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Topical REVISION NOTES

BIOLOGY

Lye Ai Fern BSc (Hons), PGDE

O LEVEL

Includes

- ✓ Comprehensive Revision Notes
- ✓ Effective Study Guide

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PREFACE

O Level Biology Topical Revision Notes has been written in accordance with the latest syllabus issued by the Ministry of Education, Singapore.

This book is divided into 16 topics, each covering a topic as laid out in the syllabus. Important concepts are highlighted in each topic, with relevant examples and diagrams to help students better understand the concepts.

We believe this book will be of great help to teachers teaching the subject and students preparing for their O Level Biology examination.

CONTENTS

TOPIC 1 Cell Structure and Organisation

Objectives

Candidates 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 surface 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

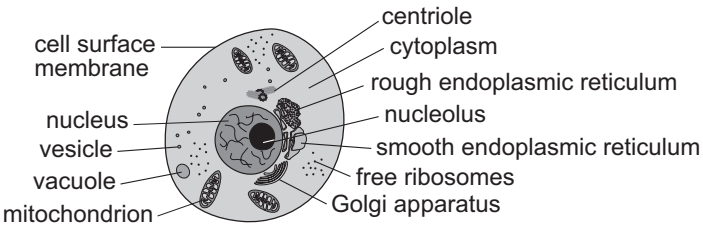
(d) compare the structure of typical animal and plant cells

(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

1.1 Animal cell

1. The following is a diagram of a generalised animal cell as seen under an electron microscope:



A generalised animal cell

2. The **cell surface membrane** or plasma membrane is a partially permeable membrane surrounding the cytoplasm of the cell. It controls substances entering or leaving the cell.

3. The **cytoplasm** is the gel-like matrix embedded with organelles. It is the site of most cellular activities.

4. The **cell vacuoles** are small fluid-filled spaces bound by a membrane. In animal cells they store water and food substances. They are usually not permanent.

5. The **nucleus** is an organelle surrounded by an envelope called the nuclear envelope. It contains darker bodies called nucleoli (singular: nucleolus) and thread-like structures called chromatin which are made of DNA. The nucleus controls cellular activities such as growth, repair, and cell division.

6. The **endoplasmic reticulum** (ER) is a network of membranes forming tubes and flattened spaces. There are two types of ER:

   (a) The **smooth endoplasmic reticulum** (SER) does not have ribosomes attached to it. It synthesises fats and steroids such as sex hormones. It also contains enzymes that detoxify drugs and poisons.

   (b) The **rough endoplasmic reticulum** (RER) is studded with **ribosomes**. Ribosomes in the cell can either be free ribosomes (i.e. they lie freely in the cytoplasm) or be attached to the membrane of the RER. Ribosomes synthesise proteins.

7. All proteins made in the RER depart in membrane-bound vesicles to the Golgi apparatus.

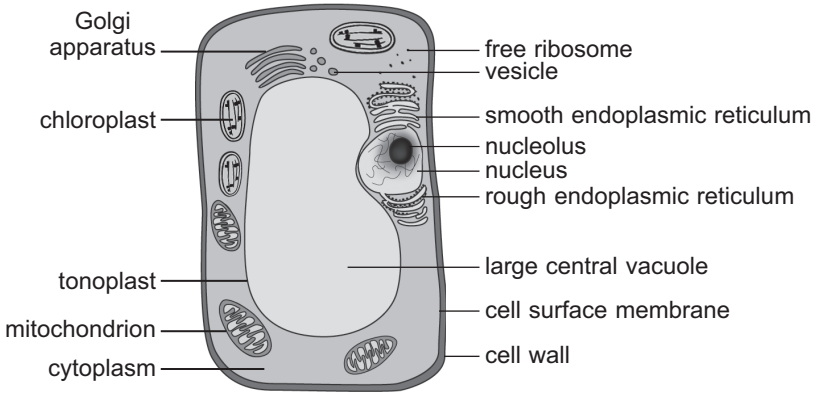
8. The **Golgi apparatus** resembles a stack of flattened disc-shaped spaces surrounded by membranes. It stores, sorts and modifies substances made by the ER, and packages them in vesicles to be secreted out of the cell.

9. The **mitochondria** (singular: mitochondrion) are small elongated organelles with folded inner membranes. Aerobic respiration takes place in the mitochondria. Aerobic respiration is the process where energy is extracted from food substances in the presence of oxygen. This energy is used by the cell to perform cellular activities such as growth and cell division.

10. The **centrioles** are a pair of barrel-shaped structures at right angles to each other. They play a role in cell division. Centrioles are usually absent in plants.

1.2 Plant cell

1. The following is a diagram of a generalised plant cell as seen under an electron microscope:



A generalised plant cell

2. The plant cell contains most of the structures present in an animal cell, with a few differences:

   (a) Instead of many small vacuoles, plant cells have a **large central vacuole** filled with cell sap, surrounded by a membrane called the **tonoplast**. Cell sap is mainly made up of water, with dissolved amino acids and mineral salts. Besides storage, the vacuole also takes in waste products and water.

   (b) Presence of a cellulose **cell wall** – The cell wall is non-living and fully permeable. It protects the cell from injury and gives the cell its shape.

   (c) Presence of **chloroplasts** – Chloroplasts are oval membrane-bound organelles filled with chlorophyll. They are the sites of photosynthesis, which is the process by which plants make food.

   (d) Centrioles are absent.

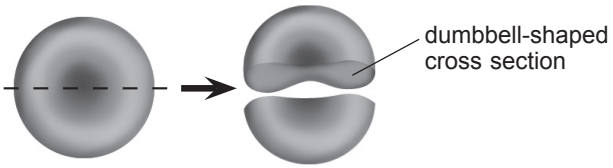
Note: The structures visible under a light microscope would be: cell membrane, cytoplasm, nucleus, vacuoles, cell wall and chloroplasts.

1.3 Adaptation of cells to their functions

1. Red blood cells deliver oxygen to the body tissues via the blood. Adaptations to this function include:

   (a) Red blood cells contain haemoglobin, an oxygen-carrying protein.

   (b) Red blood cells have no nucleus, so they have a flattened biconcave shape with a dumbbell-shaped cross section. This enables them to have a higher surface area to volume ratio for faster diffusion of oxygen. It also allows the cell to be more flexible when squeezing through blood capillaries.

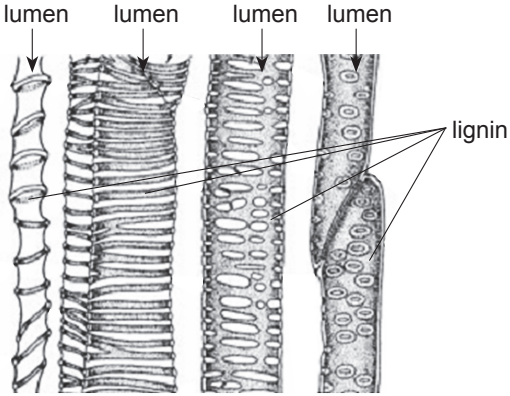


Cross-section of a red blood cell

2. Xylem vessels are elongated hollow tubes that are made of xylem cells linked end to end. Xylem cells are dead at maturity. They conduct water and mineral salts from the roots to the leaves of the plant. They also play a role in mechanical support. Adaptations to these functions include:

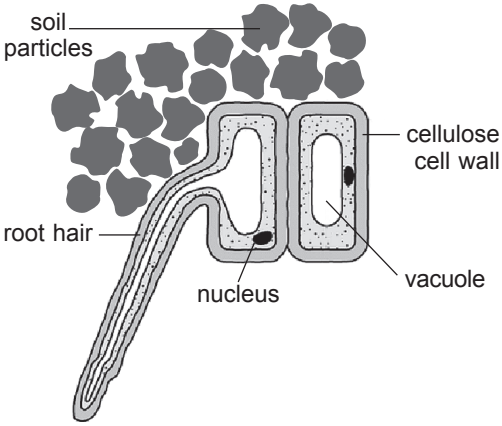
   (a) Absence of protoplasm and cross-walls which could impede water flow through the lumen (internal cavity)

   (b) Deposition of lignin on the cell walls which strengthens vessel walls, providing support



Xylem vessels

3. Root hair cells are cells which extend into the soil to absorb water and mineral salts. An adaptation to this function is a long and narrow structure called the root hair, which extends into the soil to absorb water. This increases the surface area to volume ratio of the cell, resulting in faster absorption.



A root hair cell

1.4 Organisation of a multicellular organism

1. The cell is the most basic unit of a living organism that can be classified as living.
2. A group of cells of the same type that are found near each other and carry out the same function comprises a **tissue**.
3. An **organ** is made up of different tissues working together to perform a specific function or a group of functions within an organism. An organ has a distinct shape which allows it to carry out its function well.
4. A group of functionally-related organs form an **organ system**.
5. Many organ systems working together make up a multicellular organism.

TOPIC 2 Movement of Substances

Objectives

Candidates 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

2.1 Diffusion

1. Diffusion is the net (overall) movement of molecules from a region of higher concentration to a region of lower concentration down a concentration gradient. Concentration refers to the number of particles per unit volume.
2. A **concentration gradient** is the difference in concentration between a region of higher concentration of a substance and a region of lower concentration of the substance.
3. When the concentration gradient is steeper, the rate of diffusion will be faster.
4. When a concentration gradient exists, diffusion will take place until the particles are evenly distributed throughout the region.

2.2 Diffusion in biological systems

1. Diffusion is an important mode of nutrient uptake and gaseous exchange in cells.
2. The cell surface membrane is a **partially permeable membrane** that allows gases such as oxygen and carbon dioxide to pass through freely but not some other substances.
3. In cells which undergo respiration, oxygen is continually being used up within the cell. This creates a concentration gradient where oxygen concentration is lower inside the cell than in the surroundings. Thus, dissolved oxygen diffuses into the cell.

4. Carbon dioxide and other waste products are generated by the cell. This sets up a concentration gradient where the concentration of these substances is higher within the cell than outside. Thus, the substances leave the cell by diffusion.

5. In unicellular organisms such as the amoeba, diffusion is an important mode of nutrient uptake.

2.3 Osmosis

1. Osmosis is the net movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane.

2. **Water potential** is a measure of the tendency of water molecules to move from one region to another. Since water is the solvent, forming the volume of a solution, it is not meaningful to think about the concentration of water, i.e. the number of water molecules per unit volume.

3. Water molecules that surround solutes causing them to dissolve are not able to move about freely as they are bound to the solutes. The more concentrated a solution is, the lower the number of freely moving water molecules present, hence the lower the water potential of the solution. As a result, a dilute solution has a higher water potential than a concentrated solution and pure water has the highest water potential.

Example

A U-tube filled with sucrose solutions of different concentrations was set up as shown in Fig. (a). After a few hours, it was observed that the water level in one arm of the U-tube had increased while the water level in the other arm had decreased as shown in Fig. (b). Describe and explain what had taken place in terms of the movement of the particles in the sucrose solutions.

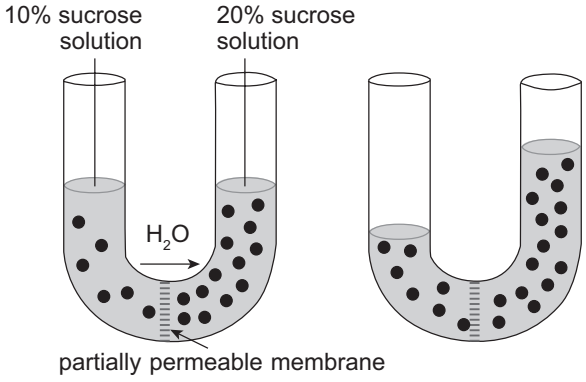
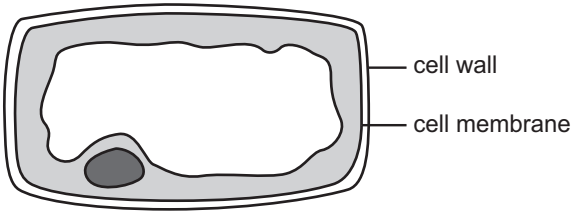


Fig. (a) Fig. (b)

Answer: The 20% sucrose solution is more concentrated than the 10% sucrose solution. Hence, it has a lower water potential as compared to the 10% sucrose solution. The partially permeable membrane does not allow sucrose molecules to pass through as sucrose molecules are too big; it only allows water molecules to pass through. As a result, water will move through the partially permeable membrane by osmosis, from the arm with the 10% sucrose solution (higher water potential) to the arm with the 20% sucrose solution (lower water potential), until the water potentials of the sugar solutions in both arms are the same. The net movement of water molecules is from left to right, hence the right arm has a higher water level at the end of the experiment.

2.4 Osmosis in plant cells

1. Osmosis in living systems refers to the movement of water molecules across the partially permeable cell surface membrane. The cell wall is fully permeable.
2. As the large central vacuole occupies most of the space in a plant cell, the water potential of the cell sap is considered to be the water potential of the plant cell.
3. When a plant cell is immersed in a solution of higher water potential relative to its cell sap, water molecules enter the cell by osmosis.
4. The vacuole increases in size and the expanded cell contents exert pressure on the cell wall.
5. The cellulose cell wall of a plant cell is strong and rigid.
6. The cell wall exerts an opposing pressure on the cell contents, preventing the entry of more water. This prevents the cell from overexpanding and bursting.
7. At this point, the plant cell is very firm or **turgid**. Turgor pressure provides mechanical support for many non-woody plants.

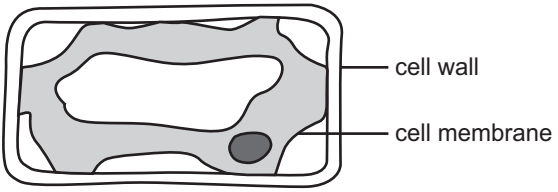


A turgid plant cell

8 . When a plant cell is immersed in a solution with a lower water potential relative to its cell sap, water diffuses out of the cell into the solution by osmosis.

9. The vacuole shrinks and the cell stops exerting pressure on the cell wall. The cell becomes limp or **flaccid**. If it is placed in a solution with a high water potential at this point, turgidity can be restored.

10. If more water leaves the cell, the vacuole and cytoplasm shrink to such an extent that the cell surface membrane pulls away from the cell wall. The phenomenon in which the cell surface membrane pulls away from the cell wall is called **plasmolysis**. This can be lethal if the cell is not quickly transferred to a solution with a higher water potential relative to its cell sap.



A plasmolysed plant cell

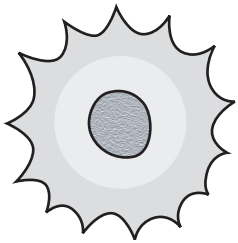
2.5 Osmosis in animal cells

1. When an animal cell is immersed in a solution with a higher water potential relative to its cytoplasm, water diffuses into the cell by osmosis.

2. The cell swells. As more water enters the cell, it swells to such an extent that it bursts. This is because it does not have a cell wall. This process is called **cytolysis**.

An animal cell undergoing cytolysis

3. When an animal cell is immersed in a solution with a lower water potential, relative to its cytoplasm, water diffuses out of the cell by osmosis.
4. The cell shrinks and become dehydrated. In red blood cells, little spikes appear on the cell surface membrane, and the cell is said to have undergone **crenation**. The animal cell will die if it is not removed from the solution.



A crenated red blood cell

2.6 Active transport

1. Active transport is the process in which energy is used to transport substances across a biological membrane against a concentration gradient.
2. The energy used for active transport is obtained through cellular respiration.
3. Uptake of dissolved mineral salts by root hair cells and glucose uptake by cells in the villi of the small intestine are examples of active transport.

TOPIC 3 Biological Molecules

Objectives

Candidates should be able to:

(a) state the roles of water in living organisms
(b) list the chemical elements which make up
- carbohydrates
- fats
- proteins

(c) describe and carry out tests for
- starch (iodine in potassium iodide solution)
- reducing sugars (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

(e) explain enzyme action in terms of the 'lock and key' hypothesis
(f) explain the mode of action of enzymes in terms of an active site, enzyme-substrate complex, lowering of activation energy and enzyme specificity
(g) investigate and explain the effects of temperature and pH on the rate of enzyme catalysed reactions

3.1 Role of water in animals

1. About 70% of the human body consists of water. Water is found in cell cytoplasm, blood, digestive juices, tissue fluid, fluid in joints and contained within organs i.e. spinal cord, the brain, the eyes, gastrointestinal tract, etc.
2. Water moderates body temperature. It has a high specific heat capacity, which means that a lot of energy is required to raise the temperature of water by 1°C. Hence, water helps the cell resist changes in temperature.
3. It plays a role in **evaporative cooling**. Water is a component of sweat, which removes heat from the body when it evaporates.
4. Water is a reactant in certain chemical reactions in the body, such as the **hydrolysis** of food molecules during digestion.
5. Water is a component of body fluids with lubricative or protective properties such as lubricants in joints, coating the stomach lining, mucus in the oesophagus, and cervical mucus in the female reproductive system.

6. Water is an extremely versatile **solvent**. More things dissolve in water than in any other solvent. Because of this property,

   (a) water is the medium in which chemical reactions take place in living organisms, and

   (b) water serves as a **transportation** medium. It transports water-soluble food products from the small intestine to other parts of the body and waste materials from cells to the excretory organs for removal. It transports hormones to the target organs or tissues. Blood is the main transport medium in the body.

3.2 Role of water in plants

1. Water is a key reactant in photosynthetic processes.
2. It provides physical support to the plant in the form of turgor pressure.
3. Water is required to transport dissolved mineral salts from the roots to other parts of the plant through xylem vessels.
4. Water is required to transport sugars made in the leaves to other parts of the plant.

3.3 Simple carbohydrates

1. Carbohydrates are organic molecules made up of carbon, hydrogen and oxygen with the general formula for most carbohydrates being $C_nH_{2n}O_n$.
2. Carbohydrates are classified into 3 main groups: **monosaccharides**, **disaccharides** and **polysaccharides** depending on the number of basic sugar units they have.
3. Monosaccharides are the most basic unit of carbohydrates and are the simplest form of sugars. Common examples are glucose, fructose and galactose.
4. Disaccharides are formed when two monosaccharides undergo a condensation reaction. Common examples are maltose (formed by 2 glucose units), sucrose (1 glucose, 1 fructose) and lactose (1 galactose, 1 glucose).
5. A **condensation reaction** is a chemical reaction when two molecules combine together to form a single molecule with the elimination of a water molecule.
6. A disaccharide can be split into its component monosaccharides by undergoing **hydrolysis** in which a water molecule is added to the disaccharide to break it down into its component monosaccharides. Enzymes are usually required for this process.

3.4 Test for reducing sugars

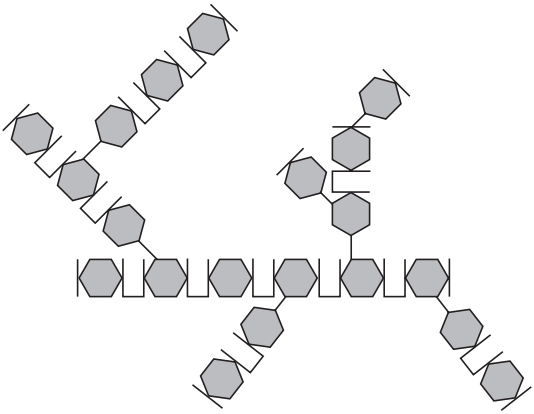
1. The test for reducing sugars is known as the Benedict's test.
2. The main reagent is Benedict's solution which contains copper(II) sulfate.
3. Reducing sugars can reduce copper(II) ions in Benedict's solution to copper(I) in the form of copper(I) oxide, a brick-red precipitate.
4. Reducing sugars are glucose, fructose, galactose, maltose and lactose. Sucrose is not a reducing sugar.
5. Procedure: Add 2 cm^3 of Benedict's solution to 2 cm^3 of sample solution and mix the contents thoroughly. Heat the test tube in a boiling water bath for 5 minutes. If the sample is an insoluble solid, crush it or cut it into small pieces before adding 2 cm^3 of water and 2 cm^3 of Benedict's solution.
6. The colour of the solution changes from green to orange to brick-red with increasing amounts of reducing sugars present.

3.5 Complex carbohydrates

1. Polysaccharides include starch, glycogen and cellulose. They are long chains of glucose molecules linked together in condensation reactions. Each chain may contain thousands of glucose molecules.
2. In starch, the glucose molecules are linked together in long straight chains or branched chains. It is a storage molecule in plants.

A starch molecule

3. In glycogen, the glucose molecules are linked together in highly branched chains. It is a storage molecule in animals and fungi.



A glycogen molecule

4. In cellulose, the glucose molecules are linked in long straight chains. The linkage between the glucose molecules is not the same as that in starch. Cellulose is the tough material found in cell walls of plants. Cellulose is the fibre necessary in a healthy diet.

A cellulose molecule

5. Glycogen and starch are the storage forms of glucose in animal and plant cells respectively. This is because

   (a) they are insoluble in water and do not affect water potential in cells,

   (b) they are too large to diffuse out of the cells and thus remain within the cells,

   (c) they have compact shapes, and

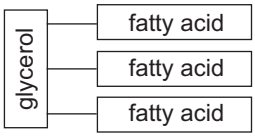
   (d) they can be easily hydrolysed into glucose for cellular respiration.

3.6 Test for starch

1. The test for starch is called the iodine test. Iodine is added to the sample and the colour change (if any) is observed.
2. Procedure: Add a few drops of iodine solution to the sample. If the sample contains starch, it will turn blue-black in colour.

3.7 Fats

1. Fats (lipids) are organic molecules made up of carbon, hydrogen and oxygen. There is no general formula for fats. The ratio of hydrogen to oxygen is much higher in fats than in carbohydrates, where the ratio of hydrogen to oxygen is 2 : 1.
2. Fats are made from two types of smaller molecules: glycerol and fatty acids. Each fat molecule contains a glycerol molecule and 3 fatty acids. Each fatty acid is linked to the glycerol backbone in a condensation reaction.



A fat molecule

3. When 3 water molecules are added to a fat molecule with the help of enzymes in a hydrolysis reaction, the fat molecule breaks down into fatty acids and glycerol.

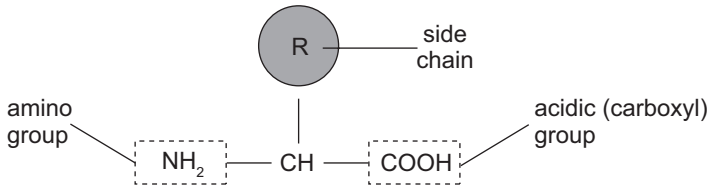
4. Fats are storage molecules that can store a large amount of energy.
5. They are also an important component of cell membranes.
6. Fats are used to make steroids and certain hormones.
7. Fats are also used as insulating material to prevent the loss of body heat.
8. Fat is also a solvent for fat-soluble vitamins.

3.8 Test for fats

1. The test for fats is known as the ethanol emulsion test.
2. Ethanol is added to the sample to allow the fats present in it to dissolve. Water is then added to the ethanolic mixture. Since fats do not dissolve in water, they precipitate out of the solution to give a cloudy white emulsion.
3. Procedure: Add 2 cm^3 of ethanol to the sample in a test tube and shake the contents thoroughly. Add 2 cm^3 of water and mix the contents. If fats are present, a white emulsion will be observed.

3.9 Proteins

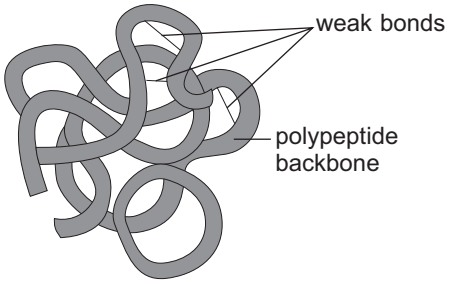
1. Proteins are complex organic molecules made up of carbon, hydrogen, oxygen and nitrogen. They may also contain sulfur.
2. In the form of enzymes, proteins participate in all cellular processes and are responsible for almost everything living organisms do.
3. There are tens of thousands of different proteins, each serving a different function and having a unique structure.
4. Proteins are made up of **amino acids**.
5. An amino acid is a molecule with the general structure:



An amino acid

6. There are about 20 different naturally-occurring amino acids which have different side chains (also known as R groups).
7. Amino acids are combined in many different ways to form different protein molecules.

8. Amino acids link up in a condensation reaction to form a **polypeptide** chain. The bonds between the amino acids are known as peptide bonds.
9. Proteins are made of one or more polypeptide chains twisted, folded and coiled into a unique 3-dimensional structure.
10. The bonds between the amino acids, peptide bonds, are strong but the bonds that hold the 3-dimensional coiled structures together are weak and can easily be broken by heat or by changes in pH. Examples of such bonds are hydrogen bonds, ionic interactions and van der Waals interactions.



A protein molecule

11. When these bonds are broken, the protein loses its 3-dimensional conformation. This process is called **denaturation**. Proteins can be denatured if they are heated or placed in an environment with unsuitable pH. Denaturation usually leads to loss of function as proteins require their 3-dimensional shape to function. Denaturation can also cause proteins to lose their solubility and precipitate out of the solution.
12. Many proteins are enzymes, which catalyse chemical reactions within our body.
13. Structural proteins found in muscle cells play a role in movement.
14. Other proteins take part in cell growth, repair and reproduction.
15. Antibodies are proteins in our body that help us fight diseases.

3.10 Test for proteins

1. The test for proteins is known as the biuret test.
2. The main reagents are sodium hydroxide and copper(II) sulfate.
3. Procedure: Add 1 cm^3 of sodium hydroxide solution to 1 cm^3 of sample solution in a test tube and mix thoroughly. Add a few drops of 1% copper(II) sulfate solution dropwise into the mixture, shaking after each drop. Allow the mixture to stand for 5 minutes.
4. If proteins are present, a violet colouration will be observed.

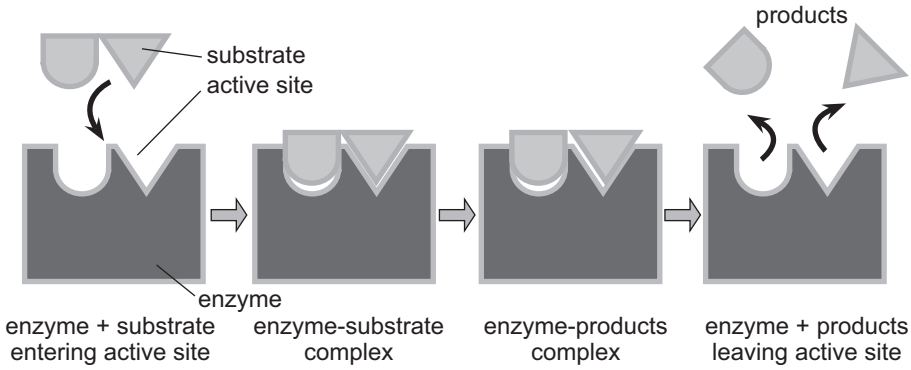
3.11 Enzymes

1. Enzymes are biological **catalysts** that speed up the rate of chemical reactions without being altered in the reaction. They are made of proteins.
2. Enzymes work by lowering the **activation energy** of a chemical reaction. Activation energy is the amount of energy needed for a reaction to take place.
3. Enzymes allow biochemical reactions to take place without drastic conditions such as high temperatures because less heat energy is required to start a reaction.
4. Enzymes can break down or build up biological molecules.
5. Enzymes are required in small amounts because they remain unchanged in the chemical reactions they catalyse and can be reused.
6. They are **substrate-specific**. Substrates are the reactants that an enzyme acts on. Each enzyme can only act on the particular substrate of the reaction they are supposed to catalyse. For example, amylase can only digest starch and not cellulose even though they are both polymers of glucose.
7. Therefore, each enzyme catalyses a different reaction. This is due to its unique 3-dimensional structure.

3.12 'Lock and key' hypothesis

1. The 'lock and key' hypothesis relates enzyme specificity to the presence of active sites. An **active site** is the region on an enzyme molecule that the substrate binds to. It is usually a pocket or groove on the surface of the enzyme that is part of the enzyme's unique 3-dimensional structure.
2. The shape of the active site conforms to the substrate. Only the correct substrate is able to fit into the active site.
3. The process begins when the substrate molecule binds to the active site of the enzyme to form an **enzyme-substrate complex**.
4. The reaction is then catalysed at the active sites to convert the substrate into product molecules.
5. The product molecules depart from the active site, leaving the enzyme free to catalyse another reaction.

