Remains of dead trees form **coal**, a fossil fuel.

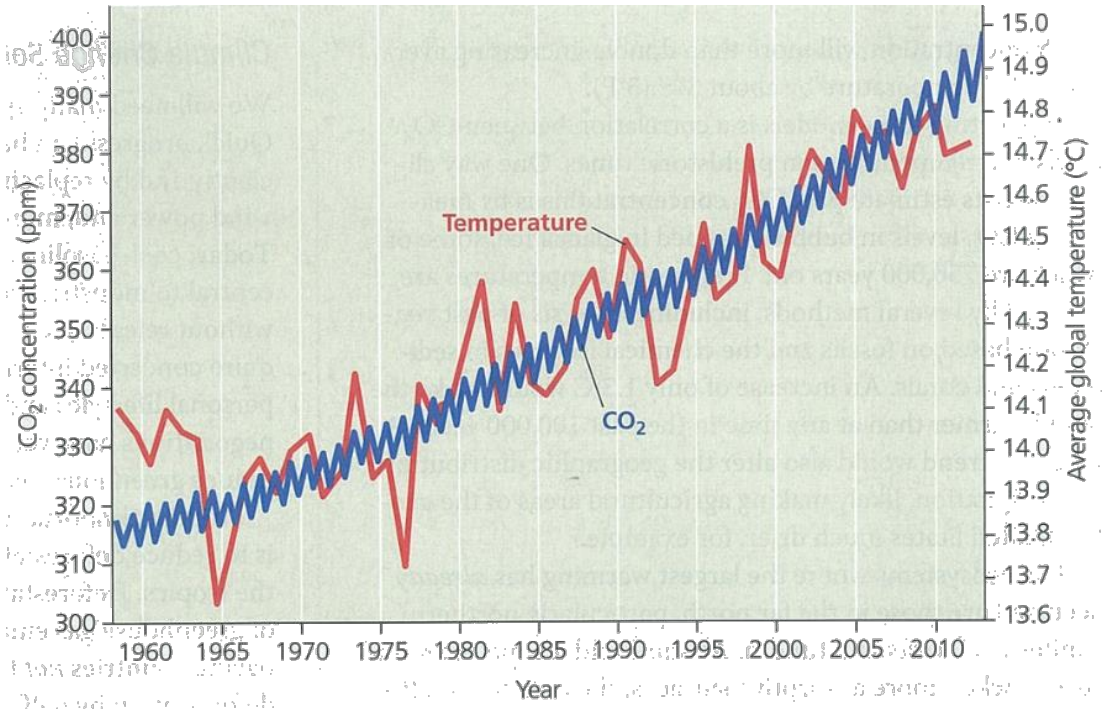


Figure 21.9 Relationship between rising carbon dioxide levels (parts per million) in the atmosphere and global average temperature (ºC)

4. PYRAMID OF NUMBER, BIOMASS AND ENERGY

- Feeding relationships in a community can be quantified and represented in an **ecological pyramid**. There are three types of ecological pyramids;
  (1) Pyramid of numbers
  (2) Pyramid of biomass
  (3) Pyramid of energy

4.1 Pyramid of numbers

- A **pyramid of numbers** shows the **number** of organisms for each species at each trophic level at **any one time**.
- The number of organisms for each species is represented by the length of the bar.
- All organisms at each trophic level at a particular time are counted, regardless of size or developmental stage.

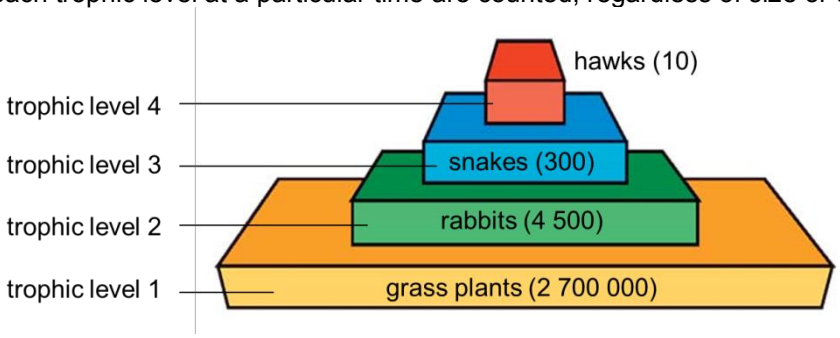


Figure 21.10 Pyramid of numbers

- A pyramid of numbers may be **inverted** if:
  (1) producer is a single, large **tree**
  (2) organisms of one trophic level are **parasitic** on the organisms of the previous trophic level

