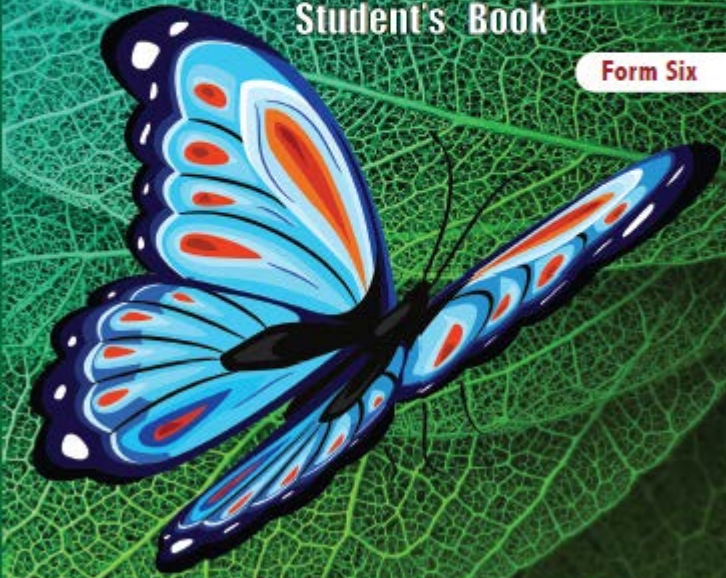
Biology

for Advanced Level Secondary Schools

Student's Book

Form Six



Tanzania Institute of Education

Biology

for Advanced Level Secondary Schools
Student's Book

Form Six

THE UNITED REPUBLIC OF TANZANIA
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Preface

This book, *Biology for Advanced Level Secondary Schools,* is written specifically for Form Six Biology Students in the United Republic of Tanzania. The book is prepared according to the 2009 Biology Syllabus for Advanced Level Secondary Education, Form V-VI, issued by the Ministry of Education and Vocational Training.

The book is divided into six chapters, which are: Transportation in living organisms, Growth and development, Reproduction, Genetics, Evolution, and Ecology. In addition to the content, each chapter contains activities, illustrations, exercises, and revision questions. Learners are encouraged to do all activities and answer all questions so as to enhance their understanding and promote the acquisition of the intended skills, knowledge, and attitudes.

Tanzania Institute of Education

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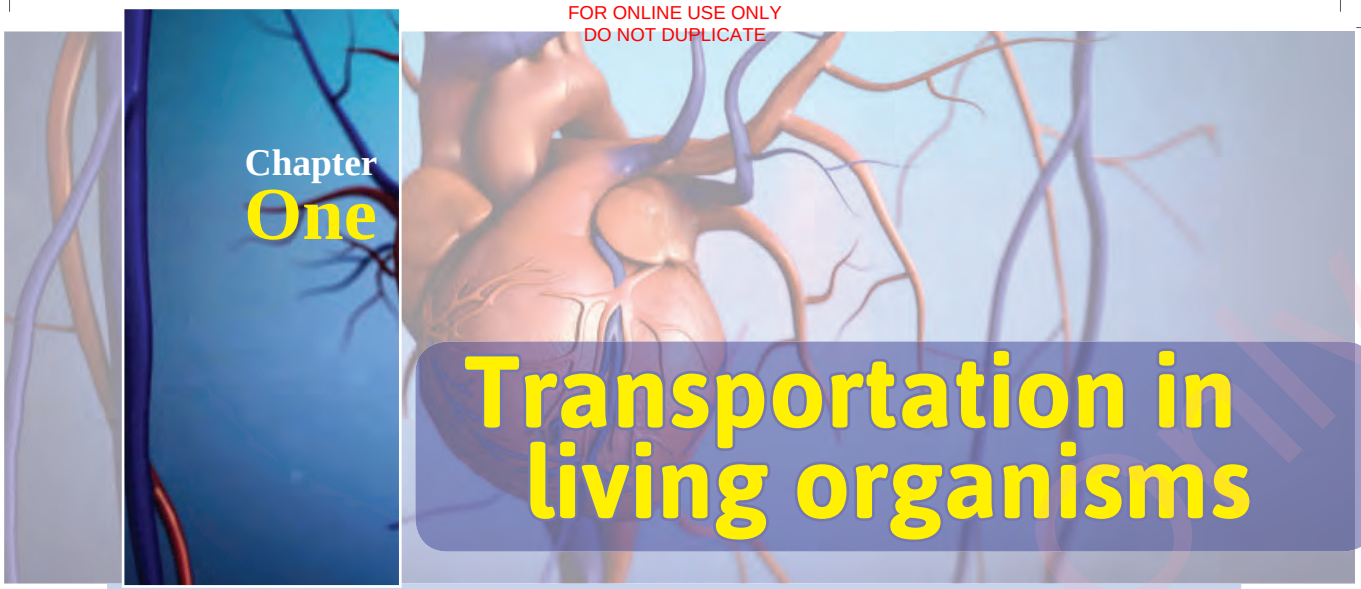


Chapter
One

Transportation in living organisms

Introduction

Every living organism constantly needs the exchange of substances such as nutrients, waste products, and respiratory gases with the environment in order to survive and grow. In this chapter, you will learn about transportation in plants, types of vascular tissues in plants, and movement of materials across the roots. While learning about transportation in plants, you will do several activities, including demonstration of the movement of water and sap in plants. You will also learn about transportation in animals, particularly components of vertebrate circulatory systems, the blood, mechanism of blood clotting, structure of the heart, the cardiac cycle, and the foetal circulatory system.

Transportation in plants

Plants absorb water and minerals through their roots and transport them to the leaves for metabolic use such as photosynthesis. Transportation in plants mainly occurs through a vascular system, which is made up of different types of tissues. These vascular tissues are structurally different and have various adaptations to suit their roles. The transportation of materials in plants from soil to the leaves and that of photosynthetic products from leaves to various parts can be either passive or active.

Types of vascular tissues in plants

Plants have tissues which transport food, water, and dissolved mineral salts from one part to another. There are two types of vascular tissues in plants, namely: xylem and phloem, which together form the vascular system as shown in Figure 1.1. Between phloem and xylem, there is a layer called cambium whose function is to divide and to form new xylem and phloem cells.

The vascular system is made up of complex tissues, which have different types of cells that work together to achieve the essential function of transporting materials in plants. The vascular tissues also provide mechanical support to the plant. Xylem transports water and dissolved mineral salts from the soil to the upper part of a plant while phloem is involved in the transportation of photosynthetic products from the leaves to other parts of the plant such as stems, leaves, fruits, and roots.

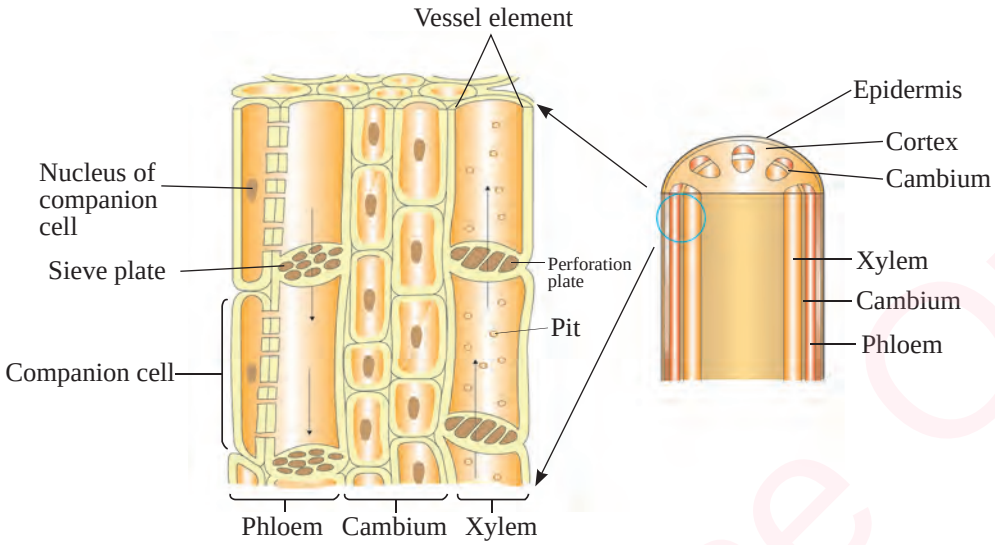


Figure 1.1 Longitudinal section of vascular tissues in plants

Activity 1.1 Identification of vascular tissues and their arrangement in the stem and root of monocots and dicots

Materials: Sharp razor blade, dropper, microscopic slides, coverslips, light microscope, young maize, and bean plants of 2-3 weeks old, watch glass, petri dish, white tiles, and safranin stain.

Procedure

(i) Collect samples of young maize and bean plants. Make sure you uproot the whole plant with its roots intact.

(ii) Cut through a transverse section a thin layer of a young stem of a maize plant. Mount it on a microscopic slide. Stain it with safranin and cover it with coverslip.

(iii) Place the mounted slide under the light microscope and start to observe using a low magnifying lens. Then, you can increase magnification accordingly.

(iv) Observe the distribution and arrangement of vascular tissues, which are arranged in bundles in the young stem of a maize plant. Draw a well-labelled diagram to represent what you have observed.

(v) Repeat steps (ii) to (iv) for the young root of a maize plant as well as the young stem and root of a bean plant.

Results: In a transverse section of a young dicot stem or root, the vascular bundles are arranged in a ring. In a young monocot stem and root, the vascular bundles are scattered.

The xylem tissue

This forms a continuous system of columns stretching from roots to the leaves. It has two major functions, which are mechanical support and conduction of water and mineral salts. It is composed of four types of cells, namely: tracheids, xylem fibres, vessel elements, and xylem parenchyma cells as shown in Figure 1.2.

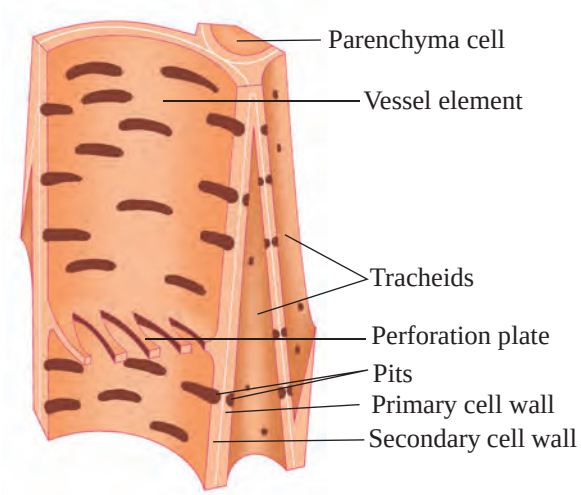


Figure 1.2 The structure of xylem

Structural components of xylem and their functions

As shown in figure 1.2, one of the structural components of the xylem tissue is the tracheids. These are made up of secondary cellulose cell wall thickened with lignin and consist of single elongated cells with pointed ends. Their walls contain numerous pits but have no perforations in the primary cell wall. They lack living protoplasm at maturity and their tubular shape at maturity allows vertical transportation of water and mineral salts. The vertical upward movement of substances in the xylem is by conduction. The lignin helps in strengthening the cell walls to make them rigid.

The xylem fibres are shorter and narrower than tracheids and have much thicker and overlapping end walls. These overlapping end walls have pits but they do not conduct water. They are stronger and provide additional mechanical strength to the xylem tissue.

Like tracheids, vessel elements are tubular xylem structures which allow vertical transportation of water and mineral salts (upward the plant). Each vessel has a typical length of 10 cm. The walls are made up of cellulose and lignin, which provide structural support to the vessel elements. They are connected together into long tubes which enables easier transportation of water and mineral salts. They possess perforation plates in their end walls which are not found in tracheids. These perforations help to adjoin other vessel elements. Furthermore, the vessel elements have no cytoplasm and nuclei at maturity. These features enable them to transport large volumes of water and mineral salts. Like tracheids, the vessel elements have pits on their lateral walls.

However, vessel cells are continuous through their perforation plates, while tracheids are discontinuous in their arrangement. The xylem parenchyma is present in both primary and secondary xylem. It has a cellulose cell wall and a living protoplasm. Its function is to store food and conduct water sideways. In some cases, the xylem parenchyma cells serve as storage devices for starch.

There are pieces of evidence to show that the xylem tissue transports water and mineral salts in plants. Such evidences are supported by the following explanations.

(a) If a leafy shoot is cut and placed in water containing a dye such as red eosin, it takes up the dye. When the shoot is removed from the dye and cut at various heights, only the xylem tissue is stained red indicating that it transports water.

(b) The removal of a ring of tissues outside a woody stem does not affect the flow of water. This is because only the bark, including the phloem is removed. However, if the outer layers of the woody part (xylem) are removed, upward transport of water stops and the leaves wilt.

(c) Metabolic poisons, such as cyanide, do not impede water flow through the xylem. This proves that transportation of water is a passive process and takes place in the dead cells of vessel elements and tracheids.

(d) If the lumen of the vessel element and tracheid cells are artificially blocked by fats, the uptake and transportation of water cease and the plant wilts.

Activity 1.2 Demonstration of the movement of water through xylem tissue

Materials: Razor blade, young bean seedlings, potassium permanganate solution, and light microscope.

Procedure

(i) Cut a section of the shoot and place it in a dilute solution of potassium permanganate ($KMnO_4$) or a dye such as eosin.

(ii) Wait for ten minutes and observe the movement of the dye in the xylem vessel to the shoot system.

(iii) Cut a cross section of the shoot and examine it under a light microscope.

(iv) Record and draw what you have observed.

Results: The xylem tissue will take the stain of potassium permanganate solution or eosin, indicating that, the xylem is responsible for conducting water from the soil.

Adaptation of the xylem to its functions

The xylem is capable of transporting water and dissolved mineral salts from the roots to the shoot. This is because, firstly, the vessel elements and tracheids have narrow lumina that allow water to rise up the stem by capillary action. Secondly, these cells have lateral pits that allow lateral movement of water. Thirdly, they have dead cells at maturity, which enable them to transport large amount of water and dissolved mineral salts. Fourthly, the vessel elements and tracheids have lignified walls to prevent them from collapsing and withstand the high pressure created by moving water. The presence of lignified walls also provide strength and support to the plant. Fifthly, the vessel elements have perforations at their end walls and are joined end to end to enable a continuous flow of water between the vessel elements. Lastly, the overlapping xylem fibres provide additional strength to xylem tracheids and the overall plant.

The phloem tissue

The phloem forms the primary food conducting tissue in vascular plants. It possesses tubular structures that are modified for translocation. It is composed of living cells with cytoplasm, some of which have mechanical functions. It consists four types of cells, namely: sieve elements, phloem parenchyma cells, companion cells, and fibres as shown in Figure 1.3.

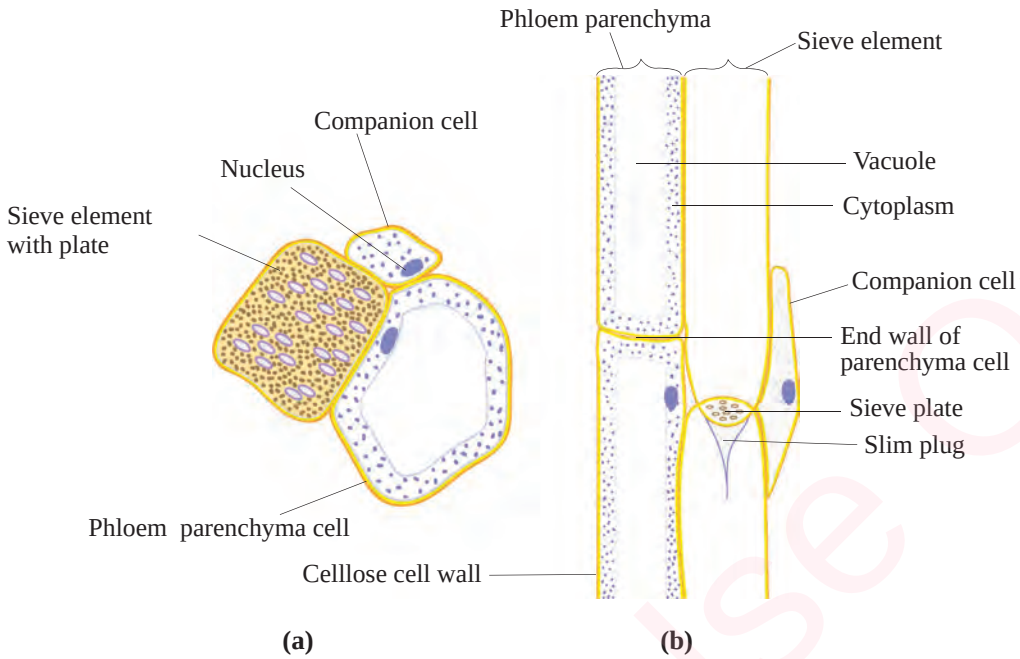


Figure 1.3 (a) Transverse section of phloem and **(b)** Longitudinal section of phloem

The structural components of phloem and their functions

As indicated in figure 1.3 (a) and (b), one of the structural components of the phloem tissue is sieve elements, also called sieve members. These are conducting cells responsible for transporting food substances. They also constitute sieve tubes. Each sieve element is separated from the other by a sieve plate, which contains pores that allow the flow of fluid from one element to the other. The pores occur when the plasmodesmata of the end walls enlarge greatly or expand. The pores are open channels for transportation in sieve plate between sieve elements. Each sieve element is associated with one or more companion cells as shown in Figure 1.4.

The phloem parenchyma cells are generally, living and elongated cells. They are mainly for storage and consist of stored carbohydrates and accumulated tannins and resins. When tightly packed together, they provide mechanical support to the plant. The companion cells have dense cytoplasm with small vacuoles and other cell organelles. They are very crucial for regulating the activities of sieve elements. The companion cells are metabolically active since they contain many mitochondria for cellular respiration, which produce the energy needed for active transport. There are also numerous ribosomes which are responsible for the active and constant production of respiratory enzymes. Companion cells and sieve tube elements are connected by strands of cytoplasm called plasmodesmata.

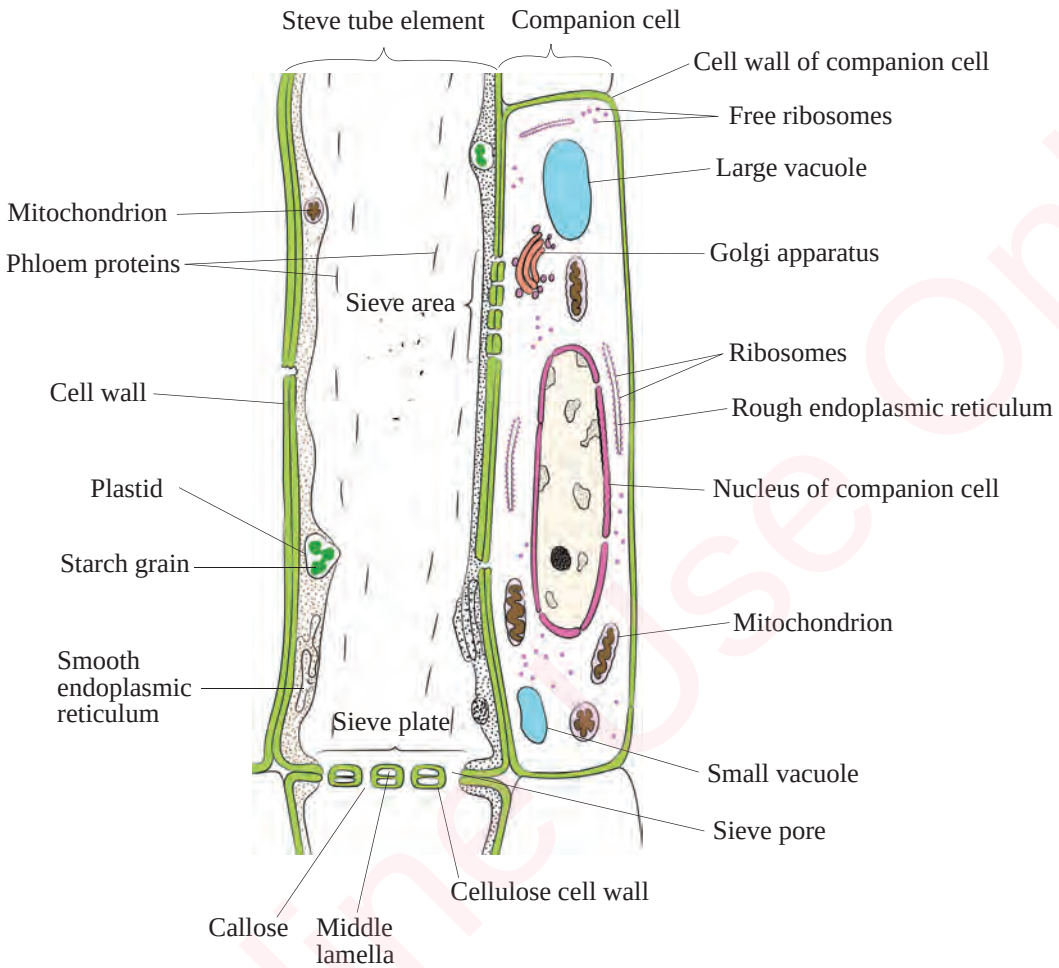


Figure 1.4 A longitudinal section of sieve element and companion cell

The phloem fibres are slender, flexible and elongated sclerenchyma cells with tapering ends. They are found in the inner bark of the stem. Their main role is to provide strength or mechanical support to mature plant stems.

Generally, phloem is responsible for the translocation of soluble synthesized foods, such as sugars and proteins. It is also responsible for transporting ions and hormones from the source tissues such as photosynthetic leaf cells to the sink tissues such as non-photosynthetic root cells or developing flowers.

There are pieces of evidence that show organic materials formed during photosynthesis are carried in the phloem tissue. Such evidences are supported by the following explanations.

(i) Cutting of the phloem makes the solution contained in the sieve tubes to exude. Examination of this solution reveals the presence of organic materials such as carbohydrates. The exudation of food solution from the sieve tubes shows that the contents of the phloem are transported under pressure.

(ii) The concentration of sugars in the phloem depends on environmental conditions. During the day when photosynthesis is taking place, the concentration of sugars in the phloem is higher compared to the concentration in the dark when there is no photosynthesis.

(iii) When a ring of the phloem is removed from around the stem, movement of food materials downwards becomes interfered; and because of this, food accumulates above the ring.

(iv) If a photosynthesizing plant is subjected to CO_2 from a radioactive isotope of ^{14}C as a photosynthetic substrate, the end products of photosynthesis if traced later in the phloem will be found to contain ^{14}C.

(v) Aphids are insects that feed on the contents of the sieve tubes of a living plant. Analysis of the juice extracted from the aphids reveals the presence of sugars and amino acids that are products of photosynthesis. The juice is obtained after anesthetising the feeding aphid, then cutting off its body to let its stylet exude juice sucked from the sieve tubes.

Adaptations of phloem tissues to their functions

The structure of the phloem tissue suit its function of translocation of food in that, its sieve tubes form a tubing column through which the food solution flows. There are lateral pits in the walls of the sieve tube members which allow lateral movement of food materials. The food materials flow through the phloem tissue by an active mechanism. The energy to facilitate this flow is supplied by the mitochondria present in the companion cells. Additionally, the sieve tube elements have a tendency of losing organelles in order to increase the size of the lumen for easy passage of food.

Passive and active transport in plants

The plant can absorb water and dissolved mineral salts using two transportation mechanisms, namely: active and passive transports.

Active transport: In active transport, materials or molecules are transported against the concentration gradient. For example, sometimes the soil may have a low concentration of mineral salts than the cell sap, but mineral salts can still move from the soil to the cell sap by active transport, which requires energy to pump materials against the concentration gradient.

Passive transport: In passive transport, materials move along their concentration gradient. In this case, energy is not required. For example, ions from the soil, which are in high concentration can diffuse to the cell sap with low concentration. However, passive transport may involve the movement of water molecules from a region of low solute concentration to a region of high solute concentration. Thus, the mechanisms for passive transport are osmosis and diffusion.

Osmosis: This is a special kind of diffusion that moves water molecules from a place of its higher concentration to a place of lower concentration to create a stable and equal cellular environment. It may also involve the movement of liquids or molecules from a region of low solute concentration (high water potential) to the region of high solute concentration (low water potential) through a differentially permeable membrane. Osmosis is an important process in the transport of materials for the proper

functioning, growth and stability of plants. For example, if osmosis was not present, photosynthesis would never occur, and the plant would wilt and finally die. This is because the stomatal guard cells have vacuoles that filled up with water and other fluids. During osmosis, the guard cells becomes turgid as they swell and the resulting turgor pressure triggers the stomata to open. The stomata then take in carbon dioxide from the air to be used in the production of food through photosynthesis. Furthermore, osmosis distributes water through selectively permeable membranes in order to maintain the volume and pressure of all plant cells. For instance, the movement of water and dissolved substances from one cell to another is largely facilitated by the osmosis process. A wilted plant looks weak because the vacuoles of their cells do not have proper amounts of water mainly obtained through osmosis. In plant roots, osmosis occurs when the water concentration outside roots is higher than inside. This pressure difference triggers the roots to take in water through the root cell walls thereby creating a pressure balance.

Diffusion: This involves the movement of molecules of liquid and gases or ions from a region of high concentration to that of low concentration. Movements of materials of this nature may also be called simple diffusion. Sometimes, movement can be aided by channel and carrier proteins.

In this case, it is called a facilitated diffusion**,** which refers to the type of passive transport under the aid of proteins. The transport proteins, which allow the passage of ions are called ion channels. These are selective and therefore, they open or close in response to certain signals. For example, the binding of specific ions, make them open and in the absence of such ions, the channels are closed. This helps the cell to control the movement of molecules and ions in and out of it. The rate at which diffusion occurs is affected by various factors. Firstly, the diffusion gradients or the difference in the concentration gradients between two points, the higher the gradient the faster the rate of diffusion. For example, in the lungs, diffusion is achieved by speeding up the flow of blood through the lungs or by breathing faster. Secondly, the large the surface area of a membrane through which diffusion is taking place, the greater the rate of diffusion. For example, membranes with microvilli, have a large surface area for the absorption. Lastly, the rate of diffusion decreases rapidly with the increase in the distance; for effective diffusion, a very short distance is required. The differences between passive and active transport in plants are summarised in Table 1.1.

Table 1.1 Differences between passive and active transport in plants

Passive transport	Active transport
It does not require cellular energy for the movement of molecules from high to low concentrations.	With active transport, cellular energy in the form of Adenosine Triphosphate (ATP) is needed to pump molecules against the concentration gradient.
Occurs along the concentration gradient. The movement of molecules occurs from a low concentration of solute to high concentration in order to maintain equilibrium.	Occurs against the concentration gradient. The movement of molecules occurs from a high concentration of solute to a low concentration of solute.
It maintains the dynamic equilibrium of water, gases and nutrients between cells and extracellular environment. No net diffusion or osmosis after the equilibrium is established.	It disrupts equilibrium, which is established by diffusion.
Involves channel protein molecules for transporting anything soluble in lipids, monosaccharaides, water, oxygen, carbon dioxides, and hormones.	Involves carrier protein molecules for the transportation of larger particles such as protein, ions, large cells, and complex sugars.
It is a physical process such as osmosis, diffusion, filtration, and facilitated diffusion.	Chemical processes to release energy are involved.

Exercise 1.1

1. Describe the structure, function, and adaptations of the xylem tissue.
2. Differentiate between the following terms as used in transportation in plants:
   (a) Osmosis and diffusion.
   (b) Passive and active transport.
3. Provide evidence to show that the xylem and phloem tissues perform their respective roles.
4. Describe the structure, function and adaptations of phloem tissue.
5. With the aid of a diagram, describe the structure of the phloem tissue.

The movement of materials across the root

The plant root has three main functions, which altogether facilitate growth and development of the plant. These functions include anchoring of the plant in the soil, absorption of water and soluble mineral salts, and storage of food in some plants such as cassava and sweet potatoes. A plant requires water and mineral salts from the soil for its growth and development. There are different pathways in the plant through which water and mineral salts move from the soil into its entire body across the roots. The endodermis of the roots has waterproof suberized bands or Casparian strips, which control the movement of water between cell wall and cytoplasm.

Pathway of water and mineral salts movement across the root

Absorption of water and mineral salts mostly takes place in the root hair zone. The root hairs, which extend from the epidermal cells are delicate structures which are always replaced by new ones through active mitosis. They lack cuticle to allow absorption of water, the root hairs provide a large surface area for absorption. They also have sticky walls through which they adhere tightly to soil particles. Their large numbers and possession of extremely thin layers provide a large surface area for absorption. Root hairs take in water from the soil mainly through the process of osmosis.

The passage of water into the roots is through the thin walls of the root hair and the epidermal cells of the root tips. From the epidermal cells, the water passes laterally through thin-walled cortical cells and then through the endodermal cells. From the endodermis, the water moves into the xylem tissue where the direction of movement is upward. The xylem tissue is continuous from the root to the aerial parts of the plant and through the stems to the petioles of leaves and terminates in the mesophyll of the leaf. There are three pathways in which water move in the roots. These pathways are apoplast, symplast and vacuolar pathways as indicated in Figure 1.5.

The apoplast pathway

This is the movement of water across the cell wall through intercellular space. The highest percentage of water movement in plants goes through the apoplast pathway. The movement of water in this pathway occurs exclusively through the cell wall and intercellular spaces without the involvement of any membranes or cytoplasm. In the apoplast pathway, the system of adjacent cell walls is continuous throughout the plant. Around 50% of a cellulose cell wall is 'free space', which can be occupied by water. When water evaporates from the mesophyll cell walls into the intercellular air spaces, a tension develops in the continuous stream of water in the apoplast. As a result, water is drawn through the walls in a mass flow by the cohesion of water molecules.

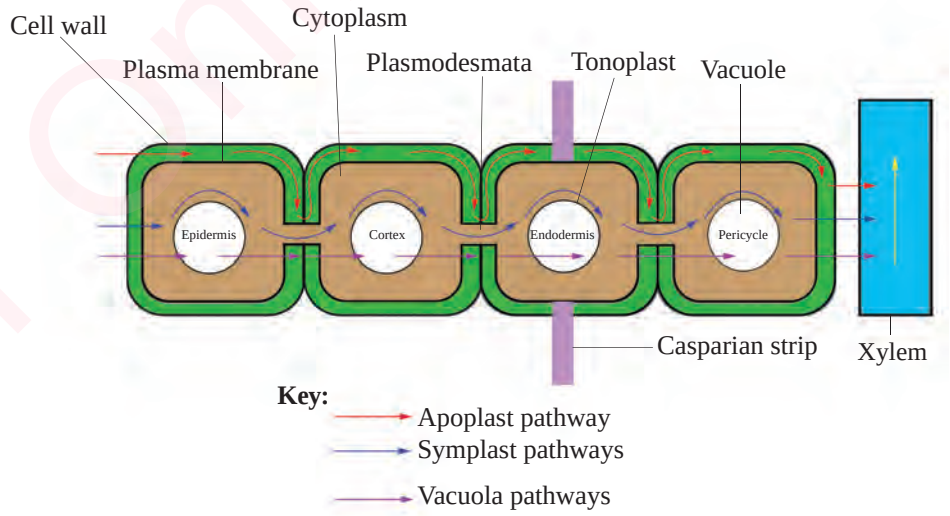


Figure 1.5 Apoplast, Symplast and Vacuolar pathways in plants

The movement of water through the cell walls in the apoplast is prevented by wax-like material known as suberin, which is deposited in the cell wall to form Casparian strips in the endodermis. In this movement, water is thereby forced to enter the living protoplast of the endodermal cell, as the only available route to the xylem. The movement of water is important because salts from the endodermal cells may then be actively deposited into the vascular tissues. This process lowers the water potential in the xylem, which becomes more negative causing water to be drawn in from the endodermis.

Roles of Casparian strips

The Casparian strip is a band of water proof which provides living support to the endodermis of roots. For example, if a root endodermal cell undergoes plasmolysis, the loss of water results into the falling off of the cell surface membrane onto the cytoplasmic region. However, due to the presence of Casparian strips, the membrane remains held in place. Therefore, when the cell gains water, the whole membrane goes back to the cell wall and the entire cell resumes a normal life. Additionally, the Casparian strips cause an active secretion of salts from endodermal cells into the xylem. This leads to more negative water potential in the xylem and as a result, it enhances the movement of water from the endodermal cells to the xylem. Moreover, by restricting the movement of water passing through the protoplasm, the Casparian strips limit large volumes of water which could be contaminated with toxins to pass through the cells. In this way, the strip offers a protective function against the entry of toxic substances.

The symplast pathway

Symplast pathway involves the movement of water and other low molecular weight solutes such as sugars, amino acid and ions between adjacent cells through the cytoplasm. In this pathway, there is the movement of water and mineral salt molecules from cell to cell by means of plasmodesmata, which are the cytoplasmic strands extending through pores in adjacent cell walls. The plasmodesmata forms a network of the cytoplasm of all cells. Water and solutes contained in the cytoplasm of one cell can move through the symplast pathway without crossing further membranes. The movements in the symplast pathway are aided by cytoplasmic streaming.

Apoplast and symplast pathways are both involved in the movement of water across the root. Water flows through apoplast in the cortex, enters the symplast pathway in the endodermis where the walls are impermeable to the flow of water due to the presence of Casparian strips.

In the endodermis, plasmodesmata help to allow the passage of water into pericycle from where it enters the xylem. Mineral nutrients also use the same pathway as that of water. However, their absorption and passage into the symplast pathway mostly occur through active absorption. The movement of water inside the xylem is purely along the pressure gradient.

The vacuolar pathway

In this pathway, water moves from vacuole to vacuole of neighbouring cells, crossing both symplast and apoplast pathways. In the process, water passes through membranes and tonoplasts by osmosis. However, the water molecules encounter high resistance; as a result, little flow usually occurs making this pathway insignificant. Therefore, apoplast and symplast pathways are the major routes for the movement of water in plants. Water moves by osmosis across the vacuoles of the cells of the root system and it moves down the concentration gradient from the soil solution to the xylem.

Exercise 1.2

1. With the help of a diagram, briefly describe how plants obtain water and dissolved mineral salts from the soil to the xylem.
2. Describe the structure of a root hair cell and state the ways in which its structure relates to its function.
3. Discuss the location of a Casparian strip and explain its role in water movement in higher plants.
4. Briefly differentiate between apoplast and symplast pathways of water movement and state which one of these would need active transport.

Upward movement of water and mineral salts

The upward movement of water and mineral salts from the soil to the upper part of the plant occurs as a result of a number of forces. These forces include osmosis, diffusion, transpiration, and capillary action. Water from the soil enters the root hairs by the process of osmosis. This is possible because water potential is higher in the soil than in the roots. The rise up of water at the base of the stem is caused by the capillary action whereas the root pressure pushes water upward the stem.

The adhesion and cohesion make columns of water to move up through the xylem. The continuous pull of water in the xylem is due to transpiration pull caused by water evaporation through stomata in the leaves. This upward movement of water and mineral salts from the soil to the shoot through the xylem tissues of a plant is known as the ascent of sap. It is called the sap because it contains many dissolved minerals. The movement of sap is facilitated by cohesion, adhesion, root pressure, capillarity, and transpiration pull. At the leaf surface, the plant loses water by transpiration and guttation processes. However, the plant loses much water by transpiration through stomata pores than by guttation through hydathodes. The process of transpiration has a number of effects to the plants including traspiration pull and cooling of the plant. Explanation of the forces responsible for upward movement of materials in plants is provided in the following subsections.

The cohesion-tension theory

The upward movement of water by cohesion is bestly explained using cohesion-tension theory. The theory suggests that plants are able to get water from the soil because water molecules are cohesive in nature. Since water molecules have an ability to hold each other without breaking, then they can be drawn up from soil particles into the root hairs by osmosis. Water is a polar molecule such that, when its two molecules approach one another, the slightly negatively

charged oxygen atom of one molecule forms a hydrogen bond with a slightly positively charged hydrogen atom of the other molecule. This attractive force along with other intermolecular forces is one of the principal factors that are responsible for the occurrence of surface tension in liquid water. These forces also allow plants to draw water from the root through the xylem to the leaf. The theory further holds that, water is constantly lost through transpiration from the leaf, when one water molecule is lost, another is pulled along by the processes of cohesion and tension. Apart from cohesion, another force of attraction between water molecules and the vessel wall also facilitates the upward movement of water. This force is called adhesion.

Root pressure

Roots absorb water from the soil by osmosis. The absorption takes place in the intercellular spaces of the root cells in the root hairs. There is a higher concentration of water in the soil than in the roots. This difference in the concentration of water between the soil and the roots creates a concentration gradient, which results into the movement of water from the soil to the roots. Thus, the xylem in the root develops a positive water potential and the water is pushed up the tubes which are formed by the xylem elements. The pressure with which the water is pushed to the xylem of the root is called root pressure. This is a force, which aids water movement up the xylem. It is caused by an active distribution of mineral nutrient ions into the root xylem. When transpiration rate is low, the ions are not carried up the stem; instead, they accumulate in the root xylem and lower the water potential thus creating a water potential gradient between the soil and root xylem. Water then diffuses from the soil into the root xylem due to water potential difference. Root pressure is caused by this accumulation of water in the xylem which pushes on the rigid cells. The pressure then provides a force which pushes the water up the stem.

The root pressure is responsible for transporting water to the leaves of herbaceous plants and grasses. However, in tall trees such as *Eucalyptus* and redwood whose heights may sometimes exceed 100 m, root pressure is not sufficient to transport the water up to the leaves and therefore transpiration pull complements the movement. Moreover, the ascent of sap continues even when the root pressure is absent and under normal conditions, the xylem sap is under tension (pulled) rather than pressure (pushed).

Capillarity

Capillary action is the movement of liquid within narrow spaces of a solid. It is caused by the attraction of intermolecular forces between the liquid and the solid surfaces. The xylem cells are part of the plant's transpiration system through which nutrients are transported throughout the plant. Capillarity is responsible for the movement of water up the xylem vessels because these vessels are very narrow. The capillary action brings water from the soil up to the roots, stems and the rest of the plant. The molecules of water are attracted to the walls of the xylem vessels inside the stem. As explained earlier, water molecules are also attracted to each other. Therefore, although the attraction between water molecules and xylem vessel walls is strong, the water molecules are still attracted to each other. This attraction helps to force water up from the ground and disperse throughout the plant.

Transpiration pull

When water is lost from the leaves during transpiration, the water potential of the leaves decreases. This creates a water potential gradient with neighbouring cells, which forces water to be replaced in the leaves due to water potential gradient and transpiration pull.

So long as the water column remains unbroken, and sunlight energy causes transpiration, water will keep rising and moisture will continue to move in the plant's vascular tissues (xylem vessels). The water potential of root cells is lower than that of the soil causing water to move from the soil to the roots and then moves upwards to the leaves by transpiration pull. It is important to note that, transpiration pull is sufficiently enough to move water upwards to the leaves of the plant of any height. This may work with the assistance of capillarity and root pressure in some plant species.

Activity 1.3 Demonstration of movement of sap from roots to the shoots

Materials: A fresh young plant with roots, razor blade or knife.

Procedure

(i) Cut a fresh shoot stump while the plant is still rooted in the soil.

(ii) Observe what happens.

(iii) Record what you have observed.

Result: The cut shoot stump will continue to exude sap from its xylem vessels, which indicates that there is a movement of sap from the roots to the shoots.

Solute transport across membranes in plant

The mineral salts required by plants are absorbed by roots and transported within plants in the form of ions. The cell membrane functions as a semi-permeable barrier to allow only some molecules to enter into the cell. Some solutes such as sugars are transported across the plant cell membrane in an uncharged state. These uncharged solutes are non-electrolytes and their movement across the membrane depends on concentration gradient. If the concentration outside the membrane is higher than inside, the gradient will allow solutes to move across the membrane into the cell. In contrast, the movement of solutes in the form of ions (the electrolytes) across the membrane depends on their chemical and electrical potential (electrochemical potential gradient) developed outside the membrane. This is because these solutes carry an electric charge. Therefore, the electrical properties of the cell, is an important control mechanism of ions transport through membranes. The transport of solutes across the membrane is called passive transport if it is along the chemical potential gradient or electrochemical potential gradient. There are three main kinds of passive transport, which are simple diffusion, facilitated diffusion, and osmosis. It is important to note that passive transport of ions down the electrochemical gradient across the membrane whether by simple diffusion, facilitated diffusion or osmosis is made possible by the presence of ion channels in the membrane.

Simple diffusion is the movement of molecules from a region of higher concentration to a region of lower concentration. The cell membrane allows non-polar molecules that do not bond with water to flow from an area where they are highly concentrated to an area where they are less concentrated. Embedded in the membrane are trans-membrane protein molecules called channel proteins that traverse from the outer layer to the inner layer and create diffusion-friendly openings for molecules to move through. This means that electrolytes may diffuse directly inside the cell, given that their concentration outside the membrane is higher than inside the cell as shown in Figure 1.6.

Facilitated diffusion is defined as a form of passive transport involving the movement of molecules along their concentration gradient by the guide of another molecule usually membrane protein forming a pore

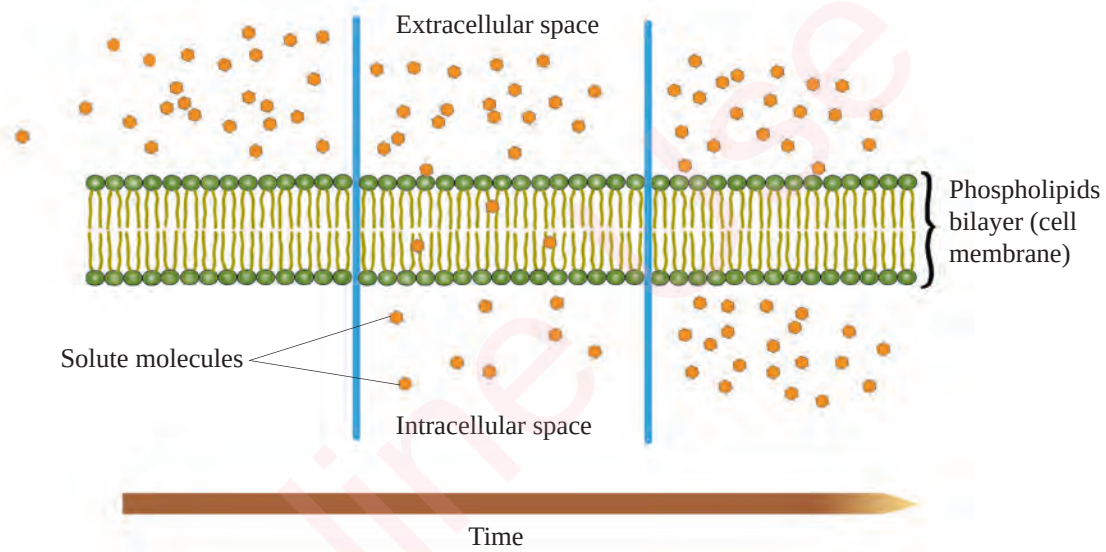


Figure 1.6 Diffusion of solute molecules across the cell membrane

or channel. When the concentration of a given solute inside the cell is lower than its concentration outside (in the membrane), the solute can also get inside the cell by facilitated diffusion. Facilitated diffusion is a process by which solute enters the cell through carrier proteins. This is used especially in the case of large polar molecules and charged ions; once such ions are dissolved in water they cannot diffuse freely across cell membranes due to the hydrophobic nature of the fatty acid tails of the phospholipids that make up the bilayers. Facilitated transport proteins shield these molecules from the hydrophobic core of the membrane, providing a route by which they can cross as shown in Figure 1.7.

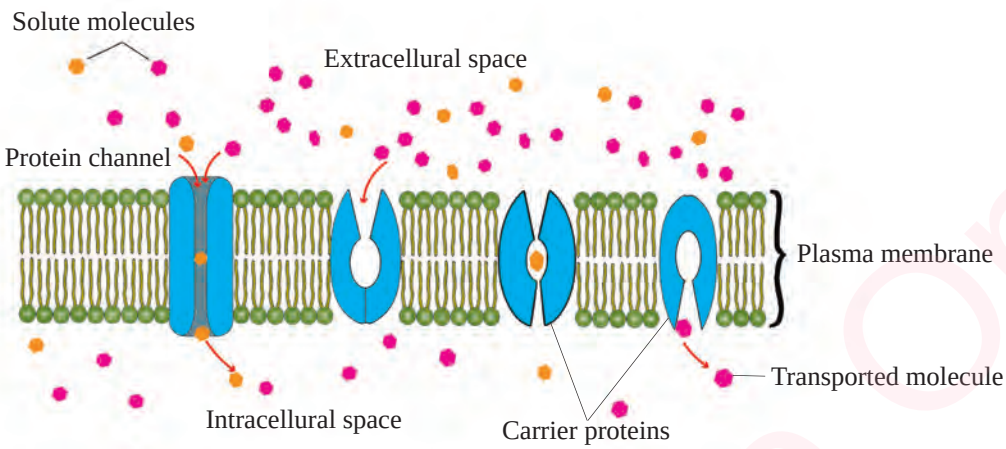


Figure 1.7 Facilitated diffusion

Osmosis is the movement of water molecules across a semi-permeable membrane from low concentration to a higher concentration of solutes. The solute cannot effectively move to balance the concentration on both sides of the membrane, so water moves to achieve this balance. It is affected by the concentration of solute in the water.

One molecule or one ion of solute displaces one molecule of water. Osmolarity is the term used to describe the concentration of solute particles per litre. Osmosis occurs when there is a difference in molecular concentration of water on the two sides of the membrane as indicated in Figure 1.8.

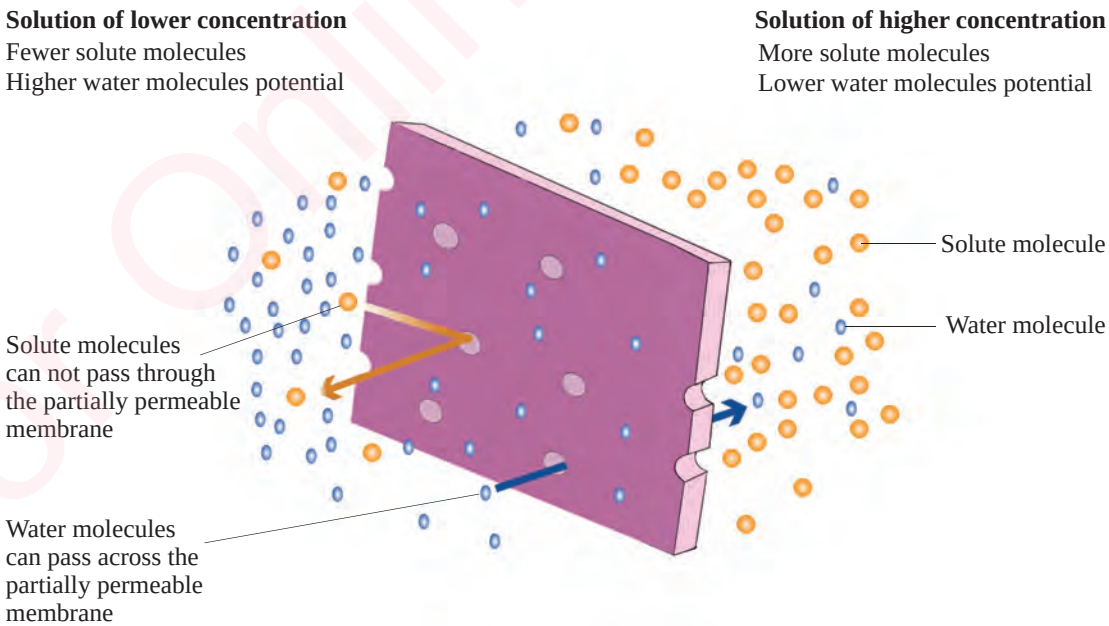


Figure 1.8 Osmosis model

Movement of ions across the membrane become active transport when it occurs against the electrochemical potential gradient. An additional input of energy in the form of ATP is needed in this case. There are varieties of cell membrane pump helping in the membrane solute transport. However, the Sodium-Potassium pump is the most known pump that uses energy to transport Sodium and Potassium ions in and out of the cell. The pump utilizes a molecule of ATP that allows the shape of the pump to change while emptying its contents either into or out of the membrane as shown in Figure 1.9.

The mechanism of this pump is such that three sodium ions from inside the cell bind to the protein pump. Then the phosphate group from a molecule of ATP binds to the

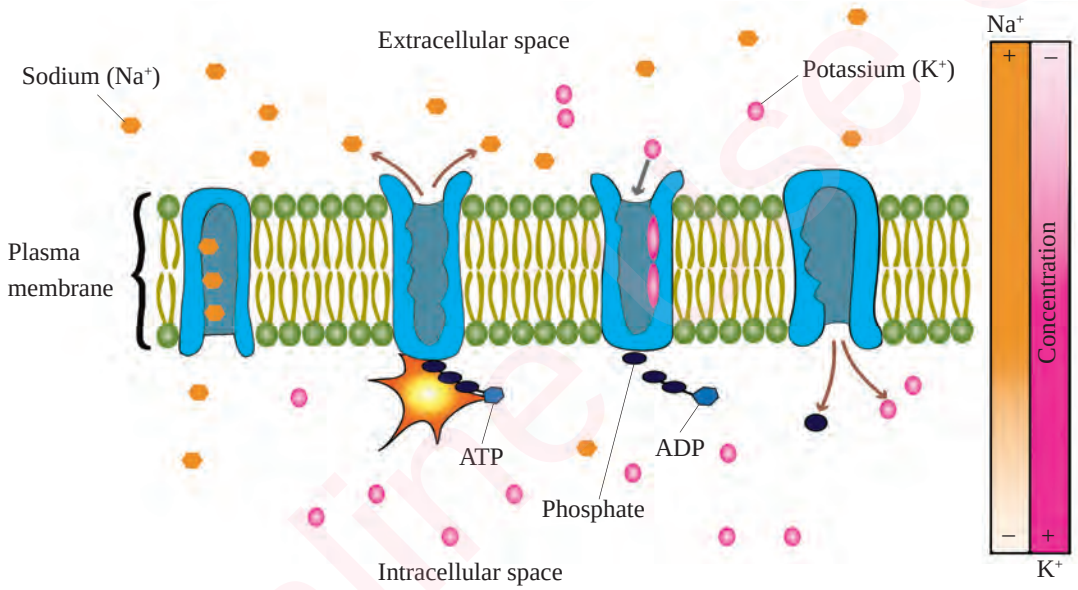


Figure 1.9 Sodium-Potassium pump

protein pump, which then changes its shape to release the sodium ions outside the cell. This is followed by two potassium ions binding to the pump before the phosphate group once again releases ATP. The pump changes its shape again by the action of ATP to release the ions inside the cell. Figure 1.10 summarizes the passive and active transport of solutes across the cell membrane.

Active and passive transport processes through the membrane result in equal and opposite ion fluxes when a cell is in a steady state. The movement of solutes or ions into the cytosol through the membrane such as plasma membrane or tonoplast is called influx. In contrast, the exit of solutes outside the cytosol or tonoplast through respective membranes is termed as efflux. Recent experiments on membrane transportation have revealed that proteins enhance movement of solutes across the membrane. These proteins are highly specific with complex structure and different ion transporting mechanism. Proteins transporting solutes across the membrane

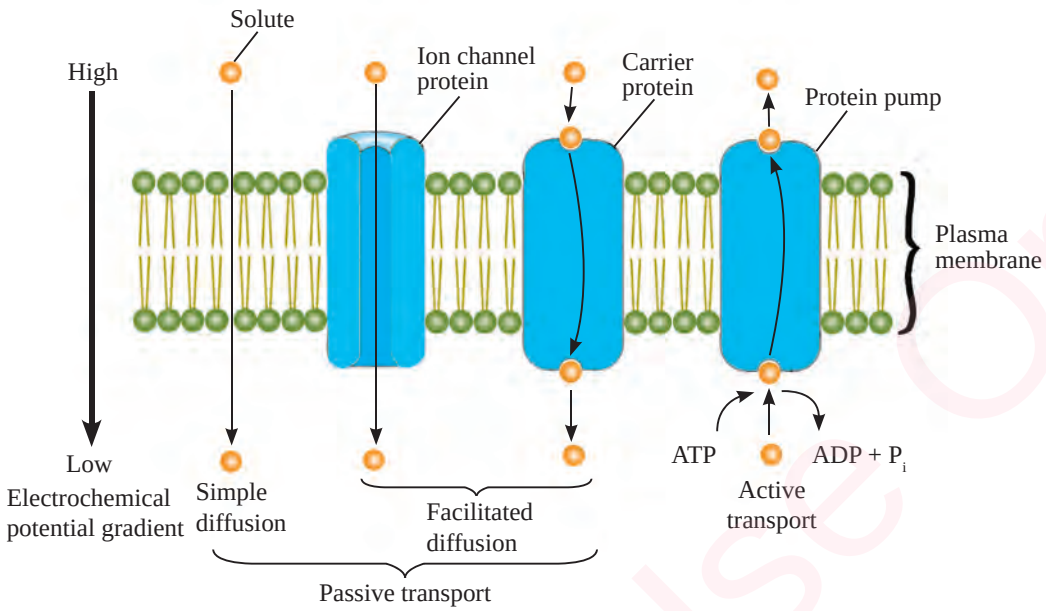


Figure 1.10 Passive and Active transport of solutes across the cell membrane

can be grouped into three categories, namely: ion-channel proteins, carrier proteins, and protein pumps.

Ion-channel proteins: These are proteins in the cell membrane which form pores that allow ions to pass through and move to the cytosol or tonoplast. Their functions include establishing a resting membrane potential, shaping action potentials and other electrical signals by gating the flow of ions across the membrane. They are selective pores through which ions can diffuse easily across the cell membrane. Movement of ions inside the cell through ion-channels of membranes is passive. Ion-channel proteins are highly specific for one or certain types of ion species. This specificity partly depends on the size of the pore itself and the density of electric charges of the ions. However, these protein channels in the membrane are not open all the time but they are gated. The opening and closing of the gates is always in response to external stimuli. These include: voltage changes, light, hormone binding and ions themselves. When ion gates are open, the ions surrounding the membrane can diffuse passively through the channels and when they are closed ions are stopped to get inside the cell. It is important to note that, channel proteins have a sensing region which responds to the stimulus by changing the conformational shape of the protein thereby opening or closing the gate as summarized in Figure 1.11.

Special techniques have been developed to detect electric current in the ion channels proteins. This is possible because these solutes in the form of ions carry a charge and their diffusion across the membrane channel establishes an electric current.

A variety of channels exists in the membrane which may open in different voltage ranges or in response to different stimuli such as K^+ and Ca^{2+}concentrations. Protein channels which allow the influx of ions are called

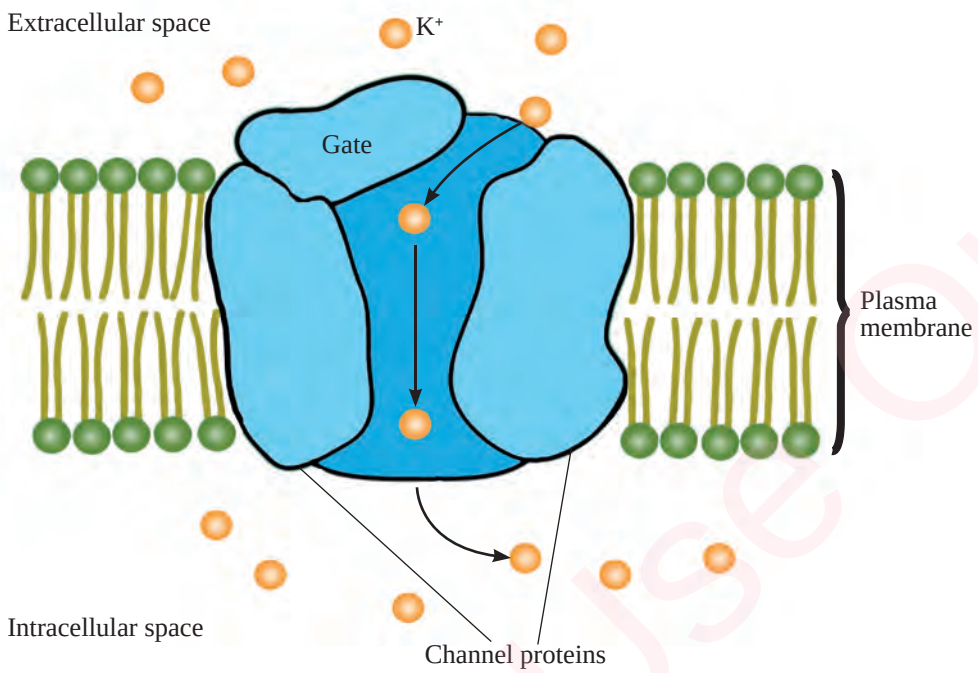


Figure 1.11 A model showing gated ion-channel

inward rectifying or inward channels and those which allow efflux are termed as outward rectifying or outward channels. For example, specific Ca^{2+} channels are inward rectifying while most anion channels are always outward. Most of the channel membrane proteins are described as inducible proteins because they are synthesized only when a particular solute is available for influx or efflux.

Carriers proteins: These are membrane proteins, which carry solutes and ions from one side of a membrane to the other. They are mostly found in a cell membrane of the cell and those of organelles. They do not form pores in the membrane instead, they selectively bind the solute to their specific sites and transport them inside. Binding of the solute is possible because proteins tend to change their conformational shape to suit the shape of the solute. After the release of solute from the binding site, the carrier protein takes back to its original shape to pick up another solute. The binding and release of solute through carrier protein resembles an enzyme catalysed reaction model. Movement of solute across the

membrane through carrier proteins is a slower process compared to ion-channels transport, but it transports much wider range of solutes. Carrier proteins transport may be passive or active. The passive transport of proteins through carriers is also known as facilitated diffusion as shown in Figure 1.12.

On the contrast, active transport of solutes takes place against the electrochemical potential gradient and in this case, the carrier proteins are termed as pumps. In active transport energy utilized comes from the hydrolysis of ATP.

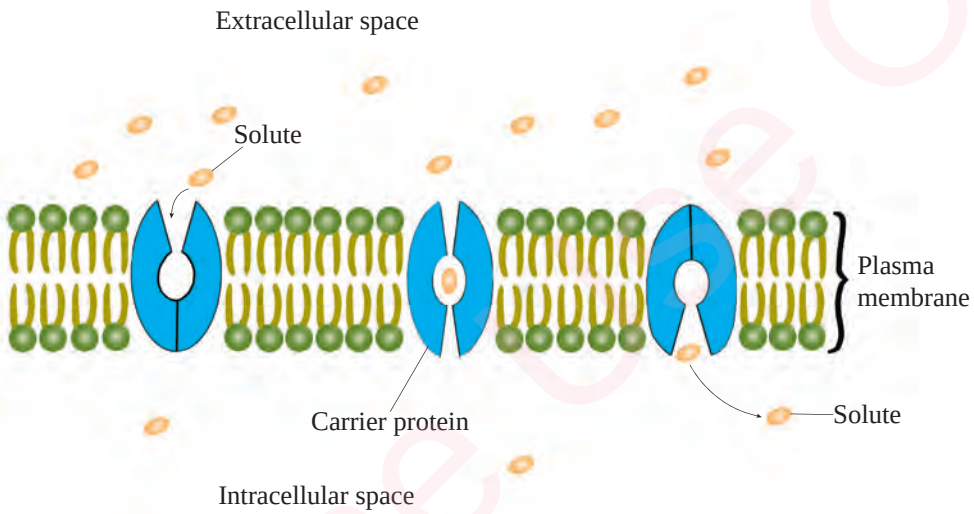


Figure 1.12 Facilitated diffusion through carrier proteins

Protein pumps: These are membrane proteins that pump ions across a membrane against their concentration gradient through active transport. This is another way by which the cell transports ions such as H^+ and Ca^{2+} across the membrane. Some protein pumps may also transport large organic solutes across the membranes. Protein ion pumps are of two types. These are electroneutral and electrogenic pumps. The electroneutral pumps are those proteins that transport ions inside the cell with no resultant net charge across the membrane as shown in Figure 1.13. For example, H^+/K^+-ATPase enzyme pumps out one H^+ for each K^+ taken in. This results to an overall no net movement of charge in the membrane and therefore termed as an electroneutral pump. In contrast, electrogenic pumps results in net charge at the membrane after it had pumped the ions inside the cell. The H^+-ATPase is a good example of an electrogenic pump because it drives out H^+ resulting in a net positive charge. Another example of electrogenic pump is Na^+/K^+- ATPase enzyme which pumps three Na^+ ions for every two K^+ ions taken in, resulting in a net positive charge in the membrane surface.

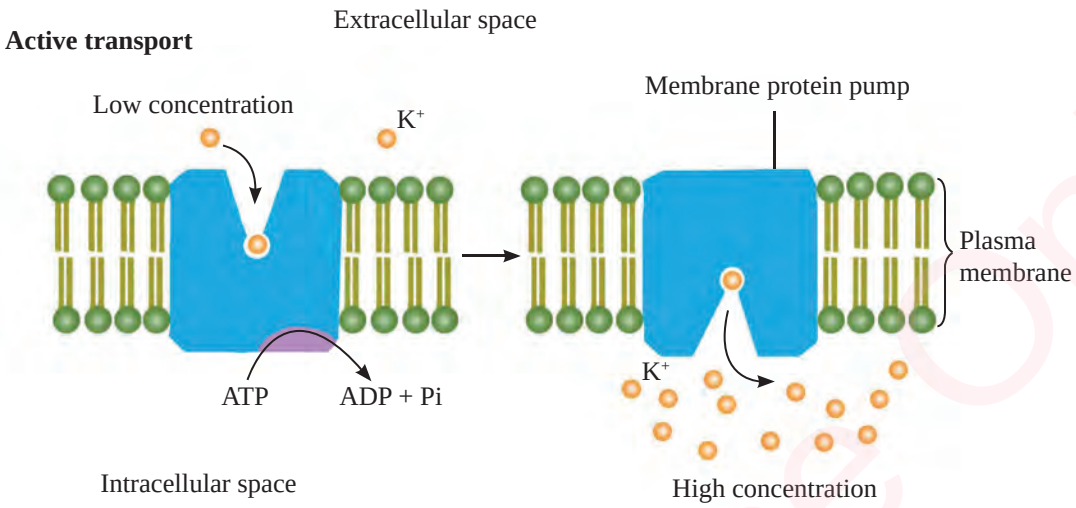


Figure 1.13 The role of protein pumps and ATP in active transport across the cell membrane

Transpiration

Most of the water taken by roots from the soil is lost to the atmosphere through stomata in the form of water vapour by a process called transpiration. Transpiration is the process by which a plant loses water in the form of vapour. It is essentially evaporation of water from aerial plant leaves. The water lost by transpiration largely evaporates through the stomatal pores. About 90% of water lost from plants occurs in this way. Some amount of water evaporates from outer walls of epidermal cells through cuticles. This kind of water movement is called a cuticular transpiration and it contributes only 10% of the total amount of water lost through transpiration. Since the stomata pores close during the night, then the only way the plants can lose water by transpiration is through the cuticle. Nevertheless, cuticle is the major barrier against uncontrolled loss of water through the leaves. There are small slits in the stem and bark of the tree for gaseous exchange. These are called lenticels and through them, sometimes water evaporates. However, the amount of water that is lost through these slits is almost negligible.

The mechanism of opening and closing of stomata

Stomata are pores that are largely located in the leaf epidermis. They are more distributed in the lower surface of the leaf compared to the upper surface. It is through these pores that gases diffuse in and out of the leaves. Each stoma is surrounded by two guard cells. Unlike the other epidermal cells, the guard cells possess chloroplasts and have cytoplasm with a nucleus as shown in Figure 1.14.

Changes in turgidity of the guard cells control the size as well as the closure and the opening of the stomatal pore. There are different hypotheses which explain causes of the changes in the turgidity of the guard cells and hence, the opening and the closing of the stomatal pore.

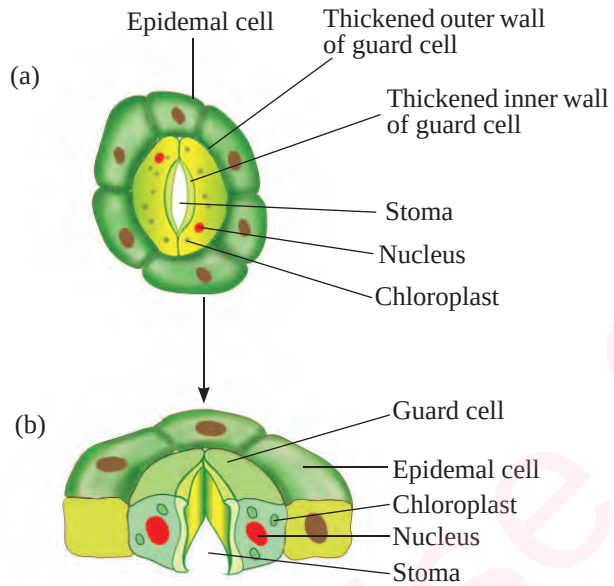


Figure 1.14 (a) The cross-section of a stoma and (b) The transverse section of a stoma

Starch-sugar hypothesis

The starch-sugar hypothesis suggests that starch-sugar interconversion is responsible for the opening and closing of stomata. The amount of starch in the guard cells increases during the day and decreases during the night. This is because photosynthesis takes place during the day. The process of photosynthesis result in the accumulation of sugars in the guard cells which increases the concentration of solute in the cells. The increase in solutes potential leads to osmotic movement of water from the neighbouring cells into the guard cells. Turgidity of the guard cells increases as the water moves in. Structurally, the inner walls of the guard cells are thicker and less elastic than the outer ones. Therefore, when water enters the guard cells, the outer walls expand more than the inner walls. The guard cells then assume a kidney shape when the outer walls become fully stretched. This leads to the opening of the stomatal aperture. During the ascent of sap, the water moves from the soil to the stem and then to the leaves where it evaporates through the stomata into the atmosphere.

The evaporation is facilitated by the differences in the water potential between the air spaces in the leaf and the atmosphere. The water vapour moves from a high water potential inside the leaf to a low water potential in the atmosphere. When the guard cells lose water and become less turgid, the stomata pore closes.

The starch-sugar hypothesis on the mechanism of the closing and the opening of the stomata faces a number of challenges. For example, studies on plant physiology have proven that sugars which accumulate in the guard cells during photosynthesis are not enough to cause the required solute potential for an osmotic movement of water from epidermal cells into the guard cells. The hypothesis also fails to explain the role of the rise in pH on the basis of carbon dioxide concentration. Moreover, sugar has never been noticed in the cell sap of

the guard cells during the opening of the stomata. The starch-sugar inter-conversion is very slow to the extent that it cannot effect quick movements of water through stomata.

Potassium ions hypothesis

The evidence from plant physiology experiments have proved that stomata can also open in the absence of carbon dioxide and light. Therefore, the starch–sugar hypothesis has been challenged in that the accumulation of sugars in the guard cells is not the main reason for turgidity changes in the guard cells. It has been proven that potassium and chlorine ions are responsible for the changes in the turgidity of the guard cell.

In the presence of sunlight, potassium ions (K^+) and chloride ions (Cl^-) enter the guard cells by active mechanism stimulated by ATPase enzyme which is located in the cell surface membrane. This is the enzyme that catalyses the decomposition of ATP into ADP, free phosphate ions, and energy that pumps out hydrogen ions (protons) from the guard cells. Potassium ions then enter the guard cells to balance the charge. These protons return to a carrier which also brings chloride ions (Cl^-) and causes potassium ions (K^+) to enter the guard cells. The movement of ions into the guard cells lowers the water potential in these cells, making it more negative. This causes the entry of water by osmosis and makes the guard cells turgid as shown in Figure 1.15 (a). The turgidity of the guard cells result in an increase in the pressure potential, which causes the stomata to open. In the absence of sunlight, for example in the night, the stomatal pore closes as a result of the reversed process of opening as shown in Figure 1.15 (b).

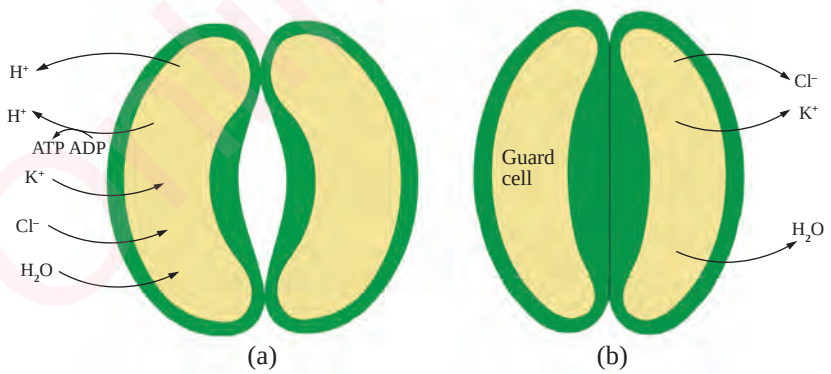


Figure 1.15 The mechanism of (a) stomatal opening and (b) stomatal closing

Effects of transpiration in plants

Transpiration should not always be considered as a hazardous process in the plant life for drawing water from the soil and causing drying of the soil. However, it has been described as "a necessary evil" because it is unavoidable but with a number of negative effects. The necessity of transpiration to the plants becomes evident through the beneficial effects gained by the plants. Transpiration pull result into availability of water and mineral salts in various parts of plants. In addition, transpiration is the source of water required for the photosynthesis process. In order for evaporation to occur, energy is needed which is obtained from the leaf. The process results in cooling the leaf surface at the site of evaporation. The cooling of the leaf avoids excessive temperatures, which could affect the rate of photosynthesis. Moreover, transpiration helps in the removal of excess water from the plant because the plant requires a very little amount of water to perform its function. It is known that out of 100% of water absorbed by the roots only 10% is needed and used by the plant, the rest 90% is lost to the atmosphere through the process of transpiration. In this way, it adds water in the atmosphere in the form of vapour. This in turn condenses and then falls as rain to make water available in the soil.

Despite its importance, transpiration can cause reduction of the water content of a plant. This can result in wilting and if this process lasts for a long time, can lead to the death of the plant. Transpiration also interferes with the process of gaseous exchange through the stomata. This is because the stomata have to open to take in carbon dioxide as a raw material for photosynthesis. However, the opening of stomata allows water to be lost to the atmosphere. Transpiration also reduces the water content of the soil.

Factors affecting the rate of transpiration

The factors which influence the rate of transpiration are of two types, namely: external or environmental and internal factors. The external or environmental factors that influence the rate of transpiration include the following.

Relative humidity and vapour pressure: The drier the air around the plant, the greater the transpiration rate. This means that when humidity is high, the rate at which the plant loses water through transpiration is low.

Air movement (wind): As the wind blows, water vapour around the external surface of the leaf is cleared away. This means that, any air movement will tend to sweep away a layer of water around the leaf surface. This creates a water potential gradient between the leaf surface and the epidermal cells of the leaf which causes water to flow out of the leaf. Therefore, windy conditions result in increased transpiration rates.

Temperature: A rise in temperature increases the kinetic energy of water molecules, which in turn, increases the rate of evaporation of water. At the same time, these changes lower the relative humidity of the air, as well as increasing the rate of transpiration.

Light: Light affects transpiration because stomata usually open in the light and close in darkness. It follows that an increase in the intensity of light increases the rate of transpiration and vice versa.

Water availability: The rate of transpiration depends on the amount of water, which is available in the soil. This means that, the greater the amount of soil water, the higher the rate of transpiration and vice versa.

The internal factors that affect the rate of transpiration include anatomical and morphological features of the plants. These factors are elaborated in the following sections.

Surface area of the leaf: The greater the total surface area of a leaf, the greater the rate of transpiration and vice versa. The reduction of the leaf surface is achieved when leaves are modified to needles as in pine plant or to spines as in cacti.

Cuticle: The thinner the cuticle the higher the rate of cuticular transpiration and vice versa.

Stomata: Generally, the greater the number of stomatal pores the higher the rate of stomatal transpiration. The rate of transpiration also depends on the stomatal distribution. Thus, in most of the dicot plant leaves, many stomatal pores are located on the lower surfaces and therefore the rate of transpiration is higher on these sides than on the upper ones.

Guttation

This is the loss of water in the form of drops of liquid from the surface of the plant leaves through special structures called hydathodes, which are found on the leaf margin or surface. Guttation is caused by root pressure and capillary action. Guttation and transpiration involve loss of water from the plant. However, several differences exist between the two pocesses as shown in Table 1.2.

Table 1.2 Differences between transpiration and guttation

Transpiration	Guttation
It involves loss of water from plants in the form of vapour.	It involves loss of water in the form of drops of liquid water.
It takes place during the day.	It takes place during the night.
The driving force is the transpiration pull.	The driving force is root pressure.
It takes place in all terrestrial higher plants.	It takes place mostly in herbaceous plants.
It maintains the temperature of the plant.	It has no relationship with the maintenance of temperature.
Water which is given out is pure and contains no salts.	The water which is given out contains salts.
It occurs through stomata that are located on the lower side of the leaves.	It occurs through a special group of cells known as hydathodes which are located at the margins of the leaves.
It is favoured by high light intensity.	It is favoured by low light intensity and humidity.

Exercise 1.3

1. Explain the path of upward transportation of water and mineral salts in plants.
2. Describe the forces governing the upward movement of water and mineral salts in plants.
3. Discuss the mechanism of stomata opening and closing.
4. Briefly elaborate the hypotheses about stomatal opening and closing in plants.
5. Explain the internal and external factors that affect the rate of transpiration.
6. Distinguish between transpiration and guttation.

Translocation of manufactured food

Most of the carbohydrates which are manufactured in the leaves and other green parts of the plants are transported through the phloem to other parts of the plant for use and storage. This process is known as translocation. The area where carbohydrate is made is called source and the area where carbohydrate is taken for use and storage is called sink. Therefore, transportation in plants occurs in the direction of the source to the sink by translocation. Examples of the sink are roots and stems. Translocation of manufactured food from the photosynthetic cells to different parts of the plant body for use and storage requires specialized cells and it occurs through a specific path. Unlike the movement of water and mineral nutrients from the roots to the shoots through xylem which occurs in one direction only, translocation of food materials through phloem is bi-directional in the sense that the movement of materials through phloem can either be from the source to the sink or from the sink to the source. For example, during dry season, deciduous trees shed their leaves and consequently photosynthesis stops. However, during wet season, the food which was stored in the sink will be transported through the phloem to the source to facilitate the growth of new buds and leaves. This means that the movement is now from the sink to the source to facilitate the formation of new leaves for photosynthesis. Note that the transport of water in the xylem occurs only from the roots to the leaves and therefore it is uni-directional.

The path of manufactured food

Leaves are the main photosynthetic organs of the plant. However, in some plants, stem plays the role of photosynthesis. Other parts of the plant which are non-photosynthetic, and which are located far away from photosynthetic organs need to get the products of photosynthesis for their growth. These parts include growing parts of the plants such as roots, developing buds, fruits, stems and storage organs such as roots and stems. Therefore, plants have developed means of transporting the produced food from the leaves to other parts, which are non-photosynthetic. As discussed earlier, phloem is the tissue in vascular plants which carries products of photosynthesis away from the leaves to other parts of the plant.

The large percentage of food substances carried in the phloem tissue is the carbohydrate called sucrose, a disaccharide sugar, which is inactive and highly soluble. Since it is inactive, it plays a minor role in metabolism. This condition makes it ideal for being transported because there is no possibility of being used during transport. On reaching the required destination, it is converted back to the

active form of monosaccharides such as glucose and fructose ready for use. Other substances carried by phloem include amino acids, inorganic ions, vitamins, and plant hormones.

Features of phloem translocation

The following are among the important features of phloem translocation.

(a) The amount of materials carried through phloem may be very large. The stored food in plant roots and stems are carried through the phloem. Taking into consideration the amount of food substances consumed and those stored, it is obvious that phloem tissues carry large amounts of food substances.

(b) There is a higher rate of flow of materials through the phloem sieve tubes. The experiments conducted to trace the food substances carried in the phloem tissue, revealed that the rate of the flow of materials in the phloem is very high.

(c) The distance through which the food substance travels may be long. Since some trees are very tall, food substances travel along a great distance from the manufacturing site down to the roots.

(d) The size of phloem is small. It would be recalled that the phloem tissue is a thin layer of an inner layer of tree bark. This is the only part which is concerned with the translocation of food material. Furthermore, it is only the newly formed phloem tissue that is capable of translocating food substances. The older and outer layers cannot translocate food substances because they become stretched and die as the plant grows and increases in circumference. Therefore, the remaining part of the phloem, which is capable of translocating food materials, is very small.

(e) Sieve tube, which is a very fine part of phloem, is concerned with the movement of materials. The sieve tube elements display various structural adaptations such as lack of nucleus at maturity and the presence of sieve plates which make them well suited for transportation.

The mechanism of transporting manufactured food material in a phloem tissue

Several models and hypotheses have been developed to describe the movement of food materials in the plants. However, one common model is the mass flow or the pressure-flow model, which was suggested by Münch in 1930. This is the model for large scale movement of food in plants due to the active transportation of sugars into the phloem. With this model, the process of translocation of the manufactured materials starts when the glucose prepared in the leaves is converted into sugars mainly sucrose. This is then moved into the companion cells and then into the living phloem sieve tube cells by active transport. A hypertonic condition in the phloem is created as a result of this movement. This involves the movement of sugar from the sources such as leaves, followed by the passive entry of water. This creates a pressure forcing the fluid to move to a sugar sink like the root, where cells actively take up sugar from the phloem and the water returns to the xylem. Osmotic pressure rises and phloem sap moves from an area of higher osmotic pressure to the area of low pressure.

In his experiment, Münch prepared a model as shown in Figure 1.16 with two containers A and B each of which contained a sugar solution. The solution in container A was more concentrated than that in container B. Each container had a semi-permeable membrane. The two containers were connected by a tube. After being placed in water, the two solutions initially took up the water by osmosis. However, the tendency of water uptake was higher in container A than it was in container B. As the water entered in container A, the hydrostatic pressure built up in the closed system A-C-B tube, which in turn forced water out of container B. Consequently, the mass flow of solution occurred through tube C along the generated pressure gradient; due to osmotic uptake of water, the osmotic gradient also was built from container A to container B. Since the water continued to dilute the contents of container A and solutes accumulated at container B, then the system came into equilibrium.

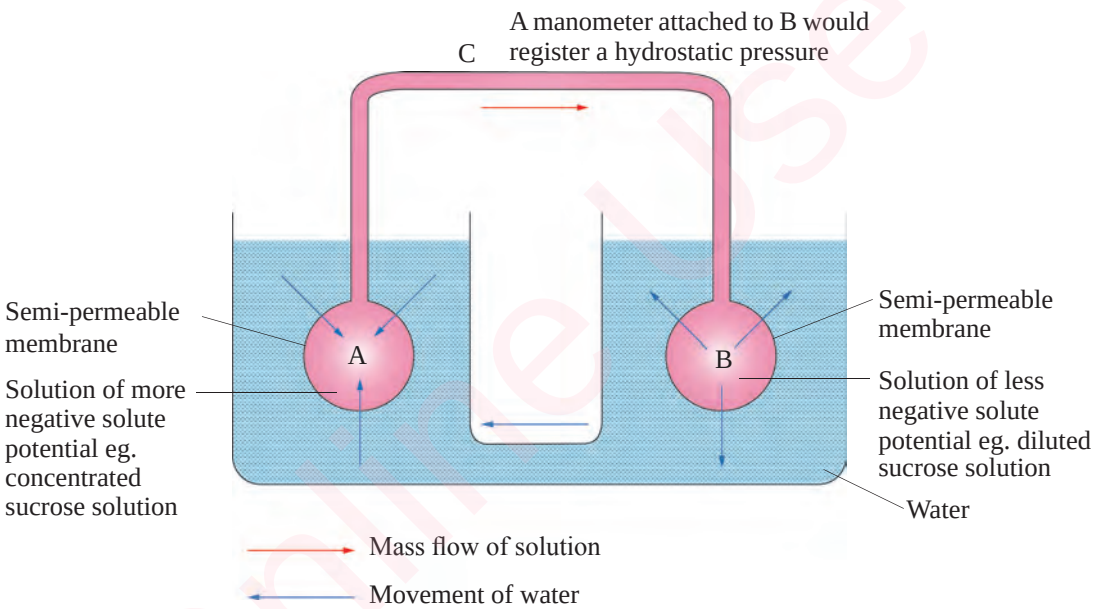


Figure 1.16 Illustration of Münch's mass flow hypothesis

This model can be used to explain the flow of sugar molecules from the leaves to the roots. Container A can represent the leaves, which are the source of sugars manufactured during photosynthesis process as indicated in Figure 1.17. Water then leaks out continuously in the mesophyll cells in the leaves making the solute potential (Ψs) of the leaf cells more negative. This causes the water to be brought to the leaf from xylem by osmosis. The process results in raising the pressure potential (Ψp). Container B can represent the sink, which is the area where sugar is used up or stored in an insoluble form. In this case, it is the root, young shoot, or fruits. The hydrostatic pressure in the leaves increases and the pressure gradient is created between the leaves (source) and the roots (sink) resulting in the mass flow of solute along the gradient. In plants, solutes are constantly being used up at the sink (B) and produced at the source (A), and therefore, the equilibrium state is not reached.

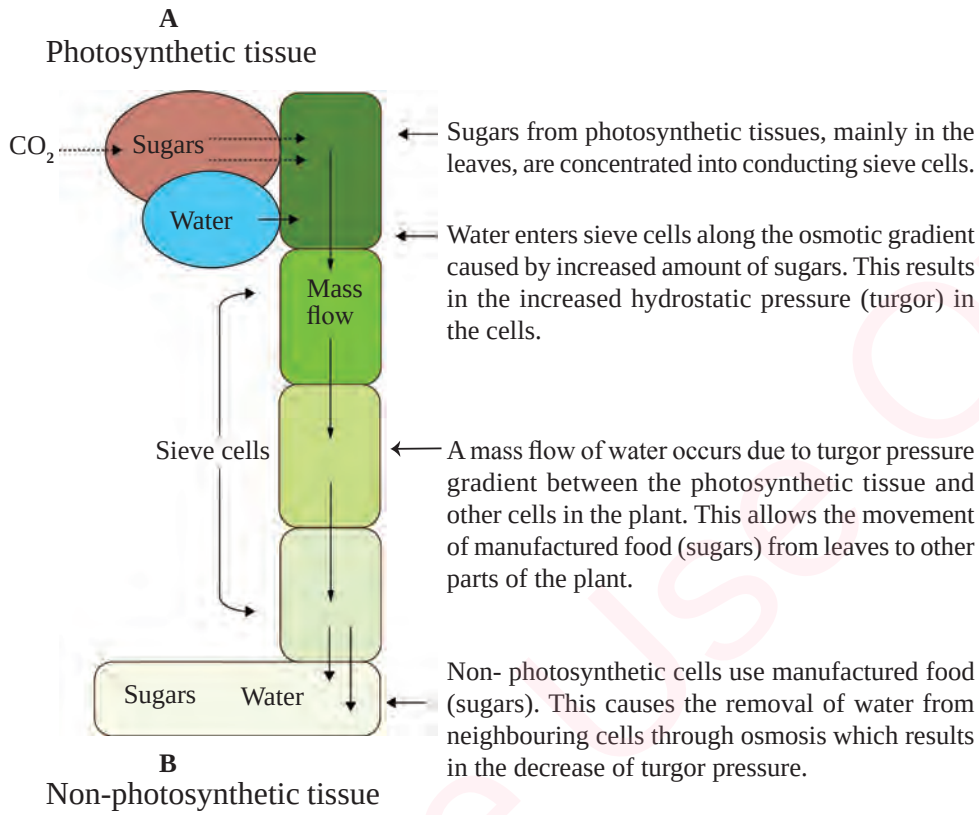


Figure 1.17 Diagram showing phloem translocation of photosynthetic product

Evidence of mass flow through the phloem

The studies on plant physiology reveal that food moves through phloem by mass flow mechanism. This is because the phloem sap flows out of the cut phloem by mass flow. This signifies a pressure gradient. Since hydrogen is actively transported out of the phloem, then the phloem sap has a high pH than it is expected. Moreover, when a feeding aphid is anaesthetized and its mouthparts carefully cut, sucrose solution flows out of the stylet of the aphid. The prolonged flow of this solution suggests a hydrostatic pressure in the sieve tubes. The rate of movement in phloem is faster than it would be if the movement was by diffusion. Additionally, the rate of transport, which is measured in the phloem, matches closely with the pressure differences which are measured at the sources and sinks. However, this is only true when the pores are open.

Criticism against the mass flow hypothesis

(i) The mass flow hypothesis neglects the living nature of the phloem. In other words, it does not explain why sieve tube cells must be living and metabolically active.

(ii) The hypothesis indicates that all organic substances in the phloem tubes are transported or swept at the same constant speed. However, experiments show that amino acids and sugars are transported at different rates.

(iii) Bidirectional movement of solutes in the translocation process, as well as the fact that translocation is heavily affected by changes in the environmental conditions such as temperature and metabolic inhibitors, are not fully explained by this hypothesis.

(iv) Furthermore, the hypothesis does not show the role of metabolism in phloem translocation. For example, the active mechanisms of loading sucrose to the sieve elements at the sources and the unloading of sucrose from the sieve elements at the sinks are not explained.

Exercise 1.4

1. Explain the features which facilitate passage of manufactured food through the phloem tissue.
2. Discuss how the Münch's model demonstrates translocation of food through the phloem from the source to the sinks.
3. Give evidence to show that food passes through the phloem by mass flow.
4. Briefly explain the challenges of the mass flow hypothesis of phloem translocation.
5. Explain why the end products of photosynthesis are safely transported from the source to the sink without being oxidized on their way.

Transport in animals

Transportation of materials in animals such as vertebrates occurs mainly through the blood vascular system. The heart whose walls are made up of the cardiac muscles pumps the circulating blood. Circulation is the movement of materials within a cell or between parts of an organism. In contrast, transportation is defined as the circulation and all other processes by which substances pass into or out of cells and move within the organism. The vertebrate circulatory system has three major components. First, the blood which is a fluid in which transported materials are dissolved. Second, the blood vessels which form a network of tubes or body spaces through which the fluid flows. A transport network of the vertebrate circulatory system is made up of arteries, veins, and blood cells. The last component of vertebrate circulatory system is the heart which is a means of driving the fluid through the tubes or spaces. Animals have two different types of circulatory systems, which are open circulatory system in arthropods and some molluscs and closed circulatory system in echinoderms, some molluscs and vertebrates. This closed system is either single or double circulatory systems. In mammals, the circulation of blood in foetus differs from that of an adult.

The blood

Blood is the first component of the vertebrate circulatory system. It is a constantly circulating fluid in the body of humans and other animals. It has a function of transporting necessary substances such as nutrients and oxygen to the cells and removing metabolic wastes away from the cells. Blood is the main component of the transport system in vertebrates. While 55% of blood is composed of the plasma, the remaining 45% constitute of blood cells. Approximately 8% of an adult's human body weight is made up of blood. The composition of blood by sex indicates that females have an average of 4 -5 litres while males have 5 - 6 litres. This is due

to differences in their body size. Males are relatively bigger in size than their females. The blood has a pH ranging from 7.35 to 7.45. Hence, it is slightly alkaline. Its viscosity is about 4.5 - 5.5 times the viscosity of water making it easier to flow in the vessels than water.

Functions of the blood

Blood has three major functions in the body, namely: transport, protection, and regulation.

Transport: This is the main function of the blood. It is the primary means of transport in the body of vertebrates. Substances transported by the blood include gases, nitrogenous wastes, hormones, and nutrients. One of the transport roles of the blood is to pick up oxygen (O_2) processed in the lungs to all body cells. Cells need oxygen for undertaking cellular respiration to generate energy, which will enable them to carry out some metabolic activities. Blood also transports carbon dioxide (CO_2) from the metabolic cells to the lungs in order to be removed outside the body. The underlying transport mechanism is summarised in Figure 1.18.

Apart from the transportation of the gases, blood also transports nutrients from the digestive tract and storage sites to the rest of the body. Waste products to be detoxified or removed by the liver and kidneys respectively are also transported by the blood. Moreover, the blood transports hormones from the glands in which they are produced to their target cells. Finally, the blood also transports heat generated during metabolism to the skin that helps to regulate body temperature.

Protection: The blood is also involved in body protection and inflammation.

For example, leukocytes, or white blood cells tend to destroy the invading microorganisms and cancer cells. Antibodies and other proteins present in blood plasma destroy pathogenic substances.

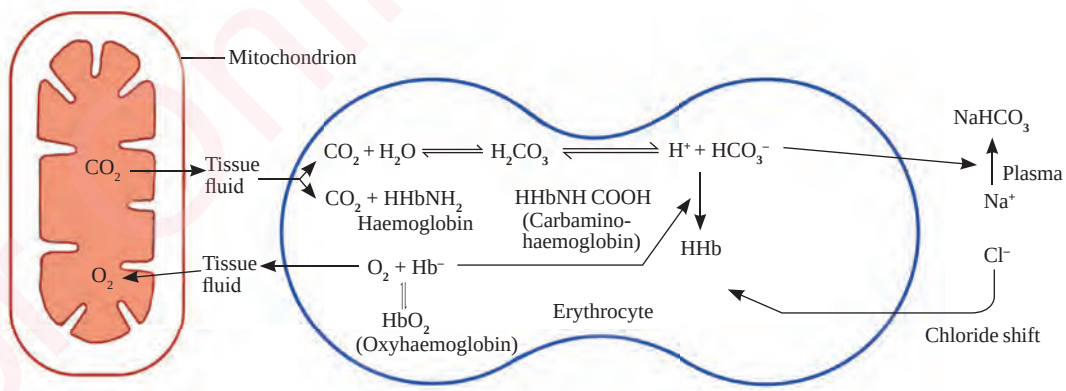


Figure 1.18 Mechanism of transportation of carbon dioxide (CO_2) and oxygen (O_2) in the body

Platelets or thrombocytes also tend to initiate the process of blood clotting and helps to minimize blood loss during an injury.

Regulation: The blood is involved in regulating the functions of many factors in the body. For example, it is responsible for controlling the concentration of hydrogen ions or pH in the body by interacting with acids and bases. It regulates the temperature of the body and maintaining it at tolerable levels. Furthermore, it controls body water balance by transferring water to and from tissues. The blood also regulates the levels of salt required in the body.

Composition of the blood

In vertebrates, blood is composed of two main components, namely: plasma and the formed elements. The formed elements of the blood include red blood cells, white blood cells and platelets or thrombocytes. They are named so because they are enclosed in a plasma membrane and they have a definite shape and structure. With the exception of platelets, all the other formed elements are cells. Platelets are tiny fragments of bone marrow cells. Figure 1.19 summarises the major components of the vertebrate blood.

Blood plasma: Plasma is a pale yellow sticky liquid component of the blood. It forms about 55% of the total blood's volume in the body. About 90% of plasma consists of water and the remaining 10% is a variety of substances in solution and suspension forms.These substances include proteins, electrolytes, nutrients, gases, hormones, and waste products. Plasma proteins are the most abundant plasma solutes and they account for about 8% by weight of plasma volume in the blood. Most plasma proteins

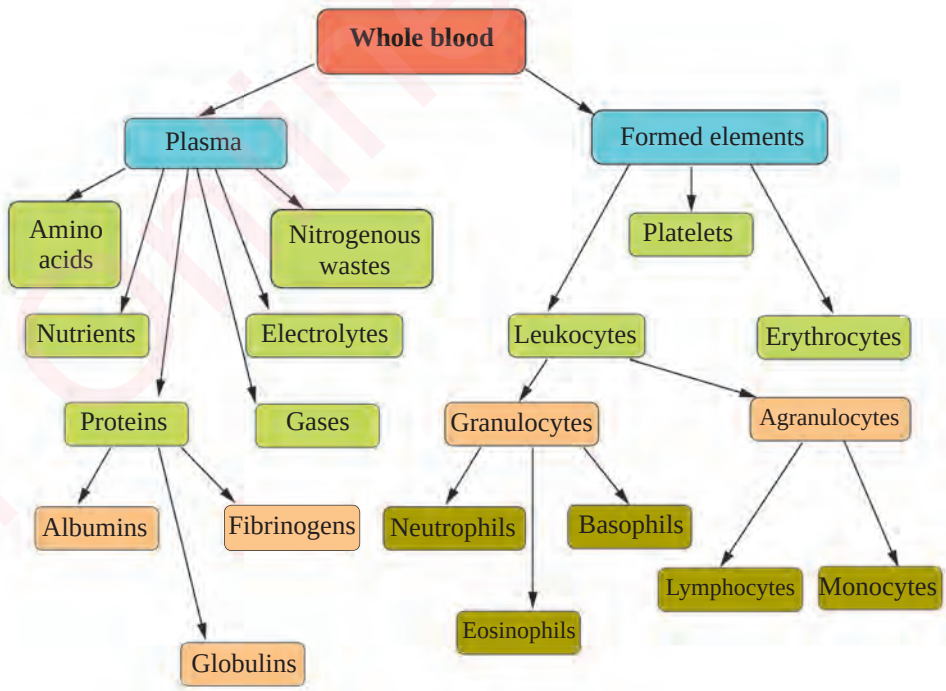


Figure 1.19 Composition of blood

are produced by the liver, except hormones and gamma globulins. Although they serve a number of functions such as maintenance of osmotic pressure and water balance in blood and tissues, they have other functions such as transport. The components of plasma vary considerably as new substances are removed or added in the blood. If a person eats a balanced diet, plasma composition is kept relatively constant by various homeostatic mechanisms. When plasma protein levels drop, the liver is stimulated to produce more proteins. In addition, when the blood becomes too acidic (acidosis), the respiratory system and kidneys restore the normal and slightly alkaline state.

Plasma proteins

There are three major categories of plasma proteins, each having its own properties and functions. They include albumins, globulins, and fibrinogens.

Albumins: These are the smallest and most abundant form of plasma proteins. About 60% of plasma proteins are albumin. These proteins act as a carrier to transport some molecules such as drugs, hormones, and fatty acids through the blood circulation. With the help of sodium ions, these are the major blood proteins which are involved in maintaining osmotic pressure of the blood. Osmotic pressure helps in maintaining water in the blood stream. It has been observed that reductions in the amount of albumin content in the plasma result in a loss of fluid from the blood and the increase of fluid in the interstitial space and tissues. This allows easier movement of ions and nutrients across cell barriers.

Globulins: These are the second category of plasma protein, which are important in immune globulin. Their abundance ranges from 36% to 38% of the total plasma proteins in the blood. These proteins can be subdivided into three classes based on their molecular weight. These are alpha, beta and gamma globulins. They include high-density lipoproteins, an alpha-1 globulin, and a low-density lipoproteins called beta-1 globulin. Lipoproteins with high density are involved in lipid and fat transport to the cells for use in metabolism, membrane synthesis, and function of hormones. They also tend to prevent cholesterol from invading and staying in the walls of blood vessels. On the other hand, the lipoprotein of low density transports cholesterol and fats to tissues to be involved in manufacturing steroid hormones and cell membranes. Therefore, globulins play a vital role in the regulation of cholesterol, and hence, they help in preventing cardiovascular diseases.

Fibrinogens: These proteins constitute 4% of the total plasma proteins. The liver produces them and they are responsible for the formation of fibrin threads of a blood clot. They are soluble precursors of a protein called fibrin and forms the framework of the blood clot.

Other components of blood plasma

Nitrogenous wastes: These form another group of solutes found in the blood plasma. They are the by-products of metabolism which include urea, uric acid, creatinine, and ammonium salts. They are toxic in nature, hence, they are cleared from the blood stream and excreted by the kidneys.

Nutrients: These include some materials absorbed from digestion including glucose, amino acids, fatty acids, glycerol and triglycerides, cholesterol, and vitamins. They are absorbed by the digestive tract and are transported in the blood plasma.

Respiratory gases: The blood plasma transports some amounts of oxygen and

carbon dioxide. In this case, oxygen is transported as it binds to the haemoglobin inside the red blood cells, while carbon dioxide is transported after it dissolves in plasma to form bicarbonate ions.

Electrolytes: Plasma is also composed of a number of electrolytes in the form of cations and anions. The cations include sodium, potassium, calcium, and magnesium. The anions include chloride, phosphate, sulphate, and bicarbonate. The most abundant of these electrolytes are sodium ions that contribute to the osmolality and normal blood pH than any other ion.

Amino acids: These are formed as a result of the breakdown of tissue proteins. They are involved in the process of protein synthesis.

Formed elements of the blood

They include erythrocytes, leukocytes, and platelets as shown in Figure 1.20. These elements are named so because they have some unusual features. Firstly, erythrocytes and platelets are not true cells. For example, erythrocytes have no nuclei and other necessary organelles such as mitochondria and ribosomes, while platelets are only fragments of cells. The leukocytes or white blood cells are the only true cells because they contain all the necessary organelles. Secondly, with the exception of white blood cells, other formed elements survive in the blood stream for only a few days compared to other blood materials. The last unusual behaviour of these elements is that they do not divide; instead, division of cells found in the red bone marrow renews them.