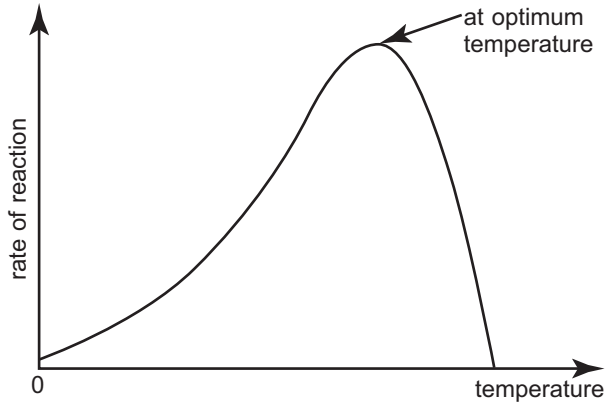
6. The diagram below illustrates the 'lock and key' hypothesis for a reaction in which an enzyme breaks down a substrate molecule into 2 product molecules:



Process of an enzyme-catalysed reaction

3.13 Effects of temperature on the rate of enzyme-catalysed reactions

1 . The effects of temperature on the rate of enzyme-catalysed reactions is shown in the graph below:



Effect of temperature on the rate of reaction

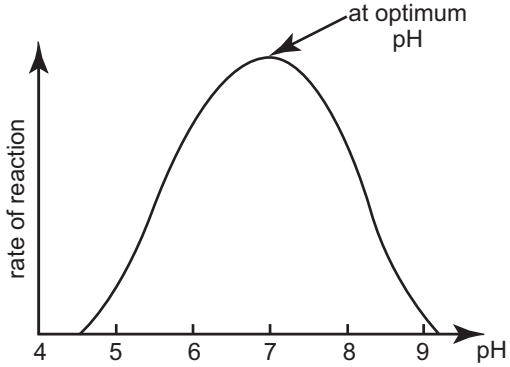
2. At low temperatures, enzymes are inactive and the rate of reaction is very low. Substrate and enzyme molecules have little kinetic energy, hence the frequency of collision is low. In addition, most substrate molecules do not contain sufficient energy to overcome the activation energy required to start a reaction.

3. As temperature increases, the rate of enzyme activity increases. Enzyme activity doubles with every 10°C rise in temperature. This is because the reactants have higher levels of energy, and the substrate molecules are able to collide with active sites more frequently.

4. At the optimum temperature, enzyme activity is the highest.
5. As the temperature increases beyond the optimum temperature, enzyme activity drops sharply. This is because enzymes are made of proteins, which are denatured at high temperatures. The enzyme loses its 3-dimensional structure and active site conformation due to the breaking of the weak bonds that hold the structure together.
6. At extremely high temperatures, the enzyme is completely denatured and the rate of reaction drops to zero.

3.14 Effects of pH on the rate of enzyme-catalysed reactions

1. The graph showing the effects of pH on the rate of enzyme-catalysed reactions is shown in the graph below:



Effect of pH on the rate of reaction of amylase

2. Enzyme activity is the highest at the optimum pH of the enzyme.
3. As the pH increases or decreases from the optimum, enzyme activity sharply decreases. This is because the hydrogen bonds and ionic bonds that hold the 3-dimensional structure are disrupted. The shape of the active site is changed as the enzyme is denatured.
4. At extreme pH levels, the enzyme is completely denatured and the rate of reaction drops to zero.
5. The optimum pH for each enzyme differs. For example, pepsin works best under the acidic conditions in the stomach, while intestinal enzymes work best under alkaline conditions.

TOPIC 4 Nutrition in Humans

Objectives

Candidates 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 the functions of enzymes (e.g. amylase, maltase, protease, lipase) in digestion, listing the substrates and end-products

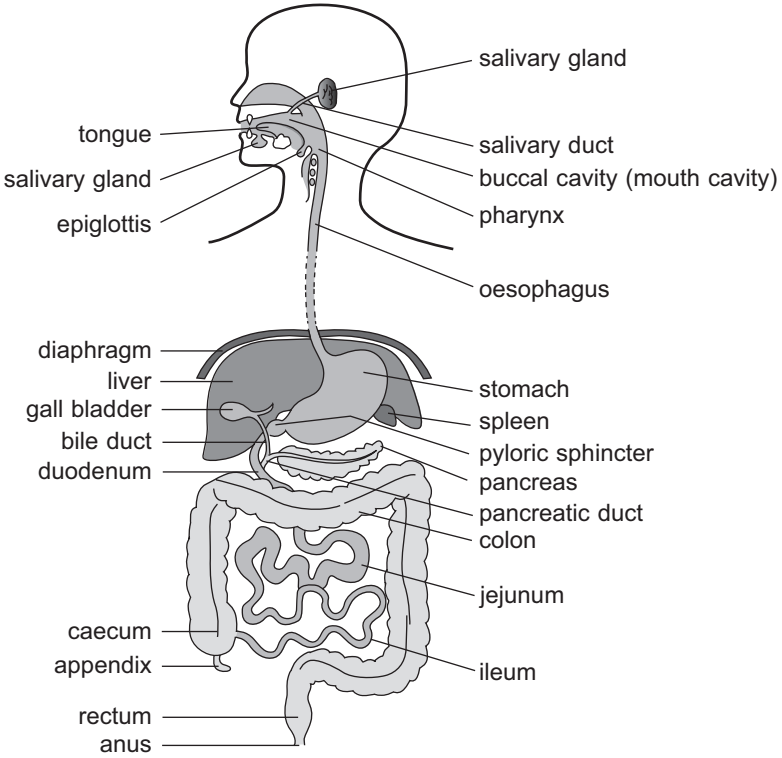
(d) describe the structure of a villus and its role, including the role of capillaries and lacteals in absorption

(e) state the function of the hepatic portal vein as the transport of blood rich in absorbed nutrients from the small intestine to the liver

(f) state the role of the liver in
- carbohydrate metabolism
- fat digestion
- breakdown of red blood cells
- metabolism of amino acids and the formation of urea
- breakdown of alcohol

(g) describe the effects of excessive consumption of alcohol: reduced self-control, depressant, effect on reaction times, damage to liver and social implications

4.1 Overview of the digestive system



The human digestive system

1. Human digestion takes place in the mouth, stomach and small intestine.
2. The alimentary canal consists of the mouth, the oesophagus, the stomach, the small and large intestines and the anus.
3. Other organs associated with digestion include the liver, pancreas, gall bladder and salivary glands.

4.2 The mouth

1. Food enters the body through the mouth, or **buccal cavity**. Physical and chemical digestion takes place in the mouth. In the mouth:
   (a) Teeth start to break the food into smaller pieces. This makes food easier to swallow and also increases the surface area to volume ratio of the food for the digestive enzymes to work on more efficiently.
   (b) Salivary glands secrete saliva which moistens the food and makes it easier to swallow. Saliva also contains salivary amylase, an enzyme which breaks down starch into maltose. The optimum pH of salivary amylase is 7.
   (c) The tongue rolls the food into a **bolus**, which is then swallowed.

4.3 The oesophagus

1. The food passes through the pharynx and enters the **oesophagus**. The oesophagus is a muscular tube that leads to the stomach.
2. It is made up of two layers of smooth muscle. The external layer is the longitudinal muscle and the inner layer is the circular muscle. These muscles found along much of the entire length of the alimentary canal.
3. These muscles contract and relax alternately to cause wave-like contractions known as peristalsis.
4. Food moves along the oesophagus due to peristalsis.
5. Digestion of starch by salivary amylase continues in the oesophagus.

4.4 The stomach

1. The food reaches the stomach, which is a muscular bag with elastic walls.
2. The stomach walls form deep pits that contain gastric glands. These glands secrete mucus which protects the stomach walls. They also secrete gastric acid and pepsinogen.
3. Peristalsis in the stomach churns the food to break the food up and mix it thoroughly with gastric juice.
4. Gastric acid is hydrochloric acid with pH 2. Gastric acid
   (a) stops the activity of salivary amylase by denaturing it,
   (b) changes the inactive form of pepsin, pepsinogen, into the active form, pepsin, and
   (c) kills germs and bacteria.
5. Pepsin is a protease. The optimum pH for pepsin is about 2.

6. Food leaves the stomach in small quantities at regular intervals, and enters the small intestine through the pyloric sphincter as a semi-liquid mass known as chyme. The pyloric sphincter is a ring of muscle at the base of the stomach that allows chyme to pass into the small intestine in small amounts at a time. Allowing the food to pass into the small intestine in small quantities ensures that the food can be completely digested by the enzymes in the intestines. If the person had a heavy meal, the contents of the stomach may be emptied over a period of up to three hours.

4.5 The small intestine

1. The small intestine is divided into three parts: the duodenum, jejunum and ileum.
2. Food is moved through the small intestine by peristalsis.
3. In the duodenum, chyme from the stomach mixes with digestive juices from the pancreas, liver, gall bladder and intestinal glands.
4. The pancreas produces pancreatic juice, which is an alkaline solution containing trypsinogen, pancreatic amylase and pancreatic lipase. Pancreatic juice enters the duodenum through the pancreatic duct.
5. Intestinal juice contains intestinal lipase, enterokinase, erepsin, maltase, lactase, sucrase and several other enzymes.
6. All enzymes in the small intestine have an optimum pH under alkaline conditions.
7. Bile, an alkaline greenish-yellow fluid, is produced by the liver and stored in the gall bladder. It passes into the small intestine through the bile duct. Bile breaks up large fat droplets into smaller fat droplets in a process called emulsification. This increases the surface area to volume ratio of the fats for lipases on work on and speeds up fat digestion.
8. Action of enzymes involved in carbohydrate digestion in the small intestine:

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

$$\text{maltose} \xrightarrow{\text{maltase}} \text{2 molecules of glucose}$$

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

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

9. Action of enzymes involved in fat digestion in the small intestine:

$$\text{fats} \xrightarrow{\text{lipase}} \text{3 fatty acids + glycerol}$$

10. Action of enzymes involved in protein digestion in the small intestine:

$$\text{trypsinogen} \xrightarrow{\text{enterokinase}} \text{trypsin}$$

$$\text{proteins} \xrightarrow{\text{trypsin}} \text{polypeptides}$$

$$\text{polypeptides} \xrightarrow{\text{peptidases / erepsin}} \text{amino acids}$$

Note: Enterokinase converts the inactive form of trypsin, trypsinogen, into trypsin.

11. Food is completely digested in the small intestine. The jejunum and ileum function mainly to absorb nutrients and water.

12. Nutrients have to be absorbed into the body from the lumen of the small intestine. The small intestine is adapted for this role by having:

    (a) An inner wall with large circular folds

    (b) Finger-like projections on the inner wall called villi

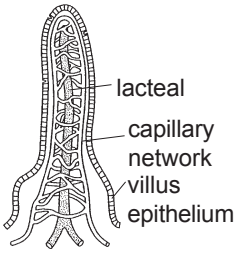
    (c) Each epithelial cell on the villi has smaller projections called microvilli

13. These adaptations increase the surface area of the small intestine, resulting in a larger surface for absorption.

14. The villi have thin walls (one-cell thick) so that food molecules diffuse over a shorter distance.

15. Within each villus is a network of capillaries and a small vessel called a lacteal.

16. Nutrients are absorbed across the wall of the small intestine and into the capillaries or lacteal. The lacteal transports fats away from the small intestine while the capillaries transport sugars and amino acids.



A villus

17. The transport of food away from the small intestine sets up a concentration gradient for diffusion.

18. Glucose and amino acids are absorbed by diffusion or active transport depending on the concentration gradient.

19. Fatty acids and glycerol are absorbed by the epithelial cells of the villi and recombined within those cells to form fats, which are transported into a lacteal.

20. Water is absorbed by passive diffusion throughout the length of the small intestine and mineral salts are absorbed in the ileum.

21. The food eventually leaves the small intestine and enters the large intestine.

4.6 The large intestine

1. The large intestine or colon is shaped like an inverted U and has the function of absorbing the remaining water and mineral salts that have not been absorbed by the small intestine. Note that most of the water that was present in the small intestine (from liquid in ingested food as well as the water content in intestinal mucus and digestive juices) had been absorbed by the small intestine.
2. The undigested waste matter moves along the large intestine by peristalsis, getting progressively drier.
3. The undigested waste matter comprises mainly cellulose, which is indigestible to humans.
4. The waste matter ends up at the rectum where it is stored before it can be eliminated from the body through the anus. The elimination of waste material is called **egestion**.

4.7 Transport of products of digestion

1. As absorption takes place in the small intestine, the blood in the capillaries of the villi becomes very rich in simple sugars and amino acids.
2. The blood capillaries of the villi converge into a large blood vessel called the **hepatic portal vein**, which leads to the liver.
3. The blood from the small intestine travels to the liver via the hepatic portal vein. The composition of blood in this vein varies greatly throughout the day depending on whether absorption of nutrients is occurring in the small intestine.

4.8 Role of the liver in carbohydrate metabolism

1. The liver is involved in carbohydrate metabolism and regulation of blood glucose concentration.
2. When the glucose level in blood is high, the islets of Langerhans in the pancreas secrete insulin, which is a hormone that stimulates the liver cells to convert glucose into glycogen. The liver cells convert excess glucose in the blood from the hepatic portal vein into glycogen, which is stored in the liver.
3. When the glucose level in blood is low, the islets of Langerhans secrete glucagon, which is a hormone that stimulates the liver cells to convert stored glycogen in the liver back into glucose. The glucose is released into the blood leaving the liver, which supplies glucose to the body cells.

4.9 Role of the liver in fat metabolism

1. The liver produces bile, an alkaline liquid which helps fat digestion by emulsifying fats.
2. It oxidises fats to produce energy.
3. It converts excess carbohydrates and proteins to fatty acids and glycerol which are exported and stored as fatty tissue.

4.10 Role of the liver in breakdown of red blood cells

1. Aging red blood cells are removed by the spleen.
2. Haemoglobin from the red blood cells is brought to the liver, where it is broken down. The iron from the haemoglobin is stored in the liver while the other metabolic by-products of the breakdown form bile pigments.

4.11 Role of the liver in protein metabolism

1. The liver is involved in the synthesis of plasma proteins e.g. albumin, and blood clotting factors e.g. fibrinogen.
2. The liver is responsible for the deamination of excess amino acids, which refers to the removal of the amino group ($–NH_2$) from an amino acid.
3. The amino group is converted into ammonia, which is toxic to cells, before it is further converted to urea by enzymes in the liver, and subsequently removed in urine.
4. The remnants of the amino acid are converted to glucose.

4.12 Role of the liver in detoxification

1. The liver breaks down toxic substances for excretion in urine or bile.
2. It also breaks down alcohol to acetaldehyde through the action of an enzyme called alcohol dehydrogenase.
3. Acetaldehyde is then converted to harmless acetic acid by acetaldehyde dehydrogenase.
4. Alcohol irritates oesophageal, stomach and intestinal linings. Excessive alcohol consumption can lead to inflammation and ulcers.
5. Excessive alcohol consumption can also lead to inflammation, scarring and destruction of liver cells.
6. The liver cells are replaced with fibrous scar tissue in a disease called cirrhosis of the liver, leading to loss of liver function.

TOPIC 5 Nutrition in Plants

Objectives

Candidates should be able to:

(a) identify and label the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section using the light 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 and symbols, for photosynthesis

(c) describe 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 uses

(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)

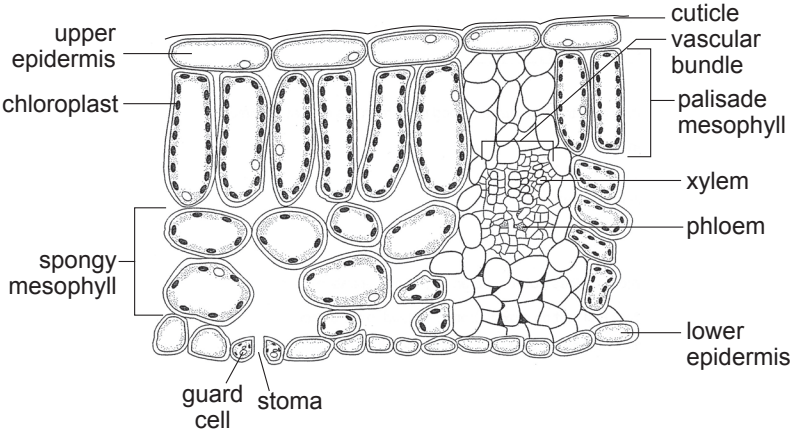
(f) discuss light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis

5.1 External leaf structure

1. The leaf blade or **lamina** is thin, with a large surface area to volume ratio, increasing sunlight absorbed for photosynthesis and diffusion of carbon dioxide and oxygen.
2. The leaf stalk or **petiole** holds the leaf away from the stem so that the leaf can get more sunlight.
3. The **mid-rib** and **vein network** carry food substances away from the leaves, and water and mineral salts to the leaves.

5.2 Internal leaf structure

1. The diagram below shows the cross section of a dicotyledonous leaf as seen under a microscope:



Cross section of a dicotyledonous leaf

2. The **upper epidermis** is a single layer of irregular, closely packed cells covered by a layer of waxy cuticle. The cuticle protects the epidermis and prevents excessive water loss through evaporation. It is transparent to allow sunlight to pass through. Epidermal cells contain no chloroplasts.

3. **Palisade mesophyll** cells are columnar in shape and closely packed. They contain a lot of chloroplasts to increase absorption of sunlight for photosynthesis.

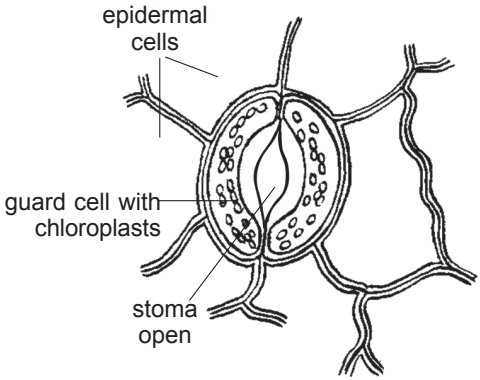
4. **Spongy mesophyll** cells are irregular in shape with numerous intercellular air spaces around them to allow for fast diffusion of carbon dioxide, which enters the leaf through the stomata, to all photosynthetic cells. They contain fewer chloroplasts than palisade mesophyll cells. They are covered with a thin film of moisture so that carbon dioxide can dissolve in it.

5. Within the mesophyll layers are the **vascular bundles** containing xylem and phloem tissue. This brings the transport tissue into close contact with the photosynthetic tissue, allowing water and mineral salts to be distributed to the photosynthetic cells efficiently and food products to be brought to other parts of the plant.

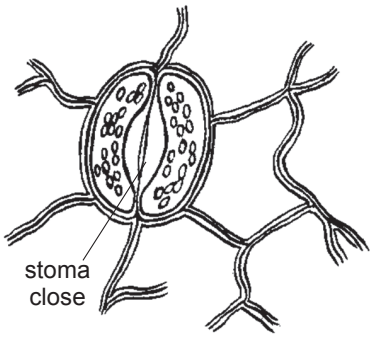
6. The **lower epidermis** is also a single layer of closely-packed cells covered by a layer of waxy cuticle.

7. **Guard cells** are bean-shaped, chloroplast-containing cells located in the lower epidermis. They control the opening and closing of the **stoma** (plural: stomata), the gap between the guard cells. The stomata allow carbon dioxide to diffuse in, oxygen to diffuse out and water vapour to escape.

5.3 Mode of operation of guard cells



Open stoma



Closed stoma

1. Plants open their stomata during the day for carbon dioxide intake and close their stomata during the night to minimise water loss through transpiration.
2. Guard cells control the opening and closing of stomata through regulation of water potential within themselves.
3. Photosynthesis in guard cell chloroplasts provides the energy for the uptake of potassium ions into the cell.
4. This lowers the water potential within the guard cells, causing water to enter by osmosis.
5. Each guard cell has a thicker cellulose cell wall on the side surrounding the stomata, as compared to the side adjacent to neighbouring epidermal cells. When water enters the cell, the side away from the stoma, being thinner, expands more than the side framing the stoma. This causes the cells to become curved such that the stoma opens.
6. When there is excessive water loss, even during the day, the guard cells lose turgor and become flaccid, causing the stoma to close.

5.4 Intake of carbon dioxide

1. When carbon dioxide within the leaf is used up by photosynthesis, the concentration of carbon dioxide in the leaf becomes lower than that in atmospheric air.
2. Carbon dioxide diffuses into the intercellular air spaces of the spongy mesophyll layer through the stomatal openings.
3. The mesophyll cells exposed to the intercellular air spaces are covered by a thin film of water. Carbon dioxide dissolves in it and diffuses into the cells.

5.5 Intake of water

1. The vascular bundles in the stem pass through the petioles and enter the leaves.
2. Within the leaves, they branch throughout the mesophyll layers, forming leaf veins.
3. Water from the roots travels through the xylem vessels in the vascular bundles and enters the leaves.
4. Once out of the xylem vessels, water travels from cell to cell through osmosis.

5.6 Photosynthesis

1. Photosynthesis is the process by which plants convert carbon dioxide and water into sugars using sunlight as energy in the presence of chlorophyll.
2. Equation for photosynthesis:

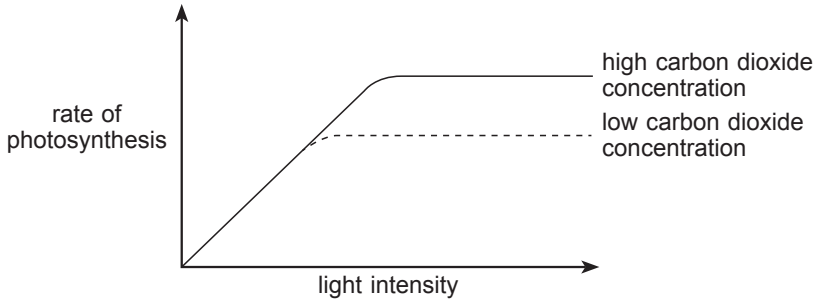
$$6CO_2 + 12H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

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

3. Photosynthesis is split into 2 stages: light-dependent stage and light-independent stage.
4. Light-dependent stage:
   (a) Light energy is absorbed by chlorophyll and used to split water into hydrogen and oxygen atoms in a process called **photolysis**.
   (b) The oxygen atoms combine to form oxygen gas which is a product of photosynthesis.
   (c) Other high-energy molecules are generated for use in the light-independent stage to convert carbon dioxide into glucose.
5. Light-independent stage:
   (a) The chemical energy stored during the light reactions as high-energy molecules is used in a series of reactions to convert carbon dioxide into carbohydrate.
   (b) Hydrogen from the light reactions is used as a reducing agent in the process.
   (c) The carbohydrate formed in this stage is converted to glucose and other carbohydrates by enzymes.
   (d) No light energy is required in this stage.

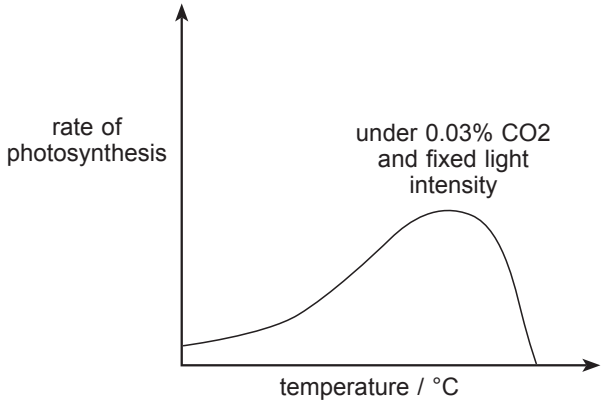
5.7 Limiting factors on rate of photosynthesis

1. **Light intensity**, **carbon dioxide concentration** and **temperature** are limiting factors on the rate of photosynthesis.
2. At a constant temperature and carbon dioxide concentration, the rate of photosynthesis increases with increasing light intensity until it reaches a plateau.
3. When the plateau is reached, light is no longer the limiting factor in the reaction. The concentration of carbon dioxide becomes the limiting factor.
4. Increasing the concentration of carbon dioxide raises the plateau reached.
5. Increasing the temperature over a certain range has little effect at low light intensities but increases the rate of photosynthesis at high light intensities.



Effect of light intensity on the rate of photosynthesis

6. Both light and dark reactions involve enzymes which would be denatured at a high temperature.



Effect of temperature on the rate of photosynthesis

TOPIC 6 Transport in Flowering Plants

Objectives

Candidates 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

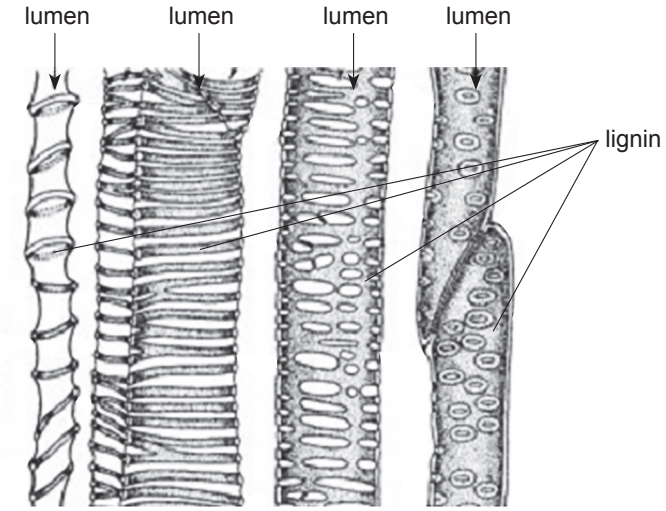
(e) define the term *transpiration* and explain that transpiration is a consequence of gaseous exchange in plants

(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

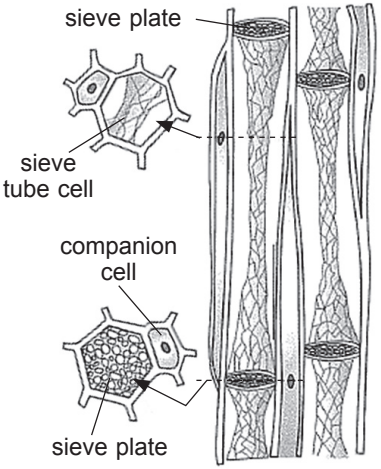
6.1 Transport vessels

1. Vascular tissues of the plant consist of **xylem vessels** and the **phloem**.
2. Xylem vessels are elongated hollow tubes that are made of xylem cells linked end to end. Xylem cells are dead at maturity.
3. Functions of xylem tissue:
   (a) Conduct water and mineral salts from the roots to the leaves
   (b) Mechanical support
4. Adaptations to these functions include:
   (a) Absence of protoplasm and cross-walls which could impede water flow through the lumen (central space)
   (b) Deposition of **lignin** on the cell walls which strengthens vessel walls, providing support



Xylem vessels

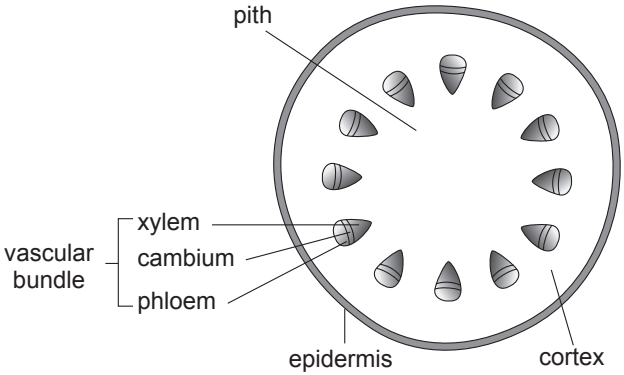
5. The phloem tissue consists of **sieve tube elements** and **companion cells**.
6. Sieve tube elements are elongated thin-walled living cells. They have degenerate protoplasm, which means they lack organelles such as the nucleus, ribosomes and the large central vacuole.
7. Sieve tube elements are arranged end to end, with porous walls called **sieve plates** between them.
8. There is one companion cell closely associated with each sieve tube element. Companion cells contain nuclei, cytoplasm and numerous mitochondria, and are responsible for performing the metabolic functions of the sieve tube elements.
9. The function of the phloem is to conduct sugars and amino acids from the leaves to other parts of the plant.
10. Adaptations to this function include:
    (a) Porous sieve plates that allow uninterrupted flow of food substances through the sieve tubes
    (b) Numerous mitochondria in the companion cells that provide energy for them to help load sieve tube members with sugar



Phloem vessels

6.2 Position of vascular tissue in dicotyledonous stems

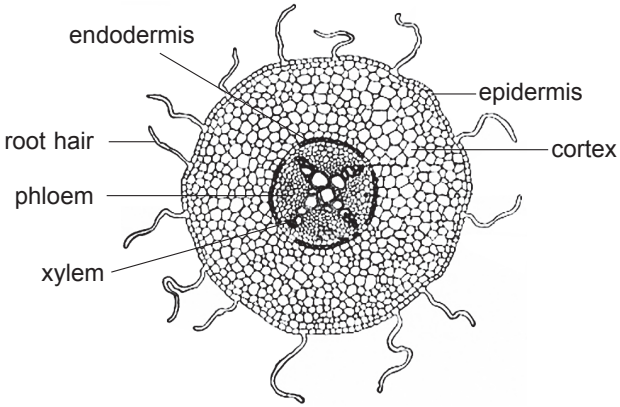
1. In dicotyledonous stems, the vascular bundles are arranged in a ring around a central pith.
2. Between the ring of vascular tissue and the epidermis is the cortex. The epidermis is covered by waterproof cuticle that minimises water loss in the stem.
3. Within the vascular bundles, the phloem tissue is found on the side facing the cortex and the xylem on the side facing the pith. Between the xylem and phloem is a layer called the cambium. Cambium cells can differentiate into new xylem and phloem tissues.
4. Food is stored in the cortex and pith.