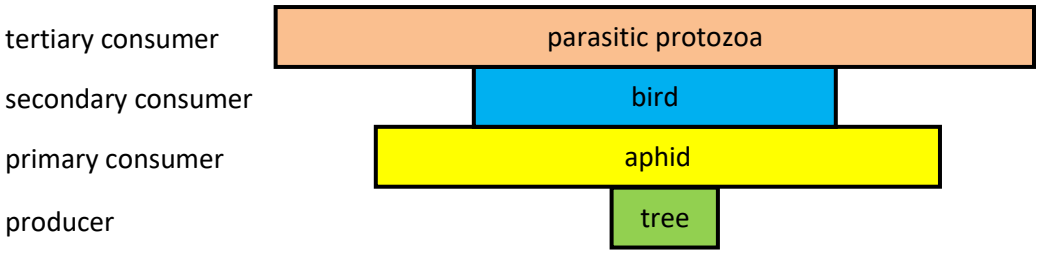


Figure 21.11 An inverted pyramid of numbers

4.2 Pyramid of biomass

- A **pyramid of biomass** shows the total **mass** of organisms at each trophic level at a **particular time**.
- The **dry mass** of organisms at each trophic level at any one time is estimated.
- It takes into consideration the **size** of the organisms so it gives a more accurate representation of the food chain than the pyramid of numbers.
- The pyramid of biomass can be **inverted** for rapidly reproducing organisms.

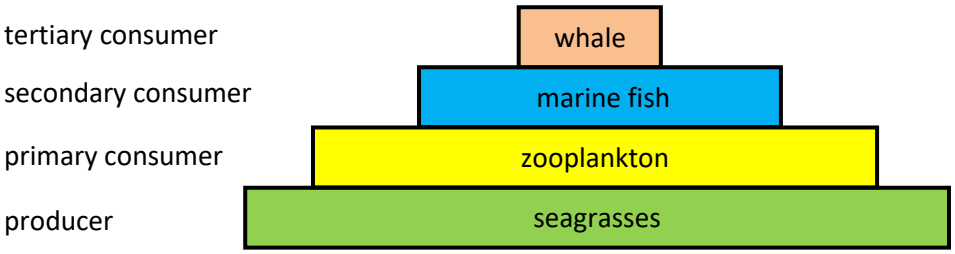


Figure 21.12 A pyramid of biomass

- Phytoplanktons **reproduce quickly** enough to replace the individuals that were consumed by the zooplankton.
- A pyramid of biomass may not be an accurate reflection of the total energy in each trophic level as two organisms of the same biomass do not necessarily have the same energy content.

4.3 Pyramid of energy

- A pyramid of energy shows the **total energy content** of each trophic level **over a certain period of time**.
- As energy is lost between trophic levels, fewer organisms can be supported at each succeeding trophic level.
- The total energy at the first trophic level is highest and lowest at the last trophic level; always an upright pyramid.