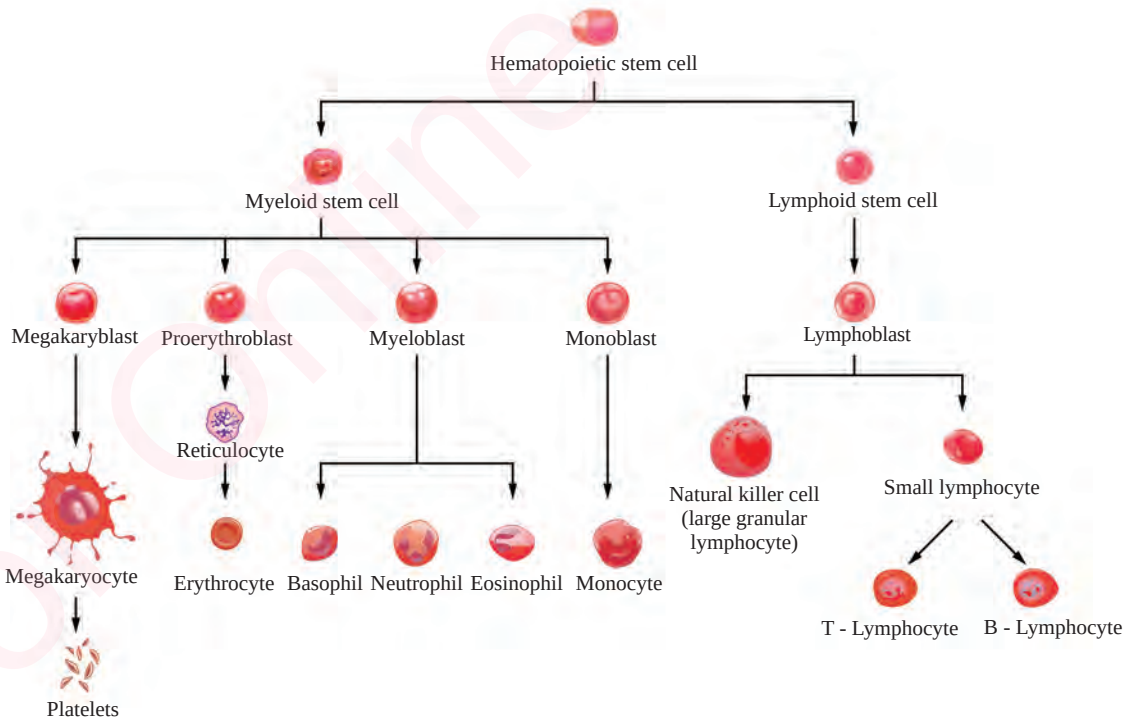


Figure 1.20 Formed elements of the blood (WBC RBC and Platelets)

Red blood cells (RBCs): A red blood cell or erythrocyte is a biconcave, disc-shaped cell with a thick rim and a thin sunken lower centre. These cells have two main functions. The first function is to pick up oxygen from the lungs and deliver it to the rest of the body. The second role is to pick up carbon dioxide from the body and unload it in the lungs. The plasma membrane of an erythrocyte has glycoproteins and glycolipids, which in turn determines a person's blood type. The proteins that determine blood type are synthesized based on the genetic information present in the DNA of an individual. The inner surface of the cell contains two types of proteins, namely: spectrin and actin. These proteins give membrane resilience and durability. As a result, the red blood cell is able to stretch, bend and fold when it squeezes through small blood vessels and capillaries. Furthermore, these proteins enable the cells to spring back to their original shape when they pass through larger blood vessels. Like any other blood cells, red blood cells are formed in a process called haematopoiesis which occurs in the red bone marrow. The latter is composed of large and soft networks of reticular connective tissues.

The cytoplasm of the erythrocytes consists of 33% solution of haemoglobin (Hb). This solution is the one that gives red blood cell its reddish colour. Haemoglobin carries most of the oxygen and some of the carbon dioxide transported by the blood. Red blood cells lose nearly all the inner cellular components during maturation. The inner cellular components or organelles that are lost include mitochondria, which are normally involved in cellular respiration and the nucleus that contains the genetic material of the cell to enable it to repair itself through mitosis. The absence of a nucleus implies that red blood cells are incapable of repairing themselves. The loss of organelles gives a red blood cells its biconcave shape. This gives the cell a greater surface area to volume ratio to enable oxygen and carbon dioxide to diffuse rapidly to and from the haemoglobin.

The life span of circulating red blood cells is about 120 days for a healthier person. After this period, red blood cells die in the spleen, where they become trapped in narrow channels, then broken up and finally destroyed through the process of haemolysis. This occurs when haemoglobin is released leaving empty plasma membranes that become digested by cells known as macrophages in the liver and spleen. The haemoglobin is then broken down into different components and recycled for further use or disposed.

White blood cells (WBCs): These are also known as leukocytes. They are the only blood formed elements that are true cells, with nuclei and the normal organelles. Leukocytes are far less numerous than their counterpart erythrocytes. Their amount is less than 1% of the total blood volume. On average, there are 4800–10,800 WBCs/µl of blood. The white blood cells are vital to our defence system against disease. They form a blood mobile army that helps to prevent and protect our bodies against the invasion of bacteria, viruses, parasites, toxins, and tumour cells. White blood cells are subdivided into granulocytes and agranulocytes.

Granulocytes

These are white blood cells that contain organelles and usually appear as coloured granules in the light microscope. Granulocytes are further subdivided into neutrophils, eosinophils, and basophils.

Neutrophils: These are the most numerous granulocytes in the white blood cells. Its population is between 50–70% of the WBCs population. They are about twice as large as erythrocytes. They contain very fine light pink cytoplasmic granules that can be seen even under a light microscope. The other name for neutrophils is polymorphonuclear as they have a variety of nuclear shapes. The main function of neutrophils is to destroy bacteria. It also releases some chemicals that kill or inhibit the growth of bacteria.

Eosinophils: In contrast to neutrophils, the eosinophils have large granules and a prominent nucleus. The nucleus of eosinophil is divided into two lobes. Their major role is in the destruction of allergens and inflammatory chemicals. They also release enzymes that disable parasites function in the body. For example, a person with tapeworm in his/her digestive tract will have an increased eosinophil count. Normally, the population of eosinophils is usually less than 3% of the total WBCs in the body.

Basophils: These are the least in numbers to all the granulocytes. They do not exceed 1% of the total white blood cells in the blood. Their nucleus is pale and usually hidden by granules. Their major role is to secrete histamine, which increases tissue blood flow, via dilating the blood vessels. They are also responsible for secreting heparin, which is an anticoagulant that promotes mobility of other WBCs, thereby preventing them from clotting.

Agranulocytes

These are white blood cells that do not contain granules. They are subdivided into lymphocytes and monocytes.

Lymphocytes: Lymphocytes are the main WBCs present in the lymph nodes. They can be medium and large lymphocytes which are usually seen in the connective tissues and only occasionally in the blood circulation. The main function of lymphocytes is to build the body immune system. They are also responsible for presenting antigens to activate other cells of the body immune system. Lastly, they coordinate the actions of other immune cells to secrete antibodies that serve in the immune memory. This is why young children have more lymphocytes than adults do because they are developing immunity to many new infectious agents.

Monocytes: They are the largest of the formed elements about 3 - 4 times bigger than red blood cells. They have an irregular shape than lymphocytes with a blue-grey cytoplasm, and a kidney-shaped nucleus. They are differentiated into macrophages and digest pathogens, dead neutrophils and dead cells. Moreover, they also present antigens to activate other immune cells.

Platelets

Platelets are tiny cell fragments in the blood that enhance blood clotting. They are also known as thrombocytes. They have no cell nucleus and other important organelles, and therefore, not termed as cells. They are small fragments of cytoplasm produced from haematopoiesis in the red bone marrow cells before entering blood circulation. Platelets have secretory factors or receptors called vasoconstrictors, which promptly constrict blood vessels in a phenomenon that is called vascular spasms. Vascular spasm is a prompt constriction of the broken blood vessel. It is the first immediate protection against blood loss as it forms temporary platelet plugs to stop more bleeding. Platelets also secrete clotting factors known as procoagulants

that promote further blood clotting. Another function of platelets is to dissolve blood clots when they are no longer needed to return the injured part into normal. They are also responsible for the digestion and destruction of bacteria. Lastly, platelets secret chemical substances that tend to attract neutrophils and monocytes to sites of inflammation.

Mechanism of blood clotting

Human body protects itself against excessive loss of blood through the blood clotting mechanism. This mechanism is haemostatic in which platelets and fibrinogen plasma protein play a major role in all stages. The term haemostasis refers to the normal response of the blood vessels to injury by forming a clot that serves to prevent haemorrhage. Blood clotting mechanism occurs in three stages namely vascular spasms, platelet plug formation, and blood clotting or coagulation. The blood clotting begins almost immediately after an injury to the blood vessel with vasoconstriction and the response is very fast, localized to the injured part and carefully controlled. The sequence of events that occur during blood clotting include the occurrence of vascular spasm, platelet plug, and blood clot.

Vascular spasm: This is the first step where the damaged vessels respond to injury by constricting blood vessels in the injured area. There are various factors involved in the initiation of vascular spasm. These factors include the release of chemicals by endothelial cells, platelets and some reflexes initiated by pain receptors. It starts with the stimulation of pain receptors, which innervate the nearby vessels, causing them to constrict before allowing other mechanisms to take over. Usually, vascular spasm lasts for about 20–30 minutes.

Platelet plug formation: The second step in blood clotting is plug formation by the actions of platelets. This is done by aggregating the earlier formed platelets and forming a plug that temporarily seals to cover the break in the blood vessel wall. The platelet plug is also known as haemostatic plug or platelet thrombus. They help to arrange the coming events that lead to clot formation. Meanwhile, endothelial cells release nitric oxide and another chemical substance called prostacyclin. These chemicals assist in restricting platelet aggregation to the injured part only. In case of severe injury, where the endothelium is injured and underlying collagen fibres being exposed, platelets will function as collagen fibres.

Blood clot: This is the final stage of blood clotting aimed at converting plasma fibrinogen into fibrin. This is a sticky protein that adheres to the walls of a damaged blood vessel. At this stage, blood cells and platelets become stuck to fibrin and form fibrin mesh which helps to seal the break in the blood vessel. The process of blood clotting involves three stages. In the first stage, a complex substance called prothrombin activator is formed from the body chemical reactions in response to damage in the blood vessels. In the second stage, prothrombin activator converts a plasma protein called prothrombin into thrombin. Thrombin is an enzyme that hydrolyses fibrinogen protein into fibrin. Fibrin is insoluble and fibrous in nature and forms needle-like fibres called fibrin mesh. This mesh traps blood cells and effectively seals the hole until the blood vessel can be permanently repaired.

Exercise 1.5

1. Discuss the composition and functions of the mammalian blood.
2. Briefly describe functions played by plasma proteins in the mammalian body.
3. Explain why do red blood cells lose their nuclei and mitochondria as they mature and state the advantages of this tendency to the cell.
4. Discuss the changes in blood composition as it passes through the following parts: (i) lungs (ii) intestine (iii) kidneys and (iv) active muscles.
5. Briefly discuss how platelets, fibrin, and red blood cells interact to form a blood clot in the injured part.

The heart

This is another component of the vertebrate circulatory system. It is a muscular organ between the two lungs behind the sternum that serves as a body's circulatory pump. It is a central component of the circulatory system and it is responsible for pumping the blood thereby distributing oxygen and nutrients throughout the body. It is because of this role that the heart is taken as the most important organ in the body so that even a minor dysfunction or abnormality causes drastic consequences to the organism. For a normal healthier adult, the heart goes 72 beats or cardiac cycles in one minute. However, this rate is different for children whose heart rates are higher and relatively faster than adults are. This is because babies' growth rate is very high and hence, their cells burn food fast to fuel growth. Another reason for their higher heartbeat rate is due to their smaller size compared to adults. This gives them a large surface area-volume ratio. Hence, they have more heat loss per unit area requiring a high metabolic rate to maintain constant body temperature.

Heart structure

The heart is surrounded by a double-walled and tough sac called pericardium and is located within a fluid-filled cavity known as the pericardial cavity. The superior end of the heart is the base, which is further attached to the aorta, pulmonary arteries, pulmonary veins, and the vena cava as shown in Figure 1.21. Its inferior part is the apex placed just above the diaphragm.

About two-thirds of its mass points to the left of the cavity and the remaining one-third is on the right. It is made up of four chambers and several valves that regulate the normal flow of blood in the body. The pericardium produces serous fluid to lubricate the heart. It is also responsible for preventing friction between the heart and the organs surrounding it. In addition, pericardium has a role of holding the heart firm in its position and maintaining a hollow space for it to expand. Pericardium has two layers, the first one is the visceral layer that covers the outside of the heart while the parietal layer forms a sac around the outside of the pericardial cavity.

Heart walls

The wall of the heart consists of three layers namely epicardium, myocardium, and endocardium. The epicardium or visceral is the outermost layer of the heart. It is a thin layer of serous membrane, which lubricates and protects the outside parts of the heart. Just below epicardium is the second layer called myocardium that is much thicker than epicardium. It is the muscular layer

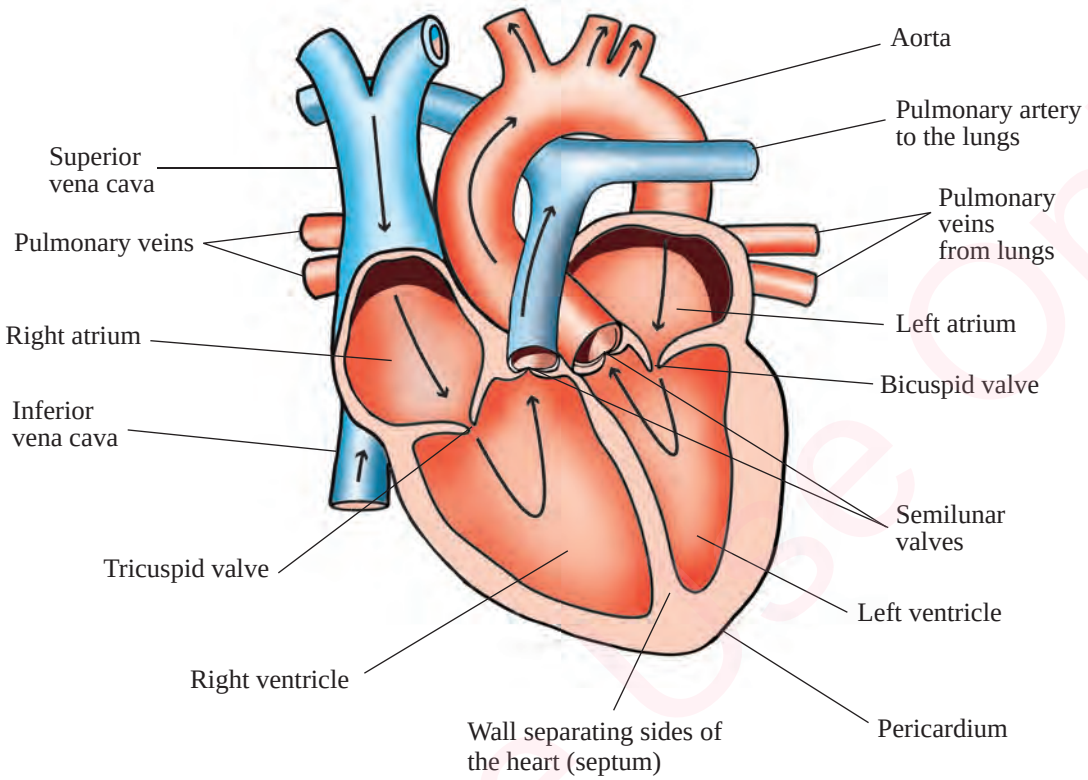


Figure 1.21 Longitudinal section of the heart

of the heart wall, which contains the heart or cardiac muscle tissues. Myocardium comprises the majority of the thickness and mass of the heart wall to enhance the pumping of the blood. The atria have a thin myocardium because they do not need to pump blood far. They only pump the blood to the ventricles. In contrast, ventricles have a very thick myocardium because they have to pump blood to the lungs and throughout the body. The same reasons explain why the right side of the heart has less myocardium in its walls than the left side. The left side has to pump blood through the entire body via systemic circulation while the right side is supposed to pump blood to the lungs via pulmonary circulation. The third and last layer is endocardium that is found just below the myocardium. It is a thin simple squamous endothelium layer, which covers the parts inside the heart.

Heart chambers

The heart is made up of four chambers. These are right and left atria (singular is atrium), right and left ventricles. The atria are present in the upper part of the heart. The right atrium is involved in receiving deoxygenated blood from the body cells. Compared to ventricles, atria are smaller chambers and have thin less muscular walls. The two valves, which separate the right and left atrial chambers from the ventricles are known as atrioventricular valves.

The left atrium has the bicuspid valve while the right atrium has the tricuspid valve. Atria are the receiving chambers, hence, they are connected to the blood veins which carry blood to the heart. Ventricles, on the other hand, are chambers found on the lower part of the heart. They are responsible for pumping oxygenated blood into all organs and cells of the body. They are larger and stronger blood pumping chambers that send blood out of the heart. Like atria, valves called semilunar valves also separate ventricular chambers from the aorta and pulmonary artery. Semilunar valves are either the pulmonary valve or aortic valve. Ventricles are connected to the arteries because these vessels carry the blood away from the heart as shown in Figure 1.22.

Heart valves

The atrioventricular and semilunar valves of the heart chambers differ in terms of their location and functions. Atrioventricular valves are positioned in the middle of the heart between the atria and ventricles. Their role is to allow the blood to flow from the atria down into the two ventricle chambers. The atrioventricular valve present on the right side is called the tricuspid valve. This is because it consists of three cusps or flaps

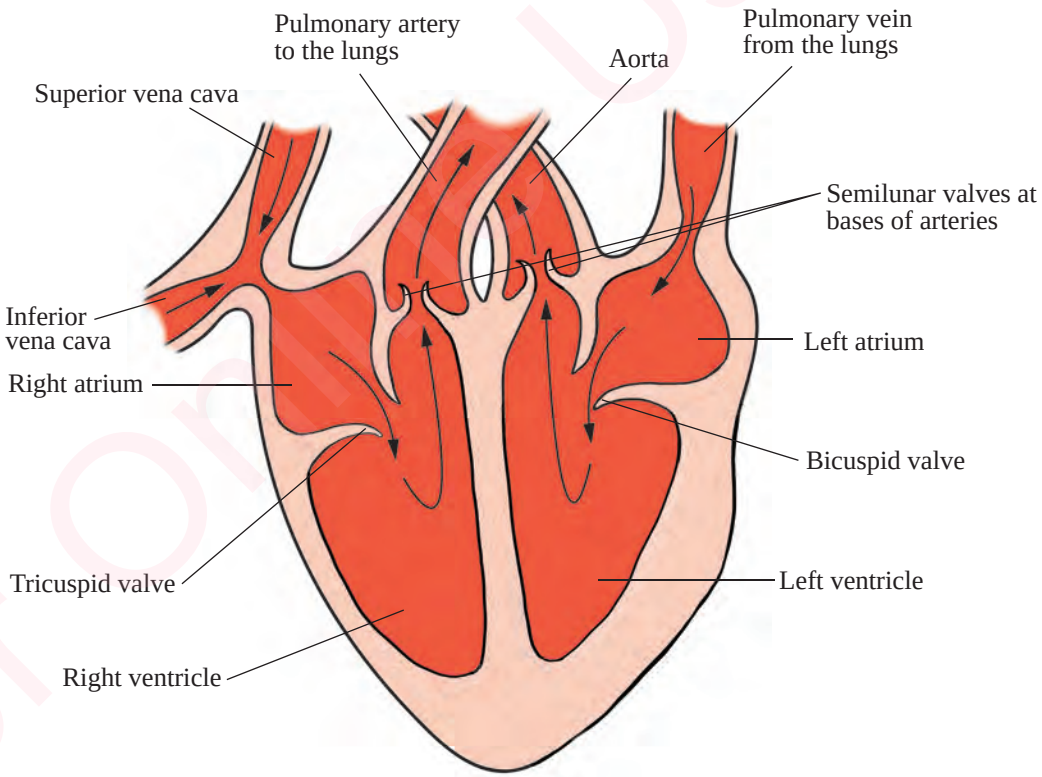


Figure 1.22 Simplified structure of the heart showing its valves and chambers

that tend to prevent or allow blood to pass through. The atrioventricular valve present on the left side is known as the bicuspid valve or the mitral valve because it has two flaps. Chordae tendineae are strings that attach both the tricuspid and bicuspid valves to the ventricular side. These strings tend to pull on atrioventricular valves in order to prevent them from folding backward thereby allowing the blood to regurgitate. Regurgitation is the process in which the blood flows in the opposite direction from normal. This occurs when chordae tendineae close the valve to block the normal direction of flow. During this process, the ventricles contract and the atrioventricular valve take a parachute-shaped structure with the chordae tendineae acting as a rope to hold the parachute thus pushing the blood to the opposite direction.

The semilunar valves are named so because they are crescent moon-shaped cusps. They are located at the point where the pulmonary artery and aorta leave the heart. The semilunar valve on the right side of the heart is called the pulmonary valve while the valve on the left side of the heart is called the aortic valve. The pulmonary valve is named so because it prevents the blood to flow back from the pulmonary trunk to the right ventricle. The aortic valve also is named so because it prevents the regurgitating blood present in the aorta from flowing back into the left ventricle chamber. The semilunar valves are smaller than the atrioventricular valves, hence; do not have chordae tendineae to hold them in place. However, their cusps have cup shapes for catching regurgitating blood and for generating blood's pressure that promptly closes it.

Blood flow through the heart

The flow of the blood through the heart starts when deoxygenated blood returning from the body enters the heart from the superior and inferior vena cava. From there, the blood enters the heart through the right atrium. Then it will be pumped through the tricuspid valve into the right ventricle. The blood will then be pumped through the semilunar valve into the pulmonary artery. The pulmonary artery carries the blood to the lungs to release the carbon dioxide and absorb oxygen. After oxygenation, the blood will return from the lungs to the heart through the pulmonary veins. Finally, the blood will enter the heart again through the left atrium. This will then contract to pump blood via a bicuspid valve to the left ventricle. From the left ventricle, the blood will be pumped through the aortic semilunar valve into the aorta. The aorta will then distribute blood into arteries through systemic circulation until the blood returns to the heart via the vena cava to restart the cycle again.

Heart sounds

The sounds of a normal heartbeat are known as lub and dup. They are caused by blood pushing on the atrioventricular and semilunar valves. The lub is the first sound to come and takes a relatively longer period than the dup. It is caused by the closing of the atrioventricular valves to initiate ventricular systole. The dup, on the other hand is shorter and have sharper sound than the lub. It is a result of the closing of the semilunar valves after the completion of ventricular systole. For a normally functioning heart, these two sounds repeat in a pattern of lub-dup-pause fashion. Any other sounds apart from these is an indicator of the heart problem such as valve leakage.

Cardiac output

Cardiac output (CO) is the term used to describe the volume of blood pumped by the heart in one minute. It is calculated from the following equation: CO = Stroke Volume (SV) x Heart Rate (HR). The value of cardiac output is expressed in L/min. In the equation, stroke volume (SV) denotes the amount of blood pumped into the aorta in each ventricular systole. It is normally measured in millilitres. Heart rate is the number of heart beats per minute. For a healthier person with an average of 70 kg, the cardiac output is around 5L/min with an assumption that the heart rate is 70 beats per minute and the stroke volume (SV) is 70 mL. Cardiac output is an effective indicator of whether or not the heart can meet oxygen and nutrients demands of the body.

Function of the heart

The primary function of the heart is to pump the blood in order to transport oxygen, nutrients and other materials in the body. The presence of two types of blood vessels, the veins and arteries facilitate this function. It pumps the deoxygenated blood through the pulmonary artery to the lungs for oxygenation before pumping it again as oxygenated blood via arteries to the body cells and tissues. The pumping mechanism of the heart is made possible by the coordination of a number of parts such as its chambers and valves. The four chambers that are present in this organ takes in and distributes both the oxygenated and deoxygenated blood. These chambers are associated with veins and arteries, which take in the pumped blood and transports it to the destinations.

The cardiac cycle

The cardiac or heart cycle refers to the sequence of events which takes place in the process of completing one heartbeat. It involves the path of the blood, as it enters into the heart then pumped to the lungs, then traveling back to the heart, and finally pumped to the other parts of the body. The events of cardiac phase are divided into four sub-phases, namely: atrial diastole phase, atrial systole phase, ventricular diastole phase, and ventricular systole phase. However, it is important to note that the events occurring in the first and second diastole phases are happening at the same time. This is also true for the events taking place during systole phases.

Atrial diastole phase: During the first diastole phase, both the atria and ventricles are in the state of relaxation and the atrioventricular valves are open. This contraction will allow the deoxygenated blood that is returning to the heart from other parts of the body to pass through the superior and inferior vena cava and flow to the right atrium. The opened atrioventricular valves (tricuspid and bicuspid valves) will then allow blood to pass through the atria to the ventricles. Electrical impulses from the sinoatrial (SA) node will then travel to the atrioventricular (AV) node. As a result, the atrioventricular node sends signals that trigger both atria to contract once again.

This contraction enables the right atrium to force the blood into the right ventricle. The tricuspid valve which is located between the right atrium and right ventricle functions to prevent the blood from flowing back into the right atrium as summarized in Figure 1.23.

Atrial systole phase: Atrial systole phase begins with a simultaneous contraction of two atria which results into the blood being pumped into the ventricles. Both ventricles will receive electrical impulses from fibre branches causing them to contract.

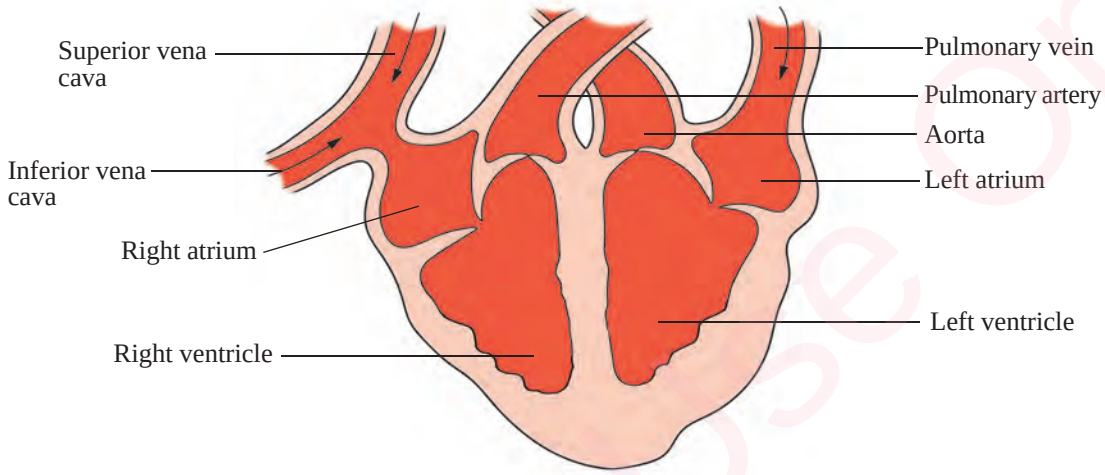


Figure 1.23 Atria in the state of diastole

When this contraction occurs, the atrioventricular valves close and the semilunar valves that include pulmonary valve and aortic valve open. The contraction will cause deoxygenated blood from the right ventricle to be pumped to the pulmonary artery. The pulmonary valve will function to prevent the blood from flowing back into the right ventricle. The function of the pulmonary artery is to carry deoxygenated blood along the pulmonary circuit to the lungs. From the lungs, the blood will pick oxygen and return to the left atrium of the heart via the pulmonary veins as indicated in Figure 1.24.

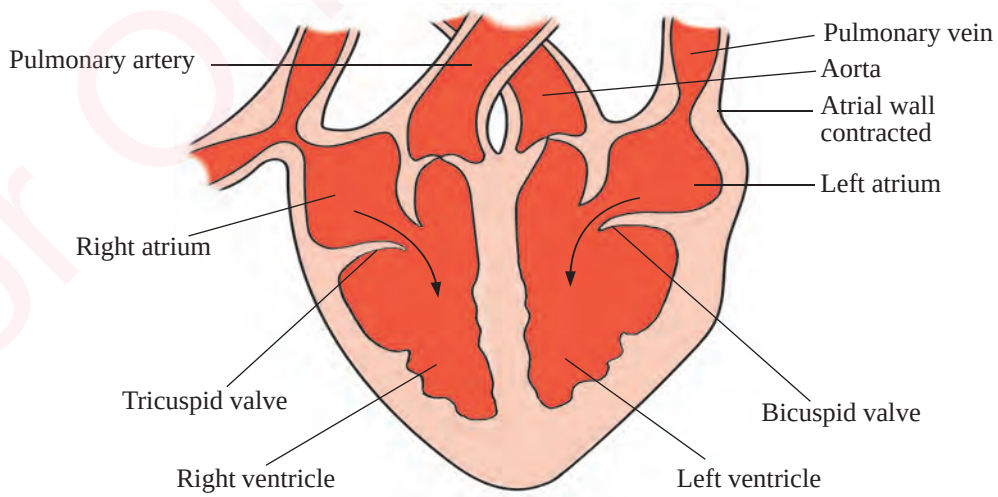


Figure 1.24 Atria in the state of systole

Ventricular diastole phase: During the second diastole phase, semilunar valves close while atrioventricular valves open. This will allow the oxygenated blood from the pulmonary vein to fill the left atrium. At the same time, the blood from vena cava fills the right atrium. The sinoatrial node contracts once again to trigger both atria to contract. This atrial contraction will cause the left atrium to force the blood into the left ventricle.

At the same time, the right atrium will also force the blood to flow into the right ventricle. The bicuspid valve, which is located between the left atrium and left ventricle, will function to prevent the oxygenated blood from flowing back into the left atrium as shown in Figure 1.25.

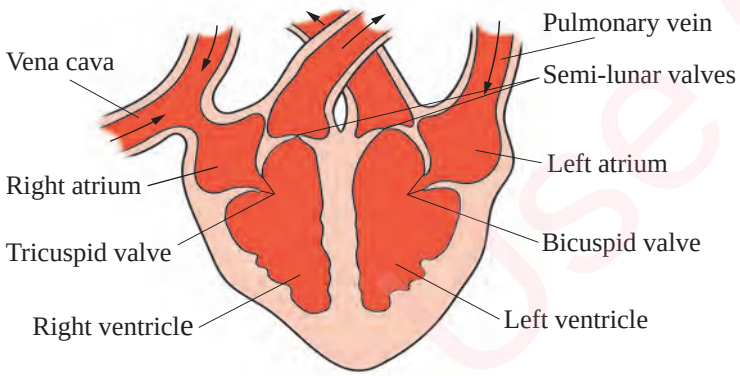


Figure 1.25 Ventricles in the state of diastole

Ventricular systole phase: At this phase, both atrioventricular valves close while the semilunar valves open. The ventricles will receive impulses and contract. This contraction causes the oxygenated blood in the left ventricle to be pumped to the aorta. While this is happening, the aortic valve will be preventing the oxygenated blood from flowing back to the left ventricle. At the same time, the deoxygenated blood will also be pumped from the right ventricle to the pulmonary artery. From the aorta, the oxygenated blood is distributed to different parts of the body via arteries and fine capillaries through the process of systemic circulation as indicated in Figure 1.26.

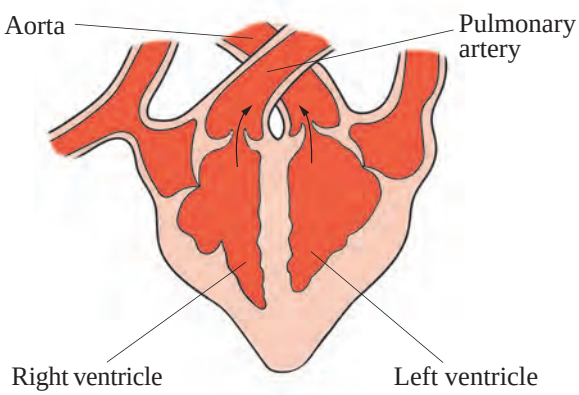


Figure 1.26 Ventricles in the state of systole

The structure of cardiac muscles

The heart is the specialized organ in chordates, which is concerned with the pumping of blood throughout the body. It is made up of the special type of muscles known as cardiac muscles. The heart beats powerfully and continuously throughout the entire life without any rest. This is because the cardiac muscles have incredibly high contractile strength and stamina.

The cardiac muscle is composed of muscle fibres each of which possesses one or two nuclei and many large mitochondria as shown in Figure 1.27. The muscle fibres are made up of many myofibrils that contain actin and myosin filaments. These proteins interact to bring about a contraction of the cardiac muscle. The muscle appears with striations due to the presence of the actin and myosin filaments. The dark bands known as intercalated discs separate the individual muscle cells from each other. In other words, these discs are cell surface membranes that separate individual muscle cells. The structure of the membrane in the muscle cells is modified to allow rapid diffusion of ions, contraction and relaxation of the muscle fibres. The fibres branch and cross-connect with each other to form a complex net-like arrangement. There is no nerve cell in cardiac muscles but only muscle fibres for conduction of electrical impulse. The rapid diffusion of ions in the membrane causes the rapid spread of action potentials (excitation) through the muscle. Thus, the excitation of one cell causes an action potential to spread to other cells quickly such that the whole mass of fibres behaves as one unit. Another feature that is unique to the cardiac muscle tissue is autorhythmicity or myogenicity. The cardiac muscle tissue is able to set its own contraction rhythm due to the presence of pacemaker cells or sino-atrial node (SAN), which stimulates the other cardiac muscle cells.

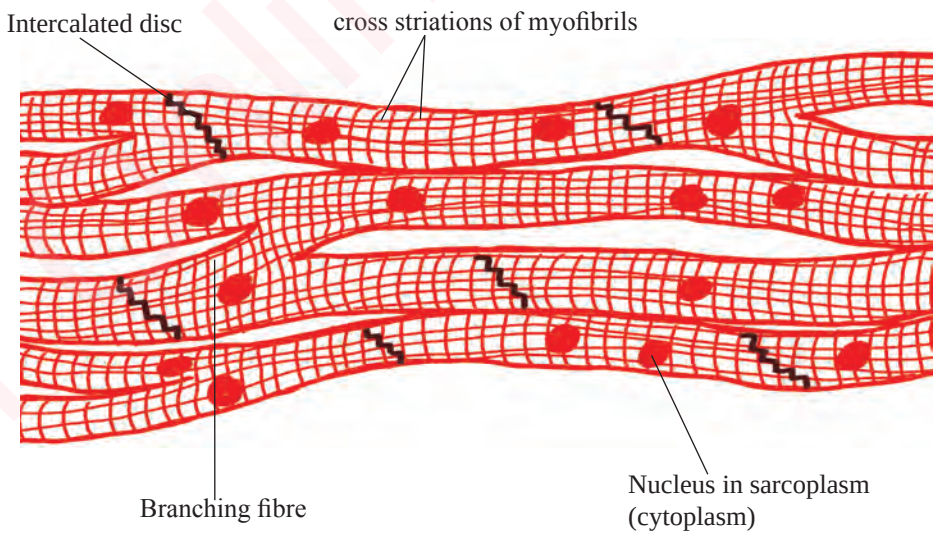


Figure 1.27 The structure of cardiac muscle

Adaptations of cardiac muscles to their functions

As explained earlier, the role of the heart is to pump the blood throughout the body. This function requires energy, the strength of the muscles in the heart and permeability of the action potential through the heart walls.

The cardiac muscle is equipped with structural and physiological features to facilitate the pumping action of the heart. The muscle is made up of striated fibres, which make it tough and strong, to withstand the pumping activity of the heart. The muscle fibres are packed with numerous mitochondria for the liberation of enough energy required for the pumping activity. Moreover, the muscle is highly supplied with blood vessels for perfusion of nutrients and oxygen. Interestingly, the cardiac muscle cells have an ability to oxidize lactic acid from skeletal muscle for energy release. Additionally, the cardiac muscle contains many connective tissues that add up to its strength, and the inner surface of the muscle has a fluid, which acts as a lubricant, to protect it from tearing.

The cardiac muscle contracts more slowly than the skeletal muscles and thus, does not fatigue as easily as the skeletal muscles. However, contraction of the cardiac muscle is efficient due to the pressure of sufficient myofibrils with actin and myosin filaments. The cardiac muscle is myogenic. That is, it has the ability of self-stimulation without the assistance of neurone. This makes the cardiac strokes to be self-generated within the heart itself. Thus, there are no neurones in the walls of the heart but the muscle fibres branch and cross-connect each other to form a net-like arrangement for the transfer of action potentials. This means that, when one cell becomes excited, the action potential spreads quickly to all other cells causing all fibres to work as a unit.

Exercise 1.6

1. Describe the structure of mammalian heart including its location and position within the body cavity.
2. With the help of well-labelled diagrams, explain what happens to the flow of blood in the heart during atrial systole and ventricular diastole phases of the cardiac cycle.
3. Describe the structure and functions of the cardiac muscle and briefly explain how it is adapted to its functions.
4. What is the significance of atrioventricular valves and semilunar valves in the functioning of the heart?
5. Compare diastolic and systolic blood pressures and the ways in which they affect the flow of blood.

The circulatory systems in animals

The circulatory system of animals is a combination of circulating fluid such as blood, tubes through which the fluid flows, for example, blood vessels and a pumping organ such as the heart or modified blood vessel. This system is used to transport blood and other materials throughout the body of an animal. Animals have different shapes, sizes, and types of circulatory systems. The animal can have either an open or a closed circulatory blood system.

The open circulatory system

This is a circulatory system in which blood and interstitial fluid may mix up as shown in Figure 1.28 (a).

The 'blood' in these organisms is called haemolymph that is an intermediate mixture of blood and interstitial fluid. In this system, the organs are directly bathed with the blood and there is little control over the direction of blood circulation. Blood moves on to the head region through waves of contraction of the muscular walls and valves, where open circulation starts again. With an open circulatory system, the blood is pumped into an open cavity and is allowed to diffuse to other parts of the body. This type of circulatory system is found in some organisms like arthropods and molluscs.

The closed circulatory system

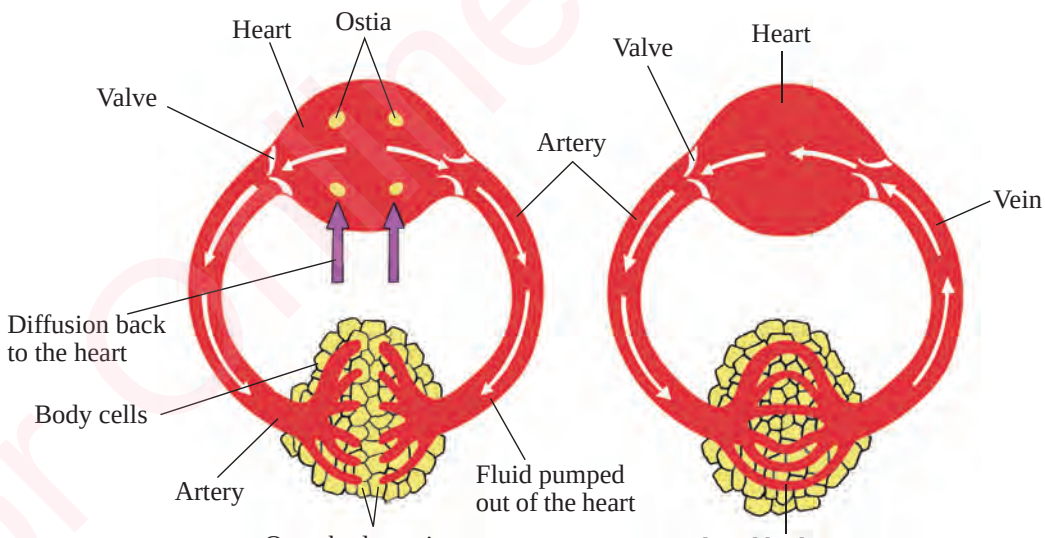
This is a system in which blood flows within a complex network of vessels or tubes that are all connected to each other as shown in Figure 1.28 (b). The heart pumps the blood throughout the body in a continuous circuit involving different types of vessels. Unlike in the open circulatory system, in the closed circulatory system, organs are not in direct contact with the blood.

They are rather bathed by the fluid leaking out of capillaries that are the narrow, thin-walled parts of the system.

This tissue fluid is also the medium in which the exchange of materials between the blood and the body tissues take place. This exchange of materials occurs before the fluid returns to the blood vessels. Vertebrates and a few invertebrates have a closed circulatory system.

The differences between open and closed circulatory systems

Generally, the closed and open circulatory systems differ in the following aspects as summarised in Table 1.3.



(a) Open circulatory system (b) Closed circulatory system

Figure 1.28 The open and closed circulatory systems

Table 1.3 The differences between open and closed circulatory systems

S/n	Open circulatory system	Closed circulatory system
1.	The blood is not confined to vessels.	The blood is confined to vessels.
2.	The organs are in contact with the blood, that is, they are immersed in blood.	The organs are not immersed in blood, that is, they are not in contact with the blood.
3.	The blood circulates slowly around the body due to low pressure.	The blood circulates rapidly around the body due to high pressure.
4.	The direction of blood flow can slightly be controlled.	The direction of blood flow has defined control.
5.	The rate of flow cannot be controlled.	The rate of flow can be controlled.
6.	The supply and elimination of materials takes place slowly.	The supply and elimination of materials takes place rapidly.
7.	The exchange of materials takes place between blood and sinuses.	The exchange of materials between blood and tissues takes place through capillaries.

Types of closed circulatory system

The flow of blood in the closed circulatory systems is of two types depending on whether the blood passes through the heart once or twice in each complete circulation. The two types of closed circulatory systems are single and double circulatory systems.

Single circulatory system

This is the blood circulation in which the blood passes through the heart, once in each circuit around the whole blood circulation system in an organism as shown in Figure 1.29. Fish is an example of organisms that have a single circulatory system. The blood in fish is pumped from the heart to the gills, where oxygen is absorbed and carbon dioxide is released. The blood then flows from the gills to the rest of the body parts before returning to the heart. The blood flow is slow because the body organs are arranged in series. These causes blood pressure to fall from one organ to another, as a result, the blood faces resistance when passing through the capillaries. The single circulatory system solves the problem of separating oxygenated and deoxygenated blood, but it does not solve the problem of low blood pressure. The blood that leaves the heart is under high pressure, but once it is far away and enters through a network of fine vessels in the gills, the pressure slows down.

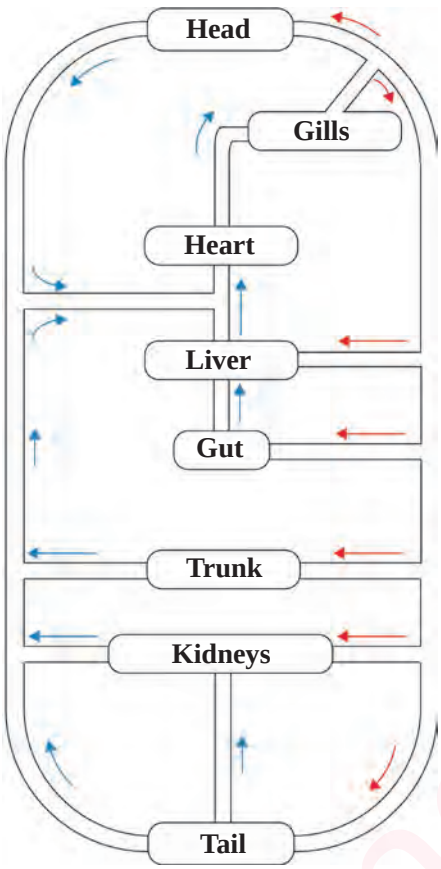


Figure 1.29 Single circulatory system in fish

Double circulatory system

In this system, blood is first pumped to the respiratory surface (lungs) to take oxygen after which it flows back to the heart before it is pumped over the body tissues. The blood passes through the heart twice for each circuit of the body. Double circulation is made possible because the heart is divided into two halves whereby one-half pumps deoxygenated blood to the lungs and the other half pumps oxygenated blood to the rest of the body. In animals with double circulation, the body organs are arranged in parallel form. The system solves the problem of mixing oxygenated blood and deoxygenated blood. It is also solves the problem of low blood pressure as blood travels to the cells far away from the heart.

The return of blood to the heart from the respiratory surface enables sustenance of high blood pressure and allows rapid circulation of blood in the body. This improves the efficiency of oxygen distribution, therefore ensuring a high metabolic rate. Examples of animals with double circulation are mammals and birds. In the double circulatory system, the blood flows through the pulmonary and systemic circulation pathways. Pulmonary circulation is the flow of the blood between the lungs and the heart. In this route, a pulmonary artery carries deoxygenated blood from the right ventricle to the lungs. The oxygenated blood from the lungs to the heart is conveyed to the left atrium by a pulmonary vein. On the other hand, the systemic circulation involves the movement of blood between the heart and all other parts of the body except the lungs.

In this case, oxygenated blood leaves the left ventricle to various parts of the body through the aorta as shown in Figure 1.30. The vena cava returns the deoxygenated blood from various parts of the body to the heart. Within the heart the blood flows through coronary circulatory system. The oxygenated blood enters the muscles through the coronary arteries and the deoxygenated blood is brought back to the heart chambers by coronary veins.

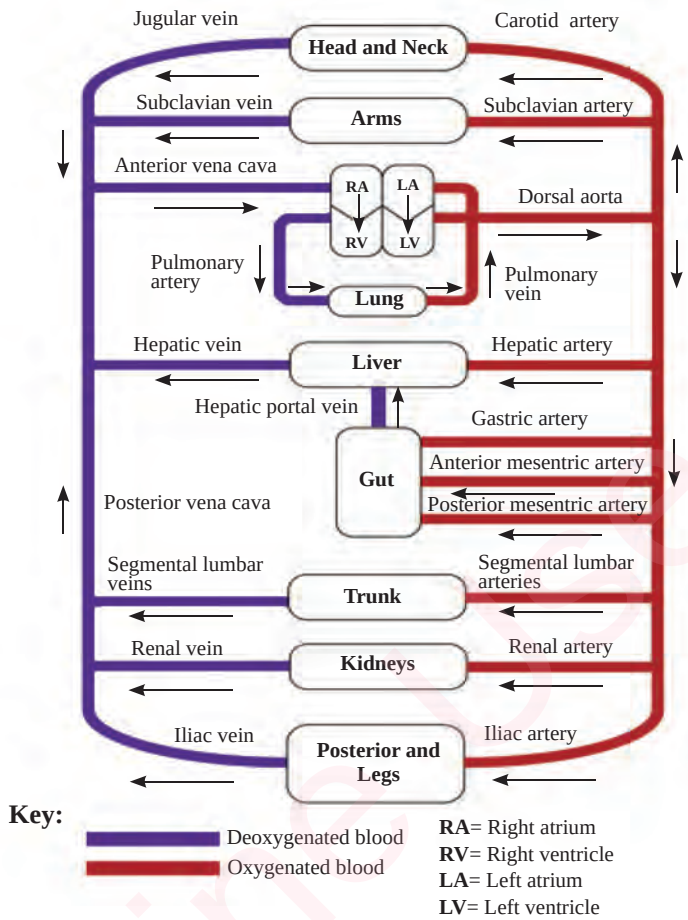


Figure 1.30 Systemic and pulmonary circulation systems (double circulation)

Exercise 1.7

1. With examples, differentiate between open and closed circulatory systems.
2. Discuss the main advantages of a double circulatory system over a single circulatory system.
3. Explain differences between single and double circulatory systems.
4. Give reasons why the flow of blood in single circulatory system is slower than in a double circulatory system.
5. What advantages do the mammals and birds gain by having oxygenated blood flowing at high pressure to the tissues?
6. Consider a red blood cell traveling from the right ventricle all the way to the right coronary artery; describe all valves it must pass before reaching the destination.

Foetal and adult blood circulation in mammals

The foetal circulation is the system which encompases the entire foetal placental circulation comprising the umbilical cord and the blood vessels within the placenta. The foetal circulation works differently from that of an adult mammal, mainly because the foetal lungs are not in use. The foetus, therefore, obtains oxygen and nutrients from the mother across the placenta by diffusion. These materials are conveyed to the foetus by blood vessels in the umbilical cord.

The umbilical vein carries the blood from the placenta to the foetus. A considerable amount of blood enters the foetal ductus venosus. This is the short vessel, which connects the umbilical vein to the inferior vena cava. Afterward, the blood is carried to the inferior vena cava, while the remaining blood enters the liver through the inferior border of the liver and then supplies the right lobe of the liver. The blood then moves to the right atrium of the heart via inferior vena cava. In the foetus heart, there is an opening between the right and left atriums called foramen ovale as shown in Figure 1.31.

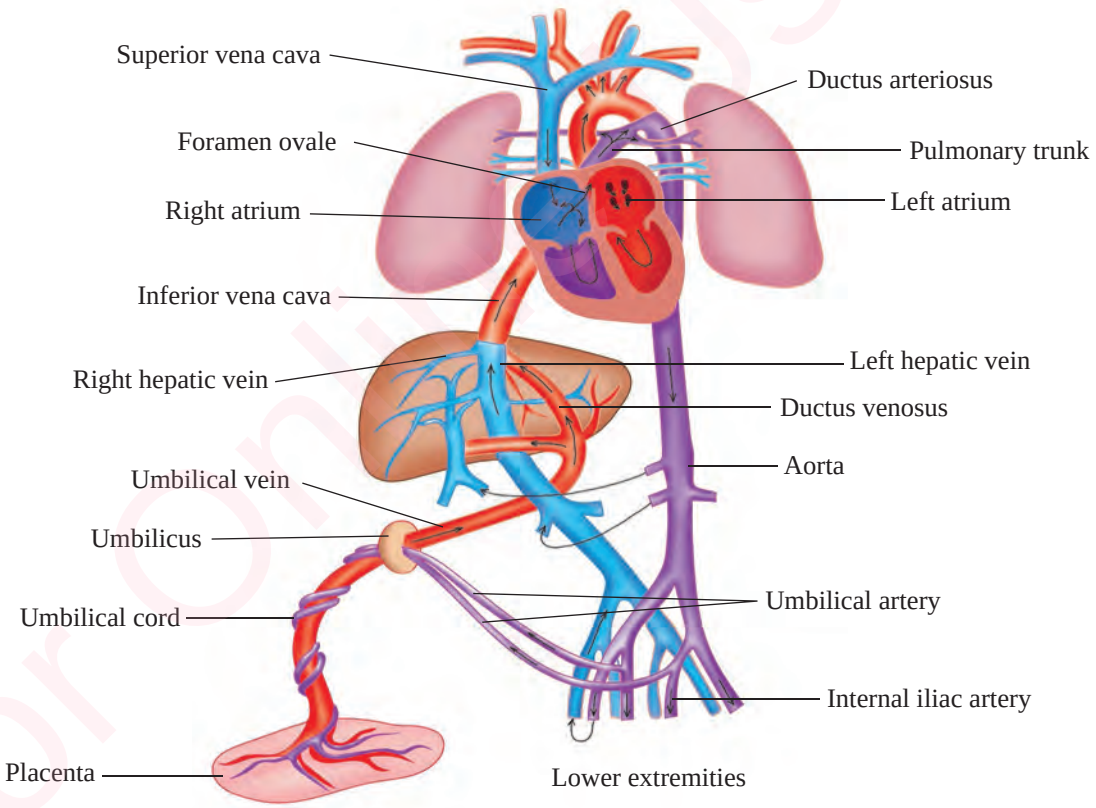


Figure 1.31 Foetal circulatory system

Most of the blood from the right atrium flows through this hole directly into the left atrium. From here, the blood flows into the left ventricle, from which it is pumped through the aorta into the body. Some of the blood moves from the aorta through the internal iliac arteries to the umbilical arteries and re-enters the placenta, where carbon dioxide and other waste products from the foetus are taken up into the maternal circulation by diffusion.

Some of the blood that enters the right atrium does not pass directly to the left atrium through the foramen ovale, but it enters the right ventricle and is then pumped into the pulmonary artery. In the foetus, there is a special connection between the pulmonary artery and the aorta, which is called the ductus arteriosus as shown in Figure 1.31. This directs most of the blood away from the lungs because the latter is not used for gaseous exchange. Apart from bypassing the lungs, the blood also by-passes pulmonary veins, atrium and ventricle of the left side of the heart. The foetal haemoglobin has a very high affinity for oxygen compared to the adult haemoglobin. This feature enables the foetus to extract more oxygen from the maternal blood supply.

As soon as the baby comes out of the mother's womb, its lungs start functioning. This reduces the resistance against the blood flow through the pulmonary vessels and therefore, allows blood to flow through the pulmonary capillaries preferentially to ductus arteriosus. Hence, the initiation of pulmonary circulation takes place as shown in Figure 1.32.

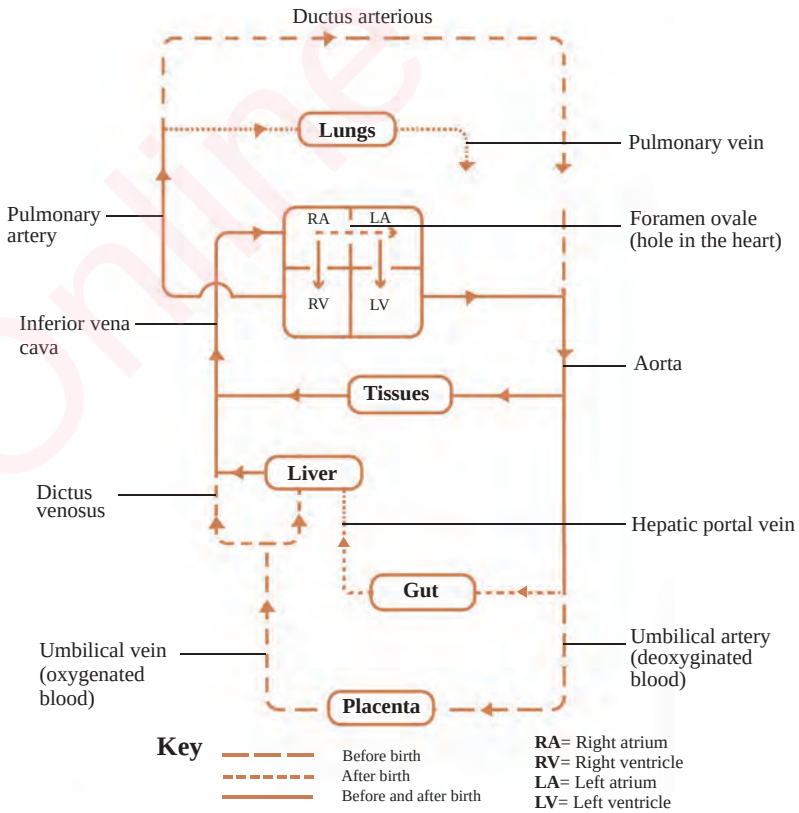


Figure 1.32 Foetal and post-natal circulatory systems

The volume of blood circulating in the body increases and the flow of the blood to the placenta is prevented due to the tying of the umbilical cord. These factors cause an increase in the blood pressure in the aorta and the left part of the heart. This increase in pressure leads to the closure of the foramen ovale in a few months after birth.

Furthermore, as the concentration of oxygen in the blood increases, the ductus arteriosus closes off in few hours after birth. In a similar way, the ductus venosus shuts down thereby allowing hepatic portal vein and hence the liver to function.

Differences between the foetal and adult blood circulation

There are both similarities and differences between the foetus and adult blood circulation systems. The cause of these differences is that most functions that are performed by the gut, kidney, liver and lungs in the adult are all performed by placenta in the foetus. For example, the placenta supplies the nutrients and oxygen in the foetus. In addition, the waste materials, which are returned to the maternal circulation, pass through the placenta. Generally, the differences between foetal and adult circulation systems are summarised in Table 1.4.

Table 1.4 Differences between foetal and adult circulatory systems

S/n	Foetal circulation	Adult circulation
1.	There are umbilical vessels.	The umbilical vessels are missing.
2.	Blood bypasses the liver due to the presence of a ductus venosus.	The blood goes to the liver as ductus venosus is sealed.
3.	There is no pulmonary circulation due to the presence of ductus arteriosus.	There is pulmonary circulation since the ductus arteriosus is sealed.
4.	There is the mixing of oxygenated and deoxygenated blood due to the presence of foramen ovale.	The oxygenated and deoxygenated blood do not mix as the foramen ovale is sealed.
5.	Lungs are not functional, thus gaseous exchange takes place at the placenta.	Lungs are functional, and therefore, are sites for gaseous exchange.
6.	There is no functional hepatic portal vein.	There is a functional hepatic portal vein.
7.	Haemoglobin has a high affinity for oxygen.	Haemoglobin has a low affinity for oxygen.
8.	The pressure is higher in the pulmonary artery than in the aorta.	The pressure is higher in the aorta than in the pulmonary artery.

Revision questions

1. Explain why transportation of materials is necessary in plants and animals.
2. Describe the structure of specialised conducting tissues of plants.
3. Explain how water and mineral salts are transported through the plant.
4. Give a detailed description of phloem translocation as conceptualised by Münch in 1930.
5. The stomatal pores open during the day and close during the night. Give an illustrated description to support this view.
6. Describe the structure, function, and adaptation of the cardiac muscle.
7. Koku has a heart rate of 50 beats per minute. Her cardiac output is 5 L/min. Her end-diastolic volume is 150 mL. Calculate her stroke volume and end systolic volume.
8. Explain the structural and functional differences between phloem and xylem tissues.
9. With the help of well-labelled diagrams, explain what happens to the flow of blood in the heart during atrial diastole and ventricular systole phases of the cardiac cycle.
10. Describe the foetal circulatory system as compared to maternal circulatory system.
11. Explain the role played by protein pumps during active transport in plants.
12. Explain why pure water has maximum water potential.
13. Name three substances apart from food molecules and water that are transported in the blood, their functions and location in the body.
14. Describe the chambers of the heart and give reasons why the left ventricle is more muscular than the right ventricle.
15. In which part of the circulatory system does blood flow:
    (a) Most rapidly?
    (b) Most slowly?
    (c) Give reasons for the rapid and slow flow of the blood in the parts mentioned in (a) and (b) above.
16. Explain how the shape and contents of a red blood cell relate to its function.
17. Explain the changes that take place in foetal circulation after birth.

Chapter
Two

Growth and development

Introduction

Growth is a fundamental characteristic of living organisms. It is an increase in the number of cells through mitosis, leading to an irreversible increase in size. In unicellular organisms, growth involves cell divisions, enlargement and increase in their numbers while in multicellular organisms it involves cell divisions, enlargement, differentiation, specialisation, and increase in size rather than numbers. In this chapter, you will learn about mitosis process, growth patterns, the role of apical and lateral meristems in primary and secondary growths respectively. You will also learn about the concept, types and significance of seed dormancy and viability, ways of overcoming seed dormancy, and the factors that govern seed viability.

Mitosis

Mitosis is a process by which a cell nucleus divides to produce two daughter nuclei, which contain sets of chromosomes identical to the parent cell. This process is followed by cleavage of cytoplasm, reformation of a cell membrane, cell wall (in a plant cell) and separation of the two daughter cells. Mitosis results in an increase in the number of cells, therefore, it brings about growth and development in multicellular organisms. In unicellular organisms, mitosis is a basis of asexual reproduction as it leads to the production of the entire organisms and hence an increase in their numbers. Normally, a series of events occurs between one cell division and the subsequent divisions. This sequence of events constitutes a cell cycle as summarized in Figure 2.1.

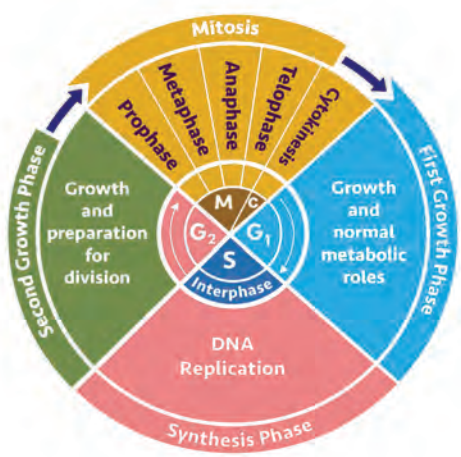


Figure 2.1 The cell cycle

The cell cycle has five phases, which are growth phase I, synthesis, growth phase II, cytokinesis and mitosis. The first three phases of the cell cycle are growth phase I (G_1), synthesis (S) and growth phase II (G_2) which together constitute the interphase.

The G_1 phase occurs soon after nuclear division (mitosis) and cytoplasm division (cytokinesis).

In the G_1 phase, there is an intensive cellular synthesis where all cell organelles, except mitochondria and chloroplasts, are synthesized. During this stage, the cell metabolic rate is usually very high. These activities result into an increase in cell size. At this stage, young cells grow as they synthesise their organelles. This process produces functional daughter cells, that are of the same size, and have all the structures needed.

The synthesis (S-phase) is characterised by DNA replication to form two copies with identical structures. Protein molecules called histones are synthesised and bound with each strand of DNA. Each chromosome duplicate in two chromatids resulting into a doubled number of chromosomes (4n). These activities lead to an increase in size of the cell.

The G_2 phase involves the division of mitochondria and chloroplasts. There is also an increase in storage of energy to be used during mitosis. G_2 phase is a stage where more cell growth occurs as mitochondria and chloroplasts divide. In this phase, chromosomes begin the process of condensation prior to their division. The formation of mitotic spindle starts.

The mitotic phase involves the separation of sister chromatids and their distribution into daughter nuclei. Mitosis involves four phases namely prophase, metaphase, anaphase, and telophase.

The last phase in the cell cycle is cytokinesis. This is a physical division of the cell which involves equal division of cytoplasm into two. This results into two daughter cells with an equal distribution of cytoplasm and organelles.

Events that take place during the mitotic stage

Mitosis comes from the Latin word *mitos*, which means a thread. Mitosis occurs in the somatic cells, and therefore, it is also known as somatic cell division. The basic characteristic of mitotic nuclear division is its tendency of resulting into two daughter nuclei, which resemble each other. Before mitosis, DNA of parent nucleus replicates, which then divides into two new nuclei each containing an exact copy of the DNA as in the parent nucleus. The sequence of events which occur during mitosis and cell division, are shown in Figures 2.2 - 2.7.

Interphase

Interphase is a non-dividing phase of the cell where important events that prepare the cell for division process take place. In this stage, the nuclear envelope remains intact and the chromosomes occur in the form of diffused chromatin fibres as shown in Figure 2.2. Interphase is a period of intensive synthesis of cell organelles and the growth of the cell. DNA replication and proteins synthesis also occur in this phase. Almost 90% of the cell's time in the cycle is spent in this phase.

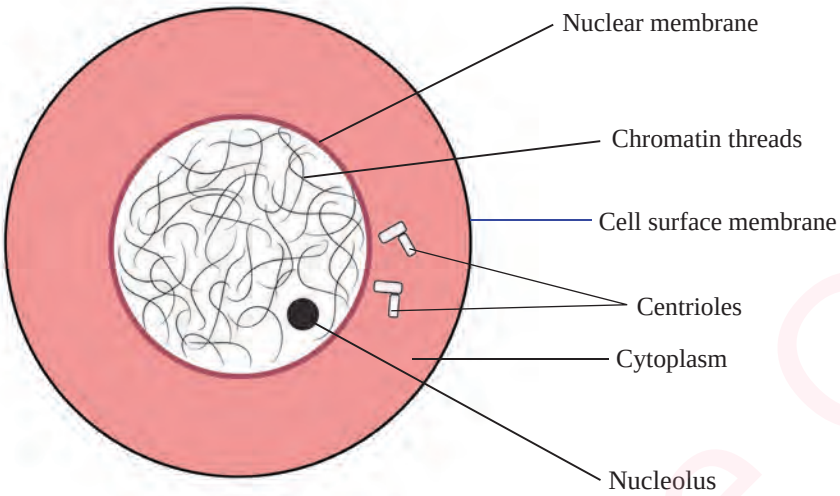


Figure 2.2 Interphase stage of mitosis

Prophase

In this stage, the chromosomes become short and thick. In animals, centrioles migrate to the opposite poles of the cell. Short microtubules may develop from each centriole and form a star-shaped structure called aster. Some of these microtubules called spindle fibres, may be seen extending across the cell from one pole to another. At the end of prophase, nucleolus and nuclear membrane disintegrate as shown in Figure 2.3. In plant cells, there are no asters.

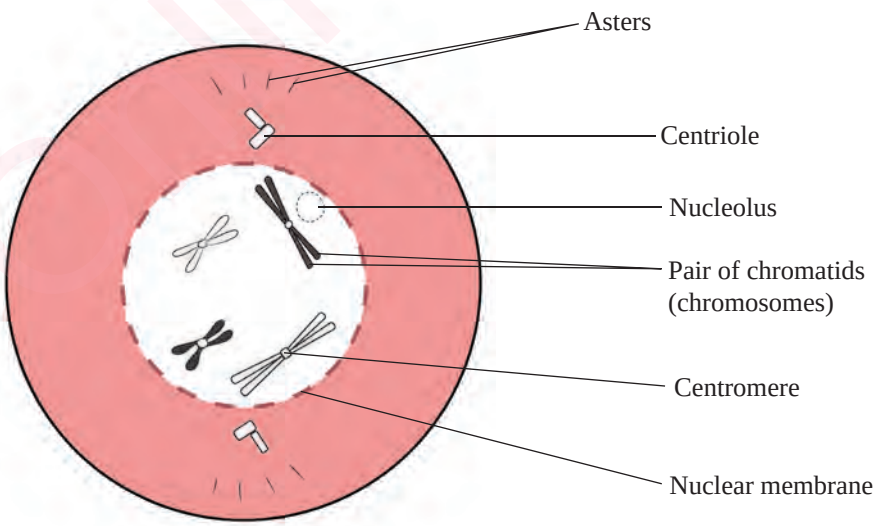


Figure 2.3 Prophase stage of mitosis

Metaphase

In this stage, chromosomes attached to their centromeres arrange themselves at the equator of the spindles as seen in Figure 2.4.

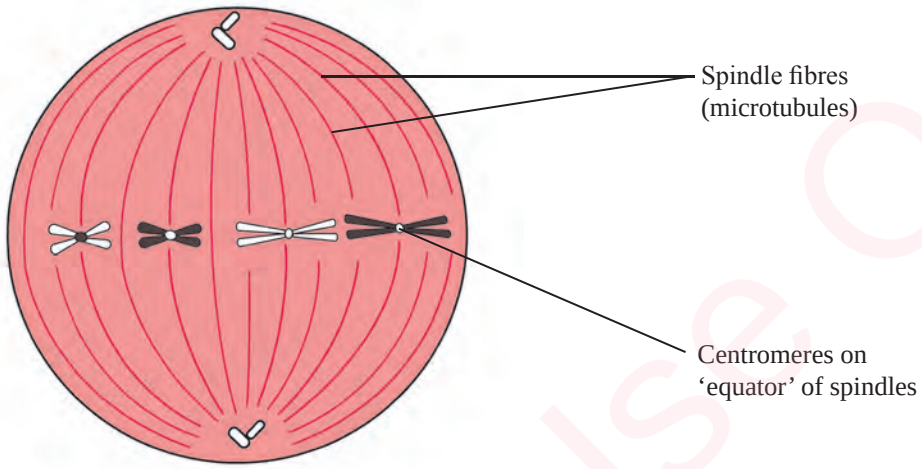


Figure 2.4 Metaphase stage of mitosis

Anaphase

During anaphase, the centromeres split into two and are pulled to the opposite poles by the spindle fibres. This leads to separation of chromosomes into two sister chromatids. As the centromere splits, the sister chromatids become separated and are pulled together with centromeres leading towards the opposite sides of the cell as the spindle fibres contract as shown in Figure 2.5.

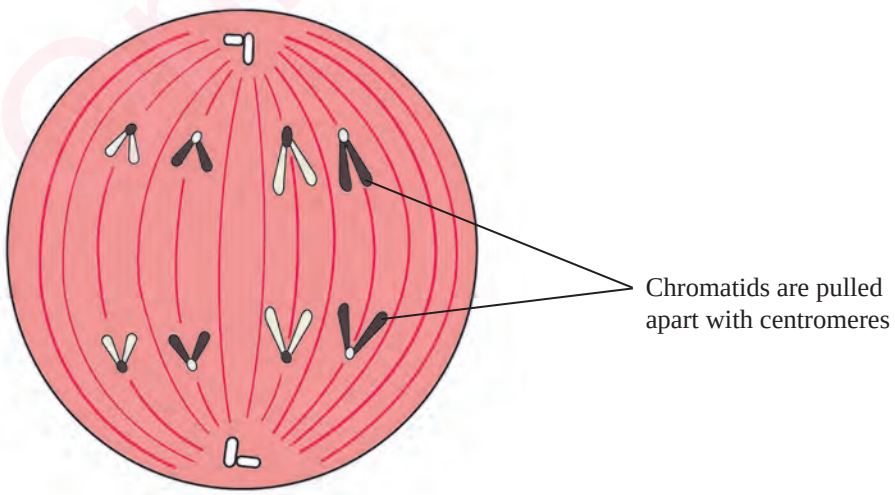


Figure 2.5 Anaphase stage of mitosis

Telophase

Daughter chromatids reach the opposite poles of the cell. They uncoil and lengthen to form chromatins which are less conspicuous. At this time, genetic content has divided equally and re-organised into two nuclei. The nuclear membrane re-forms around the chromosomes at both poles to form two daughter nuclei. Lastly, the spindle fibres disappear, the centrioles replicate and a new nucleolus reforms in each of the new nuclei as it is shown in Figure 2.6.

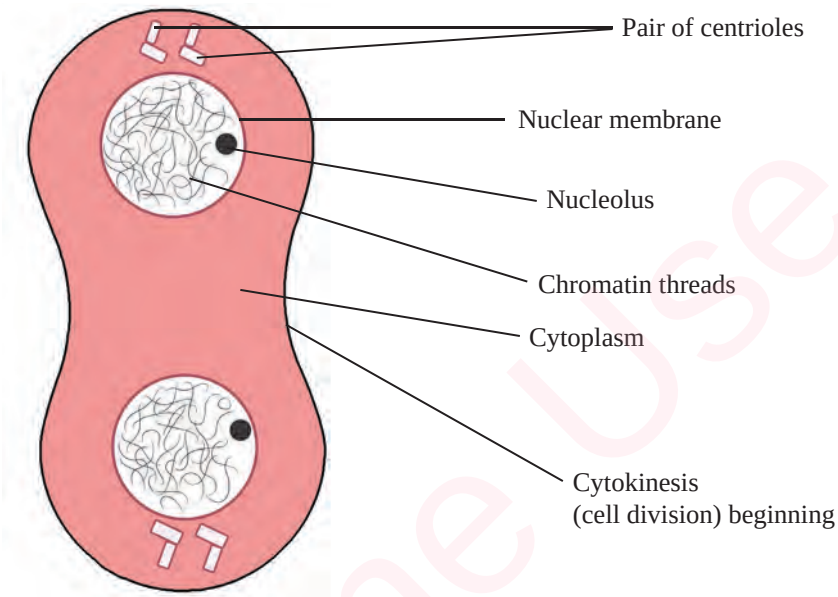


Figure 2.6 Telophase stage of mitosis

Activity 2.1 Examination of the stages of mitotic nuclear division

Materials

1. Prepared slides showing stages of mitosis.
2. Light microscope.

Procedure

(i) Place a light microscope on a flat table.

(ii) Place the prepared slides displaying any of the four stages of mitosis under a light microscope.

(iii) Observe each slide carefully under the microscope, noting characteristics exhibited by the nucleus in each prepared slide.

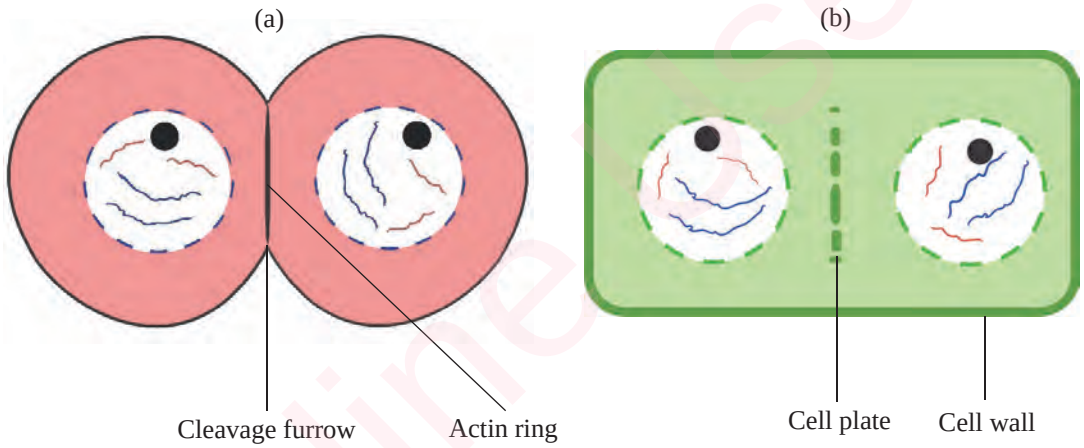
(iv) Draw and label the diagrams for each stage of mitosis observed.

(v) Name the stages of mitosis identified.

Cytokinesis

Generally, cytokinesis is a process by which the cytoplasm divides to separate the daughter cells. It begins after telophase stage. Cytokinesis in plant and animal cells is different because of their cytological differences. In animal cells, cytokinesis starts by the constriction of the cell surface membrane from outside inward. Two cleavage furrows develop as the cells constrict inwardly from the periphery as shown in Figure 2.7 (a). As the constrictions continue to deepen towards the centre, the membrane pinches off and completely separates the two daughter cells.

In plant cells, there is no constriction of plasma membrane due to the presence of a rigid cell wall. Thus, cytokinesis in plant cells starts with the fusion of Golgi vesicles to form a cell plate at the equatorial region between the two newly formed daughter nuclei as indicated in Figure 2.7 (b). More vesicles fuse with the plate, which finally develops into the primary cell wall and the two cells separate into daughter cells.



Figures 2.7 Cytokinesis in (a) animal cell and (b) plant cell

Location of mitosis in plant and animal cells

Mitosis in plants occurs only in the meristematic cells that are located at the tips of roots, shoots and the lateral meristems in the vascular cambium between the xylem and phloem. In these organs, meristematic cells are confined in specific areas called regions of active cell division just behind the tip of the radicle, plumule, and buds. These regions are capable of undergoing rapid cell division, resulting in an increase in size of the roots and stem. Mitosis in the buds leads to development of buds in either flowers, branches, stems or leaves. Lateral meristems such as cambium undergoes cell division which results into increase in width or diameter. Intercallary meristems at the nodes of monocot stem are responsible for stem elongation and leaf at the nodes.

In animals such as human beings, mitosis occurs in somatic or body cells. It starts soon after fertilisation, during which the zygote develops into an embryo and then foetus. After birth, mitosis continues to allow growth and development. After certain points of growth and specifically, after maturity, the cells in some organs cease to

divide. Examples of these organs include the brain, lungs, kidneys and other internal organs. The cells of the eyes, ears, tongue, lips, sex organs and bones, also cease to divide, and this helps to limit their sizes under normal conditions. However, the cells of the skin (cornified layer) are constantly lost. Therefore, mitosis in the germinative layer of the skin is constantly taking place to ensure a constant replacement of the lost cells.

Significance of mitosis

The mitotic nuclear division occurs in both unicellular and multicellular organisms. This process is equally important in all groups of organisms. The significance of mitosis to living organisms are as follows:

(a) Maintains genetic stability because daughter cells are identical to parent cells.

(b) Enhances growth through an increase in the number of cells.

(c) It is a means of healing of wounds and replacement of worn-out cells.

(d) Enhances regeneration of part of an organism. For example, a lizard tail.

(e) Mitosis process is used as a means of reproduction by unicellular organisms such as protozoans, which reproduce asexually.

Difference between mitosis in plant and animal cells

Although the purpose is the same, the process of mitosis differs between plant and animal cells. In animals, asters are formed during the prophase stage whereas in plants asters do not form. This is because higher plants lack centrioles. Cytokinesis in animal cells takes place when the membrane of the parent cell constricts inwardly from outside. In plants, the same process occurs when the cell plate grows across the equator of the parent cell from the centre outwards. As the cellulose is deposited on the formed cell plate, a cell wall is formed. In plants, mitosis occurs only in the meristematic cells, which are located at the node tips of roots, shoots and in the vascular cambium between the xylem and phloem. All animal cells are capable of undergoing mitosis during the early stages of development especially, during embryogenesis. However, at a certain stage after birth, mitosis ceases in some body organs such as brain, eyes, ears and reproductive organs but it continues in other organs.

Exercise 2.1

1. Explain the importance of mitotic cell division in organisms.
2. Briefly, explain why interphase is considered the most active stage of the cell cycle.
3. With the aid of illustrations, describe the phases of mitotic nuclear division.
4. Briefly explain differences between cytokinesis in plant and animal cells.
5. Differentiate between mitosis in plant and animal cells.

Growth patterns

Growth in living organisms is a result of interaction between various factors such as environmental conditions and genetic makeup of an individual. However, many organisms share similar basic patterns of growth, which can be expressed graphically as growth curves. These are obtained when growth parameters such as weight and length are plotted against time.

Plants and animals exhibit various growth patterns including isometric, allometric, limited and unlimited growth patterns. However, organisms may exhibit more than one of these patterns. For example, mammals grow allometrically and their growth is limited.

Growth patterns refer to variation in growth of organisms at different stages of their life cycle. Most of the growth patterns form S-shape curve commonly known as the sigmoid curve. This is characterized by a slow growth rate in the beginning due to a few number of cells. The slow growth rate is followed by rapid growth but ultimately tends to slow down.

Isometric growth pattern

This growth pattern occurs in some chordates such as fish, frog and some insects such as grasshoppers, where a body organ except wings and genitalia grows at the same mean rate as the rest of the body. This means that the shape of the body remains unchanged despite its increased size as in Figure 2.8.

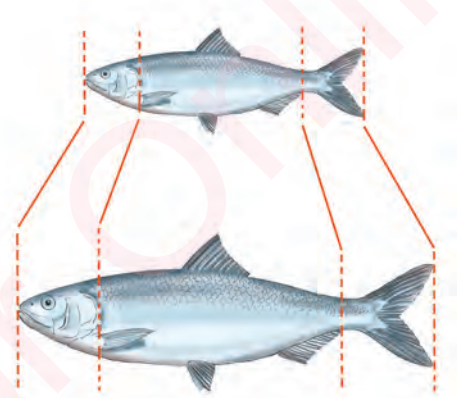


Figure 2.8 Isometric growth

Allometric growth pattern

This is a pattern of growth where different parts of the body grow at different rates with respect to each other. Animals such as mammals exhibit the pattern of growth whereby any change in the size that results from growth causes a change in shape. This is because the growth of body organs occurs at a different mean rate from the growth of the rest of the body. For example, in humans, the proportions of various structures change as a result of simultaneous changes in the patterns of growth and development. During the infant stage when acquired immunity is still weak and the risk of disease is high, the thymus gland grow rapidly to produce white blood cells, which help to fight infections. At adult age, the mass of thymus gland lessens to half. Typical curves showing the allometric growth pattern of various human organs are shown in Figure 2.9.

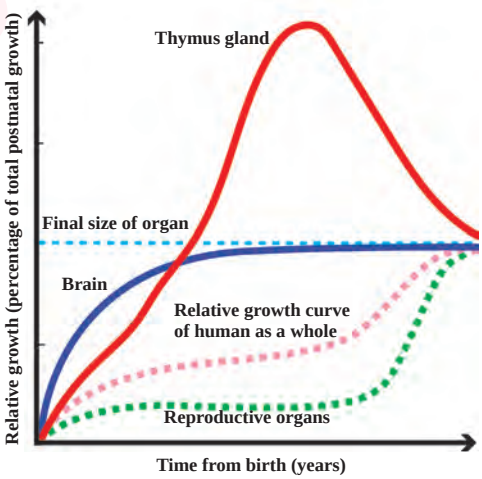


Figure 2.9 Allometric growth as shown by different parts of human body

Limited growth patterns

The annual plants and animals like humans, insects, and birds exhibit the limited growth pattern also known as definite or determinate growth pattern. In this pattern, growth is said to be limited because the organisms cease to grow after maturity. During this period, there is negative growth or senescence before death.

Growth curve of an annual plant

When a growth parameter such as dry mass is plotted against time, an S-shaped curve commonly known as the sigmoid curve is obtained as in Figure 2.10.

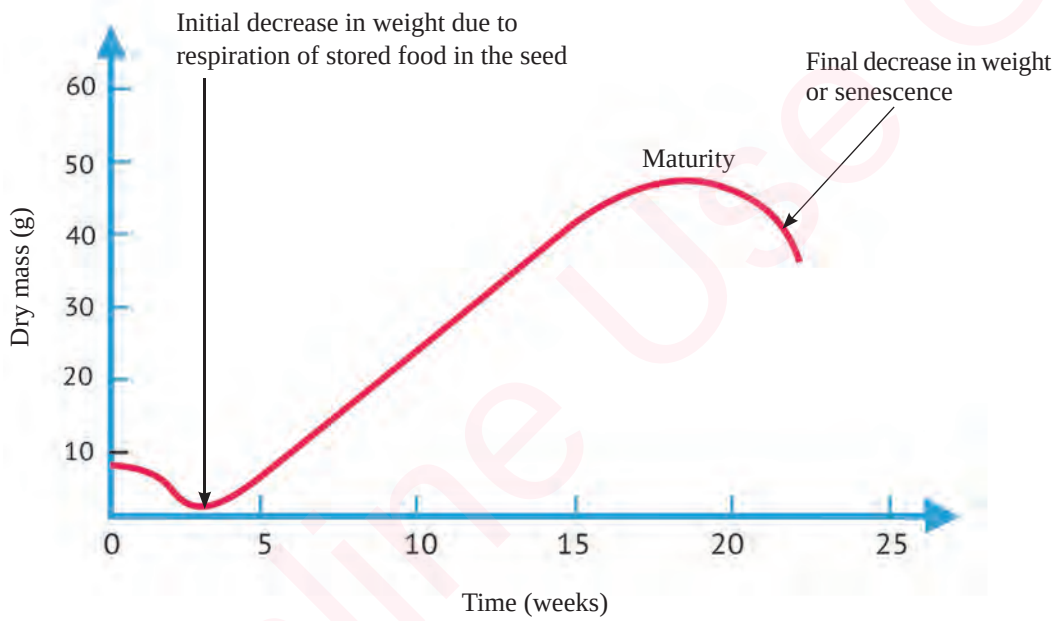


Figure 2.10 Growth curve of an annual plant

From the graph, there is a decrease in dry mass at germination because the food stored in cotyledons and endosperm is oxidized to produce energy that is needed by a developing seedling. As the first foliage leaves are formed, the seedling starts to photosynthesize food, making use of some of it and storing some too. This leads to a gradual increase in dry mass. As growth continues, the plant develops full leaves. At this stage, photosynthesis is at its maximum and anabolism exceeds catabolism, leading to an exponential increase in dry mass, hence, exponential growth of a plant. When the plant is fully matured, catabolism is equal to anabolism and therefore no growth or any increase in dry mass that occurs at this stage. This period is followed by negative growth or senescence during which catabolism exceeds anabolism. At this point, the cell death rate is high. The decrease in dry mass contributes into the dispersal of seeds and fruits.

Human growth curve

The human growth curve is characterized by five phases as indicated in Figure 2.11. These phases in ascending order are infant, juvenile, adolescence, adult and senescence. Infant is the first phase just after birth which is characterized by rapid growth because of rapid cell division. Juvenile is the second phase, characterized by a relatively slow growth. Juvenile stage spans from age 7 to onset of purberty and adolescence at approximately 10 years for healthy girls and 12 years for boys. A relative slow growth of juveniles is from the fact that, most of the digested foods are spent for the development of reproductive system and its structures. At this stage juveniles also are very active and spend most of the time in

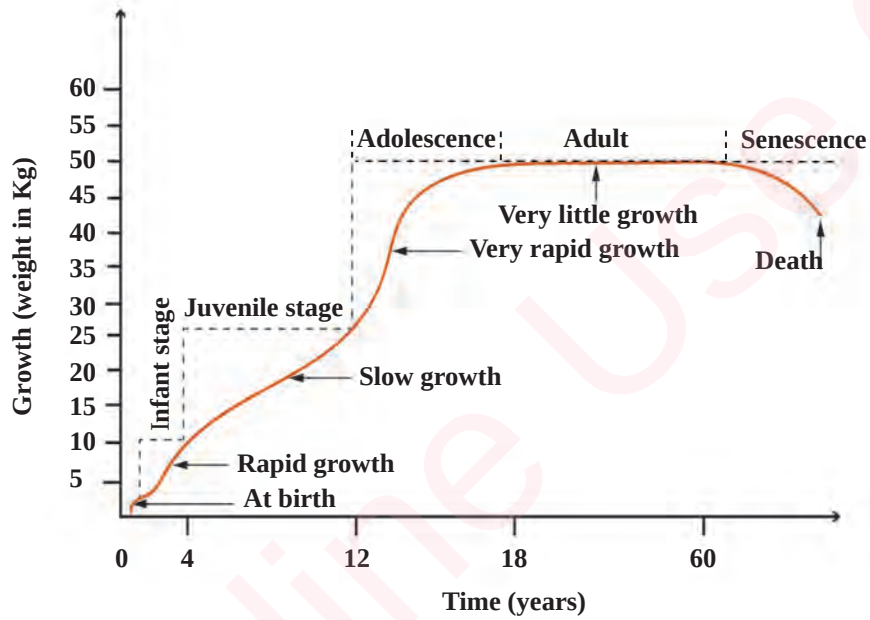


Figure 2.11 Human growth curve

playing which consumes much energy that would otherwise be stored in the body. The third phase is adolescence which is marked by the development of secondary sexual characteristics as a sign of sexual maturity. It is also accompanied by the period of very rapid growth. It is characterised by growth spurts because of increased fat composition and distribution, increased size of organs, bones and muscles. These changes occur because of simultaneous release of growth hormone and thyroid hormones which are responsible for regulating growth and metabolism respectively.

The fourth phase is the adult. At this stage, growth ceases gradually but development continues. Senescence is the last phase, characterised by negative growth because catabolism outweighs anabolism. The body gradually losses strength and loss of memory may also occur.

Growth pattern of arthropods

Arthropods such as cockroach exhibit a type of limited growth known as discontinuous or intermittent growth pattern. Arthropods often moult periodically to grow because their hard inelastic exoskeleton does not

expand, to allow growth. Moulting is the process of shedding exoskeleton in arthropods. Two hormones known as a juvenile (neotonin) and ecdysone hormones control this process. Ecdysone hormone also called a moulting hormone is produced by glands found in the first thoracic segment called prothoracic gland. Juvenile hormone is produced in the region behind the brain known as corpus allatum. If the juvenile hormone is present in high concentration, larval moult occurs but if its concentration is low, pupal moult occurs. In the complete absence of juvenile hormone, the pupa metamorphoses into an adult (imago). Moulting is followed by a sharp increase in body size often before exoskeleton hardens and limit growth. Thus, in arthropods growth occurs in spurts resulting in a step-like growth curve as shown in Figure 2.12.

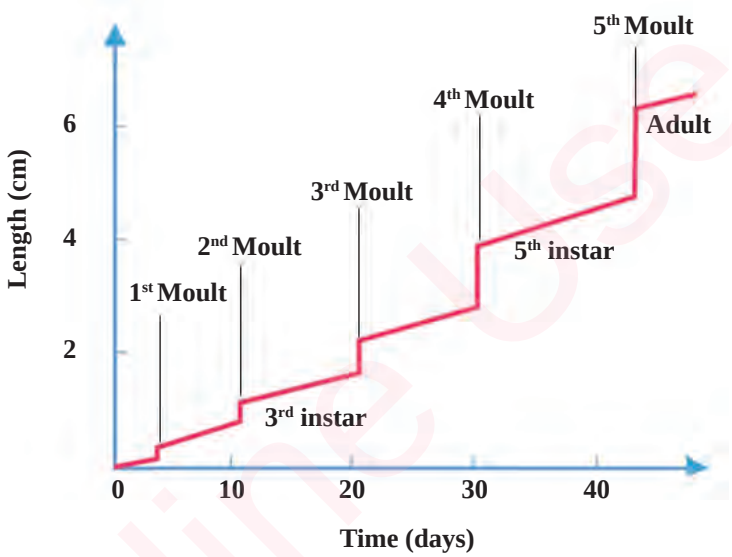


Figure. 2.12 Growth curve of arthropods

Indeterminate growth pattern

This pattern of growth is also called unlimited or indefinite growth. An organism exhibiting this pattern continues to grow even after maturity. This pattern of growth occurs in perennial plants such as woody plants whose growth curve consists of a cumulative series of sigmoid curves. Each sigmoid curve represents an annual growth as shown in Figure 2.13. In these plants, growth occurs with respect to seasonal changes. For example, during the wet season, there is a high rate of growth but during the dry season, there is low growth rate. Other organisms with unlimited growth include algae, most fish, most molluscs, and reptiles.

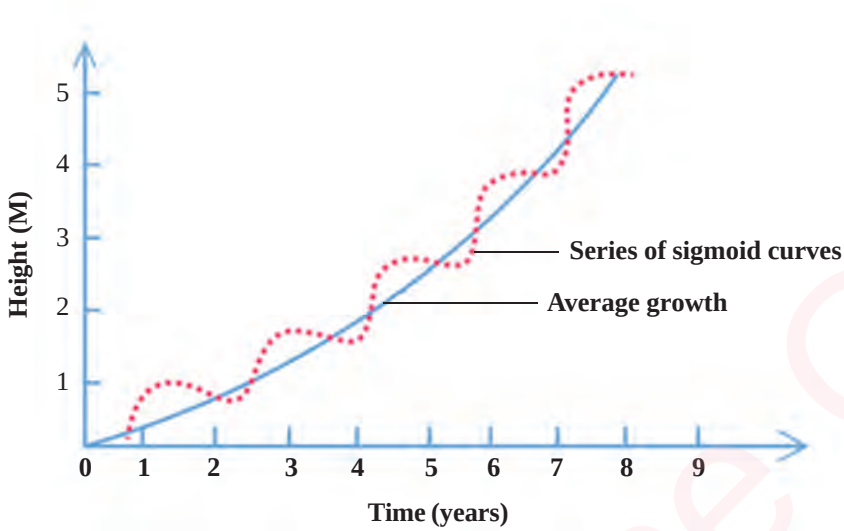


Figure. 2.13 Growth curve of a perennial plant

Exercise 2.2

1. With examples, describe allometric and isometric growth patterns.
2. Describe one way in which the growth pattern of human is different from that of an apple tree.
3. Explain how moulting is controlled by hormones in insects.
4. With the aid of illustration, explain why insects exhibit a unique growth curve.
5. Briefly explain why human thymus gland grows at a high rate compared to the rest of the body parts during infancy.
6. Differentiate between limited and unlimited growth.

Growth and development in plants

Growth in plants involves an increase in both cell numbers and cell size. The development consists of growth and differentiation and is characterized by the change in size, shape, a degree of differentiation and state of complexity. In higher plants, growth is confined to certain regions known as meristems with exception of young embryos where growth occurs throughout the body.

The term meristem came from the Greek word *meristos*, which means division. Meristematic tissues are found mostly on tips of roots and stems, in nodes, vascular cambium and cork cambium. They are also located on the lateral side of the stem and roots. The cells of the meristematic zone are capable of rapid cell division. These cells retain the ability to divide by mitosis to produce daughter cells that grow and form the rest of the plant body. After division, some of the cells differentiate to form permanent tissues while others retain their meristematic properties. The meristematic cells are characterized by the presence of numerous ribosomes, mitochondria, and hence, the high rate of metabolism. They have thin and extensible cell walls, small vacuoles and dense cytoplasm. Their thin-walled tightly packed living cells undergo frequent divisions.

Meristematic cells undergo cell division and wall formation, which is followed by differential cell expansion. The meristems are classified according to their position in the plant body into apical, lateral and intercalary meristems.

Apical meristems are found in the apex or tip of roots and shoots as shown in Figure 2.14. They are responsible for primary growth, which gives rise to primary plant body. This type of growth leads to an increase in the length of the plant body. Lateral meristems are found in the cylinder towards the outside of the stem and roots. They are responsible for secondary growth that gives rise to an increase in the girth or diameter of the plant body. Intercalary meristems on the other hand, are found at the nodes and leaf base of monocotyledonous plants such as grasses. They contribute to growth in regions of already differentiated tissues of plant stems such as grasses. They are also responsible for an increase in the base of the internode and growth of damaged leaf in grasses. The cell division of the three types of meristems give rise to two major types of growth in plants, namely: primary and secondary growth.

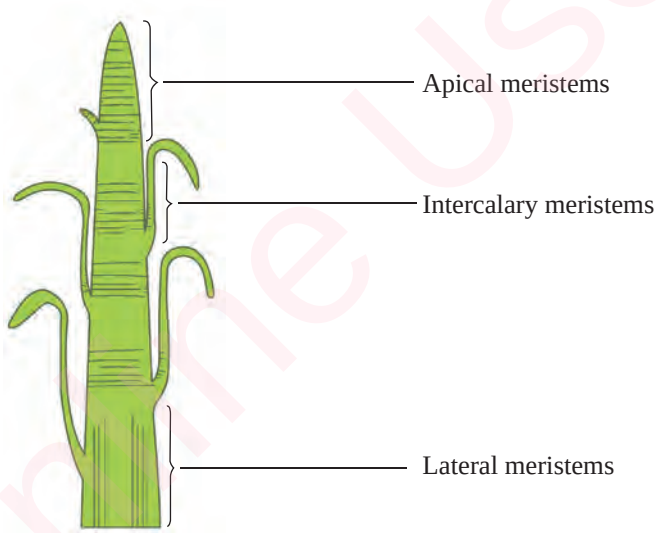


Figure 2.14 Position of meristems in plants

Primary and secondary growth in angiosperms

Primary growth is the first form of growth to occur in plants as a result of the activity of apical meristems. In some plants such as monocotyledonous and herbaceous dicotyledonous plants, it is the only type of growth, which occurs in their life cycles. Secondary growth occurs when the secondary vascular tissues are added to their primary tissues by the activity of the lateral meristems. Most dicotyledonous plants exhibit secondary growth or secondary thickening. This type of growth leads to an increase in the diameter or girth of the plant.

The role of apical meristems in primary growth

In plants, primary growth occurs at the root and shoot apex. Cell division of meristems in the apices of roots and shoots causes elongation of these parts. This type of elongation is called primary growth

and is responsible for the formation of primary plant body after the differentiation process. In the region of cell division, the meristematic cells undergo repeated mitotic division to produce many daughter cells. The vacuoles in these cells gain water, bulge and become relatively large. In the region of cell elongation, small vacuoles fuse to form large ones as shown in Figure 2.15. The result of this vacuolar fusion is the development of turgor pressure in the cell. This pressure forces the cell to elongate, because its cell wall is still thin and extensible. As the process of vacuolar fusion continues, the plant organs continue to expand and elongate.

The apical meristem at the shoot apex differentiates to form the primary stem, leaves, and flowers. On the other hand, in root apex, the meristems differentiate to produce primary root tissue. The shoot and root apices have three different zones of growth which are the zone of cell division, elongation, and maturation. The region

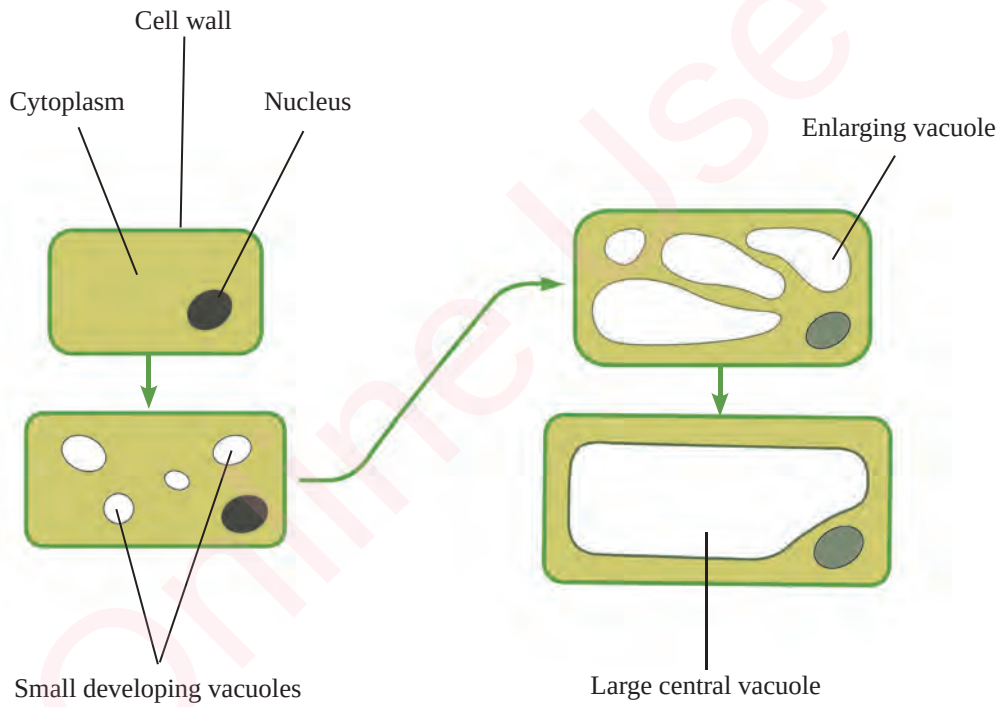


Figure 2.15 Primary growth

of cell division is composed of apical meristems. The region of elongation is positioned about a centimeter from the tip of the root. Cells in this region increases several times of their original length and width. Vacuoles of cells are tiny and occupy at least 90% of the volume of each cell formed. In the region of cell maturation, the vacuole attains its full size and almost fills the cytoplasmic region. The cell wall becomes secondarily thickened and hence unable to extend further. The whole process of development of the primary plant body requires energy, which is supplied by the mitochondria.

The mitotic cell division of the shoot and apical meristems results into three meristematic areas, namely: protoderm, ground meristem and procambium. In the course of development, protoderm gives rise to the outer protective layer of the plant called epidermis.

The ground meristems develop to the inside of the protoderm, giving rise to the ground tissue, parenchyma, and cortex cells. Procambium gives rise to the solid central cylinder in the centre of the shoot which is comprised of cambium, phloem, and xylem.

Primary growth of shoot

The primary growth in shoot apex takes place when shoot apical cells divide mitotically to form three layers of meristematic tissues namely protoderm, procambium, and ground meristem. Protoderm gives rise to epidermis while procambium gives rise to vascular tissues including cambium, phloem, and xylem. The ground meristems produce ground tissues which form cortex and pith in dicotyledonous plants as shown in Figure 2.16.