Transverse section of a stem

6.3 Position of vascular tissue in dicotyledonous roots

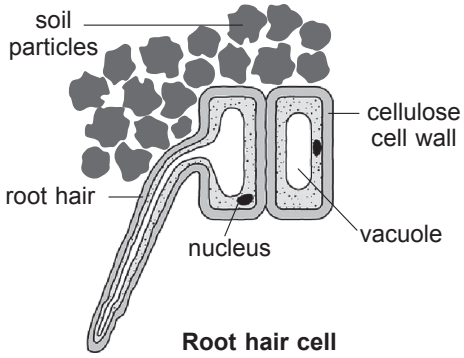
1. The outermost layer of the root is the piliferous layer. It is a single layer of cells bearing root hairs.
2. The layer below the epidermis is called the cortex. It consists of storage tissue.
3. The central region of the root contains xylem and phloem tissues. The xylem radiates from the centre, with phloem tissues alternating between them.



Transverse section of a root

6.4 Root hair cells

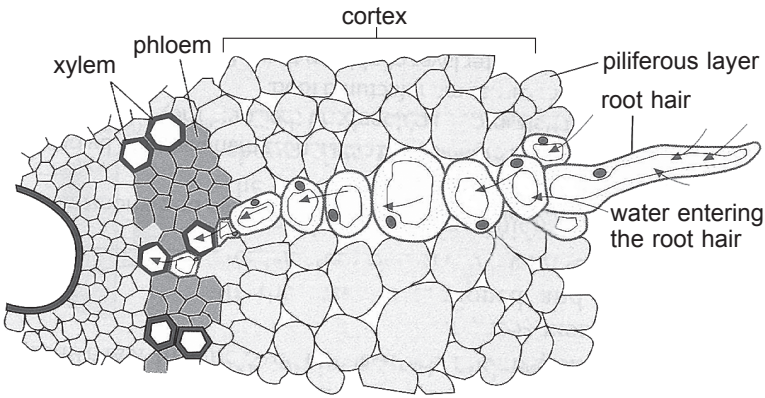
1. Root hairs are tubular outgrowths of root epidermal cells. Each root hair is usually an outgrowth of a single epidermal cell, so they are one-cell thick.
2. Being long and narrow, they have a large surface area to volume ratio for rapid absorption of water and minerals.
3. The cell surface membrane controls the water potential of the cell sap. The cell sap has a lower water potential than the soil solution, causing osmosis to take place.



Root hair cell

6.5 Absorption of water and minerals by root hair cells

1. Soil particles are usually coated with water and dissolved mineral salts.
2. The cell sap in the root hair cells contains sugars and ions that cause it to be at a lower water potential than soil solution.
3. Water moves across the partially permeable cell surface membrane from the soil solution into the cell sap by osmosis.
4. The cell sap now has a higher water potential than the cell sap in the adjoining cell.
5. Water moves across the cell surface membranes into the adjoining cell by osmosis.
6. This process continues until the water enters the xylem vessels and moves up the plant.



The path of water through the root

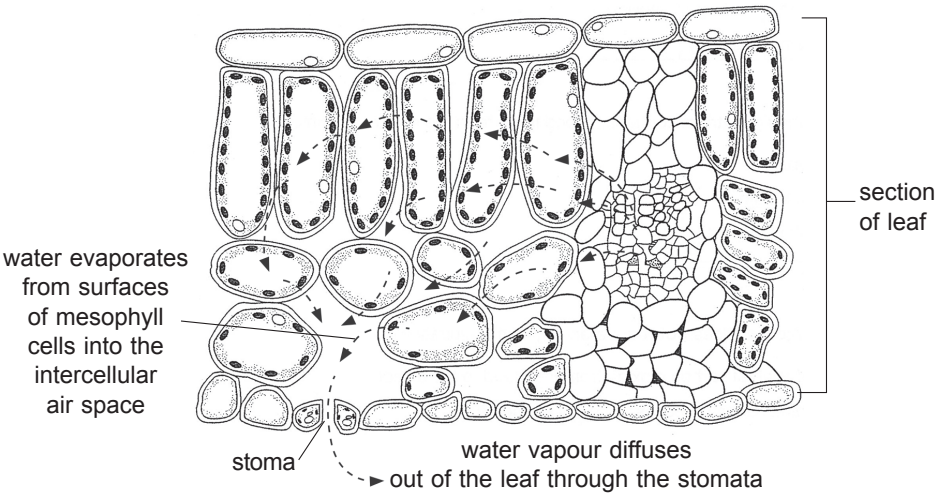
6.6 Transportation of water from the roots to the leaves

1. Water travels from the roots to the leaves against gravity through 3 primary mechanisms:
   (a) Root pressure
   (b) Transpiration
   (c) Capillary action
2. Root cells pump mineral salts into the xylem vessels using active transport. This causes the water potential of the xylem vessels to be lower than the water potential in the cortex cells. Water moves into the xylem vessels by osmosis, creating a pressure that forces water to move upwards. This is called **root pressure**.
3. Root pressure is not the main mechanism for movement of water in most plants as it can only force water to travel a short distance.
4. **Transpiration** is the loss of **water vapour** from the stomata of the leaves through diffusion.

5. The stomata have to be open for carbon dioxide intake due to photosynthesis. This allows the loss of water vapour from the intercellular air spaces in the leaves as the air outside has a lower water vapour concentration than the air inside the leaf. Transpiration is the necessary cost of carbon dioxide intake.
6. However it is also responsible for the **transpiration pull**, which is the main force that causes water to travel upwards in plants.
7. Transpiration pull is the suction force caused by transpiration that pulls water up the xylem.
8. **Capillary action** is the tendency of water to travel up the narrow xylem tubes due to the interactions between water molecules and the xylem walls. This is usually observed in young plants with narrow veins and is not significant in larger plants.

6.7 Factors affecting the rate of transpiration

1. Water vapour in the intercellular air space diffuses out of the stomata.
2. Evaporation from the thin film of water that coats the mesophyll cells replaces the water lost through transpiration.
3. As water evaporates from the mesophyll cells, the water potential of the cell sap decreases. The mesophyll cells absorb water from neighbouring cells closer to the vascular bundles by osmosis. These cells, in turn, absorb water from the xylem vessels.
4. This creates a suction force that pulls the entire column of water up the xylem vessels.
5. Factors affecting transpiration are:
   (a) **Humidity** of the surroundings – Humidity affects the concentration gradient of water vapour between the intercellular air spaces in the leaf and the external environment. The higher the humidity, the higher the concentration of water vapour in the external air. The diffusion gradient for water vapour is less steep so the rate of transpiration is lowered.
   (b) **Air movement** – Wind removes the water vapour that accumulates outside the stomata due to transpiration. This maintains the steep diffusion gradient of water vapour. The rate of transpiration will remain high as long as water vapour is continually being removed by wind.
   (c) **Temperature** – Heat increases the rate of evaporation and also increases the movement of water molecules. The higher the temperature, the higher the rate of evaporation as well as the rate of movement of water vapour, and thus, the higher the rate of transpiration.
   (d) **Light intensity** – Light intensity causes stomatal opening. Since transpiration takes place mainly through the stomata, the rate of transpiration will increase with increased light intensity.
6. **Wilting** takes place when the rate of transpiration exceeds the rate of water intake by the roots. Plant cells lose water and become flaccid.



The path of water in a leaf

6.8 Translocation

1. Translocation is the transport of sugars from the leaves to other parts of the plant. This is done by the phloem tissues. The leaves, which supply sugar, are known as the source while other parts of the plant which require sugar are known as the sink.
2. Energy is required for this process as the mode of uptake of sugars into sieve tube elements in the leaves is active transport.
3. At the end of the sieve tube where sugars are being unloaded for use, sugars are also removed from the sieve tube by active transport.

6.9 Translocation studies

1. To show that translocation occurs in the phloem, radioactive carbon dioxide may be introduced to the plant. After a few hours, slices of tissues are removed from the stems to determine where radioactivity, which indicates the presence of radioactive sugars, first appears.
2. Translocation occurs from source to sink and the direction of the movement may be upwards or downwards. To study the direction of translocation in a plant, a ring of bark, containing the phloem, is cut away from the stem. A few days later, a bulge has formed on top of the cut. This is formed due to an accumulation of phloem sap, as it is unable to move downwards towards the roots.
3. When an aphid is introduced to a plant, it will insert its proboscis into the stem to feed. The rest of the aphid is removed from its proboscis and phloem sap will continue to exude from the free end of the proboscis, which shows that there is pressure in phloem sap. This pressure is formed due active loading of sugar at the source, which will cause water to enter the phloem to generate a region of high pressure, and active unloading of sugar at the sink, which will cause water to exit the phloem, generating a region of low pressure.

TOPIC 7 Transport in Humans

Objectives

Candidates should be able to:

(a) identify the main blood vessels to and from the heart, lungs, liver and kidney
(b) state the role of blood in transport and defence
- red blood cells – haemoglobin and oxygen transport
- plasma – transport of blood cells, ions, soluble food substances, hormones, carbon dioxide, urea, vitamins, plasma proteins
- white blood cells – phagocytosis, antibody formation and tissue rejection
- platelets – fibrinogen to fibrin, causing clotting

(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

7.1 Overview of the human circulatory system

1. The components of the circulatory system are the **heart**, **blood vessels** and **blood**.

2. Blood passes through the heart twice in a complete circuit. This is termed double circulation.

3. Double circulation consists of:

   (a) **Systemic circulation** – Carries oxygenated blood (oxygen-rich) from the heart to all body organs and returns oxygen-poor blood to the heart

   (b) **Pulmonary circulation** – Carries deoxygenated blood (oxygen-poor) from the heart to the lungs for gaseous exchange before returning blood to the heart for transport to the body organs via systemic circulation

4. The three main types of blood vessels are:

   (a) **Arteries** – Vessels that carry blood away from the heart to body organs. Arteries branch into arterioles and then into capillaries.

   (b) **Capillaries** – Microscopic vessels that connect between the arteries and veins. They converge into venules which converge into veins. They form networks called capillary beds that are present in most body tissues.

   (c) **Veins** – Vessels that return blood to the heart

5. The main vessels of the human circulatory system are:

   (a) **Pulmonary arteries** that supply oxygen-poor blood from the heart to the lungs

   (b) **Pulmonary veins** that bring oxygen-rich blood from the lungs to the heart

   (c) **Aorta** that supplies oxygen-rich blood from the heart to the rest of the body. The aorta branches into: **coronary arteries** which supply cardiac tissue, an anterior branch leading to the head and arms and a posterior branch (dorsal aorta) leading to abdominal organs and legs.

   (d) Branches of the **dorsal aorta** include:

      (i) **Hepatic artery** from the heart to the liver

      (ii) Arteries to the alimentary canal

      (iii) **Renal arteries** from the heart to the kidneys

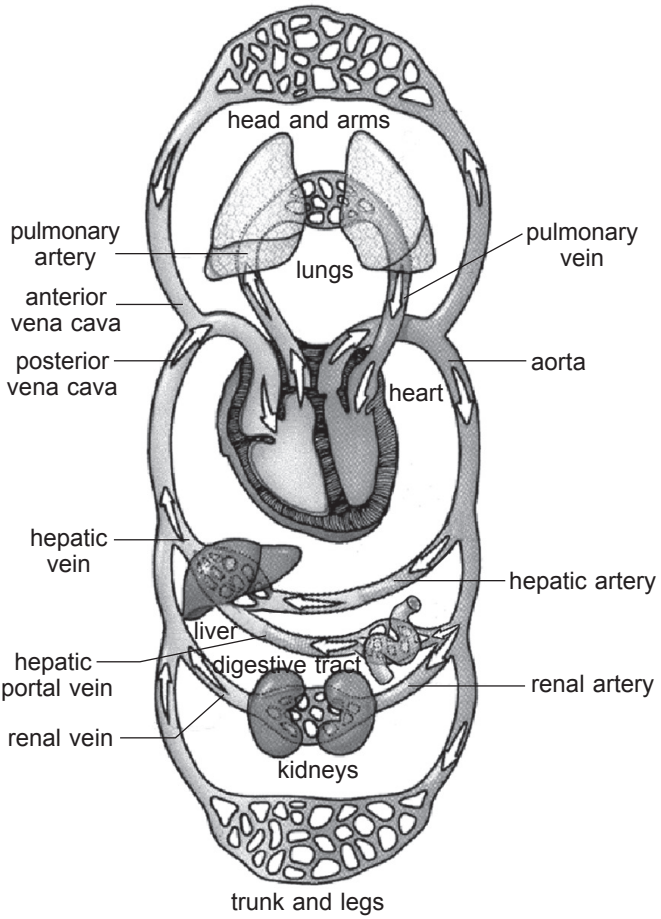
   (e) **Vena cava** consists of an anterior branch which returns blood from the head and arms to the heart and a posterior branch.

   (f) **Posterior vena cava** collects blood from the posterior parts of the body, such as from:

      (i) **Hepatic veins** from the liver to the heart

      (ii) **Renal veins** from the kidneys to the heart

(g) **Hepatic portal vein** transports blood from the alimentary canal to the liver. Blood from the liver is returned to the heart via the hepatic vein.



The human circulatory system

7.2 Components of blood

1. Blood is a connective tissue consisting of 45% cells suspended in 55% plasma.
2. Plasma is a clear yellowish liquid consisting mostly of water. It contains soluble proteins such as albumin and fibrinogen, as well as dissolved substances such as nutrients, waste products and ions.
3. Cellular elements in blood include:
   (a) Red blood cells (**erythrocytes**) which function to transport oxygen. Adaptations to this function are:
      (i) Flattened, biconcave shape without nucleus or organelles at maturity, increasing the surface area to volume ratio for faster diffusion of oxygen
      (ii) Contains haemoglobin, an iron-containing protein which is able to bind reversibly with oxygen
      (iii) Flexibility to turn bell-shaped in order to pass through the narrow lumen of the capillaries
   (b) White blood cells (**leukocytes**) are responsible for fighting infections in the body. There are two main types of white blood cells:
      (i) **Phagocytes** have lobed (bi-lobed, tri-lobed, multi-lobed) nuclei and granular cytoplasm. They engulf and digest foreign particles such as bacteria.
      (ii) **Lymphocytes** have a large rounded nucleus and a small amount of cytoplasm. They produce antibodies to protect the body from pathogens.
   (c) **Platelets** (thrombocytes) are small cell fragments which have no nuclei. They play a role in blood clotting.

Erythrocytes

Phagocyte

Lymphocyte

7.3 Role of blood in transport

1. Blood plasma transports:
   (a) Simple sugars, amino acids, fatty acids and glycerol from the capillaries in the small intestine
   (b) Waste products of metabolism from tissues:
      (i) Carbon dioxide in the form of bicarbonate ions. Carbon dioxide enters the blood from body tissues by diffusion into red blood cells, which contain the enzyme carbonic anhydrase to convert it to hydrogen carbonate. The hydrogen carbonate then diffuses out of red blood cells to be carried in plasma. In the lungs, the reverse occurs.
      (ii) Nitrogenous waste products such as urea, uric acid and creatinine to the kidneys to be removed
   (c) Hormones from the glands to target tissues
   (d) Heat from muscles and liver throughout the body
2. Red blood cells transport:
   (a) Oxygen as oxyhaemoglobin
   (b) A small amount of carbon dioxide bound to haemoglobin

7.4 Transport of oxygen by red blood cells

1. As air enters the lungs, oxygen dissolves in the fluid covering the moist epithelium of the alveoli.
2. The oxygen diffuses into the capillaries of the lungs where they bind reversibly with haemoglobin in red blood cells to form oxyhaemoglobin.
3. When blood is transported to oxygen-poor respiring tissues, oxyhaemoglobin releases its oxygen which then diffuses into tissue cells.

7.5 Immune function of white blood cells

1. **Phagocytosis** refers to the ingestion of harmful foreign particles, bacteria and dead or dying cells by certain types of white blood cells called phagocytes.
2. When phagocytes detect a foreign particle, it engulfs it by stretching itself around the particle and enclosing it. It then digests the particle and kills it.
3. After phagocytosis, these cells die and form pus.
4. **Antibodies** are special proteins found in blood and other bodily fluids that help phagocytes identify and neutralise foreign particles. Antibodies also activate other immune responses.

5. When pathogens enter the blood, they stimulate lymphocytes to produce antibodies.
6. Antibodies may be present in the blood long after infection has been cured, conferring **immunity** to that particular infection.

7.6 Tissue rejection

1. Tissue rejection occurs when the transplanted tissue is not accepted by the body of the transplant recipient.
2. During tissue rejection, the tissues of the transplanted organ are treated as foreign bodies by the recipient's immune system and are attacked by phagocytes. This causes the transplanted tissue to fail.
3. Prevention of tissue rejection:
   (a) Required tissue can be transplanted from genetically-similar donors.
   (b) Tissue can be transplanted from one part of the body to another, e.g. skin grafting, as the tissue will be recognised as the recipient's own tissue.
   (c) Immunosuppressive drugs can be taken to suppress the immune system of the recipient. Associated problems include:
      (i) Lowered resistance to infection
      (ii) Having to continue taking the drugs for their entire lifespan

7.7 Blood clotting

1. The blood clotting process begins at the site of injury when blood vessels are damaged.
2. Platelets are activated, and the damaged tissue and activated platelets release thrombokinase.
3. Thrombokinase converts plasma protein, prothrombin, into thrombin in the presence of calcium and vitamin K.
4. Thrombin converts fibrinogen, a soluble plasma protein, to fibrin, an insoluble protein that forms long threads.
5. Fibrin forms a mesh across the damaged surface and traps red blood cells, forming a clot.
6. The clot prevents further blood loss, and also restricts the entry of pathogens into the blood.

7.8 Blood groups

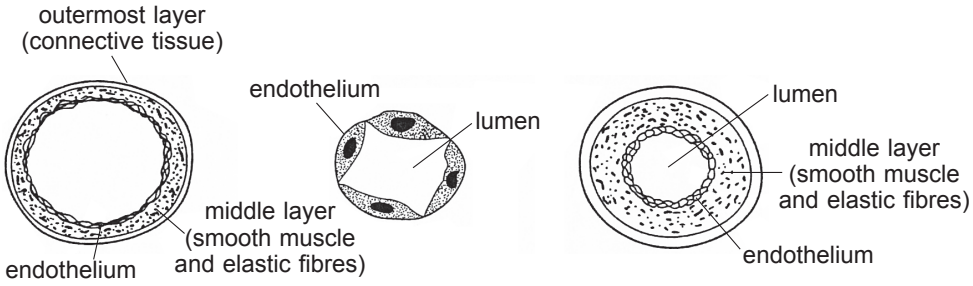
1. There are 4 blood groups: A, B, AB and O. This classification is based on certain proteins present on the surfaces of red blood cells.
2. These proteins can be recognised by antibodies present in the blood plasma as either foreign or 'self'.
3. If they are recognised as foreign, an immune response will be mounted against the foreign blood, resulting in agglutination, where the red blood cells clump together and are marked for phagocytosis.
4. When no agglutination occurs, it shows the blood can be accepted by the recipient.
5. Transfusion results between the different blood groups are shown below:

Donor	Recipient			
	A	**B**	**AB**	**O**
A	Accepted	Rejected	Accepted	Rejected
B	Rejected	Accepted	Accepted	Rejected
AB	Rejected	Rejected	Accepted	Rejected
O	Accepted	Accepted	Accepted	Accepted

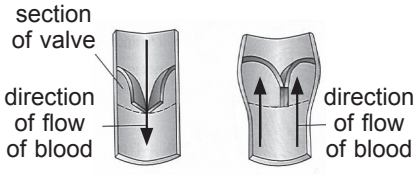
7.9 Blood vessels and their functions

1. Arteries are blood vessels which carry blood away from the heart.
2. They have thick, muscular and elastic walls that can withstand the surge of the high pressure blood pumped out of the heart.
3. The arterial wall is divided into three layers. The outer layer is a protective layer consisting of connective tissue and elastic fibre. The middle layer consists of smooth muscle and more elastic fibres and the innermost layer next to the lumen consists of the **endothelium**, a single layer of flattened cells.
4. All arteries carry oxygenated blood with the exception of the pulmonary arteries.
5. Arteries split up into arterioles which are structurally similar to arteries but smaller in diameter.
6. Arterioles control blood flow into capillary beds by:
   (a) Contracting the smooth muscle layer in the arteriole wall.
   (b) Using sphincters, which are bands of smooth muscle located where arterioles branch into capillaries. Contraction prevents blood flow into capillary beds.

7. Capillaries are microscopic vessels with walls that are only one-cell thick. Their walls consist of a layer of flattened cells called endothelial cells.
8. The endothelium is partially permeable, allowing diffusion to occur.
9. Capillaries branch to form networks called capillary beds, which infiltrate almost all tissues, allowing exchange of substances to take place.
10. The extensive branching increases the total cross-sectional area of the vessels, lowering the blood pressure in the capillaries and hence the rate of blood flow, giving more time for the exchange of substances.
11. Capillaries converge into venules which are small vessels structurally similar to veins.
12. Venules converge to form veins.
13. Similar to arterial walls, the walls of veins consist of three layers.
14. However, the middle wall contains much less smooth muscle and elastic fibres. Hence they are not as thick, muscular or elastic as arteries. Therefore, a vein has a larger lumen as compared to an artery with the same external diameter.
15. The blood pressure in the veins is much lower than that of the arteries. Blood flows more slowly and smoothly so there is no need for thick, muscular and elastic walls.
16. Blood flow through the veins is assisted by the presence of semi-lunar valves and skeletal muscle action.
17. When we move, our skeletal muscles pinch the veins and move blood through them.
18. Blood is prevented from flowing backwards by the semi-lunar valves. Blood moving backwards causes the valves to close.
19. Veins carry blood back to the heart. The exceptions are portal veins, which carry blood between two capillary beds, e.g. the hepatic portal vein.
20. Veins carry deoxygenated blood with the exception of the pulmonary veins.



Vein **Capillary** **Artery**



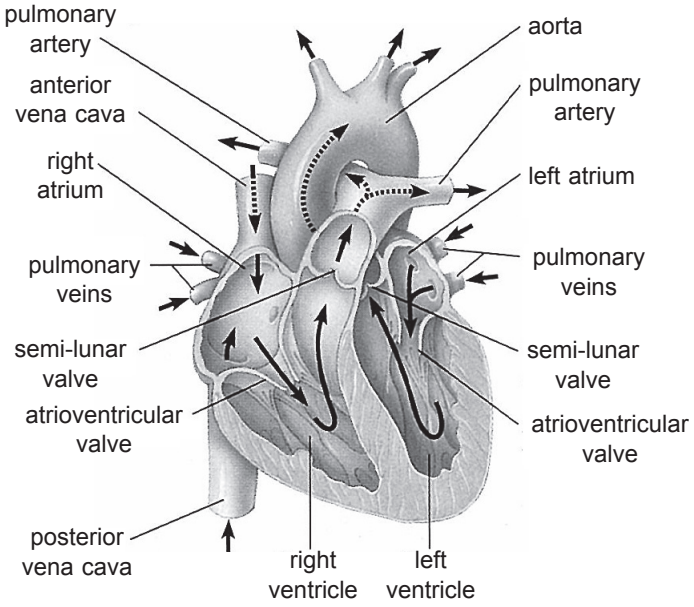
Semi-lunar valves in veins

7.10 Exchange of substances in capillaries

1. Capillaries are found between tissue cells.
2. As blood enters the capillaries, the narrow lumen of the capillaries forces red blood cells to travel in a single line.
3. Rate of blood flow decreases, allowing more time for the exchange of materials between tissue cells and red blood cells.
4. At the arterial end of capillaries, the blood pressure is high, forcing plasma through capillary walls into tissues. Plasma proteins are unable to pass through capillary walls.
5. The solution bathing tissue cells becomes known as tissue fluid, or **interstitial fluid**.
6. There is a higher concentration of nutrients and oxygen in blood than in the interstitial fluid. They diffuse across the endothelium of the capillary into the interstitial fluid, and from there, across the plasma membranes of tissue cells.
7. Waste materials from the tissue cells diffuse into the interstitial fluid, where they are present in higher concentrations than within the blood. They diffuse across the endothelium of the capillary into blood and are transported to excretory organs for removal.

7.11 Structure of the heart

1. A diagram of the heart and its associated blood vessels is shown below:



The human heart

2. The heart is mainly made up of cardiac muscle tissue surrounded by a double-walled sac called a **pericardium**. The inner membrane of the pericardium is connected to the outer layer of the cardiac muscle. Between the two layers is the pericardial fluid, which reduces friction when the heart is beating.
3. The four chambers of the heart are the right and left atria and ventricles.
4. The atria are the upper chambers of the heart, with relatively thin walls. They collect blood returning to the heart and pump it into the ventricles.
5. The ventricles have thick, muscular walls. The left ventricle has thicker walls than the right ventricle, as it has to pump blood to the rest of the body.
6. The right side of the heart pumps deoxygenated blood and the left side pumps oxygenated blood. The septum separating the right and left sides prevent the blood from mixing, so that the maximum amount of oxygen can be carried to the tissues.
7. Between the right atrium and ventricle is a valve called the **tricuspid valve** which consists of three flaps attached to the walls of the right ventricle by cord-like tendons called ***cordae tendineae***.

8. Between the left atrium and left ventricle is a **bicuspid valve** (mitral valve) which consists of two flaps, also attached by *cordae tendineae*.
9. The bicuspid and tricuspid valves are collectively known as atrioventricular valves.
10. Vessels associated with the heart are the anterior and posterior venae cavae, pulmonary veins and artery, aorta and coronary arteries. The coronary arteries are found on the heart surface itself, and supply blood to the heart muscles.
11. Located at the start of the aorta and pulmonary arteries are **semi-lunar valves**.

7.12 Cardiac cycle

1. One complete sequence of pumping and filling of the heart is called the cardiac cycle.
2. The contraction phase is called **systole** and the relaxation phase is called **diastole**.
3. The cycle starts when the whole heart is relaxed. The right atrium receives blood from the venae cavae and the left atrium receives blood from the pulmonary veins.
4. The next stage is **atrial systole**. When the atria contract, atrioventricular valves open and blood flows into the ventricles.
5. Next, the ventricles contract and atrioventricular valves close, producing the 'lub' sound of the heartbeat. This is called **ventricular systole**. The pressure in the ventricles increases, causing the semi-lunar valves in the pulmonary artery and aorta to open. Blood flows into the aorta and pulmonary artery. While the ventricles are contracting, the atria relax in **atrial diastole**.
6. Finally, the ventricles relax. This is called **ventricular diastole**. The semi-lunar valves shut because the ventricles are at a lower blood pressure than the aorta and pulmonary arteries. This causes the 'dub' sound of the heartbeat. The atrioventricular valves open due to the drop in ventricular pressure.

7.13 Coronary heart disease

1. Coronary heart disease occurs when the coronary arteries become blocked (occluded) or narrowed.
2. The heart muscles will no longer be able to receive sufficient oxygen and nutrients.
3. This can cause a **heart attack**. During a heart attack, blood supply to part of the heart muscle is completely cut off due to blockage in the coronary arteries. The affected part dies, which can affect the heart's ability to pump and lead to heart failure.