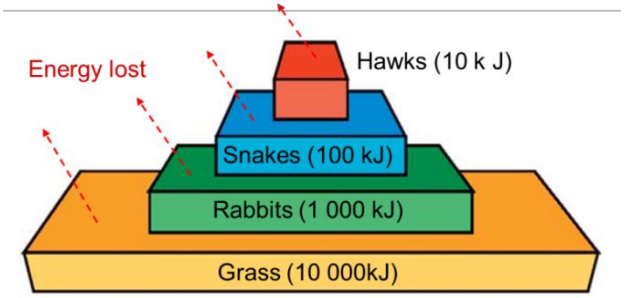


Figure 21.13 A pyramid of energy

Table 21.1 Comparison between pyramids of numbers, biomass and energy

Features	**Pyramid of numbers**	**Pyramid of biomass**	**Pyramid of energy**
Consideration of size of organism	No	Yes	Not relevant. Organisms are reduced to their energy equivalent
Ease of use	Easy – involves counting of organism only	Difficult – need to determine dry mass by drying organism at 100 °C in oven	Very difficult – samples have to be burnt in a calorimeter to determine amount of energy
Sample time	Once	Once	Throughout a period of time, e.g. 1 year

Validity of data	Only representative of that particular time of measurement	Only representative of that particular time of measurement	Valid. Data obtained over a long period of time can be used in generalisations.

5. WATER POLLUTION AND SEWAGE TREATMENT

5.1 Water pollution

- **Pollution** is the process whereby harmful substances, also known as pollutants, are added into the environment.
- Water pollution can be caused by:
  (1) **untreated sewage** from homes and industries,
  (2) excessive usage of **insecticides** from farms, and
  (3) **inorganic waste material** from industries.

(1) Untreated sewage

- Untreated sewage contains pathogenic (disease-causing) **bacteria** that can cause a large number of infections within a population over a short period of time (epidemics) e.g cholera.
- Sewage and fertilisers contain **phosphates** and **nitrates** that can lead to **eutrophication;** water enriched with nutrients allows for the proliferation of algae (**algal bloom**) and bacteria.
- Submerged plants die due to lack of sunlight.
- Bacteria **grow rapidly** and use up dissolved oxygen as they decompose the dead plants.
- Marine organisms die due to the **lack of oxygen**.