Primary growth of root

At the tip of the root, there are meristematic cells, which divide to produce cells, both inwards towards the plant body and outwards. The outwards cell division results in the formation of a mass of unorganised cells called root cap and a quiescent zone just behind the root cap. The root cap cover and protect the root apical meristem as they grow through the soil. They also have an additional function of acting as gravity sensors. The cells in the quescent zone serves as a reservoir to replace the damaged cells of the apical meristems. Thus, they are important in organising patterns of primary

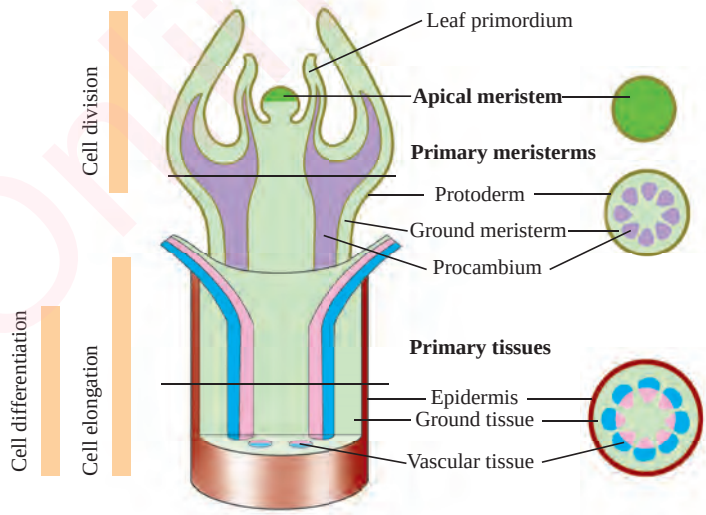


Figure 2.16 Primary meristems in the shoot apex

growth in roots. Behind the root cap and around the quescent zone, meristematic cells divide to form meristematic tissues known as protoderm, procambium and ground meristems as shown in Figure 2.17. In the root, the term procambium is used to describe the whole central cylinder of a root. Like the shoot tip, the root tip is also subdivided into three zones namely zone of cell division, cell elongation, and maturation. The zone of cell division extends 1-2 mm back from the root tip and overlaps slightly with the zone of cell elongation. The zone of cell elongation extends about 10 mm behind the root tip and its increase in length forces the roots down through the soil.

Some cell differentiation such as the development of the phloem sieve tube elements begins in the zone of cell division. Development of phloem is from the outside inwards and in the zone of elongation. The xylem vessels start to differentiate also from outside towards inwards. This kind of differentiation is termed as exarch development. This differs from endarch differentiation in stem in which xylem develops from inside towards outwards.

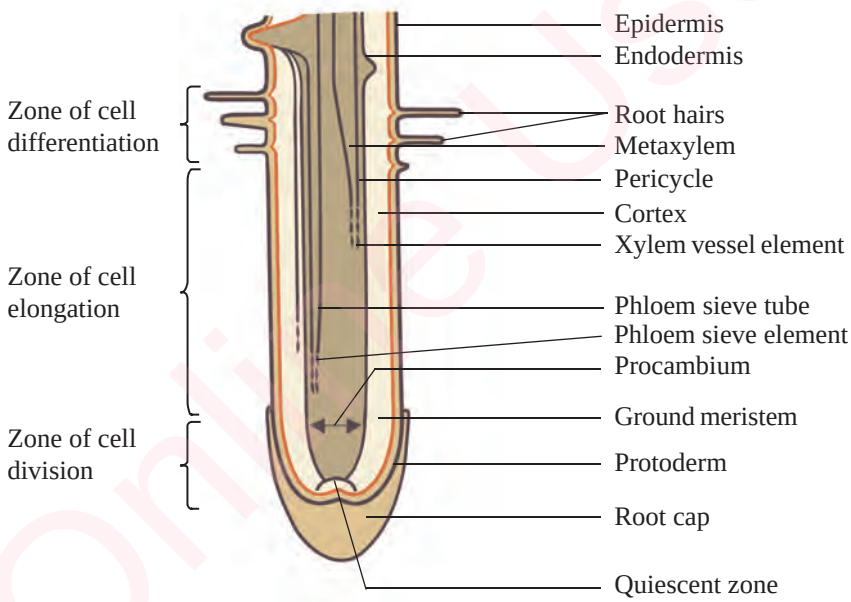


Figure 2.17 Apical meristems of the root apex

Activity 2.2 Identification of meristematic cells and their characteristics

Materials: Mature bean plants, young bean seedlings, sharp razor blade, microscope, microscope slides, safranin stain (or methyl blue, Gentian violet or iodine) and coverslip.

Procedure

(i) Cut a thin transverse section of a shoot apex of a young bean plant by using a sharp razor blade.

(ii) Mount it on the microscope slide, stain it and then cover it with a coverslip.

(iii) Place a mounted slide under a light microscope and observe it under a low magnification, then you may increase the magnification accordingly.

(iv) Note the features shown by the cells in this part of the plant.

(v) Repeat the above steps but now use a thin transverse section of a mature stem of a bean plant.

(vi) Draw a diagram of the section of the young shoot apex and mature shoot apex of a bean plant as observed under the microscope.

(vii) Compare cells observed for the transverse section of young and mature bean shoot.

(viii) Relate the features of the cells in the plant apex to the role they play in plant growth.

Results: Meristematic cells are characterised by thin and extensible cell walls, small vacuoles and dense cytoplasm unlike the mature part of the plant. They may also have numerous ribosomes and mitochondria.

The role of lateral meristem in secondary growth

The lateral meristems controls the process of secondary growth in both roots and stems. These include the vascular and cork cambium in woody plants. Monocotyledonous plants such as grasses and herbaceous dicotyledonous plants which lack lateral meristems have no secondary growth. Lateral meristems are found parallel to the long axis of a root or shoot in the pericycle region at the junction between vascular tissue and cortex. They are positioned laterally as cylinders on the sides of the plant stem and root. They are responsible for the secondary growth of the plant which results into increased diameter or girth of the plant.

The lateral meristems that produces secondary vascular tissues are of two types, namely: vascular cambium and cork cambium. The vascular cambium is found between xylem and phloem. The activity of the cells in the vascular cambium leads to the formation of secondary vascular tissues. The vascular cambium is anatomically made up of two types of cells, which are referred to as fusiform and ray initials. The ray initials differentiate to form parenchyma cells. The fusiform initials undergo mitosis to produce axial or longitudinal systems of the secondary phloem externally and secondary xylem internally. The second type of lateral meristem is a cork cambium. This later develops to give rise to phellem and phellodem which constitute a secondary cortex. Its main role is, therefore, to maintain a protective layer around the stem, which is actively increasing in diameter.

Secondary growth in woody dicotyledonous stem

In the dicotyledonous stems, secondary growth is brought about by the activity of the vascular cambium which is originally located between the primary vascular tissues. Soon after primary cell differentiation is completed, the fusiform initials in the vascular cambium divide by mitosis. Their division produces large quantities of the secondary xylem (tracheids and vessel elements) to the inside and small quantities of secondary phloem (sieve elements and companion cells) to the outside as shown in Figure 2.18.

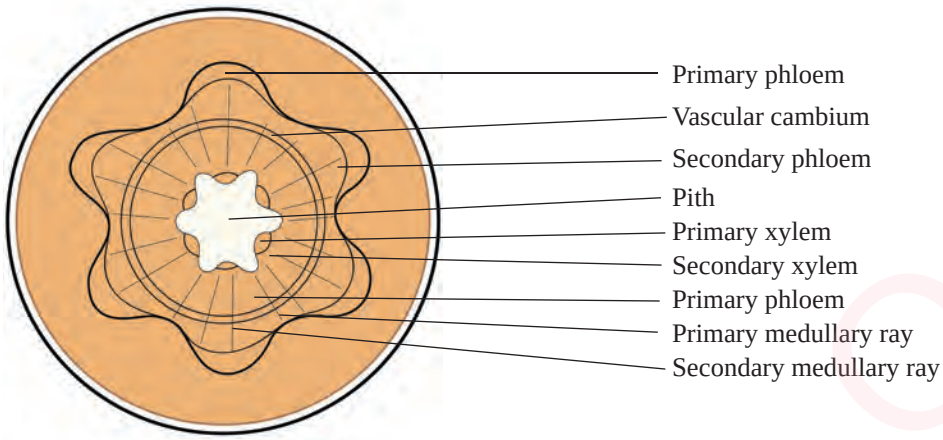


Figure 2.18: Transverse section of the stem

The formation of these secondary tissues over the primary ones leads to an increased diameter of the stem or plant organs. Usually, the cells of the secondary xylem contain lignin, the primary component of wood, which provides hardness and strength to the stem. The xylem together with pith form the dicot's woody stem while the ray initials produce parenchyma or rays. As the diameter of the stem increases, the circumference of the cambial layer also increases. This leads into rupturing of the epidermis to give room for the newly formed tissues. As this occurs, the cork cambium develops and its meristematic activities produce cells which replace the ruptured epidermal layer. Secondary growth in trees and shrubs is characterised by deposition of large quantities of secondary xylem which is a wood, this completely modifies the primary structure of the plant.

Secondary growth in the roots of dicotyledonous plants

The development of secondary xylem, secondary phloem and medullary rays in roots and stems is similar. A cork cambium develops from pericycle and serves the same function of replacing the ruptured epidermis of the expanding plant body as a in the stem. The original cork cambium may be replaced at intervals by cork cambium arising further inside the root. The process of secondary growth in roots is summarised in Figure 2.19.

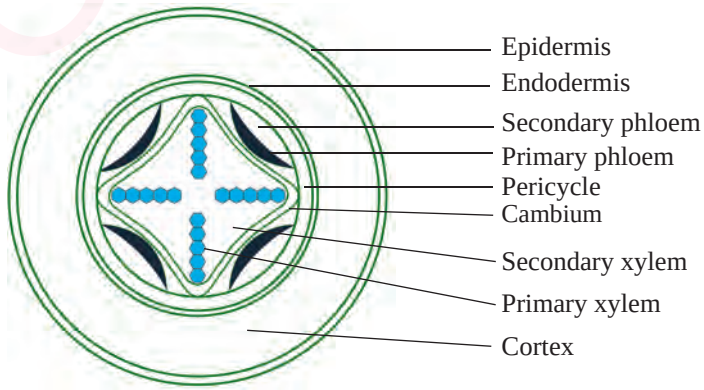


Figure 2.19 A transverse section of the root

The origin of lateral branches and lateral roots

There are two types of branching patterns in plants, namely: terminal and lateral branching. Terminal branching involves the separation of the apical meristems into two. Each of these two apical meristems continues to grow as a shoot branch. This mechanism is common in lower plants but rare in angiosperms.

Lateral branching in angiosperms occurs mainly by the growth of axillary buds. When leaf primordial are initiated, a small group of cells in their axils remains small and non-vacuolated. These are referred to as detached meristems because they retain the meristematic characteristics but do not differentiate as the neighbouring cells do. However, they become spatially separated from the apical meristems. As the shoot grows and the detached meristems attain a distance from the apex, they are differentiated into shoot meristems that are also associated with several leaf primordial or buds. At this point, they do not grow further because of apical dormancy triggered by the shoot apical meristems. The growth of the axillary meristems is inhibited by auxin hormone produced by the apical meristems. In some plants, the inhibition is temporary until the main shoot has grown beyond the inhibitory range of the apex. In un-branched plants, the inhibition is permanent unless the apical meristems are removed. When apical inhibition ceases, the lateral bud begins to grow as a branch shoot.

Lateral roots are defined as branches of the taproot. Lateral roots are formed as a result of the activity of cells in the main roots. They are endogenous in nature, meaning that their origin is from a deeper layer. The newly formed lateral roots usually occur near the root apex where there is active cell division. These roots are initiated from the pericycle at the point near xylem poles. In monocotyledonous plants, lateral root initiation can be opposite either protoxylem or phloem. In most plant species cell division occurs in endodermis in such a way that pericycle and endodermis contribute to the lateral root tissue. On contrary, adventitious roots are formed primarily on stem tissues but they have various sites of origin ranging from endogenous to exogenous from superficial tissues such as epidermis. However, in most monocotyledonous plants, adventitious roots arise from the cell division in pericycle of the stem and hence they originate from primary thickening meristems.

Seed dormancy and viability

Water, optimum temperature, and oxygen are important environmental conditions necessary for the seed to germinate. However, sometimes even in the presence of these conditions, some seeds fail to germinate. The state in which seeds are prevented from germinating even under conditions which are favourable for germination, is called seed dormancy. Seed dormancy can be caused by factors internal or conditions external to the seed. Seeds that are capable of germinating after overcoming all causes of dormancy, are said to be viable. Viability is therefore, governed by different factors such as storage conditions, embryo maturity, and enzymes.

Types of seed dormancy

There are two types of seed dormancy, namely: primary seed dormancy and secondary seed dormancy. The primary seed dormancy is a type of dormancy in which seeds will not germinate immediately after

dispersal even if the factors for germination are present. This is because they must undergo certain internal changes, which are generally described as after-ripening. These changes prevent premature germination of the seeds and increase the chances of survival and perpetuation of the species. To achieve this, there are mechanisms which ensure that germination is synchronized with the beginning of a season favourable to the continued growth of seedlings. For example, the mechanisms can involve the action of growth inhibitors present in the seed coat that can make it impermeable to water and air. Inhibitors can also prevent rupture of the seed and hence enable growth of the embryo.

The secondary seed dormancy is the type of dormancy that occurs when a seed lacks either all or some of the external conditions that are necessary for germination. If these conditions are not met then the seed fails to germinate and such dormancy cannot be broken for sometimes.

Causes of primary dormancy

Factors which causes primary seed dormancy are mainly intrinsic to the seed. Primary dormancy caused by immaturity of an embryo is one of the intrinsic factors which cause seed dormancy. However, in its dormant stage, the seed remains viable while waiting for the embryo to mature fully. Other intrinsic factors include hardness of seed testa and the presence of growth inhibitors such as abscisic acid. The hardness of the testa and presence of inhibitors collectively restricts the emergence of radicle and plumule. The hardness of the seed coat hinders permeability of oxygen and water to the embryo. This, in turn, prevents seed germination and therefore, the seed remains in a dormancy condition.

Causes of secondary seed dormancy

The main causes of secondary seed dormancy are external factors which make the embryo fail to germinate. Optimum temperature facilitates the proper functioning of enzymes. Oxygen, water, and light facilitate respiration, metabolism and raise the level of gibberellins hormone respectively. Lack of such factors is among the causes of secondary seed dormancy.

Ways of overcoming seed dormancy

There are several ways and methods used to overcome seed dormancy. The natural way of breaking dormancy occurs when the seeds get suitable environments such as adequate moisture, oxygen and temperature. Although sometimes the external force is used to break seed dormancy, methods that are employed to break seed dormancy depends on the type of dormancy and its causes. Methods of breaking dormancy include soaking the seeds in water to soften the seed coat and remove inhibitors. Mechanical scarification is the process of weakening hardness of the seed coat to allow entry of water and gases. This can be achieved by slightly striking or cutting the hard seed coat using a hammer or knife respectively. Mechanical scarification can also be done by abrasion using a sandpaper. Another method of overcoming seed dormancy is called partial digestion. It occurs in the intestine of animals such as ruminants. It naturally enhances breaking of seed dormancy by softening the hard seed coat and removing germination inhibitors from the seed coat as the seeds pass through their gut.

Chemical scarification method involves soaking the seeds in alcohol such as ethanol (C_2H_5OH) and concentrated acids such as Hydrochloric acid (HCl) and Sulphuric acid (H_2SO_4). By soaking seeds in these

acids or alcohol for a certain period of time the hard and impermeable seed coat is weakened. Usually, seeds can be treated with growth-promoting hormones or other chemicals in order to stimulate germination or to remove germination inhibition. Dry storage of seeds immediately after maturity is another strategy of overcoming seed dormancy. This allows time for the maturity of the embryo and development.

Cold and fire stratification is another method of breaking seed dormancy. It involves mimicking the exact natural conditions for seed germination. Cold stratification involves placing the seeds close together in moist sand. Fire stratification, on the other hand, involves placing the seeds close together under a thin film of sand and setting fire on top of the laid sand. This is done to mimic dry and frequent fire conditions, which are natural in areas such as wooded grasslands. Most species in wooded grassland are adapted to fire and some require fire to break dormancy. Lastly, the supply of appropriate light conditions, which are necessary to raise the level of gibberellins, in some seeds is also important on breaking dormancy.

Significance of the seed dormancy

Seed dormancy allows seeds to survive periods of unfavourable conditions to prevent germination when conditions are not friendly for its continued growth. This ensures that germination is synchronized with favourable conditions for growth. During a period of suspended growth, seed has high chances of developing after ripening changes. This prevents premature germination that might lead to the death of the germinant. In the process of germination, the developing seedling utilizes energy which comes from the oxidation of food stored in the cotyledons and endosperm. Dormancy helps to keep this food which is important in the early stages of seedling development. Moreover, the dormant seeds are easily dispersed and stored.

Exercise 2.3

1. Describe types of meristem based on their position in a plant body.
2. Explain the mechanism of secondary growth in plants.
3. Discuss the main features of meristematic cells.
4. Briefly explain how lateral branches and lateral roots are formed in plants.
5. What is seed dormancy? Explain the causes of seed dormancy.
6. State two types of seed dormancy and explain ways of overcoming each type of dormancy.

Seed viability

Seed viability refers to the ability of the seed to germinate under favourable conditions. The viable seed is one, which is capable of germinating under suitable conditions. Viable seeds are capable of germinating once supplied with conditions necessary for germination or once all the causes of dormancy have been eliminated.

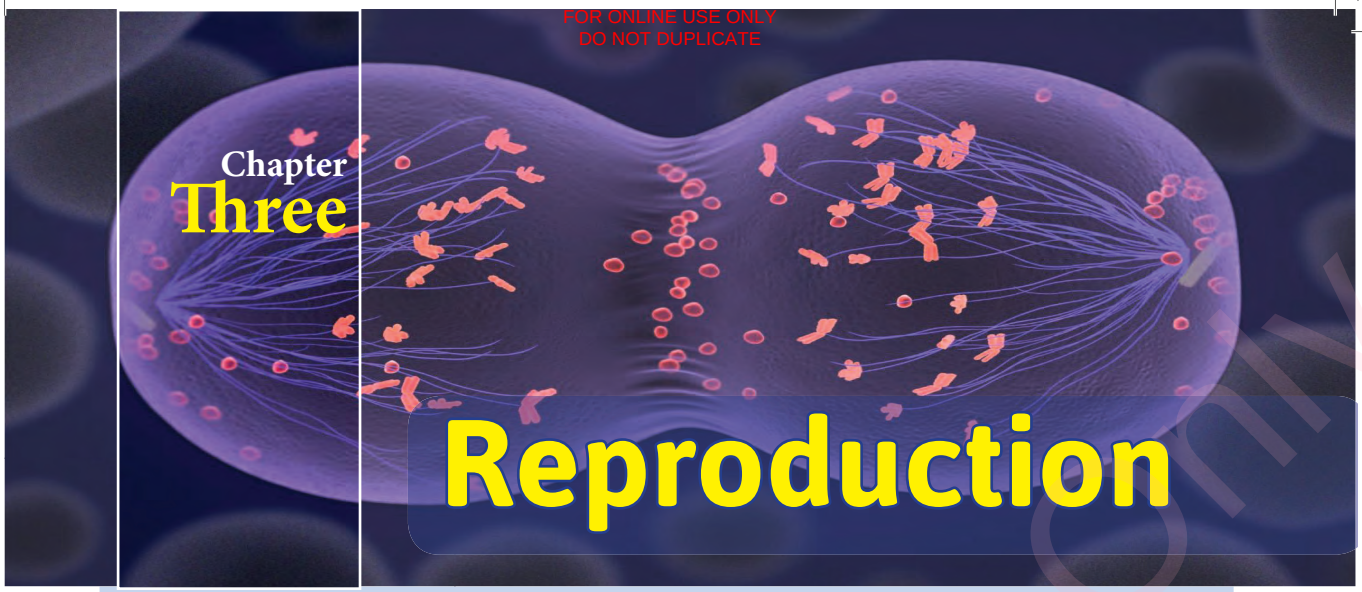
Factors governing seed viability

Various factors govern seed viability. These include embryo maturity, enzymes, time of seed storage, and absence of diseases. A seed with immature or underdeveloped embryo is unviable. Likewise, a diseased seed is likely to lose its viability. Additionally, when enzymes in the seed are inactive, the seed becomes unviable. This is because enzymes control the physiological processes of seed germination.

The length of the period during which seeds remain stored also determines their viability. Most seeds lose their viability in a period of one year following their dispersal while some seeds may remain viable for a number of years. The loss of viability results into total dormancy and hence, the death of the seed.

Revision questions

1. A viable seed was sown under optimum germination conditions. However, it did not germinate. Suggest the possible causes and ways to overcome such seed dormancy.
2. With the aid of diagrams, describe the events that take place during mitosis stages in a plant cell.
3. Annual plants such as bean and maize, exhibit a sigmoid growth pattern. Explain why their growth curve is S-shaped.
4. Differentiate between primary and secondary growth in plants.
5. Explain the role of lateral meristems in plant growth.
6. Outline the role of apical meristems in primary growth of plants.
7. With the aid of an illustration, describe the growth pattern of humans and give reasons to justify the observed growth pattern.
8. Explain the roles of vascular cambium and cork cambium in secondary growth of plants.
9. Discuss the ways in which mitosis in plant cells differ from mitosis in animal cells.
10. Briefly explain how you would identify a cell undergoing metaphase during mitosis based on the appearance of its nucleus.
11. (a) What are secondary roots?
    (b) Differentiate secondary roots from shoots based on their origin.
12. (a) Briefly explain the concept of seed viability.
    (b) Discuss factors governing seed viability.



Chapter Three

Reproduction

Introduction

Reproduction is one of the fundamental characteristics of living organisms. It is an important process for the existence of all living things. It is a process which leads to an increase in the number of individuals of a species in a given population. Without a mechanism for reproduction, life would come to an end. In this chapter, you will learn about meiosis, reproduction in animals and plants as well as development of fruits, and seeds. You will also learn about generalized life cycles of selected plants including bryophytes, pteridophytes and angiosperms as well as life cycles of selected animals including housefly, cockroach, toad, and mouse.

Meiosis

This is the process of nuclear division in which a diploid cell (2n) gives rise to haploid cells (n) in the sexually reproducing organisms. However, in some cases, this type of cell division may be from hexaploid cell to triploid cells such as in wheat. In animals, the haploid cells which are produced through meiosis during gametogenesis are sperms and eggs. When a sperm and an egg fuse during fertilisation, their two haploid sets of chromosomes recombine to form a zygote with a complete diploid set of chromosomes. This diploid set of chromosomes will be the genetic material (genome) of a new individual. This recombination is the basis for variations in sexually reproducing organisms. In plants, meiosis occurs during spore formation in the process known as sporogenesis. The process of meiosis does not apply to lower organisms that reproduce asexually like bacteria.

Like in mitosis, meiosis also involves DNA replication during the interphase stage. However, meiosis involves two consecutive cycles of nuclear and cell divisions known as Meiosis I (the first meiotic division) and meiosis II (the second meiotic division). Meiosis I involves the separation of homologous chromosomes while meiosis II involves the separation of sister chromatids. Usually, meiosis reduces the number of chromosomes from diploid to haploid state, and it is, therefore, known as a reduction division. Literally, the term meiosis means “to reduce”.

Mechanism of meiosis

The process of meiosis is accomplished in two cycles or phases, namely: meiosis I and meiosis II. Both cycles are preceded by a non-dividing phase called interphase. For a single cell, the first meiotic division (meiosis I) produces two haploid cells

while the second meiotic division (meiosis II) produces a total of four haploid cells at the end.

Meiosis I

This is the first cycle of the two consecutive meiotic nuclear divisions. Its principal role is to reduce the number of chromosomes to half before meiosis II.

Stages of meiosis I

The mechanism of meiosis I involves four stages, namely: prophase I, metaphase I, anaphase I, and telophase I.

Prophase I

This is the longest phase of meiosis which is divided into five sub-phases that are leptotene, zygotene, pachytene, diplotene and diakinesis.

In leptotene sub-phase, DNA replication is completed and sister chromatids remain thin and closely associated. Moreover, chromosomes begin to shorten and hence they become visible as indicated in Figure 3.1.

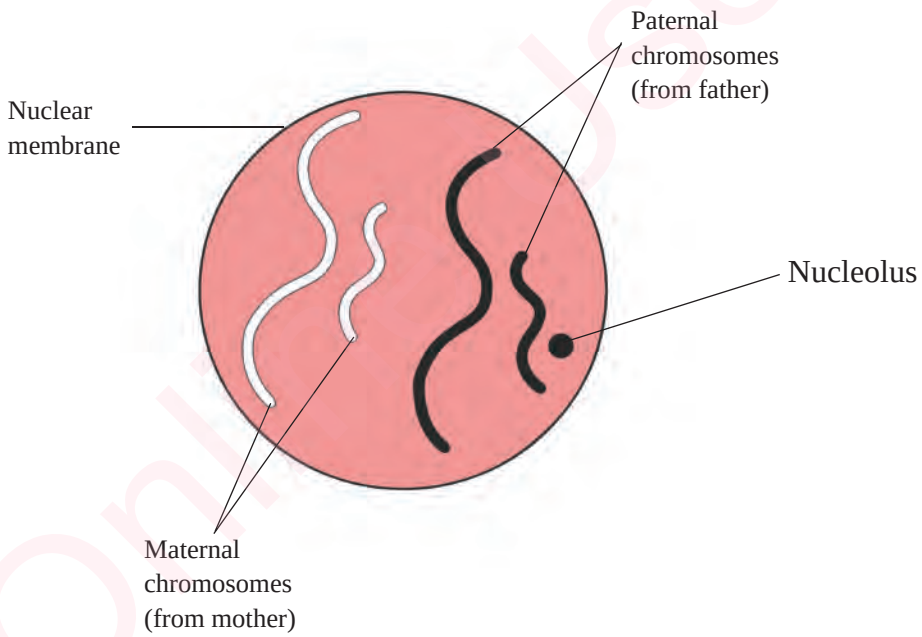


Figure 3.1 Leptotene stage

During zygotene sub-phase, paternal and maternal homologous chromosomes lie side by side. The centromeres from each chromosome lie in the same position as shown in Figure 3.2. The pairing process is called synapsis, and the paired homologous chromosomes form a bivalent.

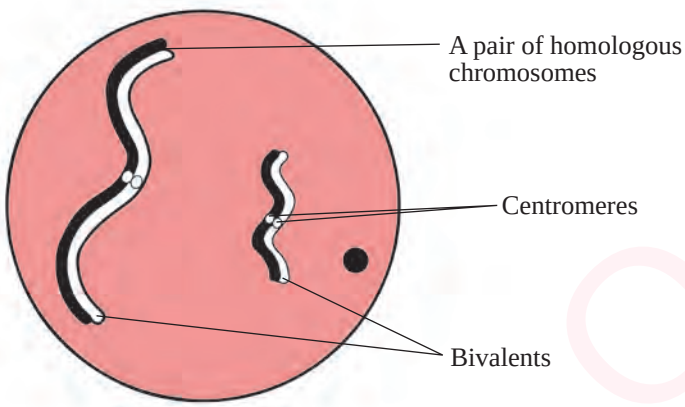


Figure 3.2 Zygotene stage

In pachytene sub-phase, chromosomes repel each other and separate partially. Each chromosome is composed of two chromatids. Repulsion of chromosomes causes each chromatid to move away from the sister chromatids and the non-sister chromatids cross each other as shown in Figure 3.3. The process is known as crossing over and the point of attachment is known as a chiasma which literally means a cross. The chiasma appears in several points of the chromosome. These points are referred to as chiasmata. They are important sites for the exchange of genetic materials between chromatids.

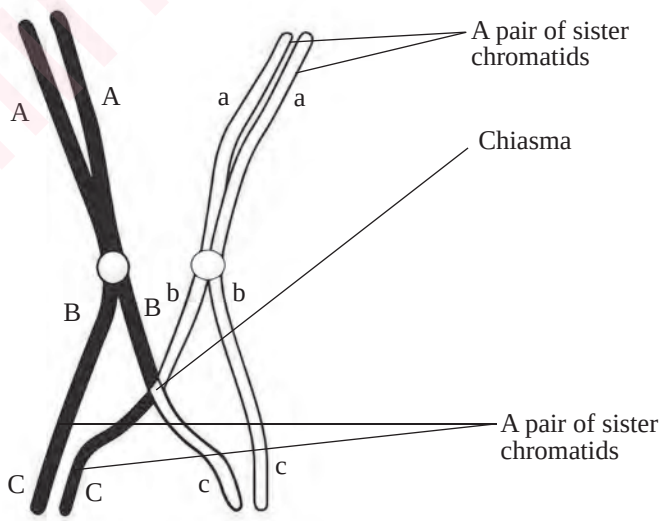


Figure 3.3 Pachytene stage

In diplotene sub-phase, the chiasmata become visible and the sister chromatids continue to repel from each other and bivalents assume a particular shape depending on the number of chiasmata as shown in Figure 3.4.

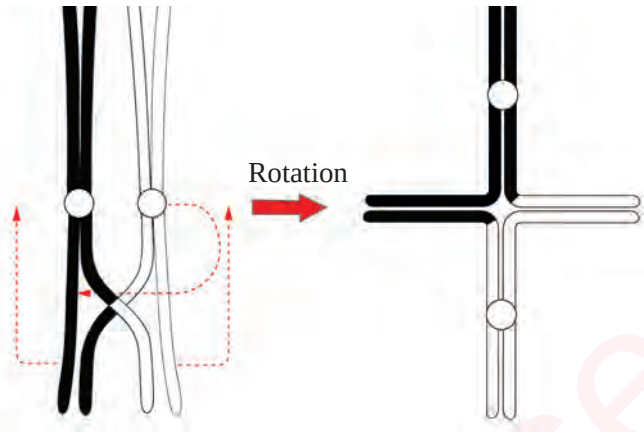


Figure 3.4 Diplotene stage

In diakinesis, the centrioles migrate to the opposite poles, the nucleoli and nuclear membrane disappear as shown in Figure 3.5. The spindle fibres start to develop and each sister chromatid moves apart to a great extent.

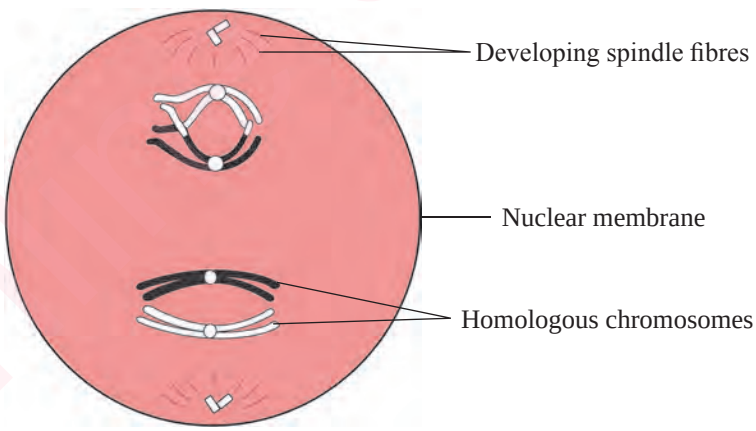


Figure 3.5 Diakinesis stage

Metaphase I

The homologous chromosomes (bivalents) attached by their centromeres become arranged on the metaphase plate and are attached to the fully formed meiotic spindles around the equator. Meiotic spindles are also known as spindle fibres or spindle microtubules. Each chromosome attaches to spindle fibres from just one pole of the spindle and the two homologous chromosome pairs are captured by spindle fibres from the opposite poles. Thus, during metaphase I, homologous chromosome pairs (rather than individual chromosomes) and line up at the metaphase plate under tension from opposite spindle poles as shown in Figure 3.6.

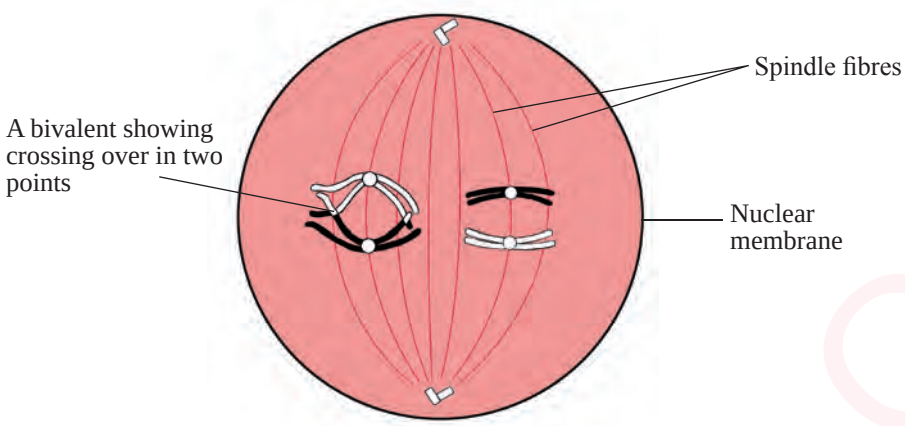


Figure 3.6 Metaphase I

Anaphase I

During anaphase I, two chromosomes in each bivalent separate and migrate towards opposite poles of the spindles with centromeres pulled first as seen in Figure 3.7. This process begins when the two chromosomes of each bivalent (tetrad) separate and start moving towards opposite poles due to the contraction of the spindle fibres. They contract as a result of the damage of cohesive proteins covering the arms of sister chromatids. This step breaks the chiasmata allowing the homologous chromosomes to move apart to the opposite ends of the cell. It is important to note that, the cohesive proteins at the centromere are not destroyed, so the sister chromatids of each homologue remain attached to each other. This is a key difference between mitosis and meiosis I whereas in meiosis I, the sister chromatids remain joined after metaphase while in mitosis, the sister chromatids separate.

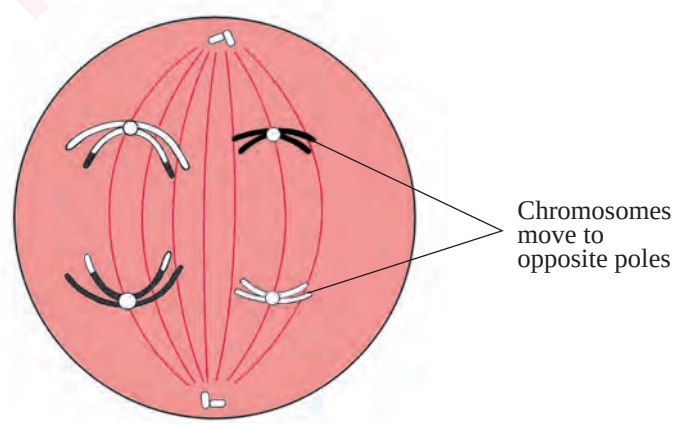


Figure 3.7 Anaphase I

Telophase I

In this stage, the homologous chromosomes arrive at the poles, nuclear envelopes form around them and the chromosomes condense as shown in Figure 3.8. In many plants, this step is skipped and the cell passes from anaphase I to prophase II directly. Cytokinesis, which refers to cytoplasmic cleavage, usually occurs during this stage. In animal cells, it involves the formation of cleavage furrow by folding of the plasma membrane inward. In plants, cytokinesis is accomplished by the cell plate formed at the equator of the old cell that will soon be two separate cells. The cell plate is the future cell wall that separates the two cells by dividing the cytoplasm. The chromosomes in these cells still have two sister chromatids each, but the chromatids are no longer identical due to crossing over. Spindle fibres also disappear at this stage.

Figure 3.8 Telophase I

Meiosis II

Cells move from meiosis I to meiosis II without replicating their DNA. Meiosis II is a shorter and simpler process than meiosis I. It is similar to mitosis because the produced daughter cells have the same number of chromosomes as the parent cells. The produced daughter cells are haploid (have one chromosome from each homologous pair), but their chromosomes still consist of two sister chromatids. These sister chromatids tend to separate, producing four haploid cells whose chromosomes have just one chromatid each.

Stages of meiosis II

The second meiotic division consists of four main stages which are prophase II, metaphase II, anaphase II and telophase II.

Prophase II

In animals, interphase II usually precedes the prophase II stage, but it does not involve DNA replication. The nuclear membrane breaks down and the spindle apparatus forms and centrioles duplicate as shown in Figure 3.9. This occurs by the separation of the two members of the pair, followed by the formation of a daughter centriole perpendicular to each original centriole. The two pairs of centrioles separate and migrate to the opposite poles. The chromatids shrink and spindle fibres start to develop.

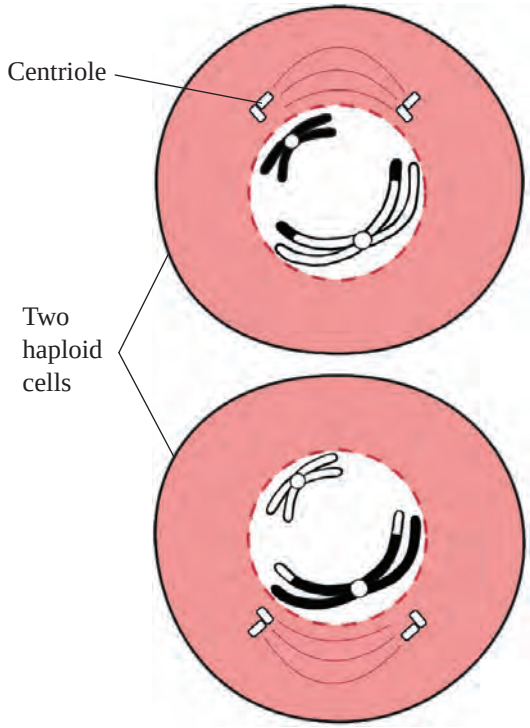


Figure 3.9 Prophase II

Metaphase II

During metaphase II, each of the daughter cells completes the formation of spindle fibres. The chromosomes line-up on the equator of the spindles and the spindle fibres attach to each chromosome at their centromeres as seen in Figure 3.10. This is in contrast to metaphase I whereby homologous pairs of chromosomes align at the metaphase plate.

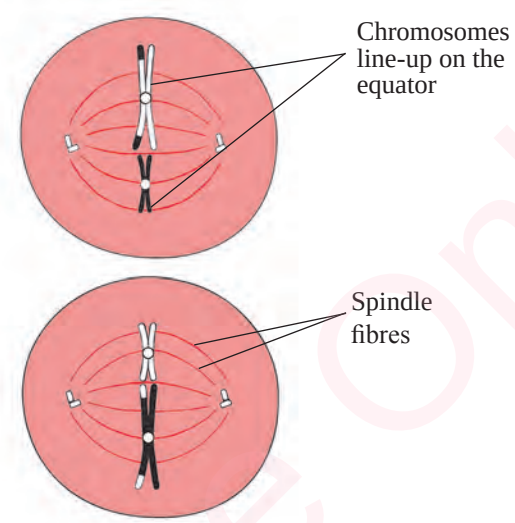


Figure 3.10 Metaphase II

Anaphase II

During this stage, the centromeres divide leading to the separation of chromosomes into sister chromatids. The spindle fibres pull the chromatids to the opposite poles with the centromere being pulled first as shown in Figure 3.11. Separation of sister chromatids occurs when the cohesive proteins that hold the chromatids together are destroyed. The separated chromatids are now called chromosomes. Furthermore, the cleavage furrow starts to develop on each of the two cells.

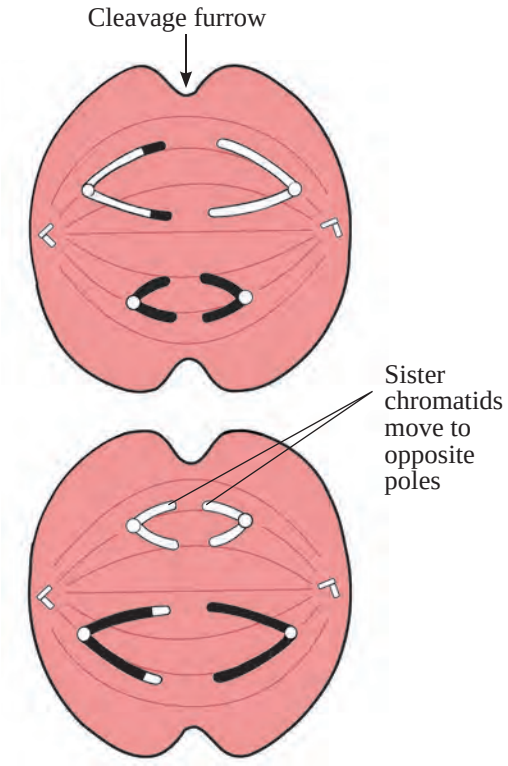


Figure 3.11 Anaphase II

Telophase II

During this phase, the chromatids reach their destination in the opposite poles of the spindles. The chromosomes become very distinct as they lengthen and uncoil. The spindle fibres disappear and centrioles replicate. The nuclear membrane emerges around each group of chromosomes containing half the number of the original chromosomes. The nucleolus reappears, followed by the completion of cytokinesis or cleavage of the cell to give four haploid daughter cells as shown in Figure 3.12. These are collectively termed as tetrad. In plants cells, cleavage is brought about by the formation of the cell plate which finally differentiates to form a cell wall.

Usually, meiosis process produces four daughter cells each with half of the number of chromosomes present in the parent cell. In a human being, the number of chromosomes in the parent cell is 46. Thus, after meiosis during gametogenesis, the number of chromosomes in each of the four haploid daughter cells will be 23.

Note that, only two pairs of chromosomes, that means four chromosomes were used in the illustrations to demonstrate the stages of meiosis in the previous sections.

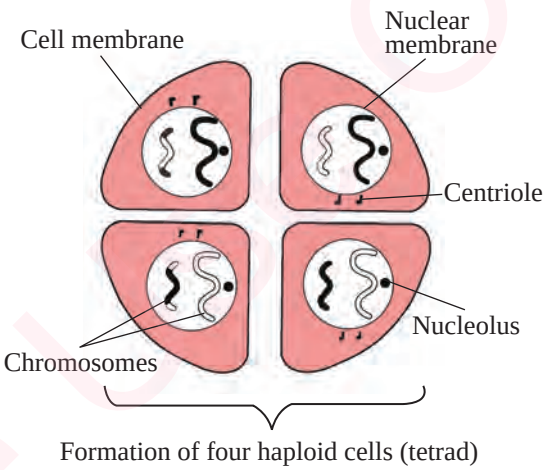


Figure 3.12 Telophase II

Activity 3.1 Observation of meiotic stages of cells

Materials: Prepared slides showing stages of meiosis and a light microscope.

Procedure

(i) Place a light microscope on a table and set it ready for observing the mounted specimen.

(ii) Place the prepared slides under the light microscope.

(iii) Observe each prepared slide under the microscope one after another.

(iv) Draw and label the diagrams of what you have observed under the microscope for each prepared slide and name the stage of meiosis represented in each slide.

Generally, stages of meiosis in plant and animal cells are characterized by more or less same events in most stages as detailed in the previous sections. However, some differences are evident at some stages as summarized in Table 3.1.

Table 3.1 Comparison between meiosis in plant and animal cells

Event	Plants	Animals
Time of occurrence	It occurs during spores formation in the processes of megasporogenesis and microsporogenesis.	It takes place during gametes formation in the processes of oogenesis and spermatogenesis.
Site of occurrence	It takes place in the anther of male and ovary of a female part of a flower.	It takes place in the testis of male and ovary of the female animal.
Daughter cells produced	It produces spores that develop into haploid gametophytes, which later produce male and female gametes, that is two male nuclei and an ovum or egg.	It produces male and female gametes (sperm and ovum).
Size of the cells produced	The produced cells such as spores and pollen grains are relatively large and conspicuous.	The produced cells e.g. sperms are relatively smaller and inconspicuous.
Telophase I	There is neither telophase I, cell wall formation nor interphase in most of the plant species. The cell passes straight from anaphase I to prophase II.	There is telophase I, where chromatids uncoil and a nuclear membrane re-appears after cleavage at each pole, then nucleus passes to interphase.
Telophase II	Cytokinesis occurs by fusion of Golgi vesicles to form a cell plate that extends to the periphery as a primary cell wall which separates the two cells.	Cytokinesis occurs by infolding of the plasma membrane of the cell towards the spindle equator. This forms a furrow in the cell surface membrane that fuses later and separates the two units into new cells.

Significance of meiosis in sexually reproducing organisms

The process of meiosis results into producing haploid cells thereby preventing the duplication of chromosomes during fertilisation, and hence maintaining the chromosome number of the species.

Meiosis is also a source of genetic variation. The gametes produced in meiosis are not genetically identical to the parent cell and to each other. The diversity of possible gametes is caused by two factors; crossing over and independent assortment of chromosomes during anaphase of meiosis I. The points where homologous chromosomes cross over and exchange genetic materials, occur more or less randomly. As a result, these points will be different in each cell that undergoes meiosis. This process produces a wide variety of recombinant chromosomes having fragments of DNA exchanged between homologous chromosomes. The more the crossing over the greater the extent of variations.

Random orientation of pair of homologous chromosomes during metaphase of meiosis I is another important source of gamete variation. The bivalent, which is defined as a pair of homologous chromosomes, consist of half the chromosome number from the father and half the chromosomes from the mother. In human beings, this is equivalent to 23 chromosomes from the mother and 23 chromosomes from the father making a total of 46 chromosomes. During meiosis I, the homologous pairs will separate to form two equal groups, but it is not usually the case that, all the paternal chromosomes will go into one group and all the maternal chromosomes into the other. Therefore, meiosis and fertilisation are key events that generate new combinations of gene variants or alleles. Meiosis can rearrange the existing alleles to make new combinations.

Comparison of mitosis and meiosis

Meiosis and mitosis processes share some similarities. Both processes pass through four stages, namely: prophase, metaphase, anaphase and telophase. However, the process of nuclear division is longer in meiosis than in mitosis. They are preceded by interphase, during which DNA replication occurs (except in interphase II). Moreover, in both cases, the parental cells at the beginning of the process are diploid in number where there is movement and rearrangement of chromosomes. Apart from the similarities, the two processes differ in some ways as summarized in Table 3.2.

Table 3.2 Differences between mitosis and meiosis

Events	Mitosis	Meiosis
Site of occurrence	Occurs in all somatic and germ cells that can be haploid, diploid or polyploidy cells. It takes place during the formation of somatic (body cells) and some spores.	Occurs only in germ cells that can be either diploid or polyploidy cells. It takes place during the formation of gametes or spores.
Cycles of cell division	It involves one cycle and single division of the chromosomes and the nucleus.	It involves two cycles of cell division and double division of the nucleus.
Prophase	Chromosomes shorten and thicken but do not associate, hence there is no crossing over.	In prophase I, homologous chromosomes pair up to form bivalents. There is crossing over or chiasmata formation.
Metaphase	Pairs of chromatids form a single row on the equator of the spindle.	Pairs of homologous chromosomes form a double row on the equator of the spindle in metaphase I.
Anaphase	Each centromere splits into two and identical chromatids separate.	Centromere does not split in anaphase I, hence, whole chromosomes that may be non-identical separate. Centromere splits in anaphase II.
Telophase	Two daughter cells are formed with equal number of chromosomes as the parent cell.	Four daughter cells are formed (although in females only one is usually functional) with half the number of chromosomes as that of the parent cell.
Cytokinesis	Follow immediately after nuclear division.	It may or may not occur at the end of first nuclear division.
Resemblance of daughter cells with parental cells (variation)	Daughter cells are identical to parental cells (in the absence of mutation)	Daughter cells are genetically different from the parental cells.

Exercise 3.1

1. Describe the events that occur during prophase I of meiosis in a reproductive cell.
2. Explain the importance of the following in the process of meiosis:
   (a) Chiasmata
   (b) Centromere.
3. Briefly discuss the mechanisms by which genetic variation is produced by the process of meiosis.
4. Differentiate the key features of the anaphase I of meiosis and the anaphase of mitosis process.
5. Meiosis is basically a reduction division. Briefly justify this statement.
6. Draw diagrams showing what happens during each phase of meiosis and label your diagrams using the following terms:

   Centrioles, maternal and partenal chromosomes crossing over, nuclear membrane, tetrad, nucleolus homologous chromosomes, spindle fibres, bivalents, sister chromatids, centromere, chiasma, and cleavage furrow.

Gametogenesis in animals

The process of gamete formation in animals is divided into two subprocesses, which are spermatogenesis in males and oogenesis in females.

Spermatogenesis

The process of spermatogenesis in males involves three phases: multiplication, growth, and maturation phases. In the multiplication phase, diploid germinal epithelial cells or primordial germ cells in the outer layer of seminiferous tubules undergo repeated mitotic division to produce diploid cells called spermatogonia (spermatogonium–singular).

During the growth phase, each spermatogonium increases in size and develops into primary spermatocytes.

During the maturation phase, the primary spermatocytes undergo meiosis I to produce secondary spermatocytes, which in turn divide by meiosis II, to produce spermatids as seen in Figure 3.13.

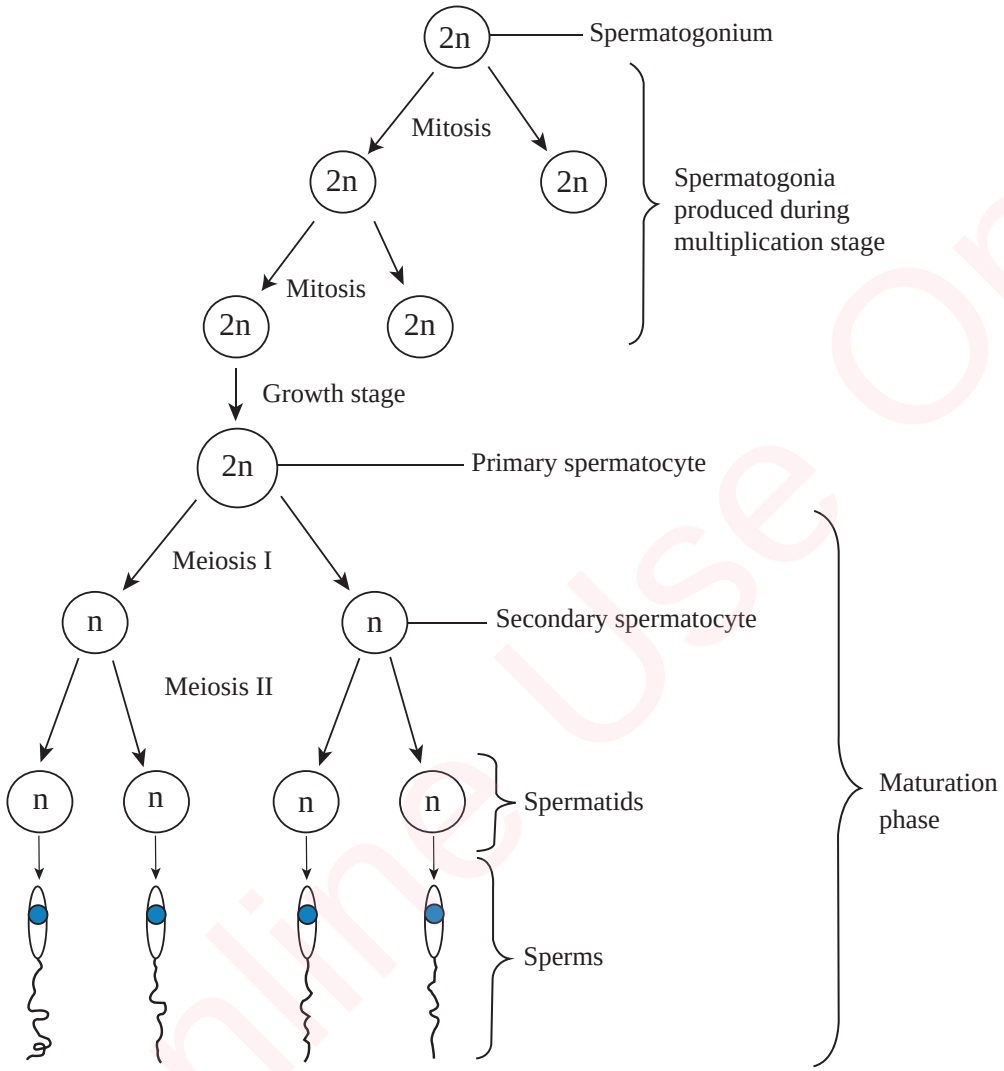


Figure 3.13 Spermatogenesis process in human

The spermatids are immature male gametes, which are finally transformed into mature spermatozoa or sperms in a process called spermiogenesis. During the entire period of development and after maturity, the spermatozoa are supported and nourished by the sertoli cells.

The sertoli cells are responsible for remoulding spermatids to develop sperms. These cells are important in nourishing the developing sperm by providing it with oxygen, nutrients, and exchange of metabolic wastes. This is done by the blood vessel going through sertoli cells. The cells secrete fluids carrying sperms via tubules. The formed sperm is extremely small and it contains head with a haploid nucleus, a short neck region with a pair of centrioles microtubules that develops axial filaments/ flagellum of the sperm tail. The middle piece contains mitochondria which liberate energy in form of ATP which is used in the beating of the flagellum. The beating of

the flagellum enables the sperms to swim from the vagina where they are deposited to the secondary oocyte in the fallopian tube in which one of them penetrates the secondary oocyte.

Spermatogenesis is controlled by both the hypothalamus and anterior pituitary gland working together. The hypothalamus secretes gonadotrophin-releasing hormone (GnRH) which travels in small veins to the pituitary gland. This hormone stimulates the anterior pituitary gland to secrete two hormones called gonadotrophins that stimulates gonads, in this case, the testis. The gonadotrophins hormones are follicle stimulating hormone (FSH) and luteinizing hormone (LH). FSH stimulates sertoli cells to mould and nourish spermatids to produce spermatozoa as shown in Figure 3.14. LH is an interstitial cell-stimulating hormone (ICSH), hence it stimulates the synthesis of testosterone by interstitial cells (Leydig cells) of the testis. Once released, this hormone triggers growth and development of spermatogonia into sperms.

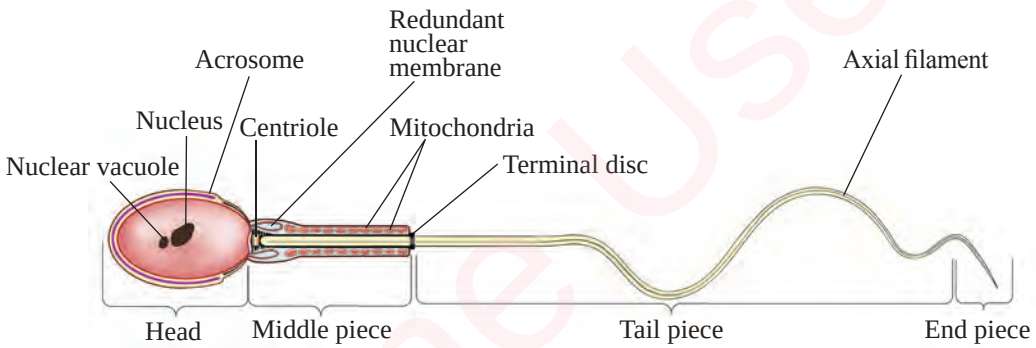


Figure 3.14 Structure of a mature spermatozoan or sperm

Oogenesis

The process of ovum or egg development is called oogenesis. Like spermatogenesis, the oogenesis process involves three phases, which are multiplication, growth, and maturation as summarised in Figure 3.15. Multiplication as the initial stage of oogenesis starts during embryonic or foetal development (before birth). During this phase, the diploid primordial germ cells undergo repeated mitotic divisions to produce many oogonia.

In the second phase called growth, each oogonium, grows and develops into a primary oocyte due to the accumulation of nutrients. The primary oocyte remains at prophase I throughout the childhood. The onset of puberty causes continued development of the arrested primary oocytes, to secondary oocyte during female's fertile years. Thus, every month, one primary oocyte completes meiosis I to produce two haploid cells. One of the two cells receives a large proportion of cytoplasm and becomes a functional secondary oocyte. The second cell receives a very small proportion of cytoplasm and becomes a non-functional unit called the first polar body. The secondary oocyte then starts meiosis II which stops at metaphase II.

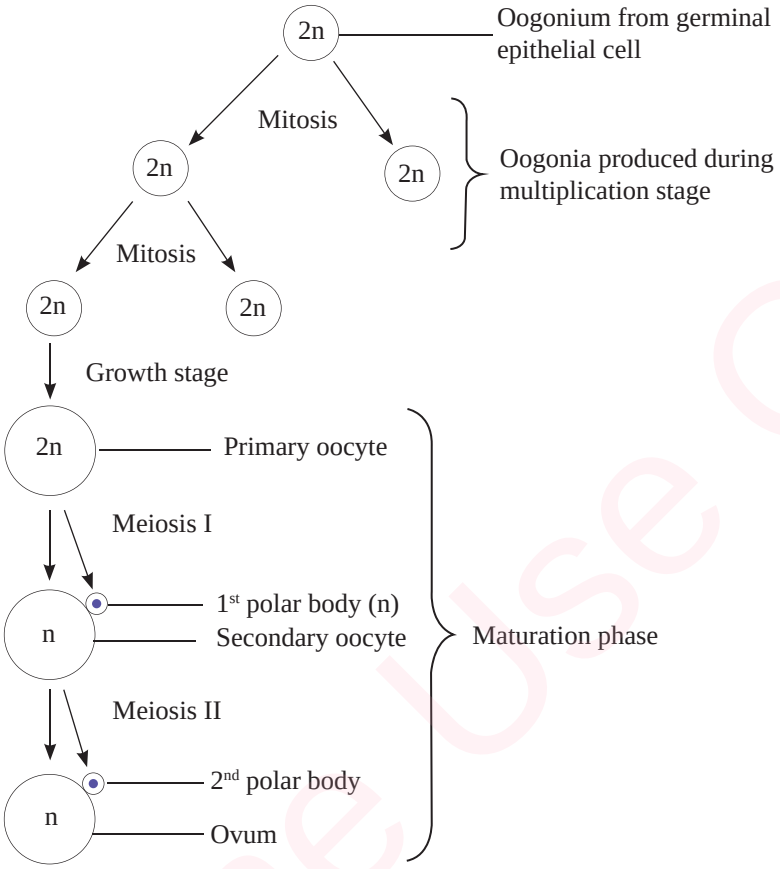


Figure 3.15 Oogenesis process in human

In some cases, the first polar body may also undergo meiosis II to produce secondary polar bodies. This stage is followed by ovulation during which the secondary oocyte is released when the mature ovarian follicle ruptures.

The changes in the released secondary oocyte depend on whether the oocyte is fertilised with spermatozoan or not. Thus, if it does not unite with the male gamete, the process does not go beyond this stage. However, if it meets the male gamete, the secondary oocyte becomes stimulated to complete meiosis II that produces a functional ootid and a second non-functional polar body. In maturation, the ootid is transformed into an ovum and the polar bodies degenerate as shown in Figure 3.16.

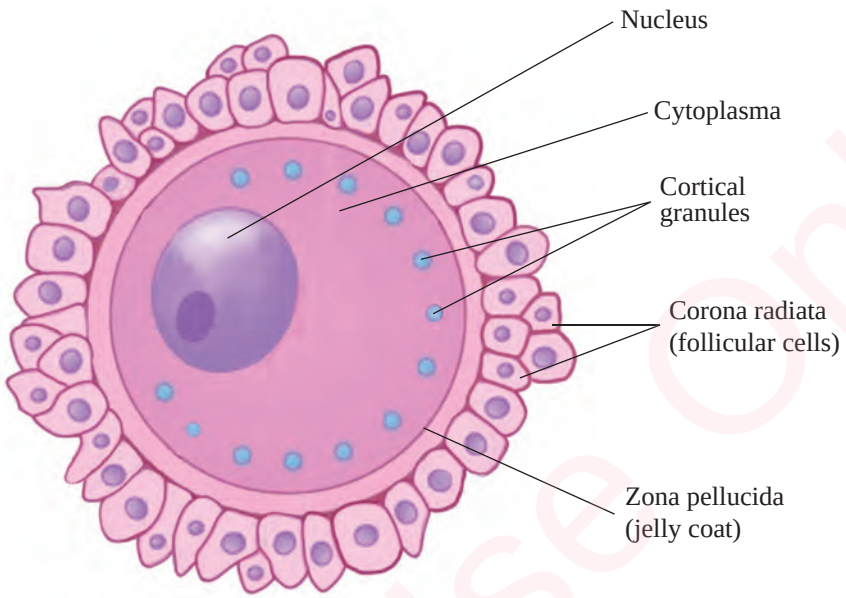


Figure 3.16 Diagram of a mature ovum

Gametogenesis in flowering plants

In flowering plants, the formation and maturation of gametes are preceded by the formation of spores, embryo sacs (megaspores) and pollen grains (microspores). The process by which flowering plants produce spores is called sporogenesis. This is divided into two sub-processes, which are microsporogenesis and megasporogenesis. The microsporogesis leads to the formation of male spores or microspores while the megasporogesis leads to the formation of female spores or megaspores. Usually, the microspores are smaller in size than the megaspores. Thus, flowering plants are said to be heterosporous because they produce two types of spores.

Microsporogenesis

This process involves the formation of male gametes or microspores or pollen grains in flowering plants. It occurs in the pollen sacs that are found in the lobes of anthers, which are the male parts of a flower. Young anthers usually contain four lobes or chambers covered by epidermal tissue. The cells of the epidermal tissue divide mitotically to form pollen sacs and hypodermis. Further mitotic division of the hypodermis results into the formation of diploid microspore mother cells that are found in the pollen sacs. In this process, the microspore mother cell or pollen mother cell undergoes meiosis I to produce two haploid cells also called dyad. The cells then undergo meiosis II to produce a tetrad of four haploid cells, which are called microspores. The four cells separate and undergo some changes which include the development of an additional wall. At this stage, each cell develops two walls, the inner wall or intine and outer wall or exine. The outer wall is made up of a hard long lasting and waterproof material called sporopollenin that increases chances of survival of the microspore. In each of the four cells, the nucleus divides

by mitosis to produce two nuclei; a pollen tube nucleus and a generative nucleus as seen in Figure 3.17. At this point, the mature pollen grain and its contents are referred to as the male gametophyte. The generative nucleus later divides mitotically to form two male gametes (sperms). When a pollen grain lands on a stigma, the tube nucleus divides mitotically to form a pollen tube that extends from the stigma to the micropyle. The function of the pollen tube is to carry two sperm nuclei to the female gametophyte for fertilization because the two sperms are not flagellated. This tendency reduces water dependence for fertilization in angiosperms.

Megasporogenesis

This is the formation of female gametes (egg) from the megaspore mother cells. This process occurs in ovules (megasporangia) found in the ovary of an angiosperm flower. Each ovule has an outer sheath called integuments that encloses a nutritive tissue called nucellus. The development of female gametophytes starts as a swelling of the nucellus. This tissue divides mitotically to form two layers called integuments that encloses the megaspore mother cell. During megasporogenesis, a megaspore mother cell divides by meiosis to produce four haploid cells. Three cells, which are found at an outer layer, degenerate and one inner cell grows and enlarges to form the embryo sac.

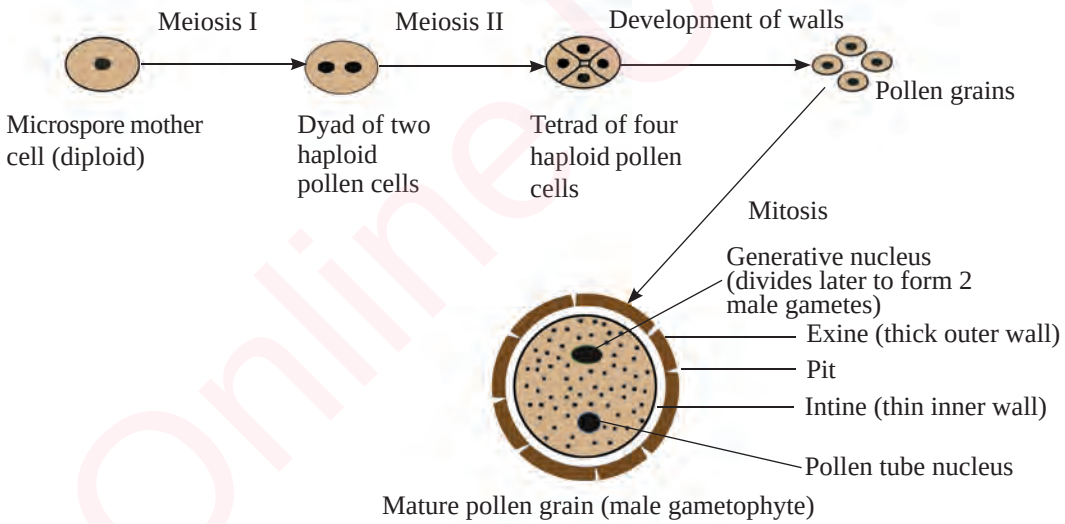


Figure 3.17 Formation of pollen grains in flowering plants

This occurs due to nutrients supplied by the nucellus. The nucleus of the embryo sac divides mitotically three times to produce eight nuclei. At this stage, the embryo sac and its contents are referred to as a female gametophyte. This is because one of its nuclei is a female gamete as seen in Figure 3.18. There is rearrangement of nuclei in the embryo sac. Two nuclei migrate to the centre to form polar nuclei. Three nuclei migrate to the chalaza end/upper end of embryo sac, these are called antipodals. The remaining three nuclei migrate towards the micropylar end/bottom end of embryo sac near the micropyle pore. They are then organized into a three - celled egg apparatus.

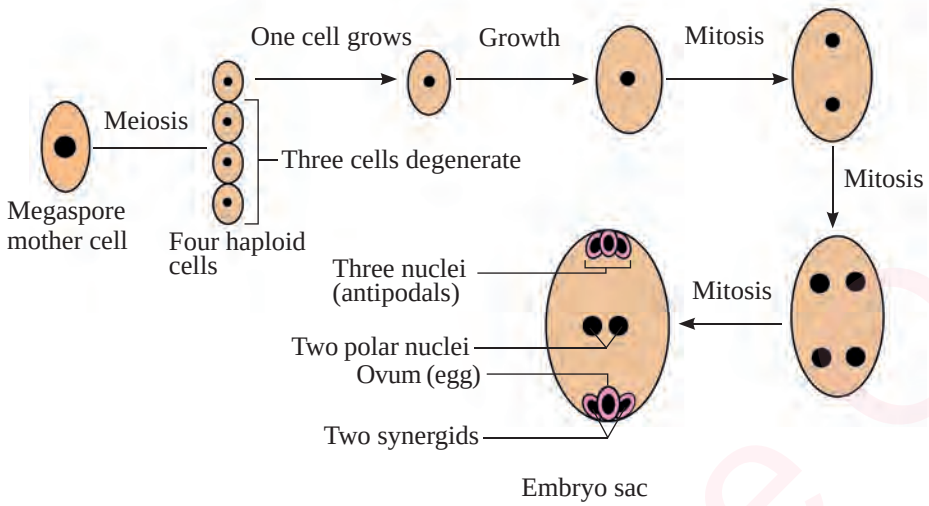


Figure 3.18 Formation of female gametes in flowering plants

This group of cells has two small cells known as synergids and one relatively large cell called an ovum or an egg, that is the female gamete.

Relationship between meiosis and gametogenesis in animals and plants

Gametogenesis is a term that refers to the process of gamete formation. The gametes produced are sperms and egg for male and female individuals respectively. The gamete forming process, which leads to the production of sperms, is called spermatogenesis while the egg or ovum forming process is termed oogenesis. Gametes are produced from specialized cells called mother cells. These cells in plants are called spore mother cells because ultimately they produce spores. The spore mother cells are found in structures called sporangia. In plants that produce two types of spores or heterosporous plants, the cells which produce spores are called microspore mother cells and megaspore mother cells for production of male and female spores respectively. The heterosporous plants, therefore, have microsporangia that produce microspores and megasporangia that produce megaspores. The equivalent of these cells in male animals are sperm mother cells (spermatocytes) and egg mother cells (oocytes) in female animals. These two types of gametes are produced in structures called gonads which are testes and ovaries in males and females respectively.

Unlike their mother cells, the spores, sperms, and eggs are all haploid cells. In order to reduce the parental chromosome number from diploid to haploid, meiosis process is very crucial. In plants, the spore mother cells in sporangia undergo meiosis to produce haploid tetrad called spores. In animals, on the other hand, meiosis takes place in the spermatogonia and oogonia which are sperm and egg mother cells respectively. In human beings, gametogenesis in males, begins at puberty with repeated mitosis of the germinal cells to form spermatogonia. However, in females, the process starts at the early stages of development before birth to form oogonia.

Exercise 3.2

1. Briefly describe the events that occur during megasporogenesis.
2. With the help of well labelled diagrams, explain the processes of spermatogenesis and oogenesis.
3. Explain how pituitary gland is involved in sperm formation.
4. Describe the mechanism of microsporogenesis in angiosperms and explain why the formed microspore is called the male gametophyte.
5. Compare megasporogenesis in angiosperms and oogenesis in mammals.

Reproduction in plants

Plants like animals reproduce sexually but they also have various ways in which they can reproduce asexually. Normally, sexual reproduction is accomplished by production of male and female gametes, which are spermatozoa/sperms and egg/ovum respectively.

Asexual reproduction in plants occur in various ways depending on the group/division of the plant. For example, members of division bryophyta such as *Marchantia* species may reproduce asexually by fragmentation. In this way, a fragment of bryophyte detached from a mother plant can grow to form a new plant under favourable conditions. The *Marchantia* species produce special cup-like structures called gemmae cups on their surface that bears small greenish ball-like structures called gemmae. The gemmae can be splashed off the gemmae cups by rain drops. Each gemma once landed on conducive environment can germinate to produce a new *Marchantia* plant.

Some relatives of division Filicinophyta can reproduce asexually by using special structures called bulbils located on the axils of their leaves. Each is capable of developing into a new plant once it lands on favourable conditions.

In higher plants such as angiosperms, asexual reproduction is through vegetative propagation in which a part of a plant organ can develop into a new individual plant. Some examples of plant organs used in asexual reproduction and their respective plants include stem as in *Manihot esculenta* (cassava); root as in *Ipomoea batatas* (sweet potatoes); suckers as in *Agave sisalan*a (sisal) and *Musa acuminata* (banana); leaf as in *Kalanchoe pinnata* (Cathedral bells) and *Bryophyllum daigremontianum* (Devil's backbone) species; rhizome as in *Zingiber officinale* (ginger) and corms as in *Colocasia esculenta* (Taro). This is advantageous to some plants because the produced new plants are genetically identical to parental plants.

Usually, asexual reproduction proceeds more rapidly than sexual reproduction. This kind of reproduction results into individuals that are genetically identical to their parents. This is because it does not involve fusion of gametes and hence, low genetic diversity. The new individuals, therefore, may fail to adapt to a new environment or changes in the environment.

Sexual reproduction in plants is preceded by the formation of male and female gametes. In plants as explained in previous section, gametogenesis comes after sporulation because male and female gametophytes develop from the spores. In bryophytes and ferns, the spores germinate to form

gametophyte generation from which male and female gametes are produced. In angiosperms, the gametophyte is the pollen grain and an ovule that are found in flower. The pollen grain is the male gametophyte which produces sperms, while the ovule is the female gametophyte, which produces an egg or ovum. In both lower and higher plants, sexual reproduction involves the union of the male gamete (sperm) and female gamete (egg) to form a zygote in the process called fertilisation.

Fertilisation in plants

Fertilisation is a crucial process in sexual reproduction through which nuclei of the reproductive cells, which are genetically different, unite to produce offspring. The resulting offspring are genetically different from each other and from each of their two parents. Sexual reproduction increases genetic diversity, which help plants to adapt better to a new environment or withstand environmental changes. In plants, this type of reproduction may result in the formation of seeds, which are important to disperse plant species and reduce competition among species. The formation and maturation of gametes come after spore formation. The process of spore formation is called sporulation or sporogenesis. A spore is a unicellular haploid cell which is capable of germinating to form a new plant body.

Events leading to fertilisation in plants

Generally, there are two groups of plants based on the types of spores they produce; homosporous and heterosporous plants. The homosporous plants produce only one type of spores that are of the same size and shape and cannot be differentiated into male and female spores. In homosporous plants, each of these spores can germinate to produce a gametophyte bearing both male and female reproductive structures under favourable conditions. The male reproductive structures are antheridia while the female reproductive structures are archegonia. A gametophyte plant refers to a gamete forming plant body. All bryophytes and majority of fern species are homosporous.

The spores in bryophytes are produced in special structures called sporangia found inside a club-like structure called a capsule. In ferns, spores are produced by sporangia but these are located inside structures called sori (sorus-singular) located on the lower side of the fern leaf called frond. In both homosporous and heterosporous plants, spores are produced by meiosis which occurs in the spore mother cell located in sporangia. Each spore mother cell produces four haploid cells after meiosis. Each of these four cells is a spore, which is very light and can be dispersed to distant areas by the wind. Upon landing on favourable conditions, spores germinate to form a haploid gametophyte generation through mitosis and cell division. A mature gametophyte develops a small club like structure called antheridium and a flask like structure called archegonium on its surface.

Matured antheridium raptures to release flagellated sperms while archegonium raptures to expose egg located at the base. The rapturing of antheridium to release sperms is triggered by the presence of water in the environment, for example when it rains. This is important to synchronize sperms release and fertilisation because water is a medium through which flagellated sperms swim to fertilize the egg in the archegonium. Special chemical attractants produced by the archegonia attract sperm to swim towards the egg in which fertilisation

occurs. After fertilisation, a zygote is formed and remains protected inside the archegonium. In bryophytes, the zygote later grows as a result of mitosis and cell division to form a capsule. In some species of bryophytes, the zygote develops first into a stalk called seta on top of which a capsule bearing sporangia develops.

On the contrary, in heterosporous ferns, megaspores germinate to produce female gametophytes bearing archegonia which produce eggs. The microspores germinate to form male gametophytes bearing antheridia which produce sperms. In the presence of water, flagellated sperms from the antheridia swim and fertilize the egg in the archegonia to form a zygote. This develops into an embryo and later a young sporophyte that grows into a mature sporophyte generation with sori bearing sporangia, which are capable of producing spores.

Double fertilisation in higher plants

In angiosperms, fertilisation occurs after pollination. This is a process of transferring pollen grains from the anthers to a stigma of a flower within the same plant or in a different plant but of the same species. Some flowers can be pollinated by their own pollens while others get pollinated by pollen grains from other individual plants of the same species. The former is termed self-pollination while the latter is called cross-pollination. Pollination is mainly by wind, insects, birds, and mammals. These together are called pollinators.

The arrival of pollen grains on the stigma of a compatible species stimulates the secretion of sugary solution including sucrose from the stylar tissues. As the pollen grain absorbs these solutions and get nourished, it starts bulging. This stimulates the pollen grain to germinate and causes the intine wall to grow through the exine via one of its apertures as a pollen tube. There are two types of apertures in the exine of pollen grain, namely pore and fissure or colpi. The growth of the tube is a result of a mitotic division of the pollen tube nucleus, which is controlled by auxins secreted by the stylar tissues. The tube grows rapidly down the stylar tissues towards the ovule.

The chemicals which are secreted by the synergids in the embryo sacs, direct the growth of the pollen tube towards the micropyle. This is an example of chemotactic growth. As the pollen tube grows, the generative nucleus in the pollen grain divides through mitosis to produce two haploid male gametes. The pollen tube enters the ovule through the micropyle. As this happens, the pollen tube nucleus degenerates and the tip of the pollen tube bursts open to release the two haploid male gametes into the embryo sac.

The entry of the sperms into the embryo sac or ovule is followed by fertilisation. Flowering plants unlike bryophytes, ferns, and gymnosperms, exhibit a unique type of fertilisation called double fertilisation which literally means two fertilisation events in each ovule. Double fertilisation in flowering plants is a result of multi-nucleate nature of pollen grain and ovule in which there are two sperm nuclei in the pollen grain and an ovule containing an egg and diploid polar nuclei. The first fertilisation event involves fusion of one of the two sperm nuclei with an egg to form a zygote. The second fertilisation event involves the fusion of the second sperm nucleus with the two polar nuclei as shown in Figure 3.19. You will recall that, these two polar nuclei are haploid and are fused into one entity thus

making them diploid. Once these two polar nuclei (2n) fuse with the second sperm (n) the result is a triploid (3n) nutritive tissue called endosperm. The predominant food storage is carbohydrate in the form of starch and sugar, the latter changes to starch as the seed grow. Lipids and proteins are also other types of stored food in the endosperm of seeds such as sunflower and nuts.

Fruit and seed development

Immediately after fertilisation, several physiological and morphological changes occur in a flower. Such changes are observed in the zygote, endosperm, and the ovary. Externally, structures of the flower such as calyx, corolla and androecium, which are no longer required in the fertilisation process change significantly. Although some of the floral parts change rapidly after fertilisation, it is interesting to note that even dead pollens

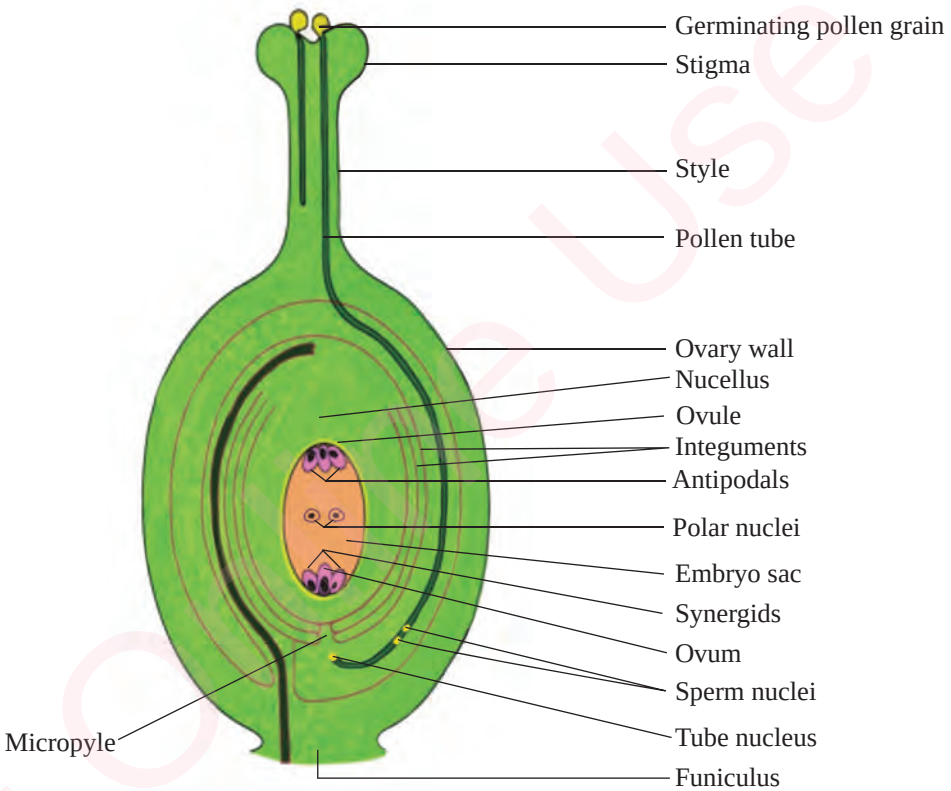


Figure 3.19 Development of pollen tube towards ovule after pollination

are important in some cases in triggering changes subsequently to fertilisation. The fruit development from an ovary is one of such changes as it may require hormones from dead pollens.

Changes which occur in flower after fertilisation

Following the process of fertilisation, various changes occur in the flower. These include disintegration of antipodals and synergids. The zygote undergoes a rapid repeated mitotic division forming a

multicellular embryo. This embryo then, differentiates into a young shoot called plumule, a young root called radicle and simple seed leaves known as cotyledons. Depending on the class of flowering plants, cotyledons may be two as in dicots or one as in monocots. The cotyledons are the food reserve tissues. The endosperm nucleus undergoes mitotic division to give rise to a mass of endosperm tissue. The embryo remains enclosed in the ovule for protection. Upon maturity, the fertilised ovule becomes a seed. Integuments of the ovules form a tough protective layer called a seed coat or testa. The micropyle remains as a small pore in the testa through which oxygen and water enter during germination of the seed.

During embryo development, nucellus disintegrates to provide nutrients for supporting initial growth. In the final stages of seed development, a drastic reduction in water content of the seed occurs. This greatly reduces the potential for metabolism which is an important step towards seed dormancy.

The flower may remain temporarily attached to the sporophyte generation (mother plant) after fertilisation. However, in the due time sepals, petals and stamens wither and fall off. The fruit develops from a mature ovary whose wall becomes differentiated into three layers, namely: exocarp which is the outermost layer, endocarp on the inner part of the fruit, and mesocarp which is a fleshy layer in between the exocarp and the endocarp. These three layers are collectively called pericarp and are distinct in fleshy fruits but fused in dry fruits. In order for an ovary to mature into a fruit, a certain quantity of hormones from decaying pollen grains is required. This means that, a fruit may fail to develop from an ovary even after fertilisation if a threshold number of pollen grains is not available. The style also withers and falls off leaving its scar on the fruit.

Events which lead to the formation of endospermic and non-endospermic seeds

As mentioned in the previous section, double fertilisation results into a triploid primary endosperm and a diploid zygote. The latter develops into an embryo whereas the former may develop into endosperm in endospermic seeds such as maize, wheat and rice. In these seeds, the primary endosperm undergoes mitotic division to give rise to a mass of endospermous tissue as seen in Figure 3.20 (a). This tissue forms the food source to the growing embryo. In some other seeds, the cotyledon stores food and they grow at the expense of the endosperms that may disappear completely. Seeds of this type are referred to as non-endospermic seeds and they include leguminous seeds such as beans as shown in Figure 3.20 (b).

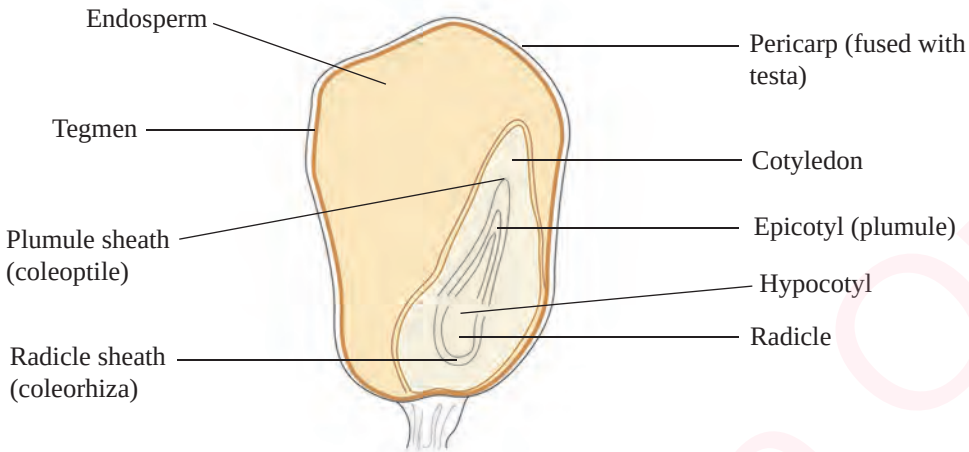


Figure 3.20 (a) Longitudinal section of maize grain showing endospermic seed

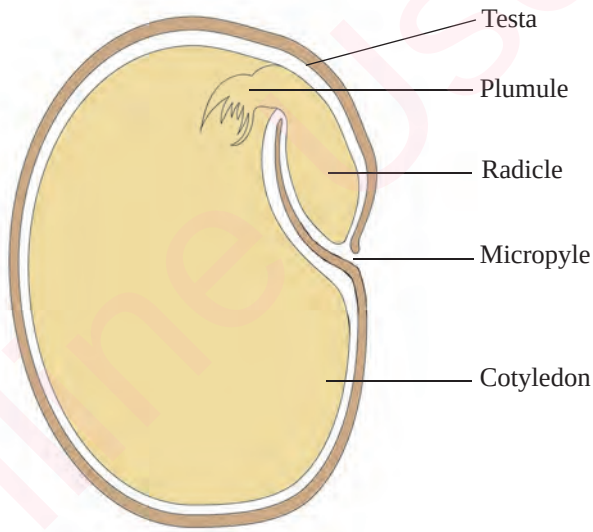


Figure 3.20 (b) Longitudinal section of bean seed showing non-endospermic seed

Exercise 3.3

1. Distinguish between pollination and fertilisation.
2. Explain the importance of fertilisation and pollination in plants.
3. Elaborate how fertilisation in flowering plants differs from fertilisation in bryophytes.
4. Briefly discuss the significance of double fertilisation in flowering plants.
5. Explain differences between sexual and asexual reproduction in plants.
6. With the aid of well-labelled diagrams, distinguish between endospermic and non- endospermic seeds.
7. Briefly explain any five changes that occur in the flower after fertilisation.

Life cycles of selected plants

Plants have two major phases in their life cycle; one in which they grow vegetatively and a second phase in which they set flowers for sexual reproduction. These two phases are common in all flowering plants irrespective of their life form. Plants may be of the following forms; herbs, grasses, shrubs, trees or whether they are annual, biannual or perennial. In lower plants such as bryophytes and ferns, sexual reproduction phase is common although they do not produce flowers. This is to say that all plants have two alternating phases, one in which they produce gametes for sexual reproduction and a second phase in which they grow vegetatively. These two phases alternate in which one phase is temporarily present while the other is permanent. The existence of alternating phases in the plants life cycle is referred to as alternation of generations. The predominance of one phase over another varies across plant divisions. A thorough understanding of the alternation of generations in various groups of plants is paramount in studying how plants reproduce, and the conditions under which sexual reproduction occurs.

Alternation of generations

Alternation of generations is a biological phrase which is commonly used to describe the life cycle of a plant. In the alternation of generations, a diploid spore producing plant body termed sporophyte alternates with a haploid gamete producing body called gametophyte as indicated in Figure 3.21. Literally, sporophyte is a combination of two terms “sporo” which means spore and “phyte” meaning a plant. Similarly, gametophyte is a combination of two words, “gameto” referring to a gamete and “phyte” standing for a plant.

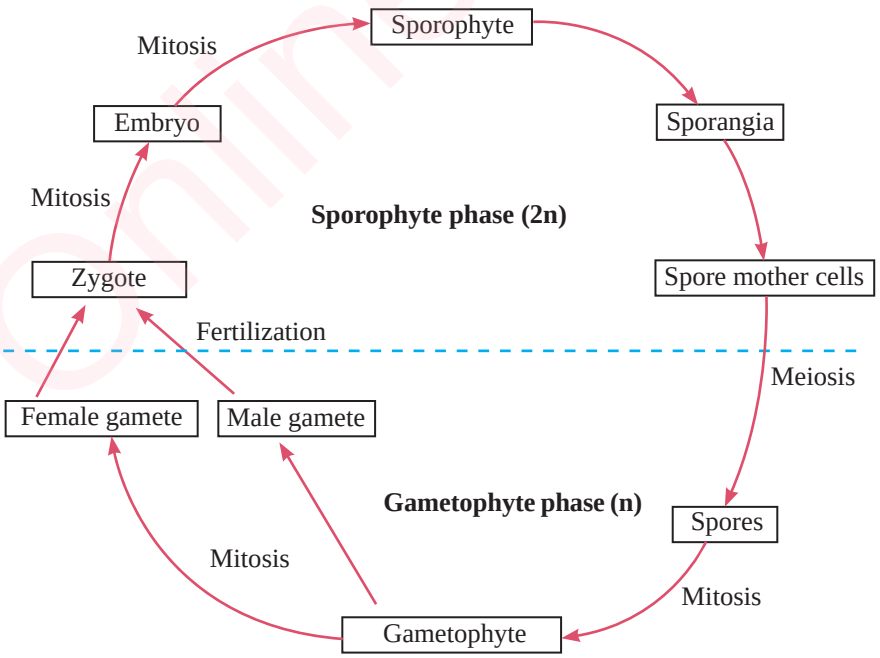


Figure 3.21 A generalised life cycle of plants

Similarly, gametophyte is a combination of two words, "gameto" referring to a gamete and "phyte" standing for a plant.

Usually, haploid spores are produced by meiosis, which occurs on the special cells called spore mother cells. These cells are found in structures called sporangia borne in the sporophyte generation. The spores are very light and can be easily blown by the wind to distant areas. The firm wall called sporopollenin found on the surface of spores makes it easy for the spores to be dispersed without suffering physical damage as they hit on different structures. Germination of spores occurs when it lands on favourable conditions, particularly in a moist environment. Each haploid spore germinates as a result of mitotic cell division to form a haploid gametophyte. Depending on a plant division or species the gametophytes can have different sizes and shapes. Generally, there is a trend of decrease in the size of gametophyte from lower plants such as bryophytes to higher plants such as angiosperms.

The mature gametophyte produces sexual reproductive structures, which produce male gametes (sperms) and female gamates (eggs). The sperms produced by bryophytes and ferns are flagellated unlike those produced by angiosperms and gymnosperms. Antheridia and archegonia are reproductive structures in bryophytes and ferns. The antheridia produce flagellated sperms while archegonia produce eggs. In higher plants, pollen grains and ovules are responsible for the production of non-flagellated sperms and eggs respectively.

In favourable conditions, fertilisation occurs to produce a zygote. In lower plants, favourable conditions include the presence of water, a medium through which flagellated sperms swim toward the egg. In higher plants, favourable conditions include the presence of pollinators and conditions triggering pollen tube development. The zygote develops as its cells divide mitotically to form an embryo that remains retained within the female gametangium. The growth of an embryo later develops into a sporophyte generation directly as in ferns and bryophytes. However, in higher plants, the young sporophyte is a seed, which can go through a stage called dormancy, before it germinates to a fully grown sporophyte. The mature sporophyte generation produce spores and the cycle starts over again.

Depending on the plant division, gametophyte generation may be dominant while the sporophyte generation is temporarily present. In bryophytes the gametophyte is dominant over sporophyte generation. In ferns, gymnosperms, and angiosperms sporophyte is dominant over gametophyte generation.

The life cycle of bryophytes

Bryophytes are members of division Bryophyta and they include Mosses, Liverworts and Hornworts which are the simplest terrestrial plants. Among bryophytes, Mosses are more common in our environment and sometimes dominate the terrain to the exclusion of other plants, particularly in moist areas.

All bryophytes undergo alternation of generations, which is distinct compared to other groups of plants, particularly, seed bearing plants and ferns. Alternation of generations in these plants is characterized by a haploid dominant phase called the gametophyte generation, which alternates with the diploid temporary phase called

sporophyte generation. The gametophyte is relatively large and more conspicuous than sporophyte generation.

The sporophyte generation is attached to, and dependant on gametophyte generation which is leafy and green in colour. The gametophyte generation, therefore, comprises of the green leafy shoot and rhizoids. The leafy shoots in mosses are small and are of three types. One is female shoot that forms archegonia on its tips from which an egg is produced. A single female shoot can have several archegonia but each is capable of producing only one egg. The second is a male shoot that bears antheridia at their tips. In each antheridium, multiple sperms are produced. The third shoot is sterile and does not bear any reproductive structure.

In the presence of water, especially, during the rainy season, the antheridium raptures and the rain drops splash the flagellated sperms off the antheridium. Most bryophyte leafy shoots are small and become easily flooded with water when it rains. This makes it easy for the sperms to swim. The released sperms swim towards the archegonium and fertilise the egg to form a zygote which develops inside the archegonium. The chemical attractants released by the archegonia direct the sperm to swim towards it. This implies that sexual reproduction cannot occur without water. As summarised in Figure 3.22, the resulting zygote divides mitotically to form an embryo, which later grows to form sporophyte generation. In erected bryophytes such as mosses, the sporophyte generation is brownish in colour and consists of a foot, stalk called seta and sporangium. In thallose bryophytes, the seta is missing. The foot is the tissue which connects sporophyte generation to gametophyte generation. It is important for the absorption of water and nutrients from the photosynthetic gametophyte.

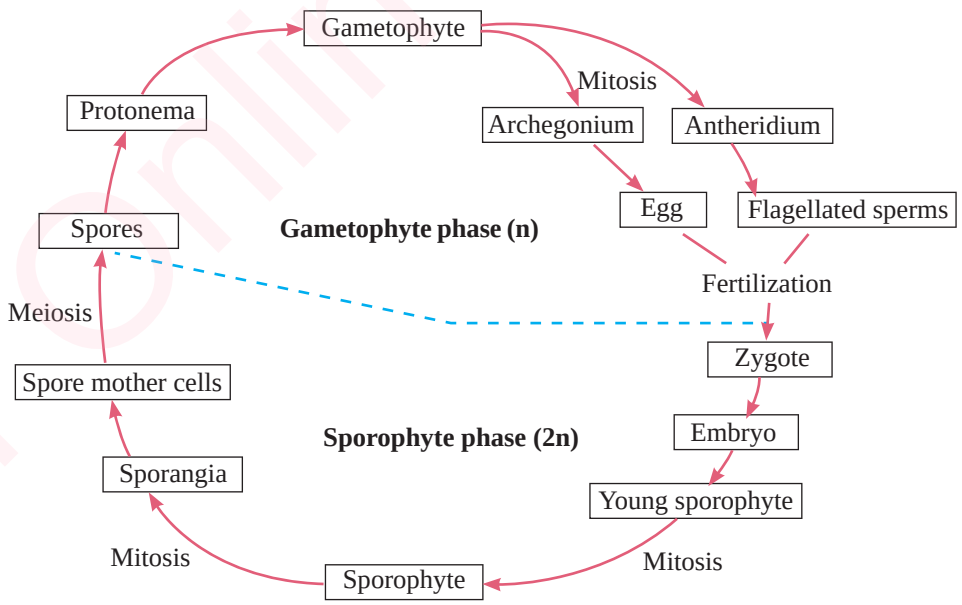


Figure 3.22 A generalised life cycle of bryophytes

This is important because the entire sporophyte is not capable of synthesizing its food. In other words, sporophyte is entirely dependent on gametophyte generation.

The stalk holds the sporangium containing capsule on its tip. The sporangium contains spore mother cells. At maturity, the spore mother cells undergo meiosis to produce spores. Once this is done, a flap known as calyptra covering the capsule withers and exposes a tissue called operculum, which seals the capsule tip. As the operculum dries and detaches from the capsule the latter splits open to release the spores. Once the spores are released, the sporophyte generation degenerates but the gametophyte persists.

The spores are dispersed to distant areas because they are very small and light. The spore which lands on moist conditions, germinates to form a small thread-like structure called protonema. This later develop rhizoids and small leafy shoots that mature to form male and female shoots. The male and female shoots produce antheridia and archegonia on their tips respectively from which sperms and eggs will be produced. At this point, the life cycle can repeat over again.

Activity 3.2 Observation of sporophyte and gametophyte generations of bryophytes

Materials: Mosses or Liverworts, white tile or watch glass, and hand lens.

Procedure

(i) Collect mosses or liverworts from a damp or shaded area.

(ii) Place the specimens on a white tile and use a hand lens to observe the structure of Mosses and Liverworts.

(iii) Observe clearly to see if there is any brown stalk protruding from the leafy green mat.

(iv) Draw and label all the observable parts of the plant to show clearly the gametophyte and sporophyte generations.

(v) Briefly explain why moist and shaded habitat is important to the survival and propagation of a moss plant.

(vi) Write short notes on asexual reproduction in bryophytes.

Results: The sporophyte has a brownish stalk emerging from the gametophyte which consists of rhizoids, leaf, and a stem-like structure.

Life cycle of pteridophytes

Pteridophytes are members of division pteridophyta also known as filicinophyta. This is a group of plants in which the true ferns are found. Ferns show alternation of generations in which the spore-producing plant phase called sporophyte is dominant and more conspicuous while the gamete-producing phase, the gametophyte is temporal as summarized in Figur e 3.23 (a). The sporophyte generation in fern constitutes of fronds which are the fern's leaves, a stem or rhizome and adventitious roots originating from the rhizome. The frond is made up of the midrib/rachis, small leaflets called pinnules and relatively larger units named pinnae. The frond is attached to the rhizome at the base by a stalk.

The fern plants do not produce flowers as reproductive structures instead they rely on spores. These are found on the lower side of the leaf where they exist in structures called sporangia. The sporangia on the lower side of the frond are clustered in circular

structures called sori. They appear as an aggregation of brown dots spread on the pinnule margins. The sori are protected by a tissue called indusium while the sporangia in it, are protected by a layer of tissue called annulus. The spore mother cells in the sporangium undergo meiosis to produce haploid spores. The mature sorus bursts and exposes the sporangia housed beneath it as its indusium shrinks. The exposure of the annulus of the sporangium to moisture results into abrupt rapturing and sudden ejection of spores out of sporangium, a process called catapulting. The majority of ferns are homosporous producing one type of spore while a few are heterosporous producing microspores (small male spore) and megaspores (large female spores).

On landing to the favourable conditions such as moist environment, spores germinate to produce a small green heart-shaped structure known as prothallus, which is a young gametophyte. The prothallus continues to grow through mitotic division to produce rhizoids on its lower surface at the centre. Additionally, the antheridia and archegonia which are reproductive structures, develop on the lower surface between the rhizoids as shown in Figure 3.23 (b). In the presence of water, mature antheridium releases flagellated sperms.

The archegonium open the neck canal by autolysis and releases chemical attractants, which direct the swimming sperms to fertilise the egg located at the base of archegonium. Once the egg is fertilised, a zygote is formed and develops through mitotic division to form sporophyte. Only one zygote will develop to the sporophyte from each gametophyte regardless of the number of eggs that may be fertilised. The young sporophyte divides mitotically to develop horizontal shoot that becomes a rhizome. Later the rhizoids develop on the underside of the rhizome while vertical shoots develop into highly coiled structures called croziers or circinate leaves.These leaves later unwind to form fronds. The gametophyte withers off and degenerates. Upon maturity, the sori bearing sporangia develop on the lower side of the frond to produce spores. At this stage, the life cycle is completed and it can start over again.