4. A cause of coronary heart disease is atherosclerosis, in which an artery wall thickens and hardens due to the deposition of plaque, which causes the lumen of the artery to become narrower.
5. The narrowing of the lumen of the arteries causes an increase in blood pressure. This causes arteries to develop rough linings, which increases the likelihood of formation of blood clots inside the arteries. This is known as thrombosis.
6. This obstructs blood flow in the afflicted artery. If it occurs in a coronary artery, a heart attack takes place.
7. Factors that contribute to atherosclerosis include:
   (a) High intake of cholesterol and saturated fats
   (b) Stress
   (c) Smoking
8. Preventive measures include:
   (a) Healthy diet – low in cholesterol and saturated fats
   (b) Not smoking – nicotine increases blood pressure
   (c) Exercising – lowers stress and strengthens the heart

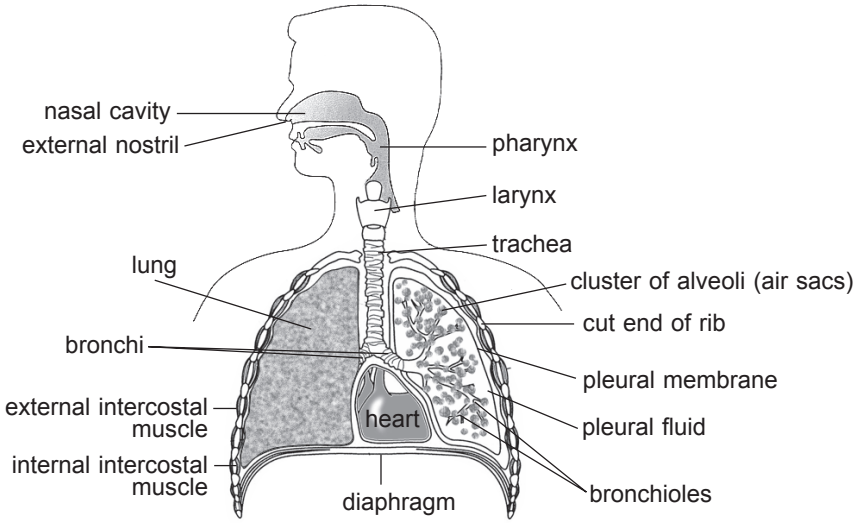
TOPIC 8 Respiration in Humans

Objectives

Candidates should be able to:

(a) identify on diagrams and name the larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries
(b) state the characteristics 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 humans
(h) describe the effect of lactic acid in muscles during exercise

8.1 Overview of the human respiratory system



The human gas exchange system

1. Breathing is the transport of oxygen from the outside air to the cells, and carbon dioxide from the cells to the outside air. This is not the same as cellular respiration, which is the process by which an organism breaks down food molecules to release energy for life processes.

2. The human respiratory system consists of :

   (a) Nasal passages – Passages leading from the nostrils lined with a moist mucous membrane

   (b) Pharynx – Common passage for the opening of the oesophagus and the trachea

   (c) Larynx – Voice box containing vocal cords

   (d) Trachea – A tube supported by C-shaped cartilage connecting the larynx and the lungs. The C-shaped cartilage prevents the trachea from collapsing as the air pressure in the lungs changes. It branches into two bronchi, one to each lung.

   (e) Bronchi – Branches repeatedly within the lungs to produce numerous finer tubes called bronchioles. The bronchioles at the end of the branching terminate in clusters of air sacs called alveoli. The epithelial lining of the bronchi and trachea are covered with a thin film of mucus and cilia, which are hair-like structures that can move. The mucus traps dust, pollen and other particles and the cilia sweeps it upwards into the pharynx to be swallowed into the oesophagus.

   (f) Lungs – Located in the pleural cavity, they are enclosed by the pleura, a two-layered membrane structure. The inner layer is in contact with the lungs while the other layer adheres to the wall of the chest cavity. The space between the two membranes is known as the pleural space, and it contains a small amount of pleural fluid, which acts as a lubricant when the lungs expand and contract during breathing.

   (g) Related muscles, ribs and diaphragm.

8.2 The thoracic cavity

1. The lungs are protected by the ribs which extend from the backbone to the sternum (breast bone).

2. Two sets of muscles attached to the ribs are involved in breathing. These are the external and internal intercostal muscles. When one set contracts, the other set relaxes.

3. The diaphragm is a sheet of skeletal muscle that forms the bottom wall of the thoracic cavity. When the diaphragm muscles contract, the diaphragm moves downwards. When they relax, the diaphragm moves up again.

4. The intercostal muscles and the diaphragm work together to change the volume of the chest cavity (thoracic cavity).

8.3 Inhalation

1. During inhalation, the diaphragm contracts, flattens and moves downwards.
2. The external intercostal muscles contract while the internal intercostal muscles relax. The ribs move upwards and outwards.
3. The thoracic cavity increases in volume.
4. This causes the air pressure of the lungs to fall below that of the atmosphere.
5. Air rushes into the lungs.
6. During inhalation, air passes through the respiratory passage in the order: nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles, alveoli.

8.4 Exhalation

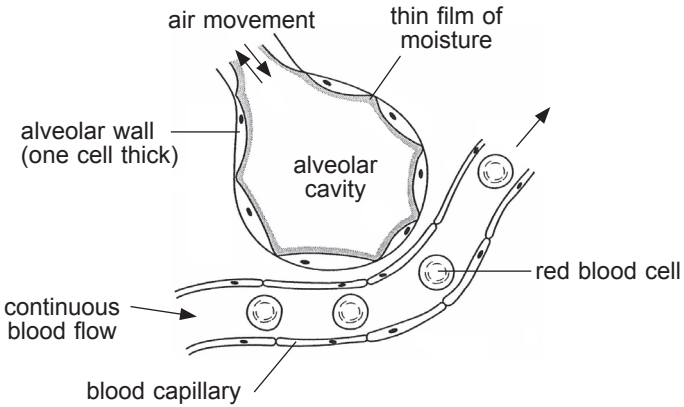
1. During exhalation, the diaphragm relaxes and arches upwards.
2. The internal intercostal muscles contract while the external intercostal muscles relax, moving the ribs downwards and inwards.
3. The thoracic cavity decreases in volume.
4. Air pressure in the lungs is now higher than that of the atmosphere.
5. Air flows out of the lungs until the air pressure in the lungs reaches equilibrium with atmospheric air pressure.

8.5 The alveoli

1. The alveoli are the sites of gas exchange in the lungs.
2. They are present in large quantities, providing a huge surface area for gas exchange.
3. The walls of the alveoli are one-cell thick, resulting in a small distance for diffusion.
4. They are covered with a thin film of water to allow oxygen to dissolve and subsequently diffuse in solution across the cell surface membranes.
5. They are well-supplied with blood capillaries which transport away diffused oxygen and supply carbon dioxide for excretion. The continuous removal of oxygen and the supply of carbon dioxide maintain the respective concentration gradients of these gases.

8.6 Mechanism of oxygen transfer in the alveoli

1. The exchange surface of the alveoli is the thin moist epithelium of the inner surfaces.
2. Capillaries branching from the pulmonary artery supply oxygen-poor blood to the alveoli.
3. Oxygen from the air in the alveoli taken in during inhalation dissolves in the moisture on the lining.
4. The dissolved oxygen diffuses down the concentration gradient across the alveolar wall and the endothelium of the blood capillaries into the oxygen-poor blood.
5. The oxygenated blood leaves the capillaries and enters the pulmonary veins to be carried back to the heart.



A section of an alveolus

8.7 Removal of carbon dioxide

1. 7% of carbon dioxide released during respiration is transported as dissolved carbon dioxide in blood plasma. 23% is transported bound to haemoglobin in red blood cells. 70% is transported as bicarbonate ions in the blood.
2. Mechanism of conversion of carbon dioxide into bicarbonate ions:
   (a) Carbon dioxide from respiring cells diffuses into blood plasma and then into red blood cells.
   (b) An enzyme, carbonic anhydrase, is present in red blood cells. It catalyses the interconversion of carbon dioxide with water to give carbonic acid, which dissociates into bicarbonate ions and hydrogen ions.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

   (c) The hydrogen carbonate ions diffuse into plasma.

3. In the lungs:
   (a) Hydrogen carbonate ions diffuse back into red blood cells where they combine with hydrogen ions released from haemoglobin to form carbonic acid.
   (b) Carbonic acid forms water and carbon dioxide.
   (c) The carbon dioxide diffuses out of the blood into the alveolar space where it is expelled during exhalation.

8.8 Effects of tobacco smoke on health

1. Harmful components of tobacco smoke are:
   (a) Nicotine
      (i) Addictive stimulant that stimulates adrenaline release
      (ii) Increases heart rate and blood pressure
      (iii) Increases risk of stroke, heart attack and impotence
   (b) Carbon monoxide
      (i) Poisonous gas that combines irreversibly with haemoglobin to form carboxyhaemoglobin
      (ii) Reduces efficiency of blood to transport oxygen
      (iii) Increases risk of atherosclerosis
      (iv) Increases risk of thrombosis
   (c) Tar
      (i) Carcinogenic
      (ii) Paralyses cilia lining air passages, reducing effectiveness of dust and irritant removal
   (d) Irritants
      (i) Paralyse cilia lining air passages
      (ii) Increase risk of chronic bronchitis and emphysema

8.9 Chronic bronchitis

1. Chronic bronchitis is caused by irritation to the respiratory lining of the airways, resulting in inflammation.
2. There is increased production of mucus by the epithelium. Cilia on the epithelium become paralysed, unable to remove mucus and foreign particles.
3. Airflow becomes blocked due to swelling and mucus.
4. Symptoms are wheezing, shortness of breath and a persistent cough.

8.10 Emphysema

1. Emphysema is caused by exposure to toxic chemicals, e.g. tobacco smoke.
2. It is a lung disease characterised by the permanent enlargement of air spaces due to a destruction of alveolar walls. This decreases the gas exchange surface area.
3. The lungs lose their elasticity and lose their ability to effectively expel air.
4. Oxygen uptake and carbon dioxide removal is impaired and severe breathlessness is experienced.

8.11 Cellular respiration

1. Cellular respiration is a process by which cells break down food molecules to release energy stored in food.
2. This energy is used to sustain vital life processes.
3. There are two modes of respiration, **aerobic respiration** and **anaerobic respiration**.

8.12 Aerobic respiration

1. Aerobic respiration is the oxidation of glucose molecules in the **presence of oxygen** to release a large amount of energy, with carbon dioxide and water as waste products.
2. The overall equation is:

   $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$

   glucose + oxygen $\longrightarrow$ carbon dioxide + water + energy
3. Respiration is carried out in a complicated series of reactions involving enzymes.
4. It occurs within the mitochondria of cells.
5. Energy released from respiration is used for:
   (a) Synthesising complex molecules from simpler molecules i.e. proteins from amino acids, hormones, enzymes
   (b) Cell growth and division: synthesis of new protoplasm and genetic material
   (c) Muscular contraction, both voluntary (involving skeletal muscles) and involuntary (cardiac muscle and smooth muscle i.e. heartbeat and peristalsis)
   (d) Active transport
   (e) Transmission of nerve impulses
6. Some energy is also released as heat during respiration.

8.13 Anaerobic respiration

1. Anaerobic respiration is the breakdown of glucose molecules in the **absence of oxygen**. Waste products vary from organism to organism. Less energy is released compared to aerobic respiration.
2. Anaerobic respiration in humans primarily occurs in the muscle cells.
3. The preferred mode of respiration in muscle cells is aerobic. However, during periods of strenuous exercise, since there is a limit to the rate of breathing and heart rate, not enough oxygen is available to the muscle cells to sustain aerobic respiration.
4. In such cases, muscle cells respire anaerobically for short durations in order to meet the energy demands of the activity.
5. The equation for anaerobic respiration in humans is:

$$C_6H_{12}O_6 \longrightarrow 2C_3H_6O_3 + \text{energy}$$

$$\text{glucose} \longrightarrow \text{lactic acid} + \text{energy}$$

6. The energy produced by anaerobic respiration supplements the energy produced by aerobic respiration.
7. When anaerobic respiration occurs, there is a build up of **lactic acid** in the muscle cells.
8. This causes **fatigue**. Anaerobic respiration in humans can only be sustained for a short time before the body needs to recover.
9. During the recovery process, more oxygen needs to be taken in. This is evidenced by heavy panting after strenuous exercise.
10. The oxygen taken in is used to restore the body to its resting state. This is done by transporting the lactic acid from the muscles to the liver, where some lactic acid is completely oxidised to carbon dioxide and water to produce energy to convert the remaining lactic acid into glucose.
11. The amount of oxygen required for this process is called the **oxygen debt**.

TOPIC 9 Excretion in Humans

Objectives

Candidates 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 the nephron with reference to ultra-filtration and selective reabsorption in the production of urine
(c) outline the role of anti-diuretic hormone (ADH) in osmoregulation
(d) outline the mechanism of dialysis in the case of kidney failure

9.1 Excretion

1. Excretion is the process by which the body removes metabolic waste products and toxic materials.
2. Metabolic processes consist of anabolic processes and catabolic processes.
3. Anabolic processes are 'building-up' processes where larger molecules are synthesised from smaller molecules. Examples include:
   (a) Synthesis of proteins from amino acids
   (b) Synthesis of glycogen from glucose
   (c) Photosynthesis with oxygen as waste material
4. Catabolic processes are 'breaking-down' processes where larger molecules are broken down to form smaller molecules. Examples include:
   (a) Cellular respiration with carbon dioxide and water as by-products
   (b) Deamination of amino acids in the liver with urea as a by-product
   (c) Breakdown of haemoglobin in the liver with bile pigments as by-products
5. Waste products have to be removed because they can be harmful if they accumulate in the body.

6. The waste products of metabolism are excreted by the following organs:

Excretory organs	Excretory products	Excreted as
Lungs	Carbon dioxide	Exhaled air
Kidneys	Excess mineral salts, urea, uric acid, creatinine, excess water	Urine
Skin	Excess mineral salts, small quantities of urea, excess water	Sweat
Liver	Bile pigments	Secreted as bile, leaves the body in faeces

9.2 Overview of the human urinary system

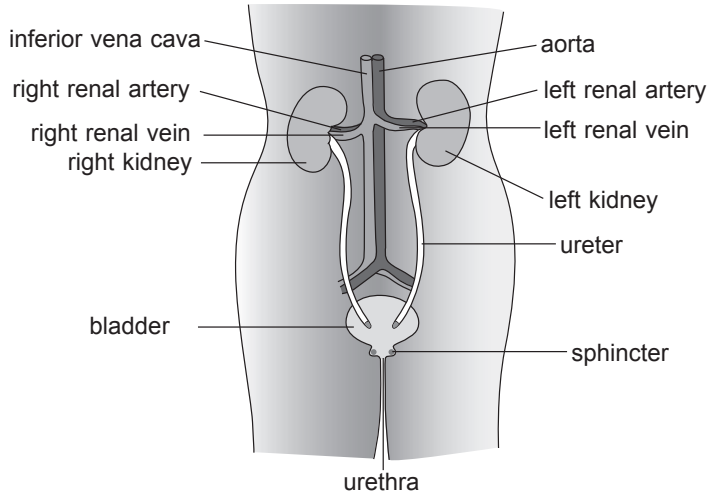
1. The human urinary system consists of :

   (a) The **kidneys**, which are two bean-shaped organs located in the abdominal cavity.

   (b) The **ureters**, which are narrow tubes that emerge from a depression in the concave surface of the kidney called a **hilum**. The ureters connect to the urinary bladder.

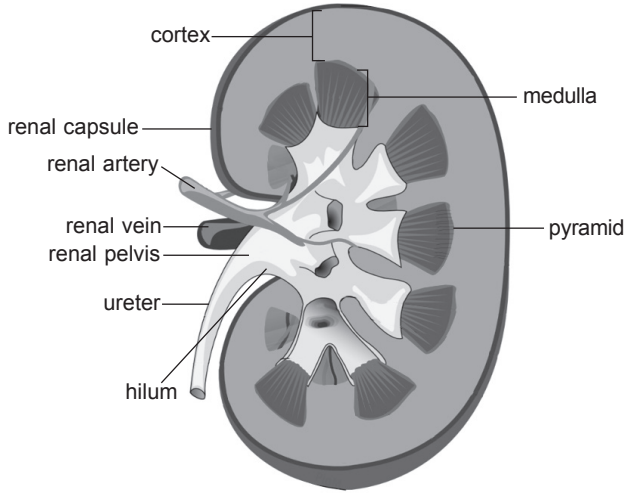
   (c) The **urinary bladder** is an elastic and muscular organ that collects and stores urine excreted by the kidneys. The sphincter muscle at the base of the bladder controls the flow of urine into the urethra. It is controlled by nervous impulses from the brain.

   (d) The **urethra** is a duct that connects the urinary bladder to the outside of the body. Urine passes through this tube to the outside.



The human urinary system

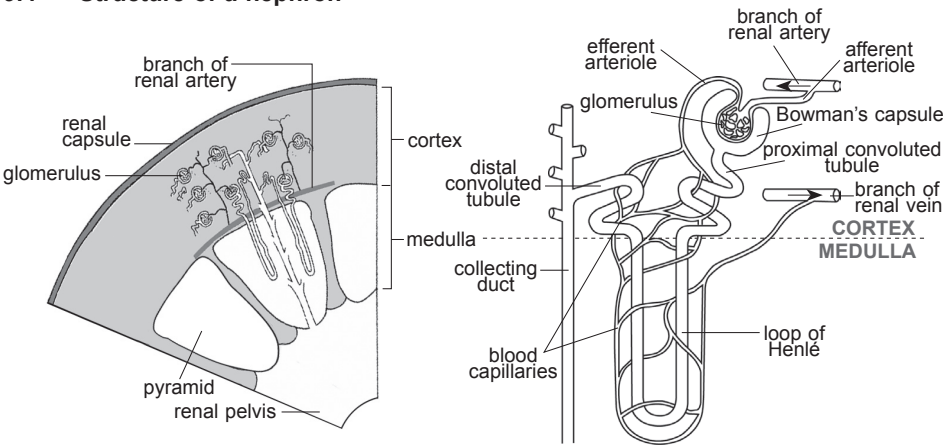
9.3 Structure of a kidney



A kidney

1. The kidney is made up of two distinct regions: an outer **cortex** and the inner **medulla**.
2. The cortex is covered by a protective fibrous capsule called the **renal capsule**.
3. The medulla consists of 8 to 18 conical **pyramids**.
4. Across the cortex and medulla are numerous excretory tubules called **nephrons**, as well as **collecting ducts** and their associated blood vessels.
5. Nephrons are the urine-producing units of the kidney.
6. The tips of the pyramids empty urine into an area called the **renal pelvis**. The renal pelvis functions as a funnel collecting urine from all the pyramids to deliver to the ureter.
7. Blood enters each kidney from the **renal artery** and leaves via the **renal vein**, both connected to the kidney at the hilum.

9.4 Structure of a nephron



A section of a kidney **A nephron**

1. Components of the nephron are:

   (a) **Glomerulus** – A ball of capillaries that obtains its blood supply from an **afferent arteriole** which branches off the renal artery. It drains into an **efferent arteriole**. The high pressure of the blood in the glomerulus forces water, urea, salts and small solutes through the partially permeable endothelium into the lumen of the **Bowman's capsule** in a process known as **ultrafiltration**.

   (b) Bowman's capsule – The start of the tubular component of a nephron. It surrounds the glomerulus in a cup-like structure. Together, the Bowman's capsule and the glomerulus make up a **renal corpuscle** (Malpighian corpuscle).

   (c) **Proximal convoluted tubule** – A convoluted tubule leading from the Bowman's capsule which straightens up as it passes into the medulla, leading into the loop of Henlé.

   (d) **Loop of Henlé** – Consists of a descending limb, a hairpin turn and an ascending limb. It re-enters the cortex.

   (e) **Distal convoluted tubule** – Convoluted portion of nephron leading from the loop of Henlé, connecting it to the collecting duct.

2. The collecting duct is a tubule into which distal convoluted tubules from several nephrons empty their filtrate. It extends deep into the medulla, opening up into the renal pelvis. It is not considered part of the nephron.

9.5 Urine formation

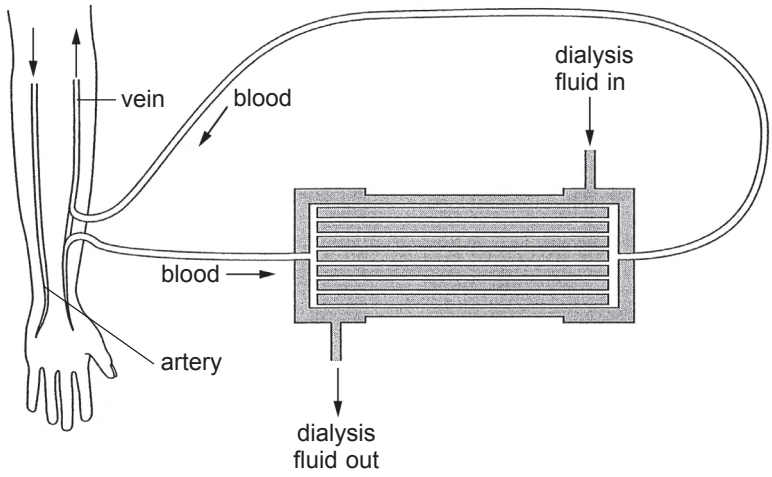
1. Excess mineral salts, nitrogenous wastes and excess water are excreted through the kidneys through ultrafiltration and selective reabsorption of useful materials.
2. **Ultrafiltration** occurs in the glomerulus. Blood enters the glomerulus through an afferent arteriole from the renal artery. Blood pressure forces water, urea, salts and other small solutes (e.g. glucose, amino acids and vitamins) into the lumen of the Bowman's capsule. Blood cells and large molecules remain in the capillaries.
3. The high blood pressure (high hydrostatic pressure) driving the ultrafiltration in the glomerulus is due to the afferent arteriole having a larger diameter than the efferent arteriole.
4. The endothelium of the glomerular capillaries and the basement membrane of the Bowman's capsule that wraps around the capillaries are partially permeable membranes, thus only small soluble substances are able to pass through.
5. The glomerular filtrate passes from the lumen of the Bowman's capsule into the proximal convoluted tubule.
6. Within this tubule, most of the mineral salts and all of the glucose and amino acids are absorbed through active transport or diffusion. Water is reabsorbed by osmosis.
7. Reabsorption of water continues in the loop of Henlé.
8. Water and salts are reabsorbed in the distal convoluted tubule.
9. Water is reabsorbed from the collecting duct.
10. Excess salts, nitrogenous waste products, excess water and processed drugs and poisons from the liver enter the renal pelvis as urine.

9.6 Kidneys as osmoregulators

1. Osmoregulation is the control of water and mineral salts in the blood.
2. The water potential of blood has to be maintained for proper functioning of the body.
3. Excessive gain in water due to drinking or excessive loss due to diarrhoea or sweating will result in a change in the water potential of blood.
4. Excess water could also cause water to move into cells from tissue fluid by osmosis. This causes the cells to swell and burst.
5. Too little water would cause water to move out of the cells into tissue fluid causing dehydration.
6. Excess water could also lead to an increase in blood pressure due to an increase in volume. This could lead to stroke.

7. The amount of water in blood is controlled by a hormone called **antidiuretic hormone** (ADH).
8. ADH is produced in the hypothalamus of the brain and is stored and released from the pituitary gland.
9. The hypothalamus contains osmoreceptor cells that can monitor the water potential of blood.
10. When blood water potential decreases beyond a certain amount, the pituitary gland is stimulated to secrete more ADH into the blood.
11. ADH works on the distal convoluted tubules and the collecting ducts in the kidneys.
12. It makes the epithelium more permeable to water.
13. This causes more water to be reabsorbed, producing a smaller volume of more concentrated urine.
14. The water potential of blood then returns to regular levels.
15. When the water potential of blood increases beyond normal levels, the osmoreceptor cells in the hypothalamus stimulate the pituitary gland to release less ADH.
16. The epithelium of the kidney tubules and collecting ducts become less permeable to water.
17. Less water is reabsorbed resulting in a larger volume of dilute urine.
18. The water potential of blood returns to normal levels.

9.7 Dialysis



1. The kidneys function to remove waste products, excess water and excess mineral salts.
2. A dialysis machine would have to perform the functions of a kidney.
3. In dialysis, blood is passed over a dialysis membrane of a large surface area which is permeable to small molecules but does not allow proteins to pass through.
4. On the other side of the dialysis membrane is the dialysis fluid, which contains the same concentration of essential substances as the blood plasma, with the exception of metabolic wastes.
5. Substances move from the blood to the dialysis fluid and vice versa through diffusion down a concentration gradient.
6. As blood flows through the tubules immersed in dialysis fluid, metabolic waste diffuses out of the tubing into the fluid.
7. Fresh dialysis fluid is continually supplied during dialysis in order to maintain a low concentration of urea in the fluid as compared to that in blood plasma.
8. The direction of blood flow is opposite to the direction of flow of the dialysis fluid in order to increase the length of exchange surface with the necessary concentration gradients. This is known as countercurrent flow.

TOPIC 10 Homeostasis

Objectives

Candidates 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 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 hypothalamus

10.1 Homeostasis

1. Homeostasis is the maintenance of a constant internal environment. It allows an organism to survive in a changing environment.
2. It involves:
   (a) Thermoregulation – the maintenance of a constant body temperature
   (b) Osmoregulation – the maintenance of a constant water potential and pH
3. Thermoregulation is the maintenance of body temperature within a range that will allow cells to function effectively.
4. Many body processes, including metabolism, involve enzymes, which have an optimal temperature range.
5. Large body temperature changes could affect the rate of cellular respiration or alter membrane properties.
6. Osmoregulation is important because changes in the water potential could affect the direction of osmosis in body cells and the electrolyte balance across cell membranes.
7. Homeostasis involves a process called **negative feedback**. Negative feedback is a corrective mechanism in which the body's response is to restore the normal conditions of the internal environment.

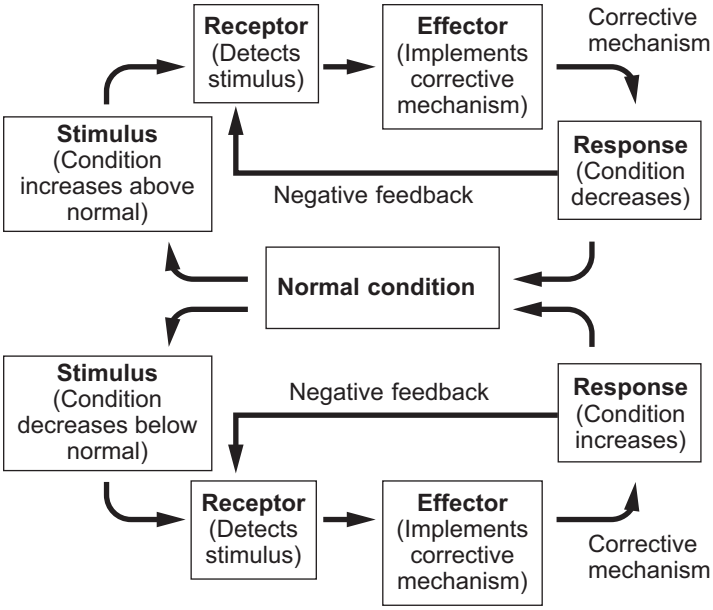
8. Terms involved in negative feedback control mechanism:

   (a) Stimulus – A change in internal environment

   (b) Receptor – Sense organs that detect the stimulus

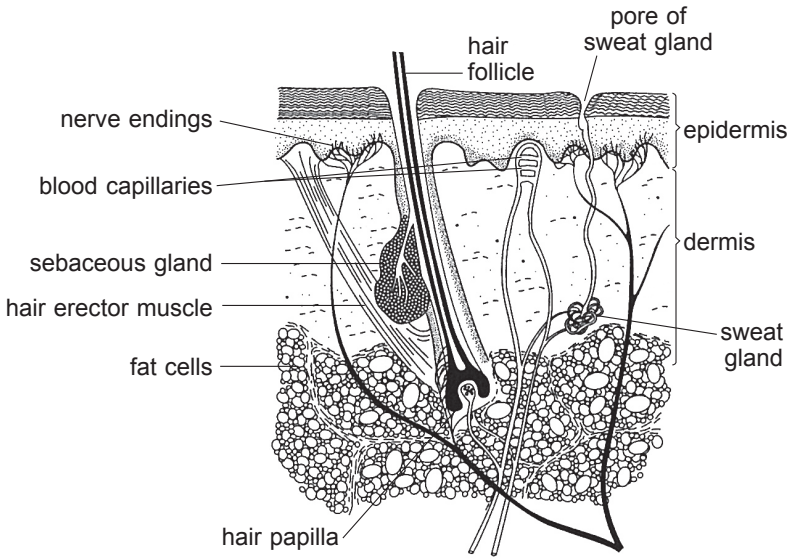
   (c) Effector – Effect corrective responses

   (d) Response – Condition returns to normal, gives negative feedback to receptor



Negative feedback pathway

10.2 Structure of the skin



Structure of the skin

1. The skin comprises two layers: the epidermis and the dermis.
2. The epidermis is the outermost layer which forms a waterproof and protective covering.
3. The dermis is the layer containing **hair follicles**, **sweat glands**, **sebaceous glands**, **blood vessels**, **mechanoreceptors** and **thermoreceptors**.
4. The arterioles leading to the capillaries in the dermis are controlled by nerves. They respond to stimulation by undergoing **vasoconstriction** and **vasodilation**.
5. Vasoconstriction is the contraction of smooth muscles in the arteriole walls. It decreases the diameter of the blood vessels, reducing blood flow. The skin looks pale when vasoconstriction takes place.
6. Vasodilation is the relaxation of smooth muscles in the arteriole walls. It increases the diameter of the blood vessels, increasing blood flow. The skin becomes flushed when vasodilation takes place.
7. Hairs grow within the hair follicles. Attached to the hair follicles are sebaceous glands which produce sebum, and hair erector muscles, which raise hair.
8. Sweat glands are coiled tubes that secrete sweat through a sweat duct. Secreted sweat contains water, sodium chloride and small amounts of metabolic waste products.
9. Sweat glands are used for body temperature regulation.