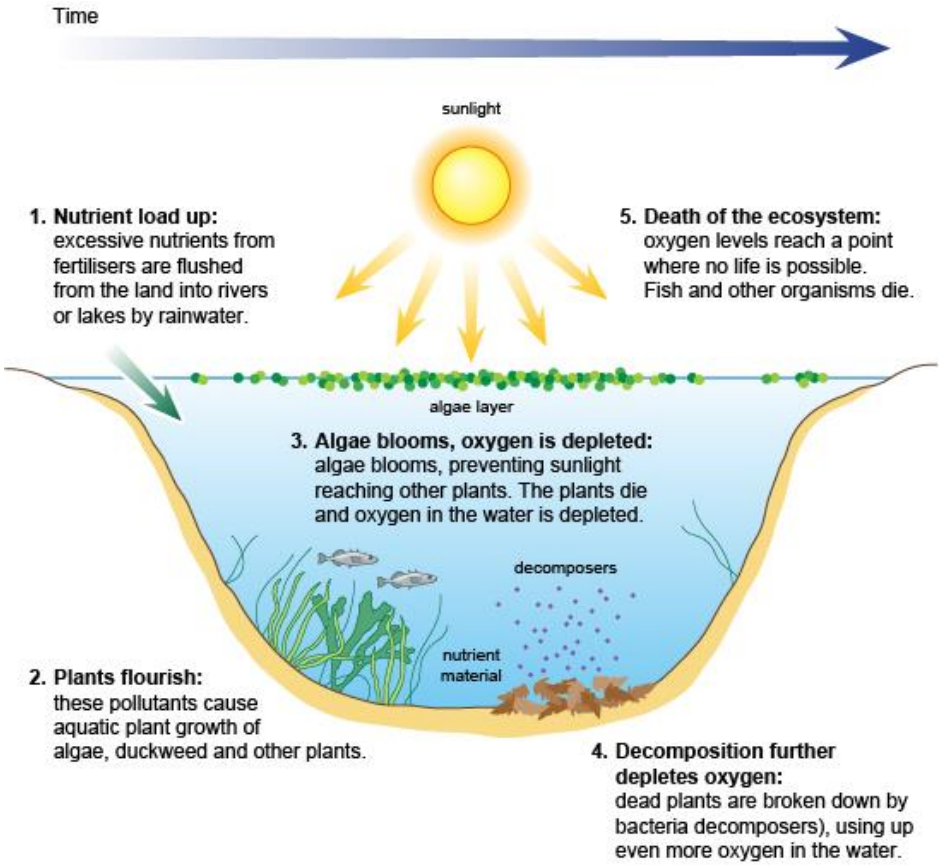


Figure 21.14 Eutrophication in a lake

(2) Insecticides

- **Insecticides** are chemical substances used to kill insect pests.
- Indiscriminate use of insecticides harms the ecosystem by poisoning organisms other than the insect pests.
- Dichlorodiphenyltrichloroethane (**DDT**) is a synthetic pesticide that was first used to control insect-borne diseases, such as malaria and typhus, by targeting the insect vectors (mosquitoes and lice).
- It was later widely used in agriculture.
- Insects can gain **DDT-resistance** and this prompts farmers to use higher dosage of DDT.
- DDT is **non-biodegradable** (resistant to decomposition by microorganisms), resulting it to be highly persistent (remaining for many years) in the environment.
- When consumed, DDT is not excreted, but stored in the adipose tissues of organisms.
- Its concentration in the body tissues increases over time as the organism continues to consume food containing DDT (**bioaccumulation**).

- As DDT passed along the food chain, its concentration in body tissues increases with each trophic level (**bioamplification** / **biomagnification**); top consumers have the **highest** concentration of DDT in their bodies.
- These top consumers are likely to succumb to **toxic effects** of DDT, e.g. eggs of bald eagles have thin shells that break before the chicks can hatch.

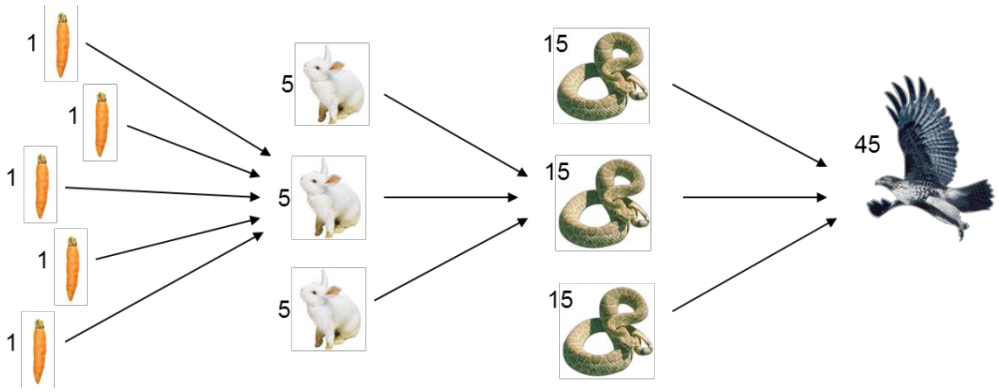


Figure 21.15 Insecticides concentration (arbitrary units) increases in the body of organism down the food chain

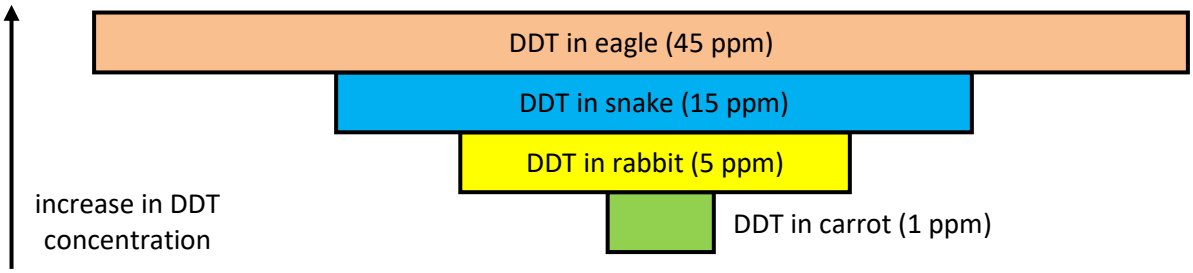


Figure 21.16 A representation of bioamplification from the food chain in Fig. 21.15

(3) Inorganic waste

- **Inorganic waste** products discharged by industries into waterbodies contain metals, such as mercury, lead, cadmium and nickel, which can be toxic even in minute amounts.
- Signs and symptoms of **mercury poisoning** include skin discolouration, excessive sweating, nerve and organ damage.