The life cycle of fern, therefore, is characterised by more or less similar events as in bryophytes. However, the gametophyte generation in bryophytes is relatively larger, dominant and more conspicuous, while in ferns it is the opposite in the sense that its gametophyte is reduced in size, less conspicuous and temporary while the sporophyte generation is dominant.

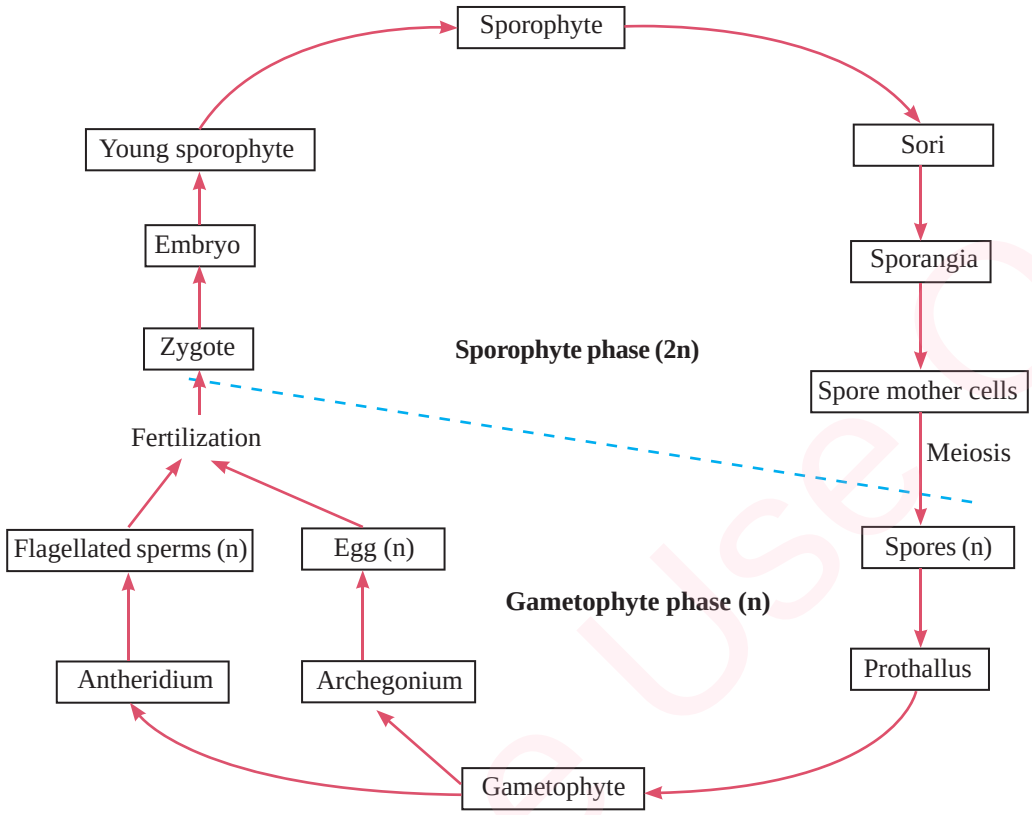


Figure 3.23 (a) A generalized life cycle of pteridophytes

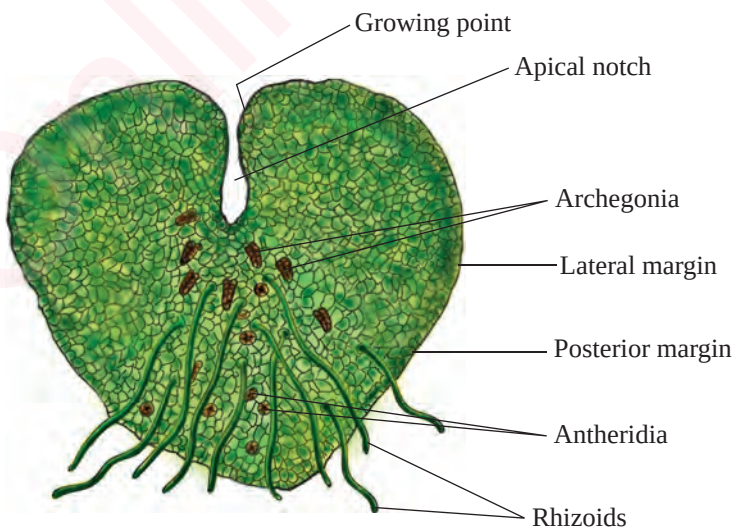


Figure. 3.23 (b) The structure of prothalus

Activity 3.3 Observation of sporophytes generation in ferns

Materials: Mature fern plants, plastic bags, and hand lens.

Procedure

(i) Collect specimens of mature fern from moist and damp places.

(ii) After collection keep the specimens in the plastic bag to avoid desiccation (drying).

(iii) Using a hand lens observe the underside of the frond and notice the rusty dot-like structures concentrated on the margins of frond pinnules.

(iv) Draw the structure of frond to display the sori.

(v) Describe the role of sorus in the life cycle of ferns.

(vi) Draw the structure of the entire fern plant to display rhizome, rhizoids, fronds and rachis.

Results: Circular brown dots appear to be spread along the pinnule margins.

Life cycle of angiosperms

Angiosperms are the flowering plants belonging to division angiospermatophyta. They are the most advanced and successful plants in terrestrial and aquatic environments. The angiosperms are better adapted to both terrestrial and aquatic environments and they are distinct from all other groups of plants due to possession of flowers. Literally, flowers are modified leaves of a plant that play an important role in the reproduction and life cycle of angiosperms.

The life cycle of angiosperms as in other groups of plants is characterized by two alternating phases, namely: the sporophyte and gametophyte generations as shown in Figure 3.24. The sporophyte of angiosperms consists of the roots, stem, branches and leaves. These are the plant parts which are dominant as they are present in a plant throughout the year. On the contrary, the gametophyte generation is temporarily present. It is borne from the gynoecium and androecium of the female and male parts of the flowers respectively.

The gametophyte generation is attached to the sporophyte generation, hence dependent on sporophyte generation for nutrition as it develops.

The flower produces two types of spores, the large spores or megasporocytes; and small spores or microsporocytes which develop to female and male gametophytes respectively. Depending on a plant species, megaspores and microspores can develop from the same flower as in perfect flowers, which have both female and male reproductive structures. However, in imperfect flowers, megaspores and microspores are borne from flowers of different individuals of the same species.

Anthers of the flower contain pollen grains in which microsporangia mother cells are found. Meiosis takes place in the microsporangia mother cell to produce haploid microspores which develop mitotically to form two sperm cells and a tube nuclei.

These three nuclei constitute male gametophyte or macrogametophyte, which is highly reduced compared to gametophytes of bryophytes and ferns (refer to microsporogenesis section). As explained earlier in megasporogenesis section, the megagametophyte develops inside the ovule leading to the formation of an egg, two synergids, two polar nuclei, and three

antipodals. These eight nuclei constitute megagametophyte or female gametophyte, which again is highly reduced, compared to bryophytes' and ferns' gametophytes.

During pollination, pollens are transferred to the stigma and each develops a tube. This tube is important in carrying the two non-flagellated sperms contained in it as it grows down to the ovule via micropyle. Fertilisation in angiosperms, therefore, does not require water medium. One of the two sperms fertilises the egg to form a zygote, which later develops to an embryo through mitotic cell division. The second sperm fertilises the two polar nuclei leading to a triploid tissue called endosperm.

The entire process of fertilisation is therefore, described as double fertilisation because it occurs twice. The whole process of fertilisation in angiosperms resembles that of gymnosperms although, the gymnosperm do not have double fertilisation.

The fertilised ovules develop into a seed and the ovary matures into a fruit. The produced seed contains an embryo, which is a young future sporophyte in resting condition. Under favourable conditions, the seed germinates and the embryo initially develops at the expense of food stored in the endosperm. This later develops into a fully-grown plant which can bear flowers with reproductive structures. This completes the life cycle of the angiosperm and the cycle can start over again.

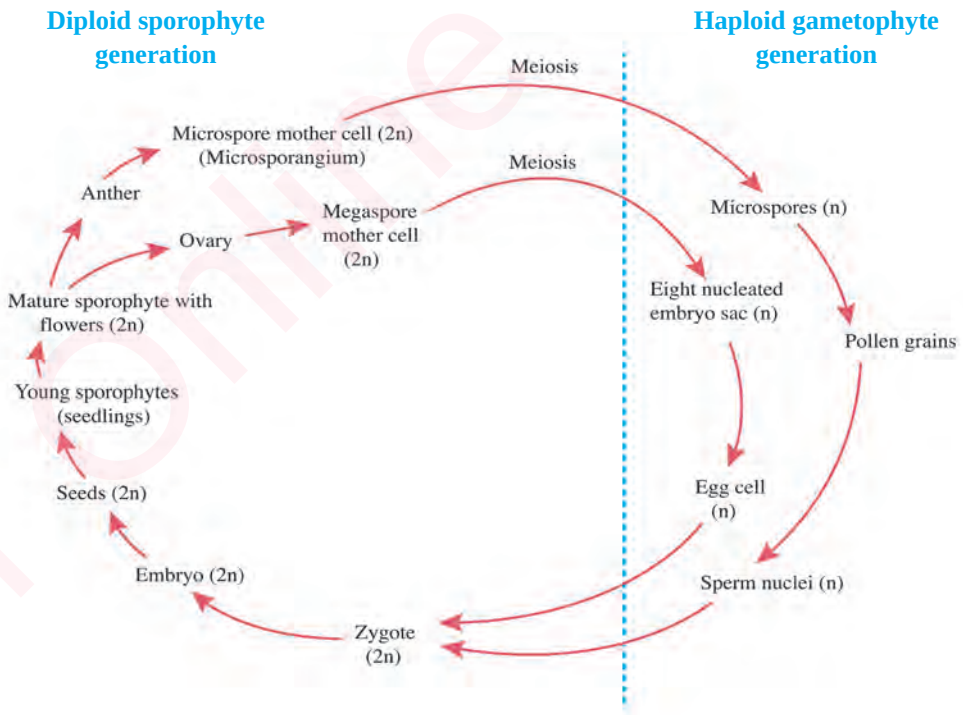


Figure 3.24 Life cycle of angiosperm plant

Activity 3.4 Observation of reproductive structures of an angiosperm flower

Materials: Herbaceous plants, plastic bags and razor blades/ sharp knife.

Procedure

(i) Collect different herbaceous plants together with their flowers in the field.

(ii) Carefully place the collected plants in a plastic bag to avoid desiccation.

(iii) In the laboratory, carefully observe all parts of each of the collected plants from the root to the shoot systems.

(iv) Draw the flower structure and label all parts you have seen.

(v) Dissect the flower into two equal halves using a sharp knife or razor blade to display its longitudinal section.

(vi) Draw and label the observed parts of the dissected flower.

(vii) Name structures which represent the female and male gametophytes.

(viii) Draw the whole plant specimen and indicate the parts which represent sporophyte and gametophyte generations, that is, microspores, and megaspores.

Results: The male reproductive parts of an angiosperm flower are stamens, that is, anthers and filaments, which technically constitute androecium. The female reproductive parts are represented by the pistil, which is made up of an ovary, a style, and stigma. These female parts together form a gynoecium.

Exercise 3.4

1. Briefly explain the term alternation of generations as applied to plants.
2. Compare the life cycles of mosses and ferns.
3. Explain why most bryophytes colonize moist habitats.
4. Briefly explain four ways in which sexual reproduction in fern is different from sexual reproduction in angiosperms.
5. With respect to their life cycles, why do you think bryophytes are primitive compared to angiosperms?
6. Describe the life cycle of angiosperms.

Reproduction in animals

Reproduction in animals is accompanied by a series of reproductive cycles. These events occur in females and they involve cyclic changes that occur simultaneously in the uterus and the ovaries. These reproductive cycles start at the onset of sexual maturity throughout the entire fertile period in the life cycle and when the animal is not pregnant. The two types of reproductive cycles are menstrual and oestrus cycles. Both cycles are controlled by hormones.

Menstruation cycle

Menstrual cycle is a monthly recurring cycle of hormone-induced physiological changes in the uterus, ovaries and in other sexual structures, which occur in order to develop an egg cell in the ovary. The cycle also prepares the uterus for implantation and feeding of a zygote. Moreover, the cycle is characterized by the breaking of the uterus wall and the shedding of blood through a vaginal canal during menstrual flow. This cycle occurs in human beings and other

primate mammals such as monkeys and chimpanzees and prepares the uterus for implantation of a fertilized egg. The events of the menstrual cycle involve changes in the ovaries (ovarian cycle) and uterus (uterine cycle). These changes are regulated by hormones secreted by ovaries, which are in turn regulated by pituitary gonadotrophins.

(a) Ovarian cycle

The ovarian cycle involves follicular, ovulation and luteal phases. In adult female primates, this cycle starts with the development of primary ovarian follicles (follicular phase). This process is influenced by follicle stimulating hormone (FSH) secreted by the anterior pituitary gland which also secretes lutenizing hormone (LH). The role of LH in the follicular phase is to induce the secretion of oestrogen from the follicular cells and stimulate continued growth and development of ovarian follicle into mature Graafian follicles. The secretion of oestrogen in this phase inhibits the release of FSH and therefore its level decreases in the blood. However, this has no effect on the level of LH. As ovulation approaches, the level of oestrogen reaches the maximum and at this point, it induces the release of both LH and FSH. Under the influence of LH, the fully-grown ovarian follicle called Graafian follicle bursts to release the secondary oocyte. The process of releasing the secondary oocyte is called ovulation. Following ovulation, the amount of FSH in the blood falls to follicular level. Meanwhile, in the presence of luteotrophic hormone (LTH), and lutenizing hormone (LH), the cells of the ruptured follicle change into a yellow body called corpus luteum during luteal phase. The corpus luteum is endocrine in nature, and therefore, it secretes large quantities of progesterone and small amounts of oestrogen. These two hormones work synergistically to maintain the structure of the mucus membrane called endometrium and to inhibit the secretion of FSH and LH from anterior pituitary gland.

If pregnancy occurs after mating, the structure of the corpus luteum is maintained for the first three months called first trimester of pregnancy, after which its function is taken over by the placenta. This explains why a surgical removal of ovaries during the first three months of pregnancy will lead to a miscarriage. However, if mating is not successful, the corpus luteum disintegrates and leaves a scar called corpus albicans. The regression of the corpus luteum leads into the fall in the levels of progesterone and oestrogen in the blood as shown in Figure 3.25. This allows the secretion of FSH and LH as they are no longer inhibited.

(b) Uterine cycle

The female sex hormones which are called oestrogen and progesterone affect the endometrium of the uterus causing a series of events in the uterus structure. The cycle has three phases which are menstruation, proliferative and secretory phases.

Menstruation is the first phase of the uterine cycle. During this phase, female sex hormones are at a lower level in the blood causing the disintegration of the endometrium and rupturing of blood vessels. The flow of blood, mucus and degenerating endometrium through the vagina during menstruation period is called a menstrual flow. The discharged substances during this period are collectively called menses and normally takes 3 to 5 days. The flow of menses is normally regarded as a sign that a woman is not pregnant. However, this cannot be taken as a guaranteed sign

because in some cases, a woman can get slight bleeding which takes place for 6 to 12 days after conception. This is called implantation bleeding or spotting and it is one of the early signs of pregnancy.

The proliferative is the second phase of the uterine cycle, which occurs between day 6 to13. The secretion of oestrogen from mature ovarian follicles causes the lining of the uterus to grow or proliferate. The oestrogen initiates the formation of a new layer of endometrium in the uterus, which is histologically identified as the proliferative endometrium. The oestrogen also stimulates crypts in the cervix to produce fertile cervical mucus. This prepares the uterus for ovulation that occurs in the 14th day of a normal cycle.

The secretory is the final phase of the uterine cycle that corresponds to the luteal phase of the ovarian cycle. It occurs during 15th to 28th days. It is characterised by an increased production of progesterone by corpus luteum that plays a vital role in making the endometrium receptive for the implantation of the blastocyst, and hence, supportive to the early pregnancy. Progesterone hormone, therefore, stimulates the secretion of mucus from peritubular glands. It also increases blood flow into the uterine walls and reduces the contraction capacity of the smooth muscles in the uterus.

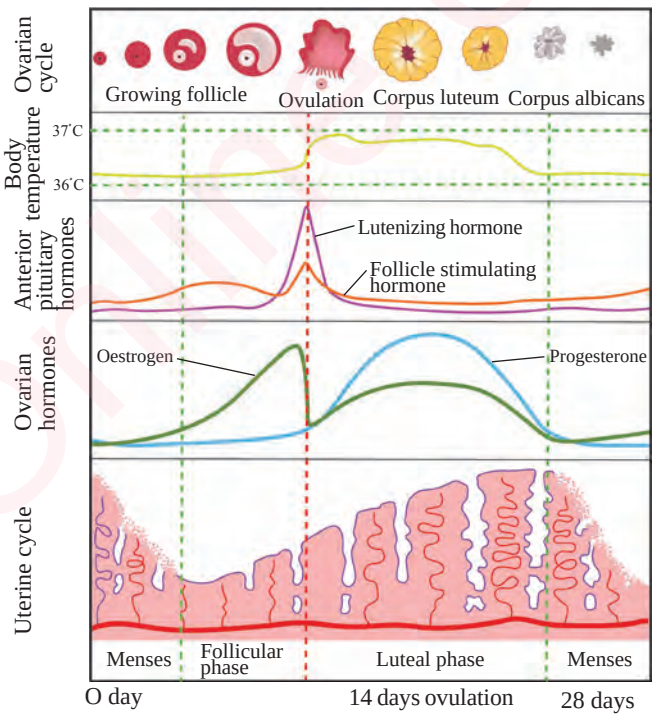


Figure 3.25 Changes occurring during menstrual cycle

Oestrus cycle

Oestrus cycle is the reproductive cycle found in most mammalian females except primates such as human beings and monkeys. It involves recurring periods when the female is sexually receptive known as oestrus or heat period. Oestrus is usually interrupted by periods when the female is not sexually receptive known as anoestrus. It is a chain of physiological events that began at one oestrus and end at the next oestrus. During heat period, there are distinctive pattern of behaviours, which indicate that the mammal is around the time for ovulation. It comprises of the physiological changes that are induced by reproductive hormones in most female mammals. Oestrus cycles start after sexual maturity in females and are interrupted by anoestrous phases or pregnancies. Typically, oestrus cycles continue until death. Some animals may display vaginal bloody discharge, often mistaken for menstruation period.

Phases of oestrus cycle

The oestrus cycle has four phases, which are pro-oestrus, oestrus, metestrus and dioestrus. Pro-oestrus is the first phase, which occurs when one or several follicles of the ovary start to grow depending on the type of the species. It can last for a short period such as one day or for a long period such as three weeks. Under the influence of oestrogen, the lining in the uterus (endometrium) starts to develop. In some animals, bloody vaginal secretions may occur. The female is not yet sexually receptive. The old corpus luteum degenerates, the uterus and the vagina expand, become contractile and secrete a thick mucus. The vaginal epithelium grows and the vaginal smear shows a large number of non-cornifield nucleated epithelial cells.

In the oestrus phase, the mammalian female becomes sexually receptive. The ovarian follicles mature and release secondary oocytes, the process that is regulated by gonadotrophic hormones. Oestrogen secretions exert their biggest influence at this stage and in some species, the labia are reddened and ovulation may occur spontaneously. The female exhibits sexual receptive behaviour, a situation that may be signalled by visible physiological changes. The signal characteristic of oestrus is the lordosis reflex. This is a naturally occurring body posture for sexual receptivity to copulation present in most none primate mammals such as cats, dogs, and elephants. It is thought that, this increased sexual receptivity and a functional design enables the female to find mates with superior genetic quality.

The metestrus phase is the second stage of oestrus cycle that is characterized by the activity of the corpus luteum, which produces progesterone. The signs of oestrogen stimulation drop or cease in this phase. The corpus luteum starts to develop and the uterine lining begins to appear.

Dioestrus phase is a period of sexual inactivity between recurrent periods of oestrus. During this phase, if pregnancy fails, this phase ends with the dispose of the corpus luteum. The lining in the uterus is not discarded instead it is reorganized for the next cycle.

The anoestrus phase occurs when the sexual cycle rests. It is typically a seasonal event, which is controlled by light exposure

through the pineal gland that releases melatonin. This may limit the stimulation of reproduction in long-day breeders and stimulate reproduction in short-day breeders. The melatonin acts by regulating the hypothalamic pulse activity of the gonadotrophin-releasing hormone. The phase is induced by several factors such as significant illness, chronic energy deficit and possibly age. After the completion or abortion of pregnancy, some species have postpartum oestrus, which is the ovulation and corpus luteum production that occurs immediately following the birth of the young. For example, the mouse has fertile postpartum oestrus, which takes place 14-24 hours following parturition.

Difference between menstrual and oestrus cycles

Mammals share the same physiological control of their reproductive systems. For example, the regulatory hypothalamic system that releases gonadotrophin releasing hormones, the pituitary gland that secretes follicle stimulating hormone and luteinizing hormone, and the ovary itself that releases sex hormones which are oestrogens and progesterone. However, despite these similarities, the two cycles differ in a number of ways.

Firstly, FSH controls the oestrus cycles while the LH controls the menstrual cycle. Secondly, animals that exhibit oestrous cycles reabsorb the endometrium if the conception does not occur while animals that have menstrual cycles shed the endometrium through menstruation. Another difference is shown in sexual activity. In species with oestrous cycles, females are generally sexually active only during the oestrus phase of their cycle. The animal at this phase is said to be in a heat period. In contrast, female's species that menstruate can be sexually active at any time in their cycle even when they do not ovulate. Humans have menstrual cycles rather than oestrous cycles.

Fertilisation and zygote development in mammals

Fertilisation is a process whereby a haploid nucleus of a male gamete fuses with the haploid nucleus of a female gamete to form a diploid zygote. In mammals, fertilisation is internal and it is preceded by a series of events, which includes preparation of spermatozoa before it penetrates and fertilises the egg. In order for a species to reproduce and perpetuate its generation, fertilisation is important. It is also important in combining parental traits, which is a major source of variation. After fertilisation, zygote undergoes some changes as it advances to an embryo. The developmental changes which take place in a zygote as it develops to embryo are referred to as embryogenesis.

Mechanism of fertilisation

In mammals, fertilisation is internal as it takes place within the female's body in the fallopian tube. In this case, the male gametes are deposited into the female's body during copulation or sexual intercourse. During the fertilisation process, the spermatozoan undergoes capacitation within the female's reproductive system before it fertilises the secondary oocyte. Capacitation is the change in properties of spermatozoan

that makes it capable of fertilising the egg when it reaches the fallopian tube. This process takes about seven hours during which glycoprotein and plasma proteins layer from the outer surface of the acrosome is removed. The glycoprotein is originally deposited by the epididymis and the plasma proteins from the seminal fluid. This reaction takes place within the female genital tract because enzymes from uterus are responsible for the removal of the two acrosomal layers. After the removal of the layers, the membrane becomes more permeable to calcium ions, which increase the beating activity of the sperm tail, and the sperm swim to the fallopian tube. When the spermatozoan reaches the secondary oocyte in the fallopian tube, the membrane of the sperm head and that of the acrosome rupture. This enables the release of hyaluronidase and protease (acrosin) enzymes that are stored in the acrosome. The changes which take place in the sperm head enables the release of the acrosomal enzymes. These changes and the actions of acrosome enzymes collectively constitute the acrosomal reactions.

The hyaluronidase enzyme digests tough corona radiata, the remains of Graafian follicles, which are found at the surface of the secondary oocyte. The continuous movement of the spermatozoan pushes it towards the outer layer of the egg cell called a zona pellucida. This is a thick layer that surrounds the secondary oocyte. This layer is digested by protease enzymes from the acrosome when it comes in contact with the spermatozoa. The digestion of the zona pellucida allows the spermatozoan's cell surface membrane to fuse with the microvilli that surround the secondary oocyte. As this occurs, the spermatozoan breaks through the egg cell membrane and enters into its cytoplasm.

Immediately after the spermatozoan has entered the secondary oocyte, the lysosomes, which are called cortical granules found just beneath the cell surface membrane, become activated and release their enzymes that catalyse the formation of a barrier. This barrier prevents multiple fertilisation of the secondary oocyte. This is called a block to polyspermy. The enzymes released by the cortical granules catalyse the formation of a fertilisation membrane by hardening the zona pellucida. They also destroy the spermatozoa receptor sites on the zona pellucida so that the other incoming spermatozoan cannot bind to the secondary oocyte. The changes that take place in the cortical granules and the action of their enzymes are known as cortical reactions.

You will recall that the nucleus of the secondary oocyte is usually remaining at metaphase II until the spermatozoan enters the secondary oocyte. Therefore, the male gamete triggers the completion of meiosis II in the secondary oocyte. This produces an ootid and the second polar body. The ootid matures into an ovum and the second polar body immediately degenerates. At the same time, the tail of the spermatozoan is lost within the cytoplasm of the ovum. During this stage, the chromatin in the nucleus of the spermatozoa becomes loose and this results into bulging of the nucleus. The swollen nucleus is called a pronucleus. The nucleus of the ovum also becomes a pronucleus. In this process of fertilisation, the two pronuclei fuse to form a diploid zygotic nucleus. Figure 3.26 is a simplified diagram illustrating the process and mechanisms of fertilisation in animals.

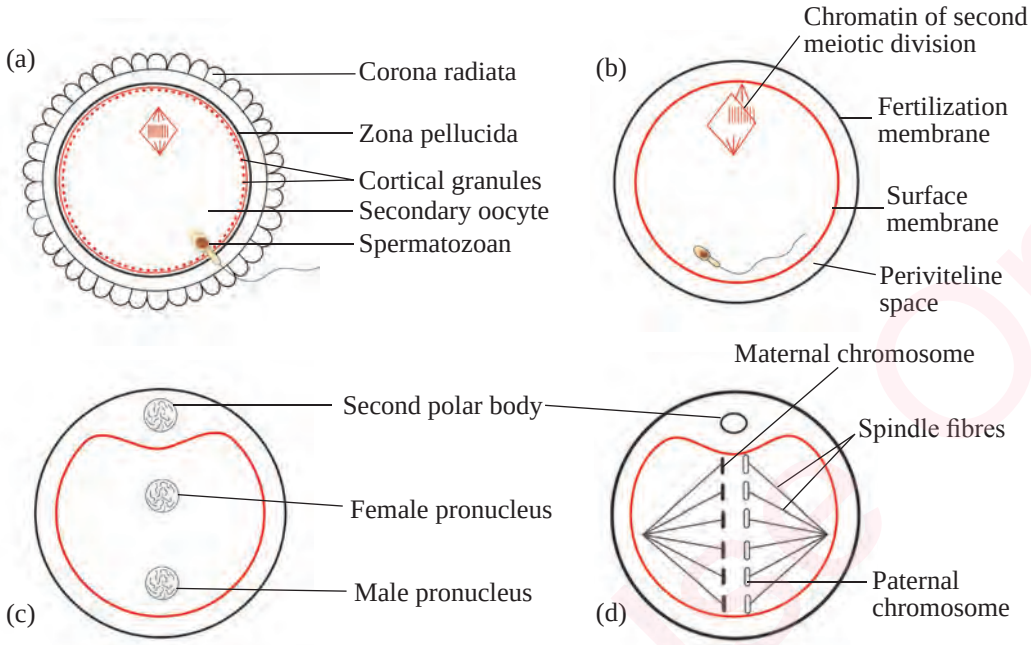


Figure 3.26 Mechanism of fertilisation and zygote development in mammals

The importance of fertilisation

Fertilisation brings together male and female gametes prior to the formation of new individuals. This is important as it helps to restore the usual diploid number of chromosomes in a given species. This is because, during gametogenesis, meiosis reduces the number of chromosomes to a half. Fertilisation also combines the characters of two parents thereby introducing variations, which make the offspring better equipped to struggle for existence. Moreover, fertilisation marks the beginning of a life in sexually reproducing organisms. Following fertilisation, the zygote develops into an embryo, foetus, and lastly a complete new organism. The result of the fertilisation process is the increase in number of organisms in the population.

Developmental changes which take place in a zygote up to gastrula stage

After fertilisation, the zygote passes down the oviduct and begins to divide. This process is called cleavage and it takes place within the zona pellucida. During this time, mitotic division occurs but the size of the resulting cells does not increase. The cells which are formed are called blastomeres and they form a ball of cells called a morula. While cleavage is taking place, the morula is in the oviduct moving slowly towards the uterus by the action of cilia in the oviduct. The cells in the centre of the morula migrate and accumulate at one end where they form an inner cell mass as indicated in Figure 3.27. The result of this cellular migration is the formation of a central fluid-filled cavity, which is called

a blastocoel. The whole structure now is called a blastocyst or a blastula, which is a hollow ball of cells made up of a single layer of cells enclosing a central cavity and the inner cell mass. The process by which the morula is transformed into a blastula is called blastulation. The outer layer of the blastula is known as the trophoblast and it is made up of trophoblastic cells. Among other functions of trophoblastic cells, is to form an endocrine apparatus that secretes a hormone called Human chorionic gonadotrophin (HCG). This hormone helps to maintain the structure of corpus luteum to ensure a continuous secretion of progesterone and oestrogen for the maintenance of the endometrium of the uterus.

When the blastula arrives in the uterus, its portion called embryonic knob implants itself to endometrium wall of uterus. This happens when the hard zona pellucida is peeled off by the enzymes in the uterus and disappears in two days. The disappearance of zona pellucida allows the cells of the trophoblast to come into contact with the endometrial cells. The trophoblast starts to invade the uterine wall from where its cells are nourished, and then multiply. The blastocyst finally sinks into a pit formed in the endometrium where it gets completely embedded the process known as implantation.

After implantation, the trophoblastic cells differentiate into outer and inner layers called chorion and amnion respectively. The chorion develops finger-like structures called chorionic villi, which grow into endometrium. The areas of the endometrium between these villi form interconnecting spaces that give a spongy appearance to this region of the uterine wall. Hydrolytic enzymes secreted by the trophoblast cause the arteries and veins in the endometrium to break down.

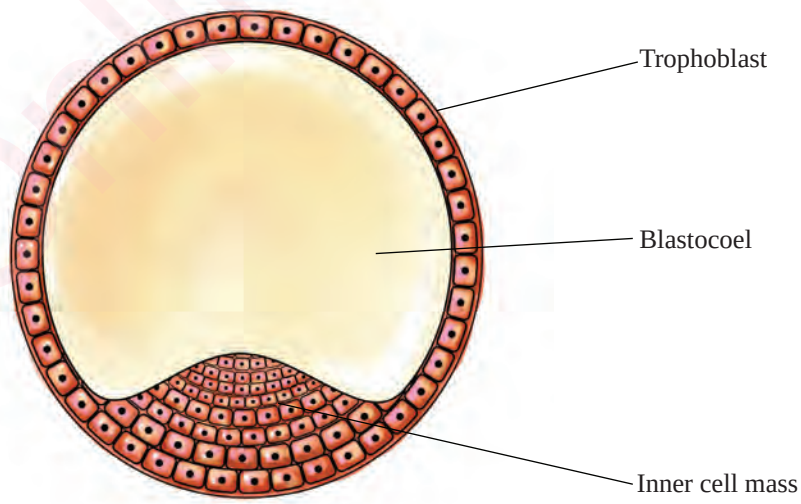


Figure 3.27 Development of a blastocyst or blastula

The blood released from these vessels is used to fill the spaces. In the early developmental stages of the blastocyst, the passage of nutrients, oxygen, and excretory materials between the cells of blastula and maternal blood occurs through the chorionic villi. Later on, this function is taken over by the placenta.

Continuous development of the blastula transforms it into a gastrula. This process is called gastrulation and involves the rearrangement of the blastula cells into a three-layer embryo called a gastrula. During this process, cells on the one side of the embryo invaginate forming a small pore, which is called a blastopore. Through this pore, about half of the cells from the outside move to the inside of the embryo. At this point, the embryo is said to turn on itself. The result of this cellular movement is the formation of two germ layers, the outer layer called ectoderm and the inner layer called endoderm. The blastocoel becomes an archenteron, which is the future digestive tract. The blastopore is the future anus. Finally, the third layer, the mesoderm forms between the ectoderm and endoderm forming a three-layered embryo as summarised in Figure 3.28. The cells forming a particular germ layer determine its fate as the embryo continues to develop. The ectoderm develops into nervous system, sense organs, epidermis of the skin and its associated structures such as hairs, nails, and glands. The mesoderm gives rise to bones, muscles, excretory, circulatory and reproductive systems. The endoderm forms parts such the liver, pancreas, glands and digestive as well as respiratory systems.

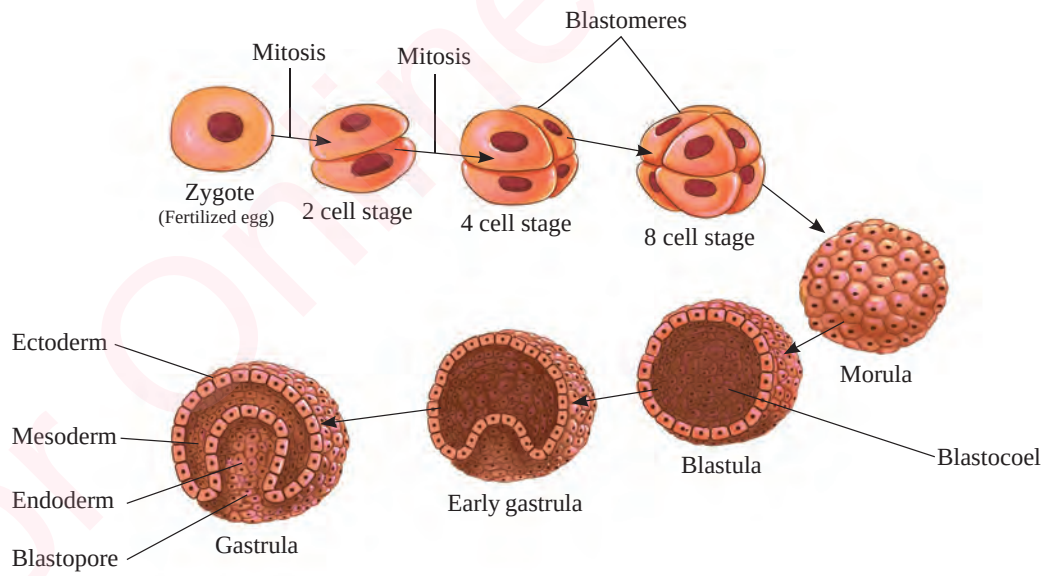


Figure 3.28 Zygote development

Embryonic membranes and their roles

In the process of embryo development, four membranes are formed. These membranes are made up of cells and are relatively thin compared to membrane surrounding cells. The first membrane is chorion, which develops to form chorionic villi, the finger-like projections that grow into endometrium. This layer is important in nourishing the embryo and removing excretory wastes from the embryo.

The second membrane is amnion, which together with the third layer called yolk sac develop as cavities from the inner cell membrane lining the embryo. The amnion appears superficially like an umbrella covering the developing embryo as shown in Figure 3.29. The fluid called amniotic fluid found in this layer has a protective function because it absorbs shock, and hence, buffers the embryo against physical damage. The yolk sac, on the other hand, has a significant role in birds and reptiles but not in mammals. The major function of the yolk sac is to link the embryo with a separate yolk forming a structure that absorbs food from the yolk to the embryo.

The fourth layer called allantois develops from the embryonic hindgut and it extends outward where it comes into contact with chorion. At this stage, the allantois develops into a structure containing numerous blood vessels than chorionic villi. This structure is called allanto-chorion, which later develops into the placenta. The allantois also contributes to the formation of the umbilical cord.

The placenta is a relatively large structure linking the mother and the foetus. In human being, it weighs about 0.6 Kg and measures 13 to15 cm in diameter when fully developed. The placenta is found in mammals only and it is the only organ with cells derived from both the foetus and the mother, which in principle are two different organisms. The chorionic villi are supplied by umbilical vein and umbilical artery of the foetus, which form a capillary network inside the villi. These blood vessels run from the foetus to the uterus.

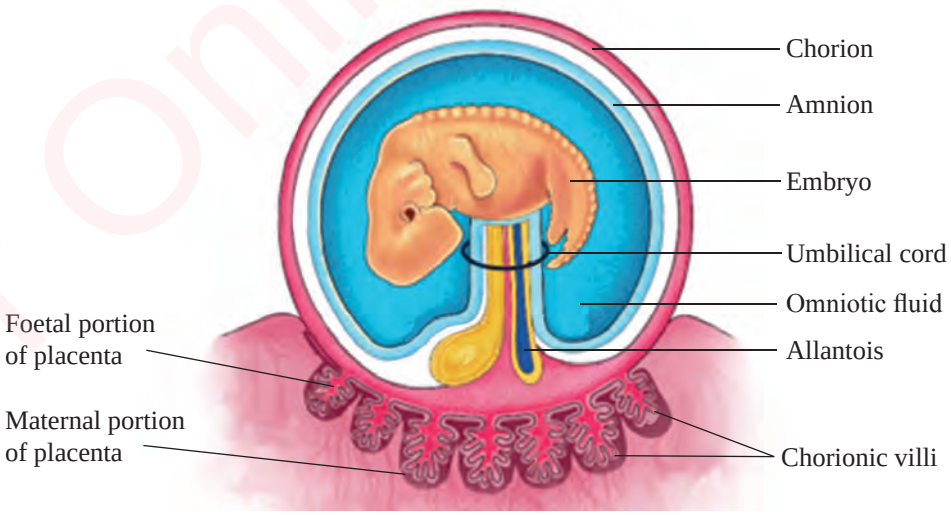


Figure 3.29 Human embryo and embryonic membranes

The placenta develops 12 weeks after conception and has large surface area created by chorionic villi for absorption. It is a temporary organ connecting the mother and the foetus but it plays fundamental roles during pregnancy. Across the placenta, water and nutrients such as glucose, amino acids, lipids, mineral salts and vitamins from the maternal blood, diffuse into the foetal blood.

The placenta acts as a site for gaseous exchange allowing the passage of respiratory gases between the maternal and foetal blood. Oxygen from the mother diffuses into the foetus and its movement is based on two important facts. The first one is that maternal oxygen concentration is higher in the mother's blood than in the foetal's blood. The second factor is that, the foetal haemoglobin has a higher affinity for oxygen than that of the mother. These two facts enable carbon dioxide as a waste product of aerobic respiration to diffuse in the opposite direction. This means carbon dioxide will always be diffusing from the foetus into the mother.

The excretory structures of the foetus, including kidneys, are non-functional and therefore, the excretory wastes such as urea that are formed in the foetus, diffuse from the foetal blood to the maternal blood across the placenta. Additionally, the mother enhances the immune system of the foetus. Thus, across the placenta, antibodies from the mother pass to the foetus. This helps to protect the foetus against the same diseases as those of the mother. In the same way of protecting the foetus against the diseases, the placenta acts as a protective barrier against entry into the foetus, of most pathogens and toxins. However, some pathogens such as *Treponema pallidum*, which cause syphilis, can penetrate the placenta. Chemical drugs such as nicotine, morphine, and alcohol (chemical tetarogens), can also pass across the placenta and affect the developing foetus. The placenta also functions as an endocrine gland as it secretes hormones such as oestrogen, progesterone and human placental lactogen (HPL) which stimulates growth and development of breasts in the preparation for lactation and human chorionic gonadotrophin (HCG).

Birth

Birth or parturition is a process whereby a fully developed foetus is expelled out of the mother's womb following the completion of a gestation period. This process goes through three major stages and is greatly controlled by hormones. The first stage is cervical dilation. It starts when true labour begins, that is, when uterine contaracts causing the dilation of the cervix up to 10 cm wide. The second stage of parturition is the actual delivery of the baby. It begins when the cervix is dilated completely and it ends with the birth of the baby. The third and the last stage is the expulsion of the placenta and associated membranes out of the womb. In some cases, two or more babies are born from the same pregnancy in human beings. However, this is common in other mammals such as dog, cat, and pig. The causes for multiple births in human beings include release of more than one secondary oocytes during ovulation, cleavage of a zygote, and age of the mother.

Events that lead into birth

Birth is greatly controlled by hormones, and therefore, as the gestation period approaches the end, the sensitivity of the uterine wall to oxytocin hormone increases. During this stage, the hypothalamus of the fully developed foetus is stimulated to release the adrenal corticotrophic-releasing hormone (ACTRH), which in turn stimulates the foetal pituitary gland to release adrenal corticotrophic hormone (ACTH). The released foetal ACTH stimulates the foetal adrenal gland to secrete corticosteroids that enter the mother's circulatory system across the placenta. The entry of corticosteroids into the mother's blood has two effects; the first one is causing a decrease in progesterone production, and hence, lowering the level of progesterone in the blood. The second effect is increasing the secretion of prostaglandins by the uterus. The decrease in the levels of progesterone causes an increase of the contraction of the uterine wall. This is because the inhibitory effect of progesterone on myometrium contractions is removed. At this point, the pituitary gland is also allowed to release oxytocin and prostaglandins hormones. Oxytocin hormone causes the contraction of the uterine wall while prostaglandins hormone increases the power of contraction in order to expel the foetus out of the uterus. These contractions of the myometrium sum up to labour pains.

The process of parturition goes through three stages. During the first stage, there is a full cervical dilation to about 10 cm wide. This process is influenced by the hormone called relaxin. The intervals between contractions decrease with time until they become regular between 10 to15 minutes. Throughout the period of pregnancy, the cervix is blocked by a plug of a sticky pinkish mucus that comes out of the birth canal only during this period. At some stages during this phase, the amnion bursts releasing the amniotic fluid that flows out of the vaginal canal. The first stage of labour, which can last between 6 to 12 hours, can be associated with pains and accompanied by increased contractions, as the production of oxytocin hormone also increases. The increased contraction of the uterus leads to increased stimulation of stretch receptors in the uterus and cervix. The contractions spread down the uterus and get strong from top to bottom, thus, pushing the body of the baby downwards until it enters the pelvis. Due to further contractions, its head gets into the cervix where it causes irritations, and hence, increased power of contraction. The first stage of labour ends when the diameter of the cervix equals that of the foetal head.

The second stage of labour is a delivery of the baby, which is marked by the passage of the head and its entire body through the vagina. Once the baby is out of the mother's womb, the umbilical cord is ligatured at two points and a cut is made between the two ligatures to give the baby its physiological independence.

The third stage of labour involves the delivery of the "after birth" in which there is the expulsion of the placenta and the associated embryonic membranes out of the womb. The process occurs between 10 to 15 minutes after the delivery of the baby. This is important because if the placenta remains in the body for a long time, its decomposition can lead to blood poisoning that may ultimately cause death of the mother.

Multiple births

Multiple births are cases in which more than one baby are born from the same mother and from the same pregnancy. In mammals such as cats, rabbits, dogs, and pigs, multiple births are common cases because several oocytes are released at their ovulation and each of them is fertilized by a separate spermatozoan. Humans are commonly singletons; in other words, they give birth to only one young individual. However, in some cases, multiple births are experienced where two individuals called twins or three individuals called triplets or even four individuals called tetrads are born.

The twins are two young individuals that are born from the same mother and from the same pregnancy. There are two types of twins, namely: monozygotic and dizygotic twins. The monozygotic twins are identical twins. These twins result from cleavage of the same zygote. Following the first cleavage of the zygote, each blastomere develops into an individual embryo. These twins are genetically identical and are of the same sex. They may share the same placenta but they are enclosed in different gestational sacs as shown in Figure 3.30 (a).

The second type of twins is fraternal twins, which occurs when two different egg cells are fertilized by two different sperm cells forming two different zygotes as indicated in Figure 3.30 (b). The twins in this category are dizygotic or non-identical and they are genetically different and not necessarily of the same sex. They may look different though may resemble family members. The fraternal twins are implanted separately and therefore each of them develops its own placenta and embryonic membranes.

Causes of multiple births

The cases of multiple births may result if there is ovulation of more than one secondary oocytes at once (hyperovulation). Each may be fertilized by a spermatozoan and may result into multiple pregnancies, and hence, multiple births. The offspring, in this case, are said to be dizygotic twins since they develop from two different zygotes.

Hyperovulation is triggered by a gene called “twin gene” which causes a woman to release more than one secondary oocytes in a single reproduction cycle. Hyper ovulation may also be induced artificially in women who use fertility medication to cause superovulation. An example of fertility drugs is clomiphene citrate whose users have 5 to 12% of bearing twins.

Moreover, after fertilisation, the zygote cleaves into two blastomeres. If the two cells separate completely such that each of them develops into an embryo, the resulting offspring are called monozygotic twins. Multiple births may be caused by the age of the mother. It has been observed that the frequency of twins increases with the maternal age. This is associated with the fact that as the mother ages there is an accumulation of FSH in her blood, however, her ovaries respond slowly to this hormone. Consequently, multiple ovulation may result to multiple births.

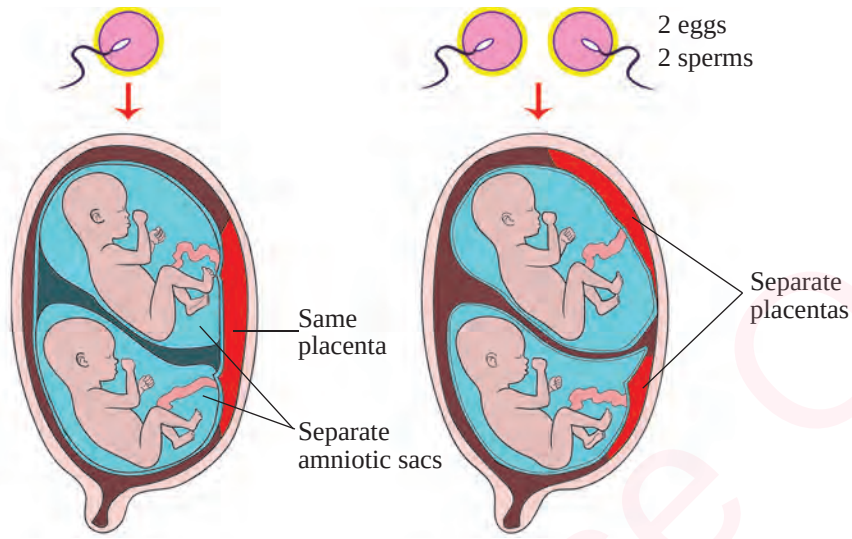


Figure 3.30 Multiple pregnancies

Exercise 3.5

1. Describe the mechanisms by which polyspermy is prevented.
2. Explain the events which take place in the uterus during the menstrual cycle of a mammal.
3. Discuss the process of fertilisation in mammals.
4. Name the embryonic membranes and explain the roles of each.
5. (a) Define multiple births and explain their causes.
   (b) Write down the differences between monozygotic and dizygotic twins.
6. Explain roles played by the mammalian placenta in the following:
   (a) Gaseous exchange.
   (b) Excretion.
   (c) Endocrine secretion.
   (d) Protection against infections.

Life cycles of selected animals

Embryo development after fertilisation is similar in most groups of animals. However, other groups of animals have distinct embryo development. Embryogenesis in mammal starts internally after fertilisation and gradually an embryo develops into a foetus. This then acquires all features of an adult individual as time goes. After the gestation period, the foetus is expelled out from the mother as a baby by a process that is largely controlled by hormones. The baby grows until he/she attains a full adult size without undergoing a transformation in structure. On the contrary, other groups of animals such as insects, crustaceans, and amphibians transform from immature to adult after hatching through a series of stages in which abrupt and conspicuous changes in body structure and feeding habit are evident. These transformation processes are termed as metamorphosis.

Metamorphosis

This is a biological process whereby insects, amphibians, crustaceans, some fishes such as bonyfish, starfish and jawless fish transform from immature to adult form after hatching. It involves a conspicuous and relatively abrupt change in the animal's body structure as a result of cell growth and differentiation. Metamorphosis involves two or more stages and is often accompanied by a change of food source or feeding behaviour.

A number of factors influence the process of metamorphosis. These factors include hormones, temperature and nutrients. Hormones such as thyroxine plays an important role in growth and development. For example, if the thyroid gland is removed from a tadpole, growth continues but the tadpole will not undergo metamorphosis to an adult frog. Environmental changes such as temperature also influence metamorphosis. At optimal temperature, the rate of metamorphosis is high while at low temperatures metamorphosis rate is low.

The levels of nutrients and mineral salts such as protein, fats, and iodine in food also influence metamorphosis. Excess fats decelerate metamorphosis whereas foods rich in protein accelerate it. Iodine accelerates metamorphosis because it is an integral part of the thyroxine hormone. For example, amphibian larvae can not metamorphose in water with an insufficient supply of iodine.

Metamorphosis in insects

Metamorphosis in insects can be categorized into two types. These are complete metamorphosis or holometabolous and incomplete metamorphosis or hemimetabolous. Metamorphosis in insects is controlled by two hormones, the ecdysone (moulting hormone) and neotonin (juvenile hormone). Ecdysone hormone is produced by a prothoracic gland and is required in all insects for moulting. Neotonin is produced from the corpus allatum region of the insect's brain. The release of these two hormones are controlled by neurosecretory cells in the brain.

High concentration of the juvenile hormone promotes the existence of insect in its larval stage. Hence, there will be no transformation of larva to pupa in the presence of this hormone. In other words, this hormone prevents the development of adult characteristics during ecdysis. On the contrary, if the juvenile hormone is present in low concentration larva transformation into pupa occurs. When juvenile hormone is lacking, the pupa metamorphoses into imago or adult.

Complete metamorphosis (holometabolous)

Complete metamorphosis is a mode of development in insects such as houseflies and butterflies. It is characterised by four life cycle stages, namely: egg, larvae (caterpillar), pupa and adult. The larva emerges immediately after hatching and it differs from an adult individual in the mode of feeding, feeding structures, and digestive enzymes. For example, the larvae in some insects such as butterflies have mandibles adapted for biting the edges of leaves. The adults have proboscis for sucking nectar from flowers. The larvae/caterpillars secrete protease, lipase, sucrase, maltase and amylase enzymes, unlike the adult which produces sucrase only. In some species, the holometabolous life cycle prevents the larvae from competing with adults because they inhabit different ecological

niches. Additionally, adults have wings while caterpillar have no wings although they are motile.

The larva undergoes moulting repeatedly and changes in appearance as it transforms into a dormant stage called pupa. As the larva transforms into a pupa, it secretes a thick protein that forms a hard case called cocoon around the entire body. At this stage, the insect becomes immotile and does not feed at all. The energy reserved from the larval stage is spent during this stage. The imago or adult stage follows the pupal stage and it involves considerable reorganisation of the pupal tissues.

Life cycle of an insect with complete metamorphosis

Adult insects with a complete metamorphosis are such as houseflies that lay eggs on organic debris. The eggs may take between 8 to 24 hours to hatch and embryos in these eggs develop into young forms called larvae or maggots. The larvae look like small worms but differs from adults. During this stage, the larvae spends its time feeding, growing and stores food for future use. After four to seven days, larva stops feeding and encloses itself in the protein case called cocoon that marks the onset of the pupal stage. This stage is, therefore, a non-feeding and non-motile stage. Finally, the pupa metamorphoses into an adult and leaves the cocoon. In order to get out of the hard casing, the housefly expands a fluid-filled pouch on top of its head to break the shell. The adult housefly then gets out of the cocoon between 10 to 20 days with its wings fully developed. After some minutes, the insect flies away. This process is illustrated in Figure 3.31.

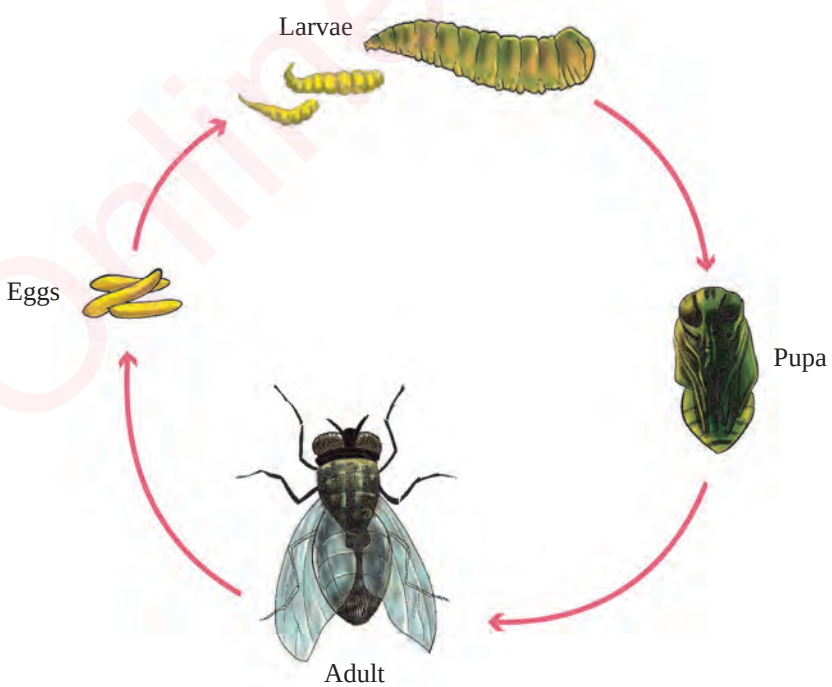


Figure 3.31 Life cycle of a housefly

Incomplete metamorphosis (hemimetabolous)

Incomplete metamorphosis is the mode of development in certain insects such as cockroaches and grasshoppers. It involves three distinct stages, including the egg, nymph and adult. Unlike complete metamorphosis, the larval and pupal stages are missing and are replaced by a nymph stage. Hence, the life cycle of these insects consist of three instead of four stages. The nymph closely resembles the adult insect but lacks wings, functional reproductive organs and it is relatively smaller in size.

The first stage in this type of metamorphosis involves hatching of the eggs containing the embryo into a nymph**.** The latter undergoes gradual changes before transforming into an adult stage. Unlike a typical larva, the nymph closely resembles an adult as shown in Figure 3.32. Nymphs undergo multiple stages of development (moults) which are called instars. The final ecdysis of the immature instars results in an imago that is an adult insect. This marks the last stage, which an insect attains during its metamorphosis. At this stage, the insect attains maturity.

The main difference between complete and incomplete metamorphoses is based on the number and characteristic features of stages which an insect go through as it transforms to adult after hatching. Generally, in a complete metamorphosis, the life cycle has four stages with two active forms, that are the larva and adult. There is no nymph stage in complete metamorphosis. On contrary, there are three stages only, with nymph in an incomplete metamorphosis. There are no larval and pupal stages and the intermediate stage or nymph closely resembles the adult insect.

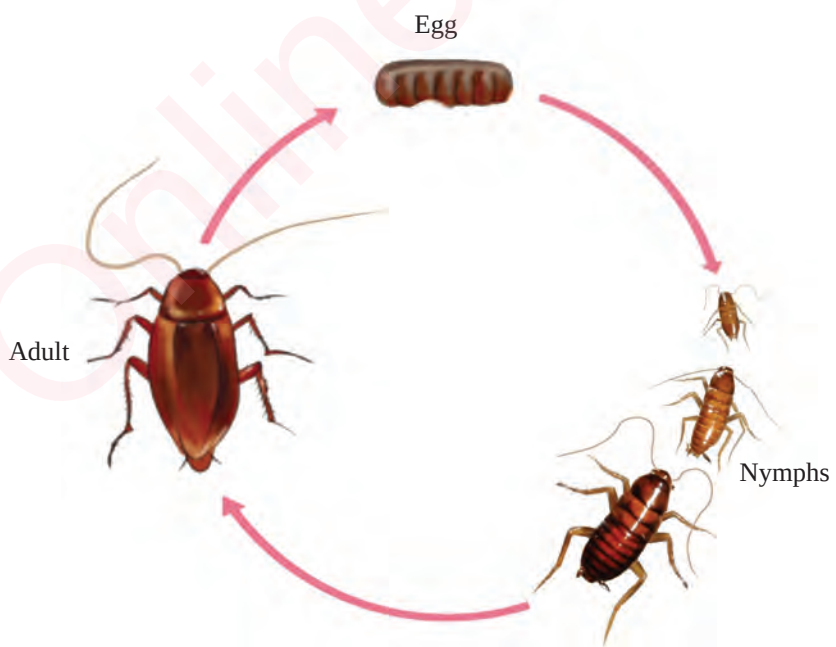


Figure 3.32 Life cycle of a cockroach

Metamorphosis in amphibians

Metamorphosis in amphibians occurs in five stages, namely: the egg, tadpole, tadpole with legs, a young frog, and an adult frog. Toads, for example, lay their eggs in freshwater where the young hatch into tadpoles. The young tadpole as a tail for swimming and gills, hence becomes well adapted to aquatic life. They feed on algae attached to rocks and other surfaces. Metamorphosis begins with the development of the hind legs in a tadpole. The lungs develop and the tadpole begins to swim to the surface of the water to breath. Intestines shorten to accommodate the carnivorous diet and the eyes migrate rostrally and dorsally. Besides these structural changes, several biochemical changes take place including the synthesis of a new visual pigment in the eyes and a new oxygen-binding protein in the blood.

The front legs then emerge in a young frog. In the last stages of metamorphosis, the body absorbs the tail as shown in Figure 3.33. However, in a more gradual form of metamorphosis, the young frogs eventually become adults that are terrestrial life. That is, they live on land, breathe with lungs and through their skin when in the water. They feed on terrestrial insects and other invertebrates. However, the toad-like amphibians must return to the water for reproduction purposes.

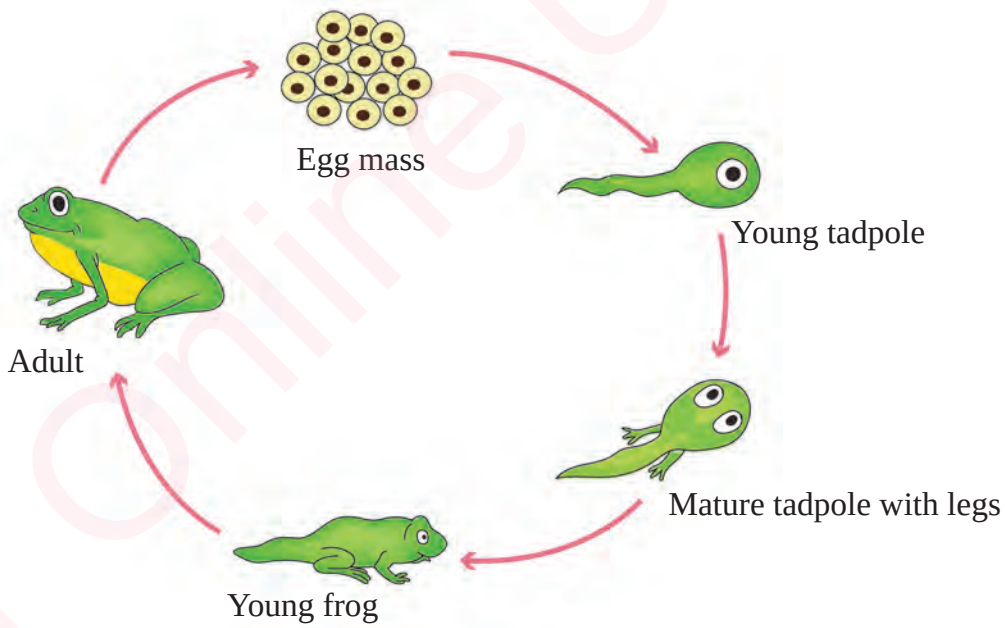


Figure 3.33 The life cycle of a frog/toad

Exercise 3.6

1. With the aid of well-labelled diagrams, describe the process of metamorphosis in insects.
2. In what ways does complete metamorphosis differ from incomplete metamorphosis?
3. Explain the life cycle of a frog/toad.
4. List the hormones involved in metamorphosis of insects and briefly explain the role of each.
5. With examples, explain the importance of metamorphosis in animals.

Life cycle of a mouse

Like in all other mammals, the life cycle of a mouse starts with the formation of a zygote as indicated in Figure 3.34. In this mammal, mating occurs during the oestrus period, which lasts between four to six days. Following copulation, female mice normally develop a copulation plug that prevents further copulation. The plug is not necessary for pregnancy initiation, as this will also occur without the plug. This plug stays in place for some 24 hours. The gestation period is about 19 to 21 days and they give birth to a litter of 3 to14 young's (average six to eight). One female can have 5 to 10 litters per year. This means, the mouse population can increase very fast. Breeding occurs throughout the year. The pups are born blind and without fur or ears. The ears are fully developed by the fourth day, fur begins to appear at about six days and the eyes open around 13 days after birth. The pups are weaned at around 21 days after birth. Females reach sexual maturity at about six weeks of age and males at about eight weeks but both can copulate as early as five weeks.

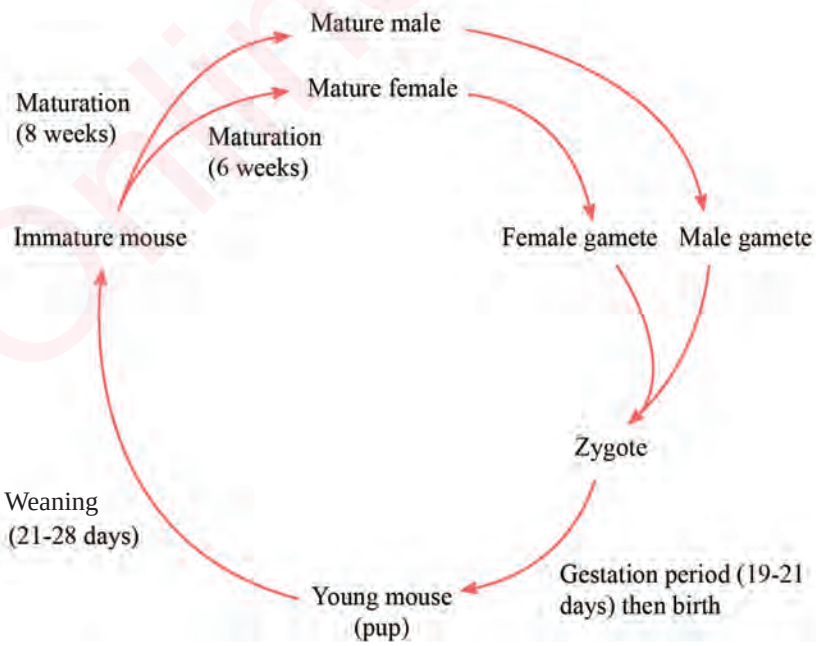


Figure 3.34 Life cycle of a mouse

Revision Questions

1. With the aid of diagrams, explain the major events that occur during the following meiotic stages in animal reproductive cell: (a) Metaphase I (b) Prophase II and (c) Telophase II.
2. Differentiate meiosis I and mitosis processes.
3. Briefly explain how gametogenesis is related to meiosis.
4. Discuss how gametogenesis in animals differ from gametogenesis in plants.
5. Briefly explain the mechanism of chiasmata formation during meiosis process.
6. With the aid of illustrations describe life cycles of bryophytes, pteridophytes, and angiospermophytes.
7. Explain the reproductive adaptations of pteridophytes and angiospermophytes.
8. With the aid of well-labelled diagrams, describe the meiotic stages in animal cell.
9. Describe the life cycle of mammals using the mouse as an example.
10. Explain the importance of water in the life cycle of bryophytes.
11. In bryophytes, the sporophyte generation exhibits a "parasitic" disposition to the gametophyte generation. Clearly explain how this behaviour differs from the usual definition of parasitism.
12. Give the reasons why megaspores are generally larger than microspores.
13. Using illustrations describe the hormonal control of the menstrual cycle in human beings.
14. Discuss how parturition is brought about in mammals.
15. Distinguish between oestrous and menstrual cycles and briefly describe main phases of an oestrous cycle.
16. Explain the processes involved in the growth of the pollen tube.
17. Discuss the development of an embryo sac and briefly show how the embryo is formed in angiosperms.
18. Describe the processes and events that lead to the development of an early human embryo.

Chapter
Four

Genetics

Introduction

Genetics refer to the study of heredity and variations or simply the science of genes. All the characteristics or traits of an organism, including behaviours, reproductive, and physical structures are governed by genes. They are transmitted from one generation to another through the process of reproduction. The ability of organisms to transmit their traits from one generation to the next is referred to as heredity. The process of meiosis initiates genetic variations in sexually reproducing organisms such as flowering plants and higher animals. In this chapter, you will learn about hereditary materials, types of genetic materials, the genetic code, and the process of protein synthesis. You will also learn about the Mendelian Principles of Inheritance, non-Mendelian inheritance, mutation, and genetic engineering.

Hereditary material

Hereditary material or genetic material is the chemical structure or unit in the chromosome, which is responsible for the passage of genetic information from one generation to another. There are two types of genetic material in the cell. These are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). They contain different chemical components, and hence different properties. The hereditary material contained in an organism is usually encoded in the DNA or RNA sequence.

Location of hereditary material in the cell

In eukaryotic cells, the genetic material is mostly located in the nucleus while in prokaryotic cells, it is found in the cytoplasm in a special region called nucleoid. In eukaryotic cells, there are several events that show genetic material is found in the nucleus. For example, during fertilisation, the nucleus of a male gamete fuses with that of a female gamete to form a zygote. This undergoes several physiological and morphological changes and finally develops into an individual organism with various characteristics that are derived from both parents. This shows that the fused nuclei have hereditary material in them obtained from the parents. Moreover, in sexually reproducing organisms, the formation of gametes involves meiosis. One of the significance of meiosis is to bring about genetic variations. This implies that, it is the manipulation of genetic material in the nucleus during meiosis, which brings about genetic variations.

The nucleus is the centre of all life processes in the cell. Heredity is among the life processes controlled by the genetic material in the nucleus. Thus, nucleus is the part of a cell, which contains hereditary material. The part of the nucleus, which contains genetic material is called a chromosome. In other words, chromosomes are the carriers of hereditary material. There are various evidences that support the location of genetic material in the chromosomes. For example, if the chromosomes are exposed to mutagenic agents, the changes that occur affect the genetic material in the chromosomes. During fertilisation process, if a sperm carrying an **X** chromosome fuses with an egg carrying an **X** chromosome, the resulting zygote will ultimately develop into a female offspring with **XX** sex chromosomes. On the contrary, if a sperm carrying a **Y** chromosome fuses with an egg carrying an **X** chromosome, the resulting zygote will develop into a male offspring with **XY** sex chromosomes. Since sex is a genetically determined characteristic, then the fused gametes are carring genetic material on their chromosomes.

Meiotic nuclear division is another process which shows that hereditary material is found in the chromosomes. During diplotene of prophase I, there is a crossing over or chiasmata formation. During this event, there is breaking and re-union of chromatids of homologous chromosomes. The consequence of this, is genetic variation among organisms. This implies that the exchanged parts of chromatids contain hereditary material, and therefore, variations stem out of new gene combination in the re-united chromatids. The analysis of the chemical composition of the chromosome reveals the presence of protein and DNA. However, experiments have proved that, it is the DNA portion of the chromosome, which is involved in heredity. Thus, DNA is the hereditary material contained in the nucleus of the cell.

Properties of genetic materials

The genetic materials have various properties. Among them, include the following:

(i) They contain hereditary information in the coded form in their specific structures called genes.

(ii) The structural elements of the genetic material are ubiquitous in their distribution, that means, they are found everywhere in life forms.

(iii) They have the ability to replicate or form their own copies.

(iv) They are in the same quantity and quality in all the somatic cells of a healthy individual.

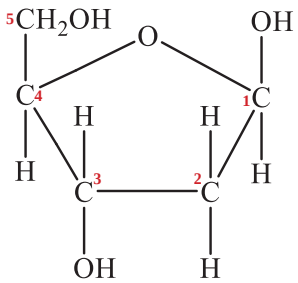
(v) They are stable both chemically and physically.

(vi) They undergo occasional changes or mutations in the structure and functioning of their genes which are of permanent nature and inheritable. This tendency is important for evolution and adaptability of organisms.

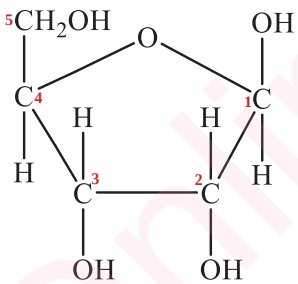
Chemical composition of the genetic material

The genetic material is composed of subunits called nucleotides. These nucleotides join together to form unbranched chains called polynucleotides. Each nucleotide of the genetic material is composed of three basic components which are the sugar, phosphate group and nitrogenous bases.

Sugar: This is a five-carbon compound with a ring structure and exists in two forms, that are ribose and deoxyribose. The sugar, which appears in the form of ribose, builds the RNA molecule and the one that appears in the form of deoxyribose builds the DNA. The key difference between deoxyribose and ribose sugars is that the deoxyribose lacks oxygen atom on carbon 2 of the sugar ring while ribose has a hydroxyl group on carbon 2 of the sugar ring as shown in Figure 4.1.



(a)



(b)

Figure 4.1 Structure of (a) deoxyribose and (b) ribose sugar

Phosphate group: This is derived from phosphoric acid, and it is this group that makes DNA and RNA to be acidic in nature. It is linked to the 5 carbon of the pentose sugar by a phosphodiester bond as seen in Figure 4.2. The phosphate group is also responsible for the strong negative charge of both nucleotides and nucleic acids.

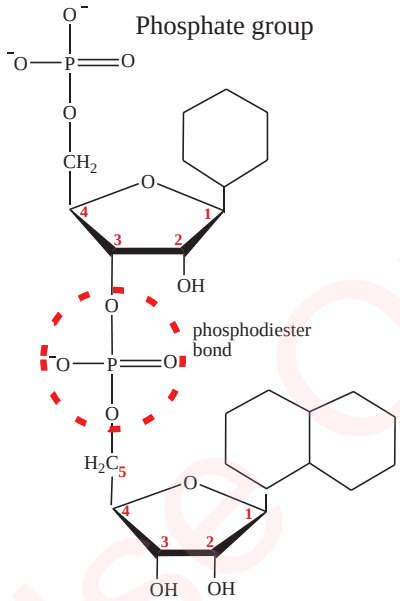


Figure 4.2 Structure of phosphate group and linkage to pentose sugar

Nitrogenous bases: These are simply nitrogen-containing organic molecules, which have the same chemical properties as bases. They are the building blocks of DNA and RNA, thus they are called nucleobases. They are divided into two classes, namely: purines (double ring structures) and pyrimidines (single ring structures). The purines are comprised of Adenine (**A**), and Guanine (**G**) bases while pyrimidines are comprised of Cytosine (**C**), Thymine (**T**), and Uracil (**U**) bases. The base Uracil (**U**) is only found in RNA and Thymine (**T**) is only found in DNA. Each pyrimidine is a single ring structure made up of one heterocyclic organic molecule. Purines, on the other hand, consists of a pyrimidine ring joined together with an imidazole ring to form a double ring structure. Both pyrimidines and purines resemble in that they are made up of a pyridine molecule, they are non-polar and are planar molecules as seen in Figure 4.3.

They have similar functions, for example, they act as a form of energy to the cells and plays an important role in DNA and RNA production. They are also involved in the production of proteins, starches, regulation of enzyme activities, and cell signalling. These bases are extremely important because their sequencing in either

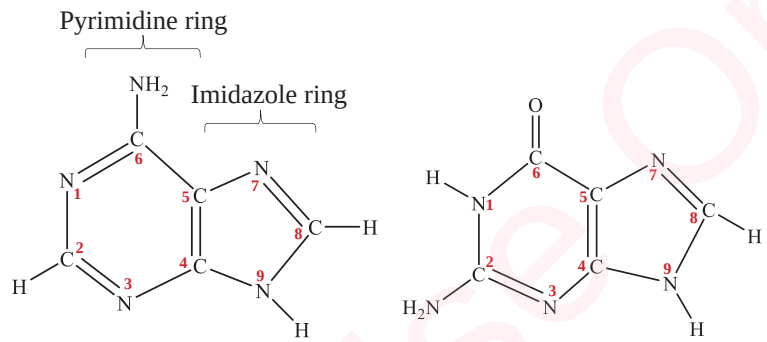
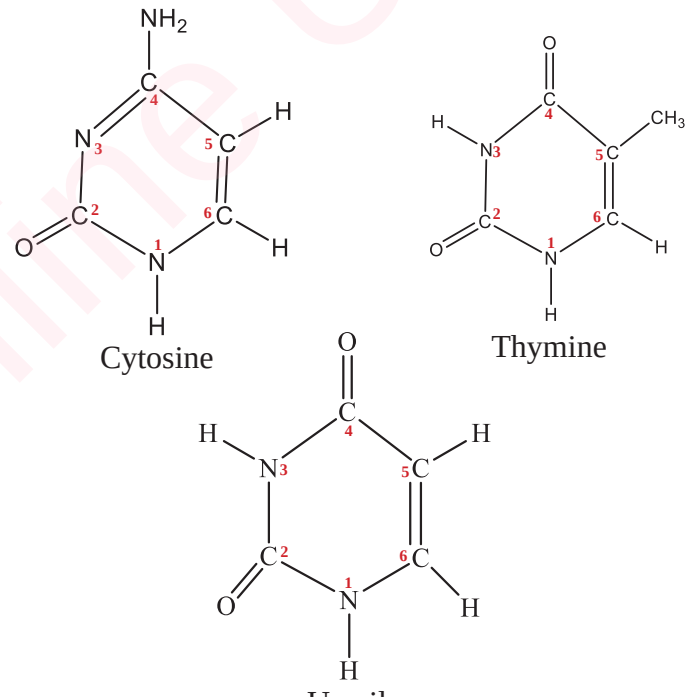
Class	Chemical structure
Purines	
Pyrimidines	

Figure 4.3 Chemical structures of purines and pyrimidines

DNA or RNA determines the way genetic information is stored in an organism.

The general and chemical structure of DNA and RNA is determined by two types of bonds, which are hydrogen bonds that hold together complimentary base pairs in DNA and RNA and phosphodiester bonds that hold the nucleotides together.

Exercise 4.1

1. Briefly explain the evidence to support the idea of hereditary material being located in the nucleus.
2. Explain the properties of genetic material.
3. Describe the chemical structures of purines and pyrimidines.
4. Write short notes on the chemical composition of genetic material.
5. Draw the structures of adenine and cytosine.

Types of genetic material

There are two types of genetic material found in the body of living organism. These are Deoxyribonucleic acid (DNA), and Ribonucleic acid (RNA). DNA is the genetic material in most of the organisms including the higher-level ones while RNA serves as the genetic material in some viruses. This is because RNA is chemically less stable than DNA, short-lived and incapable of replication in most organisms.

Ribonucleic acid (RNA)

RNA is a single-stranded polynucleotide. There are four types of nitrogenous bases in the structure of RNA, which are adenine (**A**), guanine (**G**), cytosine (**C**) and uracil (**U**). The nitrogenous base is attached to carbon 1, while the phosphate group is attached to carbon 5. Hydroxyl groups are attached to carbon 2 and 3. The phosphate group of the next nucleotide in the sequence is linked to the hydroxyl group on carbon 3 of the preceeding nucleotide. This arrangement repeats itself several times to make RNA a long structure. It has to be noted that, the positioning of the hydroxyl group in carbon 2 of the sugar gives the molecule an electrostatic negative charge. It is because of this charge that, the (-OH) group repels negatively with the negatively charged phosphate group attached to the carbon 1 of the ribose sugar. This chemical structure makes RNA a long uncoiled molecule as it appears in the Figure 4.4.

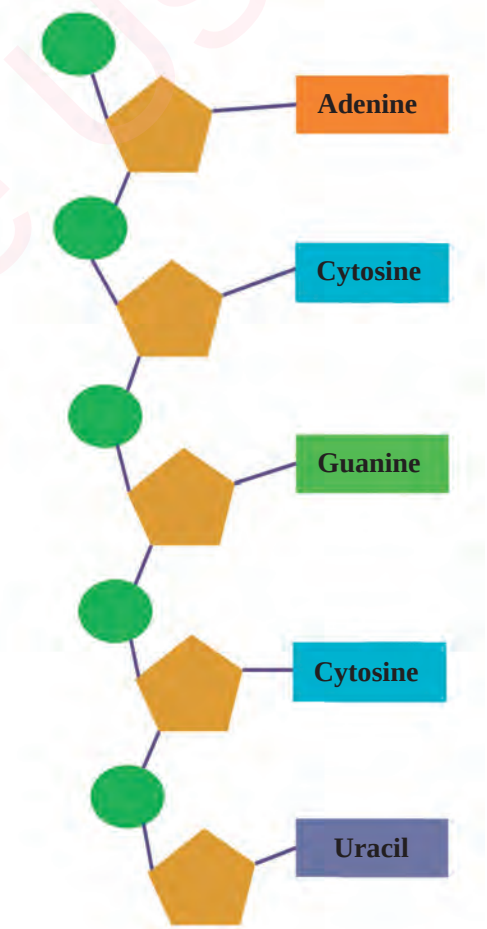


Figure 4.4 The structure of RNA

Furthermore, the presence of reactive hydroxyl group (-OH) attached to carbon 2 of its sugar makes the whole RNA molecule prone to hydrolysis. This is the reason why RNA is unstable, and hence, unsuitable for storing genetic information. Its structure is weak and it can easily fold into conformations with 3D structures, unlike the DNA. The hydroxyl group discussed here is completely absent in the deoxyribose sugar backbone of DNA, hence, the latter does not undergo hydrolysis easily making it a suitable genetic material. There are three types of ribonucleic acids (RNA), namely: messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA).

Messenger RNA (mRNA)

Messenger RNA is produced in the nucleus on a single DNA strand by a process known as transcription. The base sequence of mRNA is a complimentary copy of one of the DNA strands that is being copied and varies in length according to the length of the polypeptide chain for which it codes. The mRNA is less than 5% of the total cellular RNA. It carries genetic information from the nucleus to the cytoplasm of a cell for assembling into proteins. Thus the mRNA is particularly important in carrying instructions stored in the sequence of DNA nucleotides into protein molecules. This is because the genetic information stored in the DNA cannot be decoded directly into proteins. The mRNA transcribes the genetic code from DNA into a form that can be decoded in the process of making proteins. It is primarily composed of coding sequences that carry the genetic information for the amino acid sequence of a protein to the ribosome where that particular protein is synthesised. In addition, each mRNA molecule contains non-coding or untranslated sequences that may carry instructions for ending translation or termination of protein synthesis. The diagrammatic representation of mRNA is shown in Figure 4.5.

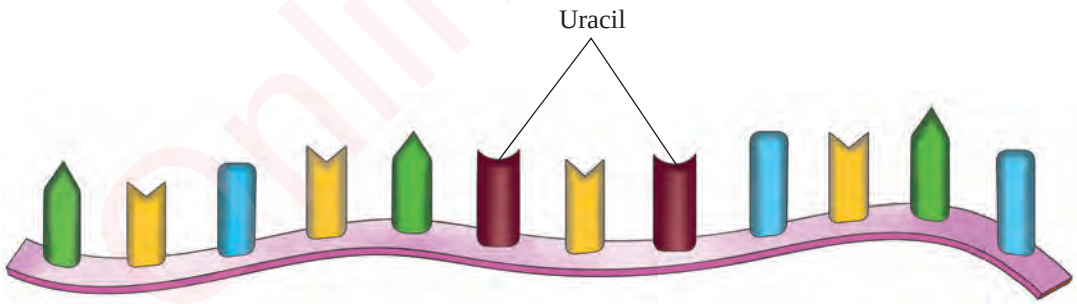


Figure 4.5 The structure of messenger RNA

Ribosomal RNA (rRNA)

This type of RNA is found in the cytoplasm where, in association with protein molecules, they form ribosomes. It is the major structural component of ribosome, which is the cell's machinery for protein synthesis. More than half of the the mass of the ribosome is made up of rRNA. It is composed of complex molecules in two sections, the large subunit (LSU) and the small subunit (SSU). These subunits are made up of one or more RNA strands and some varieties of ribosomal proteins. Ribosomal RNA makes approximately 80% of the total RNA of the cell. The ribosomal RNAs are synthesised by genes

present on the DNA in the nucleolus region called nucleolar organiser. The diagrammatic representation of rRNA is shown in Figure 4.6.The sequence of bases of rRNA is similar in all organisms from simple prokaryotes to complex multicellular eukaryotes. The role of rRNA is to direct the translation of information contained in the mRNA into amino acids, and hence, protein synthesis. Its three-dimensional shape gives ribosomes their structure, essential for protein synthesis. During protein synthesis, rRNA are also responsible for binding in the mRNA and catalysing the formation of peptide bonds between two amino acids.

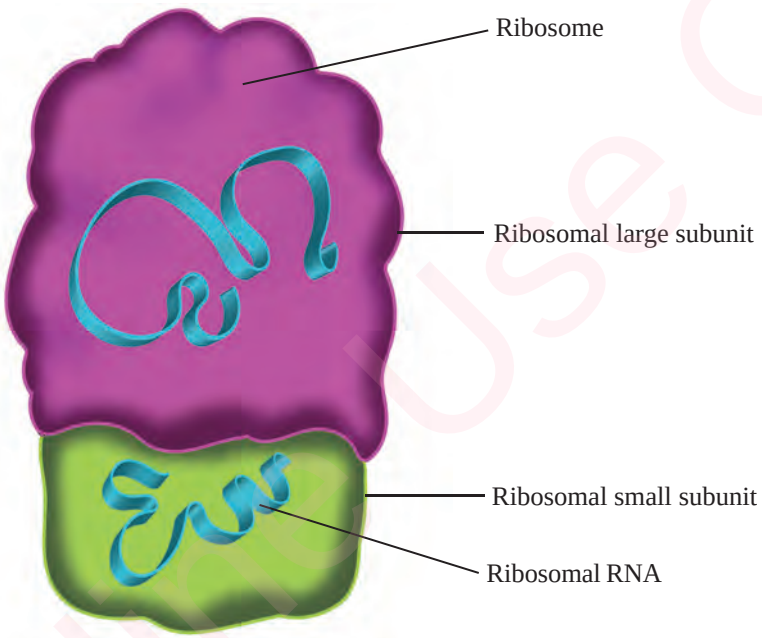


Figure 4.6 The structure of ribosomal RNA (rRNA)

Transfer RNA (tRNA)

This is a small molecule with about 80 nucleotides and constitutes about 15% of the total RNA of the cell. The tRNA as illustrated in the Figure 4.7 is manufactured by nuclear DNA. Structurally, all tRNA molecules have very similar secondary structure in which a single-stranded chain is folded in a "clover-leaf" structure with three hairpins and an acceptor stem with base sequence CCA. This is a 3' end and it is at this point where an amino acid is covalently attached. The looping of the chain results into the pairing of the organic bases and hence the formation of hydrogen bonds. The tRNA molecule has four active or recognition sites. The upper site (3' end) recognises the amino acid whereas the lower anti-codon site recognises the mRNA. The T-loop recognises the ribosome whereas the D-loop recognises an enzyme called amino acyl-tRNA synthetase. This enzyme catalyses the binding of tRNA to a specific amino acid. This catalytic process produces an amino acid tRNA complex called amino acyl-tRNA. The role of tRNA is to carry the activated amino acids from various parts of the cytoplasm to the ribosomes whenever code words on mRNA call for them to be assembled during protein synthesis.

It also helps the ribosomes to insert the brought amino acids into a growing protein chain.

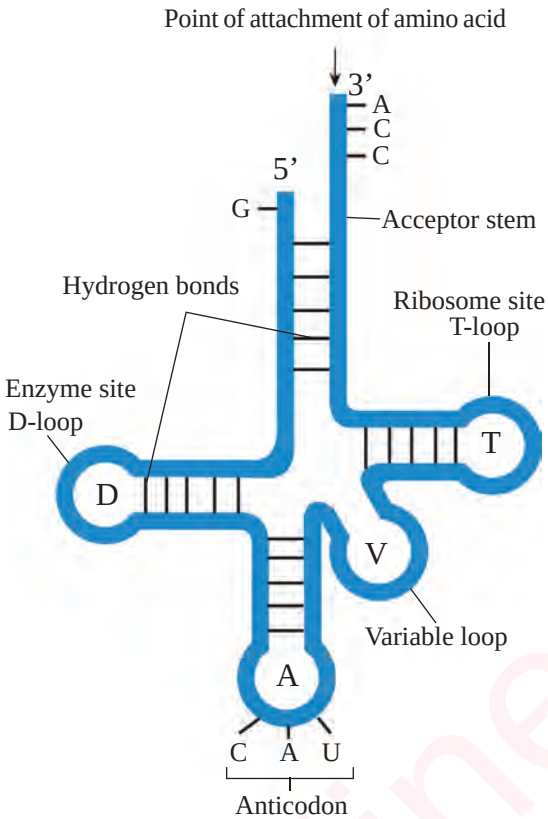


Figure 4.7 Transfer RNA (tRNA)

Deoxyribonucleic acid

Deoxyribonucleic acid (DNA) is a double-stranded helix structure that contains a polymer of nucleotides. This structure is different from RNA by being double-stranded molecule and possess Thymine as a pyrimidine nitrogenous base instead of Uracil found in RNA. Mechanism of DNA replication is the key to biological inheritance. The information in DNA structure is encoded sequentially. The coded information in DNA is translated into protein by living cells. Compared to RNA, DNA is a very stable molecule both chemically and physically, hence suitable for storing genetic information.

The structure of DNA

DNA is a double-stranded helix molecule that contains a polymer of nucleotide and has two strands running anti-parallel to each other. Each chain is a polymer of subunits called nucleotides, hence, the name polynucleotide. Individual nucleotide consists of three parts, namely: phosphate group, pentose sugar (deoxyribose) and organic base (nitrogenous base). There are four types of nitrogenous bases in DNA structure. These are adenine (**A**), guanine (**G**), cytosine (**C**) and thymine (**T**). Each strand has a backbone that is made up of (deoxyribose) sugar molecules that are linked together by phosphate groups.

The 3'carbon of a sugar molecule is connected through a phosphate group to the 5' carbon of the next sugar. This linkage is also called 3'- 5' phosphodiester linkage. All DNA strands are read from the 5' to the 3' end where the 5' end terminates in a phosphate group and the 3' end terminates in a sugar molecule as seen in Figure 4.8. Unlike the ribose sugar of RNA, deoxyribose sugar of DNA lacks an oxygen atom on carbon 2 in its ring. Hence, it uses the prefix 'deoxy' to denote that the molecule contains less oxygen in its structure than its closely related compound, that is, RNA. As a result of this, there is no electrostatic negative charge to repel the negatively charged phosphate. Consequently, the DNA molecule is twisted to form a double helix structure.

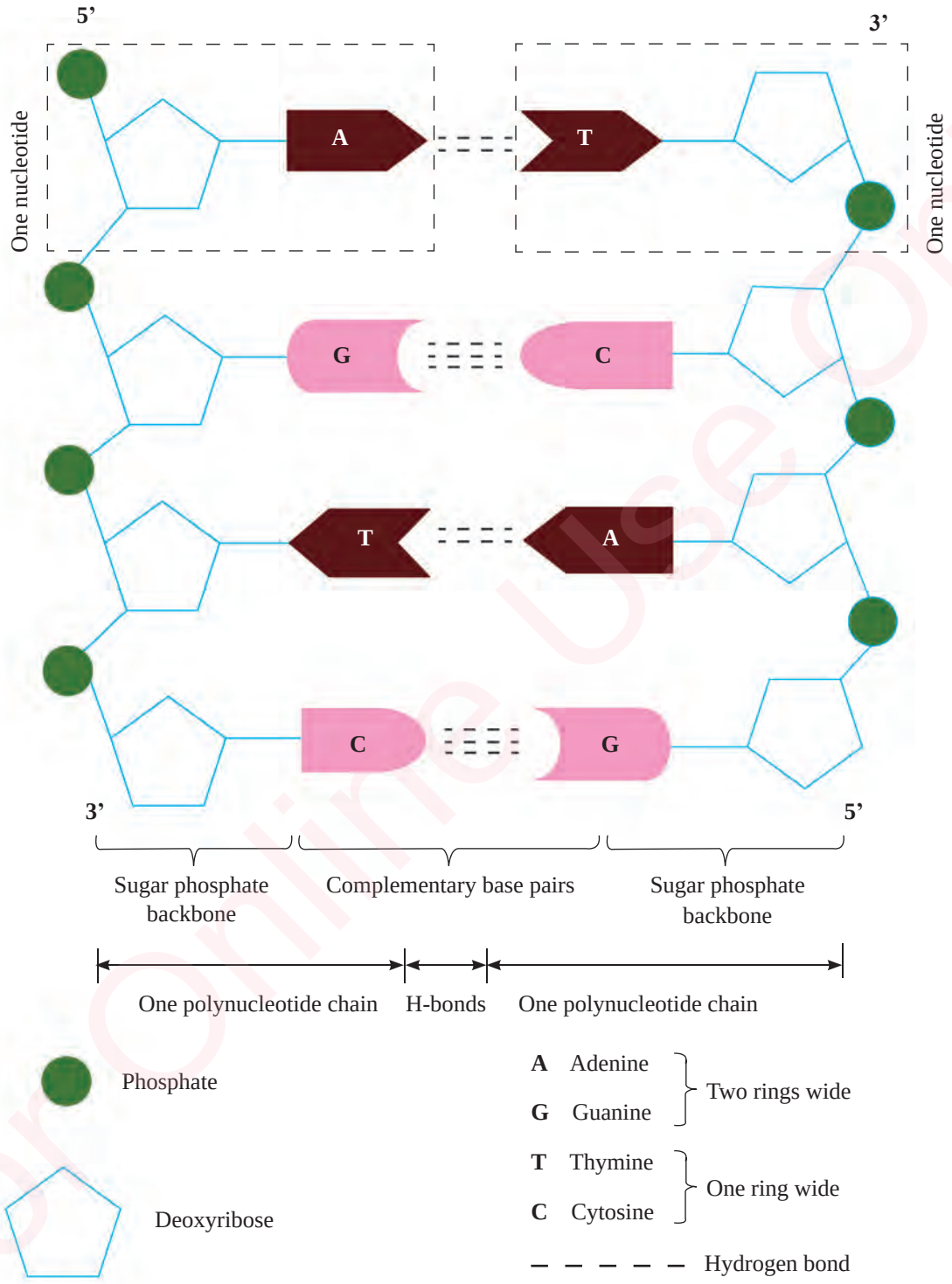


Figure 4.8 Straightened strands of DNA showing 5' and 3' ends

Each sugar molecule is covalently linked to one of four possible nitrogenous bases (Adenine, Guanine, Cytosine, and Thymine). Adenine (**A**) and Guanine (**G**) are double-ringed larger molecules known as purines while Cytosine (**C**) and Thymine (**T**) are single-ringed smaller molecules called pyrimidines.

In the double-stranded DNA, the two strands run in the opposite directions and the bases pair up such that Adenine always pairs with Thymine (A-T or T-A) and Guanine always pairs with Cytosine (G-C or C-G). The A-T base-pair has 2 hydrogen bonds and the G-C base-pair has 3 hydrogen bonds. The G-C interaction is, therefore, stronger by about 30% than A-T. Thus, the A-T rich regions of DNA are more prone to thermal fluctuations than the G-C rich regions. Along the axis of the molecule, the base pairs are 0.34 nm apart. That is there is a gap of 0.34 nm from one base pair to another. A complete turn of the double helix comprises of 10 base pairs with a length of 3.4 nm. At the unwound part, the two DNA strands are 2nm apart as indicated in Figure 4.9.

The bases are oriented perpendicular to the helix axis. They are hydrophobic in the direction perpendicular to the plane of the bases, as a result they cannot form hydrogen bonds with water. The interaction energy between the two bases in a double- helical structure is, therefore, a combination of hydrogen bonding between complementary bases and hydrophobic interactions between the neighbouring stacks of base-pairs. In a single-stranded state, the bases prefer to be stacked like the steps of a spiral staircase if the bases are identical and can have regions of helical conformation. The configuration of DNA structure is very stable to allow any of its strands to act as a template for the replication of new strands as well as for transcription of messenger RNA during protein synthesis. A specific segment of DNA which codes for the synthesis of a specific protein is called a gene.

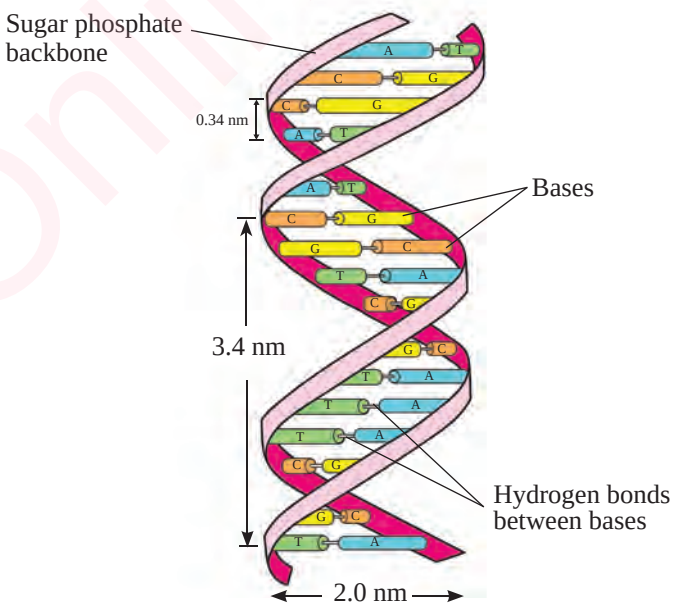


Figure 4.9 The Structure of DNA molecule

DNA replication

This is the process by which DNA makes a copy of itself by producing two identical replicas from one original DNA molecule. This biological process occurs in all living organisms and is the basis for biological inheritance. The process of DNA replication takes place during an interphase stage in the nuclear division. For a cell to divide, it must first replicate its DNA so that each daughter cell receives an exact copy of DNA.

Mechanism of DNA replication

The mechanism of DNA replication as summarised in Figure 4.10 involves a number of steps described as follows:

(a) Unwinding or unzipping of the two intertwined anti-parallel strands of the DNA

DNA replication starts with the unwinding or unzipping of the two intertwined anti-parallel strands of DNA by the enzyme called DNA helicase. This enzyme untwists the helices at locations known as replication origins and breaks the weak hydrogen bonds that hold the two strands of DNA together. The separation of the two single strands of DNA creates a "Y" shaped structure called a replication fork. Each of the two separated strands acts as a template to which complimentary sets of nucleotides would attach by base pairing for making the new strands of DNA. A single strand binding protein (SSB) stabilizes each of the unwound parental DNA strands. This prevents the winding up or the zipping up of the two strands before the replication of new strands is complete. Because the two strands of DNA are always anti-parallel, then one of the strands is oriented in the 3' to 5' direction towards the replication fork. The 3' to 5' is the leading strand whereas the other strand oriented in the 5' to 3' direction away from the replication fork is called the lagging strand. The enzyme DNA polymerase III can work only in a 5' to 3' direction.

(b) Replication of each of the parental strands to form two strands

As a result of their different orientations or anti-parallelism, the two DNA strands are replicated differently as follows:

(i) Replication of the leading strand
A short piece of RNA known as a primer that is produced by an RNA polymerase enzyme called primase, comes along and binds to the end of the leading strand. This is necessary because the enzyme DNA polymerase III cannot initiate the synthesis of new DNA strands without a primer. The primer acts as a starting point for a new DNA strand synthesis. The enzyme DNA polymerase III, then binds to the leading strand and moves along it while adding new complimentary nucleotide bases. Adding of nucleotide is done to the new strand of DNA in the 5'- 3' direction and the DNA strand must be read in the 3'- 5' direction. This process is straight forward for the leading strand and the DNA synthesis can proceed in an uninterrupted manner along the entire length of the leading strand. Hence, it is called a continuous replication.

(ii) Replication of the lagging strand
On the lagging strand, DNA synthesis is interrupted because the DNA polymerase must as well move in the 5'→ 3' direction and away from the replication fork. Since the enzyme polymerase moves away from the fork and the fork is uncovering the

new DNA, then the DNA synthesis on the lagging strand is discontinuous. Discontinuous replication occurs in short sections and produces short fragments or chunks of about100-200 nucleotides in length of DNA called Okazaki fragments. Thus, numerous RNA primers are made by the primase enzyme and bind at various points along the lagging strand. Each of these primers becomes the starting point for each Okazaki fragment. As each individual segment is replicated away from the replication fork, each subsequent Okazaki fragment is replicated more closely to the receding replication fork than the fragment before it. This type of replication is called discontinuous replication as the Okazaki fragments will need to be joined together later.

(c) Removal of the primers and filling of the gaps previously occupied by the primers

Once all the bases are matched up (**A** with **T** and **C** with **G**), an enzyme called DNA polymerase I, strips away the primers and fills the gaps which were occupied by the primers. The gaps are filled with complementary nucleotides.