10. Nerve endings of sensory neurones enable pressure, pain or temperature changes to be detected.

11. Beneath the skin is a layer which consists of connective tissue and adipose tissue. Adipose cells store fat. This layer serves as insulation and padding.

10.3 Thermoregulation

1. Heat is produced by metabolic activities within the body. Most heat is produced by the liver, the brain, the heart and the contraction of skeletal muscles.
2. Heat can be removed from the body by conduction, convection and radiation if the environmental temperature is lower than the body temperature. Otherwise, heat would be gained.
3. Heat can be removed through evaporation of sweat.
4. The skin participates in thermoregulation through vasoconstriction, vasodilation and sweating.
5. The **hypothalamus** in the brain regulates body temperature by receiving information about temperature changes from thermoreceptors located in the skin and within the hypothalamus itself, and activating mechanisms that promote heat gain or loss.

10.4 Coping with heat gain

1. When the external temperature rises above normal levels, thermoreceptors within the skin send signals to the hypothalamus in the brain. Any corresponding rise in blood temperature is also detected by thermoreceptors located within the hypothalamus itself. The hypothalamus is stimulated to send out nerve impulses to:
   (a) Arterioles in the skin, stimulating vasodilation. Increased blood flow in superficial capillaries causes more heat loss through conduction, convection and radiation.
   (b) Sweat glands, stimulating sweat production. Heat is lost through evaporation of sweat from the skin.
   (c) Hair erector muscles, which relax so that hair follicles lie flat. This ensures that no air is trapped by the hairs as air is a good insulator. This is more evident in animals.
   (d) Lungs, stimulating rapid breathing or panting. Heat is lost through exhaled air. This is also more evident in animals.
2. Body temperature returns to normal.

10.5 Coping with heat loss

1. When the external temperature falls below normal levels, thermoreceptors in the skin send signals to the hypothalamus. A decrease in blood temperature is also detected by thermoreceptors in the hypothalamus. The hypothalamus is stimulated to send out nerve impulses to:

   (a) Arterioles in the skin, stimulating vasoconstriction. Decreased blood flow in superficial capillaries causes less heat loss through conduction, convection and radiation.

   (b) Sweat glands, stopping sweat production

   (c) Hair erector muscles, which constrict so that hair follicles are raised. This traps a layer of air between the hairs which acts as an insulating layer.

   (d) Muscles, causing involuntary and increased contraction of muscles, known as shivering. This increases cellular respiration in muscle cells, producing heat.

2. Body temperature returns to normal.

3. In humans, the always-present layer of adipose tissue beneath the skin acts as insulation.

TOPIC 11 Co-ordination and Response in Humans

Objectives

Candidates should be able to:

(a) state the relationship between receptors, the central nervous system and the effectors
(b) describe the structure of the eye as seen in front view and in horizontal section
(c) state the principal functions of component parts of the eye in producing a focused image of near and distant objects on the retina
(d) describe the pupil reflex in response to bright and dim light
(e) state that the nervous system – brain, spinal cord and nerves, serves to co-ordinate and regulate bodily functions
(f) outline the functions of sensory neurones, relay neurones and motor neurones
(g) 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
(h) 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 destroyed by the liver
(i) explain what is meant by an endocrine gland, with reference to the islets of Langerhans in the pancreas
(j) state the role of the hormone adrenaline in boosting blood glucose levels and give examples of situations in which this may occur
(k) explain how the blood glucose concentration is regulated by insulin and glucagon as a homeostatic mechanism
(l) describe the signs, such as an increased blood glucose level and glucose in urine, and the treatment of *diabetes mellitus* using insulin

11.1 The human nervous system

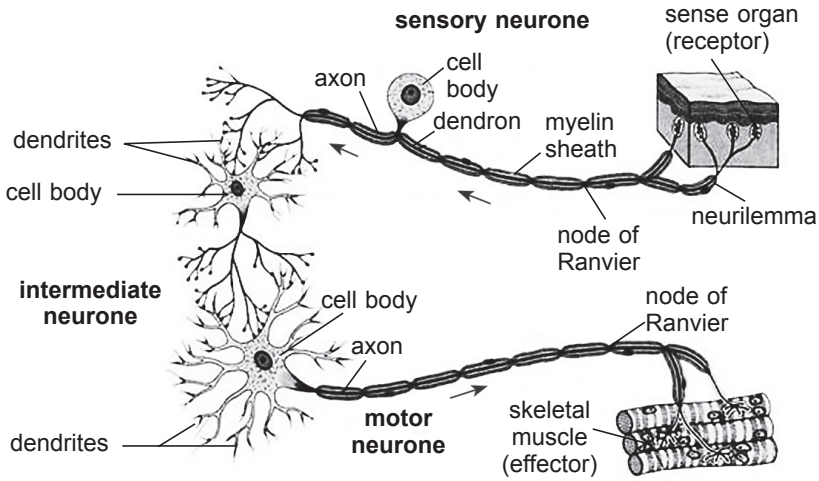
1. The human nervous system consists of:
   (a) Central nervous system (CNS) consisting of the brain and spinal cord
   (b) Peripheral nervous system (PNS) consisting of nerves connecting the central nervous system and the rest of the body. The function of the PNS is to conduct sensory and motor signals between the CNS and the limbs and organs (receptors and effectors).
2. A stimulus is a change in the environment that causes an organism to react. Stimuli are detected by sensory receptors.
3. A response is a change in the body as a result of the stimulus. Effector cells are muscle cells or gland cells, which carry out the response to stimuli.
4. Bodily functions are classified into voluntary actions and involuntary actions.

5. Involuntary actions are actions that cannot be consciously controlled, such as heartbeat, peristalsis, vasoconstriction and reflex actions.
6. Voluntary actions are actions that are consciously controlled.

11.2 Nervous tissue

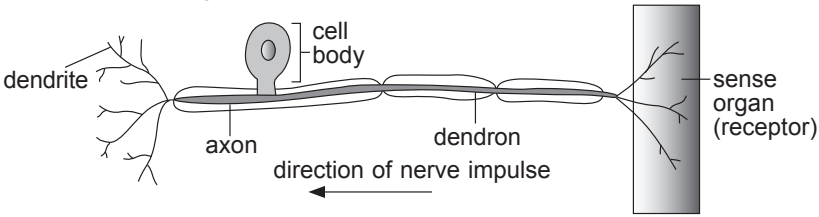
1. Nerve impulses are transmitted by nerves, which are bundles of neurones wrapped in connective tissue.
2. A neurone is a nerve cell.
3. There are three main types of neurones:
   (a) **Sensory neurones** – Respond to stimuli affecting cells of the sensory organ they are found in and relay signals to the CNS
   (b) **Intermediate neurones** (relay neurones) – Transmit nerve impulses from the sensory neurones to the motor neurones; found within the CNS
   (c) **Motor neurones** – Transmit nerve impulses from the CNS to the effector muscle cells or gland cells
4. Neurones share common characteristics:
   (a) A relatively large cell body containing the nucleus and organelles.
   (b) Slender nerve fibres that increase the distance over which nerve impulses can be transmitted. There are two types of nerve fibres.
      (i) **Axons** are long, slender projections that conduct nerve impulses away from the cell body of the neurone.
      (ii) **Dendrons** are branched projections that conduct nerve impulses towards the cell body.
      (iii) At the terminal ends of axons and dendrons, the nerve fibre branches. These branches are known as dendrites. Where the axon is connected to muscles, these branches are also known as motor end plates.

5. The relationship between sensory neurones, the CNS and motor neurones is shown below:



A neural pathway

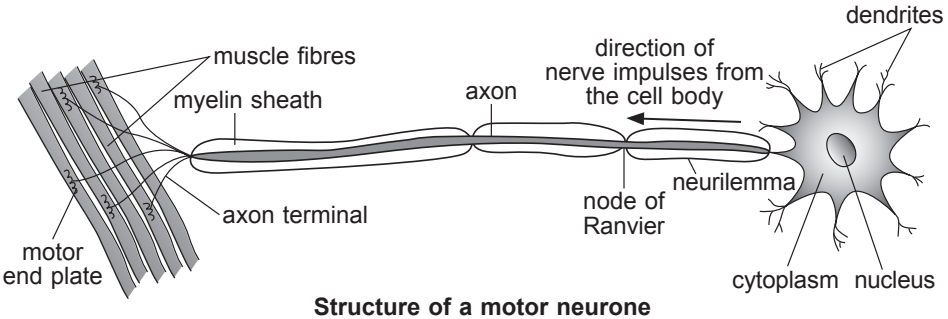
11.3 Structure of a sensory neurone



Structure of a sensory neurone

1. The sensory neurone has a smooth and rounded cell body, a single long dendrite and a short axon. The dendron is structurally similar to an axon and is myelinated.

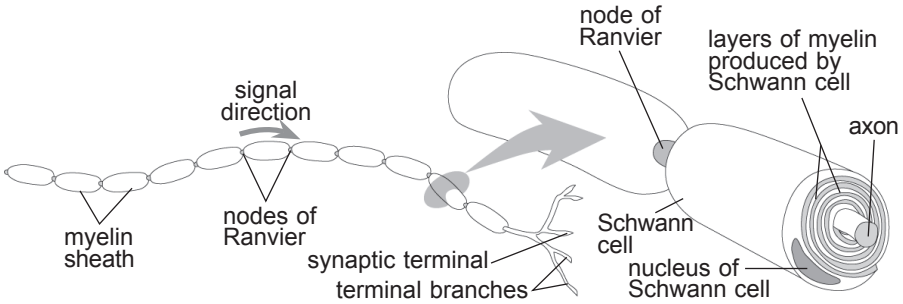
11.4 Structure of a motor neurone



Structure of a motor neurone

1. The motor neurone consists of a cell body and a long thin axon covered by a myelin sheath.
2. Around the cell body are branching dendrites that receive nerve impulses from other neurones and conduct them towards the cell body.
3. The axon conducts signals away from the cell body towards the effector cells.

11.5 Structure of an axon



Structure of an axon

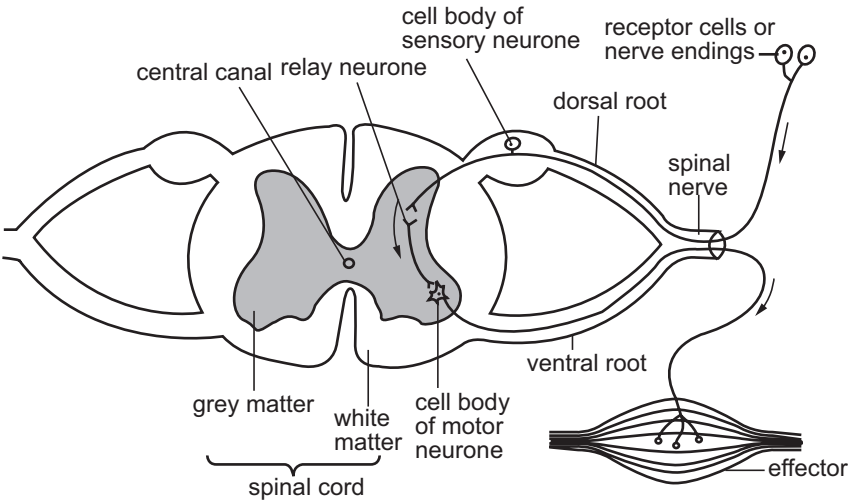
1. In the PNS, supporting cells called Schwann cells form an electrically-insulating layer around axons called the **myelin sheath**; 80% of the myelin sheath consists of lipids.
2. The gaps between adjacent Schwann cells are called **nodes of Ranvier**.
3. The myelin sheath increases the speed at which nerve impulses travel along the axon by allowing nerve impulses to jump from node to node.

11.6 Synapses

1. A synapse is a junction between two neurones or between a neurone and an effector.
2. At a synapse, impulses from the axon of one neurone are transmitted to the dendrites of another neurone or to effector cells.
3. Nerve impulses are transmitted across the tiny space of a synapse by chemicals called **neurotransmitters**.

11.7 Reflex actions

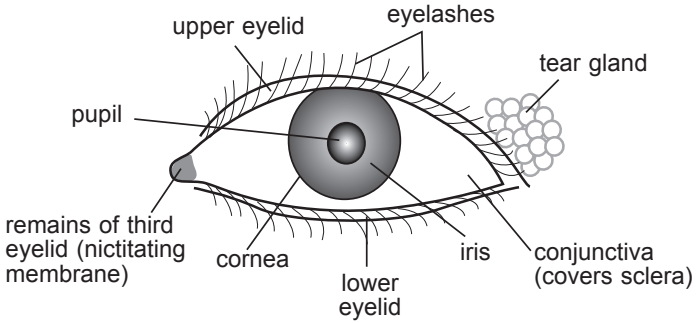
1. Reflex actions are involuntary responses to a specific stimulus. They cannot be consciously controlled.
2. The pathway by which nerve impulses travel during reflex actions is called a **reflex arc**.
3. It consists of:
   (a) Receptor
   (b) Sensory neurone
   (c) Intermediate neurone / relay neurone (located in CNS)
   (d) Motor neurone
   (e) Effector
4. The diagram below shows the reflex arc, the pathway of nervous impulses controlling a reflex response:



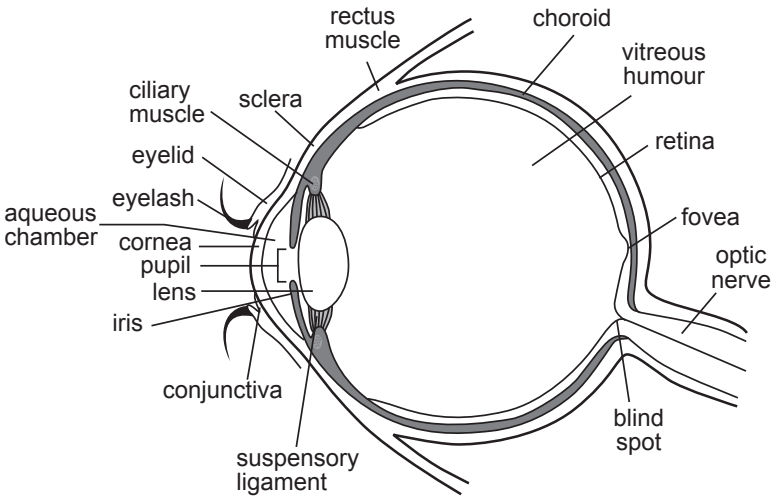
The reflex arc

5. Receptors in the skin detect the stimulus.
6. Nerve impulses are produced which are transmitted by the sensory neurone to the spinal cord.
7. In the spinal cord, the nerve impulses are transmitted across a synapse to an intermediate neurone and then across another synapse to the motor neurone. Nerve impulses are also transmitted to the brain.
8. Nerve impulses travel along the motor neurone to the motor end plate.
9. The nerve impulses stimulate the motor end plate and cause the muscle to contract.

11.8 Structure of the eye



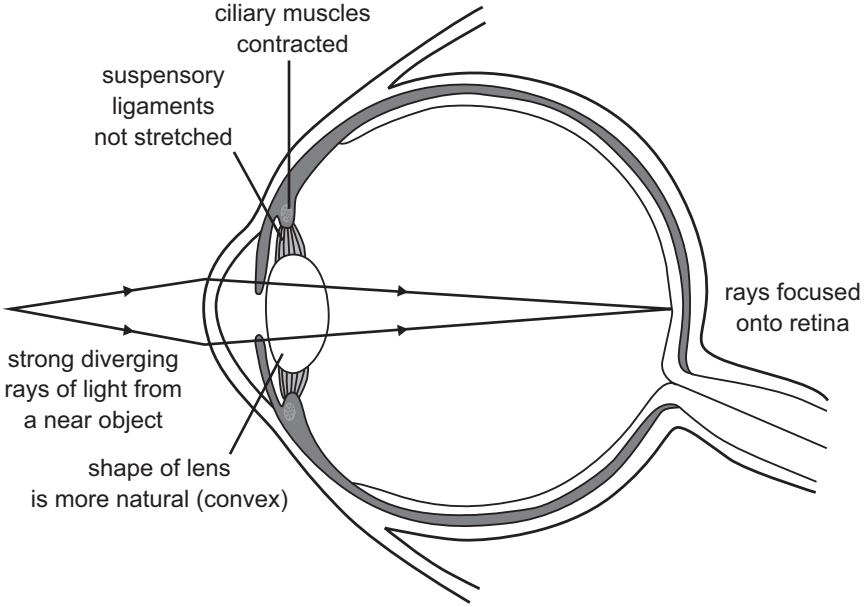
Structures at the front part of the eye



Vertical section of the eye

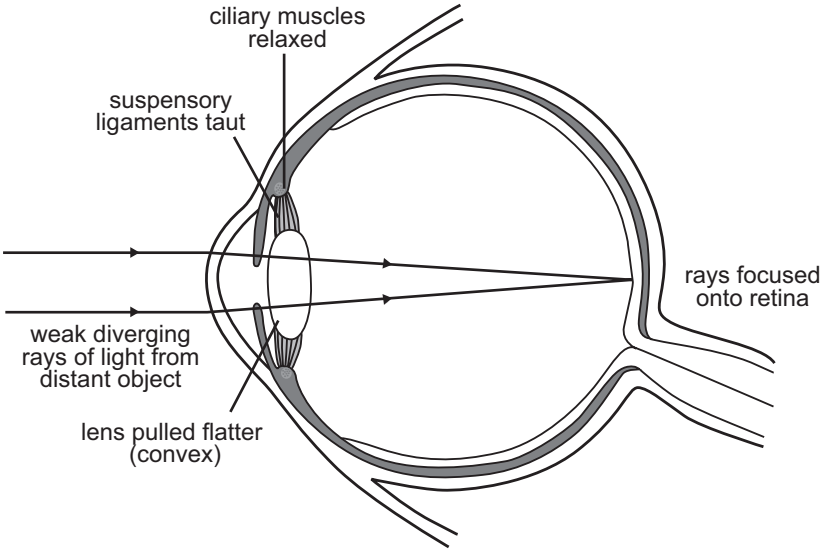
1. **Iris** – Pigmented circular sheet of muscles that control the contraction and dilation of the iris through the contraction and relaxation of the circular muscles and radial muscles
2. **Pupil** – A hole in the middle of the iris which allows light to enter the eye
3. **Sclera** – Tough white outer layer of connective tissue
4. **Conjunctiva** – Thin, transparent mucous membrane that helps to lubricate the eye
5. **Cornea** – Transparent refractive layer covering the iris and pupil. It causes the most of the refraction of light entering the eye. The cornea is continuous with the sclera.
6. **Tear gland** – Gland lying at the upper corner of the eyelid. Secretes tears which lubricate the eye, nourish the cornea and keeps it free from dust.
7. **Choroid** – Black middle layer of the eyeball, between the sclera and retina. Contains blood vessels that supply oxygen and nutrients, and remove metabolic waste products. It is pigmented black to prevent an internal reflection of light.
8. **Retina** – Innermost layer of the eyeball which contains photoreceptors. Photoreceptors are connected to nerve endings from the optic nerve.
9. **Lens** – Transparent biconvex structure that refracts light onto the retina. The lens is flexible and its curvature can be changed. It is responsible for the process of accomodation, a reflex action where the lens is able to change its curvature to focus sharp images on the retina.
10. **Ciliary body** – Contains ciliary muscles which control the curvature of the lens. It is also responsible for producing aqueous humour.
11. **Suspensory ligament** – Connects the ciliary body to the lens
12. **Aqueous humour** – A transparent, water substance filling the space between the cornea and the lens. It keeps the front of the eye firm and helps refract light into the eye.
13. **Vitreous humour** – Clear gel filling the space between the lens and the retina. It keeps the eyeball firm and helps refract light onto the retina.
14. **Fovea** – Yellow pit in the retina where images are usually focused
15. **Optic nerve** – Transmits visual information from the retina to the brain. There are no photoreceptors in the area of the retina where the optic nerve leaves the eye. This area is called the blind spot.

11.9 Focusing on a near object



1. Light rays from a near object enter the eye as diverging rays to fall on the retina.
2. The retina sends impulses to the brain, which sends impulses to the ciliary muscles.
3. The ciliary muscles contract, causing the suspensory ligaments to become slack.
4. The suspensory ligaments relax their pull on the lens. The elastic lens becomes thicker and rounder, causing more refraction of the rays of light, enabling a sharp image to be focused on the retina.

11.10 Focusing on a distant object



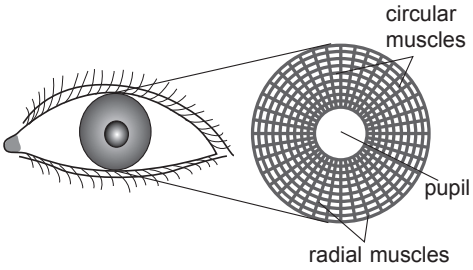
1. Light rays from a distant object enter the eye as almost parallel rays to fall on the retina.
2. The retina sends impulses to the brain, which sends impulses to the ciliary muscles.
3. The ciliary muscles relax, causing the suspensory ligaments to become taut.
4. The suspensory ligaments pull on the lens more. The elastic lens becomes thinner and less curved, causing less refraction of the rays of light, enabling a sharp image to be focused on the retina.

11.11 The pupil reflex

1. The **pupil reflex** is an involuntary action where the pupils contract or dilate in response to changing light intensities.
2. The pupils dilate to allow more light to enter the eye for better vision when light intensity is low, and contract to restrict light entry when light intensity is high as excessive light can damage the retina.
3. The size of the pupil is controlled by two sets of involuntary muscles in the iris called the **circular muscles** and the **radial muscles**.
4. The reflex arc involves these components:
   (a) Light entering the eye falls on the retina.
   (b) Retina sends impulse via optic nerve to the brain. The brain is the organ of the CNS that is nearest to the eye.

(c) The brain sends impulse to the iris muscles.

(d) The circular and radial muscles respond to change the size of the pupil, to adjust to the light conditions.



Structure of the iris

5. When light intensity is high:
   (a) Circular muscles in the iris contract.
   (b) Radial muscles in the iris relax.
   (c) The pupil constricts.
6. When light intensity is low:
   (a) Circular muscles in the iris relax.
   (b) Radial muscles in the iris contract.
   (c) The pupil dilates.

11.13 Hormones

1. A hormone is a chemical substance produced by a gland and carried by the blood, which alters the activity of one or more specific target organs.
2. Hormones are active in minute quantities and are destroyed by the liver and excreted by the kidneys.
3. They affect cellular metabolism and coordinate the growth, development and activity of an organism.
4. Glands are classified into two groups: exocrine glands and endocrine glands.
5. Exocrine glands are glands that secrete their products via ducts. Examples include sweat glands and salivary glands.
6. Endocrine glands are glands that secrete their products directly into the bloodstream. Examples include the pituitary gland, thyroid gland, adrenal gland and the gonads.
7. Some glands are both exocrine and endocrine. An example would be the pancreas, which secretes pancreatic juice via the pancreatic duct, and insulin and glucagon from the islets of Langerhans into the bloodstream.

11.14 The pancreas as an endocrine gland

1. The islets of Langerhans in the pancreas are areas in the pancreas that contain groups of endocrine cells.
2. These cells produce the hormones **insulin** and **glucagon**.
3. Insulin and glucagon are antagonistic hormones that participate in homeostatic control of blood glucose level by negative feedback mechanism.
4. When blood glucose level exceeds the normal level, more insulin is released and acts to lower the glucose level.
5. When blood glucose level falls below the normal level, more glucagon is released and acts to increase the glucose level.
6. Insulin decreases blood glucose concentration by:
   (a) Stimulating body cells to increase glucose uptake by increasing permeability of plasma membranes to glucose
   (b) Stimulating the liver and muscle cells to store glucose in the form of glycogen
   (c) Decreasing production of glucose from glycogen breakdown in the liver
   (d) Decreasing the conversion of fatty acids and amino acids to glucose in the liver
7. Glucagon increases blood glucose concentration by stimulating liver cells to:
   (a) Convert glycogen to glucose
   (b) Convert amino acids and fatty acids to glucose
   (c) Convert lactic acid into glucose

11.15 Diabetes mellitus

1. Diabetes mellitus is a condition in which the body does not produce sufficient insulin or does not respond to insulin.
2. The excess glucose cannot be completely reabsorbed by the kidneys and are excreted in the urine.
3. Symptoms include:
   (a) A persistent high blood glucose concentration
   (b) Presence of glucose in the urine
   (c) Excessive urination, excessive thirst and weight loss

4. Diabetes can cause:
   (a) Poor immune response – increased susceptibility to infections
   (b) Damaged blood vessels leading to vision loss and a decreased sensation in the limbs
   (c) Kidney failure and heart failure
5. Diabetic individuals can control their disease by receiving regular injections and controlling their carbohydrate intake.

11.16 Adrenaline

1. Adrenaline is a hormone produced by the adrenal glands located above the kidneys. It is responsible for the '**fight-or-flight response**' triggered by stress (emotional or physical threats to the organism).
2. In response to stress, the adrenal medulla secretes adrenaline into the blood.
3. The adrenaline travels to target organs, causing:
   (a) Increased conversion of glycogen to glucose in the liver and skeletal muscles
   (b) Increased glucose release into blood by liver cells
   (c) Increased metabolic rate, causing more energy to be released in cellular respiration
   (d) Increased heart rate and volume of blood pumped per unit time, increasing oxygen and glucose supply to muscle cells
   (e) Dilated bronchioles and increased breathing rate and depth, allowing more oxygen to be taken in for cellular respiration
   (f) Decreased blood supply to the digestive system, the kidneys and the skin as vasoconstriction occurs in several body parts, diverting blood supply to the heart, brain and skeletal muscles
   (g) Vasodilation occurring in other body parts, increasing blood supply to these organs
   (h) Dilated pupils, enhancing vision
   (i) Contracted hair erector muscles, producing 'goose pimples'

TOPIC 12 Reproduction

Objectives

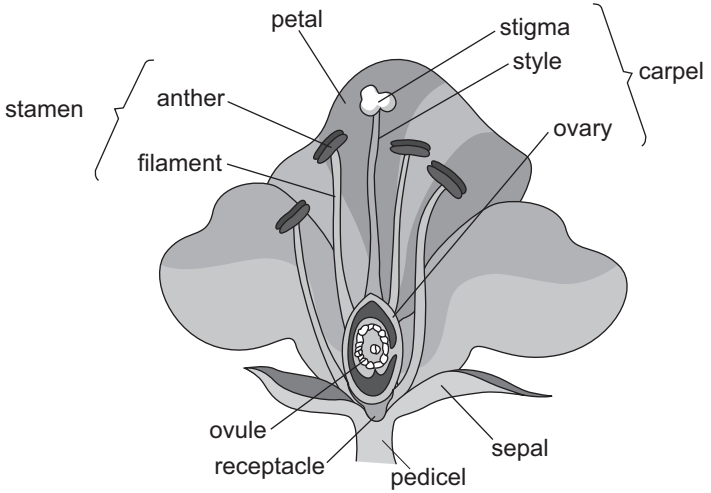
Candidates should be able to:

(a) define *asexual reproduction* as the process resulting in the production of genetically identical offspring from one parent
(b) define *sexual reproduction* as the process involving the fusion of nuclei to form a zygote and the production of genetically dissimilar offspring
(c) identify and draw, using a hand lens if necessary, the sepals, petals, stamens and carpels of one, locally available, named, insect-pollinated, dicotyledonous flower, and examine the pollen grains under a microscope
(d) state the functions of the sepals, petals, anthers and carpels
(e) use a hand lens to identify and describe the stamens and stigmas of one, locally available, named, wind-pollinated flower, and examine the pollen grains using a microscope
(f) outline the process of pollination and distinguish between self-pollination and cross-pollination
(g) compare, using fresh specimens, an insect-pollinated and a wind-pollinated flower
(h) 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)
(i) identify on diagrams, the male reproductive system and give the functions of: testes, scrotum, sperm ducts, prostate gland, urethra and penis
(j) identify on diagrams, the female reproductive system and give the functions of: ovaries, oviducts, uterus, cervix and vagina
(k) 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
(l) 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
(m) state the functions of the amniotic sac and the amniotic fluid
(n) 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)
(o) discuss the spread of human immunodeficiency virus (HIV) and methods by which it may be controlled

12.1 Reproduction

1. Reproduction is the biological process by which new organisms are produced to ensure the perpetuation of the species.
2. Reproductive methods are grouped into two main groups: **asexual reproduction** and **sexual reproduction**.
3. Asexual reproduction is when an organism produces a genetically identical offspring without the contribution of genetic material from another organism.
4. Sexual reproduction is when a genetically dissimilar offspring is produced through the fusion of two gametes, one from each parent organism, during the process of fertilisation.
5. Gametes are reproductive cells that contain half the number of chromosomes as a normal body cell.
6. The zygote produced during fertilisation contains genetic material from both parents, and is therefore genetically different from them.