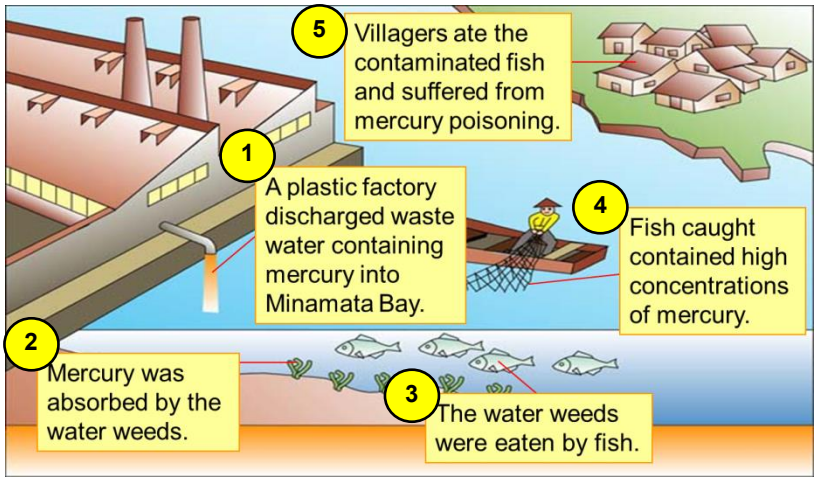


Figure 21.17 Mercury poisoning at Minamata Bay, Japan in 1971

5.2 Sewage treatment

- **Environmental biotechnology** harnesses the biological processes of microorganisms, e.g. bacteria and fungi to help reduce pollution and restore contaminated environment.
- Bacteria are mainly used in **sewage treatment plants** to treat sewage before it is discharged into the natural environment.