(d) Proofreading and correcting or repairing in case of any mistake

The enzymes, DNA polymerase III and DNA polymerase I proofread the newly synthesised strand to make sure there are no mistakes in the new DNA

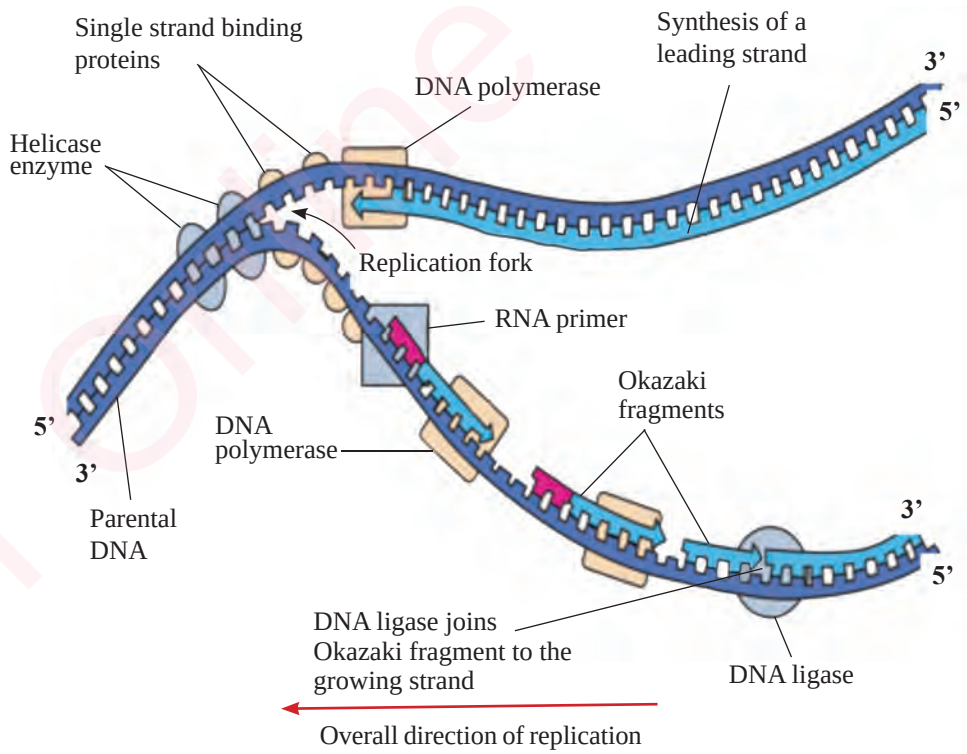


Figure 4.10 Main steps of DNA replication

sequence. They also correct and repair any incorrect base pairing.

(e) Ligation of Okazaki fragments and zipping up of both pairs of the DNA strands

At the end of the DNA replication process, the enzyme called DNA ligase joins or stiches the sugar-phosphate backbones of the Okazaki fragments to create a continuous strand of DNA. It also seals up the sequence of DNA into two continuous double strands by catalysing the construction of hydrogen bonds between the complimentary base pairs of DNA strands. Each of the constructed DNA molecules has one old strand and one new strand.

This sort of DNA synthesis is called a semi-conservative replication.

This concept of semi-conservative replication captures the idea that, in each time DNA replicates itself, it produces hybrid double molecules, one old strand and the other newly synthesised strand.Table 4.1 summarises different enzymes that are involved in the replication process and their roles.

Table 4.1 The roles of enzymes in DNA replication process

Enzymes	Function in replication process
DNA helicase	Also known as helix destabilising enzyme. Unwinds the DNA double helix at the replication fork.
DNA polymerase	Builds a new double strand of DNA by adding nucleotides in the 5' to 3' direction. It also performs proof-reading and error correction. There are many different types of DNA polymerase, each of which performs different functions in different types of cells.
Topoisomerase	Relaxes the DNA from its super-coiled nature.
DNA Ligase	Reanneals the semi-conservative strands and joins Okazaki fragments of the lagging strand.
Primase	Provides an RNA primer for DNA polymerase to begin synthesis of the new DNA strand.

Significance of DNA replication

Since it occurs in interphase prior to nuclear division, DNA replication ensures that each daughter cell receives the correct number of chromosomes. In this way, an equal distribution of genetic material in all daughter cells is ensured. Despite the fact that cells have the mechanisms of minimising errors during DNA replication, occasionally, mistakes occur which result into mutations. These are the sources of genetic variations.

Exercise 4.2

1. Differentiate between mRNA and rRNA molecules.
2. Briefly explain why DNA is the most favourable genetic material.
3. Compare and contrast DNA and RNA molecules.
4. Describe the chemical composition and structure of nucleic acids.
5. Describe the process of DNA replication and explain its importance.
6. Discuss the structural and functional relationship between DNA and RNA
7. Briefly explain the role of tRNA.

Genetic code

In living organisms, each cell contains all the information determining the characteristics of that organism. James Watson and Francis Crick (1953) suggested that, genetic materials are stored in DNA molecules. The DNA of each species differs from the other by the sequence of nitrogenous base pairs along the DNA length and not by chemicals found in the cells. The base sequence coded on the DNA determines the types of protein to be produced. Each protein can be made from only twenty amino acids and each amino acid has its own code on the DNA. The twenty amino acids are manufactured out of sixty four codes formed by what is called the triplet codes. Each triplet code is known as a codon and encodes information for a single amino acid. The full set of codons is known as a genetic code.

The knowledge about the genetic code is very important in understanding how the genes function. The genetic code is a set of rules by which information encoded in genetic material (DNA or RNA sequences) is translated into proteins in living cells. Proteins are made up of amino acids organised to form linear chains then folded into globular shapes.

Since DNA molecule contains only four bases, George Gamow (1953) suggested that the code for each amino acid could be specified by only three bases. This is because, if the code for each amino acid was made up of only one base, only four amino acids could be specified by the genetic code. If the code for each amino acid constitute two bases, only 4 x 4 or 16 different amino acids could be specified by the genetic code. But if the code for each amino acid constitute three bases, 4x4x4 or 64 different amino acids could be specified by the genetic code. Hence, a triplet code (three bases) provides more than enough codes for all the 20 different amino acids used in cells. Therefore, one amino acid can be specified by more than one codon.

Characteristics of genetic code

The features which characterize the genetic code include the following:

(a) The genetic code is triplet: The group of bases specifying one amino acid is called a codon or code word. The codons are formed using the bases which are available in the mRNA. The four nucleotide bases (A, G, C and U) in the mRNA are used to produce three base codons (4^3=64 three base groups). The 64 codons include the sense codons which are the codons that specify an amino acid and the nonsense codons that do not specify any amino acid. Therefore, there are 64 codons, which code for the 20 amino acids and since each codon codes for only one amino acid, this means that, one amino acid can be coded by more than one codon.

(b) The code is punctuated: Genetic code is punctuated, that means, it has the start and stop signals as shown in Table 4.2. The genetic code system has a codon that acts as a signal for the initiation of the synthesis of polypeptide chain. It also has full stop signals, which determine the end of polypeptide chain synthesis as indicated in Table 4.2. The codon AUG (Methionine) acts as a start signal for the initiation of polypeptide chains and the codons UAG, UAA and UGA are polypeptide chain terminating codons. Hence, they act as full stop signals during the formation of polypeptide chain. These chain termination codons do not code for any of the amino acids and for this reason they are termed as non-sense codons. They specify where polymerisation of amino acids into protein molecule should stop.

(c) The genetic code is non-overlapping: The genetic code is sequentially read in groups of threes without overlapping except in some viruses. For example, mRNA with base sequence AUGUCUCCA can be read as AUG/UCU/CCA and not AUG/ GUC/ CUC/CCA. A nucleotide that forms part of a triplet never forms part of the next triplet. Each triplet is read from 5' → 3' direction, so the first base is 5' base followed by the middle base then the last base which is 3' base.

(d) The genetic code can degenerate: All amino acids except methionine (AUG) and tryptophan (UGG) are coded by several codons, that means some codons are synonyms. This fact is called degeneracy of the genetic code. For example, Threonine is coded by four codons ACU, ACC, ACA and ACG. Thus, for many amino acids, only the first two letters appear to be significant.

(e) The genetic code is universal: The genetic code is largely universal for all living organisms and viruses. However, a few exceptions are found in mitochondria. For example, UGA is one of the termination codons, which code for tryptophan in yeast mitochondria.

Table 4.2 Triplet codes and amino acids for which they code

1st letter	2nd Letter									3rd letter
		A		G		C		U		
	A	AAA	Lys	AGA	Arg	ACA	Thr	AUA	Ile	A
		AAG		AGG		ACG				
						ACC		AUG	Meth (start)	G
						ACU				
		AAC	Asn	AGC	Ser			AUC	Ile	C
		AAU		AGU				AUU		U
	G	GAA	Glu	GGA	Gly	GCA	Ala	GUA	Val	A
		GAG		GGG		GCG		GUG		G
		GAC	Asp	GGC		GCC		GUC		C
		GAU		GGU		GCU		GUU		U
	C	CAA	Gln	CGA	Arg	CCA	Pro	CUA	Leu	A
		CAG		CGG		CCG		CUG		G
		CAC	His	CGC		CCC		CUC		C
		CAU		CGU		CCU		CUU		U
	U	UAA	Stop	UGA	Stop	UCA	Ser	UUA	Leu	A
		UAG	Stop	UGG	Trp	UCG		UUG		G
		UAC	Tyr	UGC	Cys	UCC		UUC	Phe	C
		UAU		UGU		UCU		UUU		U

Protein synthesis

DNA controls many cell activities including synthesis of proteins. Proteins are also used to produce enzymes which are also protein in nature. The DNA determines characteristics of the organism by specifying the type of proteins to be produced. The instruction to manufacture enzymes and proteins is located in the DNA. However, it is in the ribosomes in the cytoplasm where the actual synthesis of proteins occur. There must be a link to connect the flow of genetic information between the nucleus and cytoplasm in the manufacturing of proteins. This link is by a specific type of RNA called messenger RNA (mRNA). Protein synthesis is a process by which individual amino acids are joined together by peptide bonds and in a specific order. This is in accordance with the instructions in the mRNA coded from DNA to form a polypeptide chain. The two main steps of protein synthesis include transcription of DNA into mRNA, and translation of the information contained in the mRNA as shown in Figure 4.11.

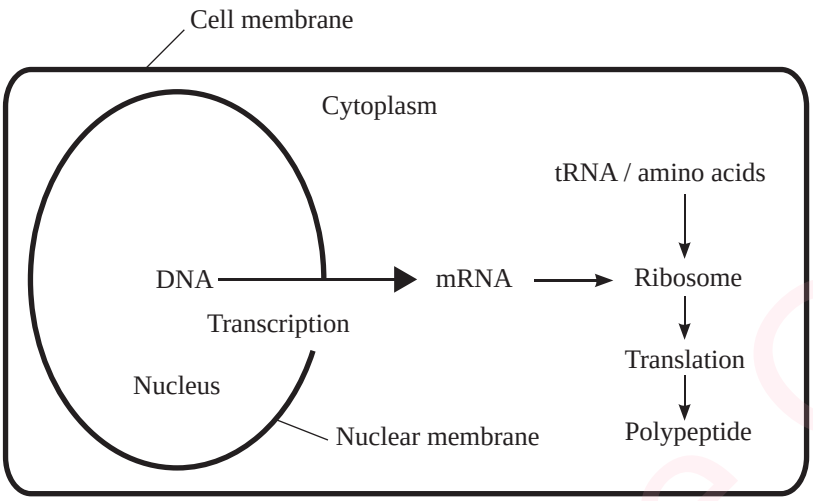


Figure 4.11 Summary of the main steps of protein synthesis

Transcription

In the transcription stage, a complementary mRNA copy or strand is made on a specific region of the DNA and codes for a polypeptide chain. Transcription is a process by which the base sequence in a section of DNA representing a gene is converted into a complementary base sequence of mRNA as seen in Figure 4.12.

During this process, the histone proteins that protect the DNA double helix are removed to expose the polynucleotide sequence of the DNA molecule. The double helix then unwinds by breaking down the relatively weak hydrogen bonds between the complementary base pairs. This process is controlled by the enzyme known as helicase and exposes the bases of the DNA strands. One of the two strands acts as a template for the synthesis of mRNA. Thus, each of the exposed bases on the transcribing strand attracts a free nucleotide in the cytoplasm according to the rules that govern the base pairing between DNA and RNA. The base pairing rules are such that, Adenine pairs with Uracil and Guanine pairs with Cytosine in producing a molecule of mRNA from DNA. The molecule of mRNA is then synthesised by joining the nucleotides together under the influence of the enzyme called RNA polymerase. The synthesised mRNA then leaves the nucleus through the nuclear pore carrying the genetic code with it to the ribosomes in the cytoplasm. Along the mRNA strand, is a sequence of triplet codes, which has been determined by the DNA. When enough mRNA has been synthesized, the RNA polymerase leaves the DNA and the two strands of DNA zip-up again reforming the double helix.

Translation

The actual protein synthesis is accomplished through the process of translation. Translation is the means by which a specific sequence of amino acids is formed in accordance with the codons on the mRNA. This involves the triplet base sequence of the mRNA molecule, which is converted into a sequence of amino acids in a polypeptide chain. The process of translation occurs on the ribosomes in the cytoplasm. The ribosome is, therefore,

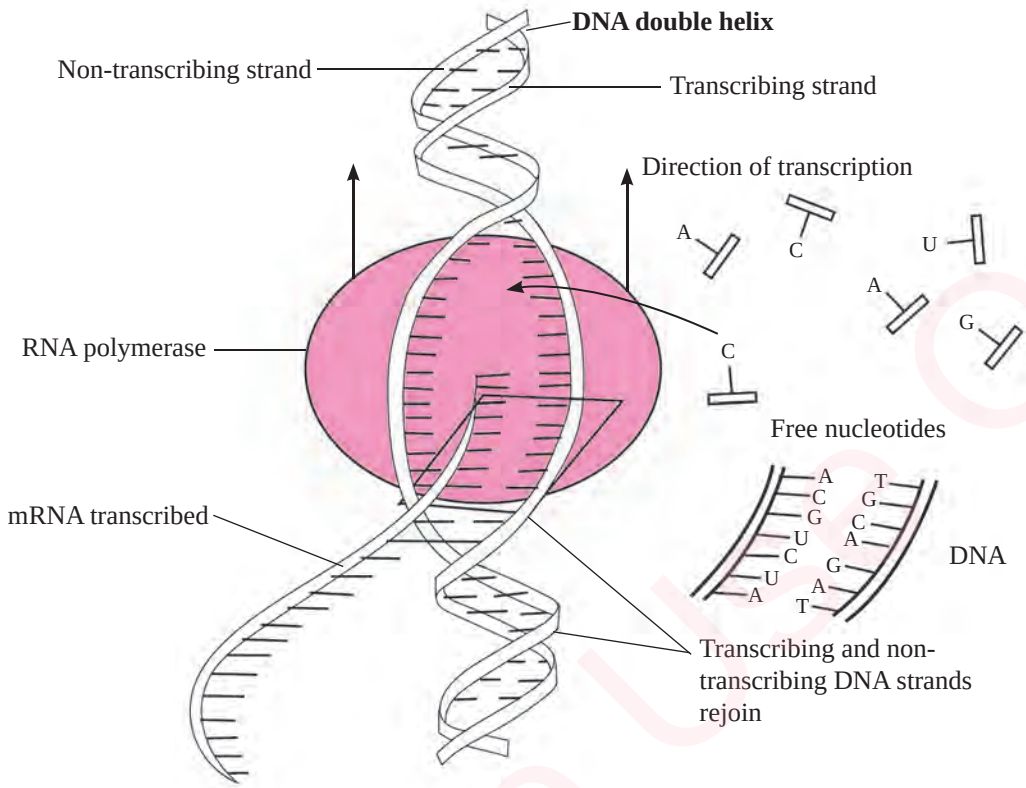


Figure 4.12 Diagrammatic representation of transcription

the rRNA-protein complex that serves as the site for translation phase of protein synthesis. Many ribosomes attached to mRNA, form a structure called polysome.

The process of translation involves the following general steps:

(a) Binding the mRNA to the ribosomes

The mRNA from the nucleus attaches itself on the small subunit of the ribosome in the presence of Mg^{2+} ions.

(b) Amino acid activation and its attachment to the tRNA

The amino acids in the cytoplasm become activated by the energy from ATP. The activated amino acids are then held by their specific tRNA under the influence of the enzyme called amino acyl-tRNA synthetase. The formed products are called amino acid – tRNA complexes.

(c) Polypeptide chain initiation

The amino acid-tRNA complexes so formed are then carried to the mRNA on the ribosomes. The first codon on the mRNA to be read by the ribosome and where the chain initiation step occurs is usually AUG (Methionine). This is a codon signalling the "start" of translation. The second codon also attracts another amino-tRNA molecule showing the complementary anticodon. These amino acids are then joined together by the peptide bonds as shown in Figure 4.13.

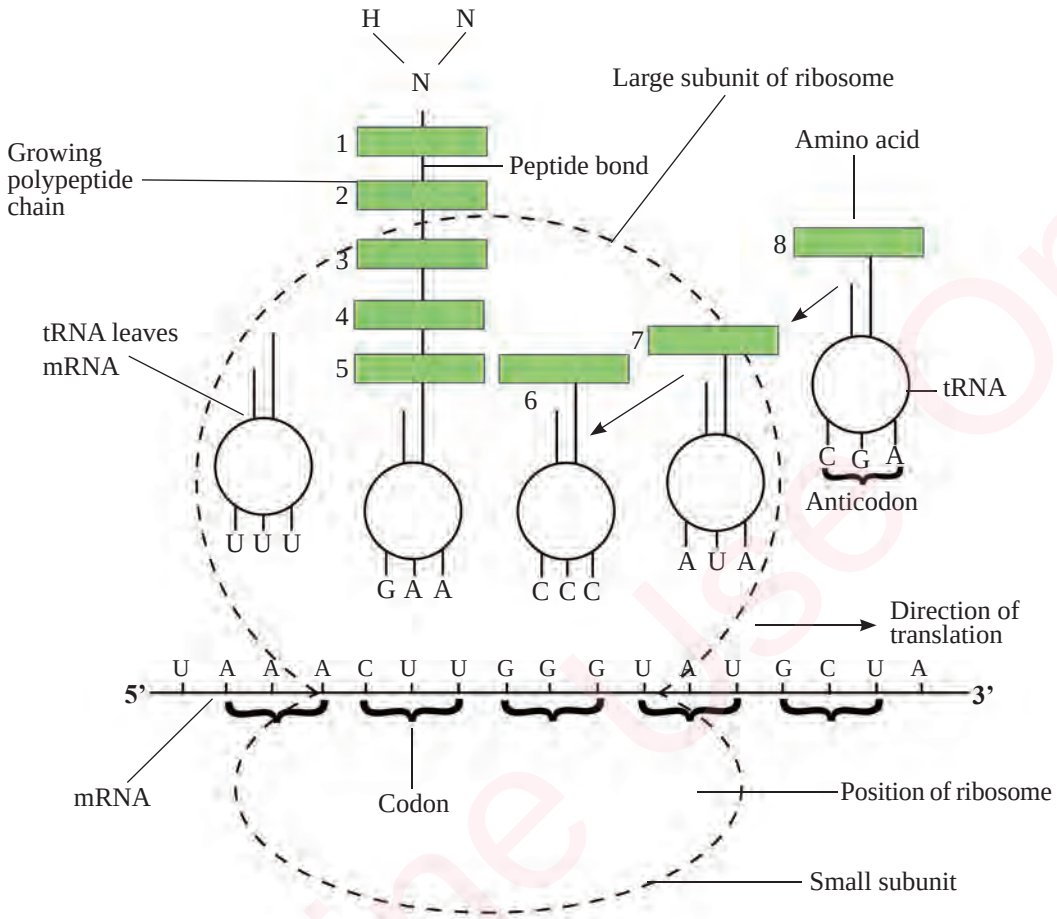


Figure 4.13 Diagrammatic representation of translation

(d) Polypeptide chain elongation

Elongation of the chain begins when the ribosome moves and "read" the next codon on the mRNA molecule. Consequently this movement attracts another amino acid-tRNA molecule by the guide of complementary anticodon. This newly brought amino acid is also joined to the previous amino acid by a peptide bond. The tRNA that was carrying the previous amino acid now is released and returns to the cytoplasm to pick up another amino acid. This process repeats in a manner that, once an amino acid is added to the growing peptide chain, the ribosome moves along the mRNA to enclose a new codon. The polypeptide chain continues to grow with every amino acid molecule addition as shown in Figure 4.14. The functions of the ribosome are thus to "read" and "translate" the mRNA and to hold the mRNA in position. The tRNA and the associated enzymes control the process until peptide bond forms between the adjacent amino acids.

(e) Polypeptide chain termination

The sequence of ribosome's reading and translating the codes on the mRNA

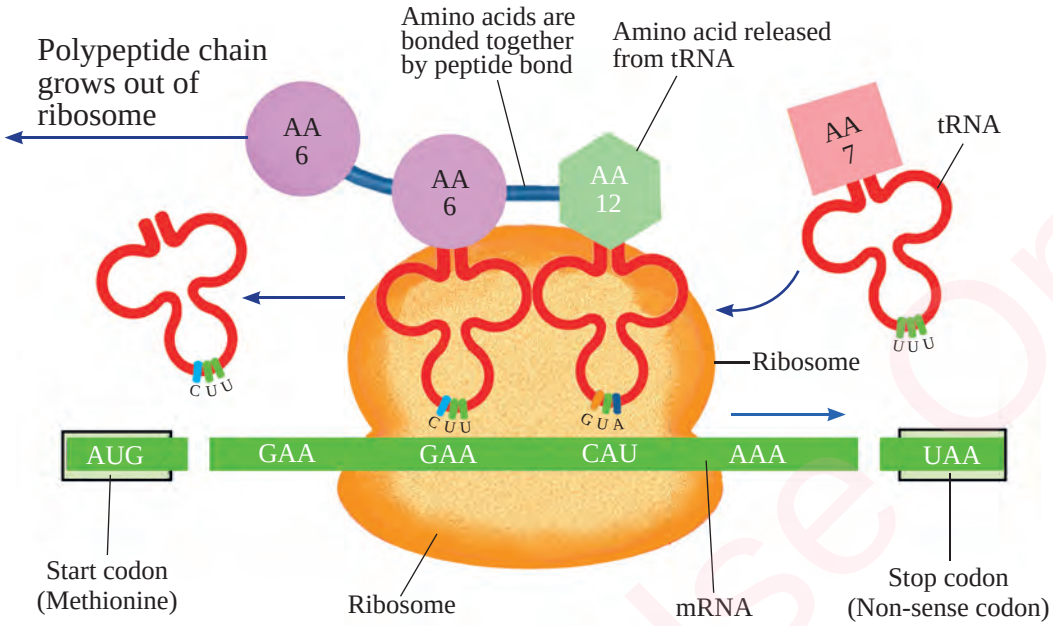


Figure 4.14 Diagrammatic representation of polypeptide chain elongation

continues until it comes to a nonsense terminator codon. The stop codons are UAG, UGA and UAA as indicated in Figure 4.15. These are called non-sense codons because they do not code for any of the amino acids. They specify where the polymerisation of amino acids into a protein molecule is to stop. At this point, the polypeptide chain leaves the ribosome and completes the translation. The released protein molecule is in its primary structure, which is then manipulated into secondary, tertiary or quaternary structures according to the needs of the cell. After the mRNA is translated, it is degraded by the cell itself.

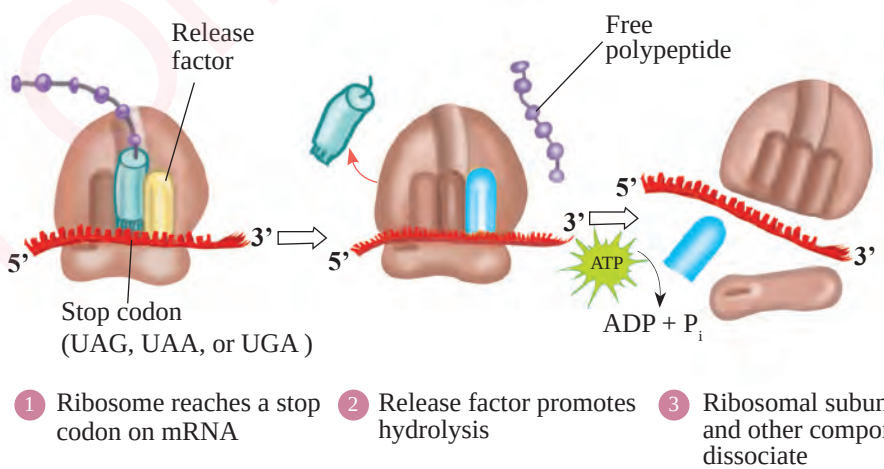


Figure 4.15 Diagrammatic representation of polypeptide chain termination

Exercise 4.3

1. Replication of DNA is said to be semi-conservative. Justify this statement.
2. Describe the process of protein synthesis.
3. Explain the features of the genetic code.
4. What differentiates the genetic makeup of one species from another?
5. Discuss the ways in which the process of DNA replication differs from transcription.
6. What do you understand by the start and stop codons?

Mendelian Principles of Inheritance

Gregory Mendel (1822-1884) was a teacher and an Austrian monk. He studied the process of heredity using selected features of the garden pea plants, *Pisum sativum*. Mendel was not the first scientist to study heredity, but he was the first to carry out numerous scientific experiments and collected sufficiently, accurate, and detailed data upon which genuine scientific conclusions could be based. While Mendel's inheritance studies were with plants, the basic laws of heredity that he developed are applied to people and other animals because the mechanisms are essentially the same. Through selective breeding of common pea plants (*Pisum sativum*) over many generations, Mendel observed that traits show up in offspring without any blending of parent traits. For instance, he cross-pollinated pea flowers, which were purple and white only and he didn't find any intermediate colors in the offspring.

This Mendel's observation was an important finding as it was contrary to the famous theory of inheritance that existed during that time stated that, the offspring's trait is an average of his parents' traits. This means the progeny inherits any trait as the average of the parents' values of that trait. This theory was known as blending theory. Mendel's findings marked the end of the popularity of the blending theory of inheritance.

However, the success of Gregory Mendel was partly by design and partly by luck. He made a suitable choice of characteristics to study. He isolated pea plants that were pure-breeding. This means that when they were crossed with each other they produced consistently the same characteristics over many generations. These characteristics were referred to as traits. The main traits used by Mendel in his experiments were flower colour which were either purple or white, flower position which were either axial or terminal and stem length which were either long or short. Other traits used by Mendel were seed shape which were either round or wrinkled, seed colour which were either yellow or green, pod shape which were either inflated or constricted, and pod colour which were either yellow or green.

The pea plant used by Mendel had the following characteristics:

(a) The species of *Pisum sativum* had several varieties with distinct characteristics

(b) The garden pea plant normally undergoes self-pollination due to its reproductive structures being completely enclosed by the petals. The result of self-pollination is the production of the same characteristics generation after generation, a phenomenon known as pure breeding.

(c) The plants used (pea plant) were easy to cultivate.

(d) In case of artificial cross-breeding between Pisum sativum varieties, the produced hybrids were completely fertile.

Mendel succeeded in many of his experiments while others had failed. The secret behind his success was based on the following:

(a) He carried out several preliminary investigations to familiarise himself with experimental organisms.

(b) He carried out his experiments very carefully so that attention was focused on one variable at a time. This helped him to make clear observations.

(c) He was very careful when carrying out the techniques and this helped him to avoid the introduction of contaminating variables.

(d) He accurately recorded all experiments and the results obtained.

(e) He gave himself enough time to collect sufficient data that were statistically significant.

Mendel studied and introduced a new theory of inheritance based on his experimental work with pea plants in the 1860's. He discovered that heredity is the result of discrete units of inheritance and that every single unit (or gene) is independent in its actions in an individual's genome. The genome is the complete set of genes or genetic material present in a cell or organism. Mendel revealed that for any given trait, an individual inherits one gene from each parent, so that the individual has a pairing of two genes.

Based on his pea plant studies, Mendel proposed that traits are always controlled by single genes. However, modern studies have revealed that most traits in humans are controlled by multiple genes as well as environmental influences. They do not necessarily exhibit a simple Mendelian pattern of inheritance.

Types of Mendelian inheritance

There are two types of Mendelian inheritance, namely: monohybrid and dihybrid inheritance.

Monohybrid inheritance and the basic monohybrid ratio

Monohybrid inheritance is a pattern of inheritance, which involves two individuals, that show contrasting characteristics of only one variation. Mendel's monohybrid crosses involved flower colour, flower position, stem length, seed shape, seed colour, pod shape, and pod colour. It is generally an inheritance of a single character only.

The monohybrid ratio is the ratio of dominant phenotypes to recessive phenotypes which is 3:1. For example, a cross involving one trait in plants such as height, that is, tall or short plants will result in a 3:1 phenotypic ratio in F_2 generation.

Mendel's experiment

In one of his experiments involving monohybrid crosses, Mendel crossed a red flowered pea plant from a pure line to a white flowered plant also from a pure line. All the products of the first filial (F_1) generation had red flowers. However, when the members of this generation were selfed, the resulting members of the second filial generation (F_2) were a mixture of red and white flowered plants in an approximate ratio of 3:1. This is the basic monohybrid ratio which is obtained from a cross involving two heterozygous parents.

Assumptions

(a) Let **R** represent a factor for red colour and **r** a factor for white colour.

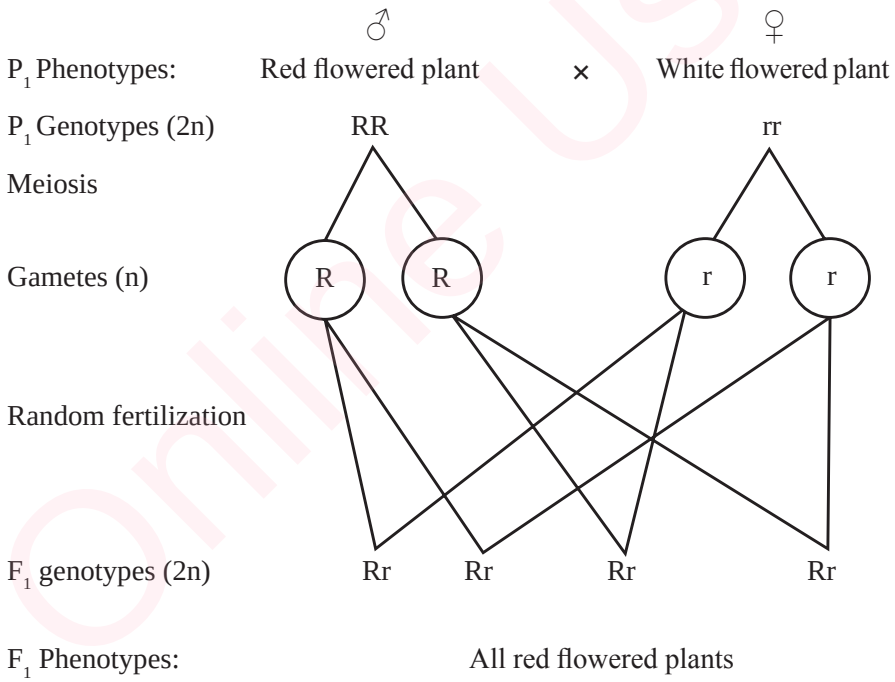
(b) Let **r** represent recessive allele for white colour

(c) Let **R** represent dominant allele for red colour, so that when these two traits are together, only the effects of **R** will be expressed externally.

(d) Let each characteristic be represented by a pair of factors, which segregates during gametes formation.

These assumptions are summarised in the genetic diagrams in Figure 4.16.

(i) The cross between a red flowered male plant and a white flowered female plant, produces red flowered plants in F_1 generation. See the following diagram:



(ii) Selfing of the F_I members renders the following results in F_2 generation:

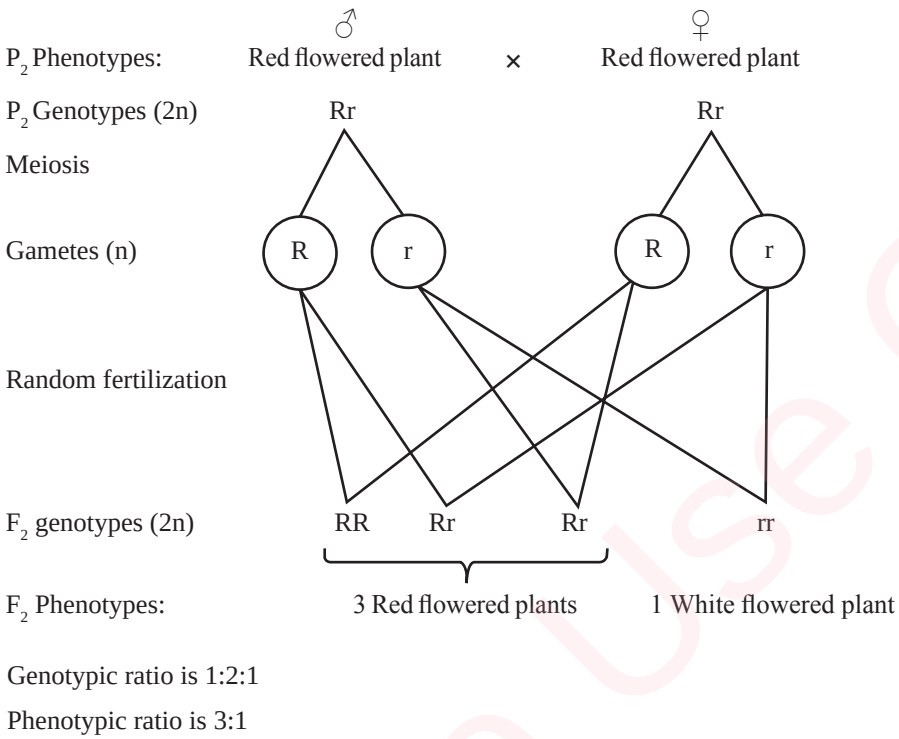


Figure 4.16 Mendel's explanation of monohybrid crosses

Thus, from figure 4.16, the F_2 phenotypic ratio is 3 Red: 1 White, and the genotypic ratio is 1RR:2Rr:1 rr. From this experiment, Mendel observed that the factor for red flowers was able to express itself in the first filial generation (F_1), where the factor for white flowers failed. He thus, referred to the factor which expressed itself, red colour in this case, as a dominant factor. The factor for white colour whose effect was not expressed in the F_1 generation because of the presence of a dominant factor was termed a recessive factor. Therefore, he concluded that the factor for white colour was present in the F_1 generation though it failed to express itself externally. He further observed that the characteristics of the parental organisms remained unaltered. For example, the red and white colours remained constant from the first parental generation (P_1) to the second filial generation F_2. That is, there were no intermediate colours. Lastly, Mendel found out that, each characteristic is controlled by internal factors that occur in pairs and that these factors do segregate during gametes formation.

These observations lead to Mendel's formulation of his first law of inheritance or the law of segregation of factors. This law states that, "The characteristics of an organism are controlled by internal factors which occur in pairs. Only one of a pair of these factors can be present in a single gamete". Thus, on the basis of his

results, Mendel had effectively predicted the existence of genes and meiosis which produce gametes with only one of each pair of factors. In the light of this prediction, Mendel's first law can be stated as, "The characteristics of an organism are controlled by alleles that occur in pairs. Only one of a pair of these alleles can be present in a single gamete".

Meiotic explanation of Mendel's first law

Although Mendel knew nothing about meiosis process, his first law can be explained by behaviour and movement of chromosomes during meiosis. During meiosis I, at anaphase I, homologous chromosome pairs separate from one another, as a result, each haploid gamete receives half of the number of chromosomes present in parental cell. The alleles also occur in pairs, each allele being located on one of the two homologous chromosomes.

Thus, when the chromosomes separate, they take their alleles with them and therefore each gamete receives only one of the alleles in a pair in a similar way as it receives only one chromosome. Thus, there is a similarity between the segregation of homologous chromosomes during meiosis and that of Mendelian factors as indicated in Figure 4.17.

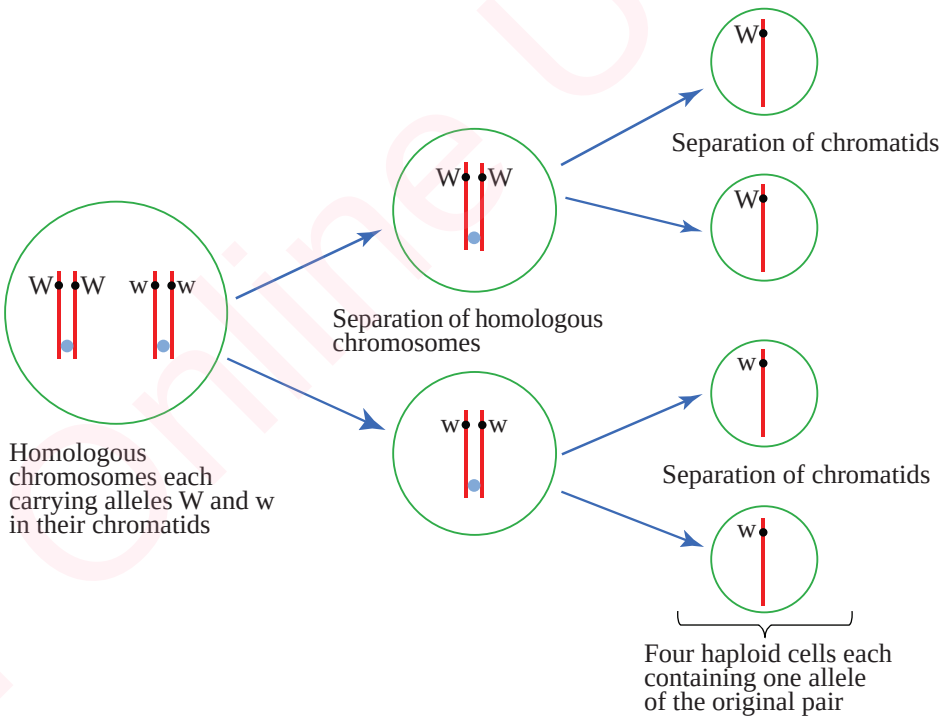


Figure 4.17 Mendel's principle of segregation of factors (alleles) W and w described in terms of homologous chromosomes which occur during meiosis

Worked example to illustrate monohybrid inheritance

If a pure strain of mice with brown coloured fur are allowed to breed with a pure strain of mice with grey coloured fur, they produce offspring with brown coloured fur. If the F_1 mice are allowed to interbreed, they produce offspring with fur colour in the proportion of three brown-coloured to one grey in F_2 generation.

(a) Use genetic crosses to explain these results fully.

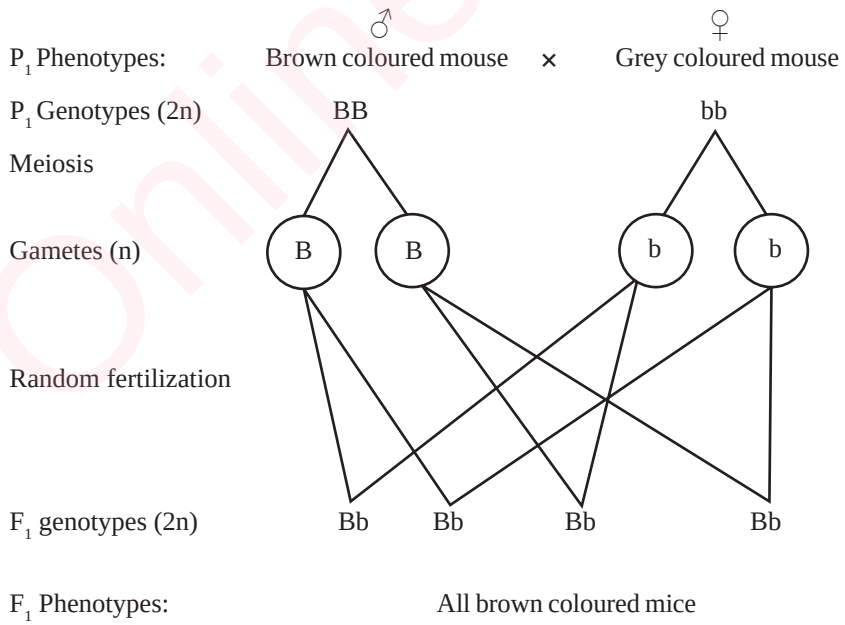
(b) What would be the result of mating a brown coloured heterozygote from the F_1 generation with the original grey coloured parent?

Solution

Since all the F_1 mice have brown coloured fur, then the gene for brown colour is dominant to the gene for grey colour. Therefore, the allele for the dominant gene is represented by **B** and that for a recessive gene is represented by **b**.

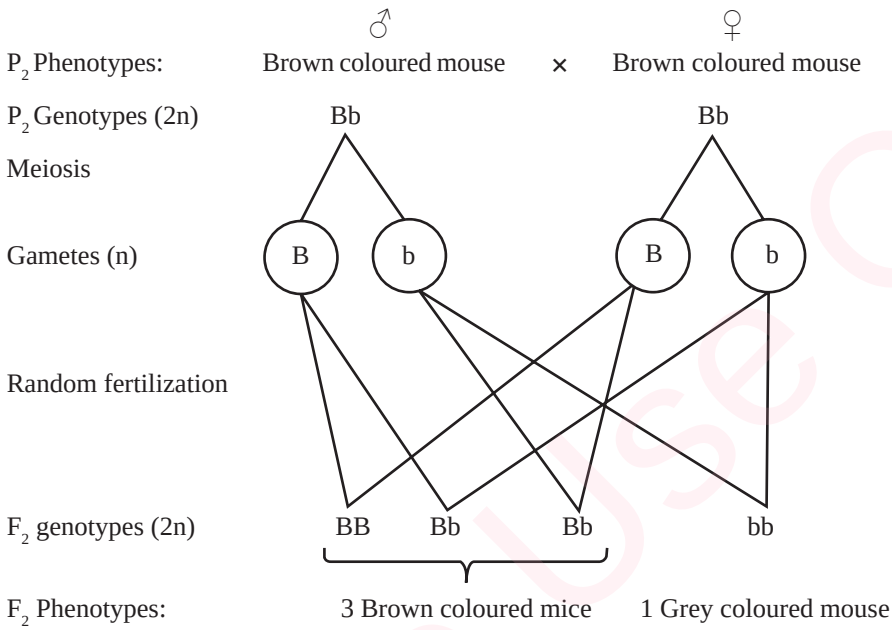
Let brown homozygous alleles be represented by **BB**, the brown heterozygous alleles represented by **Bb** and the grey recessive alleles represented by **bb**.

(i) The results of a cross between a brown coloured male mouse and a grey coloured female mouse will be as follows:



Thus, all offspring in F_1 generation will have brown coloured fur.

(ii) The selfing of individuals of F_1 generation results into a phenotypic ratio of 3:1, indicating that, the brown colour is dominant over grey colour. See the following diagram.



Genotypic ratio is 1:2:1

Phenotypic ratio is 3:1

Thus, about 3/4 or 75% of the offspring in F_2 generation will have brown coloured fur because brown colour is dominant over grey colour. The rest 25% of the offspring will have grey coloured fur.

(iii) A cross between a heterozygous brown coloured male mouse and a grey coloured female mouse from F_2 generation produces the following progeny in F_3 generation as shown in Figure 4.18.

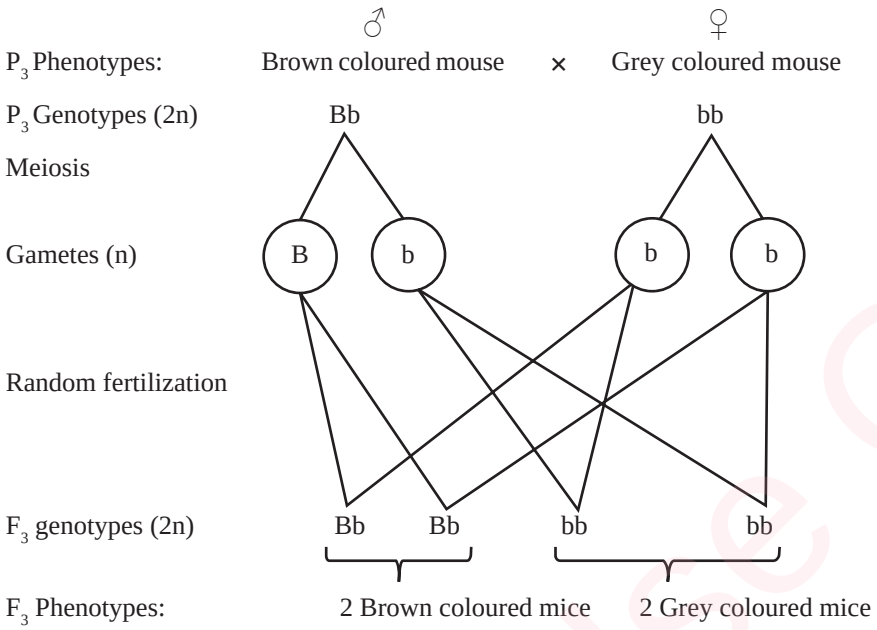


Figure 4.18 Illustration of monohybrid inheritance based on Mendel's first law

Thus, from figure 4.18, when a heterozygous brown male mouse mate with a recessive grey female mouse, then 50% of the offspring in F_1 generation will be brown coloured mouse and the rest 50% will be grey coloured mouse.

Test cross in monohybrid inheritance

In genetics, usually, one organism that exhibits a dominant character can have two possible genotypes. To determine the genotype of that organism, a test cross is used. A test cross can be defined as a genetic cross between a homozygous recessive individual with an individual exhibiting a dominant trait. This is done in order to determine whether that individual is homozygous or heterozygous for that trait. For example, a plant producing red flowers could either be homozygous dominant (**RR**) or heterozygous (**Rr**). The appearance of the flowers is identical in both cases and therefore, what can be said for sure about the plant is that the flowers are red and that there is allele **R** in its genotype. Therefore, the genotype can be represented as **R-**, where a dash (-) represents either **R** or **r**. If the genotype of this plant is to be determined accurately, it should be test crossed with a homozygous recessive, white flowered plant of the genotype **rr**. The results of this cross will provide the required information as indicated in Figure 4.19.

(a) If the entire test cross progeny come out red flowered, then the experimental red flowered plant is genotypically **RR**.

Since the entire test cross progenies have red flowers, the experimental red flowered plant (**R-**) is genotypically homozygous red flowered (**RR**).

(b) If the test cross progenies are a mixture of red and white flowered plants in the approximate ratio of 1:1, then the experimental red flowered plant is genotypically **Rr**.

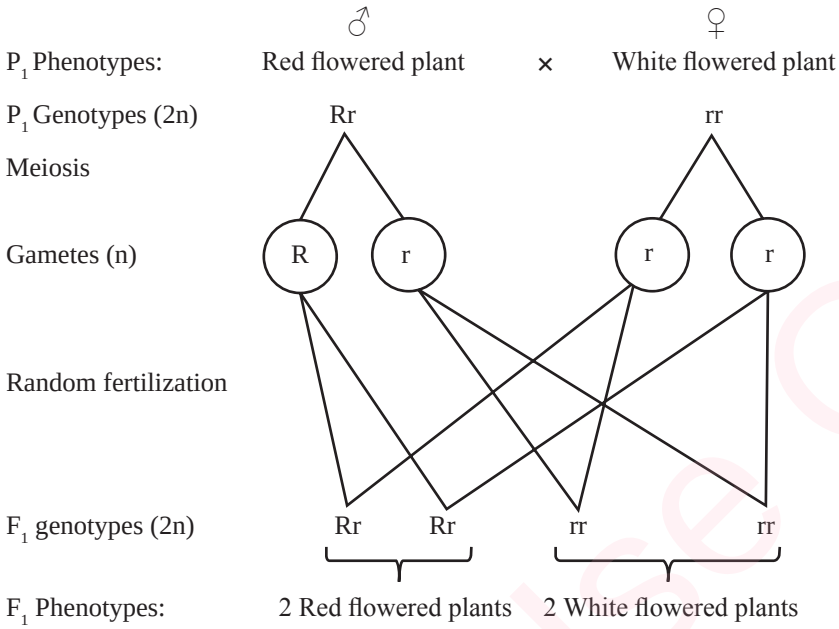


Figure 4.19 Determination of the genotype of an organism using test cross

Since the test cross progenies are a mixture of red and white flowered plants in the ratio of 1:1, the experimental red flowered plant (**R-**) is genotypically heterozygous red flowered (**Rr**). This is because the ratio 1:1 is obtained from a cross involving a heterozygous dominant organism and homozygous recessive in a monohybrid cross.

Dihybrid inheritance and the basic dihybrid ratio

Dihybrid inheritance refers to the simultaneous inheritance of two characters. It is the inheritance of two pairs of contrasting characteristics. For example, if a tall plant with red flowers is crossed with a short plant with white flowers, the two characteristics considered here are the height of the plants stem and colour of its flowers. In one of his experiments to illustrate the dihybrid inheritance, Mendel investigated the inheritance of seed shape and seed colour at the same time. He crossed pure breeding (homozygous) pea plants having round yellow seeds with pure breeding plants having winkled green seeds. All the F_1 generation seeds were round yellow. From his previous monohybrid experiments, Mendel knew that these two characteristics (round and yellow) were dominant. The members of the F_1 generation were selfed and 555 seeds were collected in the F_2 generation, which showed the following phenotypic proportions:

312 round yellow seeds.

102 wrinkled yellow seeds.

110 round green seeds.

31 wrinkled green seeds.

These proportions of each phenotype approximated to a ratio of 9:3:3:1. This is known as the basic dihybrid ratio. From these observations, two general conclusions were drawn:

(a) Two new combinations of characteristics had appeared in the F_2 generation; wrinkled yellow and round green.

(b) In the dihybrid cross, each characteristic behaves independently of the other. Thus, if each characteristic is to be considered separately, the following results will be obtained:

Seed shape

Round	Wrinkled
312+110	102+31
422	133
133	133
= 3	= 1

Seed colour

Yellow	Green
312+102	110+31
414	141
141	141
= 3	= 1

A binomial expansion of the two monohybrid ratios produces the dihybrid ratio that is, (3:1) (3:1) = 9:3:3:1. Based on those results, Mendel concluded that the two pairs of characteristics (seed shape and colour) when combined in the F1 generation, they tend to separate and behave independently from one another in subsequent generations. This forms the basis of Mendel's second law or the law of independent assortment which states that, "Any one of a pair of characteristics may combine with any one of another pair". In a more modern way, the law can be stated as follows "Each member of an allelic pair, may combine randomly with either of another pair".

Meiotic explanation of Mendel's second law

Mendel's second law is explained by meiosis as follows:

During gamete formation, the distribution of each allele in the homologous chromosome pair is entirely independent of the distribution of alleles of another pair. It is therefore random alignment on the equator in metaphase I and their subsequent separation in anaphase II, which leads to a variety of alleles in the gamete cells.

Example: Consider a pea plant with wrinkled green seeds of the genotype **WwGg**. This means that there are two pairs of homologous chromosomes, one pair bearing alleles for seed colour and another one bearing alleles for seed shape. Thus, the chromosomes bearing alleles for seed colour are homologous to one another as those for seed shape as shown in Figure 4.20.

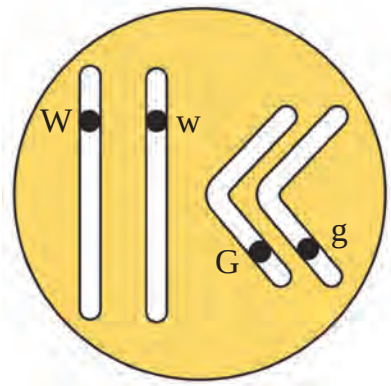


Figure 4.20 A cell showing two pairs of homologous chromosomes

In figure 4.20, the positions of two different gene loci are indicated by shaded circles. In this example, two gene loci are situated on different pairs of homologous chromosomes and each gene is presented

as two alleles. In Meiosis, the homologous chromosomes come together (assort), but they arrange themselves on the spindle fibres independently of one another as shown in Figure 4.21. They arrange themselves in one of the following ways:

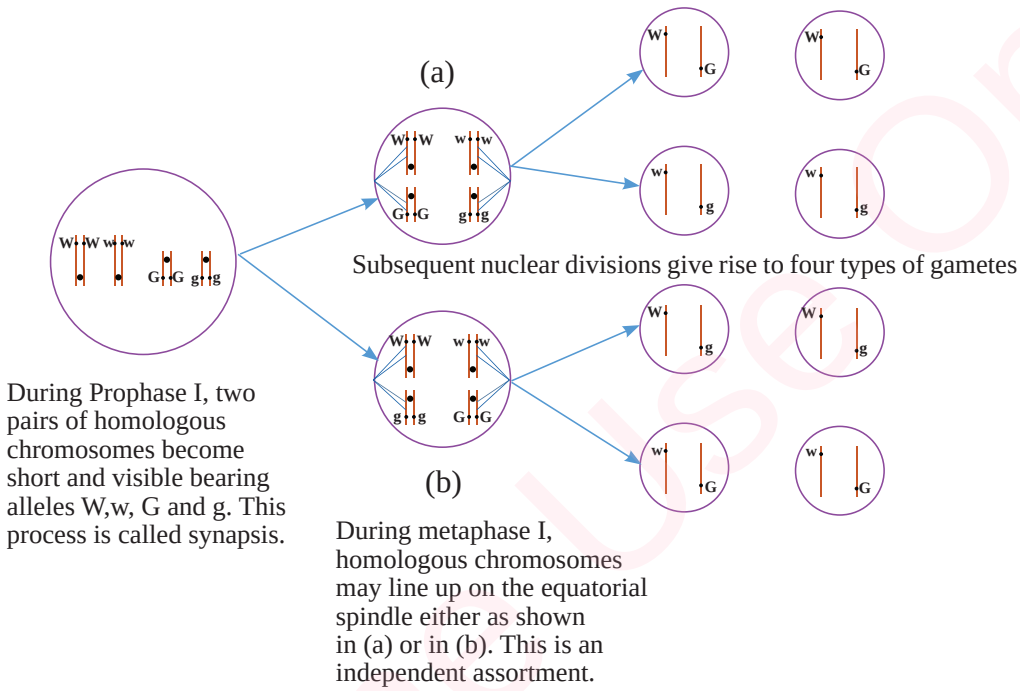


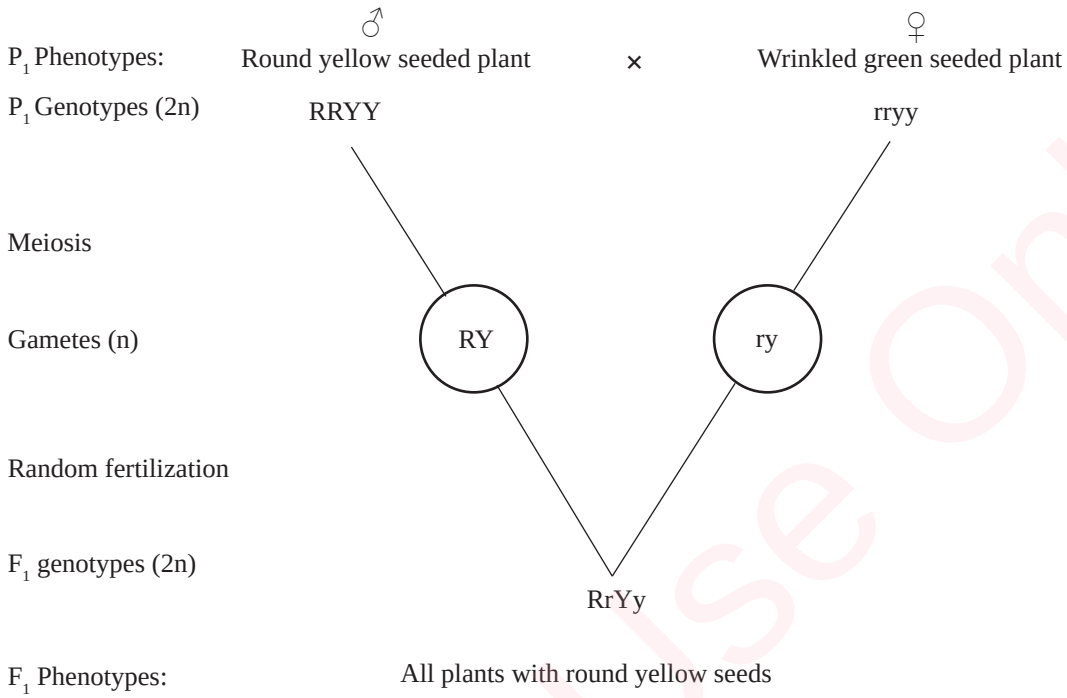
Figure 4.21 Mendel's principle of independent assortment of factors or alleles described in terms of the separation of homologous chromosomes which occurs during meiosis

Genetic representation of the dihybrid cross

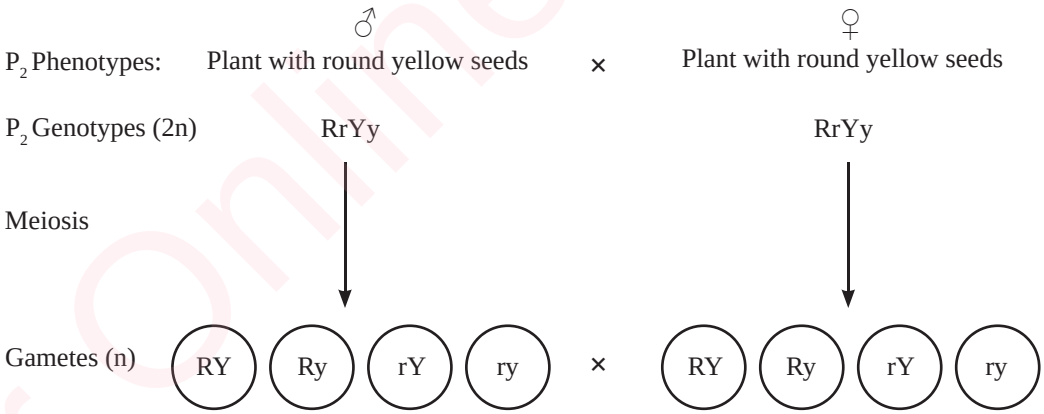
Mendel's experiment to explain dihybrid inheritance used round and yellow seeds and wrinkled green seeds as fully explained in Figure 4.22.

Let: **R** represent allele for round seeds.
r represent allele for wrinkled seeds.
Y represent allele for yellow seeds.
y represent allele for green seeds.

(a) The cross between a homozygous round yellow seeded male plant and a recessive wrinkled green seeded female plant, produces all round yellow seeded plants in F_1 generation.



(b) When selfing members of the F_1 generation renders the following:



(c) Since the plants are self-pollinated, the male and female gametes are of the same types. The offspring of this cross may be represented in a Punnett square.

	♂ Gametes			
♀ Gametes	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Figure 4.22 Genetic representation of the dihybrid cross to show a 9:3:3:1 phenotypic ratio in F_2 generation using a Punnet square

Random fertilisation of ♂ (male) and ♀ (female) gametes to produce F_2 offspring will be as shown in the Punnet square.

The above figure 4.22 is an example of a dihybrid cross because two characteristics are considered at a time. The Punnett square was used to show all possible combinations of gametes to form F_2 genotypes. From the Punnett square, the phenotypic proportions are:

9 round yellow seeds.

3 round green seeds.

3 wrinkled yellow seeds.

1 wrinkled green seeds.

Worked example

In the guinea pig (*Cavia sp.*), there are two alleles for hair colour, black and white and two alleles for hair length, short and long. In a breeding experiment all the F_1 phenotypes produced from a cross between pure breed, short black-haired and pure breed, long white-haired parents, had short black hair.

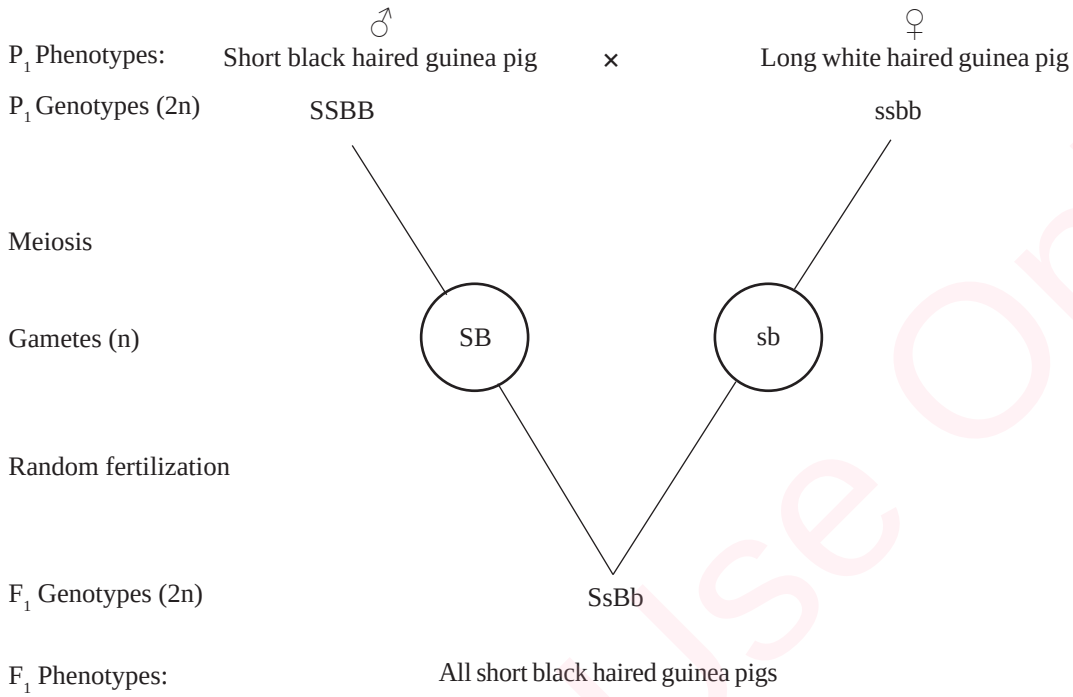
(a) Which alleles are dominant? Give reasons for your answer.

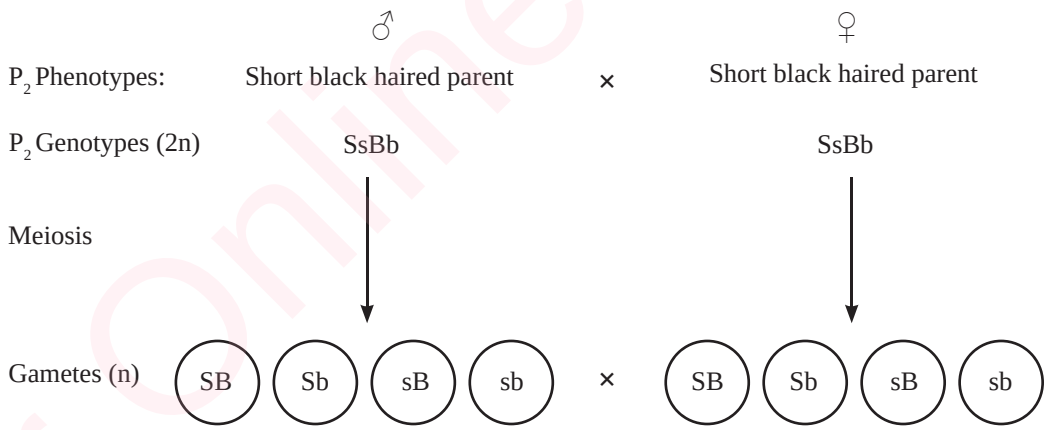
(b) Use a cross diagram to show both, F_1 and F_2 results.

Solution

(a) The dominant alleles are those for short hair and black hair. This is because short-black hair appeared in the F_1 phenotypes as shown in Figure 4.23.

(b) Let: **B** represent black hair.
b represent white hair.
S represent short hair.
s represent long hair.





The Punnett square showing the fusion of gametes by random fertilisation:

	♂ Gametes			
♀ Gametes	SB	Sb	sB	sb
SB	SSBB	SSBb	SsBB	SsBb
Sb	SSBb	SSbb	SsBb	Ssbb
sB	SsBB	SsBb	ssBB	ssBb
sb	SsBb	Ssbb	ssBb	ssbb

Figure 4.23 Worked example to elaborate the inheritance of dominant alleles using Punnett square

The results of F_2 phenotypes are:

9 short black hair guinea pigs.
3 short white hair guinea pigs.
3 long black hair guinea pigs.
1 long white hair guinea pigs.

Exercise 4.4

1. (a) State the first Mendelian law of inheritance.
   (b) Describe in detail an experiment you would conduct to test the first Mendelian law of inheritance.
   (c) State precautions you will take in order to arrive at valid conclusions in the experiment mentioned above.
2. Using examples, explain the concept of dominance and recessive traits.
3. A tall plant of unknown genotype was test-crossed with a recessive dwarf plant. Among the offspring produced, 869 were dwarf and 912 were tall.
   (a) What was the genotype of the unknown parent?
   (b) Show the cross to prove your answer.
4. In Guinea pigs, rough coat (**R**) is dominant over smooth coat (**r**) and a black coat (**B**) is dominant over white coat colour (**b**). **R** and **B** are independent genes. When a rough black guinea pig was mated with a rough white guinea pig, the following offspring were obtained:

28 rough black coated pigs.

31 rough white coated pigs.

10 smooth black coated pigs.

11 smooth white coated pigs.

(a) What was the genotype of the original parents?

(b) Confirm your answer by showing relevant crosses.

5. A tall plant with red flowers from a true breeding line was crossed with a homozygous short plant with white flowers. One of the resulting F_1 plants was crossed with a short red flowered plant of unknown parents. This cross gave the following results:

109 short white flowered plants.

29 tall white flowered plants.

100 short red flowered plants.

36 tall red flowered plants.

(a) Interpret these results.

(b) What was the genotype of the plants produced by the first cross?

Non-Mendelian inheritance

Although Gregory Mendel did great work in genetics and honoured as the father of genetics, his work was later challenged by various genetic studies carried out after him. Such challenges came from crosses which resulted in incomplete dominance and co-dominance, gene interactions and multiple allele inheritance, all of which deviated from the basic Mendelian ratios. Hence, non-Mendelian inheritance entails any pattern of inheritance in which traits do not segregate in accordance with Mendel's laws of dominance and recessiveness.

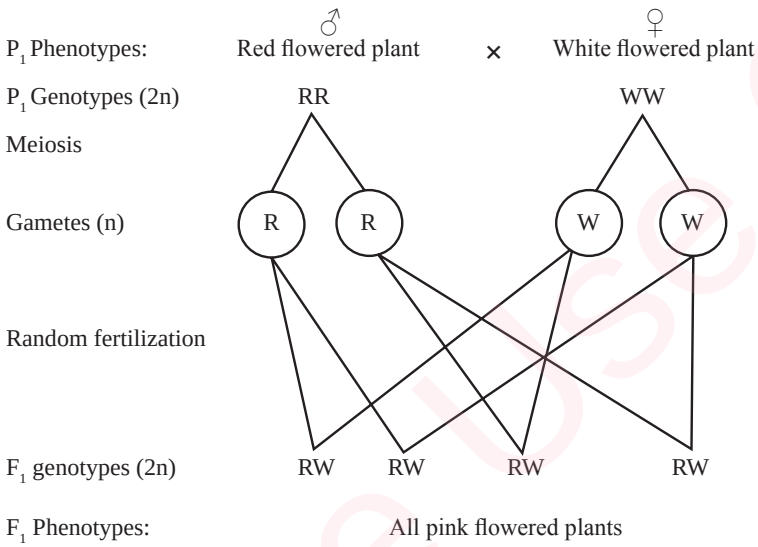
Incomplete dominance

Incomplete dominance applies where the effect of the recessive gene is not completely hidden or suppressed by the dominant gene. The results of a cross between two parents who are incomplete dominant show intermediate character of heterozygous offspring. Results obtained by Mendel enabled him to establish the principle of dominance. However, since the time of Mendel, a few cases have been discovered which do not follow the dominance-recessiveness principle. Such cases produce a hybrid, which is intermediate between the parents in appearance. This pattern of inheritance is called intermediate inheritance or incomplete dominance. Incomplete dominance can be defined as a pattern of intermediate inheritance in which one allele for a specific trait is not completely expressed over its paired allele. This leads to a new or third phenotype in which the expressed physical trait is a combination of the phenotypes of both alleles. For example, consider an inheritance of flower colour in snapdragon plants. Two common varieties of snapdragon differ in flower colour: one is pure-breeding red **RR** and the other is pure-breeding white **WW**. Surprisingly, when these varieties are crossed, the F_1 flowers, which correspond to the genotype **RW,** are all pink. In this case, the red allele **R** fails to be fully expressed over the white allele **W**.

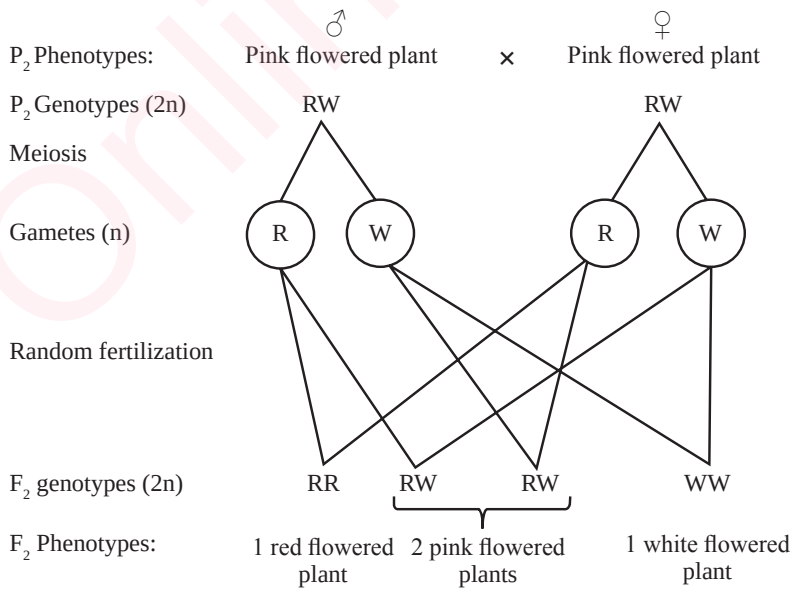
Self-pollination of F_1 generation gives rise to an F_2 generation in which the results of Mendelian segregation are clearly seen. Because each gamete contains only a single allele from any pair, the chance of a combination of F_1 gametes results in the offspring of F_2 generation having plants with red flowers, pink flowers, and white flowers. The ratio obtained in the incomplete

dominance is 1:2:1, which is deviating from monohybrid Mendelian cross ratio of 3:1. Incomplete dominance shows a failure of one allelomorphic character to dominate the other in the F_1 generation. The hybrid of F_1 does not resemble either of the original parents and instead, they have an intermediate character. This is common in both plants and animals as shown in Figure 4.24.

(a) When a red flowered plant is crossed with a white flowered plant, all offspring in F_I generation will inherit a different trait from that of both parents.



(b) Selfing the F_1 offspring, which in this case, pink flowered plants will produce the following progeny in F_2 generation:



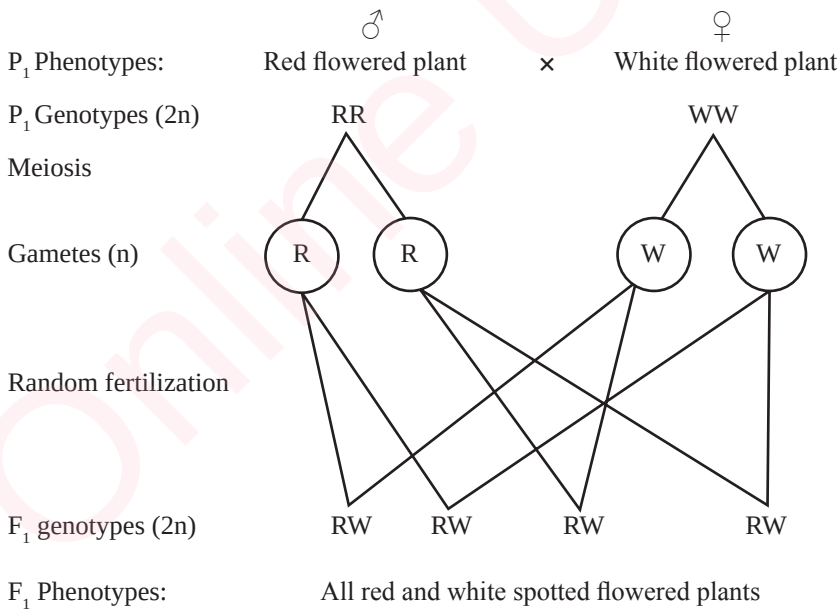
Genotypic and phenotypic ratio is 1:2:1

Figure 4.24 The 1:2:1 ratio produced in F_2 phenotypes and genotypes as a result of incomplete dominance

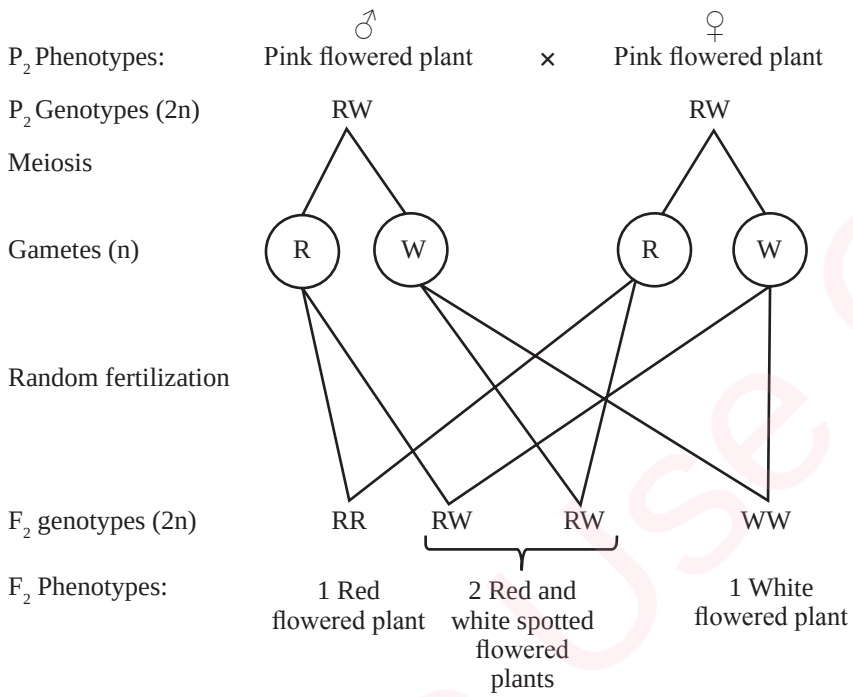
Co-dominance

Unlike incomplete dominance, in the co-dominance pattern, one allele does not dominate or mask the other alleles but both alleles have an equal chance of being expressed in their offspring. The heterozygous condition in co-dominance produces a different phenotype from the homozygous state of either allele. In this case, neither allele is dominant. For example, co-dominance is shown by certain plants such as *Camellia japonica* whereby some have white flowers and others have red flowers. When a homozygous white flowered plant is crossed with a homozygous red flowered plant, the F_1 offspring produced will have flowers with red and white spots. Self-pollination of the F_1 plants produces the F_2 generation plants with a mixture of red, spotted and white flowered phenotypes in the ratio of 1:2:1 which is the same as that of an incomplete dominance. If **R** represents an allele for red colour and **W** represents an allele for white colour, then **RW** will mean red and white spotted flower as the crosses reveal in Figure 4.25.

(a) When red flowered plant is crossed with white flowered plant, the resulting offspring in F_1 generation will all posses red and white spotted flowers.



(b) Selfing the F_1 offspring will produce the following progeny in F_2 generation:



Genotypic and phenotypic ratio is 1:2:1

Figure 4.25 The 1:2:1 phenotypic and genotypic ratio produced in F_2 generation as a result of co-dominance

Note that, the heterozygous condition produces a different phenotype from the homozygous state of either allele.Thus, the F_2 phenotypic ratio is 1 red: 2 spotted: 1 white. However, a mixture of red and white spot flowers shows that, both alleles for red and white colours have an equal chance of being expressed in F_2 generation.

Exercise 4.5

1. Discuss the concepts of incomplete dominance and co-dominance.
2. In certain species of chicken, feather colour is controlled by co-dominant genes. The allele for white is **W** and for black is **B**. The heterozygous phenotype is known as erminette.
   (a) What are the genotypes for black, white, and erminette chicken?
   (b) If two erminette chicken were crossed, what is the probability that:
      (i) They would have a black chick?
      (ii) They would have a white chick?
3. In a certain strain of plants, flower colour is controlled by one gene with two alleles. The dominant alleles **RR** produces red flowers, heterozygous alleles **Rr** produces pink flowers and

recessive alleles **rr** produces white flowers.

(a) Is this kind of trait inheritance an incomplete dominance or co-dominance?

(b) What are the expected genotypic and phenotypic ratios of red, pink, and white flowers in a cross involving two plants with pink flowers? Use crosses to confirm your work.

4. A cross between ducks with frizzled and plain feathers produced ducks with "slightly frizzled" feathers.
   (a) Is this kind of inheritance an incomplete dominance or co-dominance?
   (b) Use crosses to show the genotypic and phenotypic ratios for a cross between a slightly frizzled rooster and plain feathered duck.
   (c) Cross a slightly frizzled rooster with a frizzled duck. Show your work and ratios.
5. Explain the results obtained in F_1 and F_2 filial generations in incomplete dominance when crossing pure breeds of red and white flowered plants.
6. In certain species of cattle, the red coat colour is co-dominant over the white coat colour. The heterozygous condition is roan (both red and white hairs are produced). Show a cross between two roans coloured cattle. Indicate the genetic ratios.

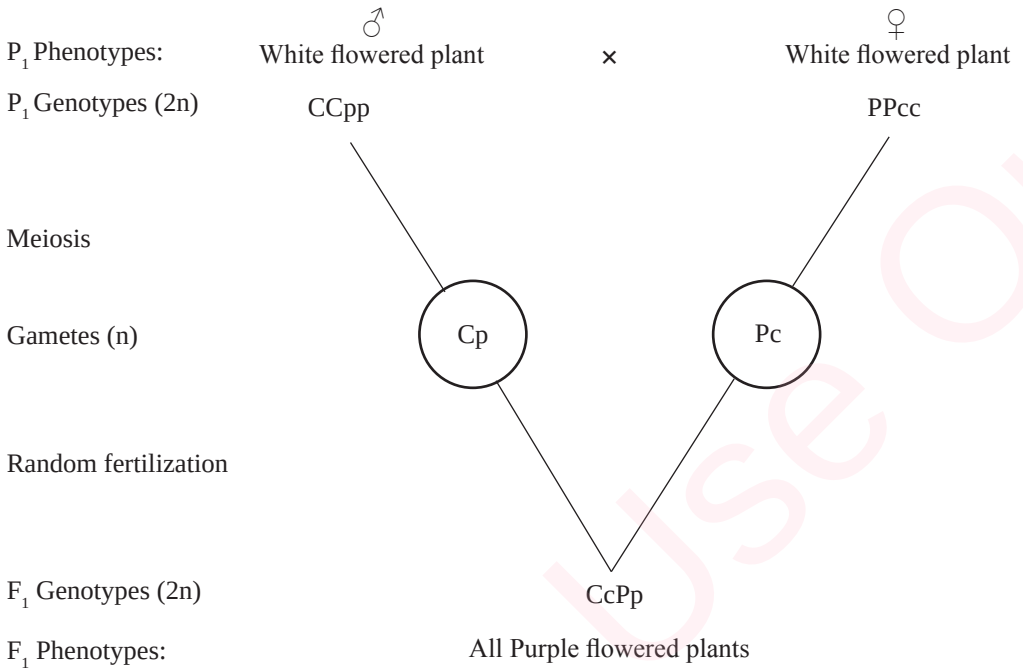
Gene interactions

Gene interaction refers to the situation whereby alleles of more than one gene control one trait in an organism. For example, in some of the dihybrid crosses, two or more genes interact to produce a single phenotype. Such an interaction may modify the basic ratios and results of Mendel's principles of inheritance. Examples of genes interaction include, complimentary genes interaction, epistasis, collaboration, and multiple gene interaction.

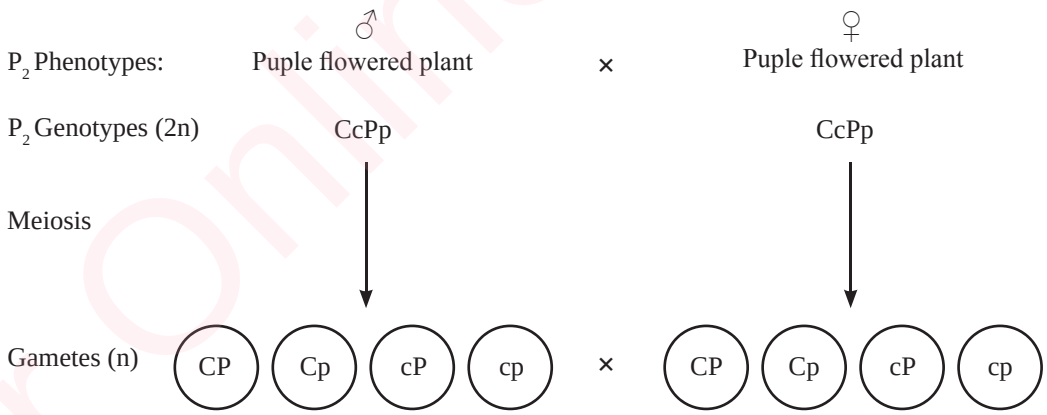
Complementary genes interaction

Complementary genes are two mutually dependent genes that are present on separate loci and interact together to produce a dominant phenotypic trait. In this case, neither of the two genes can exert its phenotypic effect in the absence of the other. Example of complementary genes is seen in the control of flower colours in sweet pea plants *(Lathyrus odoratus)*. The colour of the flowers is either purple or white. Purple colour is produced only when a dominant allele **C** is complemented by a dominant allele **P**. This means that the purple colour of the flowers is determined by two dominant genes **C** and **P**. One gene, **C** controls the production of raw materials that are necessary for the formation of purple colour while the other gene **P**, controls the conversion of the raw materials into a purple pigment. Thus, having either **P** or **C** alone, is not enough to produce a purple pigment. However, in the absence of either of these genes, the flowers are white. Therefore, a plant of the genotype **ccPP, ccPp, CCpp** or **Ccpp** has white flowers. The purple flowers are formed in plants with the genotype **CCPP, CCPp, CcPP** or **CcPp** as shown in Figure 4.26.

Consider a dihybrid cross between two strains of white flowered sweet peas.
The plants in the first filial generation, all have purple coloured flowers as follows:



The selfing of F_1 generation plants produces the following progeny in F_2 generation:



The Punnett square showing random fertilisation in F_2 generation:

	♂ Gametes			
♀ Gametes	CP	Cp	cP	cp
CP	CCPP	CCPp	CcPP	CcPp
Cp	CCPp	CCpp	CcPp	Ccpp
cP	CcPP	CcPp	ccPP	ccPp
cp	CcPp	Ccpp	ccPp	ccpp

Figure 4.26 Illustration of the 9:7 phenotypic ratio produced in F_2 generation as a result of complementary genes interaction

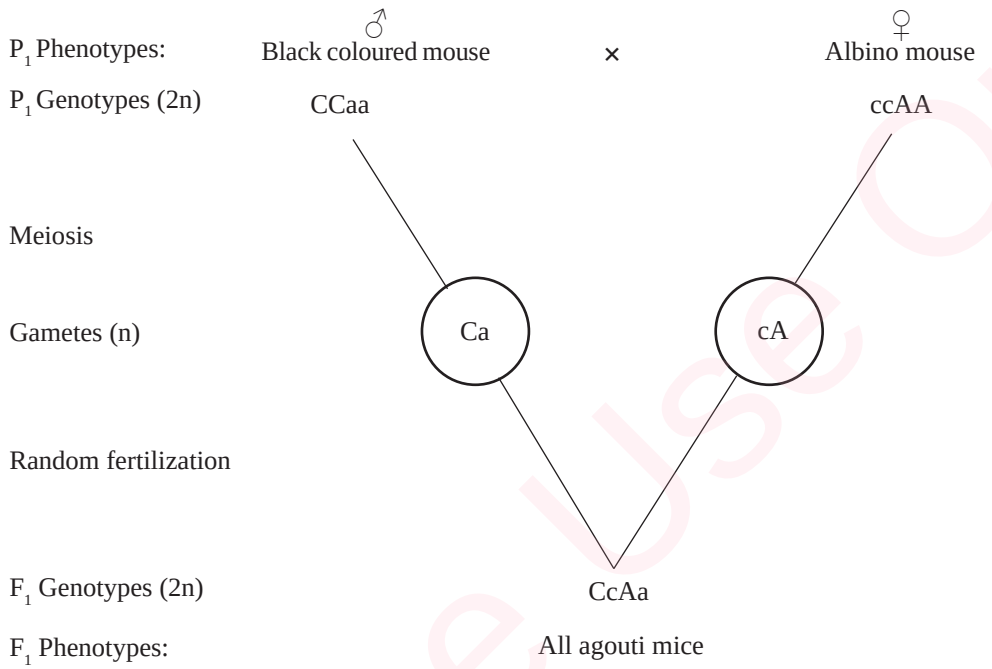
From the Punnet square in figure 4.26, the F_2 phenotypic ratio is 9 (purple) :7 (white) or simply 9:7 phenotypic ratio instead of the normal basic dihybrid phenotypic ratio of 9:3:3:1.

Epistasis

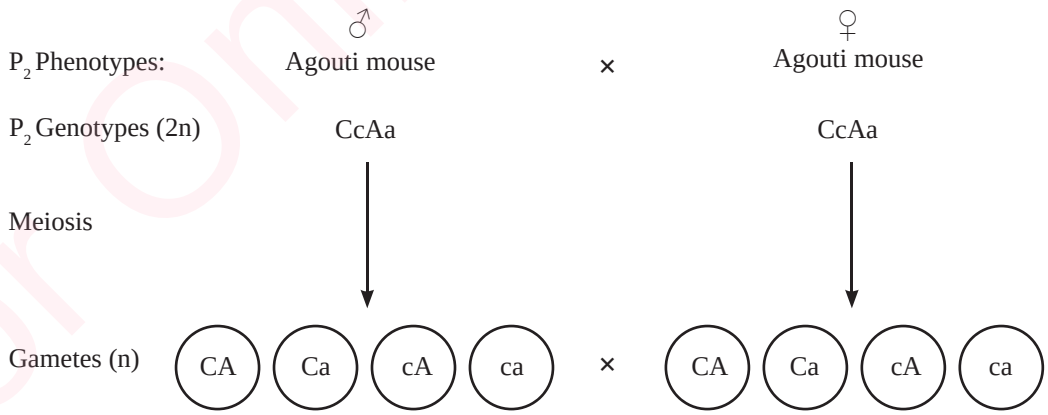
This is a situation where the phenotypic expression of one gene is masked by the presence of another gene. When two different genes contribute to a single phenotype and their effects are not merely additive, those genes are said to be epistatic. Usually, the gene suppressing the other is called "Epistatic," while the one masked and suppressed is called "hypostatic". Epistatic genes are also known as inhibiting genes because of their ability to mask the effect of other genes. One example of epistasis is that of fur colour inheritance in mice. In these animals, the wild fur colour is known as agouti, which is greyish in nature and is controlled by gene **A**, which is hypostatic to a recessive allele **c**. The dominant allele **C** in the presence of allele **a** gives black coloured mice. In the presence of the dominant allele **C**, allele **A** gives rise to agouti. Thus, the genotype **CCaa** will be coloured and **ccAA** will be albino. When black coloured mice **CCaa** are crossed with albino **ccAA**, agouti mice **CcAa** appear in F_1 generation. The gene **cc** masks the effect

of **AA** and is therefore, epistatic. Consequently, **ccAA** is albino and the basic dihybrid ratio of 9:3:3:1 is modified to 9:3:4 as revealed in Figure 4.27.

(a) When the black coloured mouse is crossed with an albino mouse will result into the following progeny:



(b) When agouti mouse is crossed with another one of the same trait, the resulting offspring in F_2 generation will be:



The following diagram shows a Punnet square elaborating random fertilisation in F_2 generation.

♀ Gametes \ ♂ Gametes	CA	Ca	cA	ca
CA	CCAA	CCAa	CcAA	CcAa
Ca	CCAa	CCaa	CcAa	Ccaa
cA	CcAA	CcAa	ccAA	ccAa
ca	CcAa	Ccaa	ccAa	ccaa

Figure 4.27 Illustration of 9:3:4 phenotypic ratio produced in F_2 generation as a result of epistatic gene interaction

From the Punnett square, the following deduction is made. The **c** locus is epistatic to the **A** locus and the results show that the F_2 phenotype ratio is 9 (agouti): 3 (black): 4 (albino). The normal F_2 basic dihybrid ratio of 9:3:3:1 has been modified to 9:3:4.

However, it should be noted that in some cases a dominant allele of one gene may hide the effect of a dominant allele of another gene. Examples are **A** masks **C** or **C** masks **A**. This is called dominant epistasis and produces a phenotypic ratio of 12:3:1. An example of this type of epistasis is seen in summer squash where there are three types of fruit colours, which are yellow, green and white. White colour is dominant over other colours while yellow is dominant over green. A gene for white colour (**W**) masks the effects of yellow colour gene (**Y**). Thus, yellow colour is formed only when the dominant epistatic gene is represented by its recessive allele (**w**). When the hypostatic gene is also recessive (**y**), the colour of the fruit is green as shown in Figure 4.28.

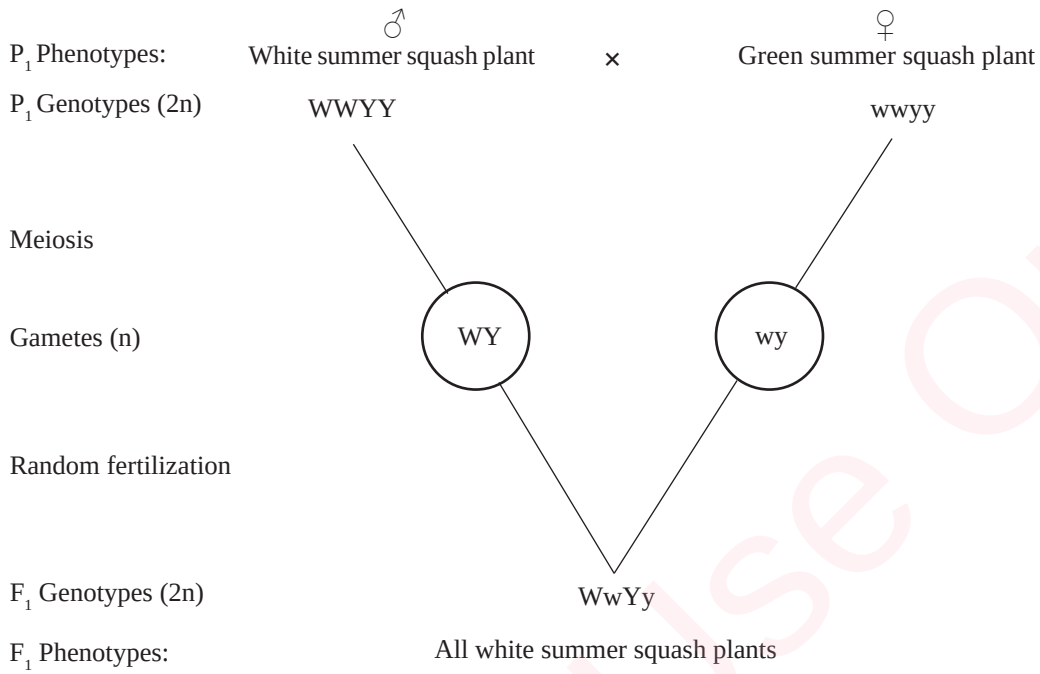
Hence:

White fruit: W-Y- or W-y-

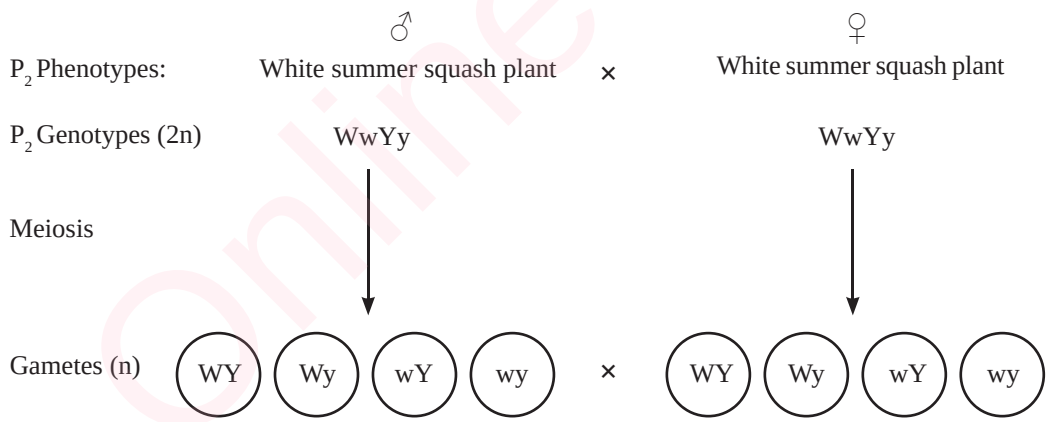
Yellow fruit: wwY-

Green fruit: wwyy.

In this regard, a cross between a pure breeding white summer squash (**WWYY**), with a pure breeding green summer squash (**wwyy**), yields white coloured fruits in the F_1 generation and when the F_1 progeny are selfed, the F_2 phenotypes are 12 white, 3 yellow and 1 green fruits.



When white summer squash plant is crossed with another plant of the same trait, the resulting offsspring in F_2 generation will be:



The Punnet square to show the fusion of gametes in F_2 generation:

♀ Gametes \ ♂ Gametes	WY	Wy	wY	wy
WY	WWYY	WWYy	WwYY	WwYy
Wy	WWYy	WWyy	WwYy	Wwyy
wY	WwYY	WwYy	wwYY	wwYy
wy	WwYy	Wwyy	wwYy	wwyy

Figure 4.28 Illustration of 12:3:1 phenotypic ratio produced in F_2 generation as a result of dominant epistatic genes interaction

From the Punnet square, the results can be summarised as shown in Table 4.3.

Table 4.3 The genotypic and phenotypic ratios resulting from dominant epistasis

Genotype	Phenotype	Ratio
W-Y-	White	9/16
W-yy	White	3/16
wwY-	Yellow	3/16
wwyy	Green	1/16

Thus, **W** is epistatic to **Y** and it is clear that the F_2 phenotype ratio is 12 white: 3 yellow: 1 green. This is the modification of the basic dihybrid ratio of 9:3:3:1.

Collaborative genes interaction

The collaborative genes interaction occurs when two genes influencing one characteristic interact to produce a new phenotype that could not be produced by either of the two genes alone. This sort of gene interaction is called collaboration and is illustrated in the control of a comb form in chicken.

In this case, one gene **R** produces a rose comb whereas its recessive allele **r** produces a single comb. Another gene **P** produces a pea comb and its recessive allele **p** produces a single comb. When **P** and **R** interact, they collaborate to produce a walnut comb, which neither of the two genes could produce alone as shown in Figure 4.29.

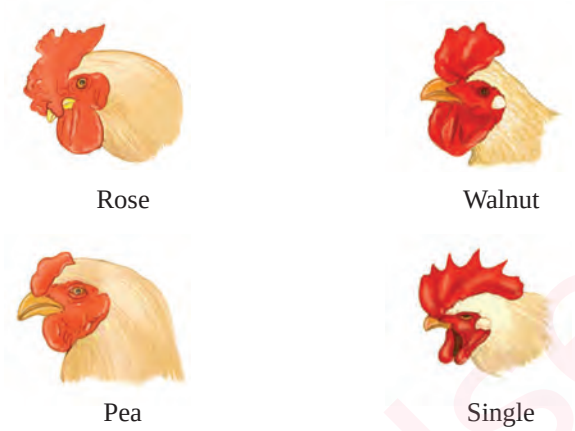


Figure 4.29 Comb shapes in chicken

The phenotypes of comb shapes in chicken have the following possible genotypes as shown in Table 4.4.

Table 4.4 The possible phenotypes and genotypes of comb shapes

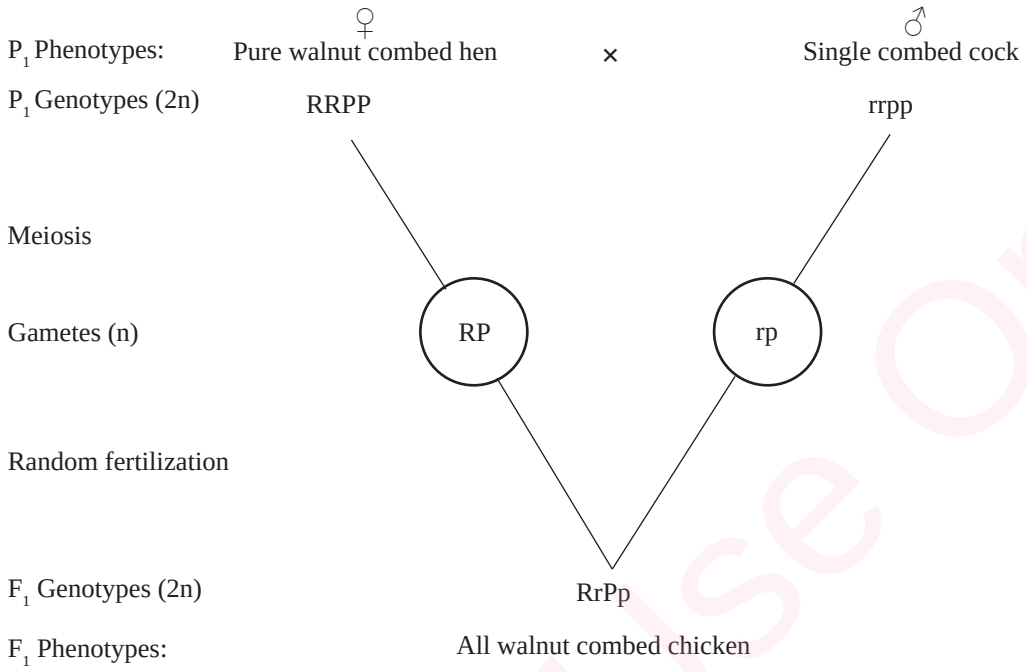
Phenotype	Possible genotype
Rose comb	R-pp
Pea comb	rrP-
Single comb	rrpp
Walnut comb	R-P-

Let: Genotype for walnut shaped comb be **RRPP** or **RrPp**.
Genotype for single shaped comb be **rrpp**.