12.2 Structure of an insect-pollinated flower

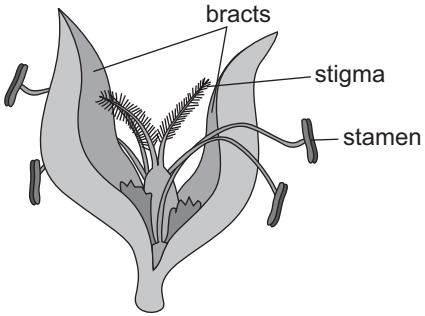


An insect-pollinated flower

1. **Pedicel** (flower stalk) – Modified stem that holds the flower
2. **Receptacle** – The end of the pedicel which holds the parts of the flower
3. **Sepals** – Modified leaves which are green in colour and are found on the outermost ring of floral leaves. They make up the calyx and protect the flower when it is in bud stage.

4. **Petals** – Modified leaves which form the most conspicuous part of the flower; they make up the corolla. They are brightly coloured in insect-pollinated plants and form a platform for insects to land on.
5. **Carpel** – Female reproductive organ. It contains an ovary with one or more ovules and has a sticky tip known as a stigma.
6. **Stigma** – Receptor of pollen grains. Secretes a sugary fluid that stimulates germination of pollen grains.
7. **Style** – Stalk that connects the stigma to the ovary. Holds the stigma in position to trap pollen grains.
8. **Ovary** – Each ovary contains one or more ovules.
9. **Ovule** – Contains female gametes
10. **Stamen** – Male reproductive organ. It consists of an anther and a filament.
11. **Anther** – Contains pollen grains. Pollen grains in insect-pollinated plants are heavy and sticky.
12. **Filament** – Stalk that holds the anther in a suitable position to disperse pollen
13. A flower can have multiple carpels. Multiple carpels form a **pistil**.

12.3 Structure of a wind-pollinated flower



A wind-pollinated flower

1. Flowers are small, dull-coloured, scentless and without nectar.
2. Flower parts are protected by leaf-like structures called bracts.
3. Stamens have long pendulous filaments that hang out of the bracts, exposing anthers to the wind.
4. Stigmas are large, extended and feathery, with a large surface area to trap the small and light pollen grains.

12.4 Differences between insect-pollinated and wind-pollinated flowers

Plant part	Insect-pollinated flower	Wind-pollinated flower
Flower	Large, brightly-coloured petals	Small and dull; flower parts protected by modified leaves called bracts
Scent	Flowers are strong-smelling	Flowers are scentless
Nectar	Present	Absent
Nectar guide	Present	Absent
Stamen	Not pendulous and do not protrude out of the flower	Pendulous and protrude out of the flower
Stigma	Small and compact, do not protrude out of the flower	Large and feathery, protrude out of the flower
Pollen grain	Fairly abundant, large and sticky	Very abundant, small and light

12.5 Pollination

1. Pollination is the transfer of pollen grains from the anther to the stigma, enabling fertilisation.
2. Mechanisms of pollination include **insect pollination** and **wind pollination**.
3. Insect-pollinated flowers contain nectar and have nectar guides which are lines that are visible to insects, guiding them to the location of the nectar.
4. When the insect enters the flower, pollen grains from the anthers stick onto the insect. If pollen grains from a previously-visited flower are present on the insect, they will be transferred to the sticky stigma.
5. Wind-pollinated flowers have their pollen carried away by the wind when the exposed anthers shake in the wind.
6. When the pollen grains come into contact with the large feathery stigmas of another flower, they would be trapped.
7. There are two types of pollination: **self-pollination** and **cross-pollination**.

12.6 Self-pollination

1. Self-pollination is the transfer of pollen grains from the anther to the stigma of the same flower, or from the anther of a flower to the stigma of another flower on the same plant.
2. Factors that promote self-pollination are:
   (a) Bisexual flowers with anthers and stigma maturing at the same time
   (b) Stigma being located directly below the anthers, allowing pollen grains to fall onto it
3. Advantages of self-pollination are:
   (a) Not dependent on external agents of pollination such as insects or wind
   (b) Less wastage of pollen and energy. During wind and insect pollination, a great number of pollen grains are lost as only a few pollen grains come into contact with a stigma of a flower of the same species.
   (c) Only one parent plant is required.
4. A disadvantage of self-pollination is less genetic variation, hence the offspring is less adapted to environmental changes.

12.7 Cross-pollination

1. Cross-pollination is the transfer of pollen grains from the anther of a flower to the stigma of a flower of another plant belonging to the same species.
2. Factors that promote cross-pollination are:
   (a) Plants bearing only male or female flowers. These plants are called dioecious plants.
   (b) In plants with bisexual flowers, the anthers and the stigmas mature at different times.
   (c) Self-incompatibility – When a pollen grain of a flower happens to land on the stigma of the same flower or another flower on the same plant, a biochemical block prevents the pollen grain from germinating.
3. Advantages of cross-pollination are:
   (a) Greater genetic variation, hence the offspring has a higher chance of surviving environmental changes.
   (b) Offspring may have inherited beneficial qualities from both parents.

4. Disadvantages of cross-pollination are:

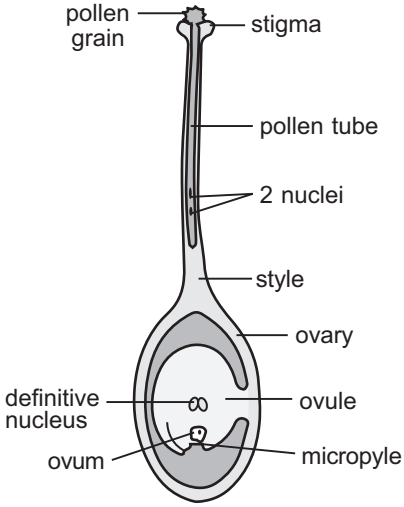
   (a) Energy-consuming – lots of energy is required to make large amounts of pollen grains.

   (b) A great number of pollen grains are wasted due to the randomness of the dispersal methods.

(c) External agents of pollination i.e. wind, insects are required.

(d) Two parent plants are required.

12.8 Double fertilisation in plants

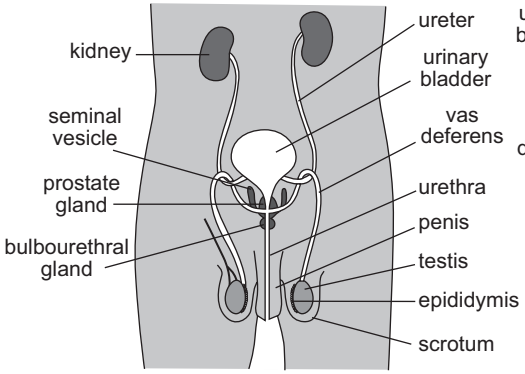


Fertilisation in plants

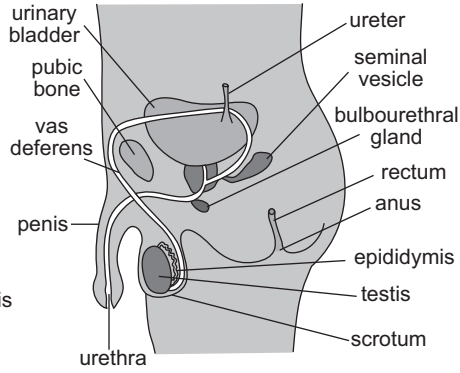
1. After pollination, a pollen tube grows out of each pollen grain in response to the sugary fluid secreted by the stigma.
2. The cytoplasm and the two nuclei of the pollen grain (generative nucleus and pollen tube nucleus) pass into the pollen tube. The pollen tube nucleus controls the growth of the pollen tube.
3. The pollen tube grows through the cells of the style by secreting enzymes to digest them.
4. The generative nucleus divides to form two male gametes.
5. The pollen tube enters the ovary and then enters the ovule through an opening in the ovule wall called a micropyle and releases the two male gametes.
6. One male gamete fuses with the ovum to form the zygote. The other male gamete fuses with the definitive nucleus to form the endosperm nucleus.

7. The zygote will divide and develop into the embryo. The endosperm nucleus will divide and give rise to the endosperm, a food storage tissue that will nourish the developing embryo.
8. The ovule will develop into a seed and the ovary will develop into a fruit.

12.9 Male reproductive system



Front view of the male reproductive system

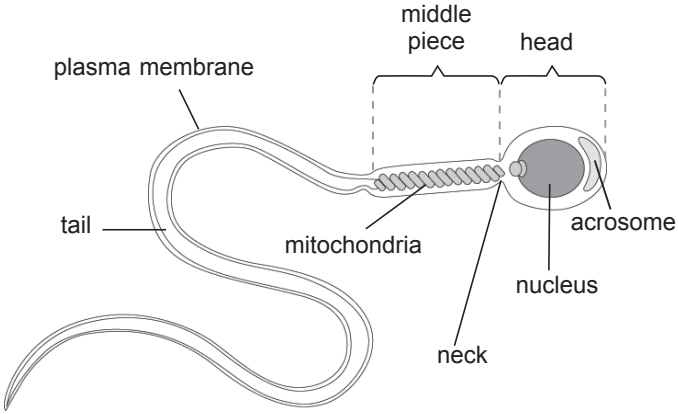


Side view of the male reproductive system

1. **Testes** (singular: testis) – The male reproductive organs (**gonads**). Produces sperms (**male gametes**) and male sex hormones e.g. testosterone. Male sex hormones are responsible for development and maintenance of secondary sexual characteristics. Leading from the end of each testis is a narrow tightly-coiled tube called the **epididymis** in which sperms are stored.
2. **Scrotum** – The two testes are held in a pouch-like sac outside the body called the scrotum. The lower temperature in the scrotum is essential for sperm production.
3. **Sperm ducts** – The sperm ducts (**vas deferens**) lead from the epididymis. During ejaculation, they transport sperm from the epididymis to the urethra.
4. **Prostate gland** – The prostate gland is a large gland which secretes directly into the urethra through several small ducts. The fluid contributes to semen. **Semen** is a composition of sperm and fluids from the sex glands containing nutrients and enzymes which nourish and activate the sperm, allowing them to swim actively.
5. **Seminal vesicles** – Ducts from the seminal vesicles join the vas deferens. The seminal vesicles are a pair of glands that secrete a fluid that makes up a proportion of semen.

6. **Cowper's glands** – The Cowper's glands, also known as bulbourethral glands, are a pair of pea-sized glands located beneath the prostate. The fluid produced by the gland contributes to semen.
7. **Urethra** – The urethra is a common passage for urine and semen to pass out of the body. The sphincter muscle at the base of the bladder prevents urine from passing out of the bladder during ejaculation of semen.
8. **Penis** – The penis consists of cylinders of spongy erectile tissue around the urethra. The tissue contains numerous spaces that allow it to fill up with blood. When that happens, the penis becomes erect and hard, allowing it to enter the vagina of a woman during sexual intercourse to deposit semen.

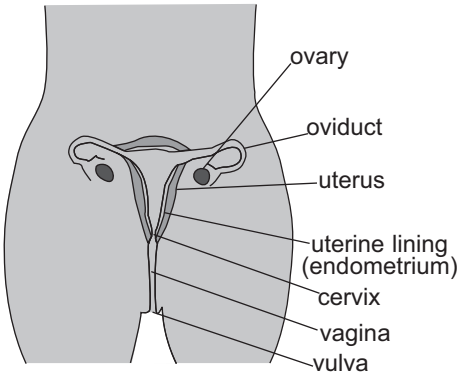
12.10 Spermatozoa



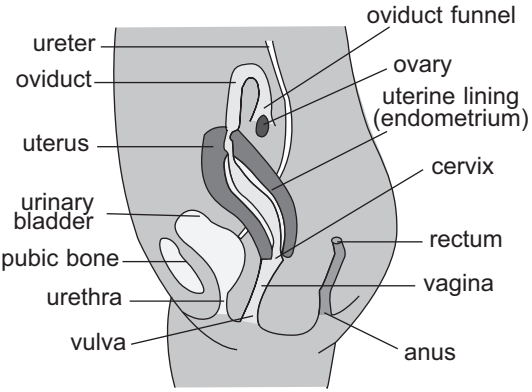
A sperm cell

1. The male gamete, the sperm (singular: spermatozoon, plural: spermatozoa), consists of a head, middle piece and tail.
2. The head contains:
   (a) An acrosome, an enzyme-containing sac. The acrosome contains digestive enzymes which break down the outer membrane of the ovum, allowing for fertilisation
   (b) A small amount of cytoplasm and a large haploid nucleus
3. The middle piece contains numerous mitochondria arranged spirally to provide energy for the sperm to swim to the egg.
4. The tail (flagellum) beats to propel the sperm towards the egg.

12.11 Female reproductive system



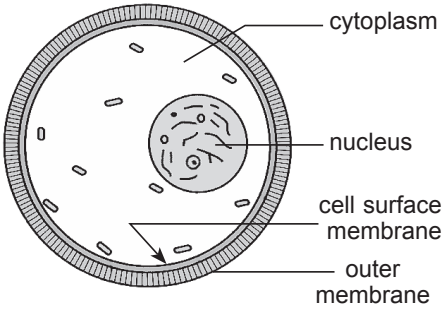
Front view of the female reproductive system



Side view of the female reproductive system

1. **Ovaries** – The female reproductive organs (gonads). Produces ova (singular: ovum) and female sex hormones e.g. estrogen and progesterone. Female sex hormones are responsible for development and maintenance of secondary sexual characteristics. Mature eggs are released from the ovaries into the oviducts.
2. **Oviducts** – The oviduct (fallopian tube) is a narrow muscular tube leading from the ovary to the uterus. The oviduct has a funnel-like opening to make it easier for ova to enter the oviduct. Cilia on the inner lining help move the ovum to the uterus. The ovum is usually fertilised in the oviduct.
3. **Uterus** – The uterus is a thick muscular organ that can stretch as the fetus increases in size during pregnancy. The smooth muscles in the uterine wall contract to expel the fetus during birth. The uterus is lined by a lining called the **endometrium** (uterine lining). The endometrium is richly supplied with blood vessels and is the site of **implantation** of the embryo post-fertilisation. It is broken down every month and flows out of the body in the process called **menstruation**.
4. **Cervix** – The cervix is a circular ring of muscle at the neck of the uterus. It opens into the vagina. It enlarges during birth to allow the passage of the fetus.
5. **Vagina** – The vagina is a thin-walled chamber where sperm is deposited during sexual intercourse. It forms the birth canal through which the baby is born.

12.12 Ovum



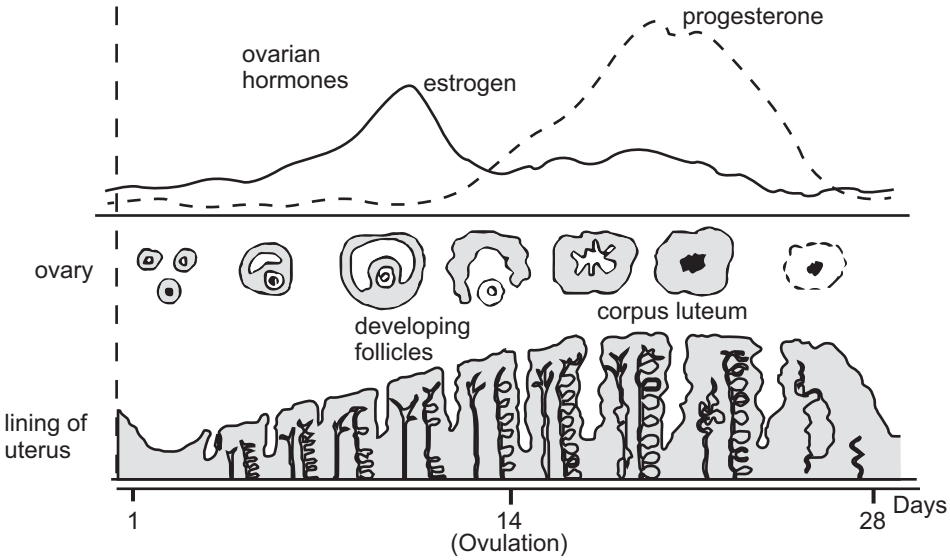
An ovum

1. The female gamete, the ovum, is a large cell containing abundant cytoplasm.
2. It has a large nucleus containing a haploid set of chromosomes.
3. It is surrounded by a plasma membrane and an outer membrane.

12.13 The menstrual cycle

1. The menstrual cycle normally spans over 28 days. There is natural variation in the length of the menstrual cycle, and it can range from 21 to 33 days.
2. **Day 1 to 5**: Menstruation lasts for 5 days. The first day of menstruation is day 1 of the menstrual cycle. The endometrium breaks down and flows out of the body.
3. **Day 6 to 13**: The ovaries secrete estrogen which causes the repair and growth of the endometrium. The endometrium becomes thicker.
4. **Day 14**: A mature ovum is released from the ovaries. Secretion of progesterone is stimulated. The ovum dies after about 1 to 2 days if it is not fertilised.
5. **Day 15 to 28**: Progesterone and estrogen are continually being secreted for continued development and maintenance of the endometrium. Progesterone maintains the endometrium by causing it to become thicker. The endometrium readies for implantation. Towards the end of the cycle, secretion of progesterone and estrogen decline sharply. The endometrium is no longer maintained and disintegrates. It flows out from the uterus together with some blood through the vagina. This marks the beginning of another cycle.
6. The **fertile phase** of the cycle is from day 11 to 17. This is because sperms can survive for 2 to 3 days in the female reproductive system. Sperms deposited in the vagina from day 11 onwards can fertilise the ovum which is released from the ovaries on day 14. The ovum can survive for 1 to 2 days after ovulation; hence fertilisation is possible up till day 17.

7. The rest of the days make up the **infertile phase** of the menstrual cycle. Sexual intercourse during this period is unlikely to result in fertilisation since no ovum is present.



The menstrual cycle

12.14 Fertilisation in humans

1. During sexual intercourse, semen containing sperms is deposited into the vagina of a woman. The fluids from the male sex glands that make up semen provide nutrients and protection for the sperms, as well as a medium for them to swim in.
2. The sperms swim up the oviducts and encounter the ovum.
3. The acrosome of the sperms release enzymes to disperse the layer of cells surrounding the ovum and break down the outer membrane of the ovum.
4. Only 1 sperm will enter the ovum. The plasma membranes of the sperm and the ovum fuse and the sperm nucleus enters the ovum. The plasma membrane of the egg undergoes a change as soon as a single sperm has entered, preventing other sperms from entering.
5. The sperm nucleus fuses with the egg nucleus, forming a fertilised ovum known as a zygote.
6. The remaining sperms eventually die.

12.15 Development of the zygote

1. The cilia on the oviduct lining help move the zygote towards the uterus.
2. In the meantime, the zygote divides many times to form a hollow ball of cells called the embryo.
3. 5 to 7 days after fertilisation, the embryo comes into contact with the endometrium and becomes embedded. This process is known as implantation.
4. Tissues growing out from the embryo invade the endometrium, forming the **placenta**. The placenta is an organ that contains both maternal and embryonic blood vessels. It allows for diffusion between the maternal blood circulation and embryonic blood circulation.
5. The placenta:
   (a) Provides nutrients (glucose, amino acids and mineral salts) and oxygen for the embryo
   (b) Removes waste materials such as urea and carbon dioxide
   (c) Allows protective antibodies to diffuse from maternal blood into embryonic blood
   (d) Provides a barrier preventing maternal blood and embryonic blood from mixing. Reasons for this include:
      (i) Maternal blood pressure is much higher than embryonic blood pressure and would damage vital tissues.
      (ii) The embryo might have a different blood group, resulting in agglutination if mixing of blood occurs.
   (e) Produces progesterone which maintains the endometrium during pregnancy
6. The embryo eventually becomes connected to the placenta by the **umbilical cord**. Embryonic blood travels to the placenta via the arteries of the umbilical cord and returns with oxygen and dissolved food substances via the umbilical vein.
7. A membrane called the **amniotic sac** begins development at the same time as the placenta, and encloses the embryo in a fluid-filled space. The fluid is known as **amniotic fluid**.
8. The amniotic fluid functions to:
   (a) Absorb shock, support and protect the embryo from physical injury
   (b) Lubricate the vagina during birth to reduce friction
   (c) Allow the fetus to move freely during development
9. About 9 weeks after fertilisation, the embryo has developed into a fetus.

12.16 Human Immunodeficiency Virus

1. Acquired Immune Deficiency Syndrome (AIDS) is a disease that can be spread through sexual intercourse.
2. It is caused by a virus called Human Immunodeficiency Virus (HIV).
3. HIV progressively reduces the effectiveness of the infected person's immune system in protecting him from infection.
4. HIV infection progresses to AIDS, the last stage of the infection, in about 9 to 10 years after infection.
5. Symtons of AIDS include:
   (a) Persistent fever, sweat, swollen glands, chills, weakness and weight loss
   (b) Pneumonia
   (c) Tuberculosis
   (d) Chronic diarrhoea
   (e) Brain infection
   (f) Tumours such as Kaposi's sarcoma (cancer of the blood vessels) and cervical cancer in women
6. HIV is transmitted:
   (a) By sexual intercourse with an infected person
   (b) By sharing and reusing contaminated needles during intravenous drug use, tattoos and piercing
   (c) By receiving a blood transfusion from an infected donor
   (d) During pregnancy and childbirth. An infected mother could pass on the disease to her child
7. Spread of HIV can be prevented by:
   (a) Having protected sexual intercourse. A condom reduces the risk of infection.
   (b) Abstinence from sex or having sex with only one partner
   (c) Not sharing objects that could be contaminated with blood or bodily fluids such as hypodermic syringes, razors and toothbrushes
   (d) Screening of blood in a blood bank for HIV infection to reduce chances of transmission during blood transfusions
   (e) Infected mothers should undergo antiretroviral therapies and give birth by caesarean section to minimise risk of transmission to the foetus. Breastfeeding should be avoided after birth.
   (f) Visiting reliable operators for tattoos, piercings or acupuncture where needles are sterilised or disposable

TOPIC 13 Cell Division

Objectives

Candidates should be able to:

(a) state the importance of mitosis in growth, repair and asexual reproduction
(b) explain the need for the production of genetically identical cells
(c) identify, with the aid of diagrams, the main stages of mitosis
(d) state what is meant by *homologous pairs* of chromosomes
(e) identify, with the aid of diagrams, the main stages of meiosis (Names of the sub-divisions of prophase are **not** required)
(f) define the terms *haploid* and *diploid*, and explain the need for a reduction division process prior to fertilisation in sexual reproduction
(g) state how meiosis and fertilisation can lead to variation

13.1 Cell division

1. New cells must be created for growth and repair in organisms.
2. Cell division is the process by which new cells arise.
3. During cell division, a parent cell divides into two or more daughter cells.
4. There are two types of cell division: **mitosis** and **meiosis**.
5. Mitosis takes place in body cells in tissues undergoing growth and repair while meiosis is only involved in the creation of gametes.

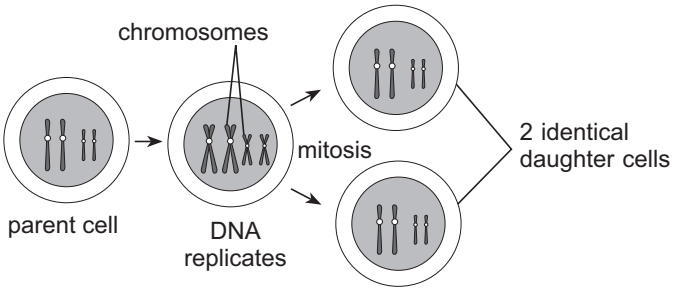
13.2 Chromosomes

1. A chromosome is a single coiled deoxyribonucleic acid (DNA) molecule containing many genes. Genes are sections of DNA that encode genetic instructions.
2. A normal human body cell contains 46 (23 pairs) chromosomes. This number is the **diploid** (2n) number of chromosomes.
3. In gametes, there are only 23 chromosomes. This number is the **haploid** (n) number of chromosomes.
4. The process of DNA replication during cell division must be finely controlled so that the daughter cells produced by mitosis would contain all the genes required for subsequent cell division and differentiation.

5. Errors occurring during DNA replication will be transferred to daughter cells during cell division.
6. This could lead to harmful changes in the genes and affect cellular function.

13.3 Mitosis

1. Mitosis is the process of cell division in which the genetic material of the parent cell is duplicated, producing two daughter cells that are genetically identical to the parent cell.
2. The daughter cells each contain the diploid number of chromosomes.
3. Mitosis is important for growth because genetically identical new cells must be produced during growth.
4. Mitosis is also required for repair. New cells are produced to replace worn-out cells that have been destroyed or shed.
5. Mitosis occurs during asexual reproduction, producing offspring that are genetically identical to the parents as well as to one another.



Mitosis

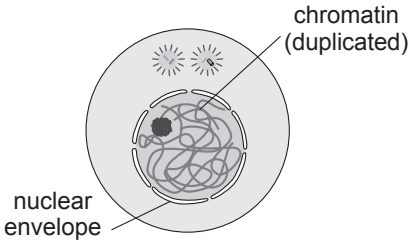
13.4 The cell cycle

1. The cell cycle is the series of events that take place in a cell, resulting in cell division.
2. It consists of a period in which the cell prepares for cell division by accumulating nutrients, increasing its size and number of organelles and replicating its DNA, called the **interphase**, and the actual **mitotic phase**.
3. The mitotic phase consists of mitosis, which is the division of the genetic material, and cytokinesis, which is the division of the cytoplasm.

13.5 Stages of mitosis

Interphase

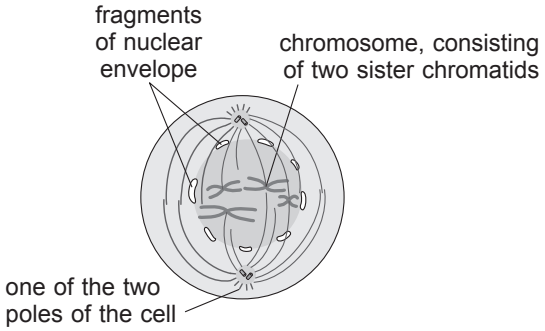
1. During interphase, the cell grows, stores energy and duplicates organelles.
2. The DNA replicates and the total DNA content of the cell doubles. The chromosome number still remains 2n.
3. The chromatin (threads of chromosomes) is in the dispersed state.



Interphase

Prophase

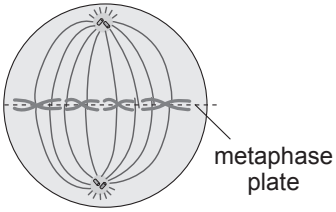
1. The chromatin condenses to form thick strands, which are visible under the light microscope. Each duplicated chromosome appears as two identical sister chromatids joined together at a central region called the centromere. The centromeres form X-shaped structures.
2. The nuclear envelope disappears.



Late prophase

Metaphase

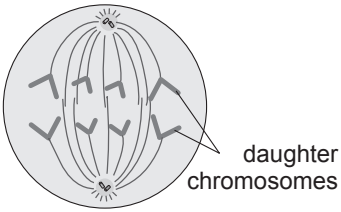
1. The chromosomes line up along the **metaphase plate**, which is an imaginary line equidistant from the two spindle poles.