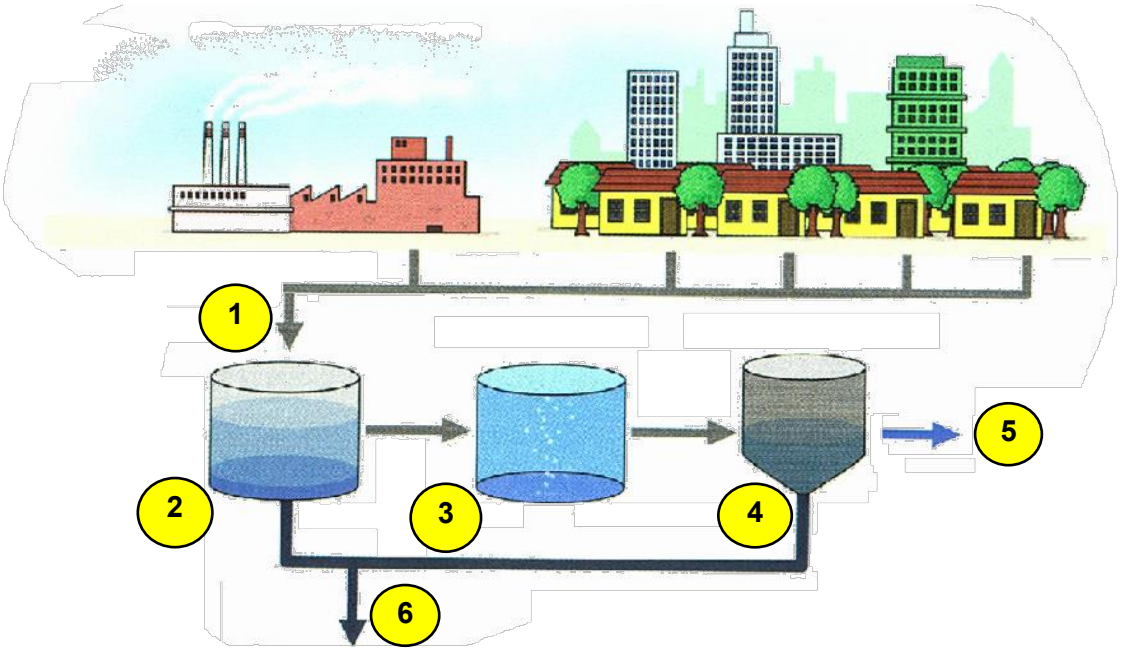


Figure 21.18 Water treatment process

- Steps in water treatment process:
  (1) Wastewater channeled from homes and industries into **water reclamation plants**.
  (2) Wastewater enters **primary settling tank**. Heavy solids settle to the bottom of the tank and are removed as **sludge**.
  (3) Partially treated wastewater is transferred to the **aeration tank** and mixed with mainly **aerobic bacteria**. **Organic pollutants** are broken down into harmless substances.
  (4) Wastewater is sent to the **final settling tank** where the bacteria and any remaining organic material are removed.
  (5) **Treated wastewater** is discharged into the sea.
  (6) Sludge is treated with **anaerobic bacteria/fungi** before being dewatered (removal of water) and disposed into a soil container.

6. CONSERVATION

Conservation efforts preserve and restore the natural environment and its resources.

6.1 Reasons for conservation

(1) To **prevent extinction** of plant and animal species
(2) To maintain a stable and **balanced ecosystem** by preventing global warming and disruption of natural cycles, e.g. water and carbon cycles.
(3) To maintain a **large gene pool** by improving agricultural produce with favourable genes, e.g. plants with better resistance to diseases and drought
(4) To maintain a source of **food** e.g. marine life
(5) To maintain **scientific value** of our ecosystem as the study of it provides useful information to humans, e.g. learning about evolution of life
(6) To preserve natural scenery and wildlife for people to appreciate its **recreational** purposes, e.g. fishing, hiking and skiing
(7) To maintain **biodiversity**, e.g. rainforests house a large number of species of animals and plants which are of great **economic** and **medicinal** purposes

6.2 Management of fisheries

- Fishing **quotas** are implemented to control the number of fish harvested; preventing **over-fishing** so that fish can replenish their populations.
- Mesh (hole) sizes of fishing nets are regulated to prevent the harvesting of **immature** fishes.
- **Drift nets** and **trawlers** are banned to prevent trapping other forms of marine life like dolphins indiscriminately.
- Detrimental fishing technique such as **dredges** which destroy coral reefs and benthic organisms (living on seabed) is banned.
- Fishing during **breeding periods** of the fishes is prohibited to allow fish populations to reproduce.
- **Marine reserves** are designated to prevent fishing.
- **Endangered** species is protected from harvesting.

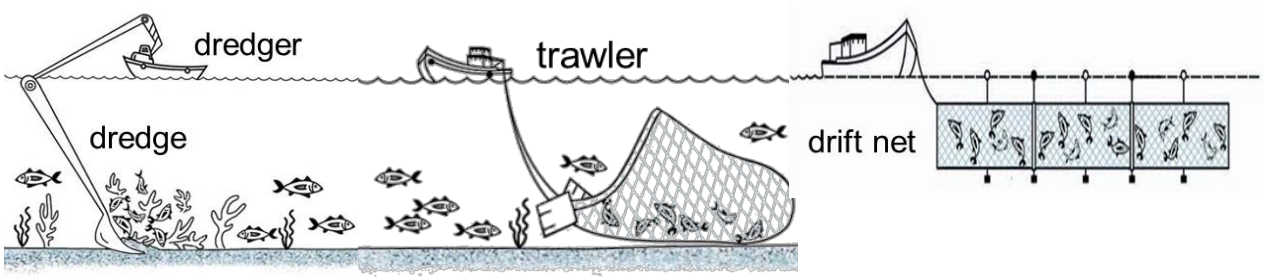


Figure 21.19 Uncontrolled fishing practices

6.3 Management of timber production

- Logging of timber is **regulated**; government legislation ensures that only selected trees are felled, not including the young trees for forest regeneration.
- Seedlings of native trees are planted to replace those that were felled (**reforestation**).
- Selected areas are designated as **forest reserves** where logging and other human activities that damage or pollute the forest ecosystem are prohibited.
- **Recycling** efforts of paper are promoted by the government.
- **Research** to improve the quality of forests.