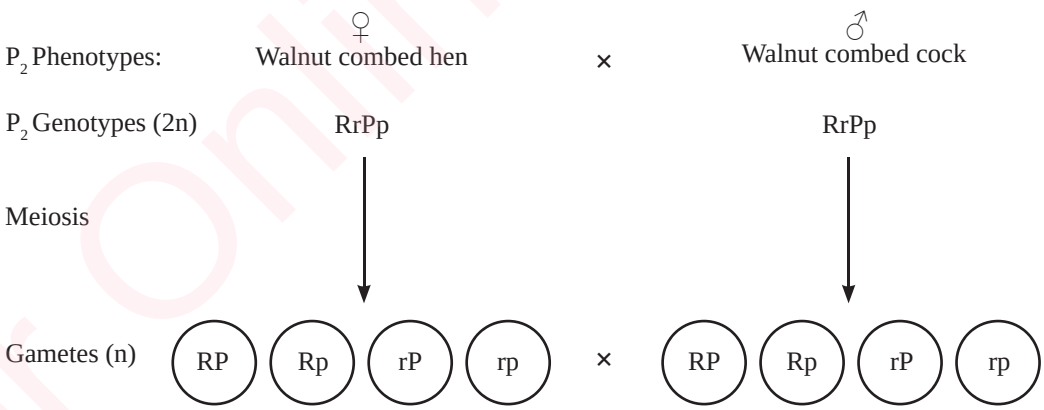
Genotype for rose shaped comb be **RRpp** or **Rrpp**.

Genotype for pea shaped comb be **rrPP** or **rrPp**.

A cross between a pure walnut combed hen and a single combed cock gives the following results in F_1 generation:



If the F_1 progenies are selfed, the products in F_2 generation will appear as shown in Figure 4.30.



The Punnett square to show random fusion of gametes in F_2 generation:

♀ Gametes \ ♂ Gametes	RP	Rp	rP	rp
RP	RRPP	RRPp	RrPP	RrPp
Rp	RRPp	RRpp	RrPp	Rrpp
rP	RrPP	RrPp	rrPP	rrPp
rp	RrPp	Rrpp	rrPp	rrpp

Figure 4.30 The 9:3:3:1 phenotypic ratio produced in F_2 generation as a result of collaborative genes interaction

From the Punnett square, the genotypic and phenotypic ratios can be summarised as shown in Table 4.5.

Table 4.5 The genotypic and phenotypic ratios in F_2 generation as a result of collaborative genes interaction

Genotype	Phenotype	Ratio
R-P-	Walnut comb	9/16
R-pp	Rose comb	3/16
rrP-	Pea comb	3/16
rrpp	Single comb	1/16

From the table above, the F_2 phenotypic ratio is 9:3:3:1. Likewise the genotypic ratio is the same. This shows that, the F_2 phenotypic ratio of 9:3:3:1 is not altered in this case. The only modification of Mendelian genetics is that in the F_2 generation there is an emergence of new phenotypes such as rose and pea comb forms which are neither seen in the P_1 generation nor in the F_1 generation.

Polygenic inheritance

Polygenic inheritance is a type of gene interaction, which occurs when one

characteristic is controlled by the combined effects of many different genes. It is also termed as multiple gene interaction or multiple factor inheritance. It is the additive effect of several genes in a single phenotypic characteristic. These genes form a special gene complex known as a polygenic system. Often, the genes are large in quantity but small in effect. In other words, the effect of each gene alone is too small to make any significant impression on the phenotype, but their combined effects will make the phenotype more conspicuous. Examples of human polygenic inheritance are height, skin and eye colours.

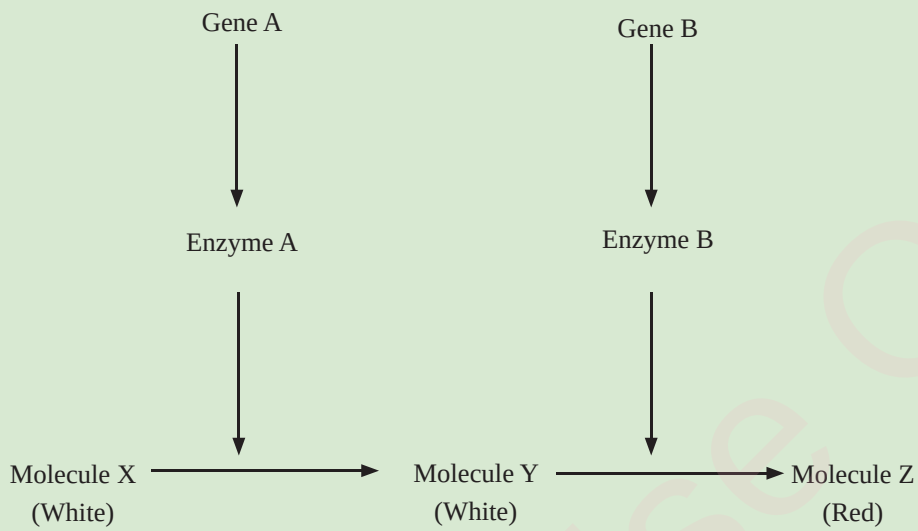
Consider a hypothetical example using skin colour with the assumption that it is controlled by three genes that are inherited separately. The alleles **A**, **B**, and **C** influence melanin production with equal effects while the alleles **a**, **b,** and **c** contribute nothing to the melanin production. Thus, the intensity of skin colour will be determined by the amount of melanin produced. This means that, the intensity of skin colour will increase in the order of **AaBbCc** < **AaBbCC** < **AaBBCC** < **AABBCC**. This implies that individuals with genotype **AABBCC** will have the highest intensity of skin colour while individuals with the genotype **AaBbCc** will have the lowest intensity of skin colour. This means that the intensity of skin colour will depend on a number of capital letters (dominant alleles) present in the genotype.

Exercise 4.6

1. With the aid of appropriate crosses, explain the following:
   (a) Complementary genes.
   (b) Collaborative genes.
   (c) Epistatic genes.
2. In white Leghorn fowl, plumage colour is controlled by two sets of genes, including the following:

   White (**W**) is dominant over other colours (**w**), Black (**B**) is dominant over brown (**b**).
   The heterozygous F_1 genotype WwBb is white. Account for this type of gene interaction and show the genotypic ratio of F_2 generation.
3. In guinea pigs, the gene for the production of melanin is epistatic to the gene for the deposition of melanin. The dominant allele **M** causes the production of melanin, **mm** individuals cannot produce the pigment. The dominant allele **B** causes the deposition of large amount of pigment and produces a black guinea pig with alleles **BB**, whereas only a small amount of pigment is laid down in animals with **bb** alleles, producing a light brown colour. Without an **M** allele, no pigment is produced so the allele **B** has no effect and the guinea pig is white. A homozygous black guinea pig is crossed with homozygous recessive white: **MMBB** × **mmbb**. Give the phenotypes of the F_1 and F_2 generations.
4. A certain kind of flower is red because of a red pigment that requires two different genes. Gene **A** encodes an enzyme which catalyses the conversion of colourless molecule **X** into a second colourless molecule **Y**. The enzyme encoded by gene **B** catalyses conversion of molecule **Y** into a red pigment molecule **Z**. Both enzymes must be

working in order to make the red pigment as shown in the following diagram:



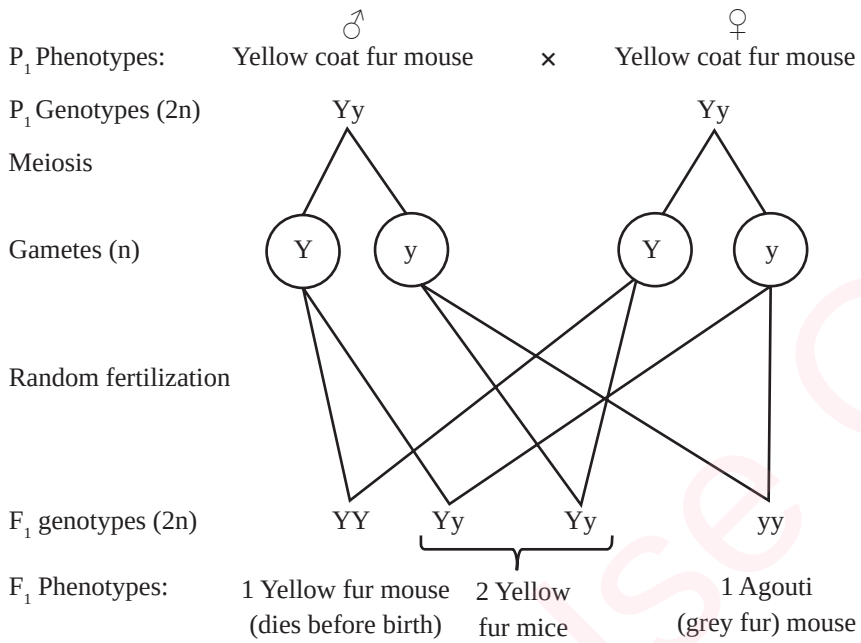
A pure-breeding white-flowered plant that produces no functional enzyme **A** or **B** is crossed with a pure breeding red-flowered plant. Predict the phenotypes and the ratios of the F_2 offspring.

5. (a) What is meant by epistasis?
   (b) How does epistasis differ from the Principles of Mendelian inheritance?

Lethal genes

The survival of an organism is largely determined by its genetic makeup. However, in some cases organisms fail to survive and therefore they die because of having certain type of genes in their genotypes. The genes that cause the death of an organism which carry them are called lethal genes. Depending on the type of lethal gene, death may occur as soon as these genes are inherited or after some years. In other words, the lethal genes can cause death of an organism before birth or any time after birth. An example of the lethal gene is illustrated by inheritance of fur colour in mice. In this case, wild mice have grey coloured fur, a condition called "agouti". Some mice have yellow fur. A cross between yellow mice produces offspring in the phenotypic ratio of 2 yellow fur: 1 agouti fur. These results are explained on the basis that yellow is dominant to agouti and that all the yellow coat mice are heterozygous. This implies that, homozygous yellow mice do not exist. They die in their early embryonic development since they inherit lethal genes as revealed in Figure 4.31.

Let: **Y** represent yellow fur (dominant) and **y** represent agouti fur (recessive).



The observed phenotypic ratio is 2:1

The expected phenotypic ratio was 3:1

Figure 4.31 Inheritance of lethal gene for fur colour in mice

From figure 4.31, the homozygous yellow mouse (**YY**) dies in the prenatal stages due to the inheritance of a lethal gene. Thus, the basic monohybrid Mendelian ratio of 3:1 is modified to 2:1.

Sex determination

Sex determination is a genetical system that determines development of sexual characteristics in organisms. In many species of plants and animals including human beings, sex of the offspring is determined by sex chromosomes carrying corresponding gene alleles in the male and female gametes. Thus, male and female organisms have different alleles that define their sexual morphology. In some rare cases, sex of the resulting offspring is determined by environmental factors. For example, in some reptiles, temperature of the nest determines the sex of the embryo. There are several sex determination systems among organisms. They include **XY**, **XX** or **XO**, **ZW**, **UV** and haplodiploidy. Sex chromosomes differ from body chromosomes or autosomes in terms of shape, size and functions.

Although a number of sex determination systems exist, but the **XY** system is exhibited by most mammals and plant species. In this system, the female provides ova with **X** sex chromosomes while males provide sperms with both **X** and **Y** sex chromosomes. Note that, **X** and **Y** are just symbols that have been proposed by scientists to represent the sex chromosomes in this system. Human beings are a good example of organisms with **XY** sex determination. Human being have 23 pairs of chromosomes out of which only one pair is the sex chromosome. The remaining 22 pairs are called autosomes. Females have identical **X** sex chromosomes while males have both **X** and **Y** sex chromosomes.

The **X** chromosome resembles autosomes or body chromosomes with long and short arm-like structures, while its **Y** counterpart has one long arm and a very short second arm.

At meiosis, male **XY** chromosomes separate to form **X** and **Y** gametes (sperms). The half of gametes formed contains **X** chromosomes and the other half contains **Y** chromosomes. Females, on the other hand, have two **X** chromosomes. This means all female eggs are identical carrying **X** sex chromosomes. Hence, in most mammals including human, males are heterogametic while females are homogametic. In mating, when the female egg is fertilised by a sperm carrying **X** chromosome, the resulting embryo is a female with **XX** sex chromosome. Eggs that are fertilised by a sperm carrying **Y** chromosome results into a male embryo with **XY** sex chromosomes. In this case, therefore, it is the male organism, which determines the sex of the resulting offspring and not the female. This means in most species, sex of the resulting offspring is determined at the time of fertilisation. The path to maleness or femaleness starts at the moment of meiosis when a sex cell divides to produce gametes with half number of chromosomes as seen in Figure 4.32.

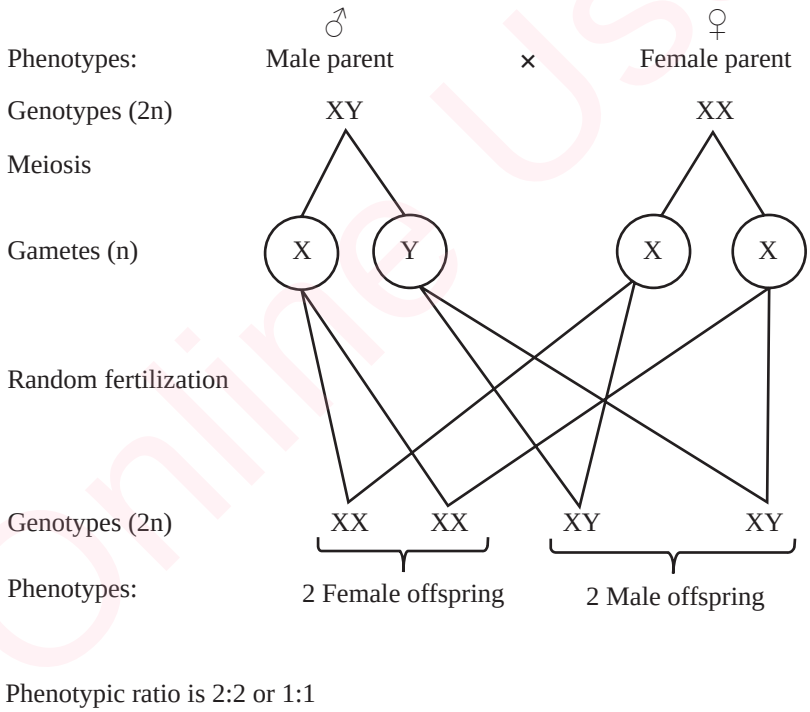


Figure 4.32 The XY sex determination system

Many insects such as *Drosophila melanogaster* (fruit flies) experience an **XO**/**XX** system. Like humans, these flies have both **X** and **Y** sex chromosomes. However, the **Y** sex chromosome in drosophila does not carry maleness instead it encodes genes necessary for making sperms. Sex of the resulting embryo is determined by the ratio of **X** sex chromosomes to autosomes or the ratio of the number of **X** sex chromosomes to the number of sets of autosomes (**X:A** ratio). In some cases, each cell of the resulting drosophila fly decides whether to be male or female independently

of others resulting into gynandromorphy case. Hence, it is the balance between female determining factors encoded in the **X** sex chromosomes and the male determining factors encoded in the autosomes that determine which sex will be initiated.

In summary **XX**, **XXY** and **XXYY** drosophila flies will be females while those with **XO** and **XY** will be males.

Sex determination in most birds is again a different process. Birds have a **ZW** sex determination system. Letters **Z** and **W** are used just to distinguish this system from other systems such as **XO** and **XY**. Hence, in contrast to **XY** and **XO** systems where it is the sperm from males which determine the sex of the resulting offspring, in birds it is the ovum from a female which actually determines the sex of the resulting offspring. **ZW** system is also found in some fish, crustaceans, and some insects such as butterflies and moths.

Sex linkage

When two or more genes are inherited together because they are located close to each other on the same chromosome, they are said to be linked. Sex linkage, therefore, refers to the carrying of genes on the sex chromosomes. These genes determine body characters and have nothing to do with sex. The **X** chromosome has many such genes. The **Y** chromosome has very few. In the case of heterogametic sex, there is a portion of the **X** chromosome where there is no homologous region on the **Y** chromosome as shown in Figure 4.33. Therefore, characteristics that are determined by the genes carried on the non-homologous portion of the **X** chromosome appear in males even if they are recessive. This special form of linkage explains the inheritance of sex-linked traits.

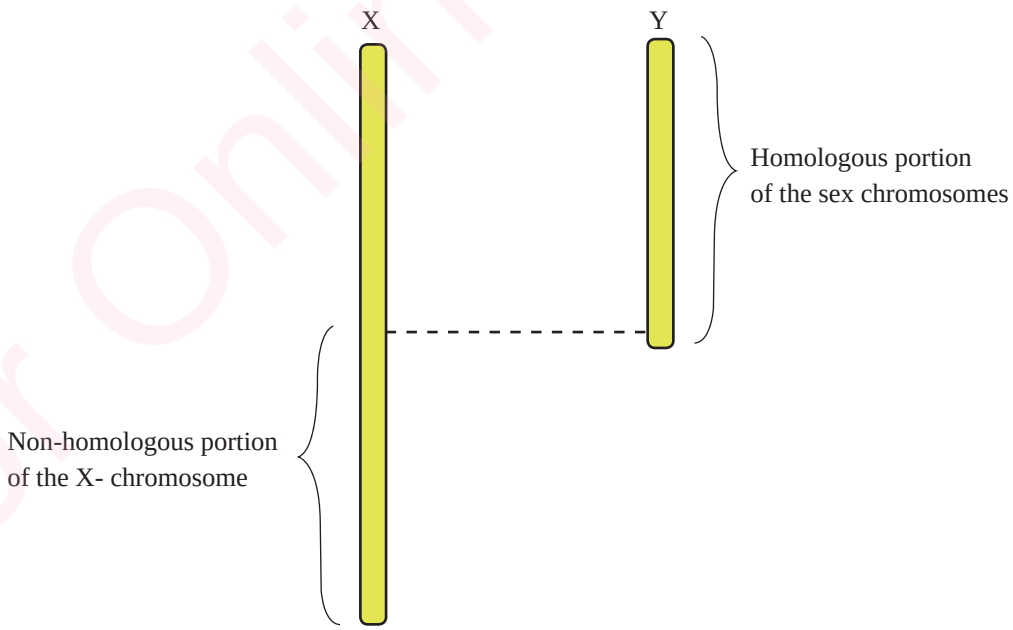


Figure 4.33 Homologous and non-homologous regions of sex chromosomes

In humans, two well-known sex-linked characteristics include haemophilia and red-green colour blindness. Both are linked to the **X** chromosome and are caused by recessive genes. These defects are more frequent in males than in females. In order for this condition to arise in a female, it requires a double recessive state. The recessive allele is relatively rare in the population, therefore, this condition is unlikely to occur frequently. In females, the recessive allele is normally masked by the dominant allele, which occurs on the second **X** chromosome. The heterozygous females are not affected themselves, but are capable of passing the recessive allele to their offspring. For this reason, such females are termed as carriers. On the contrary, when the recessive allele occurs in males, it expresses itself because the **Y** chromosome cannot carry any corresponding allele for sex-linked traits.

Red-green colour-blindness

This is the failure to distinguish red from green. In this case, normal sight is dominant over red-green colour blindness. Thus, if **B** represents the allele for normal sight and **b** represents the allele for colour blindness. Since this gene is sex-linked, then its alleles are represented as $\mathbf{X^B}$ and $\mathbf{X^b}$ respectively. Females are homogametic (**XX**) and males are heterogametic (**XY**) and their genotypes may be represented as follows:

$\mathbf{X^BX^B}$ - Normal-sighted female.

$\mathbf{X^BX^b}$ - Normal-sighted carrier female.

$\mathbf{X^bX^b}$ - Colour blind female.

$\mathbf{X^BY}$ - Normal-sighted male.

$\mathbf{X^bY}$ - Colour blind male.

A cross between a normal-sighted carrier female and a normal male produces all normal-sighted daughters, one normal son and one colour blind son as shown in Figure 4.34.

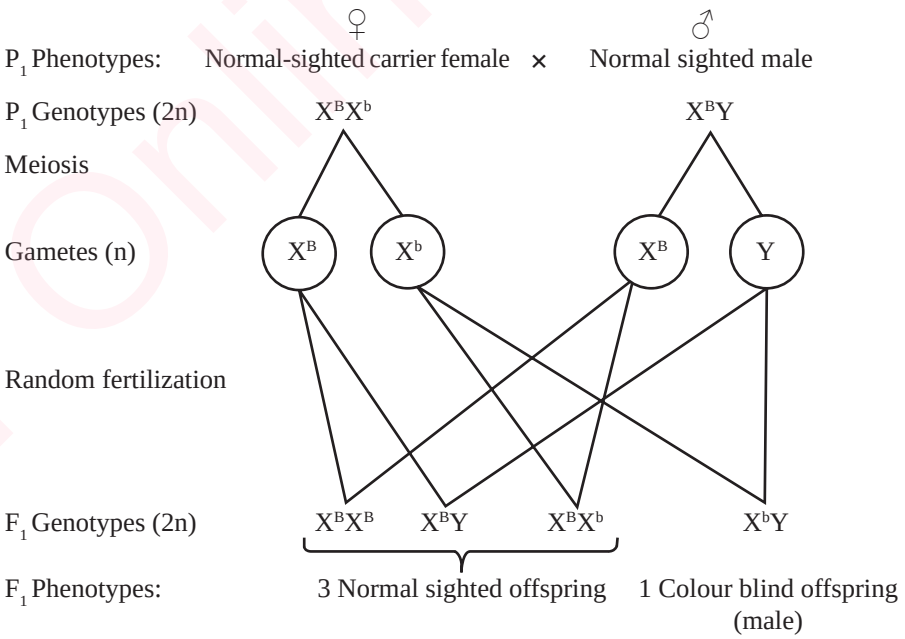


Figure 4.34 Mechanism of inheritance of the sex-linked allele for red-green colour blindness

The proportions of the F_1 generation phenotypes and genotypes are as follows:

25% Normal sighted daughters ($\mathbf{X^BX^B}$).

25% Normal sighted sons ($\mathbf{X^BY}$).

25% Normal sighted carrier daughters ($\mathbf{X^BX^b}$).

25% Colour blind sons ($\mathbf{X^bY}$).

Haemophilia

This is a sex- linked genetic disorder in which the blood either delays or fails to clot. There are two types of haemophilia, these are: haemophilia **A** and haemophilia **B**. Both types result from the lack of sufficient blood clotting proteins or clotting factors anti-haemophiliac globulins (AHG). Haemophilia **A**, also known as classic haemophilia, is caused by the deficiency of blood clotting factor VIII while haemophilia **B**, also known as Christmas disease, is caused by the deficiency of blood clotting factor IX. In the general population, the occurrence of haemophilia is rare and when it happens, haemophilia **A** is more common than haemophilia **B**. Both conditions have similar symptoms but are caused by different sex-linked genes. The haemophiliac people experience prolonged bleeding during injury, surgery or tooth uproot. In severe cases, haemophilia may result in bleeding of internal organs including brain, joints, and muscles. In mild form, spontaneous bleeding is rare and the condition becomes evident only after a serious injury or surgery.

Haemophilia is an X-chromosome linked disorder and for this reason, males are commonly affected while females are usually carriers of the trait. Although females can be phenotypically normal, their gametes carry half of the recessive genes. Because of this, even if a normal male marries a carrier haemophiliac female, there is a probability of up to 50% of their sons to be haemophiliac.

This sex-linked defect is caused by a recessive allele **h** carried on the X-chromosome, and it is inherited in a similar way as red-green colour blindness. The normal dominant allele is **H**, and the possible genotypes, therefore, are as follows:

$\mathbf{X^HX^H}$ - Normal female.

$\mathbf{X^HX^h}$ - Normal carrier female.

$\mathbf{X^hX^h}$ - Haemophiliac female.

$\mathbf{X^HY}$ - Normal male.

$\mathbf{X^hY}$ - Haemophiliac male.

Consider a cross between a normal carrier female and a normal male. About 25% of the resulting offspring in F_1 generation will express the haemophiliac trait (males) while about 25% of them will be normal carrier females. The remaining 50% of the F_1 generation offspring (males and females) will be normal without expressing any haemophiliac trait as indicated in Figure 4.35.

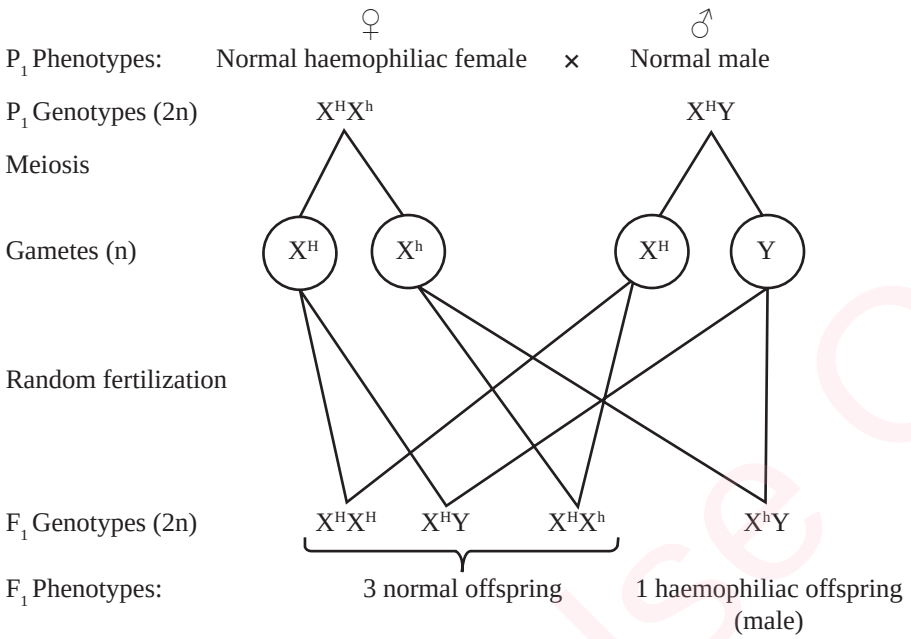


Figure 4.35 Mechanism of inheritance of the sex linked allele for haemophilia

The passage of haemophilia among members of a given family can be summarized in a pedigree or a genetic chart or family tree. Thus, the pedigree is referred to as a family tree or genetic chart which shows the inheritance of a given genetic trait from one generation to another. Figure 4.36 is an example of a pedigree summarising the transmission of haemophilia in a hypothetical family. In the pedigree, circles represent females and squares represent males The figures coloured red indicates phenotypic expression of the haemophilia while those coloured blue indicate a normal phenotype. The individuals of one parental generation are interconnected by horizontal lines while the offspring are connected to parents by vertical lines.

The genetic chart or pedigree is a good method of tracing the inheritance of sex-linked genes by tracing crosses of the trait within a family. The parental generation shows a mating between an affected male (haemophiliac) and a normal female. It indicates that, all males produced in the first generation were normal, while most females were carriers of the haemophiliac trait. The mating of one of the carrier females with a normal male produced 25% of the haemophiliac sons and 25% of the carrier daughters in the second generation. On the other hand, 50% of the children in the second generation were normal.

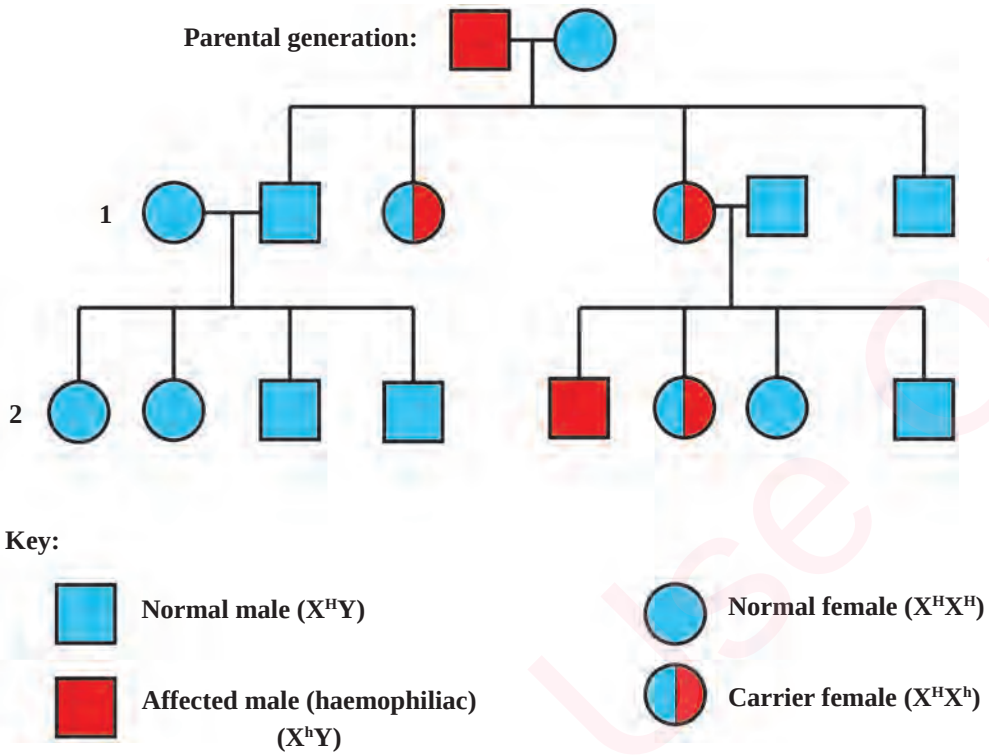


Figure 4.36 Transmission of haemophilia in a hypothetical family

Multiple alleles

Multiple allelism is a term used to describe a gene that has more than two possible alleles. Multiple alleles, therefore, are three or more alternative forms of a gene (alleles) that can occupy the same locus. However, only two of the alleles can be presented in a single organism. For example, the **ABO** system of blood groups is controlled by three alleles, only two of which are present in an individual.

Inheritance of blood groups

An autosomal gene controls the blood group. The gene locus is represented by the symbol **I** (which stands for isohaemagglutinogen) and there are three alleles which are represented by the symbols **A, B** and **O**. The alleles **A** and **B** are equally dominant and **O** is recessive to both. The presence of a single dominant allele in the genotype makes the blood produce a substance called agglutinin, which acts as an antibody. For example, the genotype I^BI^O would give rise to agglutinogen **B** on the red blood cell membrane and this has a corresponding anti-**B** or β agglutinin in the plasma. The blood group would be **B**. Thus, it is the antigen or agglutinogen on the surface of the red blood cells, which determines the phenotype of the blood group of a given person. Consider the following case as shown in Table 4.6.

Table 4.6 The phenotypes and genotypes in blood groups

Blood group (phenotype)	Gene alleles (genotype)
A	I^AI^A or I^AI^O
B	I^BI^B or I^BI^O
AB	I^AI^B
O	I^OI^O

The genetic attributes show that two alleles are responsible for determining one blood group. This makes no difference in their transmission from Mendel's work. Thus, as shown in Figure 4.37, a mating between two individuals who are both in blood group **O** must result in a child who is also blood group **O**.

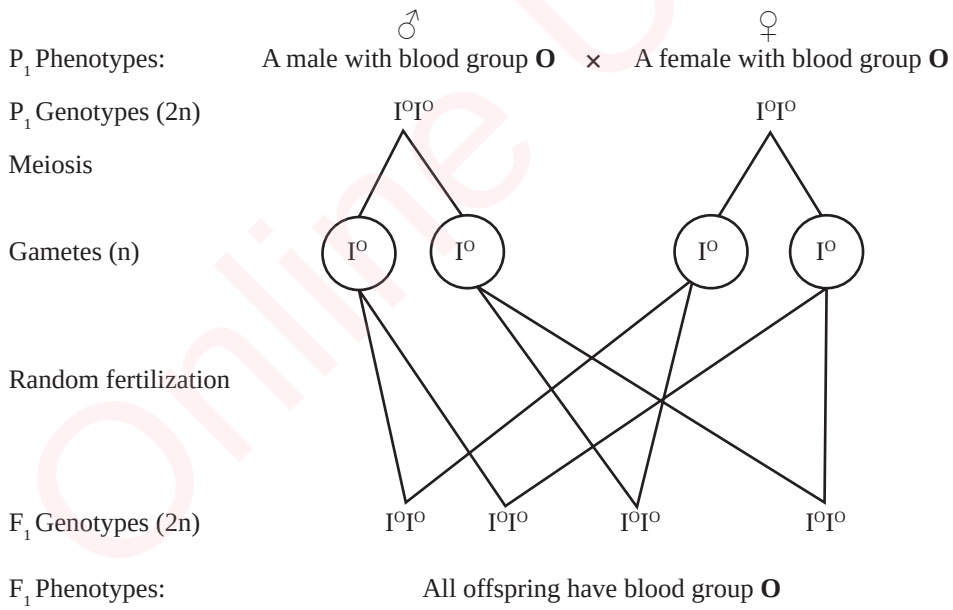


Figure 4.37 Inheritance of a blood group **O** when two individuals with blood group **O** mate

However, the result of the mating between an individual of group **A** and that of group **O** will depend on the genotype of group **A** parent. If the parents are homozygous $\mathbf{I^AI^A}$ and $\mathbf{I^OI^O}$, all children will be in group **A** as shown in Figure 4.38 (a). If one of the parents is heterozygous $\mathbf{I^AI^O}$ and the other parent is homozygous $\mathbf{I^OI^O}$, then children will be in blood groups **A** and **O** as shown in Figure 4.38 (b).

(a) If parents are homozygous **I^AI^A and I^OI^O**, then the resulting offspring in F_1 generation will be:

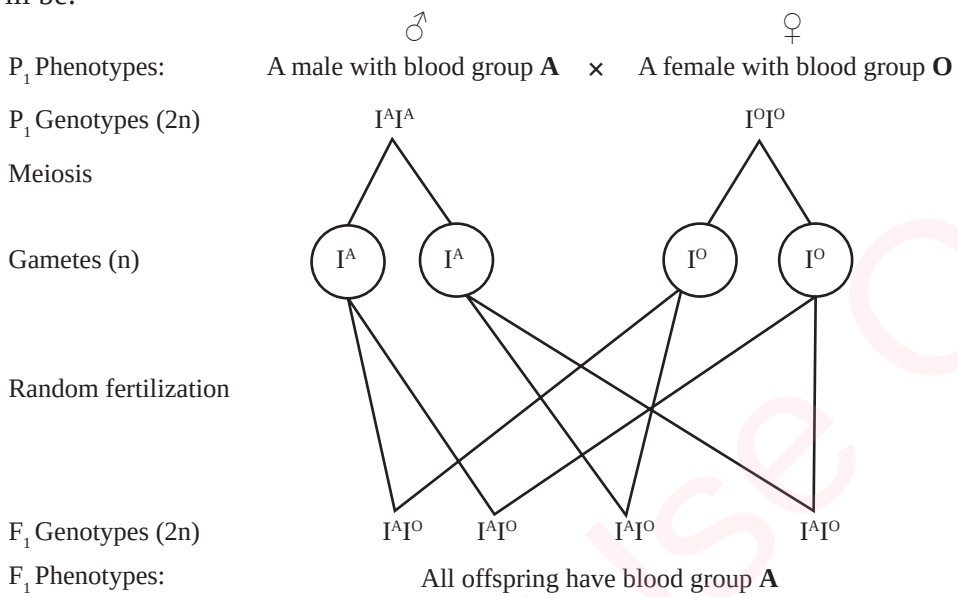


Figure 4.38 (a) Possible children's blood groups when parents of homozygous blood groups **A** and **O** mate

(b) If one of the parents is heterozygous **I^AI^O** and the other is homozygous **I^OI^O**, then the result offspring in F_1 generation will be:

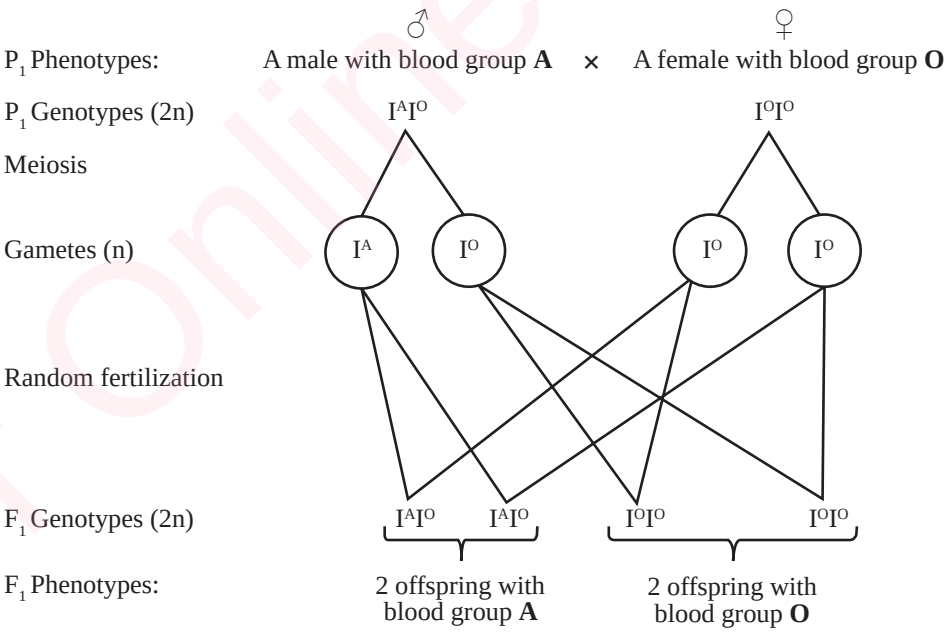


Figure 4.38 (b) Possible children's blood groups when a parent of heterozygous blood group **A** mate with a parent of blood group **O**

From figure 4.38 (b), the resulting offspring in F_1 generation, 50% will have the possibility of inheriting blood group **A** trait while the rest 50% will inherit blood group **O** trait from their parents.

An interesting aspect of multiple alleles is that, it can result in the offspring that differs from both parents. This is seen for example, when an individual of blood group **AB** is crossed with that of group **O**. The children will either be in group **A** or **B**, no any child will be in the same group as the parents. A similar situation is seen, when mating takes place between individuals with blood groups **A** and **B**, both being heterozygous for their blood groups. The children will be in any of the four groups as shown in Figures 4.39 (a) and 4.39 (b).

(a) In the first case, when an individual with blood group **AB** mate with an individual of blood group **O** then, their F_1 offspring will be:

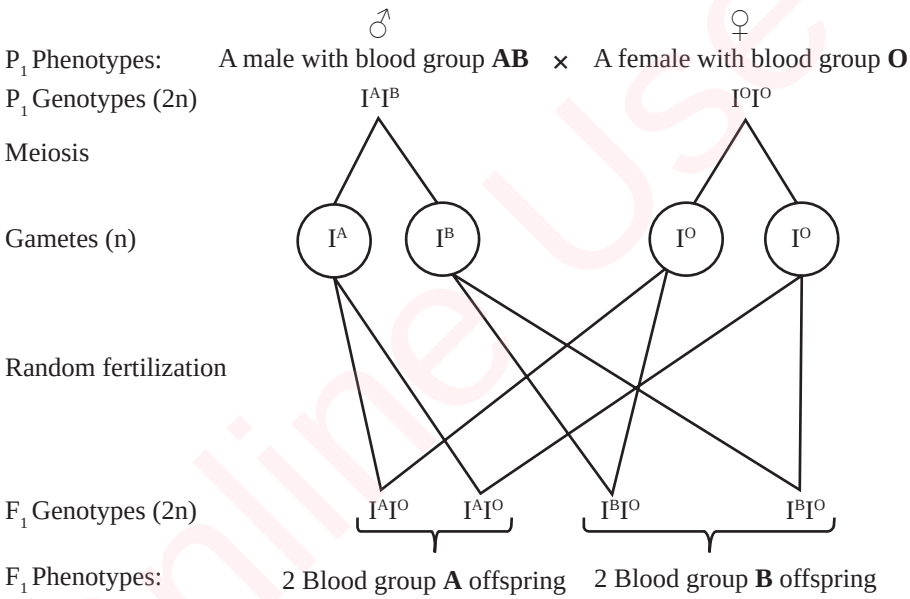


Figure 4.39 (a) Possible children's blood groups when parents of blood groups **AB** and **O** mate

From figure 4.39 (a), the resulting offspring in F_1 generation will have the possibility of inheriting alleles $\mathbf{I^A}$, $\mathbf{I^B}$ and $\mathbf{I^O}$ from their parents, and hence, 50% of them will have blood group **A** and the rest 50% will have blood group **B**.

(b) If two individuals who are heterozygous for their blood groups **A** and **B** mate, their F_1 progenies will be:

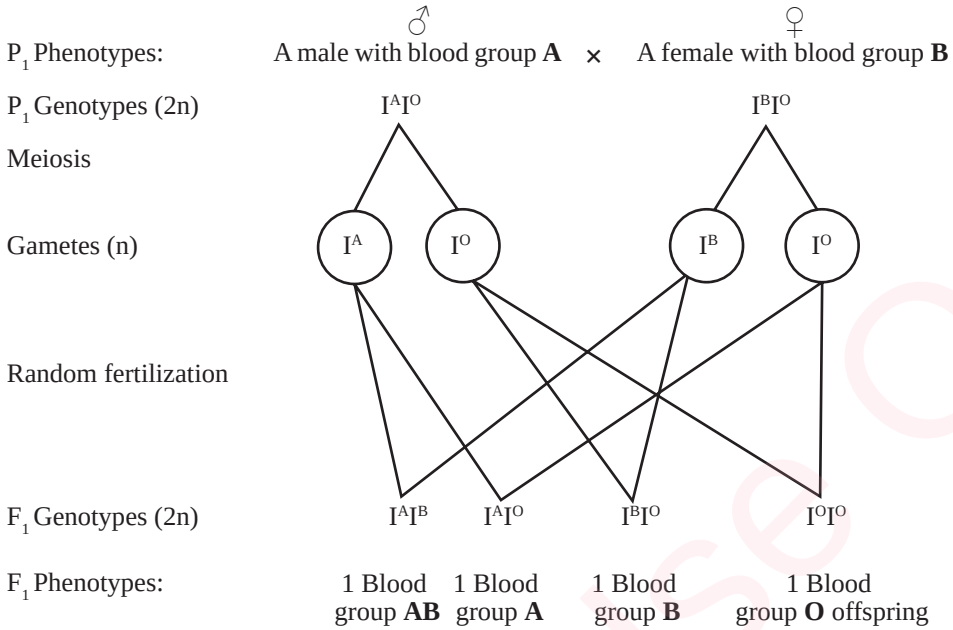


Figure 4.39 (b) Possible children's blood groups when parents of heterozygous blood groups **A** and **B** mate

From figure 4.39 (b), the resulting offspring in F_1 generation will have blood groups **A**, **B, AB** and **O** because their parents were heterozygous for blood groups **A** and **B**.

In line with some other evidences, multiple allelism has been used to solve paternity cases (genetics and the law). For example, it is obvious that a couple of blood group **O** cannot have a child of either blood group **A** or **B**. Likewise, a couple of blood group **AB** cannot have a child of blood group **O**.

Exercise 4.7

1. Yellow guinea pigs when crossed with their white counterparts always produce cream coloured offsprings. Two cream coloured offsprings when crossed produce yellow, cream, and white offsprings in the ratio of 1: 2: 1 respectively. Briefly describe this kind of inheritance and show how these colours are inherited.
2. Amina has a child of blood type **A**. Suppose Amina has been identified to have blood type **O**, what is the likely blood type of the child's father? Show this diagrammatically.
3. Suppose a father of blood type **B** and his wife of blood type **O** have a child of blood type **O**. Carry out crosses to show the chances that their next child will be of blood type **O**, **A**, **B** and **AB**.
4. A man sued his wife on the ground of infidelity. This man and his wife have normal vision, but their daughter is a red-green colour blind. The ruling was given in favour of the wife. Based on your knowledge on genetics explain whether the ruling was fair or not.
5. (a) Discuss haemophilia as a sex-linked genetic disorder.

(b) Explain the characteristics of an individual having this disorder.

(c) Using a pedigree show the possibility of inheritance of haemophilia disorder in a couple where the female is normal carrier of haemophilia trait and the male is normal.

Mutation

Changes in the genetic make-up of organism can arise as a result of changes in the structure, arrangement or amount of DNA of that organism. This is called mutation and can be defined as a sudden change of genetic makeup of an individual. Mutation produces a change in the genotype which may be inherited by cells derived by mitosis or meiosis from the mutant cells. The mutations that occur in somatic (body) cells are not passed from one generation to the next. The mutations which occur in the formation of gametes can be inherited. These mutations produce sudden and distinct differences between individuals. Hence, the basis of genetic variation.

Causes and effects of mutations

Mutations occur randomly and spontaneously, this means that any gene can undergo mutation at any time. The substances that cause mutations are called mutagens or mutagenic agents. They affect either the chemical structure of genes or a gross structure of chromosomes. The mutagens include energetic radiations such as x-rays and ultraviolet lights, high energy particles such as α-particles, β-particles and cosmic particles. Mutation rates are also increased by chemical substances such as mustard gas, caffeine, formaldehyde, some constituents of tobacco, drugs, food preservatives, cosmetics and pesticides.

In rare cases, mistakes that happen during DNA replication result in mutations. Although cells have double checking mechanisms during DNA replication, errors that lead to mutations can still occur.

The results of mutations to living organisms may be beneficial or detrimental. For example, mutations lead to genetic variation, which is necessary for organisms to adapt to the constantly changing environment. Hence, mutations can be a means of evolution. Such mutations are beneficial and they are naturally retained within the population. On the other hand, there are harmful mutations, which result in the death of organisms. In humans, such deleterious or lethal mutations are exemplified by sickle cell anaemia and cancer.

Types of mutation

Mutation can result from a change in the amount or the arrangement of DNA or a change in the structure of DNA at a single locus. This forms the basis of classifying mutations into two categories. These are gene and chromosome mutations.

Gene mutation

A change in the structure of DNA that occurs at a single locus on a chromosome is called gene mutation or point mutation. In the DNA, there is a genetic code, which determines the characteristics of an organism. This genetic code is made up of a specific sequence of nucleotides on the DNA molecule. A change to any of the nucleotides or any rearrangement of the sequence may produce a wrong sequence of amino acids in the synthesised protein. The enzyme which is often a protein, may have a different molecular shape, and hence, unable to catalyse its reaction. This means that the expected end product of that reaction

may not be formed and this may have a serious effect on the organism.

For example, a gene mutation may result in a failure of melanin formation, and hence albinism.

There are various forms of gene mutation, which include the following:

1. **Deletion**: Where a portion of the nucleotide sequence is left out.
2. **Insertion** (**addition**): Where a new nucleotide is inserted in the DNA sequence.
3. **Duplication**: In this case, a portion of the nucleotide chain becomes repeated.
4. **Inversion**: A nucleotide sequence becomes separated from the chain. It re-joins in its original position being inverted. The nucleotide sequence of this portion is therefore reversed.
5. **Substitution**: This occurs when one of the nucleotides is replaced by another which has a different organic base. Such a substitution could change a codon to one that encodes a different amino acid and cause a change in the structure of the protein produced. For example, sickle cell anaemia is caused by a substitution in the β- haemoglobin gene, which alters a single amino acid in the polypeptide chain. Another effect which is caused by base substitution is albinism.

Sickle cell anaemia

This is a disease caused by gene mutation as a result of base substitution. In this case, substitution of a thymine (**T**) with adenine (**A**) in the second position of the triplet codon, replaces an amino acid glutamine with valine. Thus, **CTC** (glutamine) is changed to **CAC** (valine) of β-haemoglobin. This change results in the formation of abnormal haemoglobin denoted as **HbS**, which makes a red blood cell to assume a crescent shape. If this gene is in its homozygous state, $\mathbf{Hb^SHb^S}$, an individual develops a clinical condition called sickle cell anaemia. This disease is characterised by fatigue and anaemia, pain crises, swelling and inflammation of the hands and feet, lungs and heart injury, sudden pooling of blood in the spleen, liver congestion and leg ulcers.

The heterozygous individual $\mathbf{Hb^S\ Hb^A}$ is called a sickle cell trait (carrier). This person has a normal phenotype and is resistant to malaria. Thus, in areas where malaria is a selection pressure, this person has a selective advantage as he/she survives the selection pressure. In genetics, this is called a heterozygous advantage.

When two parents with sickle cell anaemia traits (carriers) mate, 25% of the resulting offspring in F_1 generation will inherit the sickle cell anaemia disorder and dies in the early stages of life as elaborated in Figure 4.40.

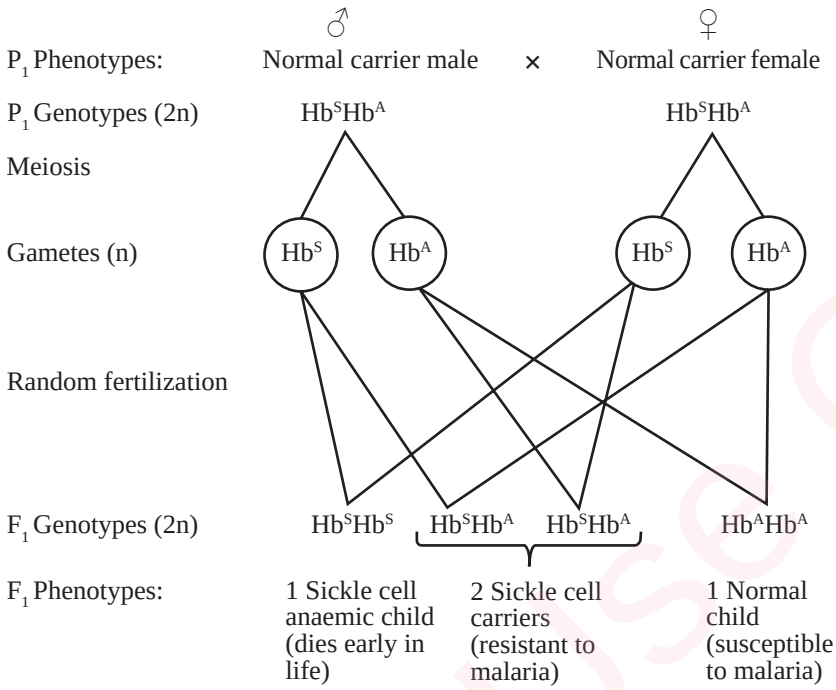


Figure 4.40 The possible sickle celled children from two parents who have sickle cell traits

Albinism

Albinism is an autosomal defect that is caused by a recessive gene, which is transmitted in a normal Mendelian fashion. The gene for albinism is a mutant one, resulting from the substitution of nucleotides. An individual with albinism fails to develop an enzyme tyrosinase, which is responsible for the conversion of amino acid tyrosine into melanin. Thus, albinism is characterised by a lack of melanin, which affects the skin, hair and eye colour. Due to lack of this pigment, an albino has high risks of skin cancer that is caused by sunburn. This genetic disease is also associated with vision problems such as crossed eyes, photophobia, involuntary rapid eye movements, impaired vision or blindness and astigmatism.

The allele for albinism is denoted as **a**, and therefore, homozygous **aa** is an albino. On the other hand, the allele for normal skin is **A**, and therefore, the genotypes **AA** and **Aa** means the normal skinned person. A cross between two heterozygous normal skinned parents produces normal and albino offspring in the ratio of 3:1 as shown in Figure 4.41.

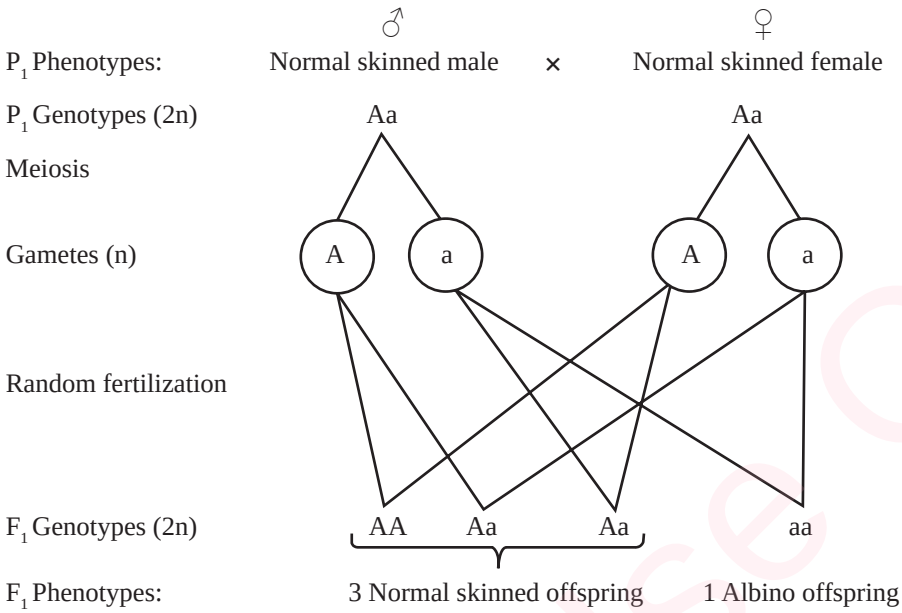


Figure 4.41 The possible inheritance of albinism in F_1 offspring as a result of a cross between heterozygous normal skinned parents

Chromosome mutations

Chromosome mutation is the one that results from a change in the number and structure of chromosomes. This type of mutation, which is also known as chromosome aberration produces effects that are easily noticed in mutant organisms. Chromosome mutation may result from either of the following:

(a) Changes in chromosome structure

Normally pairs of homologous chromosomes form chiasmata during meiosis I. It is at these points where chromatids break and re-join with the corresponding portion of chromatid on its homologous partner. During this process, mistakes arise though not frequently. The mistakes may be due to one of the following processes as summarised in Figure 4.42.

(i) **Deletion**: In this case, a chromosome may break at two points and the section between may drop out taking all its genes with it. The two ends then join up giving a shorter chromosome with a junk missing in the middle. Since this involves a loss of genes, it can have a significant effect on the organism's development, and it is often lethal.

(ii) **Inversion**: This occurs if the region of a chromosome breaks off and rotates through 180º before it re-joins the chromosome. The sequence of genes on this portion is therefore reversed and may alter the phenotype. This indicates that the sequence of genes on the chromosome is important. This phenomenon is known as position effect.

(iii) **Translocation**: This occurs when a portion of the chromosome becomes deleted and re-joins at a different point on the same chromosome or

with a different chromosome. This type of chromosome aberration may also produce position effect in the phenotype.

(iv) **Duplication**: In this case, a portion of the chromosome is doubled, resulting in the repetition of a gene sequence. This mutation results from unequal crossing over between misaligned homologous chromosomes during meiosis.

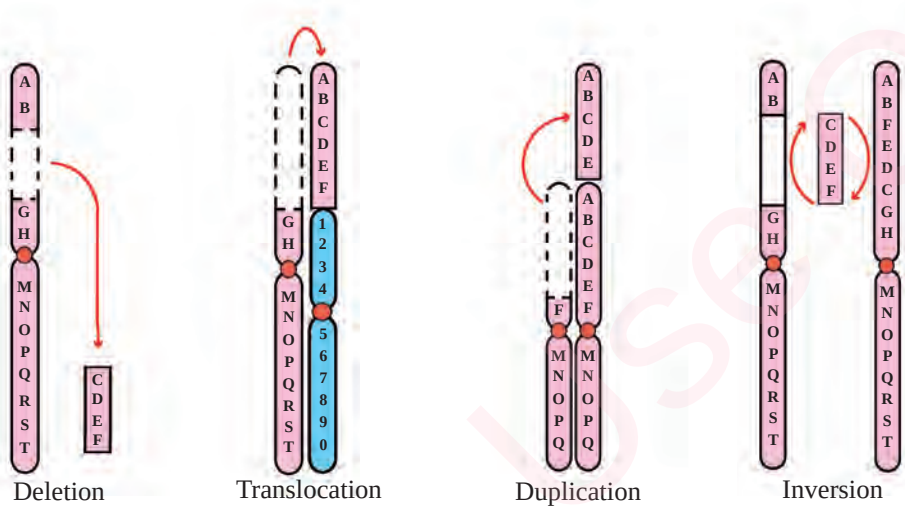


Figure 4.42 Illustration of four types of chromosome mutations

(b) Changes in the chromosome number

Changes in the number of chromosomes are usually the result of errors occurring during meiosis, but they can also occur during mitosis. These changes may involve a loss or gain of single chromosomes, a condition called aneuploidy or an increase of the entire haploid sets of chromosomes, a condition called euploidy or polyploidy.

Aneuploidy

This is a condition in which half of the daughter cells produced have an extra chromosome, for example, n + 1 or 2n + 1 and the other half have a chromosome missing, n - 1 or 2n - 1. Aneuploidy can arise from the failure of a pair or pairs of homologous chromosomes to separate during anaphase I of meiosis. The result of this is the movement of both sets of chromosomes to the same pole of the cell. The separation of homologous chromosomes during anaphase II may lead to the formation of gametic cells containing either more or less than the normal number of chromosomes. This condition is known as non-disjunction. The fusion of either of these gametes with a normal haploid gamete produces a zygote with an odd number of chromosomes. If the number is less than the diploid chromosomes, the zygote may not develop. However, those with extra chromosomes may develop although the organisms resulting from these zygotes have a number of abnormalities. In human beings, the genetic disorders found in such zygotes include Down's syndrome, Klinefelter's syndrome and Turner's syndrome.

Down's syndrome

Down's syndrome or mongolism is a genetic disorder that occurs when chromosome 21 fails to segregate during cell division, thus the gamete produced possesses 24 chromosomes. The fusion of this gamete with a normal one having 23 chromosomes, results in the offspring having 47 (2n+1) chromosomes. The 21st chromosome is relatively small and the offspring is, therefore, able to survive.

Down's syndrome children have disabilities of varying magnitude. They have a flat, broad face, severe mental retardation, short stature and relatively small skull due to poor skeletal development, protruding tongue, poor immune system and hence high risks of infection. They have low intelligent quotient (IQ) and short life expectancy. Non-disjunction in the case of Down's syndrome seems to occur during the production of ova rather than sperm. Its incidence is related to the age of the mother and therefore, the chances of having Down's syndrome child increase as the mother's age increases. At teen age, the chances are only one in many thousands, at the age of 40 years, the chance is one in a hundred and at the age of 45 the risk is three times greater. The age of the father has no effect.

Klinefelter's syndrome

This is a non-disjunction of the sex chromosomes, which may occur in meiosis during spermatogenesis in male parents or oogenesis in female parents. This genetic disorder is due to an extra **X** chromosome and the genotype is **XXY** instead of normal **XY**. The number of chromosomes is, therefore, 47 (2n+1) instead of 46 (2n).

The Klinefelter's syndrome victim is phenotypically a male, but the presence of an extra **X** chromosome may result in the development of feminine features. Generally, the person is sterile, sperms are never produced although he can erect and ejaculate. He is taller than average, breasts may develop, testes are very small and has little facial hair. Other features include a high-pitched voice, smooth skin texture, and low intelligence.

Turner's syndrome

This genetic disorder is due to a missing **X** chromosome in females. The genotype is, therefore, **XO** instead of the normal **XX** and the number of chromosomes is 45 (2n-1) instead of 46 (2n). Turner's syndrome can arise as a result of non-disjunction during meiosis. The sufferers of this disorder have short stature, averaging 1.5 m, small uterus, infertile with no ovaries and they lack secondary sexual features.

Exercise 4.8

1. (a) What are lethal genes?

   (b) Referring to the inheritance of fur colour in mice, show how the Mendelian 3:1 ratio is modified to 2:1.

2. Mr. Mkulima had a task of breeding rats for his research on plague disease. He had two varieties, black and red coloured rats whose genes are independent. In his first cross, a homozygous black solid rat was crossed with homozygous red spotted one. In the second cross, one of the F_1 progenies was crossed with a red solid rat of unknown percentage and the F_2 phenotypes were in the following proportions:

48 black solid rats.
49 red solid rats.
24 black spotted rats.
25 red spotted rats.

(a) Give the interpretation of these results.
(b) Identify the genotypes of the animals that gave rise to F_1 and F_2 generations.
(c) What modification to Mendel's work has been shown by Mr. Mkulima's experiment? Explain it.

3. Mzalendo is a form four student with blood group **A**. She recently had a baby whose father, according to her was her school's chief cook called Mchuuzi. The latter denied paternity. The case was taken to court where the following facts were established: Mzalendo has blood type **A**, the child has blood type **O**, and Mchuuzi has blood type **B**. Based on this evidence only, explain whether the law will incriminate or exonerate Mchuuzi.

4. Write short notes on mutation based on the following guidelines:
   (a) Causes and effects.
   (b) Types of mutation.

5. Hitimu and her brother Chaguzi have their elder brother who is haemophiliac. Hitimu and Chaguzi and their parents appear normal but the two children are worried about having haemophiliac children in future. If they approach you for help, what would you advise them?

6. Briefly describe the effect of mutagenic agents to the hereditary materials.

Genetic engineering (GE)

Genetic engineering or genetic modification is a deliberate alteration of the characteristics of an organism by manipulating its genetic materials in order to reduce undesirable characteristics or to produce desirable new ones. It is the biological technique in which genes of interest are isolated, modified, and inserted into an organism for the purpose of producing desirable traits. This technique is made possible by a recombinant DNA technology. When gene transfer occurs, the resulting organism is called a transgenic organism or a genetically modified organism (GMO).

Recombinant DNA technology is the procedure by which DNA from different species can be isolated, cut, and connected together. Thereafter, a new recombinant DNA is multiplied in quantity in the populations of rapidly dividing cells such as bacteria. The recombinant DNA is, therefore, a combination of DNA from different organisms or different locations in a given genome that would not normally be found in nature. The terms gene cloning, recombinant DNA technology and genetic engineering may seem similar but they are different techniques and are interrelated in biotechnology. An example of genetic engineering and gene cloning is shown in Figure 4.43.

Gene cloning

The process of gene cloning involves various steps as follows:

(i) The target gene is isolated and cut out using a restriction enzyme.
(ii) The bacteria plasmid is cut open using the same enzyme.
(iii) DNA ligase binds the target gene into the plasmid.

(iv) The resulting plasmid is known as a recombinant plasmid. This is inserted into the bacteria by a process known as transformation.

(v) The bacteria are then placed in a growth reactor, which provides the optimal growth condition allowing them to replicate many times. Finally, the bacteria are cut open; and the plasmid is extracted.

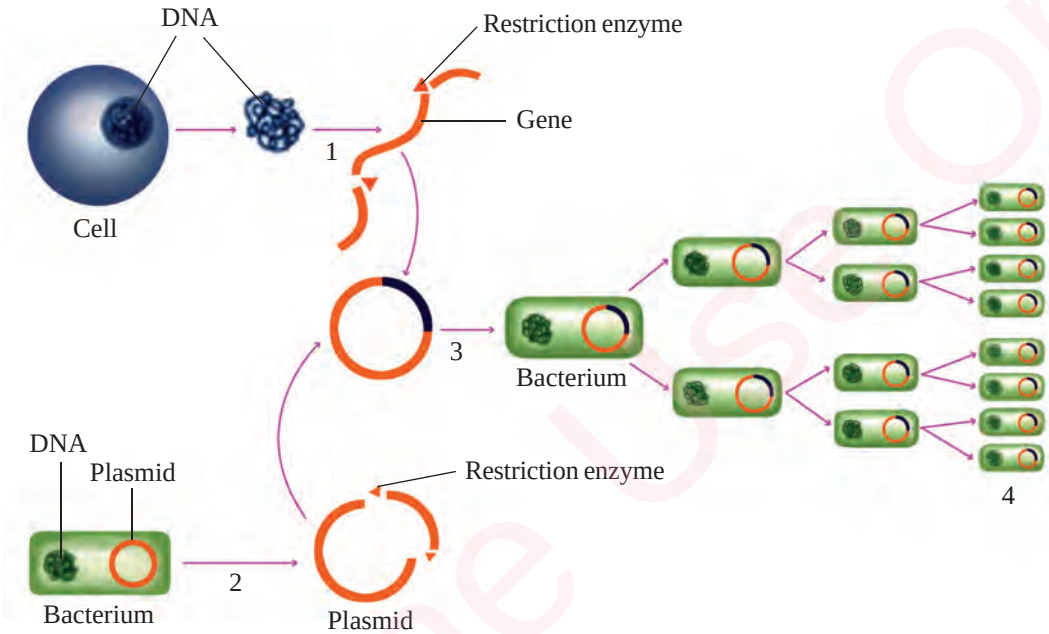


Figure 4.43 Diagram of genetic engineering and gene cloning

The process of genetic engineering has been applied in various fields. Examples of such fields include agriculture, food industries, medical products and treatment of environmental wastes. In connection with its application, genetic engineering has a number of advantages. For example, it is used to synthesize hormones such as human growth hormones, and insulin, which is used to help diabetic patients to control sugar level in the blood. Other hormones synthesised include erythropoietin, which control the production of red blood cells, and calcitonin, which regulates the level of calcium in the blood. This process also helps in the production of vaccines and antibiotics. For example, Hepatitis B vaccine, and penicillin are produced by genetic engineering. In the agricultural fields, genetic engineering improves plants' resistance to pests, improves the quality of food, and increases the yield of food crops. Plants can be made resistant to herbicides and tolerant to environmental stress such as drought. Animal products such as meat, milk and eggs may have their qualities improved by the use of genetic engineering.

Despite its advantages, genetic engineering has a number of disadvantages. Firstly, it

may make organisms more resistant to antibiotics. The vectors, which are used in transforming plant cells, contain genes for antibiotic resistance. These genes enter the transformed plant with the desired gene. Genetically modified tomatoes contain one of these antibiotic resistance genes. The concern is that, when the tomato is eaten, the gene may pass from the tomato to the *Escherichia coli* bacteria in the gut making them resistant to antibiotics. The gene may spread to other potentially harmful bacteria in the environment, and if they infect humans, they would be difficult to treat. Secondly, genetic engineering can compromise issues on ethics and morality, particularly, in religion. This is because human beings now have the ability to influence the course and law of nature. This is against some people who believe that, the ability to influence anything on earth is upon God only.

Thirdly, modification of naturally selected food crops may disturb the delicate balance of the naturally existing biodiversity. Moreover, genetic engineering may lead to disappearance of local varieties of crops. This is because, highly resistant genetically modified plants and animals have the potential of replacing local varieties. This will in the end affect the economy of people depending on these valuable products. Lastly, genetic engineering may be misused in producing genetically modified microorganisms for use as biological weapons.

Revision questions

1. Explain diagrammatically how cross-breeding of an individual that presents a dominant phenotype with another that presents a recessive phenotype (for the same trait) can determine whether the dominant individual is homozygous or heterozygous.
2. Explain the concept of genetic engineering, its applications, advantages and disadvantages.
3. (a) Define the term transcription.

   (b) If the base sequence in one of the DNA strands is AGCTAAGACTTCCAACT:

   (i) What will be the base sequence in the complementary mRNA strand formed from this DNA strand?

   (ii) State the number of amino acid molecules that are defined by the given sequence of bases in the DNA strand.

   (iii) Describe how the mRNA strand in (i) above, is formed from the given DNA strand.
4. Write brief notes on each of the following terms:
   (a) Okazaki fragments.
   (b) Replication fork.
   (c) DNA ligase.
   (d) RNA primer.
5. Explain the role of each of the following in protein synthesis:
   (a) DNA template.
   (b) RNA.
   (c) Ribosomes.
   (d) Aminoacyl-tRNA synthetase.
6. A geneticist who was verifying Mendel's laws crossed 20 homozygous

white Andalusian fowls with 20 black Andalusian fowls. The results of F_1 was 450 fowls, all with blue plumage colour. He then selfed the 450 F_1 fowls and obtained the F_2 offspring with the following phenotypes:

1292 white coloured fowl.

2570 mixed blue and black coloured fowl.

(a) Illustrate using symbols, the crosses which were made and the results obtained in the crosses described above.
(b) What is the name given to the mode of inheritance described in this experiment?
(c) How do the above observations differ from the result of Mendel work, which led him to formulate his laws of inheritance?
(d) Briefly describe a genetic test that you would carry out to prove whether or not the appearance of the blue coloured feathers in this experiment is a true deviation from Mendel's principles of inheritance.

7. Why is it not possible to use a homozygous dominant organism such as **RR** in a test cross experiment to determine the genotype of an organism showing dominant phenotype? Illustrate your answer using appropriate genetic symbols.

8. With the aid of a cross in each case, explain the following genetic disorders:

(a) Sickle cell anaemia.
(b) Albinism.

9. In corn, the trait for tall plants (**T**) is dominant to the trait of the dwarf plant (**t**) and the trait of the coloured kernels (**C**) is dominant to the trait of the white kernels (**c**). In a particular cross of corn plants, the probability of an offspring being tall is 0.5 and the probability of kernel being coloured is 0.75. Work out the parental genotypes. Show how you derive your answer.

10. Describe the set-up of Mendel's dihybrid experiment which led him to successfully formulate his second law of inheritance.

11. Use genetic crosses to show how complementary genes interaction differ from dominant epistatic gene interactions.

12. Discuss the sex determination process in (a) Humans and (b) Birds.

13. Polydactylism is the condition of having an extra finger on each hand. In humans, this condition is dominant to the typical 5-finger arrangement. Tongue rolling, on the other hand, is dominant to not being able to roll one's tongue. A man who is homozygous for 5-fingers and who cannot roll his tongue has children with a woman who is heterozygous for polydactylism and tongue rolling.

(a) Draw a Punnett square that represents the cross.

(b) What is the probability that the couple will produce a polydactyl baby who cannot roll his/her tongue?

14. What is polygenic inheritance? Using a Punnett square show how it operates in the inherritance of skin colour in human.

15. Skin colour in humans is determined by a polygenic inheritance fashion,

involving as many as 9 different genes. For the purpose of this question, let us consider the influence of 3 genes: **A**, **B** and **C**, where the dominant allele darkens skin colour. Suppose a woman who is **AABbCc** mates with a man who is **AaBbcc**.

(a) List all of the possible genotypes of the gametes that could be produced by each of the parents.

(b) Draw a Punnett square to show the possible genotypes and number each genotype from lightest to darkest skin coloration.

(c) How many dominant alleles will children with the darkest skin coloration possess, and state the theoretical fraction of the children that will have this coloration.

16. A small part of a DNA molecule contains the sequence of nucleotides **GAA GTA CCA** on one of the strands.

    (a) Sketch this part of the DNA molecule showing both strands.

    (b) What would be the mRNA nucleotide sequence formed from this strand?

    (c) What are the amino acids coded for by this small part of DNA?

17. Differentiate between epistatic and collaborative gene interactions.

Chapter
Five

Evolution

Introduction

Evolution is defined as a process of gradual changes in the heritable characteristics of biological populations over successive generations. Studying about evolution helps one to understand the origin of life, changes over time, and mechanisms which resulted into these changes. In this chapter, you will learn about theories of origin of life and theories of the organic evolution. You will also learn about evidences of organic evolution, including comparative morphology, anatomy, biochemistry, and biogeoraphy. Furthermore, you will learn about the processes of selective breeding, and speciation as well as their contribution in evolution of species.

Theories of origin of life

Several attempts have been made from time to time to explain the origin of life on earth. As a result, there are several theories that give an explanation on the possible mechanism of the origin of life. The following are some of these theories.

Special creation theory

This theory states that, the earth and all organisms living on it were created by God. This belief is found in scriptures of most of the major religions in the world and it is also the most widely accepted theory. For example, Hinduism mythology states that, "The God of Creation, created the living world in accordance with his wish". In Christianity, it is believed that, "God created this universe, plants, animals and human beings in six natural days". In Islamic studies, it has been stated that,"God created heavens and the earth in six distinct periods and Adam from a sounding clay". Special creation theory holds that there were no significant changes on the earth since its creation and that, species once created, remained unchanged.

Strengths and weaknesses of the special creation theory

The theory opened up the minds of scientists to speculate on the origin of life on earth. However, since the process of special creation occurred only once, therefore, it cannot be observed. This is sufficient to put the concept of special creation out of the framework of scientific investigation. Science concerns itself only with observable phenomena and as such, it will never be able to prove or disprove special creation theory. Moreover, it is not true that, species were created in the form in which they exist today and that, they are not capable

of undergoing any change. Species never remain unchanged, they rather change from time to time and in accordance with the environment in which they live. On top of that, the special creation theory disobeys the law of biogenesis as it stresses that, life can arise from a word or from nothing provided that there is God's will. According to the law of biogenesis, life originates from the existing life.

Spontaneous generation theory

This theory assumes that, living things arose from non-living materials on a number of distinct occasions by a process of spontaneous generation. Most scientists tentatively accepted the theory of spontaneous generation in which life was believed to evolve from lifeless matter. The main idea in this theory is that, life comes from lifeless in favourable conditions and that no causal agent such as a parent is needed. Such a hypothetical process by which life routinely emerges from non-living matter over specific periods of time is known as abiogenesis, which means life comes from non-living things.

The Greek philosopher Aristotle believed that, dead leaves falling from a tree into a pond would transform into fishes and those falling on the soil would transform into worms and insects. He also held that, some insects developed from morning dew and rotting manure. Egyptians, on the other hand, believed that, mud of the Nile river could spontaneously give rise to many forms of life.

Aristotle postulated that certain particles of matter contained active principles, which co uld produce living organisms under favourable conditions. The active principles were in fertilized eggs, seeds, sunlight, wheat, decaying meat and mud.

The idea of spontaneous generation was popular almost till the seventeenth century. Many scientists such as Descartes, Galileo, and Helmont supported this idea. In fact, Von Helmont went to the extent of designing an experiment that gave rise to mice in three weeks. In his experiment, he put a dirty cloth in dark cupboard with a handful of wheat grains. He believed that the active principle was human sweat.

The theory of spontaneous generation was disproved in the course of time following the experiments conducted by Fransesco Redi (1668), Lazzaro Spallanzani (1765) and later Louis Pasteur (1860) in his famous Swan neck experiment. A series of experiments which were conducted by these scientists, proved that, no life could emerge from a non–living matter. They came out with the theory of biogenesis, which states that, "Living things only come from other living things through reproduction".

Strengths and weaknesses of the spontaneous generation theory

The theory is scientific since it can be subjected to experimental proof and scientific research. It also offers the mechanisms to argue on how life arose on the earth. However, by assuming that life arose from non-living matter, the theory of spontaneous generation violates the law of biogenesis. According to this law, life arises from the pre-existing life.

Activity 5.1 An investigation of the origin of life based on the theory of spontaneous generation

Materials: Two test tubes, test tube rack, pieces of fresh meat, cotton wool, tap water, source of heat, 1000 ml or 500 ml beaker.

Procedure

(i) Boil 500 ml of water in a beaker.

(ii) Sterilize one test tube by bathing it in boiling water.

(iii) Label two test tubes. One of the test tubes should be the one you have sterilized in step (ii) above.

(iv) In each test tube place a piece of fresh meat.

(v) Plug tightly the sterilised test tube using cotton wool. Leave the second test tube unplugged.

(vi) Place both test tubes on a test tube rack for five days.

(vii) Record your observations daily.

Results: After 5 days, white maggots which are the larva of houseflies will start to emerge from the unplugged test tube.

Question: Based on your results, are the assumptions of the spontaneous generation theory correct? Explain.

Cosmozoic theory

According to this theory, life could have arisen once or several times in various parts of the universe. This means that life did not originate on the earth, rather, it originated somewhere in the galaxy and it was brought on the earth planet as a ready-made material. This theory was proposed by Ritcher (1865) who came out with the assumption that life reached the earth in the form of spores, germs or other simple particles from some unknown parts of the universe. It came with the Cosmic dust and subsequently evolved into various forms of life. In 1884, Helmholz speculated that life in some forms reached the earth with falling meteorites. Arrhenius (1908) postulated the panspermia theory, which states that organisms existed throughout the universe and their spores could freely travel through space from one star to the others.

Some observations have been used to show how life could have arrived on the earth from elsewhere. For example, repeated sightings of unidentified flying objects (UFOs), cave drawings of rocket like objects and "spacemen" and reports of encounters with aliens, provide evidence of the arrival of life on the earth from elsewhere. In 1996, NASA scientists in the USA identified what they thought could be the remains of bacteria like organisms in a rock from Mars.

Strengths and weaknesses of the cosmozoic theory

According to this theory, life is truly supported on earth. However, the claim that life crossed the space before reaching the earth may not be true because the living matter cannot survive the extreme cold, dryness and ultraviolet radiations of the sun. Moreover, the theory does not tell the origin of life, and therefore, it does not deserve to be called the theory of the origin of life. Furthermore, the theory does not clearly explain the mechanism through which life was brought onto to the earth. Lastly, the theory cannot be tested experimentally or scientifically.

Steady-state theory

According to the steady-state theory, the earth had no origin. It has always been able to support life and it has undergone

remarkable slight changes. The theory also asserts that life had no origin and it is supported on the earth. Thus, the living organisms had no origin, they always change their numbers by increasing or decreasing or they become extinct. The theory is against the evidence from fossil studies that the presence or the absence of dead remains can indicate the origin or the extinction of the species.

Strengths and weaknesses of the steady-state theory

The argument that the origin of species cannot be assumed through fossil records is true. It is also true that the earth undergoes slight changes through which it supports life. However, the assumption that life had no origin is not true. This is against the law of biogenesis, which indicates that life arises from already existed life. Lastly, if the species had no origin as this theory claims, then the origin of life on earth cannot be tested experimentally.

Biochemical evolution or naturalistic theory

The modern concept about the origin of life on the earth is called a physiochemical or materialistic theory. This theory state that, "Life arose on the earth according to physical and chemical laws". This means that, the cooling of the primordial earth favoured the reactions among the gaseous constituents of the early atmosphere such as carbon, hydrogen, nitrogen, and oxygen. The reactions then gave rise to the formation of simple organic compounds such as amino acids and sugars. Later, the nucleotides and nucleic acids that are the main components of all living cells, were formed. This marked the beginning of life. Assuming the conditions and components of the early, primitive atmosphere, experimental proof of the assumptions of this theory, have been carried out. For example, when a mixture of methane, ammonia, hydrogen and water vapour is heated at very high temperature and pressure, chemical constituents react to produce amino acids, fatty acids, nitrogenous bases, that is purines and pyrimidines.

A Russian scientist, Alexander Oparin (1923) suggested that, the atmosphere of the primitive earth was different from the one we have today. According to Oparin, life must have come into existence as a result of chemical evolution which took place on the primordial earth under favourable conditions of temperature and pressure. The earth is said to have originated as a hot gaseous mass some five billion years ago. The atmosphere of the early earth contained hydrogen, oxygen, nitrogen and carbon elements. Since the early earth was very hot (4000 to 9000 ^{o}C), the high temperature did not allow the formation of chemical bonds between those elements, and therefore, they existed as atoms. When the earth started cooling, the chemical bonds were formed between the atoms and the molecules were formed. Hydrogen being active and abundant, readily combined with other atoms to form compounds like methane (CH_4), water (H_2O), ammonia (NH_3) and hydrogen cyanide (HCN). In the early atmosphere, there was no free molecular oxygen, and therefore, the earth had a reduced atmosphere.

As the temperature of the earth cooled down further, water vapour condensed into liquid and very heavy rains, which were accompanied by violent bursts of lighting began. This resulted in the formation of lakes, rivers and great oceans on the earth's surface. The rain water dissolved some

of the atmospheric compounds such as methane, ammonia, and carbon dioxide. The running water contained dissolved mineral salts of rocks. There were high energy ultraviolet radiations from the sun, radiating heat from the earth's centre and frequent electrical charges in the form of lighting. Thus, the availability of simple compounds, reduced atmosphere, sterile environment, water and energy were responsible for the formation of simple organic compounds on the primordial earth.

The earliest organic compounds that were formed were sugars, fatty acids, glycerol, formaldehyde, amino acids, purines, and pyrimidines. The simple organic compounds underwent various reactions to form complex organic compounds such as lipids, polysaccharides, proteins, nucleotides, and nucleic acids. The formed protein molecules were crucial to the transformation of inanimate to animate. Because of the zwitterionic nature of protein molecules, they were able to form colloidal hydrophilic complexes. As a result, these complexes became surrounded by thin layers of water molecules. These bodies may separate from the body of the liquid in which they are suspended and form a type of emulsion. These structures, then joined together to produce a separation of colloids from their aqueous phase. This process is called coacervation. The formed colloid-rich coacervates may have undergone various chemical reactions and, by absorbing metal ions, enzymes were formed. Thus, different processes such as incorporation of the pre-existing molecule, which are capable of self-replication into the coacervate, and internal rearrangement of the lipid-coated coacervate may have produced a primitive type of cell. Through a series of physical and physiological processes, the primitive cell would have been transformed into a primitive self-replicating heterotrophic organism feeding on organic substances that are found in its medium such as water body.

Strengths and weaknesses of the biochemical evolution theory

Biochemical evolution theory is scientific and therefore, it can be experimentally tested. The theory also recognises the role of amino acids and proteins in forming the basis of life. Lastly, this theory encourages critical thinking and thus enhances the development of inquisitive mind. However, biochemical evolution theory fails to explain the transition from complex organic molecules to living organisms.

Exercise 5.1

1. What do you understand by the following terms:
   (a) Cosmology.
   (b) Abiogenesis.
2. Account for the concept, strengths and weaknesses of the following theories of the origin of life on the earth:
   (a) Special creation theory.
   (b) Spontaneous generation theory.
3. Explain why the cosmozoic theory does not deserve to be termed as a theory of the origin of life on the earth.
4. (a) State the steady-state theory.
   (b) How do you link the theory of steady-state to fossil studies?
5. (a) State biochemical theory of the origin of life.
   (b) Discuss the main ideas in biochemical evolution theory.

Theories of organic evolution

Regardless of the means by which they come into existence, scientists have observed that, organisms undergo gradual changes in their body structures, functions and efficiency. How these changes occur, the causes and effects of these changes on the genetic makeup of living organisms have been the subject of interest to scientists. Different scientists have offered explanations on the causes, mechanisms and effects of the gradual changes in the form and functions of the bodies of living organisms.

The concept of organic evolution

Organic evolution is the gradual change in structure and physiology of living organisms over a long period of time. It is a slow change in genetic composition of organisms in a population through successive generations, leading to the formation of new species from the pre-existing ones. Generally, organic evolution is characterised by a gradual change of organisms from simple or primitive to complex or advanced forms. This occurs in order to enable organisms to adapt to the changing environment as directed by the environmental needs.

There are different theories that explain the mechanism by which organic evolution operates. These include Lamarck's theory, Darwin's theory and the modern theory or Neo-Darwinian theory.

Lamarck's theory of evolution

Jean Baptiste de Lamarck was a french biologist who lived between 1744 to 1829 years. In 1809, he proposed a theory to account for the mechanism of evolution based on two conditions, which were the use and disuse of organism's parts and the inheritance of acquired characters. According to Lamarck, the environment creates the need that may lead to a changed pattern of behaviour of an organism. This change can lead to either use or disuse of certain body parts or structures. The more the body part is used, the stronger and the more efficient it becomes and vice versa. That is, if the body part is less or not used, it gradually degenerates and disappears. The new traits acquired as a result of the constant use of the body parts become part of heredity and can be transmitted to the next generation. This concept of inheritance of acquired characters states that,"Characteristics that individuals acquire during their lifetime as they adapt to their environment, become part of their genetic makeup and are thus handled down from one generation to another". In an attempt to illustrate his theory, Lamarck gave several examples, as elaborated in the following subsections.

(a) Development of long neck and legs of modern giraffe

According to Lamarck, ancestral giraffes had short necks and front legs. They lived in plains and fed on grasses. When the environmental conditions changed, grasses were not available (environmental need). This forced giraffes to feed on the leaves of tall trees. Thus, for the animals to reach the leaves, they had to stretch the muscles of their necks and front legs. The continuous stretching of front legs and neck muscles resulted in slightly longer necks and legs in each generation until the size of the present day giraffe was reached. This means that, the acquired new length of the two organs, neck and legs was inherited from one generation to another until the modern giraffe emerged as shown in Figure 5.1.

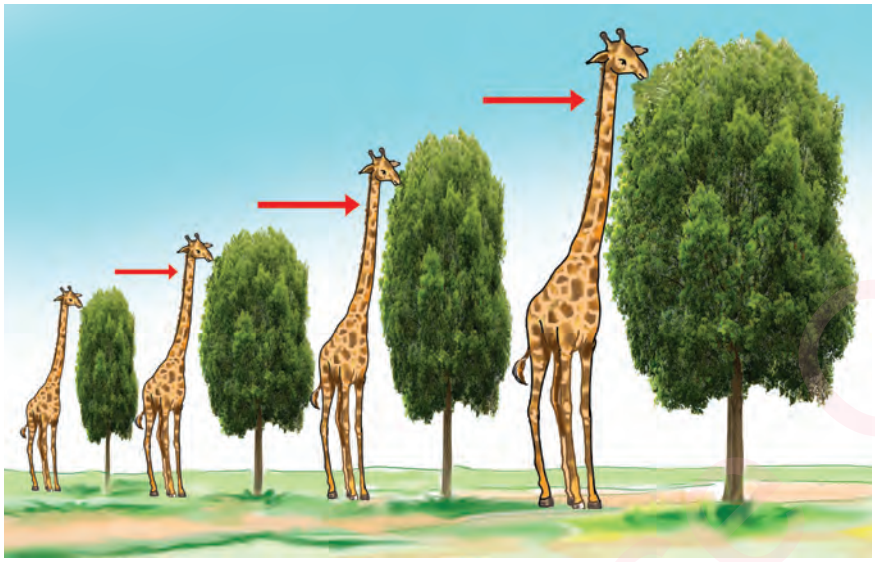


Figure 5.1 Demonstration of Lamarckism on inheritance of acquired characteristics

(b) Development of webbed feet in ducks or aquatic birds

According to Lamarck, the constant spreading of the toe bones and the skin between them in order to swim in search for food or escape predators, gave rise to the webbed feet in aquatic birds. This occured when food became scarse on the land, so ducks were forced to search food in the water. The ducks tried to stretch their toes to achieve maximum and efficient swimming. As a result the skin between their toes became stretched to form webbed feet. This acquired characteristic was inherited throughout generations. This means that, originally ducks had their feet adapted for walking and looking for food on the land.

(c) Development of flat shaped fish

Lamarck believed that, previously fish had a variety of shapes for enabling them to lie on shallow waters. When food became scarce in shallow waters, fish were forced to start searching food in deep waters. As a result, their body started to change and became flat shaped for maximum and efficient swimming in deep waters.

Strengths and weaknesses of Lamarck's theory

Lamarck's work stimulated and opened up the minds of scientists to think, study and debate on the causes and effects of organic evolution. Furthermore, in his theory, Lamarck recognised the role of environment in evolution. For example, the environment plays an important role in producing a phenotypic change of an organism as in case of body building exercises, which increase the size and strength of the body muscles. Despite these achievements, Lamarck's theory had various weaknesses.

First, it is not true that the use or disuse of the body parts or structures can determine their existence or atrophy. Second, the acquired traits only affect the phenotype and therefore, are non- genetic. Since they have no influence on the genotype, they cannot be inherited from one generation to another. To demonstrate this, Weismann cut

off the tails of mice over many successive generations. According to Lamarck, the enforced disuse of tails would lead to progeny with small tails. This was not the case, and therefore, Weismann postulated that somatic (body) acquired characteristics (resulting in phenotypic changes) did not directly affect the germ (gamete) cells. Thus, they could not be passed on to the next generation or inherited.

Darwin's theory of evolution

Charles Darwin developed the theory of evolution based on the concept of natural selection. In 1831, he accepted an unpaid post on the survey ship called HMS *Beagle,* which spent five years at sea charting the east coast of south America. During his five-year voyage, he made several observations and collected various specimens of plants and animals. More importantly, he stayed five weeks on the Galapago's Islands where he was struck by the similarities shown by the plants and animals of the Islands and mainland. In particular, he was interested in the characteristics and distribution of species of tortoises and finches. Darwin collected enough biological data about variations between organisms. Through these data, Darwin was convinced that species always change through time in order to adapt their environment. On his return home, his work on selective breeding of different domestic animals opened up his mind to the concept of artificial selection. He continued to organise his work based on these data, specimens and experience gained during the trip. In November 1859, Darwin published his theory in the form of a booklet entitled "Origin of Species by Means of Natural Selection". Similar observations were made by Alfred Russel Wallace, hence, a new theory was published by the name of Darwin-Wallace theory. This is known as the theory of Natural selection.

Natural selection

Natural selection is a mechanism by which organisms that are better adapted to their environment survive and breed, while the less adapted fail to survive. The better-adapted organisms are more likely to pass their characteristics to the succeeding generations. Thus, species tend to change from one generation to the next as they adapt to a new environment. Darwin and Wallace, therefore, proposed natural selection as a mechanism by which new species arise from the pre-existing species. The Darwin-Wallace theory of natural selection is based on three observations and two deductions (conclusions) which are summarised as follows:-

Observation 1: Overproduction of the offspring or enormous fertility power

Darwin and Wallace observed that individuals within a population tend to reproduce more than the environment can support. On average, they reproduce more offspring than they are needed to replace them.

Observation 2: Constancy in the population size of each natural species

Despite the high rate of reproduction among the members of the species, the number of individuals in each population tends to remain fairly constant.

Deduction 1: There is struggle for existence

Darwin and Wallace concluded that, over reproduction results in a severe competition among the newly produced organisms for the limited resources, such as food, shelter, space and mates. The competition can be either interspecific or intraspecific.

The interspecific competition is a form of competition in which individuals of different species compete for the same resources while intraspecific is the one in which members of the same species compete for limited available resources. During the struggle, many organisms fail to either reproduce or die before reaching the reproductive age. This explains why the population size tends to remain approximately constant.

Observation 3: Variations exist within all populations

As organisms struggle for existence, they try to become better adapted to their environment so that they successfully survive. For this reason, variations start to arise in the organisms.

Deduction 2: Natural selection or survival of the fittest

In the course of struggle for existence, only those organism with favourable adaptive variations have a reproductive advantage and high survival chances. Those with unfavourable variations have limited chance in the struggle for existence, and therefore, they perish. Thus, Darwin concluded that, nature selects only those organisms which carry favourable traits. Organisms selected in this way are better adapted to their environment and can transmit their traits to their offspring. The key factor in determining survival is adaptation to the environment. Any physical, behavioural or physiological variations, giving one organism an advantage over another organism will act as a selective advantage in the struggle for existence. The advantaged organisms, therefore, survive the struggle whereas the disadvantaged ones perish away. Hebert Spencer called this concept "survival of the fittest". The term "fit" means well adapted to the environment. As noted earlier, the favourable traits are inherited by the next generation, whereas unfavourable ones are selected out or "selected against" as their presence confer a "selective disadvantage" on that organism.

In this way, natural selection leads to increased vigour within the species and ensures the survival of that species. This is because species gain adaptive features as they struggle to exist. These adaptations are preserved and accumulated in the individuals of the species and ultimately lead to the origin of species. As natural selection continues, the differences become more pronounced to mark off the successive generations as separate species. Thus, new species of organisms arise by natural selection over many generations during which the offspring become markedly distinct from their ancestors.

Darwin's theory of natural selection can be used to explain the Lamarck's long necked giraffes. According to Darwin, both forms of giraffes existed, in other words, those with long and short necks as well as those with long and short limbs. When grasses were scarce on the land (selection pressure), giraffes had to eat the leaves of tall trees (struggle for existence). Naturally, the giraffe with long necks and legs had a selective advantage over those with short necks and legs. They could get food more easily on higher branches of tall trees and had better chances of survival (survival of the fittest). Thus, the long-necked giraffe won in their struggle for existence, reproduced and became abundant. On the contrary, the short-necked giraffes failed in the struggle, starved and gradually became extinct.

Types of natural selection

In a population, there can be a range of individuals with respect to a certain trait. A change in the environmental condition can exert selection pressure on the species in a population causing it to change in order to adapt to the new condition. The continuous variation among the individuals in the population forms a normal distribution curve, with a mean, which represents the optimum condition for the trait. There are three types of natural selection, namely: directional, stabilising and disruptive selection.

(a) Directional selection

This is the type of natural selection in which the values of a trait at one end of the distribution are selected against the values at the other end. The result is that, the population's trait distribution values shift towards other extreme. Thus, the distribution values and its mean move towards one direction. This means that, in a directional natural selection, a single extreme phenotype is favoured. For example, the long neck in giraffes is said to have evolved in this way, where the selection pressure operated against short necks. Since the animals with short neck could not reach as many leaves as possible on tall trees, they died of starvation. Consequently, the distribution of neck length shifted to favour individuals with long necks as shown in Figure 5.2.

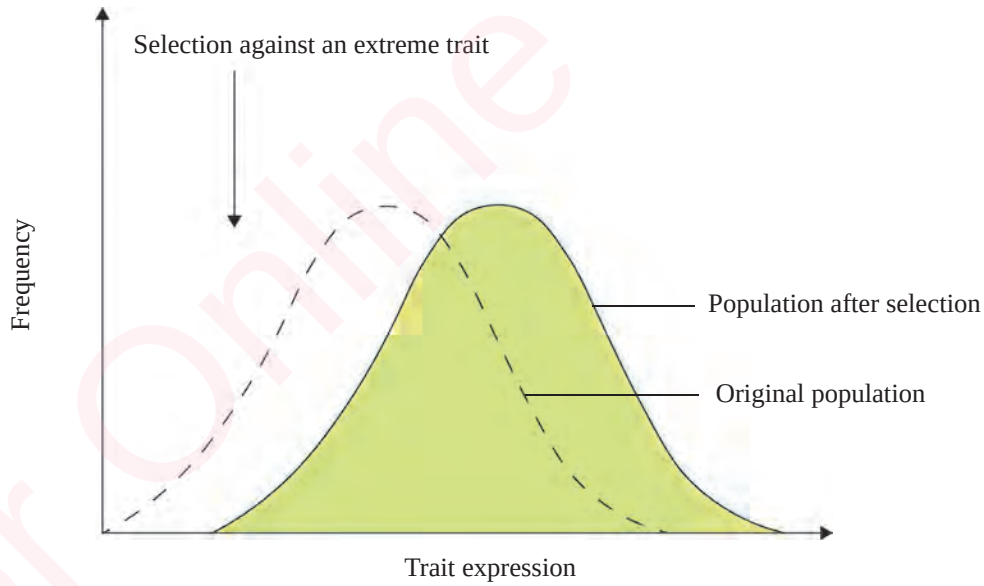


Figure 5.2 The effect of directional selection on trait distribution

(b) Stabilising selection

In this case, the extremes of a trait are selected against and the mean value of the trait remains the same. Thus, when selection pressure operates against the two extremes of a trait, the population experiences stabilising selection. For example in a population of maize, plants that are short compete with tall plants for sunlight. Extremely tall plants may also be more susceptible to wind damage. Therefore, the selection pressures will operate to select the extremes (too short and too tall plants) and maintain plants of medium (intermediate) height. Therefore, the number of plants of medium height will increase while the numbers of too short and too tall plants will decrease and finally disappear as shown in Figure 5.3. This means that, the plants of intermediate phenotypes are fitter than plants of the other phenotypes.

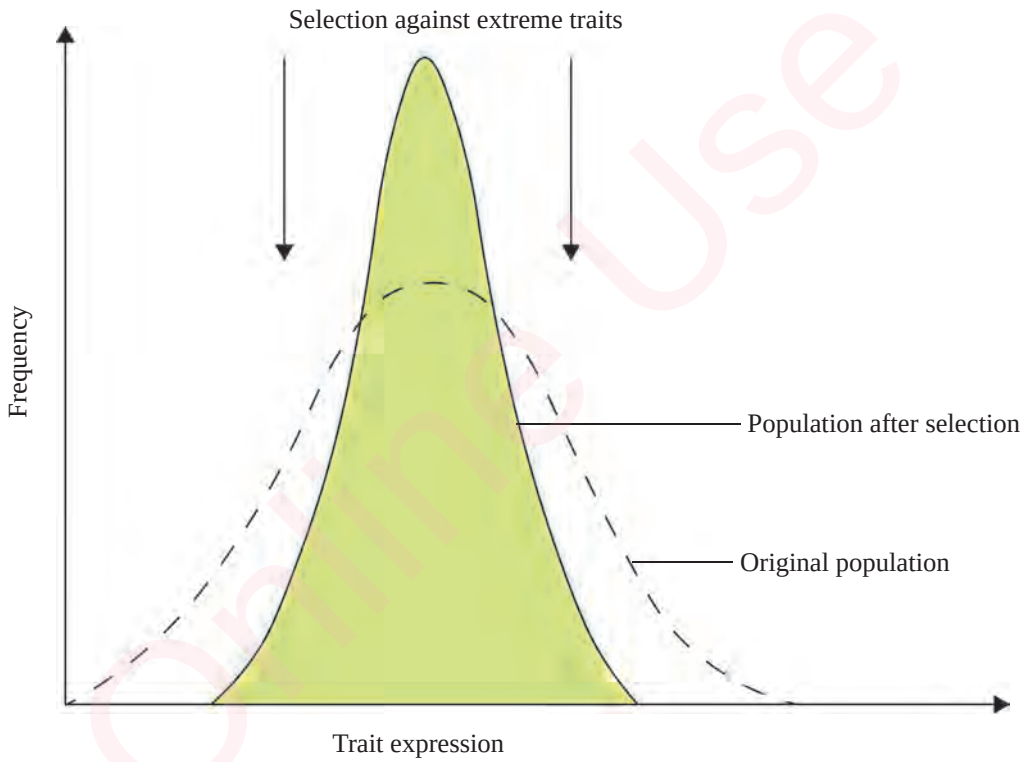


Figure 5.3 Effect of stabilising selection on trait distribution

(c) Disruptive selection

This is also known as diversifying natural selection, which occurs when extreme values for a trait is favoured over the intermediate ones. This causes the phenotypic distribution to deviate from the centre resulting in a bimodal spread or distribution as indicated in Figure 5.4. This occurs when fluctuating environmental conditions favour the presence of two different phenotypes. Continued separation of phenotypic variants causes the division of the population into two distinct species. The different beak sizes of Darwinian finches

of the Galapagos Islands are said to have evolved in this way. Due to the force of disruptive selection, intermediate beak sizes have been selected against for generations. The resulting population has almost no medium sized beaks. This means that the median is not the favourable trait in this case. Instead, both extremes are favoured for survival. However, this is the rarest type of natural selection in a population.