Metaphase

Anaphase

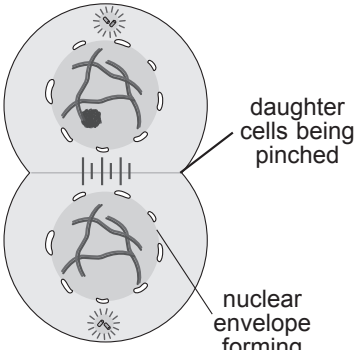
1. Each pair of sister chromatids splits at the centromeres and are pulled to the opposite ends of the cell. Each chromatid is now called a daughter chromosome.
2. At the same time, the opposite ends of the cell move further apart.
3. The two ends of the cell now have equivalent and identical collections of chromosomes.



Anaphase

Telophase

1. Daughter nuclei begin to form at both ends of the cell.
2. The chromosomes in each daughter nucleus uncoil to form chromatin threads.
3. While telophase is taking place, cytokinesis occurs. Cytokinesis is not considered a part of mitosis but is necessary for cell division.



Telophase

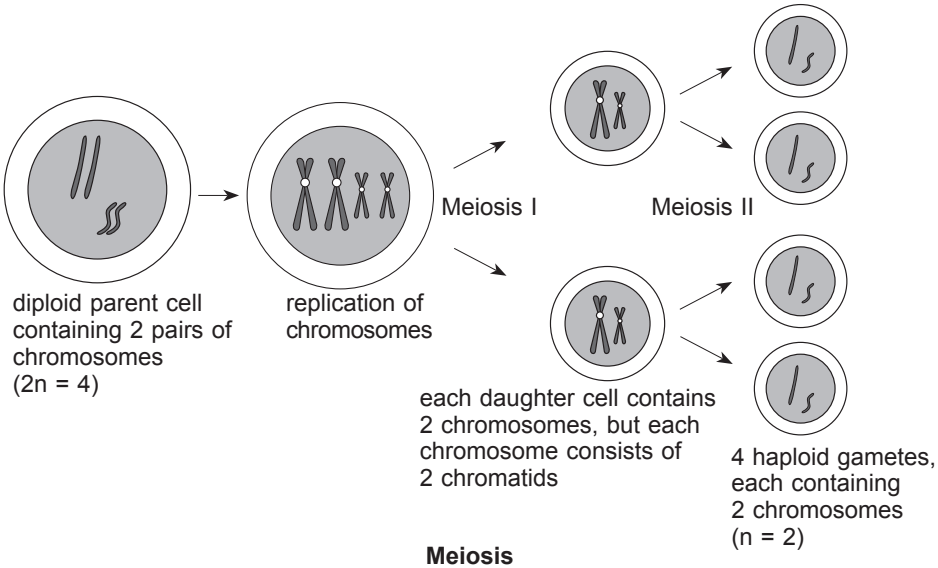
Cytokinesis

1. Cytokinesis, the division of cytoplasm, occurs at the same time the cell is undergoing telophase.
2. The two daughter cells are pinched apart.
3. Each daughter cell has a complete copy of the genome of the parent cell.

13.6 Meiosis

1. Meiosis is the reduction division in cells where the chromosome number in each daughter cell is halved.
2. Normal human body cells contain 2 sets of 23 chromosomes (a maternal set and a paternal set), making a total of 46 chromosomes. Cells containing 2 sets of chromosomes are diploid.
3. Gametes contain only 1 set of chromosomes and are known as haploid cells.
4. Gametes have to be haploid so that when sexual intercourse occurs, 2 haploid gametes can fuse to produce a diploid zygote. The zygote grows and develops by mitosis, preserving its ploidy number and giving rise to a new organism.

5. Meiosis is the process by which haploid gametes are produced.

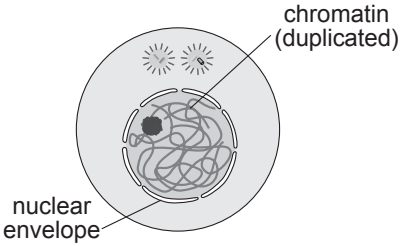


Meiosis

13.7 Stages of meiosis

Interphase

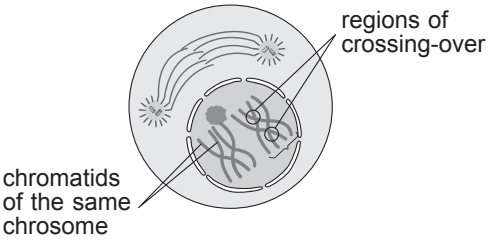
1. Interphase in meiosis is identical to interphase in mitosis.
2. Each of the 46 chromosomes is replicated and exists as two sister chromatids.



Interphase

Prophase I

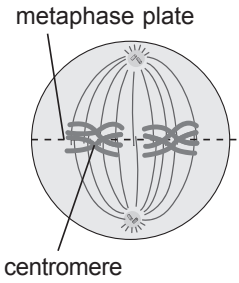
1. Chromatin condenses into chromosomes, which are thick strands that are visible under a light microscope.
2. Homologous chromosomes, one inherited from the father and one inherited from the mother, pair up.
3. **Crossing-over** occurs at many points along the paired chromosomes, where some DNA is exchanged.



Prophase I

Metaphase I

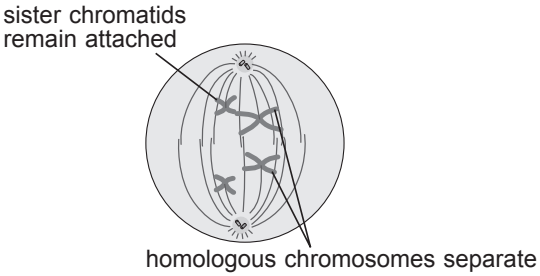
1. The homologous chromosomes line up in pairs along the metaphase plate.
2. One chromosome of each pair of homologous chromosomes ends up on one side of the metaphase plate, while its homologue (also consisting of 2 sister chromatids) is on the other side of the metaphase plate.



Metaphase I

Anaphase I

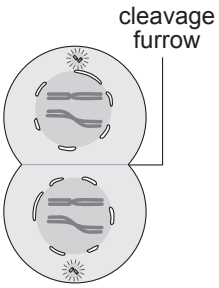
1. Homologous chromosomes separate and move to opposite poles of the cell.
2. The sister chromatids of each chromosome are still attached and move together.



Anaphase I

Telophase I

1. Nuclear membranes form around the chromosomes at each pole of the cell.
2. Cytokinesis occurs.



Telophase I

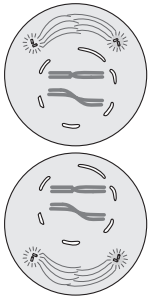
Cytokinesis

1. As in mitosis, cytokinesis involves the formation of a cleavage furrow in animals or a cell plate in plants.

In the second cell division, the sister chromatids are separated. The process is identical to mitosis.

Prophase II

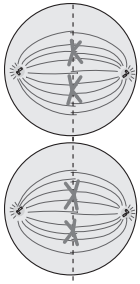
1. Nuclear envelope disappears and chromatin condenses



Prophase II

Metaphase II

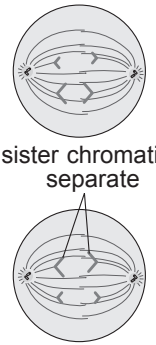
1. The chromosomes are aligned along the metaphase plate.



Metaphase II

Anaphase II

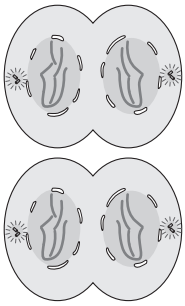
1. The sister chromatids are pulled to opposite poles.



Anaphase II

Telophase II

1. Nuclear envelopes reappear at each pole.
2. Chromosomes uncoil and lengthen.
3. Each daughter cell at the end of meiosis II has a haploid number of unreplicated chromosomes, i.e. half the amount of DNA of a usual body cell.



Telophase II

Cytokinesis

Cytokinesis occurs to pinch the daughter cells apart.

13.8 Genetic variation arising from meiosis

1. Genetic variation increases the chances of survival of the species in a changing environment.
2. Variation provides the basis for **natural selection**, a process where, over time, individuals with heritable traits more suitable for the environment are more likely to survive and reproduce, passing on their favourable genes to their offspring.
3. In a changing environment, a larger gene pool (due to genetic variation) is more likely to contain genes that express traits more suitable for the new environment. The species have a higher chance of becoming adapted instead of becoming extinct.
4. Genetic variation arises through 3 processes:
   (a) Independent assortment of chromosomes during metaphase I of meiosis. Independent assortment results in gametes with a random mixture of maternal and paternal chromosomes.
   (b) Crossing-over between homologous chromosomes during prophase I of meiosis. Crossing-over results in genetic recombination, producing chromosomes that have a mixture of maternal and paternal DNA.
   (c) Random fertilisation of gametes. Each gamete has a unique set of 23 chromosomes due to independent assortment and crossing-over in meiosis. Any one male gamete representing one out of the many different possible gene combinations, can fertilise an ovum, also representing one out of the many different possible gene combinations. This will produce variation due to the many different combinations of genes from the male and female gamete.

TOPIC 14 Molecular Genetics

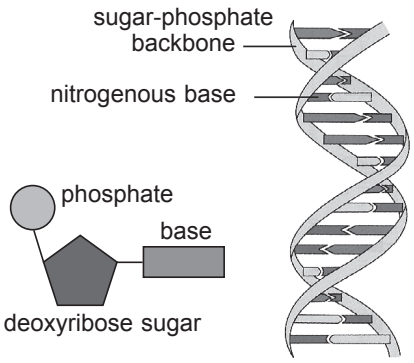
Objectives

Candidates should be able to:

(a) outline the relationship between DNA, genes and chromosomes
(b) state the structure of DNA in terms of the bases, sugar and phosphate groups found in each of their nucleotides
(c) state the rule of complementary base pairing
(d) state that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides (details of transcription and translation are **not** required)
(e) state that each gene is a sequence of nucleotides, as part of a DNA molecule
(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, with reference to a named example

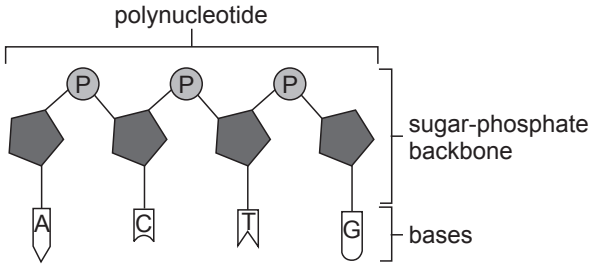
14.1 Structure of DNA

1. Deoxyribonucleic acid (DNA) is a molecule that carries genetic information used in the development and functioning of all organisms.
2. DNA consists of a pair of molecules that are twisted around each other in a shape called a double helix.
3. Each molecule of DNA is a long polymer consisting of basic units called **nucleotides**. Polymers of nucleotides are called **polynucleotides**.
4. Each nucleotide consists of:
   (a) A **deoxyribose** sugar
   (b) A **phosphate group**
   (c) A base containing nitrogen



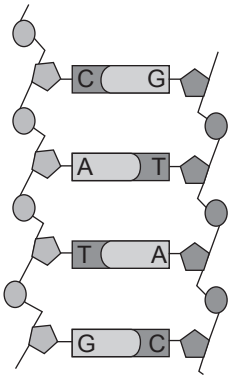
A nucleotide

5. There are four types of **nitrogenous bases**:
   (a) Adenine (A)
   (b) Guanine (G)
   (c) Cytosine (C)
   (d) Thymine (T)
6. The nucleotides polymerise to form a polynucleotide when the deoxyribose sugars of the nucleotides are joined together by phosphate groups, forming the **sugar-phosphate backbone** of the DNA molecule.



A polynucleotide

7. Two strands of polynucleotides wrap around each other to form the double helix structure of DNA. The strands are held together when the nitrogenous bases on one strand form **hydrogen bonds** with the nitrogenous bases on the other strand.
8. **Complementary base pairing** is when each type of base on one strand forms hydrogen bonds with only one type of base on the other strand.
9. **Adenine bonds to only thymine; cytosine bonds to only guanine.**

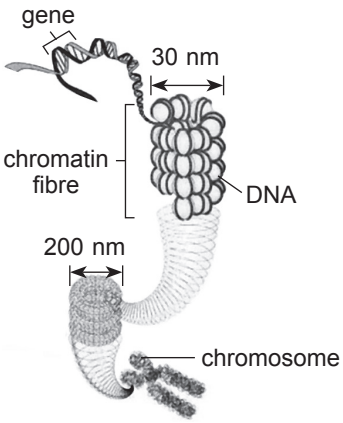


Complementary base pairing

10. Each gene is made up of a unique sequence of nucleotides. A DNA molecule contains many genes along its length.

14.2 Organisation of DNA in cells

1. DNA is wrapped around proteins to form a 'beads on a string' structure.
2. The DNA-wrapped proteins coil to form a chromatin fibre.
3. The chromatin fibres fold and coil further to form the compact structures called chromosomes seen during cell division.



Folding of DNA

14.3 From DNA to phenotype

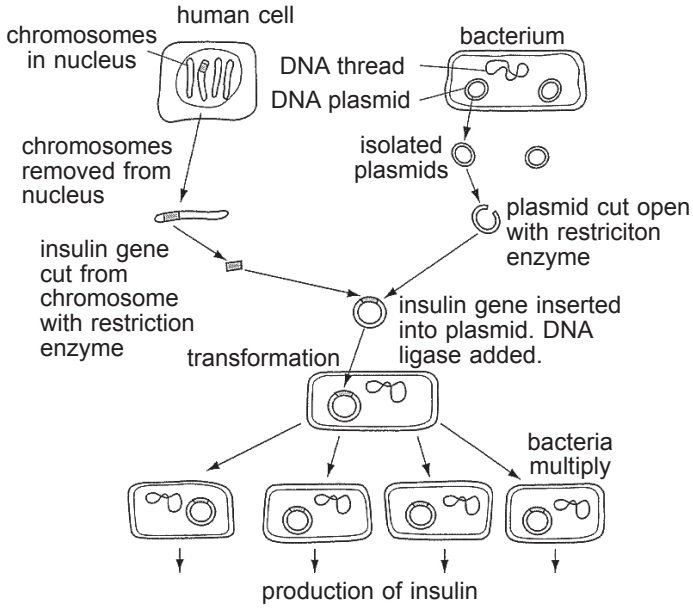
1. A **gene** is a single unit of hereditary information consisting of a specific nucleotide sequence located on the chromosome. Each gene contains information for the production of a **single polypeptide**.
2. These gene products are responsible for every aspect of a living organism e.g. appearance, resistance to specific diseases, biochemical processes necessary for life etc. For example, a gene can affect hair colour by coding for an enzyme involved in the production of hair pigment.

14.4 Genetic engineering

1. Genetic engineering is a technique where genes of interest can be inserted into the genome of a specific organism. For example, genes from bacteria or other plants that confer resistance to diseases or herbicides are inserted into crop plants like soybean or corn in order to make it grow better. Herbicides can be used on weeds growing around the crop plant without killing the crop plant. The genetically-modified plant is known as a **transgenic plant**.
2. Transgenic organisms possess a gene or genes that have been transferred from another species.

14.5 Production of human insulin

1. People suffering from type 1 diabetes mellitus require insulin injections.
2. Genetic engineering is used to produce human insulin from the bacteria *Escherichia coli*.
3. The human insulin gene is first obtained from a human chromosome by cutting it with a restriction enzyme.
4. The plasmid vector is cut with the same restriction enzyme.
5. When the plasmids are mixed with the DNA fragments, they are able to bind as the enzyme cuts both in the same way, generating 'sticky ends' that can join together. DNA ligase is added to the mixture, allowing the cut ends of the DNA to join to form a continuous double strand.
6. The recombinant plasmids are mixed with *E. coli*. Heat shock is applied to the bacteria, opening up pores on the membrane of the bacteria so plasmids enter the bacteria. This process is known as transformation.
7. The bacteria are placed in large steel tanks called fermenters under optimal conditions for growth and reproduction. Features of a fermenter include a nutrient broth containing glucose water and salts, 37°C temperature maintained by a temperature probe, optimal pH maintained by a pH probe, air supply for aeration and a stirrer to mix substances evenly.
8. At the end of fermentation, the bacteria cells are lysed open. Insulin is extracted and purified by crystallisation.



Production of human insulin

14.6 Applications of genetic engineering

1. Genetic engineering has relevance to biological research e.g. genetically-modified (GM) mice are used to study the function of genes.
2. Low-cost, high-yield production of pharmaceutical drugs e.g. insulin, clotting factors for haemophiliacs, human growth hormone.
3. Agriculture, where traits conferred through genetic modification include:
   (a) Survivability in harsh environmental conditions. Areas previously considered unsuitable can be used to grow crops. Crops are also more likely to survive bad weather such as drought.
   (b) Reduced maturation time. Multiple harvests a year translates into increased supply of food.
   (c) Resistance to pests, diseases and herbicides. Crops are less likely to succumb to diseases; farmers are able to use pesticides to remove pests and herbicides to remove weeds without killing the crops.
   (d) Production of toxins that kill pests (bioinsecticides). Farmers save money on pesticides.
   (e) Enhanced nutritional value. Genes coding for vitamin or nutrient production can be inserted into a crop species to yield a more nutritious product.

   Benefits include:

   (a) Lowered cost for farmers since fewer pesticides are used as plants can produce their own. This translates to lower consumer costs and increased accessibility to certain types of food.
   (b) Higher yield since fewer crops are lost to disease or poor environmental conditions.
   (c) GM foods with enhanced nutritional value can be used to supply nutrients to people living in areas without access to certain nutrients in their regular diet.
4. Animal husbandry and aquaculture – GM fish are designed to overproduce growth hormone, resulting in faster growth. This reduces fishing pressure on wild stock.
5. Gene therapy – Gene therapy is the insertion of genes into a person's cells or tissues in order to treat a disease.

14.7 Social and ethical implications of genetic engineering

1. **Potential health concerns** including allergen transfer, transfer of antiobiotic resistance, unknown health effects.
2. **Environmental impact** including transfer of genes to wild plants or weed varieties through cross-pollination, loss of biodiversity, reduced effectiveness of pesticides.
   (a) Genes conferring herbicide tolerance might be transferred to weed varieties, causing the development of herbicide-resistant 'superweeds'.
   (b) Pesticide-producing GM plants produce pesticides that might indiscriminately kill insects around them, even harmless insects such as butterflies. Such genes crossing over into wild varieties and ending up in a natural environment would have serious ecological implications. This results in a loss of biodiversity and affects the ecological balance.
   (c) There is a concern that insects might build up resistance to pesticides.
3. **Economic impact**
   (a) World food production would be controlled by a few biotechnology companies.
   (b) Increased dependence of developing countries on industrialised countries carrying out genetic research.
   (c) Technology modifying GM plants to produce sterile seeds to minimise the spread of genes into unintended plants and combat patent infringement would result in farmers having to purchase new seeds every year – not financially feasible for farmers in developing countries.
4. **Ethical objections**
   (a) Limitations of modern science to adequately understand the negative effects of GMOs
   (b) Unnatural to mix genes across species, tampering with nature, not respecting natural organisms' intrinsic values
   (c) Concerns about welfare of GM animals
   (d) GM food labelling is not mandatory in some countries. Consumers might be unaware that they are purchasing and consuming GM products.
   (e) GM food might not have been adequately tested
   (f) Further GM developments might be skewed towards private interests and profit instead of the public welfare

TOPIC 15 Inheritance

Objectives

Candidates 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 dominant, recessive, codominant, homozygous, heterozygous, phenotype and genotype
(c) predict the results of simple crosses with expected ratios of 3:1 and 1:1, using the terms homozygous, heterozygous, F_1 generation and F_2 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) state that variation and competition lead to differential survival of, and reproduction by, those organisms best fitted to the environment
(l) give examples of environmental factors that act as forces of natural selection
(m) explain the role of natural selection as a possible mechanism for evolution
(n) give examples of artificial selection such as in the production of economically important plants and animals

15.1 Mendelian genetics

1. Hereditary traits are characteristics that can be passed from one generation to the next.

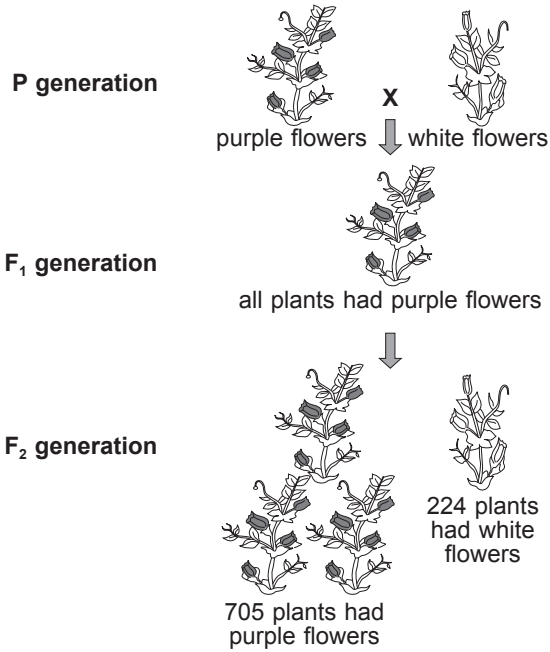
2. The study of genetics is named after an Austrian monk, Gregor Mendel, who studies heredity in garden pea plants (*Pisum sativum*).

3. Mendel focused on characteristics of pea plants that have an 'either-or' behaviour. For example, the flowers of pea plants are either purple or white, with no intermediates.

4. He started his experiments with **true-breeding** plants. When true-breeding plants self-pollinate, all their offspring are of the same type. True-breeding tall plants will produce tall offspring when self-pollinated.

15.2 Mendel's monohybrid crosses

1. A monohybrid cross begins with:
   (a) Cross-pollination between true-breeding parents (**P generation**)
   (b) P generation produces hybrid offspring (offspring from 2 different varieties), called the **F_1 generation**.
   (c) F_1 hybrids self-pollinate to produce another set of offspring, called the **F_2 generation**.
2. One of Mendel's monohybrid crosses:
   (a) P generation consisted of true-breeding plants producing either purple or white flowers.
   (b) F_1 generation consisted of all purple-flowered plants.
   (c) Self-pollination in the F_1 generation produced an F_2 generation where the ratio of purple-flowered to white-flowered plants is 3 : 1.



3. Important observations:
   (a) F_1 generation **did not possess intermediate traits** between the two parents i.e. flowers produced by F_1 generation were all as purple as flowers produced by the P generation purple-flowered plant, instead of being pale purple – an intermediate between the purple-flowered parent and white-flowered parent.
   (b) Self-pollination in F_1 generation produced offspring (F_2 generation) in which the **white-flowered trait** (not expressed in the F_1 generation) **resurfaced**.

4. Mendel's deductions:

   (a) The heritable factor for white flowers did not disappear in the F_1 generation since it was able to resurface in the F_2 generation.

   (b) Only the purple-flower factor affected flower colour in the F_1 generation. He called the purple-flower trait **dominant** and the white-flower trait **recessive**.

15.3 Mendel's model of heredity

1. Hereditary factors are responsible for transmission of characteristics from one generation to the next. These factors are now called genes.
2. Each characteristic is controlled by a pair of **alleles** (different forms of the same gene) in an organism. For example, flower colour in pea plants is controlled by an allele for purple flowers and an allele for white flowers. In other words, the gene for flower colour has two alleles: purple and white.
3. Each organism inherits one allele from the mother and one allele from the father during sexual reproduction. Each body cell of an organism contains two alleles for each trait.
4. If an organism has two different alleles, then the **dominant allele** will show its effect while the **recessive allele** will have no effect on the organism's appearance.
5. The two alleles will **segregate** during gamete formation. Each gamete will only contain one allele out of the two that are present in the body cells of an organism.

15.4 Glossary of terms involved in genetics

1. **Chromosome** – A chromosome is an organised structure of deoxyribonucleic acid (DNA) and protein that is found in the nuclei of cells. DNA contains genetic information used in the development and functioning of all organisms.
2. **Gene** – A gene is a DNA segment located in a chromosome, which codes for a single unit of inheritance. The place on the chromosome where the gene is located is called the gene locus.
3. **Allele** – Alleles are different versions of the same gene. They are located on the same gene locus in homologous chromosomes.
4. **Phenotype** – An observable characteristic of an organism. It can be physical (appearance), behavioural or physiological. It depends on the genotype of the organism.
5. **Genotype** – The genetic make-up of an organism. The genotype of an organism cannot be easily predicted from the phenotype (appearance) because of the existence of dominant and recessive alleles.

6. **Homozygous** – Each organism inherits two alleles for a given characteristic, one from the mother and one from the father. An organism is said to be homozygous for a given trait when it contains two identical alleles for that trait.
7. **Heterozygous** – An organism is said to be heterozygous for a given trait when it contains two different alleles for the characteristic.
8. **Dominant allele** – A dominant allele is the allele that is fully expressed in the phenotype under both homozygous and heterozygous conditions.
9. **Recessive allele** – A recessive allele is the allele that is only expressed in the phenotype under the homozygous condition. It is masked in the phenotype under heterozygous conditions.

15.5 Explaining Mendelian ratios

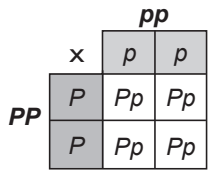
Dihybrid cross:

Let *P* represent the dominant allele for purple flowers, and *p*, the recessive allele for white flowers.

P generation phenotype: Purple-flowered × White-flowered

P generation genotype: *PP* × *pp*

Gametes: *P* *P* *p* *p*

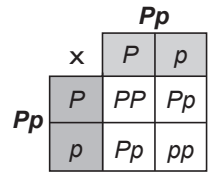


F_1 generation genotype: *Pp* *Pp* × *Pp* *Pp*

(self-pollinated)

F_1 generation phenotype: **All purple-flowered**

Gametes: *P* *p* *P* *p*



F_2 generation genotype: *PP* *Pp* *Pp* *pp*

F_2 generation phenotype: Purple-flowered, Purple-flowered, Purple-flowered, White-flowered

F_2 generation phenotype ratio: **3 purple-flowered : 1 white-flowered**

1. A homozygous dominant plant (*PP*) will only produce gametes containing a single copy of the *P* allele.
2. A homozygous recessive plant (*pp*) will only produce gametes containing a single copy of the *p* allele.

3. When cross-pollination occurs between the two plants, the gametes will combine during fertilisation to produce heterozygous (*Pp*) hybrids.
4. Heterozygous (*Pp*) plants will produce gametes containing either the *P* or the *p* allele in a 1 : 1 ratio.
5. Crossing the F_1 generation will result in a 25% chance of a homozygous dominant offspring, a 50% chance of heterozygous offspring and a 25% chance of a homozygous recessive offspring.
6. When there is a large amount of offspring produced, the observed phenotypic ratio will be approximately 3 : 1.

15.6 Deducing genotype

1. A test cross is used to determine if an individual exhibiting a dominant trait is homozygous or heterozygous for the trait.
2. It is accomplished by crossing the organism with an organism that is homozygous recessive.
3. **Test cross**:

P generation phenotype: Purple-flowered × White-flowered

P generation genotype: *PP* × *pp*

Gametes: *P* *P* *p* *p*

F_1 generation genotype: *Pp* *Pp* *Pp* *Pp*

		pp	
	×	*p*	*p*
PP	*P*	*Pp*	*Pp*
	P	*Pp*	*Pp*

F_1 generation phenotype: **All purple-flowered**

P generation phenotype: Purple-flowered × White-flowered

P generation genotype: *Pp* × *pp*

Gametes: *P* *p* *p* *p*

F_1 generation genotype: *Pp* *Pp* *pp* *pp*

		pp	
	×	*p*	*p*
Pp	*P*	*Pp*	*Pp*
	p	*pp*	*pp*

F_1 generation phenotype ratio: **1 purple-flowered : 1 white-flowered**

4. A *PP* x *pp* cross produces only *Pp* offspring. Hence, if all the offspring have purple flowers, then the unknown parent must be homozygous dominant for the trait.

5. A *Pp* x *pp* cross produces a 1 : 1 phenotypic ratio. Hence if both purple and white phenotypes appear among the offspring, then the unknown parent must be heterozygous for the trait.

15.7 Dominance

1. **Complete dominance** is when the heterozygote has the same phenotype as the dominant homozygote. The recessive allele present in the heterozygote is masked by the dominant allele.

2. **Co-dominance** is when both alleles contribute equally to the phenotype.

3. An example would be the ABO blood typing system in humans. Human blood groups are determined by 3 alleles for 1 gene: I^A, I^B and I^O.