7. ADDITIONAL READING MATERIALS

7.1 Ecological succession

- A community starts with **pioneer species** which are opportunistic colonisers of new or newly vacated habitats.
- They have high dispersal rates; they grow and mature quickly, and they produce many offspring.
- **Primary succession** begins when pioneer species colonise a barren habitat such as a new volcanic island and land exposed when a glacier retreats.
- Pioneer species include lichens and plants, such as club mosses, that are small, have short life cycles, and can survive intense sunlight, extreme temperature changes, and nutrient-poor soil.
- Pioneers improve soil volume and nutrients with the accumulation of organic wastes, favouring the invasions of new species.
- Later successional species will crowd out the pioneer species, whose seeds and spores travel in wind and water, destined for another new but temporary habitat.
- In **secondary succession**, a disturbed area within a community recovers, where other plants and animals species return.
- With the return of improved soil and keystone species, secondary succession can happen rapidly.
- **Keystone species** are plants or animals which play a unique and crucial role in an ecosystem.
- Without these keystone species, the ecosystem would be dramatically different or even fail to exist.
- For example, fig tree is a common keystone species in rainforests as it fruits all year round, providing food for many animal species.
- A **climax community** is achieved when its species are adapted to the environmental factors, forming a steady state.

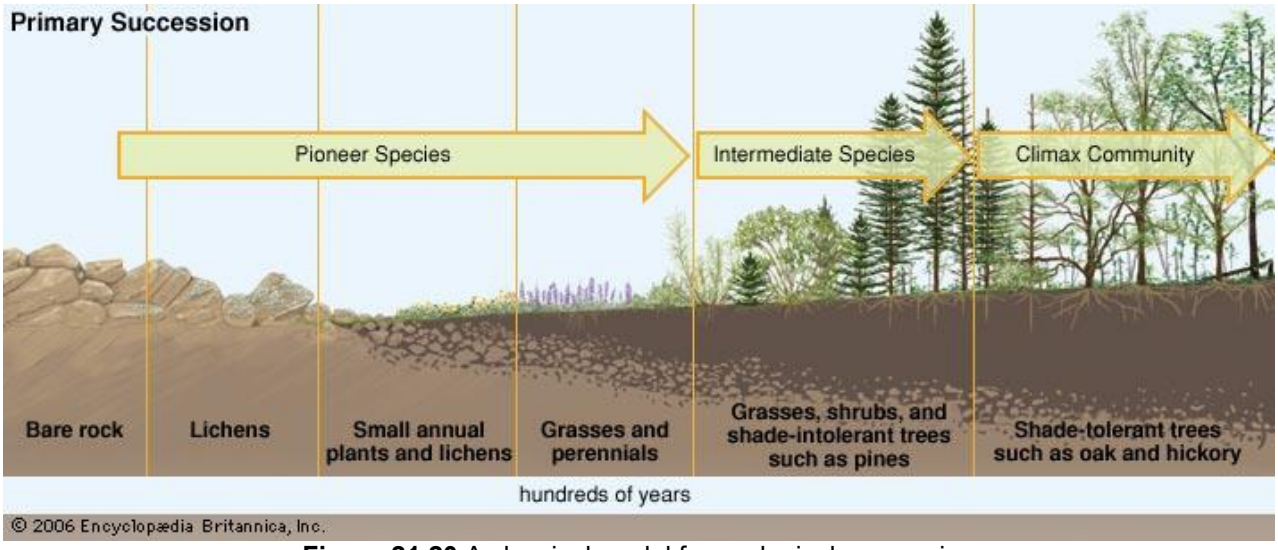


Figure 21.20 A classical model for ecological succession

The End