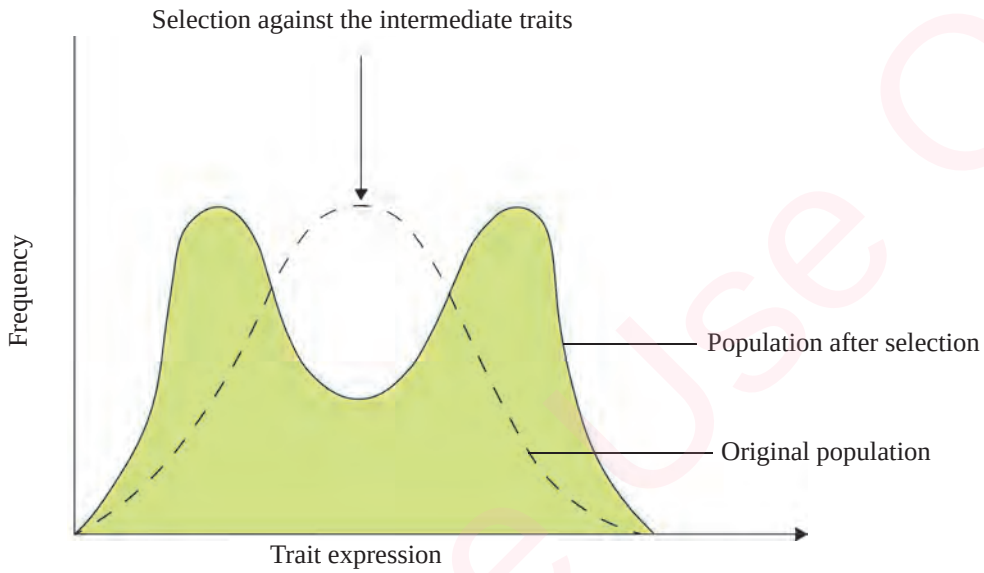


Figure 5.4 The effect of disruptive selection on trait distribution

Strengths and weaknesses of Darwinism

Darwin's theory of evolution had a number of strengths. First, the theory puts more emphasis on the role of environment in evolution. Second, the theory explains clearly the concept of the struggle for existence of organisms as they compete for the limited resources. It lays out the existence of variation among organisms. Lastly, according to Darwin, new species arise from the pre-existing species by means of natural selection. The species do not remain fixed they rather change from simple to complex forms. This idea stops the debate on the special creation theory which believed that species once created remained fixed.

However, Darwin's theory has a number of drawbacks. Firstly, the theory does not explain how variations are passed from parents to offspring. That is, it does not recognise the role of genetics in evolution. Consequently, the theory does not explain the causes of variation such as mutation and genetic recombination. Secondly, it does not clearly show how the fit traits are naturally created and maintained, although, the theory explains the survival of the fittest and the elimination of the unfit. Lastly, the theory does not explain how life originated on earth, instead, it focuses on how new species might arise from the pre-existing species.

Neo-Darwinism

The modern way of explaining evolution is known as Neo-Darwinism (Neo- means new or addition of something to the notion of). The theory of organic evolution as explained by Darwin and Wallace has been modified and explained more scientifically using evidences derived from genetics, molecular biology, ecology, palaeontology and ethology. Neo-Darwinism, therefore, is the theory of organic evolution by natural selection of genetically determined characteristics. According to this theory, the origin of species by natural selection is brought about by changes in the gene frequency or genotypes in large populations. As a result, some of the genotypes tend to be naturally selected for and others are selected against, and hence, eliminated from the populations. The naturally favoured organisms tend to reproduce giving rise to new offspring. The different aspects of Neo-Darwinism are supported by a number of current pieces of evidence that include the following:

(a) Genetic recombination

In all sexually reproducing populations, gametes are formed as a result of meiosis. During prophase I of meiosis, the exchange of genetic materials between non-sister chromatids of homologous chromosomes occurs. This exchange of genetic materials provides a new combination of genes, which brings about new characteristics in the offspring. In recombination, traits of different organisms are combined to give one trait. The resulting mixture of traits may be good for the organism to adapt to its environment. This is then passed to the next generation which may be even better adapted. In this way, organisms that are formed as a result of genetic recombination, are best adapted to their environment. Nature tends to favour their existence with gene frequency multiplying generation after generation.

(b) Genetic drift or Sewell Wright effect

The term genetic drift refers to the elimination of genes of certain traits when a section of the population migrates or dies due to natural calamity. Thus, genetic drift is defined as the change or variation in the gene frequency as a matter of chance. The chances of genetic drift are higher in small populations than in larger populations. Sewell Wright (1931) was the first scientist to recognise that genetic drift could cause changes in the gene frequency and hence evolution.

(c) Natural selection

The role of natural selection is to ensure that favourable genes are maintained and unfit ones are eliminated. The following examples illustrate how natural selection works.

(i) Industrial melanism in peppered moths

Industrial melanism in *Biston betularia* (peppered moths) is one of the best evidence for natural selection. This instance was recorded by a scientist called H.B Kettlewell in 1959. There are two varieties of *Biston betularia*, the light and the black coloured insects as shown in Figure 5.5. In the early 19th century, the light coloured moths were dominant in England. They inhabited the lichens that grew on tree trunks. The light coloured moths, having been resting upon light coloured lichens, were practically invisible to the predator birds. Later, there was a steady rise of industrialisation. The industrial pollution not only killed the lichens that were growing on the trees, but

it also made the tree trunks turn black with the deposition of soot. Consequently, the light coloured moths became vulnerable to predators and their population, therefore, started declining. The light coloured moths were soon replaced by the black ones. The latter, having been resting on dark tree trunks were not easily visible to the predators, and therefore, they had better chances of survival than the light coloured ones. However, in areas that were not affected by industrial pollution, the light coloured moths were still dominant. Thus, in the polluted area, the environmental factor (selection pressure) which selected the dark varieties against the light form is bird predation. The natural selection has operated in the direction of eliminating the gene for light colour and a gradual increase of the gene for dark colour.

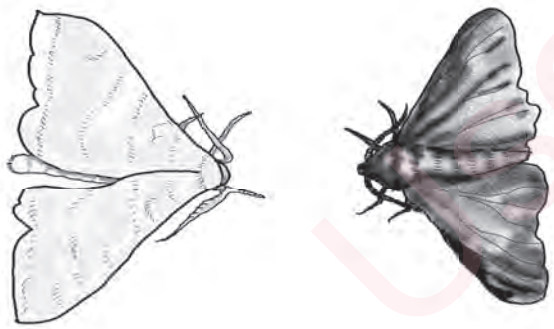


Figure 5.5 Dark and light coloured *Biston betularia* moths

(ii) Pesticides resistance in insects

Remarkable evidence of natural selection has come from the work involving the use of dichlorodiphenyltrichloroethane (DDT) to kill mosquitoes and other insects. When DDT was initially spread, nearly all the mosquitoes were killed. However, there were few mosquitoes that remained unaffected. This is because of their genetic make-up. They had a unique quality of resistance to such an insecticide. Thus, the resistant mosquitoes, which were originally present in small numbers, got a chance of multiplying rapidly. Later on, more resistant types of mosquitoes had emerged in the locality where this chemical was used. Therefore, DDT became less effective against mosquitoes as the years passed on. Eventually, a population of DDT resistant mosquitoes emerged, making the insecticide ineffective. In this case, DDT acted as a selection pressure to eliminate the mosquitoes that lacked the resistant genes. It favoured an increase of the population size of mosquitoes with the resistant genes. The process where a new species of organisms emerges especially the micro-organisms and insects is called evolution in action.

Strengths and weakness of the Neo-Darwinism theory

Neo-Darwinism is recognised for embracing the role of genetics in natural selection. Further, the theory demonstrates evolution in progress, especially at the micro level. However, Neo-Darwinism could not explain the origin of species or organisms of distinctive form and behaviour. In addition, the theory partially explains adaptation or micro-evolution as a means of species creation. For example, this

theory assumes that there is random genetic variations followed by selection. However, modern genetics demonstrates the role of directed mutation in adaptive response. Genes are said to respond to environmental circumstances by random adaptive mutations that in turn result in the creation of new species.

Exercise 5.2

1. Discuss the contributions made by Charles Darwin and Jean de Baptiste Lamarck in evolution.
2. Based on theories of organic evolution, describe the development of the following:
   (a) Loss of legs in snakes.
   (b) Lateral flattening in some fish.
   (c) Webbed toes in ducks.
3. Show how the modern view of natural selection modifies the theory put forward by Charles Darwin.
4. Explain the evolution of Plasmodia which are resistant to certain anti-malarial drugs such as chloroquine.
5. Briefly explain the following terms:
   (a) Adaptive mutations.
   (b) Micro-evolution.
   (c) Selection pressure.
   (d) Genetic drift.

Evidence of evolution

Substantial evidence exists to support the mechanism of organic evolution. One line of evidence shows that adaptation is an agent of evolution. Another line supports a common ancestral origin of different organisms and speciation as a driver of evolution. This means new species that arise from the pre-existing ones, change from time to time to adapt to their environment.

Palaeontology

Studies of organisms that existed during the past life have generated substantial evidence to support organic evolution. Evidence that supports evolution has been generated by studying the fossil records of the previous organisms. This is done by specifically studying their structures and deduce their functions. Palaeontology is the study of the remains of past life called fossils. Palaeontology links biology with geology and is supported by archaeology which involves digging up of fossils down the rocks. When plants and animals die, their remains are either decomposed by bacteria or preserved as fossils. Fossils are therefore, defined as remains, traces, or imprints of life that have been preserved at sometime in the geological past. They prove that varieties of animals and plants existed in various geological ages of the earth.

The process of fossils formation is known as fossilisation. However, not all organisms that die become fossils. This is because most of them rapidly decompose after death. The best place for fossilisation is the ocean because salt water checks the decay of organisms. In most cases, soft parts of the body are not preserved, hard parts such as bones, teeth, shells and woody parts of plants are preserved. Fossils are found mostly in the sedimentary rocks, which are formed due to slow settling down of silt, mud or volcanic ash in rivers, lakes and sea. The particles settle forming different layers. Each layer is called a stratum. The lowest stratum, which was deposited first, contains the fossils of the primitive forms of life, whereas the upper strata contain fossils of more complex and advanced plants and animals.

Types of fossils

The types of fossils, their formation and examples include the following:

(a) Entire organism

In this type of fossils, the entire organism is preserved. The preserving materials can be ice, amber, tar, or oil seeps. Examples include insects trapped in tree resin (amber) and woolly mammoth found in Siberia.

(b) Hard skeletal materials

These fossils are formed when hard skeletal parts such as teeth, bones and shells are trapped by sedimentary sands and clay; which in turn form sedimentary rocks.

(c) Petrified fossils

This kind of fossil is formed when minerals such as silica, pyrites, and calcium carbonate gradually replace the organic materials in a body of the buried organism and eventually fill the space left as the organism decays. Petrification is exemplified in the way silica replaced Micraster, which is an extinct form of echinoderm.

(d) Moulds and casts

Organisms buried in sediments slowly decompose and dissolve away leaving a cavity or mould that contains an exact imprint of the organism's shape and size. When this hollow space is filled with sediments, it takes the shape of the mould forming a cast. Although the fossil may show the characteristic of the original organism or part of the body of an organism, normally no organic material remains in the cast. Moulds and casts are three dimensional and they preserve the surface contours of the organisms. Examples are the pith cast of the calamities located in West Virginia and the casts of footprints in Laetoli site near Olduvai Gorge in Tanzania, which was discovered by Dr. Mary Leakey in 1976. Her study was based on the analysis of the foot fall impressions and it provides evidence for the theory of bipedalism in *Pliocene hominids*.

(e) Imprints

These are fossils in the form of footprints, trails, tracks and tunnels of different organisms in mud that are baked and filled with sand and covered by further sediments. A good example is footprints of dinosaurs.

(f) Compressed and carbonized plant fossils

These are fossils which are formed when oils in the plant cells are leached out and the remaining matter is reduced to the carbon film. The plants have an inner structure of rigid organic walls, which may be preserved in this manner, revealing the framework of the original cells. The plants are often fossilised through carbonization. A good example is a coal.

(g) Coprolites

These are faecal pellets that are prevented from decomposing and later get compressed in sedimentary rocks. They often contain some evidence of the food eaten. The example for this is cenozoic mammalian faecal remains.

Fossils as evidence of organic evolution

The fossil records suggest that, the complex and advanced forms of plants and animals evolved from the simple and primitive forms of life. For example, research on fossils has shown that the earliest fossils were monera, followed by protoctista and then fungi. Plants and animals appeared later. The oldest fossils of animals are those of fishes followed by amphibians and the latest are mammals.

Furthermore, the study of fossils shows that species of organisms did not remain unchanged, rather they were changing in the course of time from simple to complex. For example, the history of the horse from fossil records found in the North American sedimentary rocks is used as one of the best examples of evolutionary changes. These occurred through various generations as the animal adapted to the changes in the environment. According to the history, the development of a horse was gradual, from simple, primitive *Hyracotherium* of the Eocene times to complex, advanced *Equus* of the Pleistocene times. As shown in Figure 5.6, changes in the structure of the horse's body enabled it to cope with the changing environment around it through the process of adaptation.

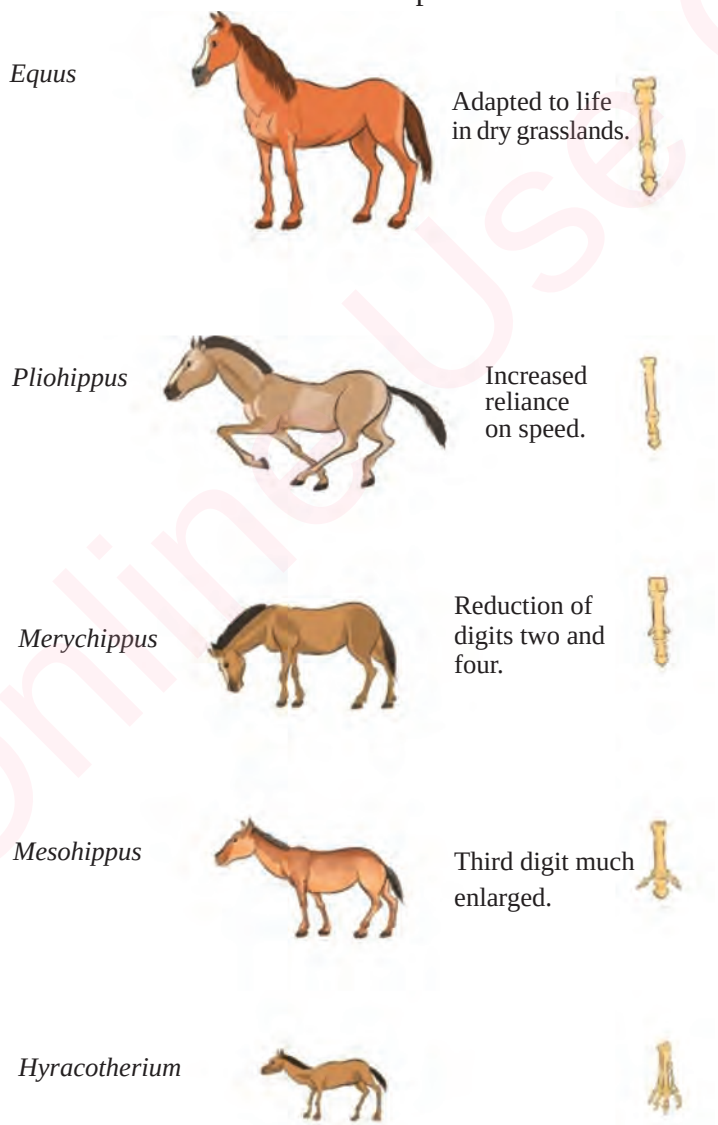


Figure 5.6 Evolution of horse from simple primitive form to complex form

Fossil records also shows that evolutionary life of a plant or animal can be reconstructed. That is, by studying fossils, the mode of life exhibited by fossilised animals such as mode of feeding can be assumed.

Weaknesses of fossils evidence

Generally, the fossil records are useful sources for tracing the evolutionary history of organisms. However, the lack of records on the continuity of fossils is a major limitation in tracing the descent of biological groups. These gaps in the fossil records are termed as "missing links".

There are various reasons for the incompleteness of fossil records or missing links. Firstly, the chances that organisms become fossilised are very low because they are soft-bodied and die in conditions that are not favourable for fossilisation. Secondly, many fossils have been destroyed through erosion and tectonic movements. Thirdly, most fossils are fragmentary, they consists of the physical fragments or small disconnected items. Fouthly, some evolutionary changes occur in population at the limits or edges of the ecological range of a species. The population of organisms at the edges is likely to be small, thus the chances of fossilisation are low. In addition, when environmental conditions change, the population of a species could be greatly reduced. This means that, any evolutionary change induced by these new conditions is less likely to affect fossilisation. Lastly, most fossils convey information about external forms, but little about how the organisms function, change in the cause of time from simple to complex.

Comparative morphology and anatomy

Organic evolution is also evident in the similarities and differences in the basic structures of different organisms. Anatomy is the study of structure and form of organs in the body of living organisms. Comparative study of the anatomy of groups of animals and plants reveals a great similarity in certain structural features. This is explained based on the following aspects:

(a) Basic structures

When the anatomy of various groups of organisms is compared, it can be found that certain basic structures are shared among the groups or within the groups of organisms. The basic structure of flowers, for example, is the same in all angiospermophytes. There is also a similarity across mouth parts of insects as indicated in Figure 5.7. These similarities in morphological and anatomical characteristics among organisms suggest a common ancestral origin. Their structural modification is due to environmental changes.

Sucking, for example, in butterfly, mandibles lost, labium reduced, and maxillae become long forming tube.

Licking and biting, for example, in honeybee, labium is long to tap up nectar, whereas mandibles chew pollen and mould wax.

Primitive state: biting and chewing. Insects such as grasshopper use strong mandibles and maximillae for manipulating food.

Piercing and sucking as it occurs in female mosquito, where labrum and maxillae form tube. Mandibles form piercing stylets, labium grooved to hold other parts.

Figure 5.7 Adaptation of insect mouth parts

(b) Homologous structures and divergent evolution

Homologous structures are body parts or organs of different species that share similar basic form or construction, but perform different roles as shown in Figure 5.8. Such structures are said to have the same origin. For example, limbs in all vertebrates are built on the same basic pattern called the pentadactyl pattern. However, due to the adaptive radiation, similar parts adapted to perform different roles. In this case,

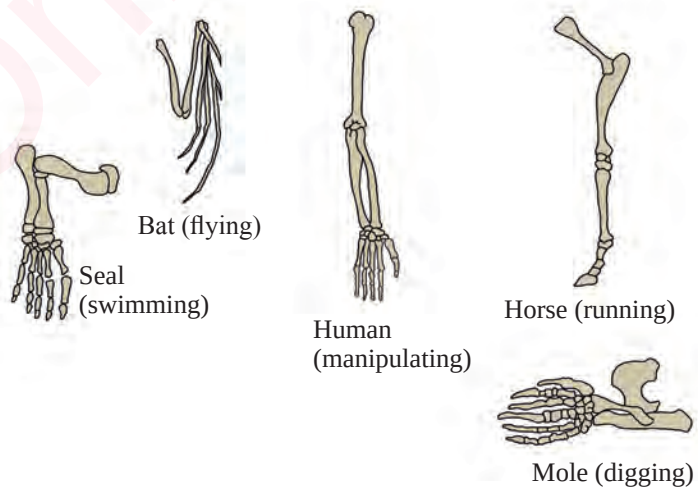


Figure 5.8 Adaptive radiation of fore limb of chordates

limbs have apparently evolved as different structures from the basic ones. Such organs can also be exemplified by flippers in whales for swimming, wings in birds for flying and fore limbs in monkeys for walking. Homologous structures suggest common ancestry, but they also suggest the existence of divergent evolution. The latter is defined as a relative phenomenon in which initial similar populations accumulate differences over evolutionary time and become increasingly distinct.

(c) Analogous structures and convergent evolution

Analogous structures are body parts or organs of different species, which have different construction and origin but perform similar roles. Examples of analogous structures include wings of insects and birds, eyes of vertebrate, squids and octopus, jointed legs of insects and those of vertebrates. Analogous structures only bear superficial similarities, and therefore, support convergent evolution as indicated in Figure 5.9. This may be explained in terms of the environment acting through the agency of natural selection, favouring these variations, which confer increased survival and reproductive potential on those organisms possessing them. Convergent evolution is thus a kind of evolution whereby organisms evolve structures that have similar functions but have unrelated evolutionary ancestry. In this process, unrelated or distantly related organisms evolve similar body forms, colourations, organs and adaptations. It describes the acquisition of the same biological trait in unrelated lineages.

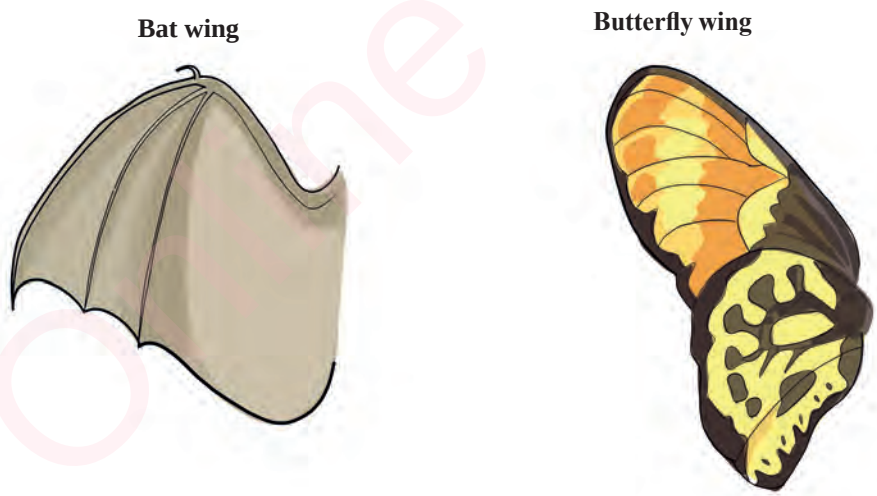


Figure 5.9 Analogous structures, butterfly and bat wings

(d) Vestigial structures

These are homologous structures in some species with no apparent function. They are smaller and simpler in structure than the corresponding functional parts in the ancestral species. The existence of vestigial organs can be explained in terms of changes in the environment or modes of life of the species. Such organs were typically functional in the ancestral species but are now non-functional or have changed functions. Examples of vestigial organs include an appendix in humans, which is

functional in the digestion of cellulose in herbivores. Others include halters (hind wings) of houseflies and leaves of some xerophytes such as *Cactus* plants. The existence of vestigial structures suggests a common ancestor from which they were inherited.

(e) Comparative embryology

It is the comparison of embryo development across the species. This is the branch of embryology that compares and contrasts embryos of different species in vertebrates to show how animals are related. The greater the similarity of structure, the more closely related the species are and the more recent their common ancestor is. The development of an embryo from fertilisation until it becomes a foetus is called embryology.

The development of embryos of vertebrates in the early stages is very similar. They all possess the same features as shown in Figure 5.10. They have external brachial grooves (visceral clefts) in the pharyngeal region and a series of internal paired gill pouches.

In fishes, these pouches join to form gill slits for gaseous exchange. In other organisms, the perforation develop and become an eustachian tube and the auditory canal involved in hearing.

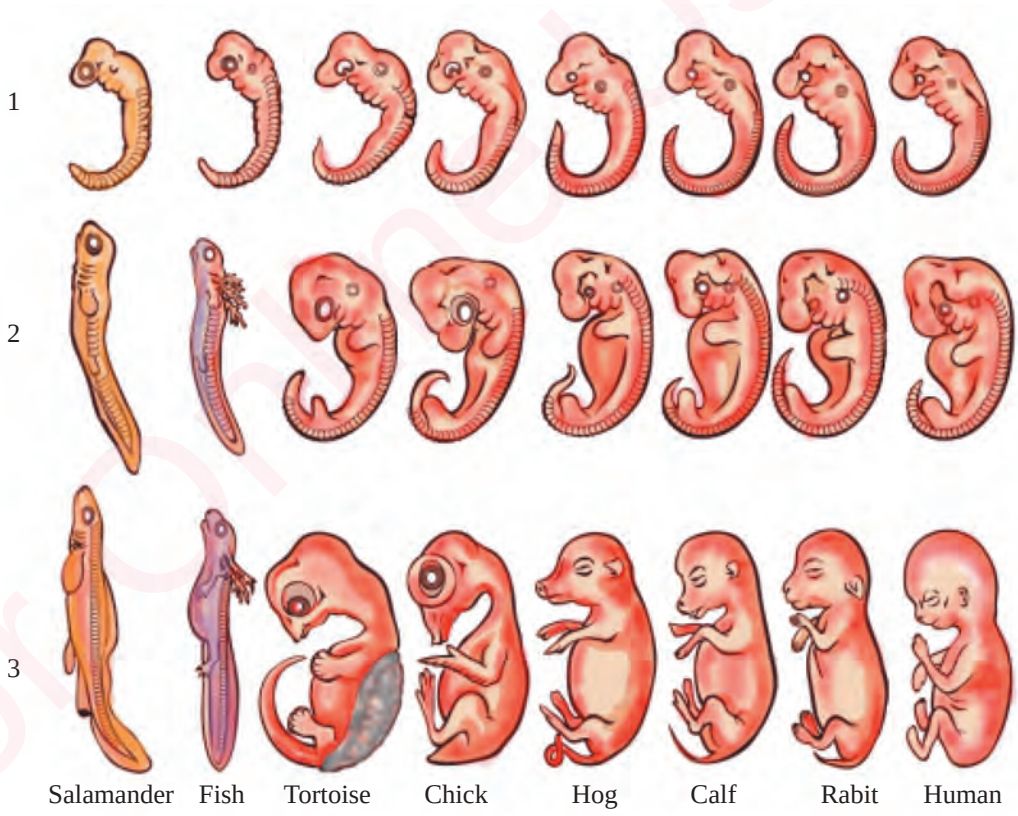


Figure 5.10 Vertebrate embryos showing stages of embryological development

In addition, both have segmental myotomes (muscle blocks) which are evident in the tail like structure retained in some vertebrates like rabbits.

Furthermore, they develop a single circulatory system which includes a two chambered heart showing no separation of the right and left halves. This situation is only retained in fishes. These embryo similarities signify that vertebrates have a common ancestor.

Activity 5.2 An examination of bones in mammalian limbs

Materials: The limb bones or limb diagrams of horse, cow, bat, rat and whale or dolphin.

Procedure

(i) Look at the drawings of limb bones or actual limb bones of the forelimbs of horse, cow, bat, rat and whale or dolphin.
(ii) List the features of each bone such as the number, size, shape and strength of the bone.
(iii) Now carefully look at the pattern of bones in each limb and note any differences and similarities.
(iv) Write down what you think this pattern is and compare your responses with your fellow students.
(v) How has the bone pattern been modified as an adaptation to flight in the bat?
(vi) How has the bone pattern been modified as an adaptation for swimming in whales?

Results: Homologous mammalian limbs demonstrate a pattern in the bones, which has become adapted for different functions, for example, wings of a bat for flying and legs of a horse for walking. However, a common pattern or features of bones suggest an evolutionary relationship between organisms.

Comparative biochemistry

Evidence to support organic evolution has also been generated by comparing the chemical composition and physiological processes among groups of organisms. The occurrences of similar chemical molecules in a complete range of organisms suggest the existence of biochemical homology. The evidence is derived from the following sources:

(a) Basic cellular component

Basic cellular components are known to occur within groups of organisms in large numbers. For example, cytochrome **C** is identical in almost all aerobically respiring organisms, as it is for human and chimpanzee. The haemoglobin of humans, gorillas, and chimpanzees is almost the same and the chemistry of chlorophyll is the same in all chlorophyllous organisms. Furthermore, the chemistry of nucleic acids is the same and the genetic code is universal in all organisms. This similarity in cellular components suggests a common stem of organisms. Thus, since the similarities can be traced back to bacterial cells, then there is an evolutionary relationship between prokaryotes and eukaryotes.

(b) Basic physiology

Various groups of organisms share similar physiological processes. For example, hormones in chordate have similar roles. Insulin hormone extracted from cattle and pigs is chemically and structurally similar to human insulin, therefore, it is used to treat diabetes. Another example involves the action of thyroxine hormone.

If the thyroid gland is removed from a tadpole lava of a frog, the immature chordate will not metamorphose into an adult frog. However, if it is injected with thyroxine hormone extracted from human, cattle, goat and the like, metamorphosis is ensured and the lava grows into an adult animal.

Another hormone of reference is prolactin. This stimulates synthesis and production of milk in mammals. However, the hormones, which are similar to prolactin, occur in various vertebrates where these hormones perform different functions. For example in bony fish, the hormone stimulates the secretion of skin mucus and increases urine production. In amphibians, it stimulates the secretion of egg jelly and increases skin permeability to water. Thus, similar physiology among chordates suggests a common ancestor.

Biogeography

Biogeography is the study of the distribution of species within ecosystems in a geographical space over geological time. It is a field of inquiry that unites concepts and information from other fields like geology, ecology, evolution, biology and physical geography. Geographical distribution of plants and animals provides another evidence for evolution. It is believed that species originated in a given area and dispersed outwards from that point. The extent of dispersal depends on the success of the organisms, efficiency of dispersal mechanisms and the existence of natural barriers such as oceans, mountain ranges and deserts. The evidence which support that distribution of organisms in different continents and oceanic islands as evidence for organic evolution are discussed in the next subsections.

(a) Continental distribution of organisms

Biologists have discovered many amazing facts about the presence of certain species on various continents and islands. All organisms are adapted to their environment to greater extents. If both biotic and abiotic factors within the habitat are capable of supporting a particular species in one geographical area, then one might expect the same species would be found in similar habitat in different geographical areas, for example, in Africa and in South America. However, this is not the case, plant and animal species are discontinuously distributed throughout the world. For example, animals in the African continent and those in South America are very different. Africa has short-tailed monkeys, elephants, lions, antelopes and giraffes, whereas South America has long tailed monkeys, congers, jaguars, and ilamas.

Even greater differences can be found if Australia is taken into consideration. Although it occupies the same latitude as South America and Africa, Marsupials such as Kangaroo are found in Australia, and totally absent in Africa. Marsupials are only represented by the opossum in South America and North America. Furthermore, the echidna and platypus which are the only living representatives of primitive egg-laying mammals (monotremes) are found only in Australia and are completely absent in the rest of the world. On the other hand, Australia has very few placental mammals except those which have been introduced by human beings.

This geographical distribution of Animals is explained by the theory of descent with modification. According to this theory, the main groups of modern mammals

arose in the Northern hemisphere and subsequently, at a time of low sea level when the intercontinental land bridges were exposed, migrated in three major directions. Firstly, they migrated to South America, via two land bridges, one connecting Asia with North America and another one (the Isthmus of Panama), connecting North America with South America. A large number of families of South American, marsupials, became extinct as a result of competition with counterparts in the Northern Hemisphere. Secondly, they migrated to Africa via the land bridge connecting Europe and Africa in the today's Gibraltar.

The third direction was to Australia via the South East Asia peninsula and the Islands, which at a time of low sea level, formed a continuous land bridge extending to Australia. The shallowness of the Bering Strait today means that the lowering of the sea level in the past would have readily exposed the land bridge between two northern continents. This permitted a relatively easy passage of animals between the two continents. Such a perspective offers a ready explanation of the present day similarity of the animals of Eurasia and North America. However, once they got down into the Southern continents, they presumably became isolated from each other by various types of barriers. For example, the submergence of Isthmus of Panama isolates the South America animals and the Mediterranean Sea and the North African desert isolate the Africa animals.

(b) Evidence for migration and isolation

Continental biogeography revealed that, camels and Ilamas arose from a common ancestor which belonged to the family camelidae. The ancestor originated from Northern America and spread in various parts of the world. With time progressive changes within the camelidae occurred during the migration to produce two genera known as *Camelus* in which camels belong and *Lama* which is the genus for Ilama.

Therefore, camels and their relatives, the Ilamas, are found in two continents with true camels in Asia and Africa, and Ilamas in South America. There are no camels in North America. Based on the theory of descent with modification, it would be expected that, the camels once existed in North America but became extinct. Indeed, there was a discovery of large fossils of camels in North America. This perspective, therefore, suggests that camels started in North America, from which they migrated across the Bering Strait into Asia and hence to Africa and through the Isthmus of Panama into South America. Once isolated, they evolved along with their own lines, producing the modern Camels in Asia and Africa, the Ilamas in South America and becoming extinct in North America.

(c) Continental drift

The same kind of fossils are found in areas that were once adjacent in the past. However, through the process of continental drift based on the concept of plate tectonics, areas are now in the widely divergent geographical locations. For example, fossils of the same types of ancient amphibians, arthropods and ferns are found in South America, Africa, India, Australia and Antarctica that can be dated to the Palaeozoic era. During this era, these regions were united as a single landmass called Gondwana land. Sometimes, the descendants of these organisms can be identified and show clear similarity to each other although they inhabit different geographical regions with different climatic conditions.

(d) Oceanic island distribution of organisms

There are two types of islands known as the coastal and oceanic islands. Coastal islands always contain indigenous species that are closely related to the one found on the coast but they are not identical. It is believed that, all the species in the coastal island crossed the short distance of water between the island and the mainland by flying, swimming and floating. This means that, the observed differences between the animals on the coast and the islands arose due to their adaptation to their environment.

Geological evidence indicates that the oceanic islands such as Hawaii and Galapagos were formed by oceanic volcanic activity which pushed them up above the sea level, so that they have never had any direct geographical link with any land mass. Plant species must have arrived on the Islands as air borne spores or seeds by wind dispersal or water dispersal as floating seeds and masses of vegetation. Aquatic and semi aquatic organisms are believed to have been carried there by ocean currents while terrestrial organism may have been carried clinging to logs or floating masses of vegetation or may have been brought by human settlers in boats. Birds, bats, and flying insects flew to these Islands.

Darwin studied the animals of Galapagos Island and noticed that they were similar to the animals on South American mainland but they were very different from animals on the other islands that had a similar environmental condition. Therefore, he concluded that animals on the Galapagos Island had migrated from South American mainland and after a long period of time they became new species as the population adapted to its new environment. These findings support the theory of descent with modification, which holds that, the present distribution of flora and fauna are related to their common origins.

Selective breeding

Selective breeding or artificial selection is a process of choosing a few organisms, plants, or animals to serve as parents for the next generation. It is a method in which humans use plant and animal breeding to selectively develop particular phenotypic traits. This is done by choosing animals or plants with superior characteristics that will sexually reproduce and have offspring. The organisms that are selected to act as parents show a favourable variation such as increased size or improved flavour. These are then artificially bred by selective mating, selective propagation or selective pollination with the aim of perpetuating the desired characteristics. By using genetic knowledge, humans through selective breeding, are preserving those animal or plant genes, which are considered desirable and eliminating those which are undesirable.

The process of selective breeding or artificial selection may occur through one of the three methods or types namely; line breeding, inbreeding, and outbreeding or outcrossing.

Line breeding is a process of breeding animals or plants that are closely related so as to fix or set desirable traits. For example, if a cattle has some qualities that the breeder likes, then a cow will be bred with a relative bull in order to reinforce the desirable traits through a gene pool. The idea is that, if one animal has desirable qualities, mating it with a genetically related animal will increase the desirable traits. In human terms, line breeding is like mating two close, but one-step removed relatives

like first cousins, uncle and niece or half-brother and half-sister for the purpose of perpetuating desirable characters.

Inbreeding involves the mating of very closely related animals or plants in the hope of retaining the desired traits in the next generation. The method of inbreeding is similar to line breeding only that in inbreeding, the crossed plants or animals should be as close as parents and offspring. Inbreeding has some serious flaws because while it may intensify the desired traits, it is also likely to intensify any faults in the parents. The line breeding is a little better because the parents are one step removed. However, the two methods may have one common genetic drawback of passing undesirable recessive genes through successive generations and thus, if they are continuously practiced, weak generations may occur.

In the outcrossing, plants or animals that bred are purely unrelated. This means that the crossed parents do not have any related ancestors in their pedigree for four or more generations. This method of breeding introduces new traits that are missing in the gene pool. It can also dilute the effects of inbreeding by reducing the concentration of undesirable genes. Therefore, breeders prefer outcrossing to the line and inbreeding methods.

Artificial selection or selective breeding describes intentional breeding for a certain trait or combination of traits. The term was utilised by Charles Darwin in contrast to natural selection in which the differential reproduction of organisms with certain traits is attributed to improved survival or reproductive ability. Thus, continuous breeding of plants and animals produce varieties that give rise to new species.

Since new characteristics and hence new species are produced through selective breeding, then this is the evidence that species arise naturally from the pre-existing species.

Exercise 5.3

1. Explain how the following pieces of evidence support the theory of organic evolution:
    a) Comparative anatomy.
    b) Comparative biochemistry.
    c) Geographical distribution of organisms.
    d) Palaeontology.
    e) Selective breeding.
2. Describe the ways in which the following concepts account for the fact that discontinuous distribution of the organisms in the world is not by ecological factors only:
    a) Adaptive radiation.
    b) Human interventions.
3. Compare selective breeding with natural selection.
4. Analogous and homologous structures depict antagonistic ways of evolution of organisms. Explain.
5. Explain the statement that “adaptation and mutation are agents of evolution”.
6. The occurrence and distribution of organisms in oceanic islands and continents support organic evolution. With examples, discuss this statement.

Speciation

Speciation is the formation of new and distinct species in the course of evolution. It involves the splitting of a single evolutionary lineage into two or more genetically independent lineages as indicated in Figure 5.11.

Speciation, therefore, is the changing of individuals within a population such that they are no longer part of the same species. This most often results from geographical isolation or reproductive isolation of individuals within the population. As the species evolve and branch off, they cannot interbreed with members of the original species any longer.

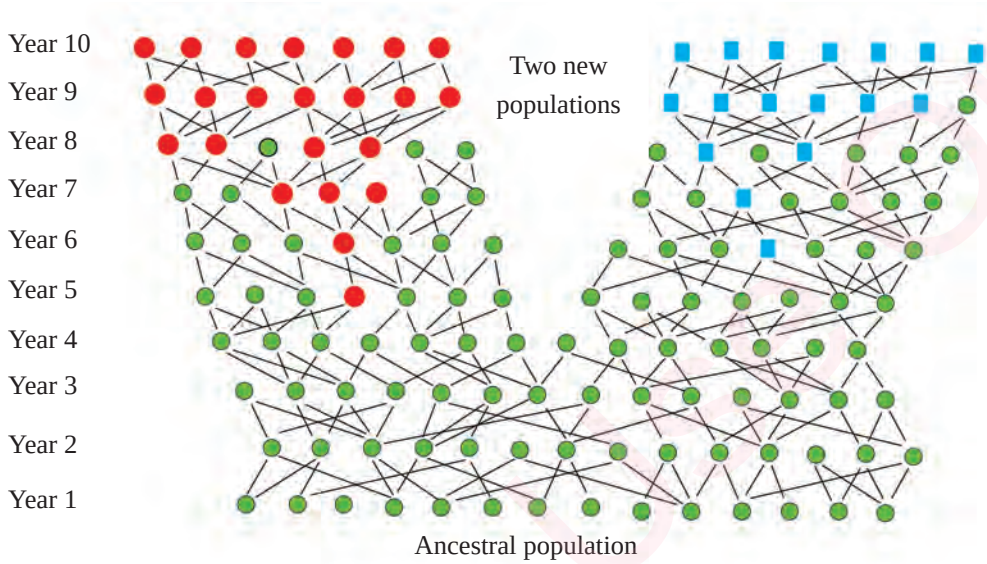


Figure 5.11 Speciation process

Types of speciation

There are three types of speciation that can occur in a population based on geographic isolation, reproductive isolation and environmental factors. The stated factors lead to three modes of speciation, namely: allopatric, sympatric, and parapatric speciation respectively, as shown in Figure 5.12.

(a) Allopatric speciation

The word allopatric derives its meaning from two terms "allo" which means "other" and "patria" which means "native place". Allopatric speciation occurs when the barriers such as mountain ranges, sea, rivers or forests, geographically isolate group of organisms that evolve to be separate species into different locations.

The geographical barriers create spatial separation that prevents mating and hence gene flow between members of two separated populations. Adaptation to new conditions or random genetic drift in a small population leads to a change in the allele and genotype frequencies. The prolonged separation of populations may result into genetic isolation even if they are brought together after a long time. In this way, new species may arise. A famous example of allopatric speciation is the use of Darwinian finches of the Galapagos Islands, which are considered to have been speciated allopatrically because of volcanic eruptions that divided the population.

(b) Sympatric speciation

This is the type of speciation that occurs among individuals in the same geographical location. Sympatric speciation does not involve geographical separation of populations as a cause of genetic isolation. It rather requires the development of some form of reproductive isolating mechanisms, which arise by selection within a geographically confined area. These may be structural, physiological, behavioural or genetic mechanisms. Sympatric speciation might thus result from a combination of sexual selection and ecological factors. Studies of cichlid fishes from Lake Nyasa and other lakes in the East African Rift Valley reveals how species flocks may have arisen from the ecologically uniform lakes. Species flocks are defined as individuals of the same species that live, feed, walk and rest together in one large assemblage. Such a condition substantially reduces the chance of allopatry from being the cause of speciation. However, it may result in groups of females within a population that develop a strong affinity for males with different extreme phenotypic traits such as scale markings, and limbs that differ in size from the average individuals. Hence, sympatric speciation is one in which reproductive isolation occurs within a population without geographical isolation.

(c) Parapatric speciation

This is a mode of speciation in which a smaller population is isolated usually at the periphery of a larger population and becomes isolated to the extent of becoming a new species. This type of speciation is not very common in populations.

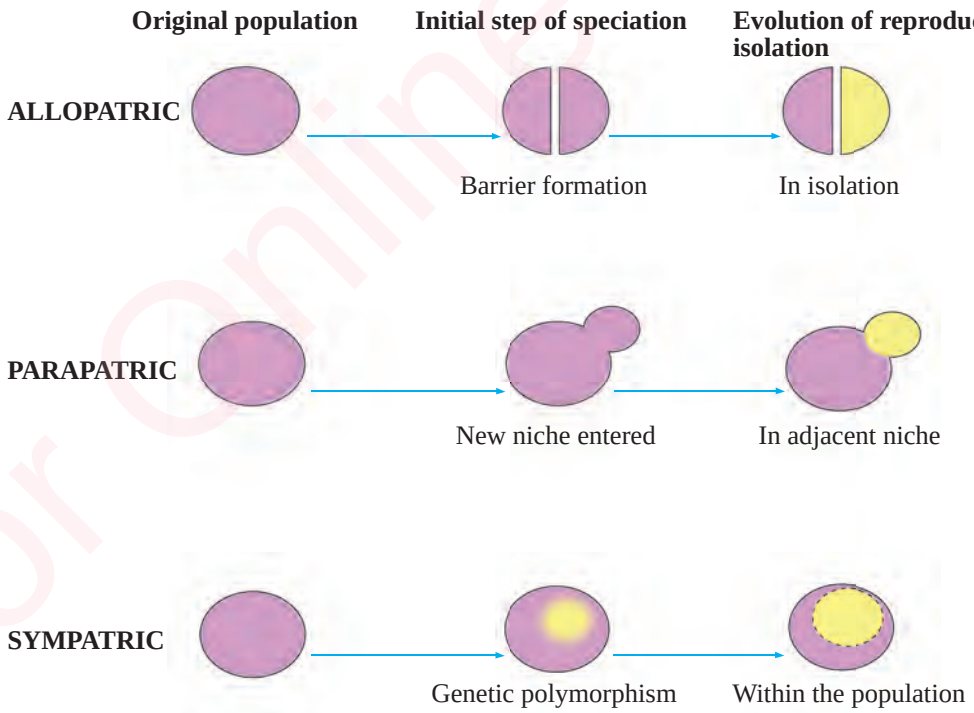


Figure 5.12 Types of speciation

It occurs when members of a population are separated not by geographical barriers like water body or mountain ranges but due to an extreme change in habitat. This can cause a population in the area to interbreed with their geographical neighbours than the individuals within the population.

Therefore, divergence may occur which can lead to the development of distinct characteristics and life style due to reduced gene flow and various selection pressure across the population. This kind of speciation is somehow similar to allopatric in that populations are prevented from interbreeding.

Exercise 5.4

1. What do you understand by the term speciation?
2. Giving examples, describe three modes of speciation.
3. Explain differences between allopatric and sympatric speciation.
4. Explain various mechanisms that contribute to the creation of new species.
5. Explain how geographical barriers such as mountains and rivers contribute to the formation of new species.

Reproductive isolation

Reproductive isolation could be defined as a condition that occurs when actively reproductive members of a given population fail to interbreed. According to Theodosius Dobzhansky (1937), the factors that prevent interbreeding are called isolating mechanisms. It is these mechanisms, which bring about speciation and they are categorised as pre-zygotic and post-zygotic mechanisms.

Pre-zygotic mechanisms

These are isolating mechanisms that interfere with the reproduction process before the formation of the zygotes. They include the following:

(a) Ecological isolation

In this case, species do not meet because they are in different habitat preference. Hence, no mating can take place.

(b) Behavioural isolation

This occurs when animals exhibit different courtship patterns, which do not stimulate or are not accepted by the opposite sex. For example, sexual songs of birds or calls of frogs must be exact if they are to elicit the appropriate breeding response from the opposite sex.

(c) Incompatibility

Incompatibility or mechanical isolation occurs in two ways:

(i) Physical incompatibility, which is caused by differences in the genitalia that prevent successful copulation.

(ii) Physiological incompatibility, which is a result of physiological changes that prevent fertilisation. These changes take place in the female reproductive system where the gametes may be prevented from meeting or the sperm may fail to survive due to the presence of natural spermicides in the female reproductive system. In plants, the pollen tube may fail to grow on a stigma.

(d) Seasonal isolation (Temporal isolation)

Seasonal isolation or seasonal barriers involve the timing of courtship behaviour and gamete production in organisms. If the breeding seasons of the two groups of organisms do not coincide, that is, if they become reproductively mature at different times of the year or in different years, they cannot breed. For example, flowering times in plants may hinder cross-pollination.

(e) Spatial isolation

This is the most obvious form of reproductive isolation which involves separation in space. It occurs in populations that are separated by great distances, sometimes it occur in populations inhabiting different parts of the same area. In plants this is portrayed in fruit trees such as walnuts, pistachio and papaya where some plants are exclusively males and others are exclusively females. This condition is known as dioecy. In animals and papaya, most individuals are hermaphrodite.

Post-zygotic mechanisms

These are mechanisms which interfere with reproduction process after fertilisation has taken place. They include the following:

(a) Hybrid inviability, this happens where hybrids are produced but fail to survive to maturity.

(b) Hybrid sterility whereby the hybrid fails to produce functional gametes. For example, a cross between a horse ($2n = 60$) and a donkey ($2n = 66$) produces a mule ($2n = 63$) which is sterile. A mule cannot produce a mule.

(c) Hybrid breakdown whereby the F_1 hybrids are fertile but members of the F_2 generation and backcross of the F_1 hybrids and parental stocks fail to develop or are infertile. Examples are the hybrids formed between species of cotton.

Revision questions

1. The theory of spontaneous generation was disproved by Francesco Redi in 1688. What do you consider was Redi's basic assumptions?
2. Considering the components of the early atmosphere, physical and chemical changes that might have taken place, explain how cosmozoic theory accounts for the origin of life on earth.
3. The concept of use and disuse as envisaged by Jean Baptiste Lamarck in his theory of organic evolution may be true for an individual organism but not from one generation to another. Explain this view using a human being as an example.
4. Briefly describe different types of fossils.
5. One major criticism of using fossil evidence to support evolutionary theory is the lack of continuous fossil records. What are the possible causes of this lack of records?
6. Explain the following terms as applied in evolution:
   (a) Homologous structures.
   (b) Divergent evolution.
   (c) Analogous structures.
   (d) Convergent evolution.
   (e) Palaeontology.
7. Explain how adaptation contributed to the evolution of black peppered moth in England.
8. (a) Differentiate between natural selection and artificial selection.
   (b) Give any four points of contrast between natural and artificial selection.
   (c) Using a graphical illustration, explain different types of natural selection.
9. Fossils and fossil records have been facing some challenges as the evidence of organic evolution. Give an elaboration on these challenges.
10. Discuss ways in which behavioural isolation mechanism between species may evolve.
11. Explain how hybridisation contributes to the process of speciation.
12. Briefly, describe the concept of reproductive isolation and how it contributes to evolution.

Chapter
Six

Ecology

Introduction

The term ecology refers to the study of the relationships between organisms and their physical environment. Organisms need to share limited natural resources such as air, minerals, space, and the environment. Lack of ecological knowledge may led to deprivation of natural resources, leading to scarcity as well as exploitation and competition of the natural resources. In this chapter, you will learn about the ecosystem, components of the ecosystem, energy flow, nutrient circulation, and ecological niche. You will also learn about ecological pyramids, methods of studying ecology, population dynamics, types of communities, population growth patterns, and ecological successions.

The ecosystem

The part of the earth's surface where life is supported is called a biosphere. This layer has several small units called ecosystems. Each unit is a more or less self-contained in terms of energy and matter. Ecosystems are exemplified by fresh water ponds, lakes, oceans, and forests. Each ecosystem has its own plant community to capture solar energy and supply organic nutrients. In addition, inorganic nutrients such as nitrogen, phosphorus, and sulphur are recycled within members of an ecosystem. An ecosystem is therefore, defined as a self-sustaining and self-regulating biological unit consisting of both biotic and abiotic components interacting in a particular area. The components of the ecosystem interact in a definite pattern to ensure energy flow and nutrient circulation. For example, the forest is an ecosystem whose physical environment such as soil, air, water, wind, sunlight, and mineral nutrients constitute abiotic components, whereas, plants, animals, fungi and bacteria are biotic components. The ecosystems are either terrestrial for example forest, grassland and woodland or aquatic, for example, lakes, rivers, and estuaries. They are distinct functional units with none or less identifiable boundaries. However, different kinds of ecosystem may overlap making boundaries between them arbitrary, as there may not be sharp boundaries. The ecosystem also gradually changes to adapt to variations in temperature, seasonality and soil conditions of the habitat. As a result, the characteristics of the new ecosystem often vary increasingly from the pre-existing ecosystem. Although most of the ecosystems are natural, there are also man-made ecosystems such as planted forests, ponds, and dams.

Components of the ecosystem

The ecosystem is made up of biotic and abiotic components. The biotic components encompasses living organisms whereas the abiotic components include the non-living components of the ecosystem.

Biotic component of the ecosystem

The biotic component of an ecosystem consists of living organisms such as plants, animals, fungi, and bacteria. Based on the flow of energy within the ecosystem, living organisms in the ecosystem can be grouped into three categories, namely: producers, consumers, and decomposers.

(a) Producers (autotrophs)

These are organisms such as plants, algae and chemosynthetic bacteria, which are capable of manufacturing their own food from simple inorganic substances such as water and carbon dioxide. Food synthesis requires light or chemical energy. The photosynthetic organisms also called photoautotrophs because they have the ability to convert sunlight energy into chemical energy during photosynthesis. This energy is subsequently stored in the synthesised organic matter such as carbohydrates. Photosynthetic organisms are the only species that can trap and convert sunlight energy into chemical energy and they are collectively called primary producers. Some bacteria are capable of synthesising their own food by using CO_2 and their own energy obtained from oxidation of inorganic molecules such as iron and sulphur. These bacteria are collectively called chemoautotrophs and are the primary producers in the ecosystem as well. The producers are ecologically important because they serve as a source of food for all organisms in ecosystems. When producers are consumed by heterotrophs, the energy stored in their food molecules is made available to heterotrophs through respiration. Producers are important in maintaining the balance of oxygen and carbon dioxide gases in the ecosystem. Moreover, producers play a vital role in carbon sequestration, a process through which atmospheric carbon is fixed by green plants and become incorporated into their tissues. The carbon fixed by autotrophs from the atmosphere is an integral part of carbohydrates, proteins and fats synthesised and stored in plants with other carbon molecules. By utilising carbon dioxide, autotrophs act as carbon sink, hence, they contribute significantly to reduce carbon dioxide from the atmosphere. By reducing concentration of carbon dioxide, which is a greenhouse gas in the atmosphere, the producers contribute largely in controlling global warming and climate change. In addition, producers ensure availability of energy in the ecosystem as they are able to convert sunlight energy into a useful chemical energy. Lastly, organisms in aerobic respiration use the oxygen gas produced by producers.

(b) Consumers (heterotrophs)

Heterotrophs are organisms that obtain their food from other living organisms as they are unable to manufacture their own food. They feed on ready-made organic matter synthesised by primary producers. These organisms fall into three levels

of consumers, which are the primary, secondary and tertiary consumers.

The primary consumers feed directly on producers and they include herbivores that are further categorised into grazers and browsers. The grazers are animals such as buffalo, zebra and cattle, which mainly feed on grasses as shown in Figure 6.1. Browsers are animals such as giraffe and goats, which largely feeds on shrubs and tree leaves. Some herbivores are aquatic organisms such as herbivorous fish and crustaceans, which feed on sea grasses and phytoplankton.

Figure 6.1 Primary consumers

Secondary consumers are animals that feed directly on primary consumers. The organisms in this level are commonly defined as carnivores or flesh feeders which include lion, leopard, and hyena as seen in Figure 6.2. Tertiary consumers are organisms that feed on secondary consumers. These animals are capable of feeding on carnivores such as snakes, birds (eagles and vultures) and marine mammals such as seal and carnivorous fish such as nile perch. Some tertiary consumers called omnivores, for example, human being can feed on all types of consumers and producers. The herbivores, carnivores and omnivores are collectively called macro-consumers. These releases carbon dioxide gas, which is required by producers for photosynthesis.

Figure 6.2 Secondary consumer

(c) Decomposers and detritivores

Decomposers and detritivores are organisms that feed on decaying or organic matter (detritus) at any feeding level ranging from producers to consumers. In the process of feeding and decomposing, they set free inorganic nutrients such as carbon, phosphorus and nitrogen, and recycle them into the nutrients pool such as soil and water. From the pool, the nutrients are absorbed by the producers and passed to various consumer levels. The decomposers, which are also known as saprophytes are ecologically important in the process of decomposition because they ensure nutrients circulation in the ecosystem. These organisms include saprophytic fungi and certain bacteria. Normally, detritivores digest food internally instead of externally as decomposers such as bacteria and fungi do. Detritivores feed on organic debris from both animals and plants, which are in the form of small particles and fragments. Decomposers and detritus feeders act as environmental cleaners as they degrade and decompose organic remains and animal excreta.

Abiotic component of the ecosystem

Water, soil, air, temperature, light, and nutrients are non-living components of the ecosystem, which constitute the abiotic component. The survival and distribution of the biotic component is largely determined by its interaction with the abiotic component. In order to understand the role of abiotic component, various abiotic factors can be divided into climatic and edaphic factors.

(a) Climatic factors

These include elements of weather conditions, namely: temperature, light, rainfall, wind, humidity and moisture of a particular area. Temperature affects the physiological process and enzymatic activity while sunlight is the driving energy of photosynthesis. Rainfall determines the type

of vegetation and influences plant growth and distribution.Wind conditions determine the rate of water loss from the plants through transpiration. Humidity, on the other hand, influences the amount of moisture in the air, which in turn determines the amount of rainfall and soil water. Humidity also determines the rate of transpiration in plants, and in some animals the rate of evaporation of water from their bodies. These factors taken together affect the distribution of organisms.

(b) Edaphic (soil) factors

Soil physical, chemical, and biological properties constitute edaphic factors. They include soil pH, salinity, soil air, soil structure, soil texture, organic matter content, water, mineral content, and topography. These factors determine the types of fauna and flora that are found in a particular habitat. The size of soil particles, that is, texture and the nature of constituent soil particles determine the properties of soil and the type of plants, which can grow on it than any other factor. The size of particles and the soil structure determine water content, air and mineral content of the soil. Soil pH and organic matter are the master variables which influence an array of other soil properties, and hence, the distribution of organisms. At high pH, some minerals may not be available while others can be available to toxic levels. Some plants prefer slightly acidic or alkaline pH, while most grow well in soil with moderate or near neutral pH. Humus or organic matter retains water and acts as cementing materials in holding soil particles together, hence, improving soil structure. Humus also releases nutrients to the soil and makes them available for plant growth. This, in turn, affects the distribution of plants and other organisms depending on them. The patchy distribution of plants is largely a result of the patchy distribution of humus and mineral nutrients. Water logged soils have poor air circulation which is detrimental to most plants except plant such as sedges which can tolerate such condition. As for the mineral content of soil, various plants require macro and micro nutrients. The ability of soil to supply these minerals will determine the distribution of plants growing in a particular soil, and hence, distribution of animals which depend on them. Generally, topography, which refers to the physical appearance of land, affects the biotic component of the ecosystem. Altitude, which is an aspect of topography affects temperature of an area. Higher altitudes, unlike lower altitude are associated with low temperature, higher precipitation, and low pressure, which altogether affect plant and animal growth and their distribution.

Interaction of components of ecosystem

The abiotic component of the ecosystem determines the survival of a living organism through various interactions. In the natural ecosystem living organisms do not exist in isolation, but they interact with each other in various ways.

One way in which the biotic components interact is through competition. This involves a struggle between organisms for the limited environmental resources such as light, food, water, mate, and space. The competition may be intraspecific when it occurs between organisms of the same species for the same limited resources. One example of intraspecific competition is when several cocks compete for the same hen for mating or plants such as maize grown very close to each other compete for light from the sun and nutrients from the

soil. Competition can also occur between organisms of different species competing for the same limited resources. Herbivorous animals such as buffalo, zebra, and antelope compete for limited fodders. This type of competition involving two or more different species is called interspecific competition.

The second way in which organisms interact is through predation. This is a biological relationship in which the hunting animal or the predator eats another animal of a different species. The eaten animal is called a prey whereas the animal that eats the prey is called a predator. In an ecosystem with a predator-prey relationship, the two populations regulate each other and result in cyclic changes in the population size. As the predators increase in number, the population of prey decreases. The shrinkage of prey population results into a stiff competition among predators for the limited prey. This diminishes the population of predators as some of its individuals fail to obtain enough food for growth and reproduction. The decrease in a population of predators due to starvation and hence deaths allows the prey to reproduce and increase in number again. This increase leads to an increase in predators and the cyclic changes continues.

The third way in which organisms interact is through grazing, which involves herbivores feeding on primary producers. The herbivores feed on vegetation such as grasses, shrubs, and trees. The larger the number of herbivores in an area, the greater the possibilities of decreased food supply which may result in starvation, death and ultimately decline in the population of herbivores. As the herbivores population declines grasses, shrubs, and trees increase and the food becomes available to herbivores. This enables them to reproduce and increase significantly in numbers again. The fluctuation in food occurs again and the cycle repeats.

The fourth way in which biotic components interact is through symbiotic relationships. Symbiosis is the relationship between two or more organisms of different species living together in which one organism (symbiont) or both may benefit from the relationship. There are three common types of symbiotic relationship, namely: mutualism, commensalism, and parasitism.

(i) Mutualism

Refers to a symbiotic association of two organisms of different species living together in which each member benefits from the association. Mutualism is exemplified by a relationship between cellulose digesting bacteria that live in the alimentary canal of ruminants such as cattle. Usually, cellulose is a valuable food to ruminants but they cannot produce cellulose-digesting enzymes. When the bacteria feed on cellulose contained in the ruminant's diet, they help to convert it into a simple compound that the ruminants can digest, absorb and assimilate. The bacteria benefit cellulose, which is their major food and shelter. The ruminant on the other hand benefit from digested cellulose. The relationship between flowers and pollinators such as bees, butterflies, and birds is another example of the mutual association. The bees visit flowers in search of nectar, which is essentially used for food and for making honey. Birds and butterflies also feed on nectar. As these move inside the flower searching for nectar, pollen grains fall and stick on their bodies' fur, legs or feathers. These pollen grains are transferred from one flower to another as these insects and birds visit flowers of different plants in search

for more food. This facilitates pollination in species with these flowers. Pollination is a very important process for an effective sexual reproduction in angiosperms. Fungi also have a mutual symbiotic association with green algae, which is called lichen. In this association, the fungi penetrate its hyphae deep to the algae body tissue. Algae, which is photoautotroph, photosynthesize food and pass some of it to the fungi body which is a heterotroph. The fungi, in turn provide algae with protection against desiccation. Lichens are commonly found growing on the rock surfaces and tree barks as shown in Figure 6.3.

Figure 6.3 Lichens (the greenish-white thallose growths) spread on the tree stem bark

(ii) Commensalism

This is the symbiotic relationship in which one species benefits the association, whereas, the other species is neither harmed nor does it benefit from the association. The species that benefits from the partnership is called commensal species and its counterpart is called a host. For example, the barnacles live on the whale and are transported to various parts of the ocean for feeding. In this relationship, the whales are neither affected nor benefitted. Another example is seen in epiphytic orchids, mosses and ferns species as shown in Figure 6.4. They grow on other plants where they get support and easy access to light. As they grow, they obtain water from the moist atmosphere, nutrients from debris and fissures on the barks of trees. In this association, the epiphytes obtain support, water, nutrients, and light as they grow on the host plant. The latter is not harmed and does not benefit from the relationship.

Figure 6.4 Epiphytic orchids *(Tridactyle teretifolia)* in Geita miombo woodland

(iii) Parasitism

It is another type of symbiotic relationship in which one organism called a parasite benefits and the other organism called a host is harmed. The parasite derives nutrients from its host and may also gain other benefits such as shelter in which it grows and reproduce. Some parasites live on the outer surface of the host and are called ectoparasites. These are exemplified by ticks and lice. In plants, ectoparasites include aphids, nematods, and larvae of butterflies.

The endoparasites live inside their hosts' bodies where they obtain food and shelter. Endoparasites include *Plasmodium* (malaria parasites), worms such as ringworm and tapeworm. Some plant parasites such as *Cassytha filiformis* grow by strangling the plant externally but later they penetrate the host plant tissue using their haustoria to absorb water from xylem and nutrients from phloem as seen in Figure 6.5.

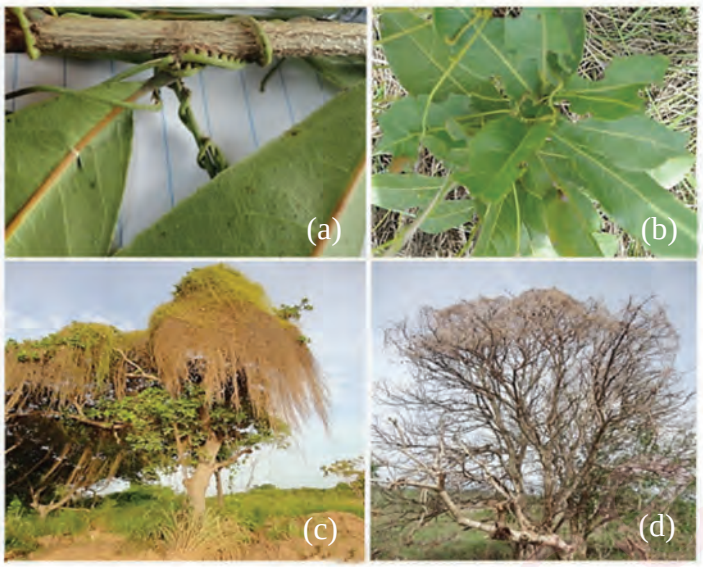


Figure 6.5 *Cassytha filiformis* showing (a) haustoria penetrating a host tree stem, [b] infested host leaves (c) parasitized cashewnut tree and (d) dead orange tree due to high infestation by *Cassytha*

Although the parasites solely rely on their hosts for food and shelter some parasites called facultative parasite do not spend their entire life inside the host. Fungi are an example of facultative parasites, which live on a living host body and when the host dies, the fungi can switch to saprophytic mode of nutrition and feed on the decaying host. The obligate parasites such as tapeworms on the contrary spend their entire life on host. In this case, death of the host may lead to death of the parasite.

Energy flow

Living organisms use energy in the form of radiant and fixed energy. The radiant energy is in the form of electromagnetic waves such as light. Fixed energy is the potential chemical energy, locked in various organic substances. Organisms that can utilize radiant energy and inorganic substances to produce organic molecules are called autotrophs**.** On the contrary, organism that depend on energy-rich organic molecules synthesized by the autotrophs, are called heterotrophs. The primary source of energy in all ecosystems is the sun. Photosynthetic organisms (autotrophs) such as green plants are the only organisms capable of converting light energy into chemical energy during photosynthesis. This energy is then fixed in the bonds of synthesized organic matter from where it is made available to the consumers. This energy is called Gross Primary Productivity (GPP), which is utilized for respiration and photorespiration. The energy which remains thereafter, is the Net Primary Productivity (NPP). This is stored in plant and made available to higher trophic level (herbivores and later carnivores) during feeding. However, not all energy and materials available in one trophic level are transferred to the next as food. Some energy is lost as heat in respiration, organic, and inorganic wastes during excretion and undigested materials. These are consumed by detritivores. The primary consumers first feed on the primary

producers and the energy flows from producers to the consumers. The energy then continues to flow through various consumer levels until it reaches the decomposers. This is a one-way and non-cyclic energy flow, as it never flows back to the sun which is the primary source of energy.

The amount of solar energy intercepted by plants depends on how plants are organised and extent to which their vegetation covers. This energy in some places is estimated to be $1x10^{-6}$ kJ mol^{-1} per year. However, only 5 - 6 % is absorbed and (95 - 96%) is lost by plants and escape from plants via evaporation, reflection, and re-radiation. About 20 - 25% of stored energy is used by plants to produce organic molecules. As the energy flows from one trophic level to the next, there is a decrease in its amount due to the fact that:

(a) Some of the energy is used to carry out physical and metabolic processes. These activities include movements, respiration and growth which may convert the stored energy into heat, and hence, lost into the atmosphere.

(b) Physiological processes such as digestion and assimilation are not 100% efficient. Thus, some of the energy remains interlocked in the molecules of the undigested food remains.

(c) Not all parts of the consumed organism are edible. For example, for the fruit plants, it is only a small portion of the energy, which is contained in the edible part of the fruit that will be passed to the consumers, in this case, frugivores. These are organisms, which feed on fruits. The remaining amount of energy which is contained in the rest parts of the plant which are not edible will not flow to the frugivore. Similarly, if a carnivore eats a herbivore, the energy which is contained in parts such as horns, bones and hooves will remain fixed in these parts as they are mostly inedible. Thus, less energy is transformed at each feeding level, which explains why the number of feeding levels also called trophic levels is always limited to four or five. The organisms in the highest tropic level, such as, the decomposers, receive a very minimum amount of energy, which cannot make them support another feeding level.

Nutrients circulation

Nutrients cycling describes the movement of elements within and between the various biotic and abiotic entities. These elements can be extracted from their mineral or atmospheric sources or recycled from their organic forms by converting them to ions that can be absorbed and ultimately returned to the nutrients pool.

In the ecosystem, the nutrients from the pool such as soil, water and air pass into the plants and become part of organic matter as they form amino acids, and hence, proteins, carbohydrates and lipids. When plants are consumed by herbivores, nutrients contained in tissues of plants pass to the primary consumers from which they move through various consumer. Death of producers and consumers attract decomposition by bacteria and saprophytes such as fungi and detritivores such as houseflies' larvae. These decomposers, release unlocked nutrients from the dead bodies of producers and consumers to the pool. Nutrients are absorbed by plants from the soil pool to support them to grow, reproduce and multiply in numbers, which in turn avail food to consumers. Upon death, the cycle starts over again. The nutrients cycled, in this case, are from an organic origin,

that is, unlocked nutrients in the bodies of dead organisms. Another common source of nutrient cycle is inorganic in which nutrients are obtained from their mineral or atmospheric sources and then fixed in organisms such as plants, as in nitrogen cycle as summarized in Figure 6.6.

Nitrogen cycle is a biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates in the atmosphere, terrestrial and aquatic ecosystems. The conversion of nitrogen can be carried out through biological and physical processes. The important processes in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification. The nitrogen cycle is of particular interest to ecologists because nitrogen availability can affect the rate of key ecosystem processes including primary production and decomposition. Nitrogen is present in the environment in the form of ammonium (NH_4^+), nitrite (NO_2^-), nitrous oxides (N_2O), nitric oxides (NO) and nitrogen gas (N_2).

During nitrogen fixation, the conversion of nitrogen gas into nitrates is carried out through biological processes. This process is effected by bacteria such as Rhizobium, which live in the root nodules of leguminous plants.

The elemental or inorganic nitrogen cannot be assimilated by plants. They absorp nitrogen in the form of nitrate or ammonium ions, for instance, Calcium ammonium nitrate fertilizer, which has first to be reduced to nitrite. This is then reduced to ammonia, the organic form of nitrogen. Ammonia will then be incorporated or asssimilated into protein and other organic nitrogenous compounds such as amino acids, nucleic acids and chlorophyll. In leguminous plants, which have a symbiotic association with Rhizobium some nitrogen is assimilated directly from the nodules in the form of ammonium ions through a process known as mineralisation or ammonification. In this process, decomposers such as bacteria and fungi convert nitrogen within the remains of dead organisms back into ammonium ions.

During nitrification there is a conversion of ammonium to nitrate by nitrifying bacteria. *Nitrosomonas* bacteria convert ammonium to nitrite, whereas in the next stage, the *Nitrobacter* bacteria are responsible for the oxidation of nitrites into nitrates.

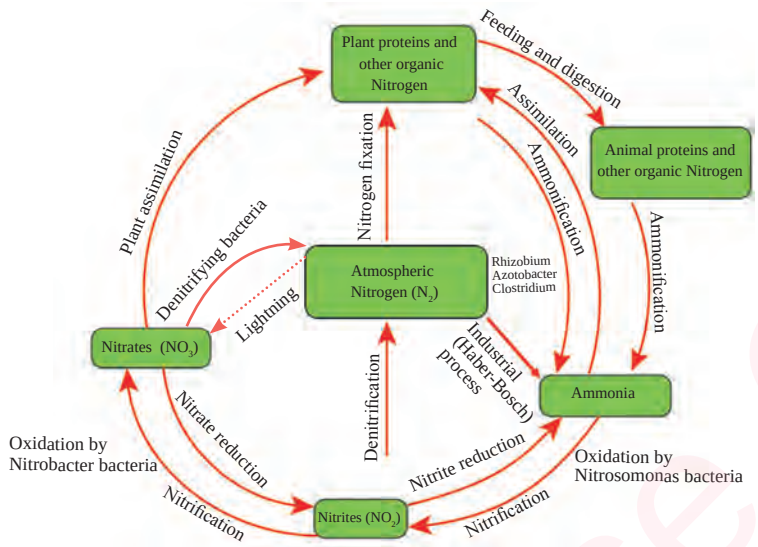


Figure 6.6 Nitrogen cycle

Ecological niche

For a species to maintain its population, its individuals must survive and reproduce. Certain combination of environmental conditions are necessary for individuals of each species to survive, obtain energy and nutrients and avoid predators. The total requirements of species for all resources and physical conditions determine its habitat and how abundant it can be at any particular place within its range. These requirements are abstractly termed as the ecological niche. The ecological niche could be moulded as an imaginary space with many dimensions and where each dimension or axis represents a range of some environmental conditions or resources that are required by the species.

The niche of a plant may include a range of temperature, which it can tolerate the intensity of light required for photosynthesis, specific humidity and minimum quantities of essential soil nutrients for uptake. Generally, an ecological niche is the role and position the species has in its environment and it encompasses how it interacts with abiotic and biotic factors of the environment to meet its needs for food, shelter, survival and reproduction.

There are two types of niches, namely: fundamental and realized niches. The fundamental niche of the species includes the total range of environmental conditions that are suitable for existences without the influence of interspecific competition or predation. In other words, it is the potential niche that would prevail in the absence of competition and other factors that might constrain its acquisition and use of the resources. The realized niche describes that part of the fundamental niche, which is actually occupied by the species. This is the actual niche, which an organism occupies as a result of competition for its resources and problems in acquiring those resources. The realized niche is smaller than the fundamental niche.

According to the competitive exclusion principle, two species cannot have exactly the same niche in a habitat and stably

co-exist. This is because species with identical niches also have identical needs, which means, they would compete head to head for the same resources such as nesting sites or territory. In the competition, one of the species will be superior to the other in utilizing the niche, and the inferior species will disappear from the ecosystem. A famous example of the competitive exclusion principle involves two species of *Paramecium*, that is, *P. caudatum* and *P. aurelia*. When raised separately in the laboratory, both species will thrive; but when raised in the same test tube (habitat), with a fixed amount of nutrients, both will grow more poorly and *P.aurelia* will eventually out compete *P. caudatum* for food leading to death of *P. caudatum*.

However, there are cases where two species partially share the niche. The two species compete in the overlapping parts of the niche for resource, nesting sites or territory. If the overlap is minimal, then both species can co-exist. The competitive exclusion may be avoided if one or both of the competing species evolve to use different resources, occupy different areas of the habitat or feed during different times of the day. The results of this kind of evolution is that, two similar species use largely non-overlapping resources, and thus, have different niches. This is called resource partitioning and it helps the species to co-exist because there is less direct competition between them.

Relationship of trophic levels in terms of energy flow

There is an existing relationship between trophic levels and energy flow. Energy always flows from lower trophic level to the upper trophic level. During this flowing of energy, some amount is lost as metabolic heat at each trophic level. Hence, energy decrease as it moves from lower to upper trophic levels. A trophic level is a group of organisms with a similar feeding behaviour or nutritional habit, for example, producers, primary consumers and secondary consumers. The first trophic level which is also the lowest level contains the producers, which include green plants, and photosynthesizing algae and sea grasses found in aquatic ecosystems. These are consumed by herbivorous or plant eaters at the second trophic level. In the third trophic level, the primary carnivores or meat eaters feed on the herbivores. The fourth trophic level constitute the secondary carnivores, which eat the primary carnivores. This feeding relationship can be observed in a linear sequence of organisms through the succession of organisms in a repeated process of eating and being eaten. This is collectively called a food chain. The design of the food chain can vary in accordance with the ecosystems. Food chains are made up of the same basic trophic levels. The organisms that constitute the food chain are thus classified based on their feeding behaviour.

Types of food chain

The classification of food chain depends on the type of organisms that constitute the first trophic level. On this basis two common types namely the grazing food chain and detritus food chain are recognized.

In the grazing food chain, autotrophs which include green plants, algae and some bacteria are the primary producers, and they constitute the first trophic level. The primary producers use light energy and inorganic compounds to synthesize their own food, the molecules of which are stored in their tissues. Heterotrophs including fungi, some bacteria and animals

obtain organic molecules containing energy to support their growth and reproduction. The primary producers are, therefore, the only channel through which energy enters the ecosystem.

The energy then passes through several levels of consumers, that is, the primary, secondary and tertiary consumers, and finally ends up to decomposers. The total amount of energy converted to organic compounds in a given area per unit time is called net primary productivity. In an ecosystem, the difference between energy fixed per unit time and energy utilised by the metabolic activities of organisms in a community is called net productivity of the ecosystem. The net primary productivity of green plants in the ecosystem is partly utilised by producers in respiration. Some energy is captured by herbivores. As producers die, decomposers and detritivores obtain energy from producers and release it to the environment. Thus, the gross energy production of green plants in the ecosystem may be oxidised in respiration, eaten by herbivores, and after death and decay of the producers utilised by the decomposers, which finally release it into the environment. The assimilated food by herbivores can be stored and transformed to more complex organic molecules. The energy from these transformations is supplied through respiration. Similarly, energy in the herbivores also passes through three routes, that is, respiration, decay of organic matter by microbes and consumption by the carnivores. The total energy assimilated by the secondary consumers follows the same course and its disposition into respiration, decay and further consumption by other carnivores is entirely similar to that of the herbivores.

In the food chain, the initial link is a green plant or producer which produces chemical energy. This energy is made available to consumers. For example, marsh grass is consumed by grasshopper, which is in turn, consumed by a toad. The latter is then consumed by snake, which is a food for a hawk as indicated in Figure 6.7.

Grass → **Grasshopper** → **Toad** → **Snake** → **Hawk**

Figure 6.7 Simple grazing food chain

The arrows in the chain mean, "eaten by" or indicate the direction of energy flow.

In detritus food chain, the dead organic remains including metabolic wastes, and exudates derived from grazing food chain serve as sources of energy in the ecosystem for a group of organisms called detritivores. Thus, the detritus food chain starts with organic debris from which decomposers and detritivores obtain nutrients and energy. Thus, the energy from the dead organic matter flows to detritivores such as millipedes, dung flies, terrestrial worms (earth worm) and burying beetles and predators of detritivores such as black sparrow bird and ultimately to the second carnivore such as a hawk as indicated in Figure 6.8. Thus, the ecosystems with detritus food chain depend on the energy derived from organic matter, which is produced by another system.

Leaf litter → Earth worm → Black sparrow bird → Hawk

Figure 6.8 Detritus food chain

Food web

In simple grazing, food chain consisting of grasses, grasshopper, toad, snakes, and hawk as explained in the previous section, each organism is shown as having only one source of food. However, in a typical environment an organism may have more than one source of food and may be eaten by several other organisms.The grasshopper, for example, does not feed on grass only, it rather feeds on other plant leaves. Likewise, the toad feeds on a variety of insects. These possibilities create a limitless number of an inter-connected set of food chains that collectively constitute a food web. Through food webs, energy is transferred in ecosystem from plants through herbivores to carnivores, omnivores, and ultimately to the detritivores and decomposers which unlock the nutrients and enrich the soil with organic matter. The food web is a mesh of interconnected food chains, representing the flow of energy from a group of organisms at one trophic level to another group of organisms at a different level.

In the example of the food web given in Figure 6.9, grasses, shrubs and herbs or plants represent the primary producers. They are the source of energy for the primary consumers such as antelope, zebra and buffalo. That means, each of

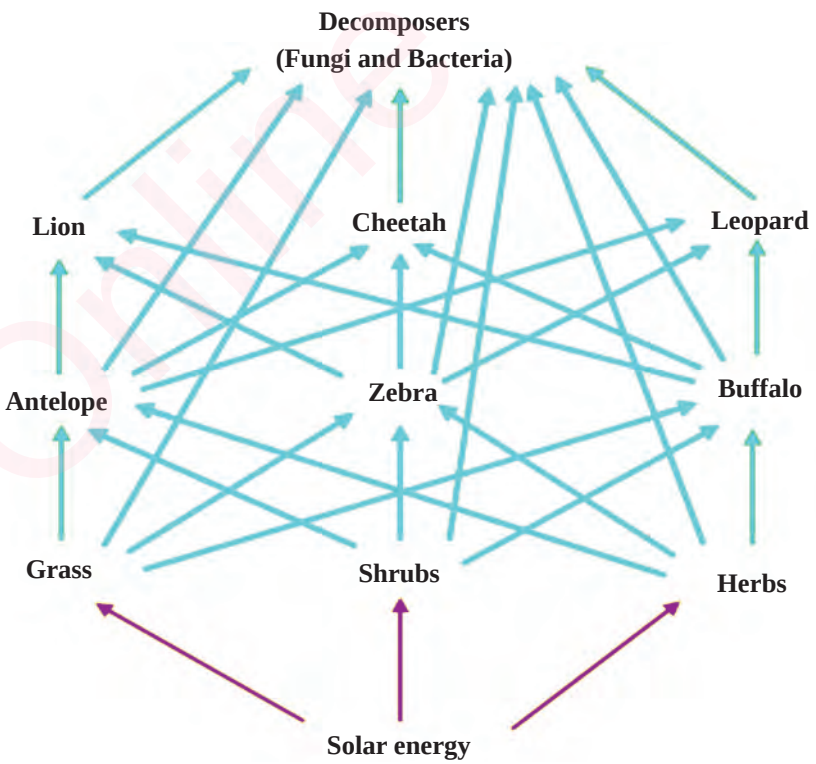


Figure 6.9 Illustration of food web

these herbivores, has three alternative plant sources of energy. The primary consumers, in turn are the source of energy for the secondary consumers, which are lion, cheetah, and leopard. Likewise, each of the secondary consumers has three alternative sources of energy, that is, antelope, zebra and buffalo.

When organisms in the first, second and third trophic levels die, their bodies are acted upon by decomposers, which apart from extracting energy, they also facilitate the release of the locked nutrients. The more alternative pathways the food web has, the more stable is the community. It is therefore, advantageous to study the community using the food webs instead of food chains. This is because the web is more informative and indicates various sources of food for the consumer levels in the ecosystem.

Ecological pyramids

Feeding relationships and the efficiency of energy transfer through the biotic components of the ecosystems have been traditionally summarised in pyramid diagrams called ecological pyramids. The first diagram of this nature was designed in the 1920s, by Charles Elton and this explains why the ecological pyramids are alternatively called Eltonian pyramids. The ecological pyramid can be defined as a graphical representation designed to depict biomass or bio productivity, the number of organisms and energy relationships at each trophic level in a given ecosystem. The ecological pyramids begin with producers such as green plants, algae or phytoplanktons at the bottom and proceed through the various trophic levels. The first trophic level consist of herbivores, which feed on plants. The second trophic level consist of primary carnivores that feed on herbivores and the third trophic level consist of secondary carnivores that feed on primary carnivores. The fourth trophic level consist of tertiary carnivores that feed on secondary consumers. The ecological pyramid consists of a number of horizontal bars depicting specific trophic levels. The length of each bar represents the total number of individuals, biomass or energy at each tropic level in the ecosystem. There are three types of ecological pyramids namely, the pyramid of numbers, biomass, and energy.

Pyramid of numbers

The pyramid of numbers represents the total number of individuals of different species at each trophic level. The width of the bars represents the numbers using linear or logarithmic scales. The numbers are taken per unit area of the terrestrial habitat or volume for aquatic habitats. The shape of the pyramid of numbers depends on the size of the bottom bar which represents the number of producers. The pyramid of numbers in a grassland community has a broad base because the producers are small and numerous as exemplified in Figure 6.10 (a). Similarly, in a pond ecosystem, the pyramid has a broad base because of a large number of phytoplanktons, which are the producers in this case. Thus, in both the grassland and the pond ecosystems, the pyramids are upright.

However, in a forest ecosystem, the pyramid of numbers has a narrow base because a single tree is likely to feed numerous herbivores. The ecological pyramid of this type is said to be inverted. An inverted pyramid is also experienced in communities with parasites, in which a single host can harbour hundreds of parasites as shown in Figure 6.10 (b).

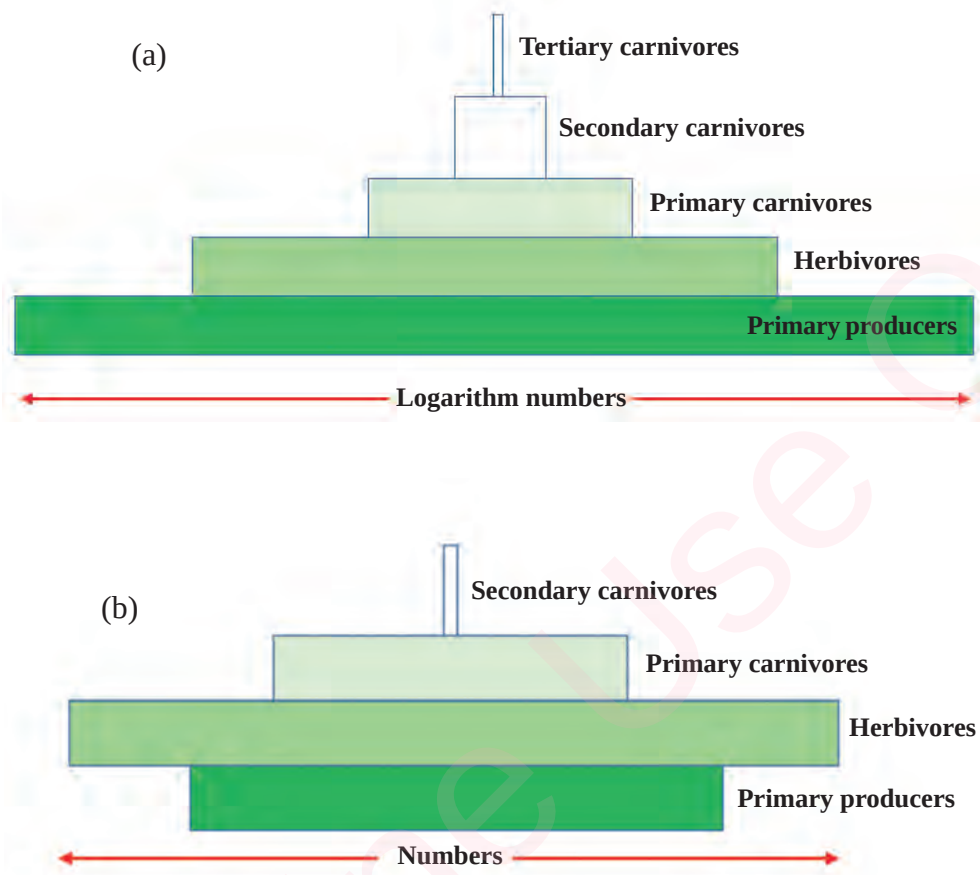


Figure 6.10 Pyramid of numbers in (a) grassland ecosystem and (b) forest ecosystem

Advantages and limitations of the pyramid of numbers

Although construction of the pyramid of numbers is confronted by some complications, its construction is relatively easy compared to other pyramids. Data collection for its construction can be easily done by using simple sampling techniques without killing any organism. Additionally, it is a good method for comparing changes in population numbers at different times of the year, for example, in wet and dry seasons.

The pyramid of numbers has a number of constraints associated with their application as follows:

Firstly, the range of numbers from the producers to the top carnivores may be so great that it becomes very difficult to draw the pyramid to scale. Secondly, the pyramid considers only the number of organisms and ignores the size. For example, the size of producers varies, and yet one grass plant is given the same status as a baobab tree. Besides that, some pyramids involving large

producers such as a tree feeding several herbivous insects or parasites example ticks feeding on consumers such as cow, are inverted. This explains why a true pyramid of numbers is not often obtained. Thirdly, the pyramid of numbers do not take into account the juveniles and immature forms of a given species whose nutritional and energy requirements may differ from those of the adult. Lastly, in the pyramid of numbers, the trophic levels of organisms are not easily determined with certainty.

Pyramid of biomass

The pyramid of biomass is more practical and useful as it represents the quantitative relationships of the standing crops because it involves recording the mass of living material at a particular time in the trophic level. Standing crop is the total biomass of an ecosystem or any of its components at a given point in time. In this pyramid, there is a gradual decrease in the biomass from the producers to the higher trophic levels. The pyramid of biomass is usually determined by collecting representative samples of all organisms occupying each trophic level separately and measuring their dry weight. This overcomes the size difference problem because the weight of all kinds of organisms at a trophic level is recorded and expressed in per unit area such as g/cm^2, kg/m^2 or t/ha.

In most terrestrial ecosystems, the pyramid of biomass has a large base of primary producers with a smaller trophic level placed on top to produce an upright pyramid. On the contrary, in many aquatic ecosystems, the pyramid of biomass may assume an inverted form. This is because the producers are tiny phytoplanktons that grow and reproduce rapidly. Phytoplanktons are consumed by larger organisms called zooplanktons that are relatively larger compared to them. As a result, the pyramid of biomass has a narrow base and the structure of pyramid, therefore, assumes inverted shape as shown in Figure. 6.11.

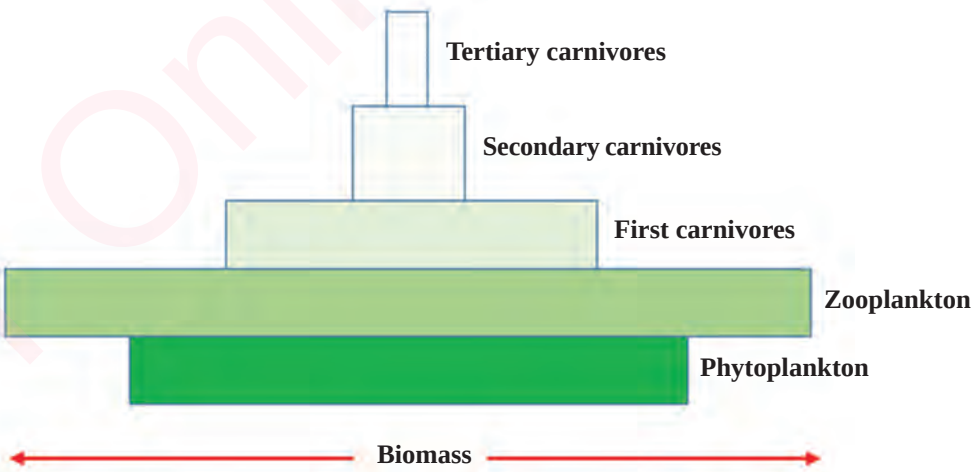


Figure 6.11 Pyramid of biomass for an aquatic ecosystem

Advantages and limitations of the pyramid of biomass

The pyramid of biomass gives a more accurate assessment or measure of energy at each trophic level since the judgment on the amount of energy is based on dry mass.

It takes into account the size difference of organisms, thus, overcoming limitations of using pyramid of numbers.

Besides its usefulness in establishing the energy flow between groups of organisms in different trophic levels, the pyramid of biomass is associated with some shortfalls:

(a) The determination of dry mass is destructive since it involves killing of organisms.
(b) It is impossible to measure the biomass of all individuals in a population, and therefore, only a small sample of individuals is taken and this may not reflect the reality.
(c) The pyramid of biomass is more laborious, and expensive in terms of time and equipment.
(d) The time of the year, in other words, the season, during which the biomass is measured affects the results unless the biomass measurements are recorded during the same season.

Pyramid of energy

The most fundamental and ideal way of representing energy relationships between organisms in different trophic levels is by means of the pyramid of energy. This is the type of ecological pyramid which represents the relative amount of energy available in each trophic level as shown in Figure 6.12. The pyramid of energy is constructed according to the rate at which food material (in the form of energy) passes through the food chain. Some organisms may have small biomass but the total energy they assimilate and pass on to higher trophic levels may be considerably greater than that of organisms with much larger biomass. The pyramid always tapers towards the apex because the energy normally decreases as it flows from one trophic level to another. Thus, the last trophic level receives a minimum amount of energy. The gradual decrease in the energy content at successive trophic levels from the producers through the consumers results in the upright shape of the pyramid of energy that is never inverted. An inverted pyramid of energy is an indication that the community is about to collapse.

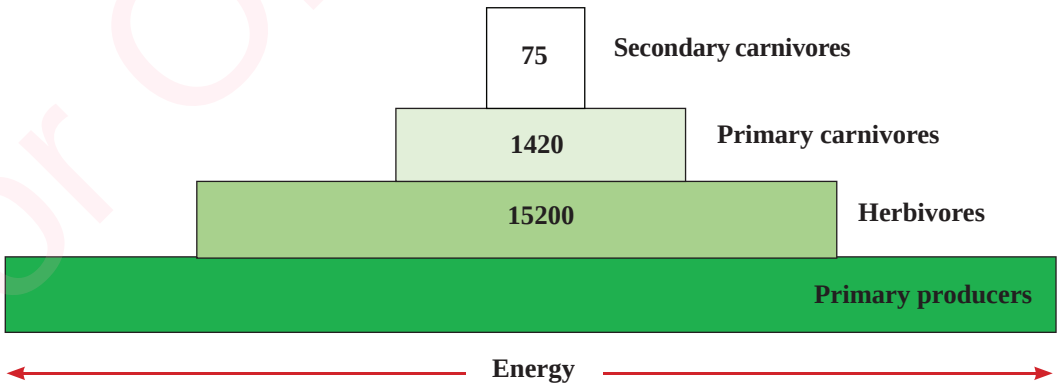


Figure 6.12 Pyramid of energy

Advantages and limitation of the pyramids of energy

The pyramid of energy takes into consideration the rate of production, per unit area or volume unlike the pyramids of numbers and biomass which depend on standing states of organisms at a particular time.

It allows comparison of different ecosystems, for example, aquatic and terrestrial ecosystem as well as comparison of relative importance of different populations within one ecosystem to be compared.

The pyramid of energy is dynamic and therefore, it is likely to accommodate changes. For example, the input of solar energy can be added as an extra rectangle at the base of the pyramid.

Despite its usefulness over other types of pyramids, the pyramid of energy also has its limitations.Firstly, the method for obtaining energy data mainly involves destructive precedures. This is because it involves killing and combustion of the representative organisms in the population in order to obtain their energy. Energy data for the pyramid of energy are the most difficult to collect because more measurements are required than for the pyramid of biomass. Secondly, it is impossible to measure the energy content of all individuals in a given trophic level. Therefore, in order to overcome this challenge, a small sample of representative organisms is usually collected whose data may not trully represent the entire population.

The most fundamental problem is that it is not easy to identify the organisms' trophic level with accuracy because many organisms feed at various trophic levels. Furthermore assigning all plant materials to producer level in ecological pyramids is considered misleading by some scholars. This is because non-chlorophyllous plant organs such as tubers, fruits, and seeds are plants but not primary producing photosynthetic organs. Moreover, some herbivores are unable to digest cellulose and others are highly selective when it comes to eating plant parts, where some feed only on seeds, fruits, roots, or nectar. The ecological pyramids are thus not designed to accommodate these differences.

The pyramid diagrams also omit the dead organic matter, which contains about 80% of the gross primary production. However, in principle, detritivores and decomposers utilize this energy.

Exercise 6.1

1. Write short notes on food chain and food web.
2. (a) What is the ecological pyramid?
   (b) In which ways do the pyramid of numbers differ from the pyramid of biomass?
   (c) Explain how limitations of the pyramid of number and biomass are overcome in the pyramid of energy.
3. (a) Explain how energy flows through the ecosystem, citing the relationship between different trophic levels.
   (b) Explain why energy flow from one trophic level to the next is not 100% efficient.

4. With examples, briefly explain how abiotic and biotic components of the ecosystem interact.
5. Explain the role of microbes in the recycling of nutrients within an ecosystem.
6. Write short notes on the nitrogen cycle citing its significance in terrestrial ecosystems.

Methods of studying ecology

The aim of studying ecology is to understand the existing relationship between organisms and how each in turn, interacts with its environment. In order to understand thoroughly this reciprocal relationship of organisms and their environment, ecological investigations or studies are inevitable. Ecological studies can be quantitative or qualitative in nature. Quantitative data are the ones obtained through measurements, and counting while qualitative data are obtained through description of things. The ecological study requires sound methods and techniques of collecting, analysing and presenting biotic and abiotic data. The aims and objectives of an ecological study will determine sampling methods and techniques to be employed. Usually, it is difficult to collect all attributes of a particular abiotic or biotic component in a particular ecosystem. In order to save time and resources, sampling efforts are required in conducting an ecological study. It is important to have a representative portion called a sample for those attributes of organisms and the environment. This ensures the relevance and reliability of the collected data for a sound conclusion.

Methods of collecting ecological data can be subjective or objective. The former are arbitrary methods, which involve estimation, for example, of cover using a scale ranging from abundant to rare or using a frequency scale. The objective methods involve direct counting methods such as photographs, observations, quadrats, and indirect methods, which involve removal-capture-recapture methods. During sampling, the data can be gathered randomly, systematically or by stratifying the population or community. In most cases, methods employed in collecting ecological data may involve more than one technique. For example, a combination of random and systematic or stratified and systematic sampling. In conducting systematic sampling, ecological data is usually collected from a designated line called transect within which small units called plots are established at regular intervals from a randomly selected point. The actual sampling is done in these units. The data collected are used to analyse various ecological parameters such as population size, a degree of pollution, species abundance and distribution.

The concept of sampling

Sampling is the process of selecting representative units from a group or population to be used as a basis for estimating the characteristics of a larger population. A sample may be defined as a small part, quantity, or group drawn from a larger population to represent the characteristics of the entire population. In ecological studies, a survey of the entire population under investigation regardless of its size is too time consuming. As a result, it is difficult for such study to be practical within the limited available time and resources. It is for this reason analysis of samples from a representative sub-area

or subpopulation within a larger area is deemed necessary. In order to achieve a representative sample, an investigator or ecologist conducts a reconnaissance survey to ascertain a representative sample stand from which samples will be gathered. The actual sampling is normally done in designated units called sample plots. Sampling is advantageous in that, it saves time, cost and efforts required to conduct an ecological study. These advantages combined together, make sampling an effective practical method for the infinitive populations. In a larger and heterogeneous population, establishing a representative sample is not easy to undertake. Consequently, there are chances of committing errors if appropriate expertise is not involved to select the samples.

Sampling techniques

Another important aspect to consider during sampling is to select the type of sampling method. The sampling method, also referred to as a sampling technique is employed in studying a fraction of the larger population. Sampling should be carefully done as this affects subsequent processes such as data analysis and conclusions to be drawn. Thus, the sample plots should be selected objectively based on probabilistic sampling procedures. The best way to implement objective sampling is by using systematic and random sampling techniques. This helps to eliminate further subjectivity in locating samples once the initial sub population or entities have been earmarked, hence, there is no flexibility. The advantages of systematic and random sampling are combined in a system called stratified random sampling. The three types of sampling techniques, that is, systematic, random, and stratified fall under probability sampling.

Simple random sampling

This is the probability sampling in which each member of the population has equal chances of being selected. It is usually carried out when the area under study is fairly uniform, very large and there is a limited time available. When using simple random sampling technique, samples are taken from segments of the larger habitat. The computer-generated numbers or table of random numbers determine the sampling points and the samples are taken using a quadrat frame. This method helps to avoid an introduction of any personal biasness and it is advantageous in that, it needs only a minimum knowledge of the study group of the population in advance. It also ensures a high degree of representativeness of the population, and it is a fair way of selecting a sample from a given population since every member is given an equal opportunity to be included in the sample. The drawbacks for this sampling technique are varied and they include the fact that, the method cannot be applied where the population units are heterogeneous in nature. Additionally, it is tedious and time consuming particularly, when dealing with large samples.