4. I^O is recessive to both I^A and I^B, while I^A and I^B are codominant when paired together.

5. The various combinations of the alleles and the resultant phenotypes are shown in the table below:

Phenotype (Blood group)	Genotypes
O	I^OI^O
A	I^AI^A or I^AI^O
B	I^BI^B or I^BI^O
AB	I^AI^B

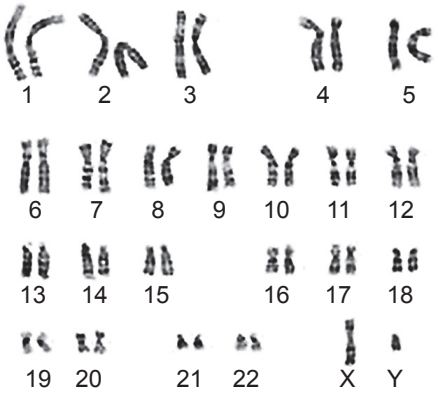
6. The gene for blood group codes for a protein present on the surface of red blood cells, called an antigen. The allele I^A codes for antigen A, I^B codes for antigen B, and no antigen is expressed for allele I^O.

7. For I^AI^B genotype, both antigen A and antigen B are expressed since each of the alleles produces its own antigen. Both alleles contribute to the phenotype, which is blood group AB.

8. The gene for human blood groups is said to have multiple alleles since it exists in more than two alleles.

15.8 Sex determination

1. A karyotype is a picture of a set of chromosomes in a cell. During the preparation of a karyotype, chromosomes are stained and examined under a microscope. A picture is taken and edited to arrange the chromosomes by size.
2. A normal karyotype will show 22 pairs of homologous chromosomes called autosomes, and 1 pair of sex chromosomes.



Human male karyotype

3. It can be used to detect extra or missing pieces of chromosomes that could lead to several congenital conditions.
4. In humans, sex is determined by sex chromosomes. Human sex chromosomes are the X chromosome and the Y chromosome.
5. From the karyotype, it can be seen that the X chromosome is much larger than the Y chromosome.
6. Human males have one X chromosome and one Y chromosome. They have the XY genotype.
7. Human females have two X chromosomes. They have the XX genotype.
8. Genetic diagram for sex determination:

Parents' phenotype	Male		Female
Parents' genotype	XY	x	XX
Gametes	X Y		X X
Offspring genotype	XX XX		XY XY
Offspring phenotype ratio	**1 female : 1 male**		

		XX	
	x	X	X
XY	X	XX	XX
	Y	XY	XY

15.9 Mutation

1. Mutation is a change in gene or chromosomal structure. Mutations that occur in gamete DNA can be passed down to the next generation.
2. Mutations that occur in normal body cells (somatic mutations) are not passed on to the next generation. However, they are responsible for certain types of cancer.
3. Spontaneous mutations can arise during the replication or repair of DNA. The DNA-replication mechanism in our cells normally has high fidelity, but occasional errors might occur.
4. Mutations can also be caused by exposure to mutagens. Mutagens are physical or chemical agents that increase the rate of mutation. Examples of mutagens are ultraviolet radiation, X-rays, radioactive particles such as gamma rays, certain chemicals such as benzene, ethidium bromide and nitrous acid.
5. Gene mutation increases the amount of genetic variation in the gene pool as it introduces new alleles. Some mutations can be favourable.

15.10 Gene mutation

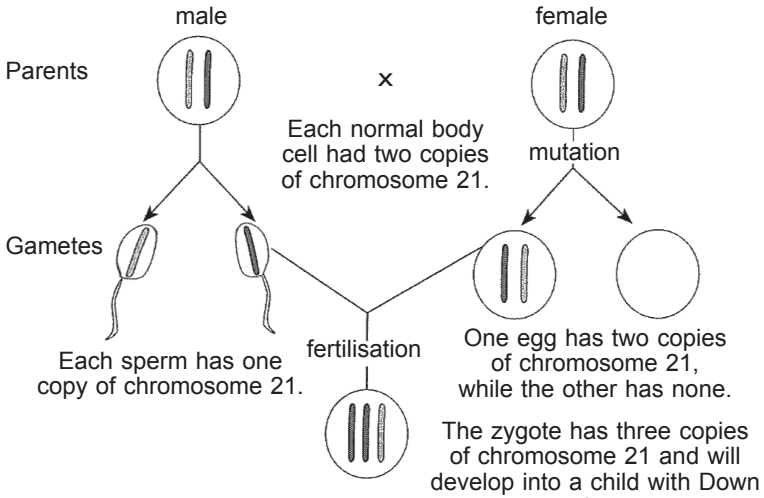
1. An example of a disease caused by gene mutation would be **sickle-cell anaemia**.
2. Sickle-cell anaemia is a blood disorder where red blood cells possess a rigid, sickle shape when oxygen concentration in the blood is low.
3. Normal red blood cells are flexible and can change their shape in order to pass through capillaries. Sickle-shaped red blood cells are not able to do so, blocking up arteries and failing to deliver blood to certain tissues, causing tissue damage.
4. Sickle-cell disease is caused by a mutation in the gene for haemoglobin production. It causes a single amino acid in the normal haemoglobin chain to be replaced by another amino acid. This causes a change in the 3-dimensional shape of the haemoglobin molecule. Hb^S molecules clump together under low oxygen concentration, causing red blood cells to become sickle-shaped.

15.11 Chromosome mutation

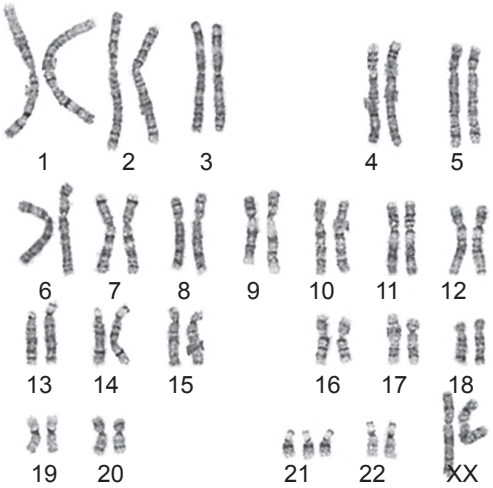
1. **Down syndrome** (trisomy 21) is a condition caused by a chromosome mutation during meiosis (gamete production). It results in mental retardation, and heart and respiratory defects.
2. The zygote inherits 3 copies of chromosome 21 instead of 2, and this mutation is present in all body cells due to mitosis during zygote development. Each body cell of the afflicted individual contains 47 chromosomes instead of the usual 46.
3. This chromosome mutation is far more likely to occur during ovum production than during sperm production.

4. Women above 30 have a higher risk of carrying babies with Down syndrome. Fetal testing is recommended for older mothers to check for Down syndrome in the embryo.

5. The genetic diagram below shows how a zygote with Down syndrome could have been produced.



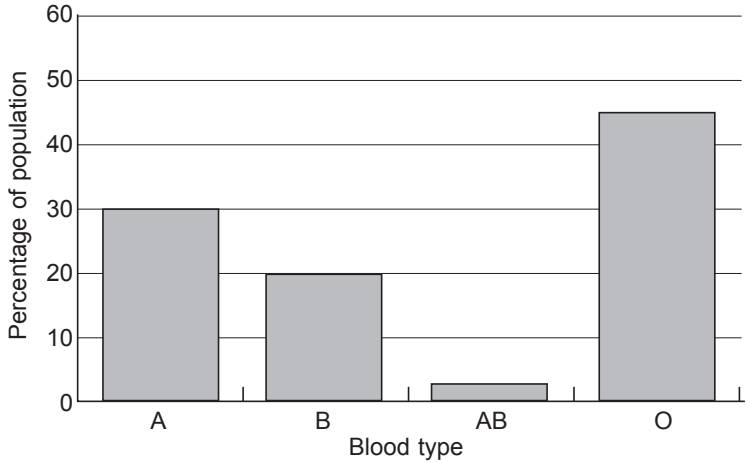
Down syndrome



Karyotype from a female with Down syndrome

15.12 Variation

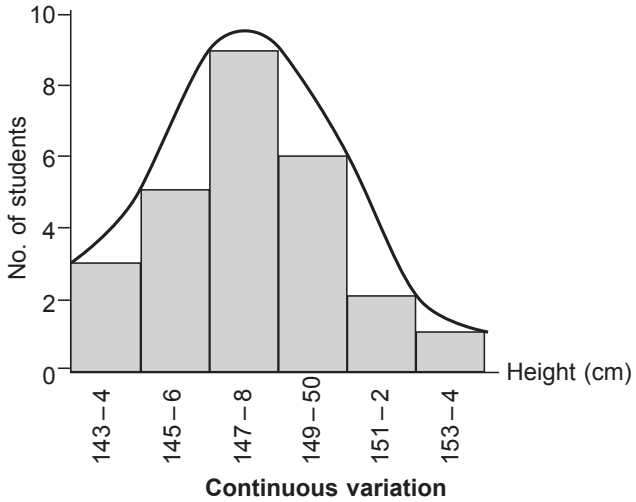
1. Genetic variations are differences in phenotypes between individuals of the same species.
2. In discontinuous variation of a characteristic, individuals possess distinct and separate phenotypes with no intermediates ('either-or' characteristics).
3. Examples of **discontinuous variation** are the flower colour in pea plants (either purple or white), ABO blood types.



Discontinuous variation

4. Discontinuous variation is controlled by alleles of a single gene or a small number of genes and is seldom affected by the environment.
5. In **continuous variation** of a characteristic, an unbroken range of phenotypes exist in the population.

6. Examples include height, skin colour, intelligence and weight, in which many intermediate phenotypes exist.



Continuous variation

7. Intermediate phenotypes are usually more common than extreme phenotypes (i.e. very tall or very short, very dark skin or very pale skin, etc), and when plotted on a graph, a bell-shaped curve is obtained.

8. Continuous variation is caused by the effect of many genes and is often affected by environmental factors.

15.13 Natural selection

1. New alleles arise in a population due to mutation. Independent assortment and crossing over of chromosomes during meiosis, and random fertilisation of gametes give rise to even more variation within the population.

2. Variation in genes results in a wide range of phenotypes in a population. These organisms compete against one another for survival.

3. However, the different varieties of organisms do not have the same chances of survival and reproduction. Some organisms possess more favourable phenotypes, and are better-suited for their environment. These organisms survive better, and reproduce, passing on their favourable traits to their offspring.

4. We say that these favourable traits are 'selected for', because they are present in a higher frequency in the next generation.

5. The differential survival of, and reproduction by organisms best fitted to the environment is known as **natural selection**.

6. **Evolution** is the change in genetic material of a population from one generation to the next. Over time, it can produce major changes in a population that could give rise to a new species.

7. Natural selection is a major mechanism by which evolution takes place because it causes helpful genes to become more common and deleterious genes to become rarer.
8. Environmental factors that act as forces of natural selection could include:
   (a) Disease – Disease-resistant phenotypes would be selected (i.e. sickle-cell trait against malaria).
   (b) Prey – Characteristics conducive to obtaining more food are selected for (e.g. Galapagos finches evolving beaks adapted to particular diets).
   (c) Predators – Methods for evading predators are selected for, such as protective colouration to provide camouflage e.g. in the peppered moth, poison glands (discourage predation), longer legs for faster running (to escape from predators), herd behaviour (animals try to get to the centre of the herd when escaping from predators because it provides protection)
   (d) Mating – Features that are more attractive to females of the same species are selected for (e.g. peacock tail, throat pouches in frigatebirds), as it increases the likelihood of finding a mate and hence reproducing.

15.14 Artificial selection

1. Artificial selection, also known as selective breeding, is the intentional breeding for particular genetic traits.
2. It is used to produce several economically important crops and animals.
3. Traits such as disease-resistance or high quality and yield of crop, tolerance to environmental pressures such as pH, salinity, drought, temperature, tolerance to insects, and tolerance to herbicides are selected for by plant breeders.
4. In animals, traits such as fast-growing, muscular, reproductively-efficient (fertile), good fat marbling (in cattle bred for meat), good milk production (in cows), and good egg production (chickens) are selected.

TOPIC 16 Organisms and their Environment

Objectives

Candidates should be able to:

(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 and biomass
(e) describe how carbon is cycled within an ecosystem and outline the role of forests and oceans as carbon sinks
(f) 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

(g) outline the roles of microorganisms in sewage treatment as an example of environmental biotechnology
(h) discuss reasons for conservation of species with reference to the maintenance of biodiversity and how this is done, e.g. management of fisheries and management of timber production

16.1 Ecology

1. Ecology is the study of the interactions between organisms and the interactions of these organisms with their environment.

2. Terms related to ecology:

   (a) **Habitat** – The place where an organism lives

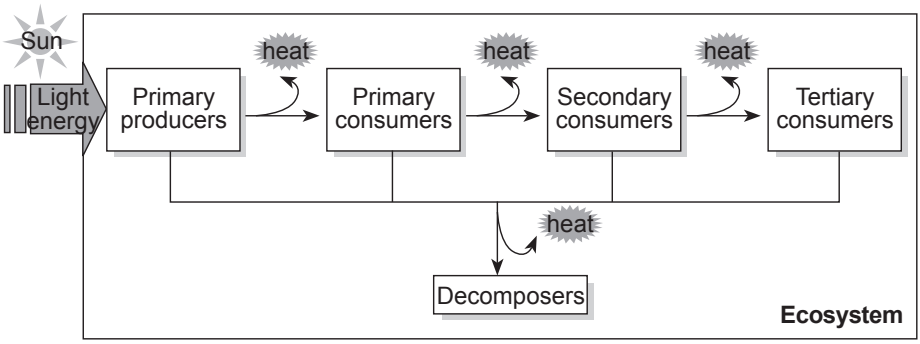
   (b) **Population** – A group of individuals of one species that live in a particular habitat

   (c) **Community** – All the organisms that live in a particular habitat. It consists of populations of organisms that live close enough to interact with one another.

   (d) **Ecosystem** – Consists of a community and its physical environment. Physical factors in the environment that the community interacts with include pH, temperature, light intensity, water and nutrient availability, oxygen / carbon dioxide availability and salinity.

16.2 Energy transfer in an ecosystem

1. A **food chain** is a sequence of energy transfer in the form of food, between organisms in an ecosystem.
2. Each level of the food chain is known as a **trophic level**.
3. **Primary producers** are photosynthetic organisms (autotrophs) that are able to convert light energy from the Sun to chemical energy that can be transferred from one organism to another within the ecosystem. They can also convert inorganic nutrients in the soil to organic nutrients that can be transferred up the food chain.
4. Consumers obtain their energy by consuming other organisms. They occupy a few trophic levels:
   (a) **Primary consumers** feed on primary producers directly. They are herbivores.
   (b) **Secondary consumers** are carnivores that eat herbivores.
   (c) **Tertiary consumers** are carnivores that eat other carnivores.
5. Food chains can be combined to form food webs since some food chains are interconnected.
6. In reality, energy flow in an ecosystem is not so direct. There are many different types of consumers that feed at different trophic levels. For example, parasites and scavengers feed on producers and consumers at every level. Decomposers (bacteria and fungi) obtain their energy from non-living organic material such as faeces, fallen leaves and dead organisms. During decomposition, nutrients from these dead organic matter are released into the soil for plants to use.
7. The flow of energy through an ecosystem:



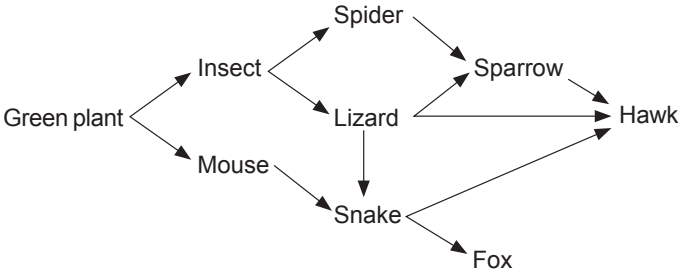
Flow of energy through an ecosystem

8. Energy enters the ecosystem from the outside. Light energy from the Sun gets converted to chemical energy in producers during photosynthesis. Some of the energy is lost as heat during respiration and other metabolic processes. The rest gets converted into organic matter called **biomass**.

9. The energy moves up the trophic levels as producers get consumed by primary consumers, primary consumers get consumed by secondary consumers etc.
10. Energy is lost at every trophic level as heat in respiration, uneaten organism parts and through waste material. Organisms at each trophic level pass on much less energy to the next trophic level than they receive.
11. Food chains seldom have more than 5 trophic levels as less energy is available at the higher trophic levels.
12. Eventually, all energy supplied to the ecosystem is lost as heat. Energy has to be constantly supplied to the ecosystem from the Sun as heat cannot be recycled into useful forms of energy.
13. Example of a simple food chain:

Grass ⟶ Grasshopper ⟶ Frog ⟶ Snake

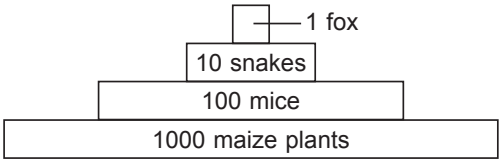
14. Example of a simple food web:



A simple food web

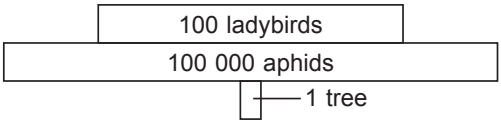
16.3 Pyramids of numbers and biomass

1. A pyramid of numbers shows the population of each trophic level in a food chain. The pyramid of numbers shown below means that at any one time in a given area, there are 1000 maize plants, 100 mice, 10 snakes and 1 fox. The size of each block in the pyramid is proportional to the number of organisms present in that level.

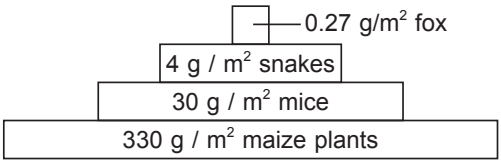


2. The pyramid of numbers can sometimes be inverted.

3. A pyramid of numbers is not an accurate estimate of the amount of energy at each trophic level because the population number does not always correspond to the amount of energy it can transfer to the next trophic level, e.g. a single tree can support a large population of aphids.

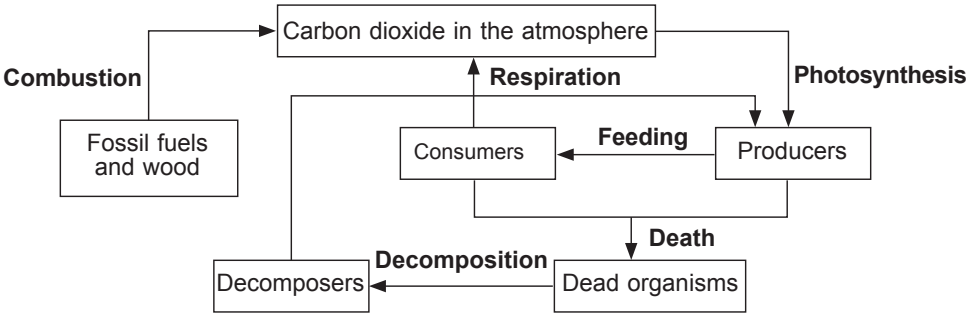


4. A pyramid of biomass shows the dry mass of organisms at each trophic level in a food chain.
5. To calculate biomass, e.g. of 1000 maize plants:
   (a) Dry 20 maize plants in an oven.
   (b) Obtain the average mass of 1 dried maize plant.
   (c) Multiply the average mass by the total number of maize plants in the given area.
6. A typical unit for a biomass pyramid is grams per square metre (g / m^2).



7. In the examples encountered in this chapter, the pyramid of biomass is upright.

16.4 Carbon cycle



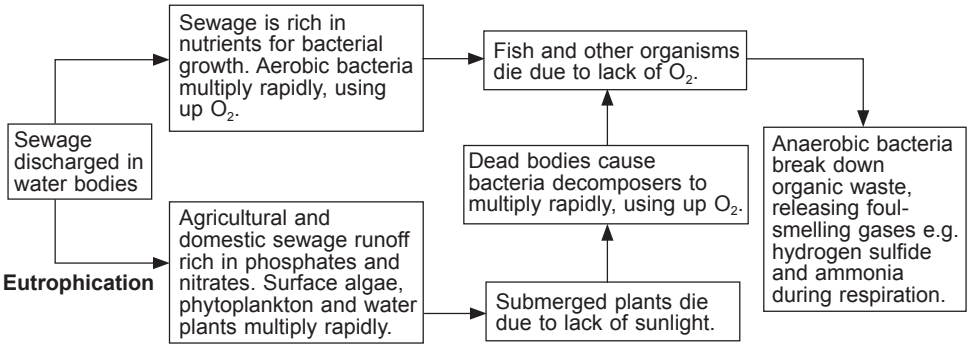
The carbon cycle

1. Green plants convert atmospheric carbon dioxide into glucose during photosynthesis. Within green plants, glucose can be converted to other organic molecules.

2. These carbon compounds are transferred to consumers through the process of feeding.
3. Carbon dioxide is returned to the atmosphere when cellular respiration takes place in living organisms.
4. When the green plants and animals die, decomposers break their organic matter down into carbon dioxide and other simple substances.
5. Fossil fuels are formed from the fossilised remains of dead plants and animals. Carbon compounds from these dead organisms are stored as fossil fuels.
6. When fossil fuels and wood are burnt, carbon dioxide is produced.

16.5 Water pollution

1. Pollution is the contamination of the environment causing harm and damage to the ecosystem. It is usually the result of human activities.
2. Water pollution occurs when pollutants are discharged directly into water without undergoing treatment. A common water pollutant is sewage.
3. Sewage is waste matter from industries and homes. It consists mainly of organic wastes such as detergents, oils and fats, insecticides and herbicides, and debris.
4. Inorganic substances from industrial waste include: leached nutrients and fertilisers (nitrates and phosphates) from farmland, ammonia, sulfur dioxide from power plants, and heavy metals.
5. Some of these pollutants can be directly toxic to the living organisms in the water, causing them to die. Others are carcinogenic and can harm humans who get in contact with the contaminated water.
6. Contaminated water usually encourages growth of microorganisms such as bacteria, parasites (certain protozoa and worms) and viruses. These could lead to diseases such as gastroenteritis, cholera, typhoid and parasitic infection.
7. Other possible outcomes:



Water pollution and eutrophication

16.6 Sewage treatment

1. Environmental biotechnology is when biotechnology is used to treat polluted environments or in environment-friendly processes such as green manufacturing technologies. Sewage treatment is an example of environmental biotechnology.
2. In sewage treatment plants, sewage is drained into settling tanks and sedimentation tanks to allow some of the solid waste to settle and be removed.
3. The sewage then enters the aeration tank, where pure oxygen is bubbled in and bacteria added. The bacteria oxidise carbon compounds to carbon dioxide, oxidise ammonium and nitrogen compounds to nitrates and eventually nitrogen gas, and remove phosphates.
4. The liquid from the aeration tank is then filtered and the solid contents are allowed to settle. Sewage water containing low levels of organic material and suspended matter remains. The sewage water is disinfected to reduce the number of microorganisms in the water before it is discharged back into the environment.
5. The solid matter left behind from the sewage treatment process is known as sludge.
6. Sludge undergoes a process of bacterial digestion to reduce the amount of organic matter and the number of disease-causing microorganisms present.

16.7 Biomagnification

1. **Biological magnification** or bioamplification is the increase in concentration of a substance up a food chain. Successive trophic levels contain high concentrations of the substance.
2. Substances that tend to accumulate up a food chain share one or more of the following characteristics:
   (a) Non-biodegradable or slow biodegradation, so it persists in the environment and can be transported by water to other areas
   (b) Cannot be broken down (detoxified) within organisms
   (c) Cannot be excreted by organisms (insoluble in water)
3. Examples of substances that biomagnify are mercury, arsenic and DDT (dichlorodiphenyltrichloroethane). DDT is a synthetic pesticide used to control mosquitoes. These chemicals are toxic, especially at high concentrations.
4. Each trophic level has to consume a larger biomass than it possesses, from the previous trophic level due to energy loss at every level. Thus, although the toxin present in the lower trophic levels might be small, larger amounts of toxins will accumulate in the higher trophic levels since each top level consumer feeds on a large amount of organisms from the trophic level below it.

5. Case study: DDT

   (a) DDT is non-biodegradable and is transported by water to far-reaching areas.

   (b) It is insoluble in water and cannot be excreted in urine which is water-based.

   (c) It is soluble in lipids and accumulates within the fatty tissues of animals. This process is called **bioaccumulation**, which is the increase in concentration of a substance due to absorption from food and the environment, in the tissues of organisms' bodies.

   (d) The concentration of DDT increases at the higher trophic levels due to **biomagnification**.

   (e) Environmental impact of DDT: DDT is toxic to aquatic life and insects. It is less toxic to mammals but causes eggshell thinning in birds. The eggs are more vulnerable to breakage during incubation, causing a drastic decline in bird reproduction rates. Birds at the top of food chains such as pelicans, ospreys and eagles are particularly affected.

   Note: Biomagnification and bioaccumulation are words that are commonly used interchangeably. However they do not have the same meaning. Bioaccumulation occurs within an organism (within a trophic level) while biomagnification occurs in a food chain (across trophic levels).

16.8 Conservation

1. Conservation is the act of protecting species, their habitats and entire ecosystems from extinction.
2. Conservation covers a wide range of activities. For example, reducing pollution and combating deforestation, preventing global warming, natural resource management and wildlife protection comes under conservation as well.

16.9 Reasons for conservation

1. Ecological value:

   (a) Organisms are interdependent.

      (i) Population fluctuations due to disruption in food chains.

      (ii) Disruption of natural cycles i.e. carbon cycle, water cycle etc.

      (iii) Existence of an organism could be directly dependent on the existence of another. Symbiotic organisms require their host species in order to survive.

   (b) Maintenance of the gene pool when there is a large population decrease in a species, there may be an increase in the chance of inbreeding which gives rise to offspring that are less adapted to environmental changes.

2. Economic value:

   (a) Maintain biodiversity

      (i) Plants have great medicinal value. Many drugs were derived from plants such as aspirin.

      (ii) Animals and plants are both a great source of genetic diversity for plant and animal breeding programs.

   (b) Resource management: It is important to manage natural resources such as timber and food sources so that it does not get depleted and we can continue exploiting it profitably.

   (c) Ecotourism: It is a source of income for several countries such as Costa Rica, Madagascar, and Kenya.

3. Educational value:

   (a) Conservation preserves the existence of species for future generations to study.

   (b) Chemicals extracted from plants or animals might be applicable to scientific research in future.

4. Aesthetic value: Conservation preserves natural scenery and wildlife for people to appreciate.

16.10 Conservation in fisheries

1. A fishery is an area with a particular species of fish or aquatic life that is harvested for its commercial value.

2. Wild fisheries are located in the oceans, lakes and rivers, where fish has to be captured or fished. They are prone to overfishing and pollution, which could lead to an imbalance in the ecosystem.

3. Farmed fisheries involve raising fish commercially in tanks. It helps to supply some of the demand for food fish but a great majority of food fish are still obtained from wild fisheries.

4. In order to develop sustainable fisheries so that fish stock is maintained for future fishing, certain measures have been taken:

   (a) Many countries have set up ministries or government organisations regulating fishing. These organisations help to control the activities in fisheries by:

      (i) Imposing taxes on fishing output

      (ii) Vessel licensing, regulating the entry of ships into fishing grounds

      (iii) Restrictions on catching techniques such as the prohibition of bottom trawling and dynamite fishing, regulation of fish traps etc.

      (iv) Imposing a catch quota

      (v) Limiting the period of fishing

(b) Breeding of endangered fish in captivity by private conservation organisations or zoos to be released back into the wild to replenish depleted stock.

16.11 Conservation of forests

1. The forests are the major source of the world's timber. The clearing of forests for timber and land is called deforestation.
2. The indiscriminate logging without sufficient reforestation has led to many environmental and ecological problems such as:
   (a) The 'slash and burn' practice used to clear forests for agriculture releases a large amount of carbon dioxide which contributes to global warming.
   (b) Changes in the water cycle resulting in a drier climate. Trees contribute to humidity by transpiration and extract groundwater through their roots to be released into the atmosphere. The loss of this causes climate changes that could lead to desertification.
   (c) Soil erosion as tree roots are needed to bind soil together.
   (d) Loss of habitat for many organisms resulting in loss of biodiversity.
3. Forest conservation includes legislation protecting forests from indiscriminate logging such as:
   (a) Regulating the rate of logging
   (b) Selective logging where young trees are not cut down
   (c) Designating land as forest reserves
4. Other conservation practices include reforestation, which is the act of restocking forests which have been depleted. New seedlings are planted to replace trees that have been felled.

O Level Biology Topical Revision Notes is a comprehensive guide based on the latest syllabus. It is written to provide candidates sitting for the O Level Biology examination with thorough revision material. Important concepts are presented in simple and concise points for easier reference. Relevant examples and diagrams are incorporated into the notes to facilitate the understanding of important concepts.

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