Systematic random sampling

Systematic random sampling is the type of probability sampling method whereby, sample members from a larger population are selected after a certain interval. The starting point is selected randomly but each piece of data is chosen at a fixed interval, say after every 500 meters along the line for the inclusion in the sample.

Normally the starting number is an integer, which must be less than the total number of individuals in the population. This integer corresponds to the first subject. Then, there is the selection of an interval, another integer

that will serve as the constant difference between any two consecutive members in the progression. For example, if one has a population total of 100 individuals and needs 12 subjects, he/she then picks the starting number, say 5. If the interval which is picked is 8, then the numbers of the sample will be 5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 85 and 93.

A researcher may prefer to use a systematic random sampling method because of its simplicity. This property allows addition of the degree of systems or processes into the randomly selected subjects. The method also ensures an even sampling of the population. However, the process of selection can interact with a hidden periodic trait within the population. If the sampling technique concedes with the periodicity of the trait, the sampling technique will no longer be random and the representativeness of the sample is compromised. In addition, the technique is more biased because not all members or points have an equal chance of being selected. In other words, it is less truly random than simple random sampling. This may cause either over or under representation of a particular trait.

Stratified random sampling

The name stratified sampling derives its meaning from the term stratum (plural = strata), which means small subdivisions. Stratified sampling, therefore, is a probability sampling method in which a population is divided into two or more groups (strata) based on one or common characteristics. This method of sampling, therefore, intends to guarantee that, the sample represents specific subgroups or strata. The application of a stratified sampling method involves dividing populations into subgroups and selecting subjects from each stratum in a proportionate manner. In this way, the method may solve problems that cannot be solved by simple and systematic random sampling methods. For example, in the systematic and random sampling techniques, the samples may not cover all areas of the habitat equally. Thus, such samples may not be representative of the whole populations, if the sampling units of the population are heterogeneous in nature. Therefore, in a situation like this, the whole population is divided into certain number of subgroups or strata in such a manner that, the small groups are homogenous within themselves, but heterogeneous between themselves.

The stratified random sampling is considered superior to simple random sampling because the process of stratification reduces sampling errors and ensures the greater level of representation. In the stratified random sampling, an adequate representation of all subgroups is ensured. When there is homogeneity within the strata and heterogeneity between the strata, the estimates can be as precise as compared with the simple random sampling.

The use of stratified sampling method is associated with some challenges. The application of this method requires the knowledge of members of the strata and ability to distinguish between strata in the sample frame at initial stages, which in practice, may create difficulties. In addition, the method takes a long time and therefore, it becomes more expensive due to an extra stage in the sampling procedure.

The use of transects and quadrats in sampling flora and fauna

Quadrats and transects are commonly used in ecological investigation in the process of collecting abiotic and biotic data. The use of transects and quadrats is important

in order to standardise the sites under investigation. Collection and sampling is often confined to the area of the transect called plots. The quadrat which is usually a square or rectangle and sometimes a circle frame is placed within the plots and sampling is conducted.

The transect is a strip or line between two points along which an ecological investigator conducts sampling. A transect can simply be a string or a rope stretched in a line on the ground, or a path between two parallel running lines or ropes. The former is called the line transect, and the latter is a belt transect. The use of modern technology has made it easy to use Global Positioning System (GPS) and topographical maps of an area under the investigation to set a transect. In this case, coordinates of the two points, the start and end points, are recorded by GPS from the map and from the start point, the end point is tracked by GPS along an imaginary straight line. This is suitable for transects covering long distances where rope can hardly be used. The type of transect to be used in an ecological survey depends on the quantitative and qualitative nature of the investigation, the degree of accuracy required, the nature of the organisms, the size of the area to be investigated, and the time available.

Line transect

In the line transect method, a tape or a string is laid on the ground of the study area in a straight line between the two points in the direction of environmental gradient as indicated in Figure 6.13.

Figure 6.13 Ecologist collecting data along a line transect denoted by a white line laid on the ground

Then the abiotic or biotic data along the length of the line randomly or systematically that touch or cover the line are recorded, at regular intervals. The line transect method is particularly useful where a transition in habitats and populations through an area is suspected. The investigator needs to construct a profile of the transect to indicate the level of change, if there is a significant height change along the transect. This is particularly, important where vertical height for instance-altitude is a major factor in determining the distribution of species. For example, on a seashore habitat the height above the sea affects the duration in which a particular habitat is submerged by a tide. This has a considerable bearing on the species that can survive on the seashore habitat because its distribution is more related to the vertical height on the shore rather than the horizontal distance along it. The height variation that are recorded along a line or belt transect are called profile transect.

Belt transect

A belt transect is a strip of chosen width running through the habitat which is made by setting up two line transects. Data collection is conducted between the lines that can be of width between 0.5 m and 1m apart. The belt transect is useful in qualitative and quantitative surveys where it is combined with the use of quadrat frame and line transect. In this case, the quadrat is laid down alongside the line transect and all species within it are recorded. It is then moved at its own length along the line and the process is repeated. This provides the record of species in a continuous belt. The quadrat may also be used at regular intervals for example, after every 100 meters or other suitable interval along transect.

Quadrat

A quadrat is a frame of a known area which is laid along a transect line during sampling of ecological data. The quadrat is usually made up of a collapsible wooden plastic or metal frame. The collapsibility of the quadrat frames makes it more portable for carrying over long distance while sampling. The quadrat may be a square frame of dimensions or a pin frame also called point quadrat as depicted in Figure 6.14 (a) and (b). The size of the quadrat is not fixed as it varies with the aim and objectives of the study. For example, in assessment of lichens density a quadrat frame of 0.5 m x 0.5 m that is 0.25 m^2 would be suitable. On the contrary, a 1m^2 quadrat (1mx1m) will preferably be used to sample grasses, herbs and sedges. In most woodland ecosystems as in Miombo woodlands relatively larger quadrats of 100 or 400 $m^{2,}$ are commonly used in sampling trees and 5 m x 5 m for shrubs.

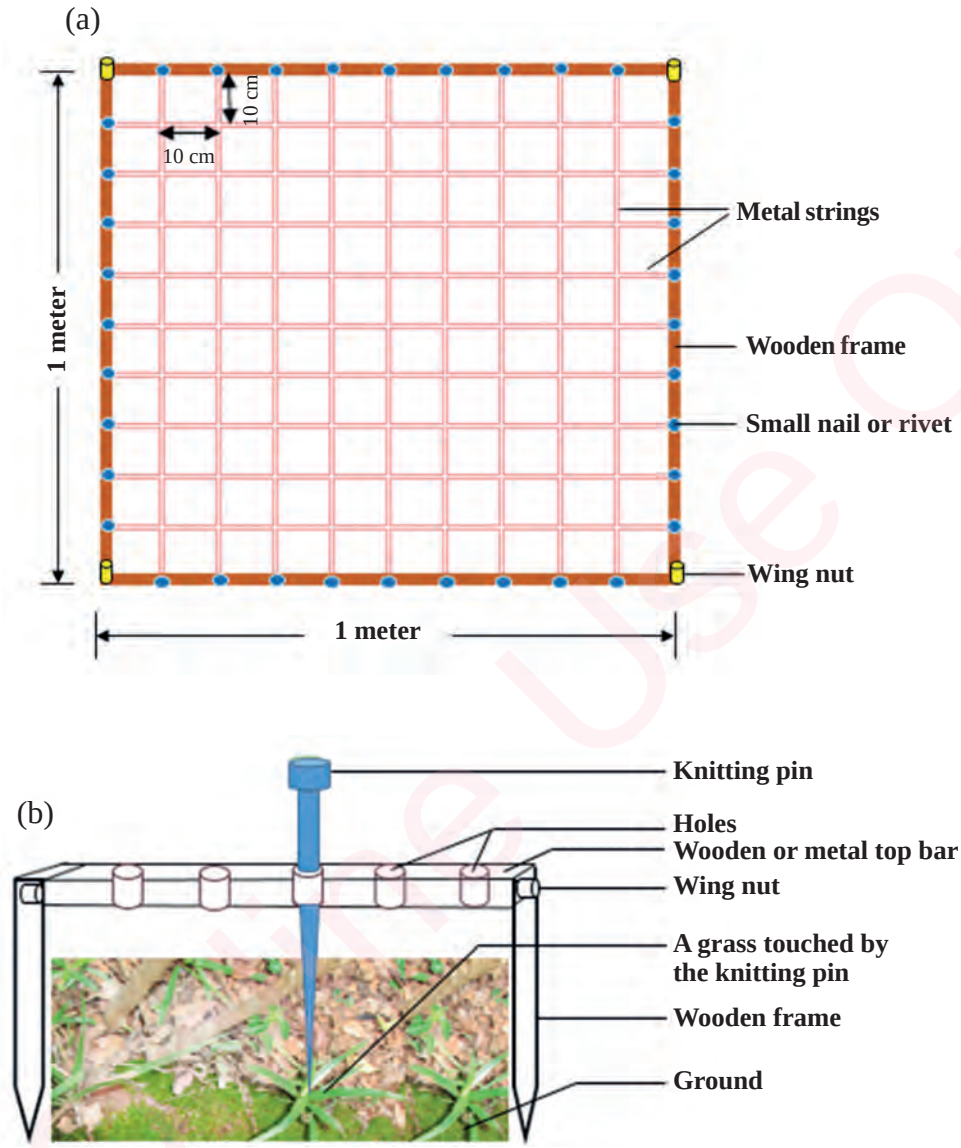


Figure 6.14 Types of quadrats (a) A collapsible graduated frame quadrat with 100 subquadrats each measuring 100 cm^2 and (b) Pin frame quadrat

Besides the portable quadrat, permanent quadrats are also common. These are set by marking an area of a known size using metal pegs, reinforced in the ground. The corner pegs of the set quadrat can be geo-referenced by GPS or delineated by a white and red coloured tape for easy reference in the future.

In floristic investigation the trees inside the quadrat or plot constitute the candidate species for study. Normally, these trees can be marked with numbered metal tag for easy reference, and to make sure that a follow up or monitoring data is taken from the same individual species. Permanent sample plots or quadrats are very useful for studies

involving seasonal or annual changes in a community as in the case of succession. In trees, it could be growth or changes in the number of epiphytes with time, fruiting and flowering phenology. On the other hand, permanent quadrats can be used to collect data for grasses or herbs within it. This could include the changes in species density, number, or cover. The abiotic data such as humidity, Cation Exchange Capacity (C.E.C), organic matter and moisture can be recorded seasonally within the permanent plot. A permanent line transect has two or more permanent plots.

The use of quadrat in sampling flora and fauna

For immobile organisms such as plants, or for every small and slow moving organisms, plots called quadrats may be used to determine the population size. Each quadrat marks off an area of the same size, typically, a square area within the habitat. A quadrat can be made by striking out an area with sticks or by using a frame quadrat. After setting up the quadrats, counts are made on the number of individuals within its boundaries. Multiple quadrat samples are performed throughout the habitat at several random locations to ensure that, the numbers recorded are representatives of the overall habitat. In the end, the collected data can be used to calculate various aspects in relation to species distribution.

During sampling, a quadrat is thrown or laid along the line transect but in some cases it can be used without a line transect particularly, in a uniform habitat, for example, on grasslands. In both cases placement of quadrat can be done systematically, for example, after every 200 meters or at random. An example of sampling species data randomly in a transect line may involve dividing the line into ten equal segments. Each segment is assigned a number and a decision on the number of sample points is made, for example, five sample points. Selection of random numbers may involve preparation of ten small pieces of papers assigned with numbers 1-10, then each piece of numbered paper is folded into a small ball that is placed in a hat. The hat containing the paper balls is shaken slightly, then a paper ball is drawn while closing the eyes.

Once drawn from the hat, the paper ball should be unfolded to reveal the number which is then recorded. This procedure will be repeated four times to obtain a total of five numbers which will be the total number or the sampling points or plots. The quadrat frame will now be placed in the transect segments corresponding to the number revealed in each of the five randomly picked paper balls. In each segment where the quadrat is placed, biotic data such as number of species, their frequency and evenness from the five sampling plots are recorded.

On the other hand, a pin frame or point quadrat is more suitable for the overgrown habitats where several species such as grasses are overlapping. This type of quadrat usually consists of an inverted 'U' shape wooden frame with the top wooden frame bearing several holes. During sampling for example for species richness, a frame is placed on top of the grassland vegetation plot. A pin is inserted through the holes and pressed downwards. The species touched by the pin as it reaches the ground is recorded. The pin is withdrawn and run through the second hole, and the species touched by it on the ground is recorded. This is repeated for all holes and the species are recorded. The pin frame quadrat can be moved to

another plot selected either randomly or systematically, where the data is collected using the same procedures. At the end, all species touched/recorded in all plots are analysed for richness and frequency or any other desired parameters.

Studies have revealed that sometimes an analysis of species within a quadrat is unnecessary, particularly, in homogenous habitat. This is due to the fact that, the number of species does not increase once a certain quadrat size or the number of plots are sampled. The quadrat size is determined by calculating the minimal area. The minimal area is, therefore, the smallest area on which a species composition is adequately represented. It gives an average number of species of a community and it works better in homogenous community where species recurrence is common.

A minimal sample area is noted when further sampling in four or five more quadrats does not yield any new species. Alternatively, a minimal area can be determined by establishing a plot of small area (1 m x1 m) or 1 m^2 and all species in this quadrat are recorded. The plot size is doubled into 2 m^2 and additional species are recorded. This procedure of doubling plot size is repeated and all additional species are recorded each time a plot size is doubled. The obtained species data is plotted against the size of the sample area as seen in Figure 6.15. The minimal area is the sample area in the graph corresponding with the point at which the graph starts to become horizontal after a steep increase. This in turn will give the size of the sample area, and hence, the number of quadrats corresponding to that area is established.

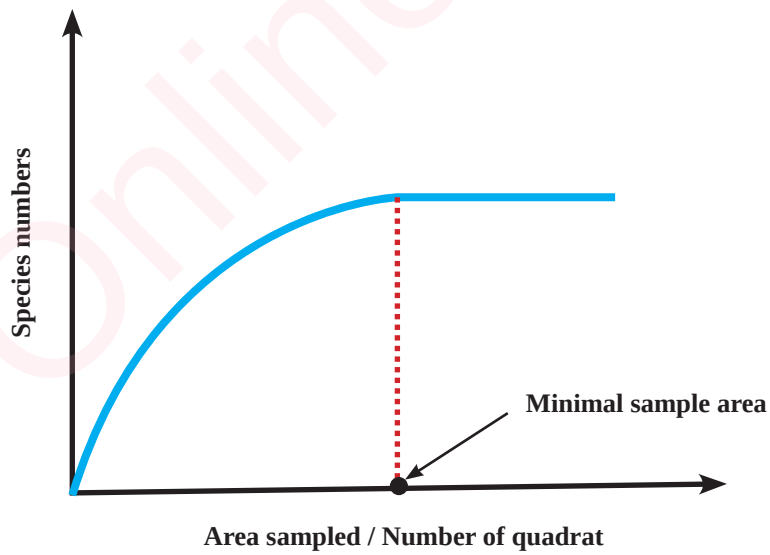


Figure 6.15 Species cumulative curve showing minimal sample area

Activity 6.1 To determine a minimal sample area

Procedure

(i) Identify any grassland community around your school.

(ii) Establish a small area such as 1m x 1m (1 m^2 quadrat) and record the number of all grass and herb species.

(iii) Enlarge the area of the quadrat twice and record the additional number of species occurring for each enlarged area separately.

(iv) Repeat the process by doubling the quadrat area four times, eight times while counting the number of species each time the quadrat size is doubled until the species added to the list become very few.

Assignment

1. Plot the number of species against the size of the quadrat area to obtain species/area curve.
2. Determine the minimal area from the graph.
3. Briefly explain the meaning and significance of a minimal sample area in ecological investigations.

Collection of ecological data

Species quantities can be estimated using the relative magnitude terms such as dominant, abundant, occasional, rare, and frequent. Similarly, absolute scale values such as percentage cover are commonly used. Species frequency and cover are important measures in ecological studies. Abundance carries the same meaning as number of individuals per species. Unlike density, the former refers more to a number estimate.

During sampling of ecological data, for example in flora surveys, a reconnaissance survey is done first to give an investigator preliminary understanding of the area under investigation. This can be achieved by moving around the study area or using both aerial photographs and topographical maps to acquire a general picture of the study site. The reconnaissance survey helps the investigator to decide among other things, the sample size, equipment to be needed and sampling methods. For example, an area with strata of different vegetation types such as forest, bushland and grassland, the stratified random sampling can be adopted. The investigator can then decide on how to sample each stratum for example by establishing the line transects and sample systematically or randomly along each transect or on each stratum.

The procedure of sampling ecological data systematically or randomly is done as explained earlier. Data collection within the plot can also be done using nested plots. In this sampling, a larger plot of 20 m x 20 m can be used to sample tree species, small plots of 5 m x 5 m placed inside the larger tree plots can be used to sample shrubs while smaller plots of 1 m x 1 m established inside the shrub plots can be used to sample grasses and herbs as shown in Figure 6.16. In this case plot **T** is the larger one for tree, plot **S** nested in plot **T** for shrubs, and subplots **G1**, **G2** and **G3** nested in plot **S** are for sampling grasses and herbs.

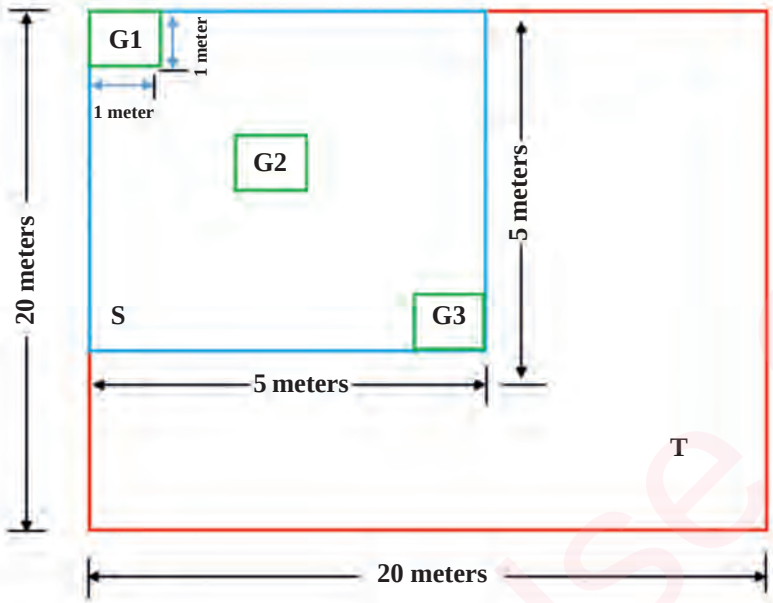


Figure 6.16 Nested plot

Prior to collecting data in the plots, it is important for the investigator to record the following information: collection date, plot number, geographical area, size of the plot, position including altitude, latitudes, longitudes, and aspect. Other information includes community name, for example, forest, woodland or grassland and general remarks on the plant condition. Species data collection requires a knowledge of the species found in a community under the study. This is important because it requires listing all species preferably by their scientific names. The list of species generated is called a checklist. This list gives an impression on species richness and the diversity of a particular area.

Species density refers to the actual count of individuals per unit area. Collection of density data is one of the easiest species analytical concept to comprehend. Collecting such data involves direct counting of individuals per species. This data is collected using quadrats of a known dimension or area and the number of counted individuals is expressed per total area covered by the quadrat. The area can be expressed in acre or hectare.

In collecting density data, each individual species is enumerated. This is very simple for the life forms such as trees, shrubs and tufted or solitary grasses because demarcating one individual from another is easy. This method may present some challenges in sampling creeping species such as stoloniferous plants like *Digitaria abyssinica* (African couch grass) or rhizomatous species such as *Zingiber officinale* (ginger). Species of this nature cannot be counted accurately because it may be hard to establish whether two individual stems seen above ground originate from one stem or rhizome or they are individual stems growing separately. The cover estimation in grassland communities is very involving, therefore time consuming. Instead, density estimation

rather than counting is commonly used for grasses. During sampling density data, the investigator should be consistent, especially in including or excluding individual species, which fall on the quadrat boundary.

The quadrat for density data collection will depend on the type of vegetation under investigation. The procedure for data collection within the plot is as stated earlier. The size of plot may vary depending on the vegetation being sampled. For examples, in grasslands, quadrats of 1 m^2 are usually used while for shrubs and trees plots of 25m^2 (5mx5m) and 100m^2 (10mx10m) can be used respectively.

In an example given in Tables 6.1 for tree and 6.2 for grasses and herbs, the total species density, that is, density of all trees is computed. Density of individual tree species can be obtained for each species per plot and per the entire site, transect line or sample area.

Table 6.1 Number of tree species in a sampled plot

Plot Number	Species name	Number of individuals
	Mangifera indica (Mango)	5
	Persea americana (Avocado)	3
1	*Prunus persica* (Peach)	7
	Albizia versicolor (Albizia)	4
	Psdium guajava (Guava)	6
	Albizia versicolor (Albizia)	5
	Citrus sinensis (Orange)	3
2	*Annona muricata* (Soursop)	9
	Persea americana (Avocado)	2
	Mangifera indica (Mango)	3
	Annona muricata (Soursop)	4
	Albizia versicolor (Albizia)	3
	Cocos nucifera (Coconut)	7
	Euphorbia tirucalli (Fire stick plant)	10
3	*Cedrela odorata* (Cedar)	5
	Bombax glabra (French peanut)	1
	Mangifera indica (Mango)	2
	Polyalthia longifolia (False ashok)	11
	Azadirachta indica (Neem)	5
	Dalbergia melanoxylon (African blackwood)	6

4	*Terminalia catappa* (Tropical almond)	3
	Cassia siamea (Cassod tree)	8
	Artocarpus heterophyllus (Jackfruit)	2
	Albizia versicolor (Albizia)	1
	Cocos nucifera (Coconut)	9
	Tamarindus indica (Tamarind)	3
	Adansonia digitata (Baobab)	2
5	*Ceiba pentandra* (Silk cotton)	6
	Albizia versicolor (Albizia)	2
	Mangifera indica (Mango)	4
	Cocos nucifera (Coconut)	3
Total		**144**

Table 6.2 Number of grasses and herbs in a sampled plot

Plot number	Species name	Number of individuals
1	*Pennisetum mezianum* (Fountain grass)	9
	Cynodon dactylon (Bermuda grass)	11
	Panicum maximum (Guinea grass)	20
	Ageratum conyzoides (Ageratum)	15
	Setaria homonyma	25
2	*Setaria sphacelata* (African bristle grass)	5
	Hyparrhenia rufa (Jaragua grass)	10
	Hyparrhenia filipendula (Tambookie grass)	20
	Ageratum conyzoides (Goat weed)	5
	Cyperus rotundus (Nut grass)	15
	Cyperus distans (Slender cyperus)	30
	Cyperus exaltatus (Spear of the stream)	10
	Panicum maximum (Guinea grass)	5
	Panicum trichocladum (Donkey grass)	2
3	*Paspalum vaginatum* (Seashoe paspalum)	1
	Digitaria ciliaris (Tropical finger grass)	1
	Ageratum conyzoides (Goat weed)	5
	Conyza stricta (Horseweed)	10

	Panicum repens (Torpedo grass)	15
	Panicum maximum (Guinea grass)	5
	Cynodon dactylon (Couch grass)	2
4	*Launaea cornuta* (Bitter lettuce)	5
	Ageratum conyzoides (Goat weed)	2
	Conyza stricta (Horse weed)	6
	Tridax procumbens (Coat buttons)	8
	Bidens pilosa (Black jack)	12
5	*Commelina benghalensis* (Benghal dayflower)	6
	Ageratum conyzoides (Goat weed)	6
	Conyza stricta (Horse weed)	8
	Cyperus exaltatus (Spear of the stream)	5
	Eleusine indica (Indian goosegrass)	2
	Panicum maximum (Guinea grass)	3
Total		284

Species frequency

The specie frequency is the number of times a species occur in a certain number of plots. It is expressed as a fraction of number of times a species appears in a certain number of plots to the total number of sampled plots expressed in percentage. Unlike, density, frequency data is easily obtained because it does not require counting of individual species but recording its presence or absence in the sample plots. Frequency is, therefore, an objective assessment that provides for a non-absolute measure. The species frequency is determined by the size and shape of the plot. This implies that species frequency can vary with an increase of plot size. The frequency data is also affected by the distance between plant species whose frequency is being determined. Thus, the size of the quadrat must be stated. It should be noted that, frequency of a species is recorded as present without regard to the number of individuals of the species present or their cover. For example, if the number of individuals of species X are 5 within a quadrat, its frequency is recorded as present but not five. This method of measuring species quantities is thus quick, easy and it can be used in large-scale ecosystems such as woodland.

It is possible to get high species frequency values even for species with very few individuals spread out evenly over the entire sample area. On the contrary, the low frequency values can be obtained for species with many individuals or extensive cover but limited to a small portion of the sample area. It is for this reason that frequency gives little or no indication of cover.

The distribution of quadrats can be conducted randomly or systematically. A worked example on how frequency is calculated is done for the data obtained for

trees in table 6.1, for grasses and herbs in table 6.2. The frequency data are expressed in percentage as summarized in Tables 6.3 and 6.4. In the collected data, the total number of plots was five for both trees, grasses and herbs. The frequency data is computed by establishing the total number of times in which a species is recorded in each of the five sample plots. For data collected in tables 6.1 and 6.2, the frequency data is calculated for *Mangifera indica*, *Persea americana*, *Albizia versicolor*, *Cocos nucifera* and *Tamarindus indica* species for trees. As for grasses and herbs, data is calculated from, *Cynodon dactylon*, *Panicum maximum*, *Eleusine indica*, *Ageratum conyzoides* and *Conyza stricta*. It should be noted that, the individual species is recorded as present once even if it is represented by more than one individuals in a plot.

Table 6.3 Species frequency for Trees

S/n	Species name	Frequency	Percentage
1	*Mangifera indica*	4/5×100	80
2	*Persea americana*	2/5×100	40
3	*Albizia versicolor*	5/5×100	100
4	*Cocos nucifera*	3/5×100	60
5	*Tamarindus indica*	1/5×100	20

Table 6.4 Species frequency for grasses and herbs

S/n	Species name	Frequency	Percentage
1	*Cynodon dactylon*	2/5×100	40
2	*Panicum maximum*	4/5×100	80
3	*Eleusine indica*	1/5×100	20
4	*Ageratum conyzoides*	5/5×100	100
5	*Conyza stricta*	3/5×100	60

Species cover or species abundance

The specie cover is a measure of proportion of ground occupied by species expressed as a percentage of the total area. This method is commonly used to estimate the plant species cover for grasses or herbs where individuals are hard to count due to their large number and the fact that some are rhizomatous or stoloniferous as shown in Table 6.5. The total area covered by a particular species is obtained by adding individual species cover obtained in each plot in a particular study site. In other words the cover gives an estimate of the shoot area occupied by species on the ground expressed as percentage of reference area. This method also applies to trees where it refers to the outline of the plant near the ground surface. This can be measured by determining the trees basal areas, which is

obtained by measuring circumference of the tree stem base immediately above the ground and convert it to area. The total stem basal area is then expressed as percentage to the reference area. Trees cover can also be estimated from the crown diameter by measuring the crown diameter of each individual tree. It is obtained by using a tape measure laid out on the ground from one side of the crown perimeter of the tree to obtain the first reading. Another tape laid perpendicular to the first tape to obtain the second measurement. The crown cover is then calculated from the following formula:

Where Cc = crown covered

$$Cc = \left(\frac{D_1 + D_2}{4} \right)^2 \pi$$

D_1= first measured crown diameter

D_2= second measured crown diameter

π = 3.14

Table 6. 5 Species percentage cover

Plot	Species name	Cover (%)
	Pennisetum mezianum	5
	Panicum maximum	20
1	*Setaria homonyma*	25
	Hyparrhenia rufa	10
	Cyperus exaltatus	35
	Ageratum conyzoides	25
	Conyza stricta	20
	Leersia hexandra (Cutgrass)	10
2	*Sporobolus pyramidalis*	5
	Setaria homonyma	20
	Setaria sphacelata	15
	Themeda triandra (Tussock)	5
	Cyperus distans	30
	Tridax procumbens	10
3	*Hyparrhenia rufa*	15
	Launaea cornuta	5
	Eleusine indica	10
	Cynodon dactylon	20
	Emilia javanica (Irish poet)	40
	Panicum trichocladum	20

4	*Bidens pilosa*	10
	Commelina benghalensis	15
	Leersia hexandra	10
	Tagetes minuta (Marigold)	25
5	*Eleusine indica*	35
	Tridax procumbens	5
	Setaria homonyma	15
	Commelina africana	10

As for the density and frequency, the cover measurement is obtained within the established plots, which can as well be randomly or systematically distributed. To estimate cover for grasses and herbs, a quadrat of $1m^2$ can be used. In order to simplify the counting, the quadrat is subdivided into small 100 grids using ten equal distanced (10 cm) strings as shown in Figure 6.17.

(a) (b)

Figure 6.17 Ecologists estimating species cover using grid frame quadrat

The crown shoot outline and the area occupied by plant forms is recorded accurately by transferring the filled squares from the quadrat grids to a graph paper with small 100 squares. The cover of each species is then evaluated by counting the squares filled by particular species and expressed as percentage of the total squares.

For example, if the total number of squares filled by *Panicum maximum* are 70 then its cover would be:

$$K = \frac{70}{100} \times = 70\%$$

In the quadrat shown in figure 6.17, the cover for species X would be:

$$X = \frac{10}{100} \times 100 = 10\%$$

while the cover for species P would be:

$$P = \frac{15}{100} \times 100 = 15\%$$

The overall species cover in this quadrat (species cover for species K, X and P) will then be the total number of squares occupied by species over the squares (100) =

$$\frac{31}{100} \times 100 = 31\%$$

Species density

This refers to the number of individuals of a given species in a given area. It is determined by counting the number of organisms in the randomly distanced quadrats. The method is advantageous such that, it is accurate and thus it allows different areas and different species to be compared. Furthermore, it provides an absolute measure of abundance. However, this method is time consuming, and it requires individuals to be defined.

To calculate the total species density per hectare for the data collected as presented in tables 6.1 and 6.2, the total number of individuals in each plot is calculated. The total number of individuals in all plots together is then calculated to get the species density for the entire sample areas summarised in Table 6.6. In order to present the total density per hectare, the total plot area is converted into hectare as follows:

Table 6.6 Summarised tree, grasses and herbs density

Plot	Trees' density per 100 m^2	Grasses and herbs density per m^2
1	25	80
2	26	100
3	28	41
4	45	33
5	20	30
Total number of individuals species	144	284

Total number of plots $= 5$

Size/area of each plot $= 100\,m^2$

Total area sampled $= 100\,m^2 \times 5$

$= 500\,m^2$

Total tree density $= 144$ individual trees per 500 m^2

The total area of 500 m^2 can be converted to hectares as follows

1 hectare $= 10{,}000\ m^2$

$X \text{ ha} = 500\,m^2$

$$X \text{ ha} = \frac{1 \text{ hectare} \times 500\ m^2}{10{,}000\ m^2} = 0.05 \text{ ha}$$

Therefore, 144 individuals were found in 0.05 hectare. Thus, the total tree density will be:

$$\frac{144 \text{ trees}}{0.05 \text{ ha}} = 2{,}880 \text{ trees per hectare}$$

As for the grasses and herbs, the total species density is calculated from the total area covered by total sampled quadrats from the data recorded in Table 6.2 and summarised in Table 6.6. In this example, sampling was done in the five quadrats of each measuring 1 m^2. Their total area is, therefore, $5\,m^2$. The total density of all grasses and herbs will be $284 \text{ plants} / 5\,m^2$, which is obtained by adding number of all individuals in each plot. By converting 5 m^2 into hectare as done for trees, the total grasses and herbs density per hectare, would be 56,800 plants per hectare.

Density can be calculated for each individual tree species as well as per plot and per total study area. To calculate individual species density the total number of individuals for each species in all plots for data collected in tables 6.1 and 6.2 is as summarised in Table 6.7.

Table 6.7 Summarised total density of the tree in the study site

Species name	Number of individuals
Adansonia digitata	2
Albizia versicolor	15
Anonna muricata	13
Artocarpus heterophyllus	2
Azadirachta indica	5
Bombax glabra	1
Cassia siamea	8
Cedrella odorata	5
Ceiba pentandra	6
Citrus sinensis	3
Cocos nucifera	19
Dalbergia melanoxylon	6
Euphorbia tirucalli	10
Mangifera indica	14
Persea americana	5
Polyalthia longofolia	11
Prunus persica	7

Psdium guajava	6
Tamarindus indica	3
Terminalia catappa	3
Total	144

An example to calculate a total density for an individual species per hectare is done for *Albizia versicolor*, within the entire transect or sampled area is summarised in Table 6.8

Table 6.8 Individuals species density of *Albizia versicolorwww*

Plot number	Number of individuals
1	4
2	5
3	3
4	1
5	2
Total	15

Once the total number of individual species in all plots obtained, the second step is to calculate the total area sampled (that is, number of sample plots considering area of each). The total sample area is obtained from the size of each plot multiplied by the total number of plots. In this case, there were five plots each measuring (10 m x10 m). Hence, the total sample area will be: $10\ \text{m} \times 10\ \text{m} \times 5\ \text{plots} = 500\ \text{m}^2$

The density of *Albizia versicolor* will be: $\frac{15\ \text{individuals}}{500\ \text{m}^2}$

This density can be converted to individuals per hectares as follows:

$1\ \text{hectare} = 10{,}000\ \text{m}^2$

$500\ \text{m}^2 = \text{X ha}?$

$$\text{X} = \frac{1\ \text{hectare} \times 500\ \text{m}^2}{10{,}000\ \text{m}^2} = 0.05\ \text{hectare}$$

Thus, there are 15 individuals of *Albizia versicolor* in 0.05 hectare.

The total specie density of *Albizia versicolor* will be:

$\frac{15\ \text{plants}}{0.05\ \text{ha}} = 300$ plants per hectare.

Activity 6.2 How to apply random sampling in collecting density and frequency data for tree species

You are required to randomly determine species density and frequency of trees in a community of plants species in your school woodlot or nearby environment.

Procedure

(i) Establish two plots each measuring 20 meters by 20 meters using a tape measure. In each plot, only sample 5 individuals randomly.

(ii) Locate about 10 trees in each plot in a way that from the first tree to the last one no tree is skipped in between.

(iii) Assign numbers 1 to 10 to the identified 10 trees. The number can be written on a hard paper or plastic number tags or by directly numbering trees using a permanent marker pen or spraying an easily noticeable paint on the tree stem or trunk.

(iv) Prepare small pieces of papers roughly measuring 4 cm x 4 cm and assign each paper any number between 1and 10.

(v) Roll each piece of numbered paper individually into a paper ball to conceal the numbers.

(vi) Place all numbered paper balls in a hat and shake the hat vigorously to mix them properly. Close your eyes and draw one paper ball from the hat, open it and record its number on a separate paper. Shake the hat again, close your eyes and draw the second paper, open and record its number. Repeat this procedure until you obtain 5 numbers at random.

(vii) Using the randomly obtained numbers, locate trees tagged with corresponding numbers in each of the established plot.

Assignment

1. Identify and record each tree species using their scientific names or common names.
2. What is the total sample area in this investigation?
3. Determine the total species density and frequency in hectares.
4. What are the advantage and disadvantage of random sampling methods?
5. Prepare a species checklist for the sampled area.

Activity 6.3 Stratified and systematic sampling

Conduct a reconnaissance in or around your school compound to gather preliminary information on the vegetation community types. After the survey, categorize the vegetation into strata of plant communities based on its physiognomic composition such as grassland and open woodland. In each stratum, conduct the following:

Assignment 6.3 (a)

(i) In the open woodland stratum, select any starting point at random.

(ii) Using a tape measure, establish 2 sampling plots, each measuring 10 m x 10 m.

(iii) Place the two established plots at an interval of 10 m from each other.

(iv) Identify and record all tree species in each of the two established plots.

(v) In each of the located point, establish nested plots measuring 5 m x 5 m for

shrubs and two small plots measuring 1 m x 1 m nested in the 5 m x 5 m plot for grasses and herbs.

(vi) In each nested plot identify and record number of individuals from the 5 m x 5 m and 1m x 1m plots.

(vii) Determine the density of each tree, shrub and grass/herb species.

(viii) Establish the frequency of tree and shrub species.

(ix) Prepare a species checklist for all sampled plant species in this community.

Assignment 6.3 (b)

(i) In the grassland community stratum, establish any starting point at random.

(ii) Prepare a quadrat frame with an area of 1 m^2 and partition it into 100 small grids of 10 cm^2 each.

(iii) Establish 5 quadrats placed at an interval of 10 meters.

(iv) Place a 1 m x 1 m quadrat frame partitioned into 10 cm grids on the ground and study the grass and herb species within the whole grid area.

(v) Record species inside the frame and assign percentage cover to each species. The percentage cover of each species is estimated with respect to the entire area of the quadrat; that is the percentage cover of each species out of 1 square meter area.

(vi) Giving reasons, state the method of sampling used in this activity.

(vii) Prepare a species checklist for the sampled plant species in this community.

Exercise 6.2

1. Explain the concept of sampling.
2. Describe systematic random and stratified sampling.
3. (a) Outline the use of transect and quadrats in sampling flora and fauna.
   (b) What is the difference between a pin frame, quadrat, and a square quadrat.
4. Distinguish species frequency from species density.
5. Write short notes on line and belt transect.
6. Explain why reconnaissance survey is important prior to data collection in ecological studies.

Population dynamics

Population is defined as a group of individuals of the same species found in a particular area, and isolated geographically from other individuals of different groups. Individuals of the same population can interbreed to produce fertile offspring. Different populations constitute a community. An example of the plant population is *Combretum molle* of wetter miombo woodlands or *Brachystegia spiciformis* of drier miombo woodlands. In animals, this could be exemplified by populations of elephants in Mikumi National Park and lions in Serengeti National Park. Usually, populations are temporarily and spatially dynamic, and they change at all possible scales. Dynamism in population is caused by gradual or abrupt changes in population structure caused by disturbances such as wildfires and floods. The gradual changes in the structure are wide spread, and arise

as the population or community itself modifies various environmental variables such as nutrient levels and water. These progressive modifications are also called succession where the changed species are mostly adapted to grow, survive, and reproduce. This in turn, cause changes in population growth pattern and the community at large. In some cases, areas become overpopulated as they contain organisms beyond the carrying capacity. This is called population explosion and has various consequences to the environment as well as other populations.

The population is better understood by studying its characteristics such as the birth rates also called natality, how it grows, how it is maintained, death rates or mortality and how it declines. The study of how and why these changes occur in a population is called population dynamics.

Population growth is an increase in the actual number of organisms in a population. This is also called a population size. The size of a population is primarily determined by natality, mortality, and migration which may be immigration or emigration. Population size is regulated by some factors, collectively regarded as environmental resistance. The absence of predators, competition for food and space, may be summed up as an absence of environmental resistance. Under these circumstances, the struggle for existence is low, survival is high and species realise their full reproductive potential. Normally, a population characterized by a few individuals will grow exponentially, doubling with time provided that shelter is available and the area has no food shortage and predators. Increased growth of the population triggers the environmental resistance to start operating, thereby stopping the continued growth of the population. As the environment ultimately becomes saturated with a particular species, it reaches its full carrying capacity, which is the maximum population size an environment can support indefinitely without deteriorating. At this point, natality and mortality are nearly equal. The resources available to the population in a particular area always determine the carrying capacity. These resources are collectively called limiting factors because they limit the size of the population.

Types of communities (biomes) and their global distribution

The community is a group of different population of plants or animals co-occurring in time and space. The co-occurrence of populations of different organisms in a particular geographical area is due to their overlapping tolerance ranges to the existing environmental conditions. In plants, communities are exemplified by subdivisions of vegetation cover such as woodlands, and grasslands while in animals they can be exemplified by co-occurrence of populations of herbivores such as antelopes, zebra, buffalo and carnivores such as lions and leopards. Communities of plants can be distinguished based on floristic composition, and physiognomic characteristics. Floristic composition refers to different kinds of plant species constituting a particular community while physiognomic characteristic refers to the physical appearance of the plant community. The plant community can be identified physiognomically as a forest, woodland and grassland. Floristically, the plant community is identified based on dominant species, for example, *Acacia* woodland or *Brachystegia*-*Combretum* woodland.

Communities can change in temporal scales, in species composition, spacing, height of plants and growth form, which corresponds to spatial changes in the environment. Changes in communities may be abrupt, transitional, gradual or diffuse. These changes depending on ecologist experience may be evident or non-evident particularly, on the first inspection. The ability to recognise changes is a skill which can be learned and it increases with frequent analyses, comparisons and experience. Beside plants' and animals' communities which are easily identified, there are also fungi, algae and microorganisms which are very important in nutrient circulation to the entire community.

Assemblage of communities constitute biomes that can be marine or terrestrial. The biomes are, therefore, the world's major communities and are distinct unit with clear discernible boundaries. These boundaries occur as transitional zones called ecotone, which separate the two biomes. The ecotone contains species of both adjacent biomes but also unique species as well. This makes ecotone to have more species diversity than the two adjacent biomes. The terrestrial biomes are categorized globally according to the dominant vegetation. They are characterized by adaptations of organisms to a particular environment. The terrestrial biomes fall into nine major types based on dominant vegetation communities as shown in Figure 6.18.

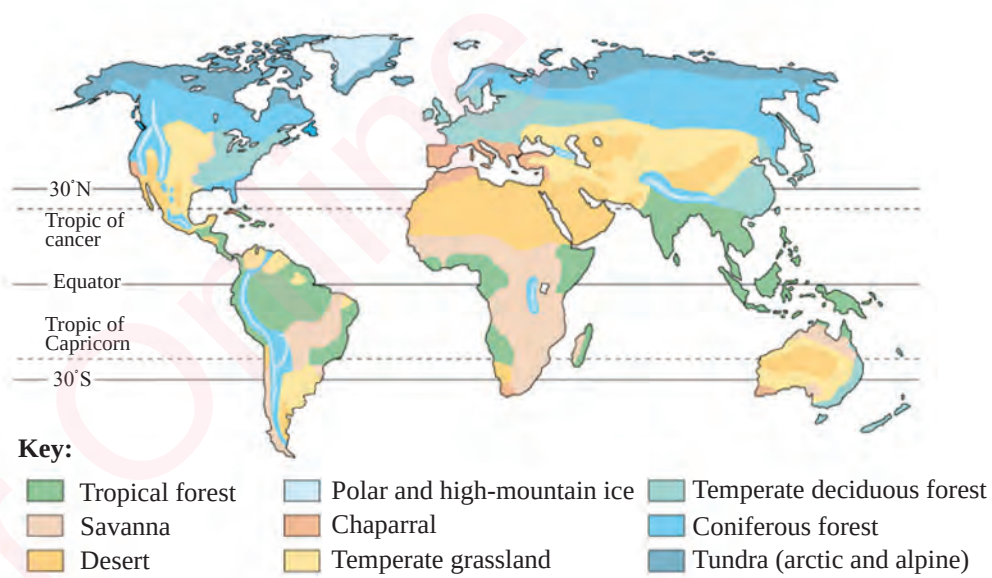


Figure 6.18 Global distribution of biomes

Tundra

Geographically, tundra extends above 60° North covering parts of North America, Europe, and Asia in the northern hemisphere, just south of the ice cap. It is characterized by an extremely cold climate. The temperature is extremely low ranging between -34°C and 12°C and precipitation is less than 250 mm/year. The seasonal temperatures are low and the growing season is short lasting for about sixty days. This climatic condition makes the tundra biome the least productive biome globally. The ecosystem is therefore characterised by extensive tree-less plains and overall low biodiversity. The vegetation is dominated by lichens, grasses, sedges and dwarf woody plants, for example, willows and birches.

Boreal forests

The boreal forest biome, also known as the northern evergreen forest or northern coniferous forest biome is found immediately south of the tundra biome. This ecosystem extends from Alaska across Canada, and Northern Europe through Russia. It is also found on mountain sides in the western United States. The boreal forests climate is characterized by annual precipitation of about 650 mm and very cold winters but relatively less severe compared to the tundra. The growing season is short, lasting only from June to August. The vegetation diversity in these forests is also low having two tree species of Pine family. namely: the spruce and balsam fir which bear evergreen needle-like leaves as illustrated in Figure 6.19. The needles which are the leaves dominating this biome form a litter layer ranging between 7 and 15 cm deep on the ground. They are resistant to decomposition and contribute to a slow rate of litter decomposition. The climatic conditions and the acidic nature of the evergreen needles make the soil acidic after decomposition. The soils occur in thin layers overlying rocks exposed by glaciation.

Figure 6.19 Boreal forest with evergreen needle-like leaves

Temperate deciduous forests

This forest covers south of the evergreen forest biome. In the United States, it covers the entire eastern part but does not extend to southern Florida. It is also found in southern Scandinavia, Ireland, central parts of China, the British Isles, central Europe, Japan and Eastern Russia.

The climate in this biome is characterised by distinct summer and winter seasons. During winter, all regions are subject to freezing temperatures. Generally, the precipitation, which is in the form of snow and rainfall, is distributed more or less evenly throughout the year and it ranges between 750 mm and 1500 mm. The annual temperature ranges between -3ºC and 30 ºC.

Temperate deciduous forests biome is a home to a wide various of animals such as variety of insects, wolves, foxes, bears, deer, mountain lions, rabbits, snakes, bob cats, eagles and humming birds. There are about 40 different tree species which make-up the canopies. This makes such forests to have higher species richness than tundra and boreal forests. High species diversity in this biome is largely contributed by the deciduous characteristic of its forest species. This characteristic allows for the presence of lichens, mosses, a rich variety of herbs and shrubs in the understorey layer. These grow during the spring season and complete their life cycle activities before the canopy closes. The forest is also characterised by a dense canopy dominated by beach, basswood, maples, hickories, and oaks while the understorey tree species is dominated by dogwood, magnolia, and ironwood as shown in Figure 6.20. The deciduous tree leaves decompose more easily due to warm summer temperatures which contribute to thick humus. This hastens the release and recycling of mineral nutrients into the upper soil layers and ultimately to plants. This makes the temperate deciduous forest soils more fertile than the tundra or boreal forest soils.

Figure 6.20 Temperate deciduous forest

Temperate grasslands

This is found in the inland parts with too little growth of forest trees due to low moisture levels. In South America, this grassland occurs in Argentina while in North America it stretches from Mexico through the southern, central and northern parts of the United States and southern parts of Canada. In Europe, the temperate grasslands are found on the eastern part. In Asia, they occupy the southern part of Russia, parts of Syria, Turkey, Northern Iraq, large part of Iran and Pakistan, North-western parts of India as well as the northern parts of Mongolia and China. In Australia, the temperate grasslands stretch from North-west coast between Brome and Onslow across the northern territory. It continues to Queensland closer to the East coast band and turns southwards to New South Wales and then westwards ending at Geraldton on the south-west coast.

Annual precipitation in the temperate grasslands biome is fairly low ranging from 250 mm to 750 mm. The biome is characterized by wide seasonal temperature variations, which are as high as 38ºC during summer but very low in winter where they go down to -32ºC. The assemblage and spatial distribution of species in this biome is determined by the aridity of the particular habitat. However, at larger scale the biome is maintained by wildfires and small quantities of precipitation. The temperate grassland plants become dormant to survive the dry summer periods. Usually, during spring and early summer, the moisture is adequate to support plant growth. During this period, the grassland plants store a sufficient amount of food to survive periods of dormancy during dry summer.

Deserts

Deserts are sandy or rocky biomes that occupy regions with annual precipitation of less than 250 mm. Rainfall in deserts often occurs as cloud bursts and is sparse, infrequent and largely unpredictable. Diurnal temperatures variation is very high with high temperatures during the day (41ºC) and low temperatures at night (- 4ºC) but this temperature vary with location. For example, in temperate regions, temperatures at night may go down to -18ºC. The plants that live in desert biomes are well adapted to live in extreme conditions such as drought. In the event of torrential rainfall, seeds of most plants germinate, grow rapidly and set flowers and seeds in a few weeks' time.

Desert plants such as cactus are drought resistant and have developed features such as thick cuticle, succulent stem, highly reduced leaf surface, multi-layers palisade tissue and sunken stomata to prevent excessive water loss. Soils are coarse textured, and rich in mineral salts, but poor in organic content. Due to extreme aridity, the productivity of desert biomes is very low and some deserts are completely devoid of plants. The desert biome covers about one-fifth of the earth's surface and is categorized into hot and cold deserts. Animals in this biome include herbivores such as camels, deer, pronghorn antelope, desert bighorn sheep, jack rabbit, and kangaroo. There are also bats, birds such as owls, hawks, and road runners and insects such as ants, beetles, butterflies, flies, and wasps. Other fauna includes reptiles such as tortoise, rattlesnakes, and lizards.

(i) Hot deserts

This type of desert covers several parts of the world including the United States where they cover the southwest part. In Mexico, hot deserts are found in the northern and western parts while in South America they cover western parts of Peru, and northern parts of Chile. In Africa, hot deserts are the Sahara in the northern part which covers countries such as Chad, Algeria, Libya, Sudan, Egypt, Niger, and Tunisia other hot deserts includes Namib, and Kalahari in Namibia, and Botswana respectively as indicated in Figure 6.21 represent part of Sahara desert. The hot deserts in the Middle East cover Saudi Arabia, Oman South Yemen, southern parts of Pakistan, the southern tip of Afghanistan, and Jordan. Other hot deserts are found in several states in Australia, namely: the Great Sandy Desert in western Australia, the Great Victoria Desert in South Australia, and the Simpson desert in Queensland, and the Northern Territory.

Figure 6.21 A section of hot desert biome in North Sudan

(ii) Cold deserts

These occur in the temperate regions. In the United States, the cold desert occurs in the Great Basin stretching from Nevada State through Idaho, Utah, and on to the eastern part of Washington State. In the eastern and central parts of Argentina, Kazakhstan, Uzbekistan, southern Mongolia, northern China, and the Atacama desert in southern parts of Chile.

Chaparral

This biome occurs along the southwest coast of the United States on the West coast of Chile, in countries bordering the Mediterranean Sea, and along the southern coast of Australia. The Chaparral biome is similar to desert biome by both being hot and dry but it differs from desert biome by receiving relatively more rainfall per year. The climate in this biome is characterized by dry summers, and high annual rainfall

ranging from 250 mm to 430 mm during winter. The temperature during this season is -1° C but may go as high as 38°C in summer. The dominant vegetation are the fire resistant evergreen shrubs which re-sprout profusely in winter season as it rains. The frequent late summer fires favours the growth of shrubs while inhibiting trees growth.

Tropical rain forests

This is the oldest remaining biome on earth perhaps having over 60 million years of age. The tropical rain forests are situated in the equatorial region. They cover the lowlands of the humid tropics of Africa, Central and South America, Southeast Asia, and the Islands of Indonesia. Diurnal and seasonal temperature variations are small in the tropical rain forests but the annual rainfall is high and commonly exceeds 2000 mm. Usually, there is one or more relatively dry periods each year. The temperature ranges between 20° C and 34° C and the humidity is relatively low.

The tropical rain forests biome has the highest biodiversity compared with other biomes. For example, a two-hectare area can have over 100 species of trees, whereas the same area in the temperate deciduous forest may contain less than 25 species of trees. The broad leaved evergreen trees and large woody vines and climbing plants are the flora of the equatorial rainforests. The evergreen trees can grow to a height of 70 meters forming a dense top canopy. The understorey comprises of shorter trees and vines. Trees of all heights are found beneath the upper canopy and epiphytes are abundant. The closed nature of the canopy growth allows little light to penetrate to the forest floor. Generally, this results into sparse ground flora except where the canopy is broken by fallen trees. The warm temperatures and high moisture content accelerates litter decay, and nutrients recycling resulting in the soils with a thin litter layer. The nutrients are immediately absorbed by a vast root network, which makes vegetation, a major reservoir of nutrients rather than soil. However, due to high rainfall, and rapid litter decay, soils are nutrient poor. Fauna in this biome includes predators such as jaguars; the herbivores such as antelopes, gazelles and giraffes; mammals such monkeys; amphibians such as frogs; insects such as butterflies and beetles, ants and ant eaters.

Tropical savannas

The tropical savanna biome is found between the tropical rainforest and the desert biomes. Geographically, these biomes are located near the equator, mainly between latitudes 5° and 15° North and South of the equator. This biome is found in warm areas, which receives an annual rainfall of 1000-1500 mm as well as a pronounced dry period for at least four months in a year. The savannas are generally warm annually with temperatures ranging from 20 °C to 30 °C. The tropical savanna biome is typically grassland characterized by a continuous cover of open grasslands with patches of scattered trees and shrubs as indicated in Figure 6.22. Specifically, these grasslands cover large parts of Africa; Tanzania, Kenya, Zimbabwe, Botswana, South Africa, and Namibia. They are also found in Australia, South America, especially in Venezuela, and Columbia.

The soils are porous and therefore have rapid drainage of water. The humus layer, which provides vegetation with nutrients is thin. There are frequent natural fires originating from lighting and intentional fires set by

poachers during the dry season. Due to the prevalence of fires both trees and grasses in this biome are fire-resistant. There are tall perennial grasses with an extensive root system that help for a quick recovery either following grazing or burning.

The dominant fauna includes elephants, giraffes, zebras, rhinoceros, buffalo, lions, leopards and cheetahs. Others include baboons, crocodiles, antelopes, ants, termites, kangaroos, ostriches, and snakes. The predator-prey relationship is common in the savanna. Camouflage and mimicry are very important to the animals of these biomes whereby predators often blend with their environment in order to sneak up on unsuspicious prey. On the other hand, the preys may use this same technique as defence mechanism to conceal themselves from animals higher up on the food chain.

Figure 6.22 A section of tropical savannah in Arusha Tanzania

Activity 6.4 To identify vegetation communities

Take a tour across the vegetation within or around the school compound to observe different plant communities in their particular environment. Take note of the species growth form or habit, spacing, the physical appearance of the entire community, composition of species and dominant species.

Assignment

1. Identify and classify types of plant community encountered based on physiognomic and floristic characteristics.
2. Giving reasons, comment on the observed spatial distribution (whether it is uniform, random or clumped) of each population in the plant community types named in (1) above.

Factors affecting population growth and distribution

Population growth and distribution are affected by factors both within and between species. Factors within the population which affect population growth and distribution, are called intraspecific factors while factors between different populations are referred to as interspecific factors. Intraspecific factors usually start to operate once the population has completed its growth phase, and they become more evident as the number of individuals or density within the population increases. It is for this reason, these factors are also called density dependent factors. Normally, changes in population growth cause fluctuations or cycles, which may be regular. On the other hand, the population may continue to grow in size until some factors such as fires, temperature, and flood which do not necessarily depend on its size, cause a sudden reduction. These factors are collectively called density independent factors.

Density dependent factors

Density dependent factors involve the interactions of individuals. These factors have a direct effect on population growth as they affect natality and mortality of the individual species directly. These factors include food shortage, predation, overcrowding, dispersal and territorial behaviour, which affect the birth rate of individuals of the population.

Territorial behaviour refers to defending of a breeding territory from being intruded by individuals of the same species. It is a spatial type of interaction exhibited by a wide range of animals, including social insects, birds, mammals and reptiles. In defending their territory, some species normally sing as in birds or vocalize as in frogs, and may involve a visual display as seen in some birds, which display their coloured breast. In some cases, the intruder and competitor individuals may fight briefly leading to retreat of the intruder without necessarily causing serious harm to either species. The neighbouring territories sometimes overlap if the resources such as food are not limited. As the available resources are reduced and individuals increase in numbers, the ability of territory to support many individuals and the space partitioned to each individual decrease. As the territory size decreases, some individuals within the territory may completely fail to establish their territory, and hence fail to breed.

Overcrowding is another density dependent factor which significantly affects populations growth in many mammals such as the natural populations of a rat. Studies show that the reproductive behaviour of individuals of the rat population is affected significantly as the number of individuals increases. The increase in individuals of a population triggers hormonal changes which ultimately disrupt ability of individuals to copulate and enhances infertility, cannibalism, abortions and reduction of survival as the young individuals leave their nests early. Overcrowding also results in the competition of organisms for limited resources within a population.

Dispersal timing, particularly, in some insects such as aphids, plays a vital role to determine insects' fitness. A delayed arrival of insects to their host plant for example, may result in the mismatch between the arrival and availability of nutritionally quality fodder. This may significantly reduce the growth rates of herbivorous insects. Moreover, emigration from large aggregations of aphids can affect timing

by their natural enemies which are likely to focus more on aggregated and most abundant prey.

Adequate food or nutrients favour natality and facilitate the immigration of organisms leading to population growth. On the contrary, insufficient food leads to a decrease in population size, due to competition for the limited food, emigration, low rate of reproduction, and mortality. Competition for limited resources such as food, shelter, light, water, and space, has a profound effect on population growth. Individuals that are too young, old or weak can poorly compete with the fully energetic ones. The consequence of competition is the increase in the population of a wining species and a decrease in the population of the looser or unsuccessful one.

Density independent factors

These factors can change the size of the population significantly. The density independent factors are seen in various inter-specific relationships across the populations. Predator-prey relationship is one of such relationships. This is a kind of relationship whereby one organism (predator) hunt and kill another organism (prey) as a source of food. As the predators feed on preys in the community, the population of preys decrease, hence, food for predators decrease and their population gradually decreases as they compete for the limited resources. Thus, the relationship between predators and preys causes cyclic variation in the sizes of their populations as shown in Figure 6.23. When the predators' population increases, the population of the prey decreases. This is because the predators eat the preys thereby reducing their numbers. As the prey's population starts to decline, the predators begin to compete for the diminishing prey. Since the prey becomes more limited, the population of predators also begin to decline and the weak individuals that cannot compete begin to starve, and ultimately die of hunger.

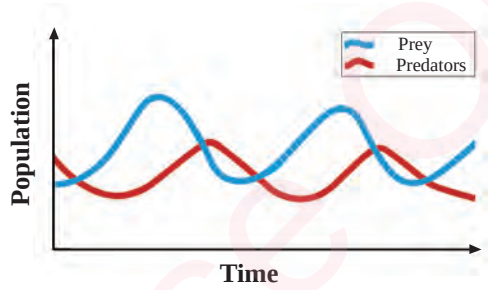


Figure 6.23 The predator–prey relationship

As explained earlier, the decline in predators' number gives room for the preys' population to increase and subsequently support an increase in the number of predators. This predator-prey relationship results in the oscillations in the number of the two populations.

Similarly, herbivory is common in plants where certain insects can consume the entire plant population. This causes a shortage of food supply to other herbivores, a situation which may results into their death.

Parasitism is another form of inter-species relationship that affects population size in which one species depends on others for food and other physiological processes. Some parasites such as the *Ascaris* obtain their shelter and food from the mammalian intestines. This helps them to reproduce and increase in population size. As the size of *Ascaris* population increases, the host will be deprived of nutrients and may die, thus reducing its population size.

In an ideal environment, it is difficult to separate density dependent factors from density independent factors for the reason that complex interactions between the two are sometimes inevitable. Climatic factors such as water, temperature and light, for example, may be regarded as density independent factors affecting population growth but they also interact with density dependent factors.

Availability of water and air plays an important role in determining the survival of species. Both water and air favour high reproduction rate and immigration of organisms, which ultimately increase the population size.

The quality, quantity, and duration of sunlight, have a direct influence on the growth of plant populations as this is vital for photosynthesis. In the presence of adequate light, photoautotrophs synthesise enough food, reproduce enormously and their population's growth becomes high. In an environment deprived of these conditions, natality is low, and mortality is high due to lack of enough food and consequently, population growth rate becomes low.

Temperature, wind, rain availability, humidity and similar aspects also affect population growth in the ecosystems. Each species can survive within a certain range of each of these factors. A species exposed to an environment near the upper and lower limits of its tolerance range, experiences stress which affects its health, growth and reproduction, as a result, the population size goes down.

Population growth patterns and their interpretation

Experimental data obtained from studies in the growth patterns of different groups of organisms reveals two basic growth patterns. These are J-shaped or exponential growth pattern and S-shaped or Sigmoid growth pattern, also called logistic growth pattern.

J – shaped growth curve

This curve describes the population growth of organisms in the environment where resources such as water, food and space are abundant. This type of growth is characterized by a few individuals available for reproduction in the initial establishment stage which cause the population to grow at a relatively slow rate. This stage of the population growth is called a lag phase. As the number of potentially reproductive individuals increases with time, there is an increased birth rate. This stage is called an exponential stage because the population growth is exponential as indicated in Figure 6.24. The J-shaped curve represents an ideal situation for unicellular organisms such as yeast cells. In the beginning, each yeast cell is capable of dividing to form two cells. This process continues such that for every division, the population doubles. Ideally, if nothing happens in the environment that interferes with the metabolism, the population growth will continue.

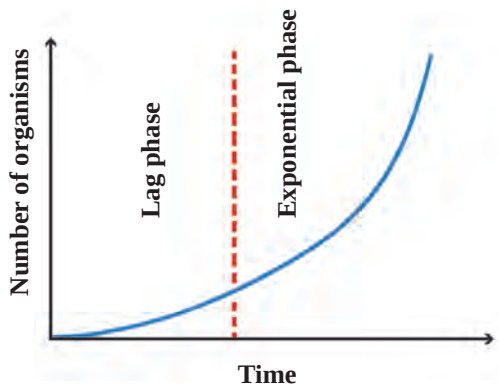


Figure 6.24 J-shaped growth curve

S-shaped or sigmoid growth curve

Under normal conditions, growth cannot continue indefinitely because the habitat can only support a limited number of organisms. In the case of yeast, the material requirements for yeast growth, toxic products of fermentation and the death of some cells can limit growth. Therefore, in reality because resources are limited, the growth patterns of organisms is S-shaped sigmoid curve.

An area with plenty of resources, enough breeding space, absence of predators, and competition of any kind is said to have no environmental resistance. If few individuals are introduced in this area, their population density will initially increase slowly in a positive acceleration phase also called a lag phase. At this stage, the number of reproducing individuals is still small and they are still adapting the environment.

The lag phase is followed by a rapid increase in the population approaching an exponential or logarithmic growth rate as in the J-shaped curve. At this stage, there is no environmental resistance and individuals are well adapted to their environment. The natality is higher than mortality and the number of reproducing individuals is large.

The third stage is characterised by an initial decline in growth rate resulting in the deceleration or negative acceleration. This occurs as the environmental resistance sets in, leading to increased mortality than natality. Eventually, the growth rate reaches a stable equilibrium phase where it levels off as the mortality equals natality as shown in Figure 6.25. This is also called a zero growth rate phase which leads to population stabilisation. This point is known as the saturation value or carrying capacity of the environment for such organisms.

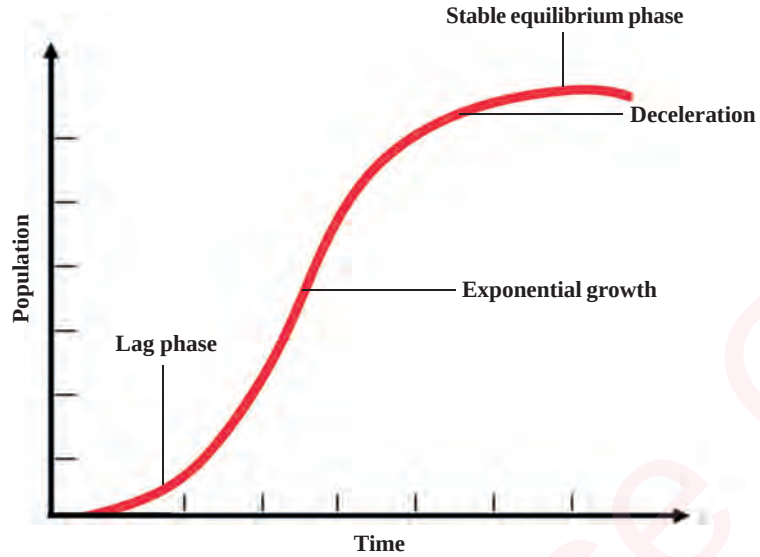


Figure. 6.25 The Logistic curve (also known as an S- (Sigmoid) curve)

Population explosion and their consequences

The size of a population of a particular habitat is determined by natality, mortality, immigration, and emigration. Birth and immigration increase the size of a population whereas death and emigration decrease the population size. Overpopulation occurs when the number of species in a population exceeds the carrying capacity of their respective environment. Depletion of resources in some places results in the overcrowding in other areas where the resources are abundantly available.

In human beings, population explosion is a global phenomenon and its consequences are evident on the biosphere. The population overgrowth emanates from increased food production and distribution, improved public services such as water, sanitation and improved medical technology and communication. However, the high growth rate of the global human population has biological and social consequences tied to the declining environmental quality in all spheres of the earth because the growing population means growing needs.

The biological consequences include competition for the available resources such as food and space. This is experienced in densely populated areas such as urban areas and in areas inhabited by refugees. These areas also experience rapid spread of epidemic diseases such as cholera, and the chances of being infected by such diseases increase with increased overcrowding. The impacts of human population explosion on the environment include pollution in which water, air and soil are negatively affected. Pollution refers to the discharge of toxic substances or contaminants into the environment that is likely to have adverse effects on the natural environment or life.

In the urban areas, overpopulation is tied to the growing economic activities such as industrialization. In some developed countries such as China, Japan and USA, industrial activities have contributed significantly to emissions of pollutants into the atmosphere thus causing atmospheric pollution. The emissions containing nitrous and sulphur oxides to the atmosphere

may cause acid rain. The emission of Chlorofluorocarbons (CFCs) to the atmosphere contributes significantly to ozone layer depletion. This occurs as these gases react with ozone (O_3), an atmospheric blanket, which absorbs strong ultraviolet rays from the sun, making it thin and finally forming holes in it. The hazardous ultraviolet rays may pass through the holes and upon reaching the earth's surface they can cause human skin cancer and death of plants. On the other hand, the exhaust emissions from combustion of fossil fuels in cars and industries generate CO_2 known as a greenhouse gas. Elevated levels of this gas in the atmosphere form a blanket, which prevents the sun's heat on the earth surface from escaping back to the atmosphere. This scenario is called a greenhouse effect and is a major contributor to global warming. Thus, the acid rain, ozone layer depletion and greenhouse gas effect are the major drivers of global climate change. Besides global climate change, air pollution may also cause respiratory diseases such as asthma and some airborne diseases.

Intensive agricultural activities employing advanced modern techniques such as intensive use of inorganic fertilizers, herbicides and pesticides are geared towards increased yields to cope with increasing population growth. However, the entry of these chemicals into the soil and their seepage to the water bodies can tremendously cause soil and water pollution. This can significantly affect biodiversity in aquatic and marine ecosystems. In the soil, entry of chemicals may severely impact microbial activities, leading to disruption of nutrient cycles which can impair plant growth. Inorganic fertilizers may significantly change the soil pH, a master variable which changes various soil parameters, and hence, soil quality in various ways. The discharge of industrial wastes and mining effluents into water bodies also cause water pollution.

Population explosion also has an impact on overexploitation of natural resources due to increased needs. Human activities or anthropogenic practices such as infrastructure development, expansion of settlements, large scale open pit mining, huge demand of traditional energy (fuel wood and charcoal), large scale agriculture, slash and burn agriculture, and overgrazing have contributed significantly to wide spread deforestation. The consequences of deforestation include increased desertification, loss of species habitat and species extinction. Other consequences are increased endangered species and species vulnerability which are currently a global conservation concern. Plants assemblages such as forests are vital in carbon dioxide fixation and hence, regulating the concentration of atmospheric carbon dioxide and oxygen gases in the atmosphere through photosynthesis. Increased deforestation, therefore, results into increased levels of atmospheric carbon dioxide and its ill consequences to the environment as stated above. The forests also play an important role in enhancing the quality of environment by influencing the ecological balance and life support system in checking soil erosion, maintaining soil fertility, conserving water, regulating nutrients cycle, water cycles and floods. Therefore, their removal will naturally disrupt these provisions.

The human population growth has social impacts such as poverty, malnutrition and famine because people have to spend a large portion of their resources for betterment

of their families. This may result into less saving and low rate of capital formation. In some cases, improvement in the production technique becomes impossible due to poverty which may result into famine and malnutrition.

Migration of people from rural to urban areas seeking for employment causes overcrowding in town and city areas leading to high competition for resources and spaces. Overcrowded areas are mostly unhygienic and are associated with relatively high frequency of communicable diseases.

In the wild population of fauna, overpopulation of prey often causes growth of predators' populations. The predator-prey relationship controls the prey population and ensures its evolution in favour of genetic trait which decreases its vulnerability to predation. The prey population normally increases, in the absence of the predators and its growth is bound by the resources available in their environment. Abundant supply of resources may produce a population boom followed by a population crash.

The introduction of exotic species has often caused ecological disturbance as the introduced species struggle and successfully adapt to the new environment. In Zanzibar, Tanzania, *Corvus splendens,* the Indian black house crow were introduced from India and South East Asia in limited number to supplement methods of managing disposed domestic wastes which have been a challenge in the Islands. These food wastes are among the sole food sources of these birds. During that time nobody ever thought that these garbage in the town and the aggressive behaviour of these exotic bird species would lead to a dramatic explosion of their population. These birds lay up to seven eggs which have high chances of hatching into young ones due to high degree of parental protection. These birds multiplied rapidly and spread to Dar es Salaam city and recently to Tanga and Lindi regions. In Dar es Salaam, the *C. splendens* population in 2010 was estimated to be approximately 1.5 million. In recent years, the relevant city authorities have been struggling to control the population of these birds. Besides feeding on garbage, the *C. splendens* feeds on cereals, young maize, cashewnuts, fruits and can reduce the potential for agriculture. They also eat eggs of chicken and other native birds, chicks of chicken, ducks and birds. The *C. splendens* carries and may potentially spread diseases. It is for this reason, *C. splendens* are considered invasive and a concern to the environment and populations of native birds. The city has put up a project to reduce population of these invasive birds by using traps, poison and direct killing using stones and poles. This has resulted into eradication of over 900,000 individuals of *C. splendens* birds.

Some species such as rodents, experience large natural cyclic variations experienced by farmers as plagues. Studies conducted to establish rodent damage to growing crops in tropical and subtropical regions revealed that rodents are animal pests and economic losses caused by them are widely distributed and quite severe in some countries. Invasion of rats in agricultural areas of Western Kenya in 1962 damaged several maize, wheat and barley plantations. In the previous years, population explosion of rodents was considered a plague in some regions of Tanzania. In 1989 farmers were forced to harvest their crops unripe in Muheza district, Tanga region due to rodent epizootics.

In 1989, Lindi, Mtwara, and Coast regions also experienced large rodent population explosion, which caused alarming losses of agricultural products during the major farming season.

Populations that exceed their historic carrying capacity can cause widespread problems. Large populations of herbivorous species such as caterpillars and locusts can overgraze the plants in their community, leaving little food for other herbivorous species. These large animal populations also have direct effects on humans.

The overgrowth of plant species such as *Parthenium hysterophorus* (carrot weed), which is now an invasive weed species in some parts of the northern Tanzania is posing significant problems in agriculture and pastureland. This species produces a copious number of seeds within short growing cycles and they grow at detriment of other native plant species including crops fodder, livestock and wild herbivores. Additionally, *Maesopsis eminii* is a tree species which was introduced in Amani Natural Reserve, in Muheza Tanga as part of afforestation efforts. This tree species has high competitive ability due to its fast growth rates, prolific seed production and efficient dispersal. As a result in the recent years its successful invasion has made its population very conspicuous in disturbed areas and open patches in the forest edges in the forests of Amani nature reserve. It is perceived as a potential threat to the diversity of the native tree species including the endemic tree species. The ecological impacts of this species include poor growth of under canopy shrubs and herbs, alteration of the canopy density, soil parameters including pH and water retention capacity.

Another population explosion in the plant species was evident in the Lake Victoria's wide spread weeds, the water hyacinth, *Eichronia grassipes*. This weed species originated from Rwanda through River Kagera in 1980s. It then spread prolifically as it took advantage of lack of its natural predators, optimal temperature for its growth, large space availability in the lake unlike in the river and hence abundant nutrients availability. The latter was also contributed by nutrient enrichment from the industrial, domestic and agricultural activities around the lake. These conditions lead to the rapid population increase of hyacinth between 1992-1998 as shown in Figure 6.26. During that time, its bloom was considered a problem to the lake ecosystem and water vessels navigation. In 2001, the population of hyacinth was reduced significantly through direct interventions and its proliferation has been decreasing.

Figure 6.26 Water hyacinth in Lake Victoria

Ecological succession

Ecologists have a strong interest in understanding how communities form and change overtime. This involves long term investigation on how complex communities such as forests arise from a bare land or rocks and vegetation regrowth following volcanic eruptions, glacier retreats, wildfires and anthropogenic influence. Studies have revealed gradual processes of change in ecological communities with time. In many cases, a community arising in a disturbed area, goes through a series of changes in species composition and structure, often over the course of many years due to changes in the environment. These series of progressive directional and accumulative changes through which the structure of a biological community evolves over time is referred to as ecological succession. During this process, there is a series of gradual and orderly replacement of one biotic community by another, until a dynamically stable community or equilibrium is established.

In plant communities, succession is evident when a bare land is colonized by a variety of species. The species will later on modify one or more environmental factors, for example, by organic matter in the soil, reducing erosion and improving water holding capacity of the underlying soil. These modifications of the environment, in turn, favour the establishment of more species.

The ecological succession is characterised by six important phases. The initial phase called nudation involves the initiation of succession process after a major disturbance in the environment. The disturbance could be emanating from fires, volcanic eruption or landslide. The second phase is migration marked by the arrival of plant

species collectively called migrules. These species start growing and occupy the bare environment. The migrules upon maturity set spores or seeds, which germinate, grow and result into their establishment. The third phase is called excesis and is followed by a fourth phase called competition in which the established species struggle for scarce resources such as nutrients, water, and light. The competition may result into stronger species replacing the weaker ones. The presence of plant species in this environment may bring about changes in the environment. The changes such as increased organic matter, improved soil structure, nutrients, optimum pH level, reduced erosion and reduced evaporation will allow new species to enter and inhabit the area. This is the fifth phase termed as a reaction at which these species induce changes in the environment. The sixth or ultimate phase called stabilisation or climax is achieved when the plant community attain an equilibrium where no more changes are expected unless subjected to a major disturbance, which may start the process afresh. The individual successions are called seres while the developmental phases are called seral stages. At each stage in this gradual evolution, a dominant species can be recognised.

Types of ecological succession

There are two types of succession. The first type is called primary succession, which occurs in areas that have never been inhabited by vegetation. The second type is called secondary succession. This occurs in an environment which was formerly inhabited by vegetation but later disturbed significantly. As a result, its vegetation is wiped off due to overgrazing, intensive cultivation, fires or by catastrophic events such as volcanic eruption, massive land slide and glacier retreats.

Primary succession

Primary succession clearly illustrates the process of succession. It involves initial development of plant species in areas where no soil originally existed. Ecologically, all communities evolved from simple populations which gradually became complex. The primary succession starts in hostile conditions such as on barren areas like sandy beaches, bare rocks or sand dunes. The first stage in primary succession is colonisation and establishment of primary coloniser or pioneers which are autotrophic species. Lichens, mosses and fern species are examples of primary colonizers which inhabit rock surfaces and release chemicals that enhance disintegration of rocks into smaller particles. This marks the beginning of weathering, and hence, soil formation. As some of these species die and decompose, organic matter is formed and accumulates in small depressions and cracks in the rocks. This forms a good source of food for decomposers. The products of decomposition mix with rock particles to form the first soil.

The second stage in primary succession is characterized by arrival of increasingly demanding plants called early colonizers. These plants characteristically have good mechanisms of seed dispersal and can tolerate wide range of environmental stress. Thus, they are called generalists or opportunists. Example of plant species in this stage are short and tall grasses as well as simple leguminous plants which can fix nitrogen. These species continue the disintegration of the rocks and increase organic matter as they decay. This builds-up a thicker layer of soil and creates a

relatively more conducive environment for more competitive and resource demanding species but with narrow tolerance range to environmental conditions such as shallow and later deep rooted shrubs. At this stage, a succession is at mid-level and the environment becomes more modified and biotic interactions increases. The increasing number of plants means more nutrients locked in their tissues, hence detritivores and decomposers are crucial in unlocking and recycling nutrients once these plants die. As changes in the environmental conditions continue such as soil depth, organic matter and soil moisture, small trees set in and progressively tall and long lived trees ultimately establish themselves. This marks the late succession in which a climax community characterised by a more or less stable community is established as shown in Figure 6.27.

During successional process interaction among the biotic components is established at all trophic levels from decomposers to all forms of consumers and it intensifies as climax community is realised. The climax community is usually characterised by one dominant species or several co-dominant species. A good example of the climax community is the tropical rainforest which has established itself for a very long time.

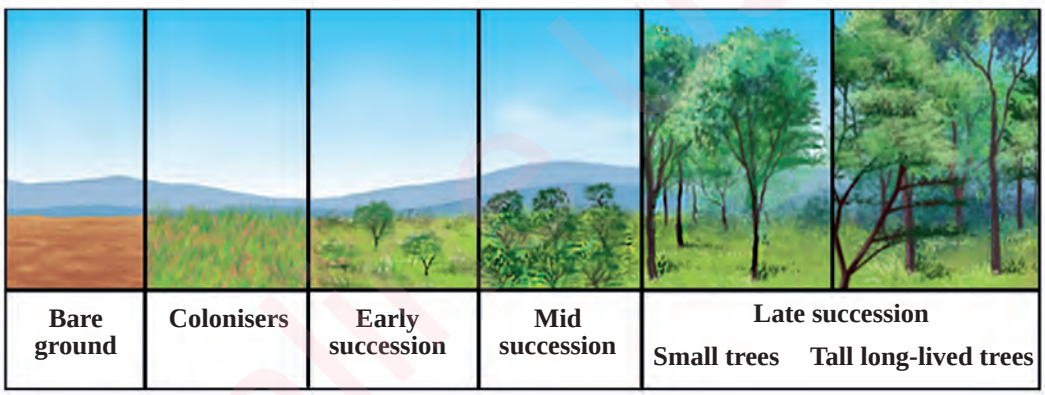


Figure 6.27 Primary ecological succession

Secondary succession

Secondary succession is a process of repairing a damaged plant community. A classic example of secondary succession is seen in a forest cleared by rampant fires. The fire is destructive because of its potential to kill the above ground vegetation, seeds and spores housed in the soil. It also burns and kills animals that are unable to flee the area. The nutrients which are contained in the dead organisms, however are returned to the ground in the form of ash after the fire event. Since the disturbed area already has nutrients rich soil, it is recolonised much more quickly than a bare rock as in primary succession.

Due to fire, most trees do not sprout back immediately. The first plants to grow back during secondary succession usually are annual plants. Within a few years, an influx of the quickly growing and spreading grasses occurs. The growth of grasses and similar species over many years causes environmental changes that favour the

growth of shrubs. Later tall trees emerge and gradually increase in number. This eventually, limits further disturbances in the community and pave a way for more trees to grow forming a dense canopy dominated by tall trees. At this stage, the community starts to assume its previous state and with time it will re-gain its original pre-fire species composition as shown in Figure 6.28. The secondary succession often takes not less than 150 years for the woodland forests as in Miombo woodland. Unlike the primary succession that may take up to 400 years or more to reach the climax, secondary succession may take up to 50 years to reach the stable climax.

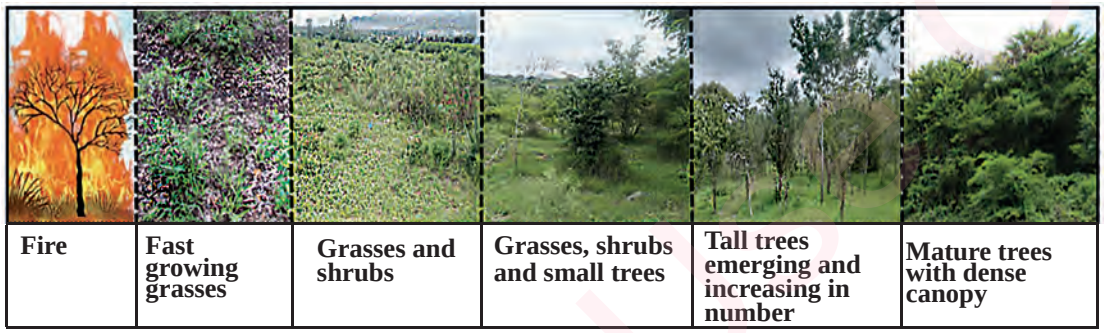


Figure 6.28 Secondary ecological succession

Revision questions

1. Explain edaphic factors that affect living organisms in the ecosystem.
2. Write short notes on each of the following concepts:
   (a) Primary ecological succession.
   (b) Secondary ecological succession.
   (c) Trophic level.
   (d) Ecological niche.
   (e) Biome.
3. Explain the process of energy flow and nutrient circulation in terrestrial ecosystem.
4. Using a well-labelled diagram explain the feeding relationship between sea grasses or algae and other trophic levels in any aquatic ecosystem.
5. Briefly explain the following:
   (a) Gross primary production (GPP).
   (b) Respiratory loss.
   (c) Net primary production (NPP).
   (d) Climax community.
6. (a) Briefly explain how a combination of simple, random and stratified sampling techniques can be used in investigation of species density and frequency in a woodland vegetation with extensive patches of grasslands traversed by a riparian vegetation.
   (b) Explain the advantages and limitations of simple, systematic and random sampling techniques.
7. With the aid of illustrations, describe the following:
   (a) Exponential population growth.
   (b) Logistic population growth.
8. Using examples, briefly explain the meaning, causes and consequences of population explosion in plants and animals.
9. (a) What is an ecological pyramid?
   (b) With the aid of illustrations describe how ecological pyramids are constructed.
   (c) Explain the advantages of the following ecological pyramids:
   (i) Pyramid of numbers.
   (ii) Pyramid of biomass.
   (iii) Pyramid of energy.
10. Briefly explain why populations do not continue to grow at unlimited rates.
11. Discuss limitations of each type of ecological pyramids.
12. Citing examples, give an account on how economic development activities can alter ecosystems.
13. With the aid of a sketch map examine the characteristics of any two biomes found in Tanzania.

Glossary

Abiogenesis	The theory of origin of life which states that life arises from non-living things in favourable conditions
Abiotic component	The non-living part of an ecosystem
Adaptive radiation	The development of several divergent structures from a primitive and unspecialised ancestor
Allantois	A membrane of the amniotic egg that functions in respiration and excretion in birds and reptiles, and plays an important role in the development of placenta in most mammals
Allele	One of two or more alternative states of a gene or a variant of a specific gene
Allometric growth	Growth that occurs when an organ grows at a different rate from the rest of the body
Allopatric speciation	A speciation that occur when two populations of the same species become isolated as a result of geographic changes
Ammonification	The process by which decomposers convert nitrogen within the remains of dead organisms back into ammonium ions
Amnion	The inner most membrane of the extraembryonic membranes. It forms a fluid filled sac around the embryo in amniotic eggs
Analogous structures	Body parts of different organisms with similar function but different evolutionary origin
Androecium	Collective term for stamens in a flower
Anticodon	A nucleotide triplet at the end of transfer RNA molecule that is complementary to a codon on messenger RNA molecule
Apical	Pertaining to tip or apex position of root or shoot
Apical meristem	The undifferentiated young tissue at the root and shoot apices, responsible for primary growth
Apoplast	The space outside the cell plasma membrane, which enables free diffusion of materials
Apoplast pathways	The movement of water, which occur exclusively through the cell wall without crossing any membrane

Autecology	Study of relationships between individual species and environment. It also refers to species ecology
Autosome	A body chromosome in eukaryotic cell
Bark	Part of woody stem outside secondary xylem
Biogenesis	The theory of thorigin of life which states that living things originates from other living things
Biogeochemical cycle	The process by which nitrogen is converted into multiple chemical forms
Biomass	The total mass of organisms in a given trophic level
Biome	One of the world major biological communities, which is characterised by pre-dominant vegetations whose existence is determined by certain climatic and physical conditions
Biotic component	The living part of an ecosystem
Bivalent	A pair of synapsed homologous chromosomes in the first meiotic division
Blastocoel	The central cavity of the blastula stage of vertebrate embryo
Blastocyst	A mammalian development stage consisting of a hollow ball of cells called trophoblast with an inner cell mass at one end that gives rise to embryo
Blastomere	One of the cells of a blastula formed by cleavage of a fertilized egg/ovum during early embryonic development
Blastula	An embryo after cleavage and before gastrulation
Cambium	Undifferentiated meristematic tissue that brings about secondary growth in thickness in a plant. It is a meristematic band of cells such as cork cambium or vascular cambium
Capillarity	Rise in water in tubes of small diameter (capillaries) kept in a vessel containing water
Carrier	The heterozygous individual capable of passing recessive allele to offspring without himself or herself being affected
Carrying capacity	The maximum number of organisms that the environment can support and maintain
Casparian strip	A band of suberin deposited in primary cell walls of root endodermis. It is also known as a Casparian thickening

Cell division	A process by which a mother cell produces new cells. It is a means of reproduction in lower organisms such as amoeba and bacteria
Cellulose	Primary carbohydrate component of plant cell walls
Centriole	A cellular organelle of microtubular organisation, which occur in animal cells only
Centromere	A specialised structure on the chromosome appearing during cell division as the constricted central region where the two chromatids are held together. It is also known as kinetochore
Chiasma	A point of contact and interchange of genetic materials between chromatids of homologous chromosomes during prophase I of meiosis
Chlorophyll	Complex magnesium porphyrin compounds forming green photosynthetic pigment contained within chloroplasts
Chloroplast	Plastid containing chlorophyll, the site of photosynthesis
Chromatid	One of the two identical longitudinal halves of a chromosome which share a common centromere
Chromosome	Nucleoprotein structure, generally more or less rod like during nuclear division. It is the physical site of nuclear genes which are arranged in a linear order
Climax community	A group of organisms inhabiting a particular environment whose members form a final stage of an ecological succession
Codominance	The condition in which the effects of both alleles at a particular locus are expressed in the phenotype of the heterozygote
Codon	A basic unit of a genetic code or the sequence of three adjacent nucleotides in a DNA or mRNA which code for particular amino acid
Cohesion	Mutual attraction of molecules of the same substances, for example water
Community	A collection of all populations inhabiting a particular environment and whose members interact with one another
Companion cell	A parenchymatous cell associated with sieve tube element in phloem
Competition	A biological interaction which occurs among organisms of the

	same or different species in an ecosystem associated with the need for a common resource such as food , water and mates that occurs in a limited supply relative to demand
Consumer	An animal that obtains its energy from another animal or its part
Cork	A suberised tissue which forms the outer layer of a plant stem, also called a periderm. It is formed during secondary growth and can also be developed as a response to injury
Cork cambium	A lateral meristematic tissue that lie beneath the epidermis that gives rise to a cork on its outside and secondary cortex on its inside. It is responsible for secondary growth and replaces the epidermis in roots and stems. It is also called phellogen or phelloderm
Cortex	Region in stems and roots between epidermis and central part
Cotyledon	The first leaf of the embryo in a germinating seed
Crossing over	A process by which genes are exchanged between non-sister chromatids of homologous chromosomes or exchange of corresponding chromatid segments between homologous chromosomes. It is responsible for genetic recombination between homologous chromosomes
Cuticle	A protective hard layer made up of waxy material or cutin covering the epidermis of a plant or an invertebrate. It also refers to the dead skin at the base of finger or toe nails in human
Cytokinesis	The division (cleavage) of the cytoplasm following a nuclear division
Decomposers	Saprophytic organisms that breakdown complex organic materials into simple inorganic forms in an ecosystem
Detritivores	Heterotrophs that feed on pieces of dead organic matter
Development	The sequence of processes in the overall life history of a cell or an organism including growth, differentiation, maturation and senescing
Diffusion	Random movement of individual molecules from a region of higher concentration to a region of lower concentration

Diploid	An individual or a cell having two complete sets of chromosomes (2n)
Directional selection	A type of natural selection in which extreme phenotypes in one direction are favoured over other phenotypes
Disruptive selection	A mode of natural selection whereby extremes in either direction are favoured over the mean phenotypes. This is also called a diversifying selection
Dormancy	A state of inhibited growth of seeds or other plant organs as a result of internal causes
Ecological pyramid	A bar diagram drawn to indicate the relative numbers of individuals at each trophic level in a food chain, amount of energy utilized at each trophic level or the amount of dry mass of all organisms at each trophic level
Endoplasmic reticulum	A continuous membrane-bound system of flattened sacs and tubules permeating cell cytoplasm, sometimes coated with ribosomal particles
Endosperm	Seed storage tissue, formed by fusion of one sperm cell with two polar nuclei (usually triploid)
Energy flow	The transfer of energy between organisms in different trophic levels through a feeding process
Epicotyl	A seedling axis above cotyledons
Epigeal germination	Seedling germination type in which cotyledons are carried above the ground
Epigynous flower	A flower with inferior ovary (that is, the ovary is attached to the receptacle above the level of insertion of the stamens and perianth parts)
Epistasis	A form of gene interaction in which one combination of genes has a dominant effect over other combination
Fibre	An elongated, narrow tapering, thick-walled, and hollow cell lacking contents at maturity. It possesses simple pits and usually occurs as part of a group, mostly composed of cellulose and lignin for strength and support in vascular plants
Filament	A stalk of stamen in a flower
Fossilisation	The process by which fossils are formed

Fossils	The remains, impressions and traces of past organisms
Food chain	The sequential flow of energy from one organism to another in a community
Gastrula	The embryonic stage in which the blastula with its single layer of cell turns into a three-layered embryo made up of ectoderm, mesoderm and endoderm, surrounding a cavity with one opening called blastopore
Gene flow	Passage of alleles between members of the two populations as a result of interbreeding
Gene pool	A total variety of genes and alleles present in a population at a specific time
Genetic drift	Random variation in allele frequencies over time by chance
Genome	The genetic constitution of an organism
Genotype	The genetic composition of an organism
Growth	An irreversible increase in mass and volume of an organism which is accompanied by a change in form or structure
Growth ring	A distinct growth increment caused by differential rates of growth during a growing season (in secondary xylem)
Guard cell	One of a pair of specialized cells in the epidermis of a leaf or stem that surrounds stomatal pore and controls rate of transpiration and gaseous exchange in plants
Guttation	Secretion (usually passive) of water droplets, often at hydathodes
Gynoecium	The female part of a flower made up of one or more carpels
Trichome or hair	Epidermal appendage or outgrowth from the epidermis of a plant
Haploid	The term used when a cell has half the usual number of chromosomes or an individual or cell having a single set of chromosomes (n)
Heterozygote	An organism with a non-identical alleles of a particular gene
Homologous chromosomes	Chromosomes occurring in pairs, one derived from each of two parents, normally morphological alike and bearing the same gene loci

Homologous structures	Body parts of different organisms with the common evolutionary origin but perform different functions
Homology	Similarity due to a common evolutionary origin
Homozygote	An individual with identical alleles of a particular gene
Hydathode	A type of pore in angiosperms which is responsible for secretion of water droplets (usually on the epidermis of leaf margin)
Hypocotyl	Seedling axis bearing cotyledons and shoot apex
Hypogeal germination	A type of germination in which cotyledons remains below the ground
Hypogynous flower	A flower with superior ovary, that is, ovary attached to seed coat after radicle has emerged
Instar	A stage between moults in a life cycle of an arthropod such as insects
Isolating mechanisms	Behavioural, morphological or physiological factors preventing genetic exchange between individuals of different populations or species
Isometric growth	Growth which occur when an organ grows at the same rate as the rest of the body
Lignin	Strengthening material deposited with cellulose in plant cell walls, giving rigidity. It is a high polymer composed of several different types of phenyl-propane units
Locus	Refers to the position that a gene occupies within a DNA molecule
Macrogametophyte	Cellular component of mature pollen grain in angiosperms consisting of vegetative cell and generative cell, also refered to as a male gametophyte
Megagametophyte	Mature embryo sac, most commonly consisting of seven cells and eight nuclei (two synergid cells, an egg cell, three antipodal cells, two polar bodies). It is also called a female gametophyte
Megaspore	Female haploid cell resulting from meiosis, usually one of four (or two), of which only one is functional
Megasporocyte	A diploid cell that gives rise to four haploid megaspores following meiosis, also refered to as megaspore mother cell

Megasporogenesis	A process of megaspore formation from megaspore mother cell (megasporocyte)
Meiosis (I and II)	Two successive divisions of a diploid nucleus to form haploid gametes
Meristem	A group of similar and immature cells which are capable of dividing and forming new cells or is a group of cells that retain the ability to divide by mitosis to produce daughter cells which grow and form the rest of the plant body
Meristematic region	Region of cell division and tissue differentiation
Microfibril	Thread-like component of cell wall, primarily cellulose
Micropyle	An opening at one end of ovule, usually surrounded by integuments
Microsporangium	A pollen sac contained within anther
Microspore	Individual haploid cell that gives rise to microgametophyte It undergoes unequal mitotic division to form vegetative and generative cells. Microspores following meiosis
Microsporocyte	A diploid cell that will give rise to four haploid
Microsporogenesis	Developmental process leading to production of four haploid microspores from a diploid microsporocyte by meiosis and cytokinesis
Middle lamella	Layer between walls of neighbouring cells
Mitochondrion	A mitochondrion (mitochondria-plural) is one of the cytoplasmic organelles of the cell responsible for ATP formation used for driving life processes in a cell
Missing links	The gaps in the fossil records
Mitosis	A nuclear division in which the duplicated chromosomes separate to form two genetically identical daughter nuclei or cell division to form two cells of equivalent chromosome composition to parent cell. It involves four main stages: prophase, metaphase, anaphase and telophase
Morula	A solid ball of cells formed in the early stages of embryonic development
Mutation	The change in genetic composition of an organism

Net productivity	The amount of energy that an organism accumulates after utilizing some of it for its physiological needs
Niche	The precise point at which an organism fits into its environment, both in terms of where it lives and where it does occur
Oestrus	The period of maximum female sexual receptivity associated with ovulation of the egg. It is a period of heat in animals such as goat, cow, dog and rodents
Organic evolution	The gradual change in structures, functions and efficiency of the organisms over a long period through successive generations , leading to the formation of new species
Osmosis	The diffusion of water through a semipermeable membrane
Permanent quadrat	A rectangular area of a ground, repeatedly recorded over a number of years to monitor ecological succession or investigate seasonal changes
Phloem	A food conducting tissue in vascular plants basically composed of sieve elements, phloem parenchyma, fibres, and sclereids
Population	A group of organisms of the same species, all dwelling in a particular habitat
Predator	An organism that capture and eats another organism of a different species
Prey	An organism eaten by another organism (predator), often of a different species
Primary growth	The first form of growth to occur in plants as a result of activity of the apical and sometimes intercalary meristems
Procambium	The primary meristematic layer that gives rise to vascular tissue
Quiescent centre	A group of cells in the centre of root apex where mitotic division is very slow
Recessive allele	An allele whose phenotype expression is suppressed in the presence of dominant allele
Reproductive barriers	Mechanisms that act either before or after fertilisation to prevent successful reproduction among organisms resulting into the creation of a new species
Root	A descending axis of the plant, which is normally, found below

	the ground It anchors the plant and serve as the major point of entry of water and minerals
Root cap	Thimble like mass of tissue made of epidermal cells covering and protecting the growing tip of the root
Root pressure	The transverse osmotic pressure with the cells of a root system that causes sap to rise through a plant stem to the leaves
Secondary growth	An increase in stem and root diameter made possible by cell division of the lateral meristem. It produces secondary plant body in angiosperms
Seed	A fertilized mature ovule that possesses embryonic plant, stored material and a protective coat
Selection	The process whereby the best adapted organisms in a population survive to reproduce and pass on their alleles to the next generation
Selection pressure	A combination of environmental resistance and population size which eliminates the less adapted organisms from the population during the struggle for existence
Senescence	The process of aging or the gradual deterioration of functional characteristics in organisms, sometimes referred to as a biological aging
Sexual recombination	A collection of three factors namely crossing-over during meiosis, independent segregation during meiosis and random fertilisation, which cause genetic variation
Sexual reproduction	Fusion of gametes to form zygote
Sieve tube	A series of sieve tube members arranged end to end and interconnected by sieve plates
Sperm	A mature male gamete. It is usually motile and smaller than the female gamete
Spermatogenesis	A process by which spermatogonia develops into sperm
Spindle	A motive assembly that carries out separation of chromosomes during cell division
Spore	A haploid reproductive cell, usually unicellular, capable of developing into adult without fusion with another
Sporophyte generation	A spore producing, diploid (2n) phase in the life cycle of a

	plant with alternation of generations
Stabilizing selection	A mode of natural selection whereby the mean phenotypes are gradually favoured over the extreme phenotypes
Succession	The slow orderly progression of changes in community composition that take place through time. Primary succession occurs in nature over long periods and secondary succession occurs in an area previously colonised by vegetation and that has been disturbed
Symplastic pathways	Movement of water from cell to cell through the plasmodesmata
Synecology	Refers to the study of relationships between communities and the environment. It is also called community ecology
Transcription	Is the first step of gene expression, in which a particular segment of DNA is copied into RNA
Translation	A process by which the sequence of a messenger RNA molecule is translated to a sequence of amino acid during protein synthesis
Transpiration	Loss of water in form of water vapour from plant to the atmosphere
Trophic level	A group of organisms with a similar feeding habit in a community
Uterus	A chamber in which the developing embryo is contained and nurtured during pregnancy in mammals
Vascular cambium	The dividing layer that separates xylem from phloem
Viability	Ability of seeds to germinate in favourable conditions
Xylem	A specialized tissue of vascular plant composed of primarily elongated, thick walled conduction cells, which transports water and mineral salts from the soil to the leaves

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